LABORATORY INSTRUCTION MANUAL

Basic Electrical Engineering Laboratory ES-EE 191

Lab Manual Version: July,2018

DEPARTMENT OF ELECTRICAL ENGINEERING

SILIGURI INSTITUTE OF TECHNOLOGY

SILIGURI INSTITUTE OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL ENGINEERING

General Information

All assigned experiments must be performed as per the schedule. Most of the work for an experiment should be done during class time in the laboratory. In order to allow for further analysis and graphing, the notebooks are to be submitted after completing the work within the stipulated submission date. Submit your completed notebook to the instructors/class teacher for evaluation. The laboratory performance is evaluated based on the instructor's observations of you while you are performing the experiments. Among the factors considered are your ability to construct circuits, your competency in using test equipment, your preparation prior to starting the experiment, answers given to any questions asked during the laboratory, as well as attendance, tardiness, and attitude. Keep in mind that your behaviour influences your grade; act professionally at all times.

The following guidelines should be followed when using your notebook:

- The first page should contain a table of contents as per the attached format.
- All pages in the notebook must bound, numbered and dated.
- Use a pen or permanent marker, never pencil.
- Write legibly and coherently. Extreme neatness is not required but anyone should be able to read and understand what you have written.
- Never erase errors or remove pages. Simply draw a line through any mistakes.
- The notebook should be a complete record of your work, i.e. what you actually do in the laboratory, and sufficiently detailed that a knowledgeable person could reconstruct what you did.
- All measurements, notes, and calculations should be directly recorded in the notebook. Never write information on scraps of paper for later transcription into the notebook.
- Do not paste the laboratory manual into your notebook
- Any graphs or printouts relevant to the experiment should be pasted into your notebook.
- Be sure to label all diagrams, schematics, graphs, and waveform printouts.
- All numbers should include appropriate units.
- Include an equipment list if any.

Electrical Engineering Laboratory Regulations

<u>**General**</u>

Students working in the electrical laboratories should be very cautious during the lab work. The electric potentials used in many experiments are dangerous and may cause injury. Students must observe all safety precautions and must not work alone with potentials exceeding 25 V. The rotating machines used in some experiments are dangerous. Keep loose clothing, jewellery, and other objects away from any rotating parts.
Food and drinks are not permitted in the laboratories.

<u>**Equipment**</u>

All equipment must be returned to its proper storage location at the end of the lab period. Instruments and equipment are delicate and expensive. Improper use of equipment can result in instantaneous damage; check with you instructor or the equipment's manual if you are in doubt.
Damaged or faulty equipment should be given to the technicians/instructor along with a description of the problem.

> *Keep the laboratory neat & clean*
>
> *Shut down the computers after completion of work*
>
> *Keep your mobile switched off / in silent mode while*
>
> *the laboratory is going on*

Basic Electrical Engineering Laboratory

Code :- ES-EE 191

L-T-P: 0-0-2

Credit : 1

LIST OF EXPERIMENTS

1. First activity: Introduction to basic safety precautions and mentioning of the do's and Don'ts. Noting down list of experiments to be performed, and instruction for writing the laboratory reports by the students. Group formation. Students are to be informed about the modalities of evaluation.

2. Introduction and uses of following instruments : (a) Voltmeter (b) Ammeter (c) Multimeter (d) Oscilloscope Demonstration of real life resistors, capacitors with color code , inductors and autotransformer.

3. Demonstration of cut-out sections of machines: DC machine, Induction machine, Synchronous machine and single phase induction machine.

4. Calibration of ammeter and Wattmeter.

5. Determination of steady state and transient response of R-L, R-C and R-L-C circuit to a step change in voltage.

6. Determination of steady state response of R-L and R-C and R-L-C circuit and calculation of impedance and power factor.

7. Determination of resonance frequency and quality factor of series and parallel R-L-C circuit.

8. (a) Open circuit and short circuit test of a single-phase transformer

(b) Load test of the transformer and determination of efficiency and regulation

9. Demonstration of three phase transformer connections. Voltage and current relationship, phase shifts between the primary and secondary side.

10. Measurement of power in a three phase unbalanced circuit by two wattmeter method.

11. Determination of Torque –Speed characteristics of separately excited DC motor.

12. Determination of Torque speed characteristics and observation of direction reversal by change of phase sequence of connection of Induction motor.

13. Determination of operating characteristics of Synchronous generator.

14. Demonstration of operation of (a) DC-DC converter (b) DC-AC converter (c) DC-AC converter for speed control of an Induction motor

15. Demonstration of components of LT switchgear.

Skills that the Basic Electrical and Electronics Engineering I lab (ES 191) experiments help to develop

Skills	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Ability to measure and analyse various electrical parameters for different electrical devices.	Y	Y	Y					Y	Y	Y	Y			
2. Determine the Error in between measured value and actual value.	Y		Y											
3. Analyse characteristic of DC & AC machines.										Y	Y			
4. Estimation of losses and power consumption for AC circuits.							Y		Y					
5. Understanding to work in a team and improve communication skills	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6. Improve technical Writing Skill	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Siliguri Institute of Technology
Department of Electrical Engineering

REPORT ON

Basic Electrical Engineering Laboratory

Name :

Department :

Semester :

Roll No. :

INDEX

Exp. No.	Title of the Experiment	Date of Experiment	Date of Report Submission	Page No.	Signature of Teacher

Title Sheet

Laboratory Workbook for Basic Electrical Engineering Lab (ES-EE 291)

Experiment No.   **:**

Description   **:**

Date of Performance   **:**

Date of Submission   **:**

Name   **:**

Department / Sem   **:**

Roll No.   **:**

Signature of the Student

Vision of Institute

To be a recognized institution offering high quality education, opportunities to students to become globally employable Engineers/Professionals in best ranked industries and research organization.

Mission of Institute

To impart quality technical education for holistic development of students who will fulfil the needs of the industry/society and be actively engaged in making successful career in industry/research/higher education in India & abroad.

Vision of the Department

To emerge as a leading Department of Electrical Engineering that caters to the latest needs of power sector, electrical & allied industry in the region.

Mission of the Department

To evolve as an innovative & globally competent Electrical Engineering department that contributes to the socio - economic growth of region by utilizing the advancement in Electrical Engineering by providing conducive learning and interactive environment to students and faculty.

PI stands for Performance Indicators.

Performance Indicators for Evaluation of Lab Report		Inadequate (0 -4) 1	Average (5-6) 2	Admirable (7-8) 3	Outstanding (9-10) 4
PI 1	Timely Submission	Student is not disciplined at all in submitting the lab report	Student is fairly disciplined in submitting the lab report in time to time	Student is disciplined in submitting the lab report in time to time	Student is very much disciplined regarding the submission of lab report in time to time.
PI 2	Organization and Preparation of Report	Organization and Preparation of report is not good at all.	Organization and preparation of report is not up to the mark.	Organization and preparation of report is good.	Organization and preparation of report is very good.
PI 3	Results and Conclusions	Result and conclusion obtained by the student is wrong.	Result and conclusion obtained by the student is satisfactory.	Result and conclusion obtained by the student is good.	Result and conclusion obtained by the student is very good.

Performance Indicators for Lab Performance monitoring		Inadequate (0 -4) 1	Average (5-6) 2	Admirable (7-8) 3	Outstanding (9-10) 4
PI 1	Participation and regularity	The attendance record of the student in the lab is poor.	The attendance record of the student in the lab is average.	The attendance record of the student in the lab is good.	The attendance record of the student in the lab is very good.
PI 2	Safety Procedures and direction	Demonstration of safety procedure and direction is poor.	Demonstration of safety procedure and direction is average.	Demonstration of safety procedure and direction is good.	Demonstration of Safety procedure and direction is very good.
PI 3	Ability to Work in a Group	Ability to work in a group is poor.	Ability to work in a group is average.	Ability to work in a group is good.	Ability to work in a group is very good.
PI 4	Lab Techniques	The way and approach of demonstration of lab techniques is poor.	The way and approach of demonstration of lab techniques is average.	The way and approach of demonstration of lab techniques is good.	The way and approach of demonstration of lab techniques is very good.

Name :

Department / Sem :

Roll No. :

Performance indicators

PI 1 : Participation & Regularity PI 1 : Timely Submission

PI 2 : Lab Techniques   PI 2 : Organization & Preparation of report

PI 3 : Safety Procedures & Directions PI 3 : Results & Conclusions

PI 4 : Ability to work in a group

DATE	EXPERIMENT NO.	PI 1	PI 2	PI 3	PI 4	TOTAL	PI 1	PI 2	PI 3	TOTAL	SIGNATURE OF TEACHER	REMARKS

BASIC ELECTRICAL ENGINEERING LABORATORY (ES-EE 191)

EXPERIMENT NO. 2

Introduction and uses of following instruments:

a) Voltmeter b) Ammeter c) Multi meter d) Oscilloscope

Demonstration of real life resistors, capacitors with code, inductors, autotransformer.

Objective: To become familiar with the basic measuring instruments and the passive elements' practical identity for electrical appliances.

EQUIPMENT USED:

1. Voltemter 2. Ammeter 3. Multi meter 4. Oscilloscope 5. Resistors with different colour codes
6. Capacitors 7. Inductor 8. Autotarnsformer.

SL. NO.	Name of the instrument / accessory	Qty	RANGE/ RATING	Type
1	Ammeter			
2	Voltmeter			
3	Multimeter			
4	Resistors			
5	Capacitor			
6	Inductor			
7	Auto transformer			

THEORY:

1. **An ammeter (from Ampere Meter)** is a measuring instrument used to measure the current in a circuit. Electric currents are measured in amperes (A), hence the name. Instruments used to measure smaller currents, in the **milliampere** or microampere range, are designated as *milliammeters* or *microammeters*. Early ammeters were laboratory instruments which relied on the Earth's magnetic field for operation. By the late 19th century, improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems. It is generally represented by letter 'A' in a circle.

Type of the ammeters: a) Moving Coil: Measures DC quantity.

b) Moving iron: Measures RMS value of AC quantity

c) Electro dynamic: Measures true RMS value of AC.

d) Hot wire: Measures true RMS value of AC

e) Digital: uses analog to digital converter.

2. A **voltmeter** is an instrument used for measuring electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog to digital converter.

A voltmeter in a circuit diagram is represented by the letter *V* in a circle

Type of the voltmeters:

a) Permanent magnet moving coil: Measures DC quantity.

b) Moving iron: Alternating quantity

c) Electro dynamo meter : Both Ac and DC quantity can measure

d) Rectifier type: Measures Dc

e) Digital volt meter (DVM).

3. A **Multi meter** also known as a **VOM** (volt-ohm-milli ammeter) an electronic measuring instrument that combines several measurement functions in one unit. A typical multi meter can measure voltage, current, and resistance. Analog multimeters use a micro ammeter with a moving pointer to display readings. Digital multi meters (DMM, DVOM) have a numeric display, and may also show a graphical bar representing the measured value. Digital multi meters are now far more common due to their cost and precision, but analog multi meters are still preferable in some cases, for example when monitoring a rapidly varying value.

A multi meter can be a hand-held device useful for basic fault finding and field service work, or a bench instrument which can measure to a very high degree of accuracy. They can be used to troubleshoot electrical problems in a wide array of industrial and household devices such as electronic equipment, motor controls, domestic appliances, power supplies, and wiring systems.

A multi meter is a combination of a multi range DC voltmeter, multi range AC voltmeter, multi range ammeter, and multi range ohmmeter. An un-amplified analog multi meter combines a meter movement, range resistors and switches; VTVMs (Vacuum tube volt meters) are amplified analog meters and contain active circuitry.

For an analog meter movement, DC voltage is measured with a series resistor connected between the meter movement and the circuit under test. A switch (usually rotary) allows greater resistance to be inserted in series with the meter movement to read higher voltages. The product of the basic full-scale deflection current of the movement, and the sum of the series resistance and the movement's own resistance, gives the full-scale voltage of the range. As an example, a meter movement that required 1 mA for full scale deflection, with an internal resistance of 500 Ω, would, on a 10 V range of the multi meter, have 9,500 Ω of series resistance.

For analog current ranges, matched low-resistance shunts are connected in parallel with the meter movement to divert most of the current around the coil. Again for the case of a hypothetical 1 mA, 500 Ω movement on a 1 A range, the shunt resistance would be just over 0.5 Ω.

Moving coil instruments can respond only to the average value of the current through them. To measure alternating current, which changes up and down repeatedly, a rectifier is inserted in the circuit so that each negative half cycle is inverted; the result is a varying and nonzero DC voltage whose maximum value will be half the AC peak to peak voltage, assuming a symmetrical waveform. Since the rectified average value and the root mean square (RMS) value of a waveform are only the same for a square wave, simple rectifier-type circuits can only be calibrated for sinusoidal waveforms. Other wave shapes require a different calibration factor to relate RMS and average value. This type of circuit usually has fairly limited frequency range. Since practical rectifiers have non-zero voltage drop, accuracy and sensitivity is poor at low AC voltage values.[8]

To measure resistance, switches arrange for a small battery within the instrument to pass a current through the device under test and the meter coil. Since the current available depends on the state of charge of the battery which changes over time, a multimeter usually has an adjustment for the ohm scale to zero it. In the usual circuits found in analog multimeters, the meter deflection is inversely proportional to the resistance, so full-scale will be 0 Ω, and higher resistance will correspond to smaller deflections. The ohms scale is compressed, so resolution is better at lower resistance values.

Amplified instruments simplify the design of the series and shunt resistor networks. The internal resistance of the coil is decoupled from the selection of the series and shunt range resistors; the series network thus becomes a voltage divider. Where AC measurements are required, the rectifier can be placed after the amplifier stage, improving precision at low range.

Digital instruments, which necessarily incorporate amplifiers, use the same principles as analog instruments for resistance readings. For resistance measurements, usually a small constant current is passed through the device under test and the digital multimeter reads the resultant voltage drop; this eliminates the scale compression found in analog meters, but requires a source of precise current. An autoranging digital multimeter can automatically adjust the scaling network so the measurement circuits use the full precision of the A/D converter.

In all types of multimeters, the quality of the switching elements is critical to stable and accurate measurements. The best DMMs use gold plated contacts in their switches; less expensive meters use nickel plating or none at all, relying on printed circuit board solder traces for the contacts. Accuracy and stability (e.g., temperature variation, or aging, or voltage/current history) of a meter's internal resistors (and other components) is a limiting factor in the long-term accuracy and precision of the instrument.

Quantitates measured by multimeter: a) Voltage (ac or dc in volts) b) Resistance (ohms) c) Capacitance (micro farad to farad range) d) Continuity tester e) Current (ac or dc) if clamp meter is provided.

4. An **oscilloscope**, previously called an **oscillograph**, and informally known as a **scope** or **o-scope**, **CRO** (for cathode-ray oscilloscope), or **DSO** (for the more modern digital storage oscilloscope), is a type of electronic test instrument that allows observation of varying signal voltages, usually as a two-dimensional plot of one or more signals as a function of time. Other signals (such as sound or vibration) can be converted to voltages and displayed.

Oscilloscopes are used to observe the change of an electrical signal over time, such that voltage and time describe a shape which is continuously graphed against a calibrated scale. The observed waveform can be analyzed for such properties as amplitude, frequency, rise time, time interval, distortion and others. Modern digital instruments may calculate and display these properties directly. Originally, calculation of these values required manually measuring the waveform against the scales built into the screen of the instrument.
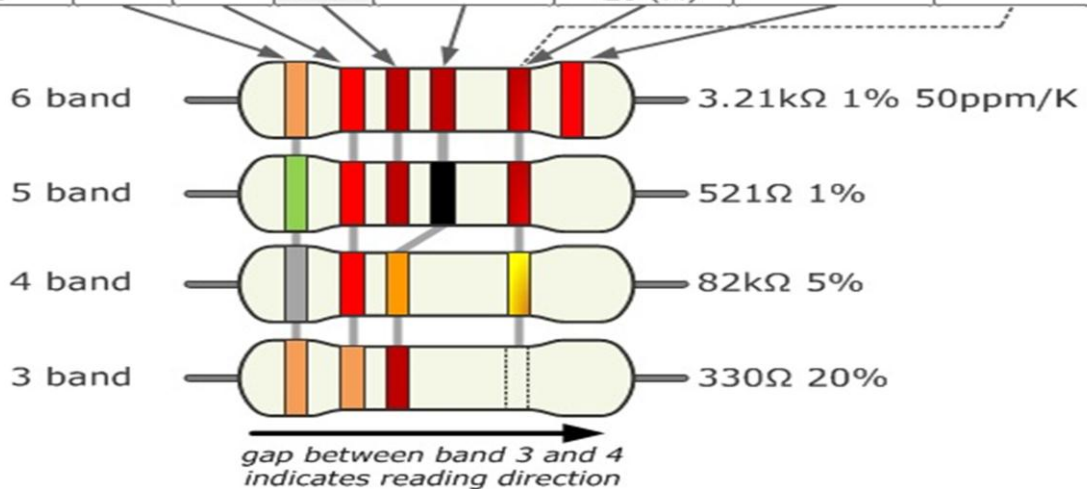
The oscilloscope can be adjusted so that repetitive signals can be observed as a continuous shape on the screen. A storage oscilloscope allows single events to be captured by the instrument and displayed for a relatively long time, allowing observation of events too fast to be directly perceptible.

Early oscilloscopes used cathode ray tubes (CRTs) as their display element (hence they were commonly referred to as CROs) and linear amplifiers for signal processing. Storage oscilloscopes used special storage CRTs to maintain a steady display of a single brief signal. CROs were later largely superseded by digital storage oscilloscopes (DSOs) with thin panel displays, fast analog-to-digital converters and digital signal processors. DSOs without integrated displays (sometimes known as digitizers) are available at lower cost and use a general-purpose digital computer to process and display waveforms.

5. A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat, may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

Color	Signficant figures			Multiply	Tolerance (%)	Temp. Coeff. (ppm/K)	Fail Rate (%)
black	0	0	0	× 1		250 (U)	
brown	1	1	1	× 10	1 (F)	100 (S)	1
red	2	2	2	× 100	2 (G)	50 (R)	0.1
orange	3	3	3	× 1K		15 (P)	0.01
yellow	4	4	4	× 10K		25 (Q)	0.001
green	5	5	5	× 100K	0.5 (D)	20 (Z)	
blue	6	6	6	× 1M	0.25 (C)	10 (Z)	
violet	7	7	7	× 10M	0.1 (B)	5 (M)	
grey	8	8	8	× 100M	0.05 (A)	1(K)	
white	9	9	9	× 1G			
gold			3th digit only for 5 and 6 bands	× 0.1	5 (J)		
silver				× 0.01	10 (K)		
none					20 (M)		

6 band — 3.21kΩ 1% 50ppm/K

5 band — 521Ω 1%

4 band — 82kΩ 5%

3 band — 330Ω 20%

gap between band 3 and 4 indicates reading direction

6. A **capacitor** is a passive two-terminal electrical component that stores potential energy in an electric field. The effect of a capacitor is known as capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a capacitor is a component designed to add capacitance to a circuit. The capacitor was originally known as a **condenser**.

Generally, the actual values of Capacitance, Voltage or Tolerance are marked onto the body of the capacitors in the form of alphanumeric characters.

However, when the value of the capacitance is of a decimal value problems arise with the marking of the "Decimal Point" as it could easily not be noticed resulting in a misreading of the actual capacitance value. Instead letters such as p (pico) or n (nano) are used in place of the decimal point to identify its position and the weight of the number.

For example, a capacitor can be labelled as, n47 = 0.47nF, 4n7 = 4.7nF or 47n = 47nF and so on. Also, sometimes capacitors are marked with the capital letter K to signify a value of one thousand pico-Farads, so for example, a capacitor with the markings of 100K would be 100 x 1000pF or 100nF.

To reduce the confusion regarding letters, numbers and decimal points, an International colour coding scheme was developed many years ago as a simple way of identifying capacitor values and tolerances. It consists of coloured bands (in spectral order) known commonly as the **Capacitor Colour Code** system and whose meanings are illustrated below:

Capacitor colour code table:

Colour	Digit A	Digit B	Multiplier D	Tolerance (T) > 10pf	Tolerance (T) < 10pf	Temperature Coefficient (TC)
Black	0	0	x1	± 20%	± 2.0pF	
Brown	1	1	x10	± 1%	± 0.1pF	-33×10^{-6}
Red	2	2	x100	± 2%	± 0.25pF	-75×10^{-6}
Orange	3	3	x1,000	± 3%		-150×10^{-6}
Yellow	4	4	x10,000	± 4%		-220×10^{-6}
Green	5	5	x100,000	± 5%	± 0.5pF	-330×10^{-6}
Blue	6	6	x1,000,000			-470×10^{-6}
Violet	7	7				-750×10^{-6}
Grey	8	8	x0.01	+80%,-20%		
White	9	9	x0.1	± 10%	± 1.0pF	
Gold			x0.1	± 5%		
Silver			x0.01	± 10%		

Capacitor Voltage Colour Code Table

Band	Voltage Rating (V)				
Colour	Type J	Type K	Type L	Type M	Type N
Black	4	100	-	10	10
Brown	6	200	100	1.6	-
Red	10	300	250	4	35
Orange	15	400	-	40	-
Yellow	20	500	400	6.3	6
Green	25	600		16	15
Blue	35	700	630	-	20
Violet	50	800	-	-	-
Grey	-	900	-	25	25
White	3	1000	-	2.5	3
Gold	-	2000	-	-	-
Silver	-	-	-	-	-

7. An **inductor**, also called a **coil**, **choke** or **reactor**, is a passive two-terminal electrical component that stores energy in a magnetic fieldwhen electric current flows through it. An inductor typically consists of an insulated wire wound into a coil around a core.

When the current flowing through an inductor changes, the time-varying magnetic field induces an electromotive force (*e.m.f.*) (voltage) in the conductor, described by Faraday's law of induction. According to Lenz's law, the induced voltage has a polarity (direction) which opposes the change in current that created it. As a result, inductors oppose any changes in current through them.

An inductor is characterized by its inductance, which is the ratio of the voltage to the rate of change of current. In the International System of Units (SI), the unit of inductance is the henry (H) named for 19th century American scientist Joseph Henry. In the measurement of magnetic circuits, it is equivalent to weber/ampere. Inductors have values that typically range from 1 μH (10^{-6} H) to 20 H. Many inductors have a magnetic core made of iron or ferrite inside the coil, which serves to increase the magnetic field and thus the inductance. Along with capacitors and resistors, inductors are one of the three passive linear circuit elements that make up electronic circuits. Inductors are widely used in alternating current (AC) electronic equipment, particularly in radio equipment. They are used to block AC while allowing DC to pass; inductors designed for this purpose are called chokes. They are also used in electronic filters to separate signals of different frequencies, and in combination with capacitors to make tuned circuits, used to tune radio and TV receivers.

8. An **Auto-transformer** (sometimes called *auto-step down transformer*) is an electrical transformer with only one winding. The "auto" (Greek for "self") prefix refers to the single coil acting alone and **not** to any kind of automatic mechanism. In an autotransformer, portions of the same winding act as both the primary and secondary sides of the transformer. In contrast, an ordinary transformer has separate primary and secondary windings which are not electrically connected.

The winding has at least three taps where electrical connections are made. Since part of the winding does "double duty", autotransformers have the advantages of often being smaller, lighter, and cheaper than typical dual-winding transformers, but the disadvantage of not providing electrical isolation between primary and secondary circuits. Other advantages of autotransformers include lower leakage reactance, lower losses, lower excitation current, and increased VA rating for a given size and mass.

Autotransformers are often used to step up or step down voltages in the 110-115-120 V range and voltages in the 220-230-240 V range - for example, providing 110 V or 120 V (with taps) from 230 V input, allowing equipment designed for 100 or 120 V to be used with a 230 V supply.

Operating principle of autotransformer:

An autotransformer has a single winding with two end terminals, and one or more terminals at intermediate tap points, or it is a transformer in which the primary and secondary coils have part of, or all of their turns in common. The primary voltage is applied across two of the terminals, and the secondary voltage taken from two terminals, almost always having one terminal in common with the primary voltage. The primary and secondary circuits therefore have a number of windings turns in common. Since the volts-per-turn is the same in both windings, each develops a voltage in proportion to its number of turns. In an autotransformer part of the current flows directly from the input to the output, and only part is transferred inductively, allowing a smaller, lighter, cheaper core to be used as well as requiring only a single winding. However the voltage and current ratio of autotransformers can be formulated the same as other two-winding transformers.
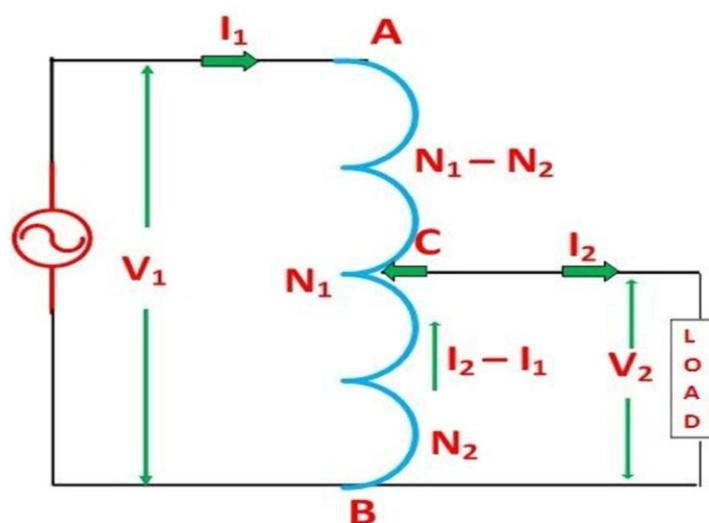
Fig.1. Autotransformer circuit diagram

The primary winding AB from which a tapping at C is taken, such that CB acts as a secondary winding. The supply voltage is applied across AB, and the load is connected across CB. The tapping may be fixed or variable. When an AC voltage V_1 is applied across AB, an alternating flux is set up in the core, as a result, an emf E_1 is induced in the winding AB. A part of this induced emf is taken in the secondary circuit.

Let,

- V_1 – primary applied voltage
- V_2 – secondary voltage across the load
- I_1 – primary current
- I_2 – load current
- N_1 – number of turns between A and B
- N_2 – number of turns between C and B

Neglecting no load current, leakage reactance and losses,

$V_1 = E_1$ and $V_2 = E_2$

Therefore the transformation ratio

$$K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

As the secondary ampere-turns are opposite to primary ampere turns, so the current I_2 is in phase opposition to I_1. The secondary voltage is less than the primary. Therefore current I_2 is more than the current I_1. Therefore, the resulting current flowing through section BC is $(I_2 - I_1)$

The ampere-turns due to section BC = current x turns

$$\text{Ampere turns due to section BC} = (I_2 - I_1)N_2 = \left(\frac{I_1}{K} - I_1\right) x N_1 K = I_1 N_1 (1 - K) \ldots\ldots\ldots (1)$$

$$\text{Ampere turns due to section AC} = I_1(N_1 - N_2) = I_1 N_1\left(1 - \frac{N_2}{N_1}\right) = I_1 N_1(1 - K) \ldots\ldots.(2)$$

Equation (1) and (2) shows that the ampere turns due to section BC and AC balance each other which is characteristic of the transformer action.

Circuit Diagram:
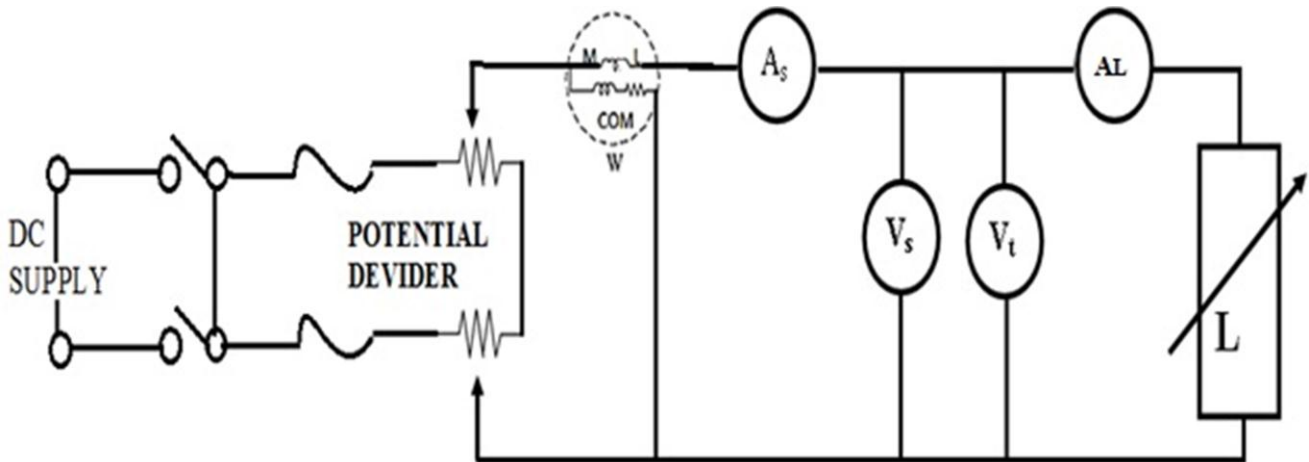
Fig.2 Demonstration of the ammeter, voltmeter, wattmeter and multi meter

PROCEDURE

1. Make connection as shown in figure – 2.
2. Switch on the DC/AC supply and fix up the voltage.
3. Increase the load current by varying the load and record the wattmeter, voltmeter and ammeter reading in the observation table.
4. Put the multimeter in requisite mode and measure the parameters.
5. Take at least five readings changing the voltage and load of the full load. Compare the readings with multimeter readings.

OBSERVATION AND RESULTS

Demonstration of voltmeter, ammeter and multimeter:

Sl No	Supply Voltage (Vs)		Load/ Terminal Voltage(Vt)		Consumed Power	Load Current (A_L)	
	Voltmeter	Multimeter	Voltmeter	Multimeter		Ammeter	Clamp meter

Measurement of resistors:

Sl No.	Colour code	True Value	Measured Value

Measurement of capacitors:

Sl No.	Colour code	True Value	Measured Value

Observation:

BASIC ELECTRICAL ENGINEERING LABORATORY (ES-EE 191)

EXPERIMENT NO. 04

CALIBRATION OF AMMETER AND VOLTMETER

NAME OF THE INSTRUMENT / ACCESSORY

SL. NO.	Name of the instrument / accessory	Qty	RANGE/ RATING	MAKERS NAME
1	Ammeter (MI type)			
2	Wattmeter (electro dynamometer type)			
3	Voltmeter (PMMC type)			
4	Ammeter (PMMC type)			
5	Potential divider			
6	DC power supply			
7	Load (resistive type)			

THEORY:

DC ammeter and voltmeter are generally permanent moving-coil type instruments. The basic instrument for making an ammeter or a voltmeter is a mile voltmeter which is converted into ammeter by connecting appropriate value of low resistance in parallel with the meter (called shunt). The voltmeters are made by connecting high resistance in series with the basic instrument. Multi range ammeter and voltmeter which are common in laboratories have different values of resistances connected either as shunts or in series as per requirement of the range. The ammeter and voltmeter are manufactured with different values of accuracy varying from ±5% to ±0.05% more accurate ones are obviously costlier than the less accurate ones.

Accuracy of the measuring instrument is mentioned on the front panel by the manufacturer. These instruments are to be calibrated periodically to ascertain their claimed accuracy. The best method of calibration is to measure the true value of current or voltage in the circuit and compare it with the value measured by the given ammeter or voltmeter. The percentage error of the instrument can be calculated as follows:

The term error in a measurement is defined as: Error = Instrument reading – true reading.

Error is often expressed in percentage as: (Instrument reading-True reading)/True reading X 100%

A graph is plotted between percentage error and measured value for the complete range of the instrument. This graph will enable a user of the meter to know the true value for a given measured value.

CIRCUIT DIAGRAM:
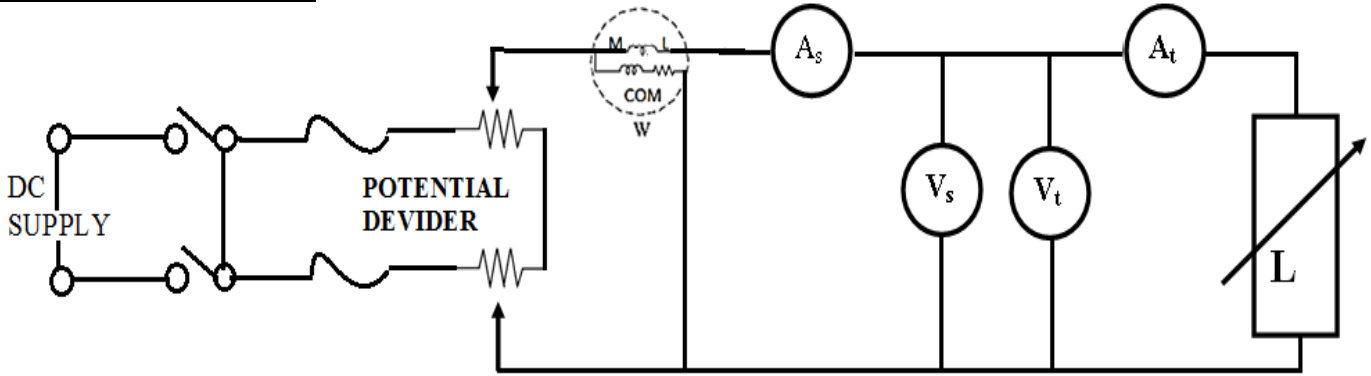
Figure-1. Calibration of moving iron type Ammeter and Electro-Dynamo type wattmeter
by comparison of standard PMMC type Ammeter and Voltmeter.

PROCEDURE

1. Make connection as shown in figure – 1.
2. Switch on the DC supply and fix up the voltage.
3. Increase the load current by varying the load and record the wattmeter, voltmeter and ammeter reading in the observation table.
4. Take at least five readings changing the voltage and load of the full load rating of the meter to be calibrated.
5. In each step Measure the power by multiplying standard voltmeter (V_s) and ammeter (I_s) [i.e. $W=V \times I$] and calculate the percentage of error.

OBSERVATION AND RESULTS

SL. NO.	Load	Test Ammeter (A_t)	Standard Ammeter (A_t)	Test Voltmeter(V_t)	Standard Voltmeter(V_t)	Test Wattmeter (W_t)	Standard Wattmeter(W_s)	Error in At	Error in $V_t=(V_t-V_s)$	Error in W_t	% of Error in A_t	% of Error in V_t	% of Error in W_t
1													
2													
3													
4													
5													
6													

Calculation:

Report: Draw graph showing percentage error vs test values for Ammeter, Voltmeter and Wattmeter.

Conclusion:

EXPERIMENT NO. 10

MESUREMENT OF POWER IN A THREE PHASE UNBALANCED CIRCUIT BY TWO WATTMETER METHOD

Objective: To experimentally compute the consumed power by an unbalanced three phase circuit fed by a three phase supply.

NAME OF THE INSTRUMENT / ACCESSORY:

Sl. No.	Name of the instrument / accessory	Quantity	Range / Rating	Make
1				
2				
3				
4				

THEORY:

Delta connected system. In delta connected system the three phases from a closed loop and according to Kirchhoff's second law. $v_1 + v_2 + v_{3=0} \ or \ v_1 = -(v_2 + v_3)$

Instantaneous power, $p = v_1 i_1 + v_2 i_2 + v_3 i_3$

$$= -(v^2 + v_3)i_1 + v_2 i_2 + v_3 i_3 - -v_3(i_1 - i_3) + v_2(i_2 - i_1)$$

Since $-v_3$ is the instantaneous prudential across pressure coil and $(i_1 - i_3)$ is the instantaneous current flowing through current coil of wattmeter w_1 so wattmeter w_1 reads average of $-v_3(i_1 - i_3)$ and similarly wattmeter w_2 reads average of $v_2(i_2 - i_1)$.

Hence total power, $p = w_1 + w_2$

Hence the algebraic sum of two wattmeter reading gives the total power of the circuit irrespective of the fact that the circuit is balanced or unbalanced and star-connected or delta-connected.

CIRCUIT DIAGRAM:
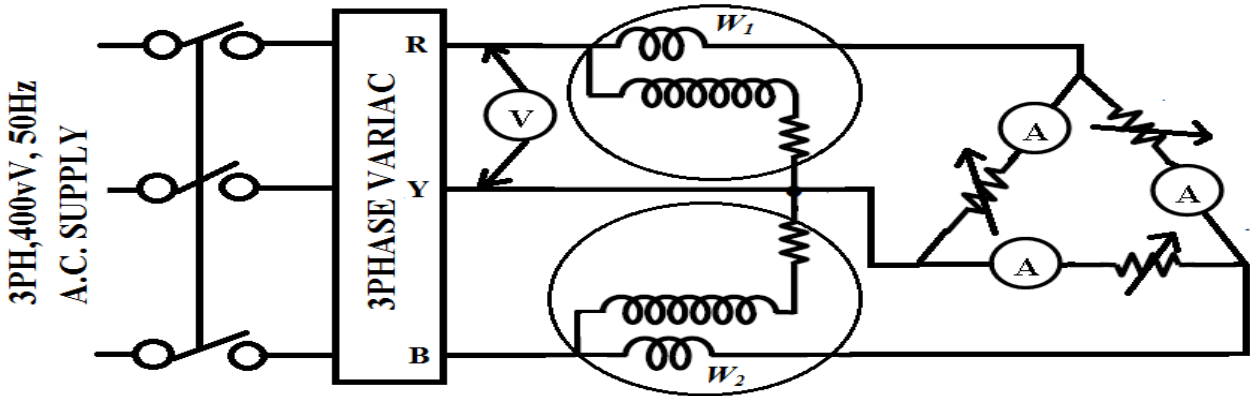
PROCEDURE:

1. Connect two wattmeter to measure total power taken by 3-phase delta connected resistive load as shown in fig.
2. Set the voltage at 100 volts. Adjust the resistance so that the reading of the three ammeters are equal (below 1 amp).
3. Take down voltmeter, ammeter and wattmeter reading and record in Table-No-1.
4. **Change the resistance values so that three ammeters show different readings. (Unbalanced Condition)**
5. Repeat procedure 3.

OBSERVATION AND RESULTS:

Type of load	Line Voltage	Ammeter Reading in amps			Wattmeter Readings in watts		Total power in watts [w=(w₁+w₂)]
		I_1	I_2	I_3	w_1	w_2	
Resistive (Balanced)							
Resistive (Unbalanced)							

BASIC ELECTRICAL ENGINEERING LABORATORY (ES-EE 191)

CONCLUSION:

EXPERIMENT NO. 8.(a)

OPEN CIRCUIT AND SHORT CIRCUIT TEST OF A SINGLE PHASE TRANSFORMER

OPEN CIRCUIT TEST

Objective: To perform the tests to determine the losses and equivalent circuit parameters.

APPARATUS USED:

SL. NO.	DESCRIPTION	RANGE/ RATING	MAKERS NAME	TAG NO/SERIAL NO
1				
2				
3				
4				
5				

.

THEORY:

 The purpose of this test is to determine the core of iron loss (w_0), no load current (I_0) and there by the parameters of the shunt branch R_0 and X_0 of the equivalent circuit.

   The core loss and iron loss i.e. The no load loss in a transformer is determined by performing the no load test at normal sine wave impressed voltage. Through the iron loss in a transformer is not governed by the supply being connected to primary or secondary side but when measuring this no load loss, it is more convenient and safer from the testing personnel. To determine the shunt branch, parameter of the equivalent circuit, the primary side (L.V) is connected to a normal supply voltage and rated frequency and secondary side (H.V) terminal are kept open. The wattmeter connected in the primary, will then read the total hysteresis and eddy current loss (W_0) in the single phase transformer. Since the primary no load current is small, the copper loss due to it can be neglected. If the supply voltage is V volts.

$VI_0 cos\phi_0 = W_0$
$Where\ cos\phi = no\ load\ power\ factor, I0 = no\ load\ current$
$\phi_0 = cos^{-1}(W_0/VI)$

No load Current energy component $Ie = I_0 Cos\phi_0 = W_0/V$

No load Current magnetizing component $I_M = \sqrt{(I_0{}^2 - I_e{}^2)} = I_0 sin\phi_0$

$R_0 = V / I_0 cos\phi_0$
$G_0 = I_0 cos\phi_0 / V$
$X_0 = V / I_0 sin\phi_0$
$B_0 = I_0 sin\phi_0 / V$

Where, R_0 = *shunt branch resistance*
X_0 = *shunt branch reactance*
B_0 = *shunt branch susceptance*
G_0 = *shunt branch conductance*
In no load test, the shunt branch parameters
$(B_0$ = *shunt branch susceptance,* $G0$ = *shunt branch conductance) are known.*

CIRCUIT DIGRAM:

Figure 1 Circuit Diagram for Open – Circuit test.

PROCEDURE

1. Connect the circuit diagram as shown in fig. 1.

2. Set the Variac to its minimum value and switch on the supply.

3. Vary the applied voltage to the primary winding from zero to 120% of its rated value.

4. Record at each step the readings of all the meters.

5. Reduce the applied voltage to zero value.

6. Switch off the supply.

OBSERVATION TABLE:

TABLE -1 (FOR OPEN CIRCUIT TEST)

Primary voltage(V)	Input current (I_0)	Input power (W_0)	Active current (I_e)	Magnetizing current (I_m)	R_0	X_0	Secondary voltage (V)

CALCULATION:

CORE LOSS (at rated voltage)**:**

REPORT:-

1. Plot the variation of the load current with applied voltage.

2. Plot the variation of no load power with primary voltage and hence find the core loss at rated voltage.

CONCLUSION:

SHORT CIRCUIT TEST

THEORY

The purpose of this test is to determine the full load copper loss and equivalent resistance and equivalent referred to metering side.

This test is done on a single –phase transformer to find out the series parameters of the equivalent as well as to obtain the full load copper loss. For this test fig. below terminals of the low voltage side of the transformer are short circuit and adjust the voltage (by a factor of 5 to 20 lower than the rated voltage, depending on the type of transformer) on the other side so that full load current flows, It is preferable to short circuit the voltage side (as the current rating of the side is higher). This loss during this circuit will be full load copper losses in both the primary and secondary windings, the core loss being very small and is quit negligible. Precaution is to be taken about the magnitude of applied voltage at the H.T side such that full load current is not exceeded.

Therefore, if a wattmeter (U.P.F) is connecting in the supply side it will read full load copper loss of the single- phase transformer.

If, W_s = wattmeter reading = short circuit power. V_p = supply voltage at short circuit, I_{p} = Primary current. Full load copper loss $P_c = I_S^2 R_{eq} = W_s$

Then equivalent impedance referred to the primary side is

$Z_{eq} = V_P / I_P$

Equivalent resistance referred to the primary side is

$R_{eq} = W / I_p^2$

While the equivalent reactance referred to the primary side is given by

$X_{eq}^2 = Z_{eq}^2 - Req2$

CIRCUIT DIAGRAM:
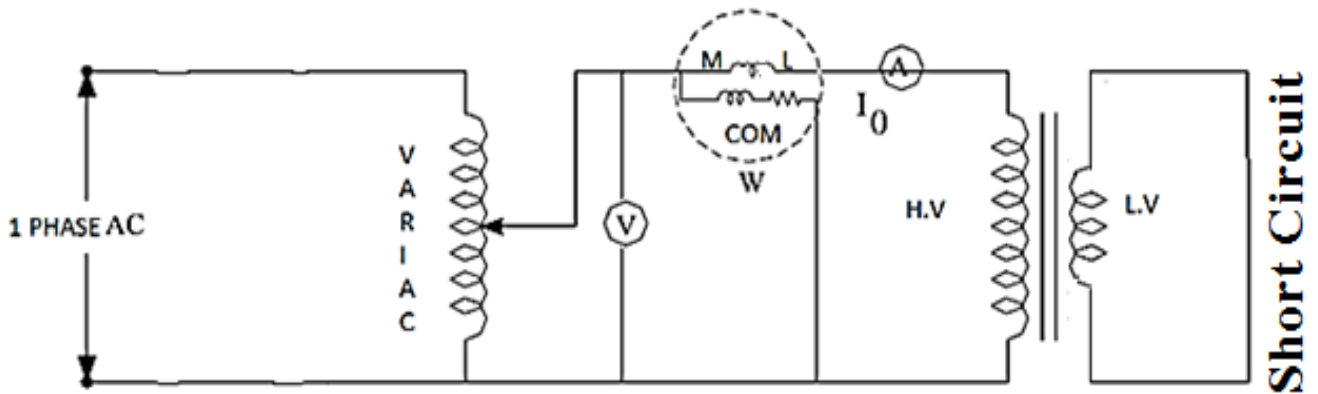
Figure: 2 Circuit Diagram for Short – circuit test.

PROCEDURE:-

1. Connect the circuit diagram as shown in fig. 2. Here the low – voltage winding is short – circuited by a having negligible resistance and good contacts. Preferable by an ammeter.

2. Set the variac to its minimum value and switch on the supply.

3. Maintain the supply frequency constant; increase the variable supply voltage from zero, in small step to a value until the rated primary current (this will imply rate secondary current as well) is reached.

4. Load the reading of all the meters.

5. Reduce the applied voltage to zero value.

6. Switch of the supply.

OBSERVATION:-

TABLE -2 (FOR SHORT CIRCUIT TEST)

Primary Voltage (V_p)	Primary Current (I_p)	Short circuit power (W_S)	Req. $= W/I_p^2$	Xeq $= \sqrt{Z_{eq}^2 - R_{eq}^2}$	Zeq $= V_P / I_P$

Full load cu loss =……………………watt

CALCULATION: -

CONCLUSION:

LOAD TEST of THE TRANSFORMER and DETERMINATION of EFFICIENCY AND REGULATION

OBJECTIVE: To perform load test on unity power factor and lagging load on a single phase transformer.

APPARATUS USED:

SL. NO.	DESCRIPTION	RANGE/ RATING	MAKERS NAME	TAG NO/SERIAL NO
1				
2				
3				
4				
5				

.

THEORY:

When an electrical load is connected to the secondary winding of a transformer and the transformer loading is therefore greater than zero, a current flows in the secondary winding and out to the load. This secondary current is due to the induced secondary voltage, set up by the magnetic flux created in the core from the primary current.

The secondary current, I_S which is determined by the characteristics of the load, creates a self-induced secondary magnetic field, Φ_S in the transformer core which flows in the exact opposite direction to the main primary field, Φ_P. These two magnetic fields oppose each other resulting in a combined magnetic field of less magnetic strength than the single field produced by the primary winding alone when the secondary circuit was open circuited.

This combined magnetic field reduces the back EMF of the primary winding causing the primary current, I_P to increase slightly. The primary current continues to increase until the cores magnetic field is back at its original strength, and for a transformer to operate correctly, a balanced condition must always exist between the primary and secondary magnetic fields. This results in the power to be balanced and the same on both the primary and secondary sides.

CIRCUIT DIGRAM:
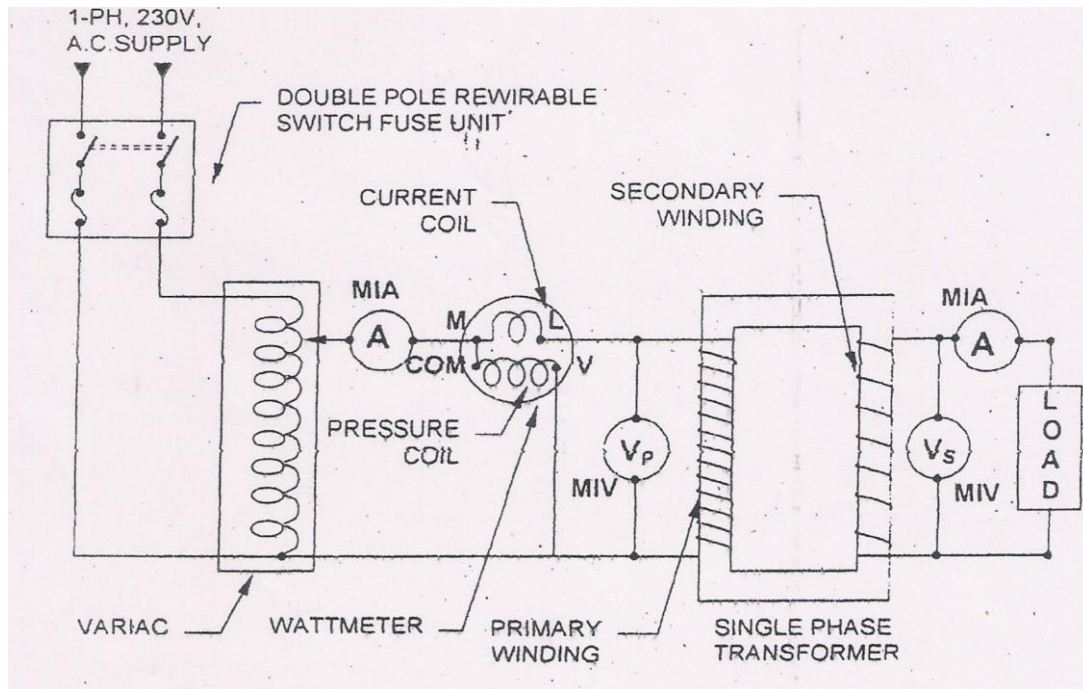
Fig. LOAD TEST

PROCEDURE

1. Connect the circuit diagram as shown in figure.

2. Set the Variac to its minimum value and switch on the supply.

3. Vary the applied voltage to the primary winding up to the rated value.

4. The load is increased and for each load, Voltmeter, Ammeter and Wattmeter readings on both primary and secondary sides are noted.

5. Record at each step the readings (5 times) of all the meters according to the table.

6. Reduce the applied voltage to zero value.

7. Switch off the supply.

N.B. The primary voltage should be kept constant throughout the load test. Another wattmeter is to be connected at load terminal to measure the power.

OBSERVATION TABLE:

(For Resistive load and inductive load individual observation table is to be written.)

Primary voltage	Input current	Input power	Secondary current	Secondary Voltage	Power Output	Efficiency	Regulation

CALCULATION:

Output Power = W$_2$ x Multiplication factor **(W$_2$ is the wattmeter connected across the load)**
Input Power = W$_1$ x Multiplication factor **(W$_1$ is the wattmeter connected across the supply terminal)**

Efficiency = (output Power/Input Power) x 100%

Regulation-Down = [(V$_{no\text{-}Load}$ − V$_{full\text{-}Load}$) / V$_{no\text{-}Load}$] x 100%

Regulation-Up = [(V$_{no\text{-}Load}$ − V$_{full\text{-}Load}$) / V$_{full\text{-}Load}$] x 100%

N.B. The same calculation is to be done for inductive load.

REPORT:-

1. Plot the efficiency versus load curve

2. Plot the regulation versus load curve.

3. Calculate theoretical efficiency and regulation of the transformer at full load unity power factor from the equivalent circuit parameters. Compare the values with test results.

CONCLUSION:

EXPERIMENT NO. PC EE 593 / 01

FAMILARISATION WITH MAT- LAB- CONTROL SYSTEM TOOL BOX, MATLAB - SIMULINK TOOL BOX & PSPICE.

Objectives:
- Using 'MATLAB base program + Control System toolbox', for control systems analysis and design.
- Building simple Simulink simulations.
- Running Simulink simulation to predict a system's behaviour.
- Transient analysis using PSPICE

MATLAB, an abbreviation of **MAT**rix **LAB**oratory, is a high-level technical computing environment suitable for solving scientific and engineering problems. The MATLAB family of programs includes the base program plus a variety of application-specific solutions called toolboxes . Toolboxes are comprehensive collections of MATLAB functions that extend the MATLAB environment to solve particular classes of problems.

The MATLAB base program along with the functions from the Control System Toolbox, can be used to analyze and design control systems problems. Control System Toolbox includes interactive analysis and design tools called LTI Viewer, and SISO Design Tool. The LTI Viewer uses a Graphical User Interface (GUI) to generate and view time and frequency response plots of Linear Time-Invariant (LTI) transfer functions and obtain measurements from these plots. The SISO Design Tool uses a GUI to provide a convenient and interactive way to design Single-Input-Single-Output (SISO) control systems by the conventional trial-and-error approach.

ASSIGNMENT - 1

MATLAB basics

1. Open MATLAB command window. Observe the commands poly, polyval, roots, diff, int, deval, solve, dsolve, laplace, ilaplace, residue, tf, series, parallel, feedback, plot, zp2tf, tf2zp

2. Write a MATLAB program to find the roots of the polynomial
    $2s^5 + 4s^4 + 3s^3 + 5s^2 + 11 = 0$

3. Find the general solution of the following quadratic equation.
    a) $x^3 + 6x^2 + 8x + 12 = 0$
    b) $2x + y + 3z = 15, \quad x + 8y + 9z = 12, \quad 4x + 2y + z = 4$

4. Find the general solution of the following differential equation.

$$\frac{d^2y}{dt^2} + 3\frac{dy}{dt} + 6y + 11 = 0, y(0) = 1, Dy(0) = 2$$

5. Consider the two matrices

$$A = \begin{bmatrix} 4 & 76 & 5 \\ 3 & 5 & 3 \\ 1 & 3 & 7 \end{bmatrix} \quad and \quad B = \begin{bmatrix} 7 & 5 & 33 \\ 9 & 3 & -1 \\ 5 & 2 & 8 \end{bmatrix}$$

Write a MATLAB program to determine
- A+B
- B^{-1}
- A^{T}B^T

6. Write a MATLAB program to generate an overlay plot of

$y_1 = \sin 3t$
$y_2 = \cos 2t$
$y_3 = t$ For $0 \le t \le 2\pi$

7. i) Write a MATLAB program to find Laplace transform of - $5t\sin\omega t$

  ii) Write a MATLAB program to find Inverse Laplace transform of $\frac{(s+4)(s+7)}{s^2(s+2)(s+9)}$

8. Find out the poles, zeros and gain of the following transfer functions using MATLAB.

a) $F(S) = \frac{3s^2+2s+6}{s^4+2s^3+7s^2+s+4}$

b) $F(S) = \frac{4s+7}{2s^3+S+9}$

9. Determine the transfer function from the given poles, zeros and gain.

a) Zeros are at S= -1 and -3, poles are at S= 0, -4.5198, -0.7401$\pm$2.1522i and gain is k=2.

b) Zero is at S= -5, poles are at S= -1, -0.3542$\pm$3.546i and gain is at k=2

10. Form the transfer functions

a) $G(S) = \frac{2(S+3)(S+7)}{S(S+6)(S+5)}$

b) $G(S) = \frac{(S+1)}{S^2(S+4)^2}$

11. Find the overall transfer function.

1. Connecting $G_1(S) = \frac{2(S^2+7s+3)}{S(S+5)(S+2)}$ and $G_2(S) = \frac{(S+7)(S+10)}{(S+6)(S+9)(S+11)}$ in series.

b) Connecting $G_1(S) = \frac{S(S+3)(S+4)}{(S+14)(S+9)(S+5)}$ and $G_2(S) = \frac{(S+1)(S+2)}{S^2(S+5)(S+6)}$ in parallel.

12. Find the closed loop transfer function of $G(S) = \frac{3(S+2)}{S^2(S+3)}$

- With unity –ve feedback
- With unity +ve feedback

- With the negative feedback having transfer function $H(S) = \frac{1}{(S+1)}$

13. Find overall transfer function by block diagram reduction technique
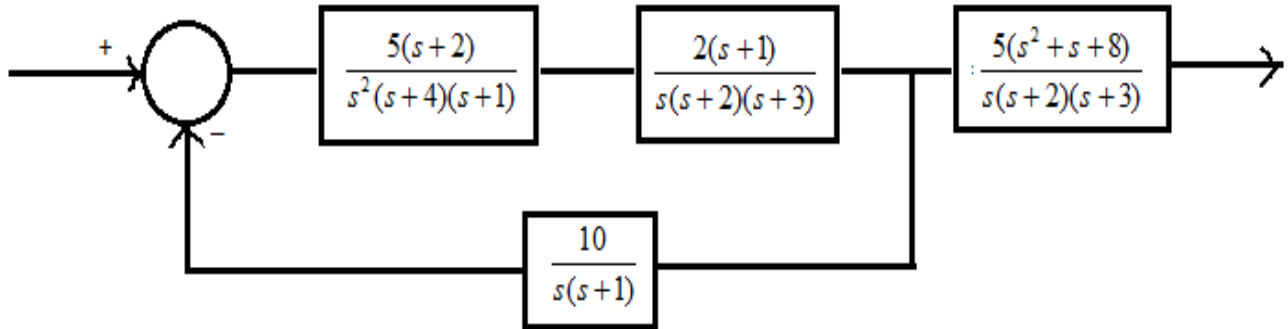
14. For the given system compare the step response specifications for open loop and closed loop.

$$G(S) = \frac{(S^2 + 1)}{(S^2 + 2S + 1)}$$

ASSIGNMENT - 2

Running Simulink simulation

SIMULINK (**SIMU**lation **LINK**) is an extension of MATLAB for modeling, simulating, and analyzing dynamic, linear/nonlinear, complex control systems. Graphical User Interface (GUI) and visual representation of simulation process by simulation block diagrams are two key features which make SIMULINK one of the most successful software packages, particularly suitable for control system design and analysis.

Simulation block diagrams are nothing but the same block diagrams we are using to describe control system structures and signal flow graphs. SIMULINK offers a large variety of ready-to-use building blocks to build the mathematical models and system structures in terms of block diagrams. Block parameters should be supplied by the user. Once the system structure is defined, some additional simulation parameters must also be set to govern how the numerical computation will be carried out and how the output data will be displayed.

To start SIMULINK, enter **simulink** command at the MATLAB prompt. Alternatively one can also click on SIMULINK icon .

1. Expand the **Continuous**, **Discontinuities**, **Discrete**, and **Math Operations** sub nodes. Study the purpose of various blocks in these sub nodes in description box.

2. Simulate the following equation using SIMULINK blocks
   $$x(t) = 3\sin\left(\omega t + \frac{\pi}{3}\right)$$
   ω is 10 rad/sec

3. Consider the mass-spring-dashpot where the spring and the dashpot are connected in parallel to the mass.
   The mathematical model for this system is described by $f(t) = 3\ddot{x} + 2\dot{x} + 9x$
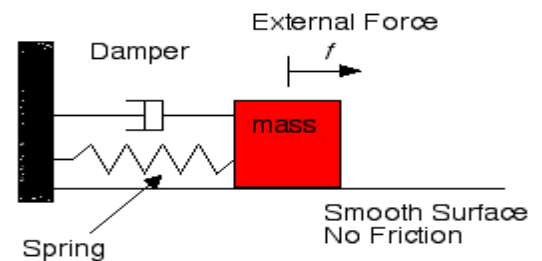
   Use SIMULINK to simulate the response of this system to unit step input.

HOME WORK:

1. Proof all the experimental results with theoretical calculations.

2. Write a MATLAB program to find the roots of the polynomial
   $$9s^4 + s^3 + 5s^2 + 2s + 11 = 0$$

3. Find the general solution of the following differential equation.

$$\frac{d^2 y}{dt^2} + 2\frac{dy}{dt} + y = 0$$

4. Consider the two matrices
$$A = \begin{bmatrix} 4 & 76 & 5 \\ 3 & 5 & 3 \\ 1 & 3 & 7 \end{bmatrix} \quad and \quad B = \begin{bmatrix} 7 & 5 & 33 \\ 9 & 3 & -1 \\ 5 & 2 & 8 \end{bmatrix}$$
   Write a MATLAB program to determine
   - AB
   - B^T
   - A^{-1}

5. Write a MATLAB program to generate the plot of
   $$y = 3\sin t \qquad 0 \le t \le 2\pi$$

6. i) Write a MATLAB program to find Laplace transform of the following
   $$t\cos 3\omega t$$

   ii) Write a MATLAB program to find Inverse Laplace transform of the following

   $$\frac{(S^2+1)}{(S^2+2S+1)}$$

7. Find the overall transfer function.
   a. Connecting $G_1(S) = \frac{2(S+3)(S+7)}{S(S+6)(S+5)}$ and $G_2(S) = \frac{(s+4)(s+7)}{s^2(s+2)(s+9)}$ in series.
   b. Connecting $G_1(S) = \frac{(S+1)}{S^2(S+4)^2}$ and $G_2(S) = \frac{3(S+2)}{S^2(S+3)}$ in parallel.

8. Find overall transfer function by block diagram reduction technique
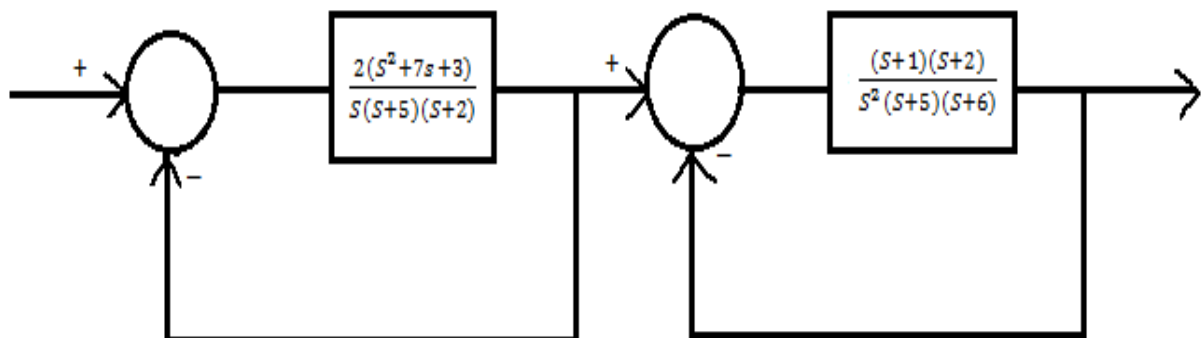
DETERMINATION OF STEP RESPONSE FOR FIRST ORDER & SECOND ORDER SYSTEM. WITH UNITY FEEDBACK ON CRO &CALCULATIONS OF CONTROL SYSTEM LIKE TIME CONSTANT , % PEAK OVERSHOOT, SETTLING TIME ETC., FROM THE RESPONSE. SPECIFICATIONS

Objective:
 Determination of step response of 1st & 2nd order system and calculation of control system specification

EQUIPMENT DESCRIPTION

The present set up has been designed to provide a convenient means of studying the transient response of linear systems. Block diagram approach has been employed as a standard technique, with Fig. 1 depicting the features available to in the set up.

A dynamic system of the desired configuration may be constructed by a suitable interconnection of the basic blocks available. Following type of blocks have been included in the system.
- Error detector-cum Gain
- Integrator
- Time constant
- Disturbance adder
- Uncommitted Amplifier (to invert the feedback signal for getting negative feedback.

The set up has an internal $\pm$ 12V IC regulated Power supply.

With the help of the above sub-systems a very large variety of simulated systems can be constructed. Besides SISO systems this would include MIMO systems as well.

A good quality dual trace oscilloscope is the only external equipment required for the experiments.

System Schematic Diagram
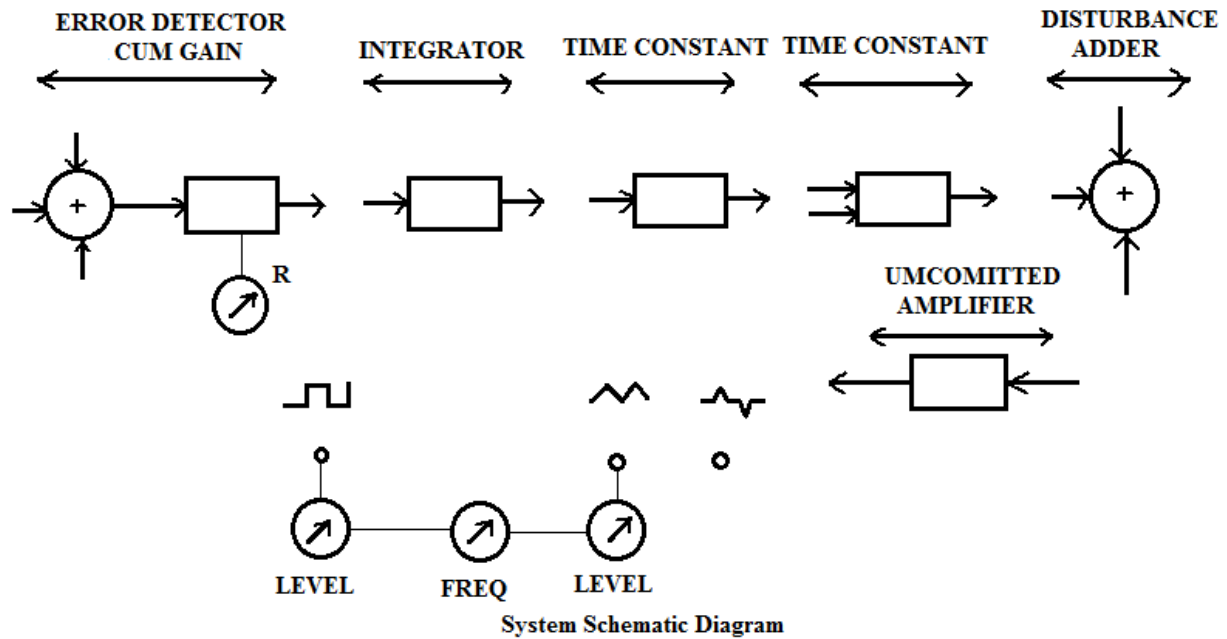
FIRST ORDER SYSTEM:

These are characterized by one pole and/or a zero. A pure integrator and a single time constant, having transfer function of the form K/s and K/(sT +1), are the two commonly studied representatives of this class of systems. Many thermal systems and electrical systems with RC/L-R element are the examples of first order systems.

Unit step response of the systems are computed as follows and are shown in fig.2(a)

$$\frac{C(s)}{R(s)} = G(s) = \frac{K}{s} \text{ then for R(s)} = \frac{1}{s}$$

$$C(s) = \frac{K}{S^2} \text{ and c(t)=Kt} \tag{1}$$

Again if $G(S) = \frac{K}{(ST+1)}$ then with R(s)= $\frac{1}{s}$

$$C(s) = \frac{K}{s(sT+1)}, \text{ and c(t)} = K\left(1 - e^{-t/T}\right) \tag{2}$$

Time constant of the system is defined from eq.(2) as t=T which gives

c(t)= $K\left(1 - e^{-1}\right)$=.632K

This is an important characteristics of the system which is also defined in terms of the slope of the response curve at t=0.

For a proper viewing on a CRO, the step input needs to be replaced by a square wave of sufficiently low frequency (to allow c(t) in eq.(2) to reach up to 99% of its final value).This is shown in the figure bellow. A triangular wave output results since a pure integration block does not saturate .it may further be seen that if the square was is of frequency f and peak to peak input amplitude is 1v ,the peak to peak amplitude of the triangular wave at the output of the pure integrator is given as K/4f.

SECOND ORDER SYSTEM:

These systems are characterised by two poles and upto two zeros. For the purpose of transient response studies, zeros are usually not considered primarily because of simplicity in calculations and also because the zeros do not affect the internal modes of the systems. A great deal of analytical results regarding second order systems are available in the textbooks.This forms the basis of studying higher order systems many of which cn be approximated to second order.

A second order system is represented in the standar form as—

$$G(S) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad,$$

Where δ is called the damping ratio and ω_n the undamped natural frequency. Depending upon the value of δ, the poles of the system may be real, repeated or complex conjugate which is reflected in the nature of its step response. Results obtained for various cases are:
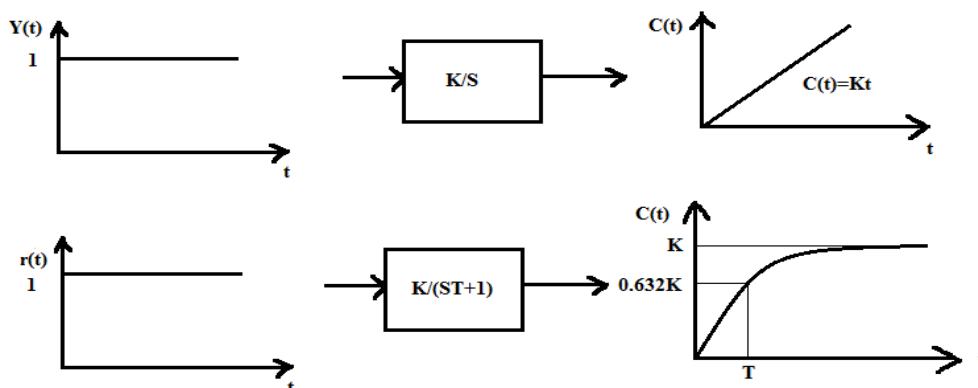
Unit step response of first order transfer functions
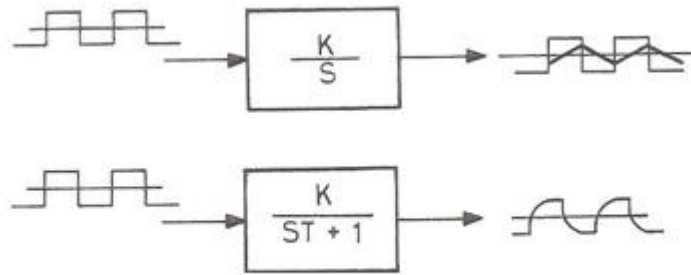
Square wave response of first order transfer functions

(a) Uderdamped case(0<δ<1):

$$c(t) = 1 - \frac{e^{-\delta\omega_n t}}{\sqrt{(1-\delta^2}} \sin\left(\omega_d t + \tan^{-1}\frac{\sqrt{(1-\delta)^2}}{\delta}\right)$$

Where $\omega_d = \omega_n\sqrt{(1-\delta)^2}$ is termed the damped natural frequency.

(b) Critically dampedcase (δ=1):

$$c(t) = 1 - e^{-\omega_n t}(1 + \omega_n t)$$

(c) Over damped case (δ>1):

$$c(t) = 1 + \frac{\omega_n}{2\sqrt{(\delta^2-1)}}\left(\frac{e^{-s_1 t}}{s_1} - \frac{e^{-s_2 t}}{s_2}\right)$$

Where $s_1 = \left(\delta + \sqrt{(\delta^2-1)}\omega_n\right)$ and $s_2 = \left(\delta - \sqrt{(\delta^2-1)}\omega_n\right)$

CLOSED LOOP SYSTEM:

Close loop or feedback systems involve a measurement of the output of the system And generation of control signals which are based on decision making under the influence of a command or reference and the measured value of output such systems are of great interest to control engineers due to features like automatic correction, disturbance rejection immunity to noise and parameter variation etc. A study of the performance of closed loop system is the basic objective of this experiment. The closed loop transfer function for different open loop functions are shown below:

(i)   For $G(S) = \frac{K}{s}, \frac{C(S)}{R(S)} = \frac{K}{s+K} = \frac{1}{\frac{s}{K}+1}$

Which gives a step response similar to equation (2) with time constant describing as K increases.

(ii)   For $G(S) = \frac{K}{ST+1}, \frac{C(S)}{R(S)} = \frac{K}{sT+K+1} = \frac{K/(1+K)}{\frac{sT}{1+K}+1}$

Which has a step response similar in nature as obtained above.

(iii)   For $G(S) = \frac{K}{S(ST+1)}, \frac{C(S)}{R(S)} = \frac{K}{s^2T+s+K} = \frac{K}{s^2+\frac{s}{T}+\frac{K}{T}}$

Which gives response similar to eq (3), (4), (5) depending upon the value of K.
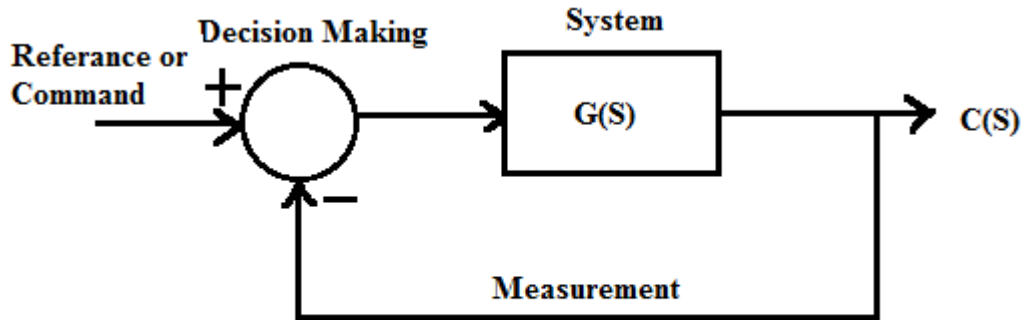
Block Diagram of a Closed Loop System
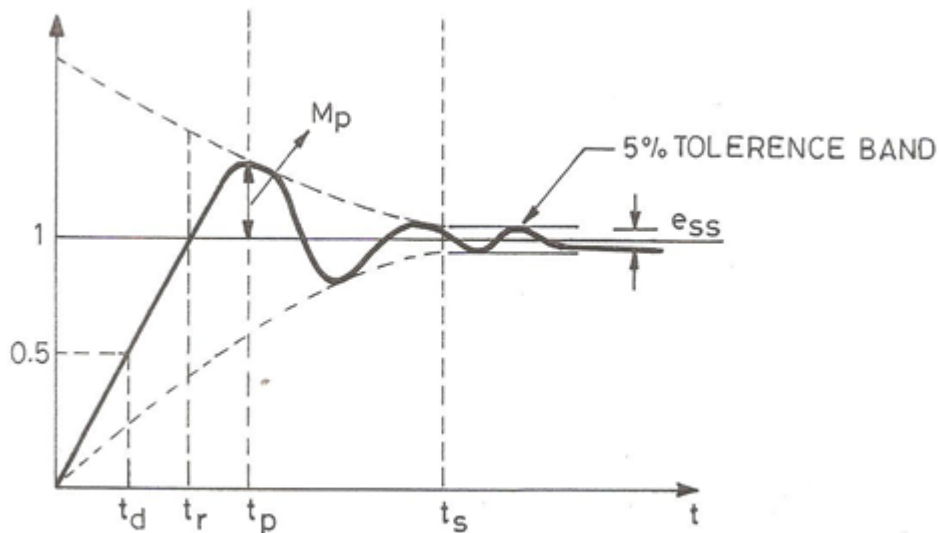
Step Response of an Underdamped System

Thus the response of a closed loop system can be altered by varying the open loop gain K and as a consequence it should be possible to choose K to obtain a suitable performance. This leads to the concept of performance characteristics as defined on the step response of an underdamped second order system in above figure.

(i)   Delay time(t_d): it is defined as the time needed for the response to reach 50% of the final value

(ii) **Rise time(t_r):** it is the time taken for the response to reach 100% of the final value for the first time**.**

$$t_r = \frac{\pi - \beta}{\omega_d}, \text{ where } \beta = \tan^{-1} \frac{\sqrt{(1-\delta^2)}}{\delta}$$

(iii) **Peak time(t_p):** it the time taken for the response to reach the first peak of the overshoot**.**

$$t_p = \frac{\pi}{\omega_n \sqrt{(1-\delta^2)}}$$

(iv) **Maximum overshoot (M_p):** is straight way difference between the magnitude of the highest peak of time response and magnitude of its steady state. Maximum overshoot is expressed in term of percentage of steady-state value of the response. As the first peak of response is normally maximum in magnitude, maximum overshoot is simply normalized difference between first peak and steady-state value of a response.

$$M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} \times 100\% = e^{-\frac{\pi\delta}{\sqrt{1-\delta^2}} \times 100\%}$$

Its value indicates the relative stability of the system.

(v) **Settling time(ts):** is the required by the system response to reach and stay within a prescribed tolerance band, which is usually taken as +_ 2% or +_5%. An approximate calculation base on the envelops of the response for a low damping ratio system yields, t_s($\pm$5% tolerance band)=3/$\delta\omega_n$

   t_s($\pm$2% tolerance band)=4/$\delta\omega_n$

(vi) **Steady state errors(e_{ss}):** for unity feedback system, e_{ss} is defined as
$$e_{ss} = \lim_{t \to \infty} (r(t) - c(t))$$

A simpler way to calculate steady state error without actually computing the time response is available in the complex frequency domain. Application of final value theorem of Laplace Transform to unity feedback system gives

$$e_{ss} = \lim_{s \to \infty} sE(s) = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)}$$

STEP RESPONSE – FIRST ORDER SYSTEM

- Two forms of first order closed loop system, as shown in bellow figure are possible. Make proper connections for the configuration chosen.

- Apply a 1 volt p-p square wave input and trace the output waveform on a tracing paper for K = 0.5, 1.0, 1.5 …….. Calculate the time constant in each case and compare with theoretical results.

- If the open loop transfer function in the chosen configuration was of type-1, the steady state error above would be zero for a step input.

- Tabulate the result in the following table.

K	Time Constant		Steady State Error	
	Experimental	Theoretical	Experimental	Theoretical
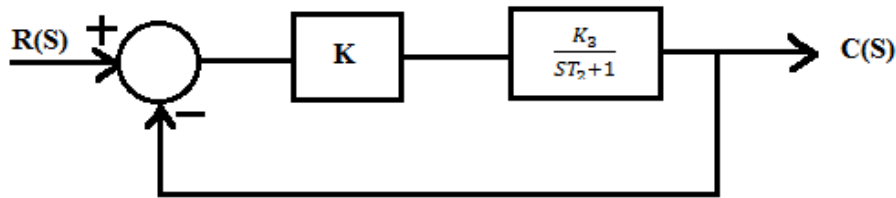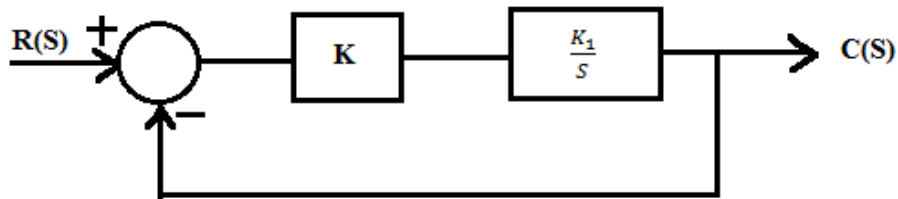
Closed Loop Options for First Order Ststem

STEP RESPONSE – SECOND ORDER SYSTEM

- Form a suitable second order system configuration as shown in the figure below.
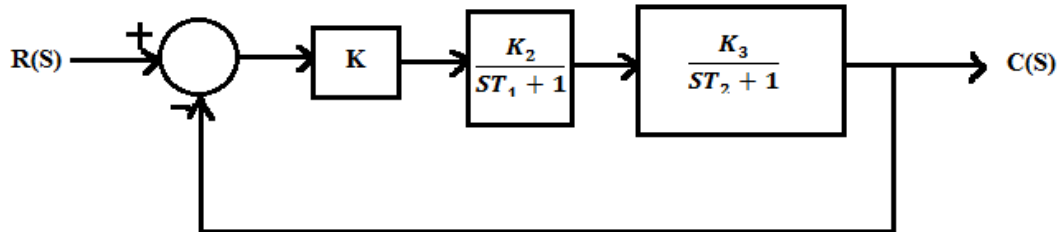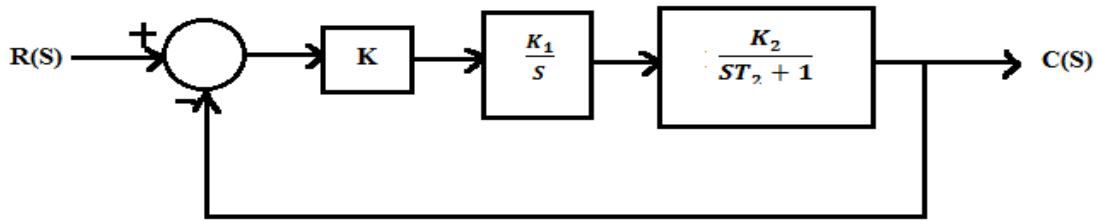
- Apply a 1 volt p-p square wave input and trace the output waveform on a tracing paper for different values of K. Obtain peak percent overshoot, settling time, rise time and steady state errors from the tracing and calculate ζ and ω_n. compare with theoretical results.
- Tabulate the result in the following table

- If the open loop transfer function in the chosen configuration was of type-1, the steady state error above would be zero for a step input.

- Tabulate the results in the following table.

K	M_p	t_r	t_P	t_s	ζ		ω_n	
					Expt.	Theo	Expt.	Theo

LIMITATIONS OF THE SYSTEM

The accuracy of the results in an experimental measurement is always limited. Most measurements are done using a CRO which may not be better than $\pm$ 5%

QUESTIONS

1. Give an example of 1st order & 2nd order system.
2. Write down the merits & demerits of a closed loop system.
3. Develop the circuit configurations which simulate the 'Integrator'.
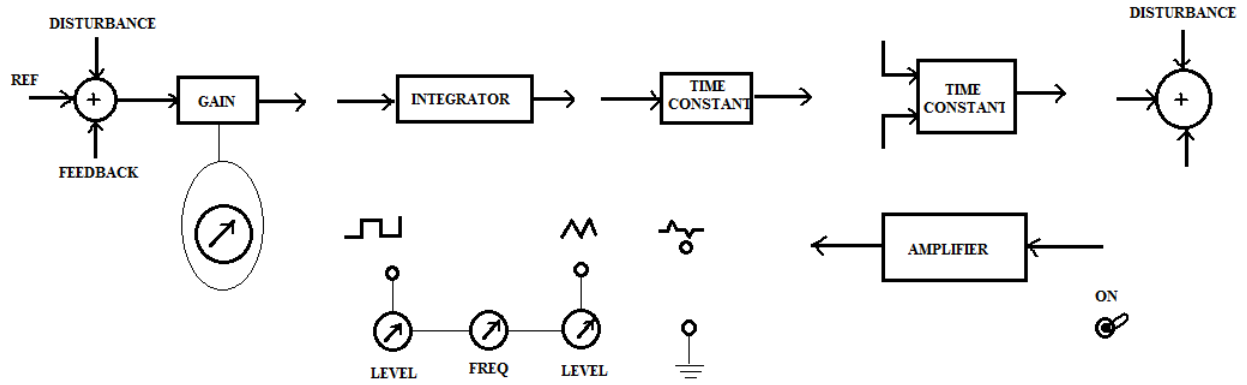
PANEL DRAWING

SIMULATION OF STEP RESPONSE & IMPULSE RESPONSE FOR TYPE-0 , TYPE-1 & TYPE–2 SYSTEM WITH UNITY FEEDBACK USING MATLAB & PSPICE.

Objectives:
- Developing MATLAB Program to find the step & impulse response of a system.
- Building simple Simulink simulations to find step & impulse response of a closed loop system.
- Transient analysis using PSPICE

To determine the response of a system using MATLAB first the system is to be modeled to get the transfer function. The transfer function is to be expressed as a ratio of two polynomials, *numerator* polynomial & *denominator* polynomial.

Two MATLAB-vectors, one containing the coefficients of the numerator polynomial (denoted by "**num")** taken in descending orders - and one for the denominator polynomial (denoted by "**den")** of the transfer function are created.

Once **num** & **den** are known, MATLAB command

step(num,den) or *step(num,den,t)*

Will generate plots of the unit step responses of the given system. The user specified time is given by 't' in the step command.

The unit impulse response of a system can be obtained using MATLAB command

impulse(num,den,t)

To determine the response to an arbitrary input, the command *lsim* may be used.

lsim(num,den,r,t), r is the input time function.

Another way to find the step & impulse response using MATLAB is to use **LTI Viewer**. It is a graphical user interface for viewing and manipulating response plots of LTI system.

The MATLAB command *ltiview('step',sys)* will open a window displaying the step response of the LTI model sys.

ASSIGNMENT

1. Open MATLAB command window. Observe the commands step, ramp, lsim, ltiview

2. Form a type-0, 1st order system with unity feedback. Find the step & impulse response of the system.

3. Form a type-0, 2nd order system with unity feedback. Find the step & impulse response of the system.

4. Form a type-1, 2nd order system with unity feedback. Find the step & impulse response of the system.

5. Form a type-2, 3rd order system with unity feedback. Find the step & impulse response of the system.

6. Use LTI Viewer to find the step response of the system $\frac{C(s)}{R(s)} = \frac{8}{s^2+2s+15}$. From the response determine the step response specifications.

7. Use SIMULINK to compare the response obtained from the unit step input for the systems considered in question 3 and 4.

HOMEWORK:

1. Form a type-0, 3rd order system with feedback $H(S) = \frac{S}{(S+1)(S+2)}$. Find the step and impulse response of the system.
2. Use LTI Viewer to find the step response of the system $\frac{C(s)}{R(s)} = \frac{(S+2)}{(S+5)(S+7)}$. From the response determine the step response specifications.
3. Use SIMULINK to compare the response obtained from the impulse response for the system considered in question 1 and a type-1, 3rd order system with unity feedback.

EXPERIMENT NO. PC EE 593 / 4

DETERMINATION OF ROOT LOCUS, BODE- PLOT, NYQUIST PLOT USING MATLAB CONTROL SYSTEM TOOLBOX FOR 2ND ORDER SYSTEM & DETERMINATION OF DIFFERERNT CONTROL SYSTEM SPECIFICATIONS FROM THE PLOT.

Objectives:
- Developing MATLAB Program to find the Root locus, Bode plot, Nyquist plot of open loop transfer function.
- Determining the closed loop poles from the root locus.
- To determine Frequency domain specifications from the Bode plot.

Consider open loop transfer function $sys = \dfrac{num}{den}$ where numerator polynomial is denoted by

"**num"** & for the denominator polynomial it is denoted by "**den".**

STABILITY USING ROUTH HURWITZ

routh(poly) makes a routh array and checks the stability of the system by finding if there are any roots on right half of the s-plane. It also displays the routh array band the reports about the stability of the system.

PLOTTING ROOT LOCI

rlocus(sys) computes and plots the root locus of the single-input, single-output LTI model dented by open loop transfer function 'sys' .

rlocus(sys,k) uses a user-specified vector K of gain values.

sgrid(z,wn) plots the grid lines for the given values of damping ratio z and natural frequency wn in row vector. If it is desired to omit either the constant z lines or constant wn circles, empty brackets [ ] can be used in the corresponding arguments of sgrid command. For example, sgrid(0.6, [ ]) will draw a line for damping ratio z=0.6 only and will not draw any circle.

rlocfind Find root locus gains for a given set of roots.

[k,poles] = rlocfind(sys) is used for interactive gain selection from the root locus plot of the SISO system SYS generated by *rlocus*. *rlocfind* puts up a crosshair cursor in the graphics window which is used to select a pole location on an existing root locus. The root locus gain associated with this point is returned in K and all the system poles for this gain are returned in POLES.

PLOTTING BODE PLOT

bode(sys) draws the Bode plot of the LTI model sys (created with either TF, ZPK, SS, or FRD). The frequency range and number of points are chosen automatically.

To specify the frequency range, use the command

w=logspace(d1,d2,n)

bode(sys,w)
Here MATLAB generates n points logarithmically equally spaced between decades 10^{d1} to 10^{d2}.

[gm,pm,wcg,wcp] = margin(sys) computes the gain margin Gm, the phase margin Pm, and the associated frequencies Wcg and Wcp, for the SISO open-loop model SYS.

DRAWING NYQUIST PLOT

The command *nyquist(sys)* draws the Nyquist plot of the LTI model sys (created with either TF, ZPK, SS, or FRD).

The command *nyquist(sys,w)* calculates the frequency response at the frequency point ω in rad/sec.

ASSIGNMENT

1. Open MATLAB command window. Observe the commands routh, rlocus, bode, nyquist, margin.
2. Consider the characteristic equations:
   a) $S^4 + 10S^3 + 2S^2 + 36S + 20 = 0$
   b) $S^5 + S^4 + 3S^3 + 3S^2 + 4S + 8 = 0$

   Check the stability with Routh-Hurwitz criterion using MATLAB.

3. Plot root locus and examine the stability of the following system using MATLAB:
$$G(S)H(S) = \frac{0.4K}{S^3 + 2S^2 + 4S + 5}$$
   If the gain K is varied over a range of:
   a) K=2,4,6,8
   b) K=2,4,6,8,10
4. Find the values of K for damping ratios mentioned in the following transfer functions using MATLAB:
   a) $\frac{K}{S(S+4)(S+5)}$ for ξ=0.5
   b) $\frac{K(2S+2)}{S(S+3)(S+4)}$ for ξ=0.4
5. Obtain the Bode diagrams for the following transfer functions in the specified frequency range using MATLAB:
$$G(S) = \frac{(S+5)}{S(S^2+3S+1)}, \omega=0.01 \text{ to } 1000 \text{ rad/sec}$$

6. Obtain the Bode plot of the system $\frac{50}{S^3+9S^2+30S+40}$. using MATLAB. From the plot determine gain margin, phase margin, gain cross-over frequency & phase cross-over frequency.
7. Consider unity feedback system with the following open-loop transfer function $G(s) = \frac{1}{S^2+S+1}$. Determine the Nyquist plot using MATLAB and examine the stability of the closed loop system.
8. Sketch a Nyquist plot for a system with the open loop transfer function (for K=10);
$$G(S) = \frac{K(1 + 0.5S)(S + 2)}{(1 + 5S)(S - 2)}$$

HOMEWORK:

1. Proof all the experimental results with theoretical calculations.

2. Consider the characteristic equations of a system are given by:

   a) $S^5 + 2S^4 + 4S^3 + 8S^2 + 3S + 1 = 0$
   b) $S^5 + 2S^4 + 2S^3 + 4S^2 + 4S + 8 = 0$

   Check the stability with Routh-Hurwitz criterion using MATLAB.

3. Consider a unity feedback system with the following transfer function:
$$G(S) = \frac{K}{S(S^2 + 2S + 3)}$$
   Plot the root locus and draw grid line for damping ratio, $\xi=0.5$. Determine closed loop poles that have the damping ratio $\xi=0.5$ and find the gain value, K at this point.

4. Obtain the gain and phase margins, phase cross over and phase cross over frequencies of the following transfer function: $G(S) = \frac{50}{S^3+9S^2+30S+40}$

5. Draw a Nyquist plot using MATLAB for the following transfer function: $G(S) = \frac{S+2}{S^2-1}$ and comment on stability.

EXPERIMENT NO. PC EE 593 / 5

DETERMINATION OF PI, PD,PID CONTROLLER ACTION OF FIRST ORDER SIMULATED PROCESS.

Objectives:
  - To determine the effect of controller on a system.

To achieve the desired control action a controller is used to modify the error signal to be finally fed to the plant.
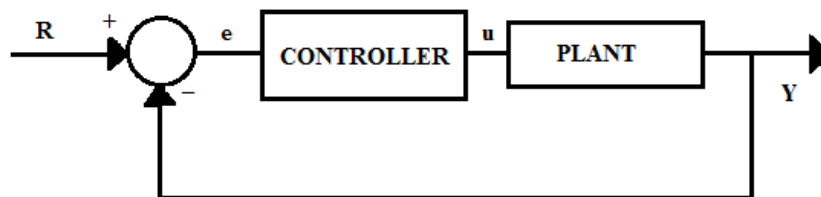
Controller can be on-off type or continuous type.

There are three basic modes of continuous control actions.

Proportional (P)

A proportional controller attempts to perform better than the On-off type by producing a control action that is proportional to the error. i.e. controller output = K_pe, with K_p being the proportional gain.

Derivative (D)

A derivative controller produces a control action that is proportional to the rate of change of the error. i.e. controller output = K_d(de/dt), with K_d being the derivative gain.

Integral (I)

A integral controller produces a control action that is proportional to the integral of the error. i.e. controller output = $K_i \int e.\,dt$, with K_i being the integral gain.

The transfer function of the PID controller looks like the following:

$$K_P + \frac{K_I}{S} + K_D S = \frac{K_D S^2 + K_P S + K_I}{S}$$

The Characteristics of P, I, and D controllers are as tabulated

CLOSE LOOP RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

Tips for Designing a PID Controller

1.   Obtain an open-loop response and determine what needs to be improved.

2.   Add a proportional control to improve the rise time

3.   Add a derivative control to improve the overshoot

4.   Add an integral control to eliminate the steady-state error

5.   Adjust each of Kp, Ki, and Kd until you obtain a desired overall response.

ASSIGNMENT

1. Consider unity feedback system with the following open-loop transfer function $G(s) = \frac{10}{(S^2+S+2)}$ .Determine closed loop transfer function of the system. Also determine the closed loop transfer function of the system with PD controller in the forward path with K_P=1 and K_D=0.2.

    Compare the step responses for the systems –

    a. Without PD controller
    b. With PD controller

2. Consider a unity feedback system with the following open-loop transfer function $G(s) = \frac{1}{(s+3)}$.

Design a PI controller satisfying the following requirements :
$\zeta = 1$ and $\omega_n = 5$ rad/sec

DETERMINATION OF APPROXIMATE TRANSFER FUNCTION EXPERIMENTALLY FROM BODE PLOT.

Objectives:
- To set up a 1ˢᵗ order system using RC circuit.
- Determine the frequency response to develop Bode Plot Experimentally
- Determine the Transfer function from the Bode plot.

A graphical approach is usually the easiest way to analyze and design feedback systems. Bode's method consists of plotting two curves, the log of gain, and phase, as functions of the log of frequency.

Usually the gain in decibels, abbreviated dB, and the phase are plotted linearly along the y axis on graph paper that has several cycles of a log scale on the x axis. Each cycle represents a factor of ten in frequency. This special paper is known as semilog graph paper

In this experiment, we will measure theMagnitude and Phase response of a RC-electrical circuit to a sinusoid at various frequencies.

The RC circuit is as shown in the figure.

By viewing the circuit as a voltage divider, the voltage across the capacitor is:

$$V_C(s) = \frac{1/Cs}{R + 1/Cs}V_{in}(s) = \frac{1}{1 + RCs}V_{in}(s)$$

The transfer function for the circuit is

$$H_C(s) = \frac{V_C(s)}{V_{in}(s)} = \frac{1}{1 + RCs}$$

The bode plot for the system is given by as shown in the plot.

The break frequency or the corner frequency will be at

$$w_C = \frac{1}{RC}$$
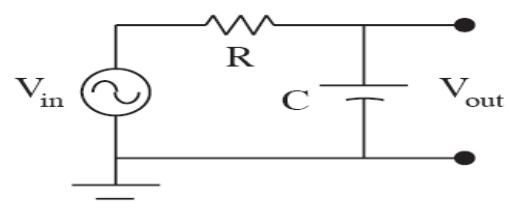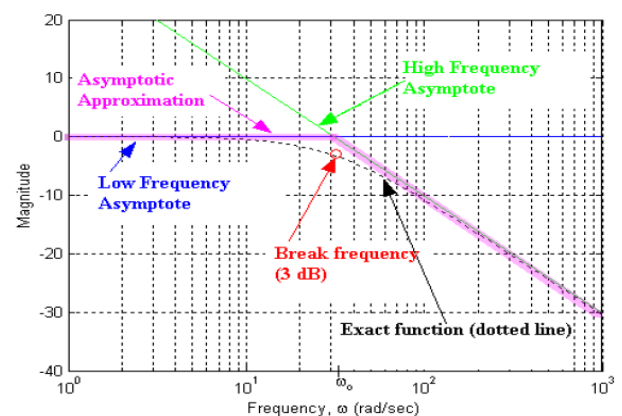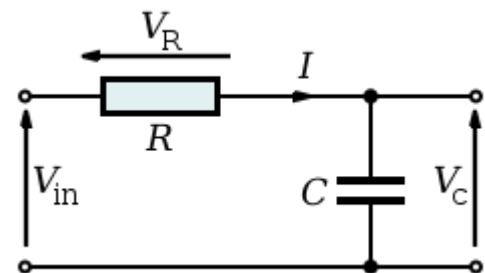
Procedure

- Set up the *RC* circuit using $C = 0.1\mu$F and $R = 1$Kω.
- A signal generator is used to generate variable frequency sine wave.
- Set the amplitude of the signal generator to 5 volt.
- The oscilloscope is connected to measure v_{in} and v_{out}. The peak-to-peak magnitudes of v_{in} and v_{out} are measured. The ratio of these magnitudes is equal to the transfer function magnitude.
- To measure the phase using an oscilloscope, the oscilloscope is triggered by vin(t), and the time per division is adjusted so that one period of vin nearly fills the entire width of the screen (from the left edge of the graticule to the right edge). The trigger and horizontal position controls are adjusted so that a positive-going zero crossing of vin(t) occurs at the center of the screen. The positive-going zero crossing of v_{out}(t) is then found, and the horizontal distance between the positive-going zero crossings of v_{out} and vin is measured. The phase shift between v_{out} and v_{in} is then given by

$$< H(j\omega) =< \hat{V}_{out} -< \hat{V}_{in}$$
$$= (360^0)\frac{(time\ between\ zero\ crossing)}{(waveform\ period)}$$

- Change the frequency of the signal generator and tabulate the data in Table – I.
- Draw the Bode plot using the experimental results.
- Determine the slope of the Bode plot (dB per decade) in the high or low frequency
- limit . Make a plot of your data together with a theoretical function drawn through (or near?) the data.
- Determine the frequency at which low frequency asymptote meats with the high frequency asymptote. This gives the corner frequency.
- Compare your measured value to the calculated value.

Table - I

Frequency(f)	V_{IN}	V_{OUT}	$\|M\| = \left\|\dfrac{V_{OUT}}{V_{IN}}\right\|$	$20Log_{10}\|M\|$	Δt	φ

EXPERIMENT NO. PC EE 593 / 7

EVALUATION OF STEADY STATE ERROR, SETTING TIME, PERCENTAGE PEAK OVERSHOOT, GAIN MARGIN, PHASE MARGIN WITH ADDITION OF LEAD COMPENSATOR & BY COMPENSATOR IN FORWARD PATH TRANSFER FUNCTION FOR UNITY FEED BACK CONTROL SYSTEM USING PSPICE OR OTHERWISE.

Objectives:
- To determine the effect of adding a Lead compensator in forward path transfer function.
- To compare the unit step response parameter of an uncompensated & compensated system.

Software used – MATLAB

The most important thing for the design of the controller to control one process or a system is to select the controller that fits to the process. Selecting the appropriate controller that is suitable for the process is no less than completing 90% of the design work.

Lead Compensator or Lead Controller is the same terminology and let's call it $G_C(s)$. This consists of one pole point and one zero point and can be expressed as
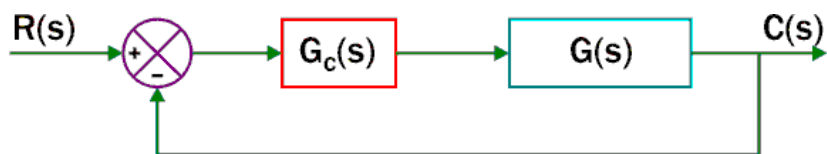

$$G_C(s) = \frac{s+a}{s+b}$$

Goal of compensation is to improve system dynamics in **transient** and **steady-state** responses

Lead compensation: typically used when substantial improvement in damping is required. The effect of lead compensator is similar to that of adding a PD controller.
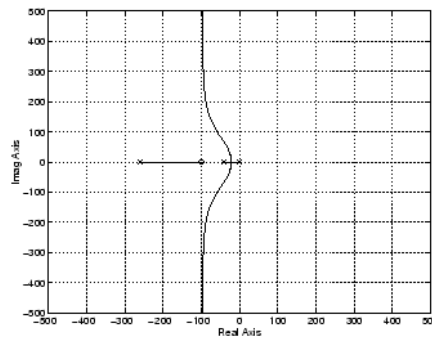
Lag compensation: to improve steady-state response characteristics without changing transient response characteristics significantly. The effect of Lag compensator is similar to that of adding a PI controller

Lead+Lag compensation : when improvements in both phase margin and low- frequency gain are needed

The lead compensator helps speed the response of the system by moving the closed-loop poles to the left. Without the lead compensator, the root locus has a vertical asymptote halfway between the integrator (s=0) and the open loop pole (as shown below).
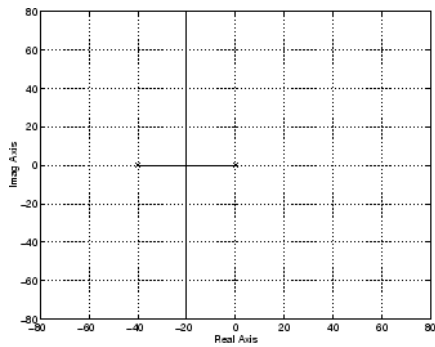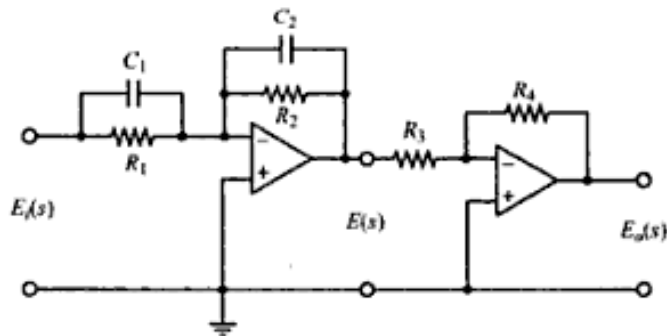
Uncompensated Root Locus   Compensated Root Locus

The lead compensator can be realized using the following circuit.

The transfer function is given by

$$\frac{E_o(s)}{E_i(s)} = \frac{R_2 R_4}{R_1 R_3} \frac{R_1 C_1 s + 1}{R_2 C_2 s + 1} = \frac{R_4 C_1}{R_3 C_2} \frac{s + \dfrac{1}{R_1 C_1}}{s + \dfrac{1}{R_2 C_2}}$$

$$= K_c \alpha \frac{Ts + 1}{\alpha Ts + 1} = K_c \frac{s + \dfrac{1}{T}}{s + \dfrac{1}{\alpha T}}$$

where

$$T = R_1 C_1, \qquad \alpha T = R_2 C_2, \qquad K_c = \frac{R_4 C_1}{R_3 C_2}$$

$$\frac{E_0(S)}{E_i(S)} = \frac{R_2 R_4 R_1 C_1 S + 1}{R_1 R_3 R_2 C_2 S + 1} = \frac{R_4 C_1 S + \dfrac{1}{R_1 C_1}}{R_3 C_2 S + \dfrac{1}{R_2 C_2}}$$

$$\alpha \frac{+1}{}$$

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ASSIGNMENT - 1

Open-loop transfer function of a unity feedback system is given by
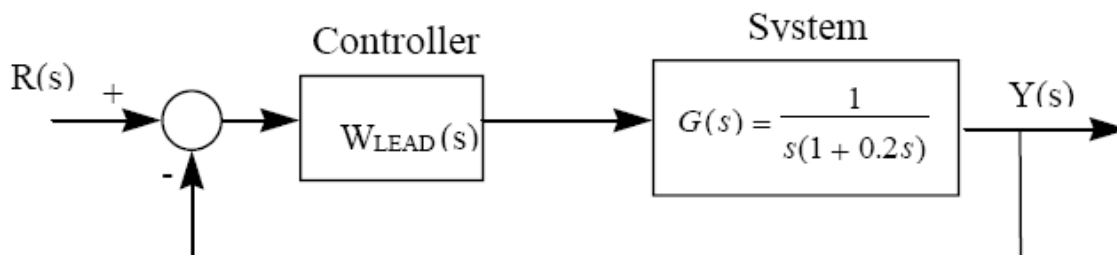
$$G(s) = \frac{1}{s(1+0.2s)}$$

Using MATLAB plot the unit step response of the uncompensated & compensated system using lead compensator given by

$$G_C(s) = \frac{s+0.088}{s+0.022}$$

Compare the performance characteristics.

ASSIGNMENT - 2

Consider a unity feedback system

A lead compensator is introduced into the forward path where,

$$W_{LEAD}(s) = \frac{s+0.3}{s+0.03}$$

Determine the bode plot of the compensated system.
Determine the peak magnitude & the bandwidth of the closed loop frequency response.

STUDY OF A PRACTICAL POSITION CONTROL SYSTEM & DETERMINATION OF CONTROL SYSTEM SPECIFICATIONS FOR VARIATION OF SYSTEM PARAMETERS.

Objectives:
- To study & observe the performance characteristics of a dc angular position control system.

The schematic diagram in Fig. 1 shows the various built-in subsystems of the set up.
The position control is achieved through a good quality permanent magnet dc gear motor having the specifications :

- Operating voltage – 12 V dc
- Full load current – 1.2 amp
- Rated speed – 50 rpm
- Torque (basic) – 750 gm-cm (approx)

Angular position of the motor shaft is sensed by a special 360^0 potentiometer attached to it. A calibrated disk mounted on the potentiometer indicates its angular position in degrees.

BACKGROUND

3.1 Position Control - a second order system

A second order system is represented in the standard form as,

$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

where δ is called the damping ratio and ω_n the undamped natural frequency. Depending upon the value of δ, the poles of the system may be real, repeated or complex conjugate which is reflected in the nature of its step response. Results obtained for various cases are :

(a) underdamped case $(0<\delta<1)$

$$c(t) = 1 - \frac{e^{-\delta\omega_n t}}{\sqrt{(1-\delta^2)}} \sin(\omega_d t + \tan^{-1}\frac{\sqrt{(1-\delta^2)}}{\delta}) \qquad (1)$$

where, $\omega_d = \omega_n\sqrt{(1-\delta^2)}$ is termed the damped natural frequency. A sketch of the unit step response for various values of δ is available in the text books.
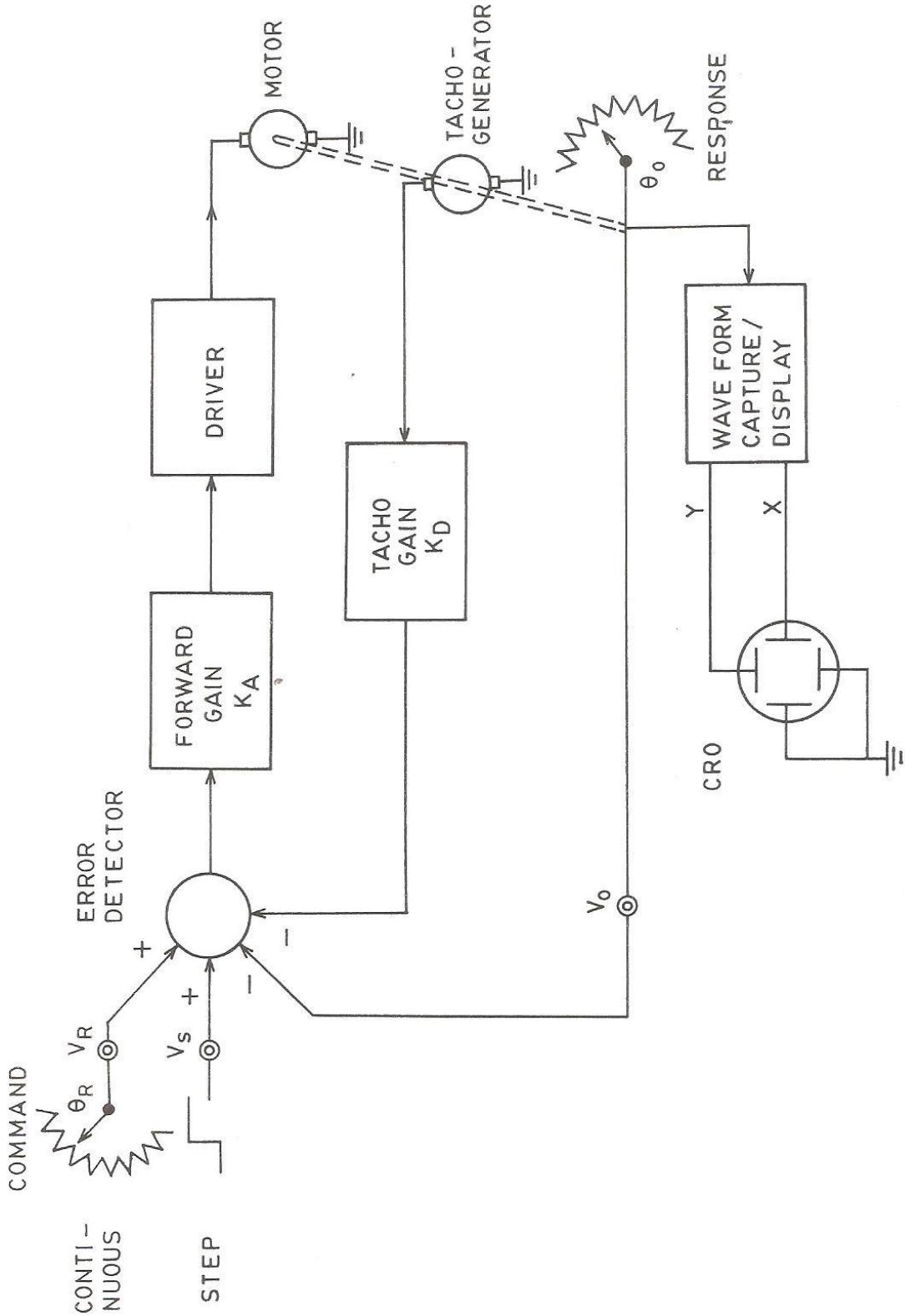
FIG. 1 SYSTEM SCHEMATIC

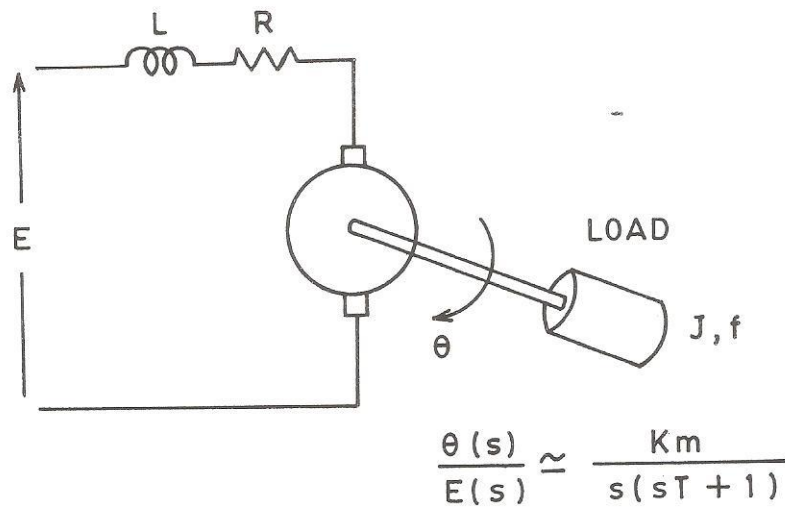$$\frac{\theta(s)}{E(s)} \simeq \frac{Km}{s(sT+1)}$$

FIG. 2 TRANSFER FUNCTION OF A D.C. MOTOR
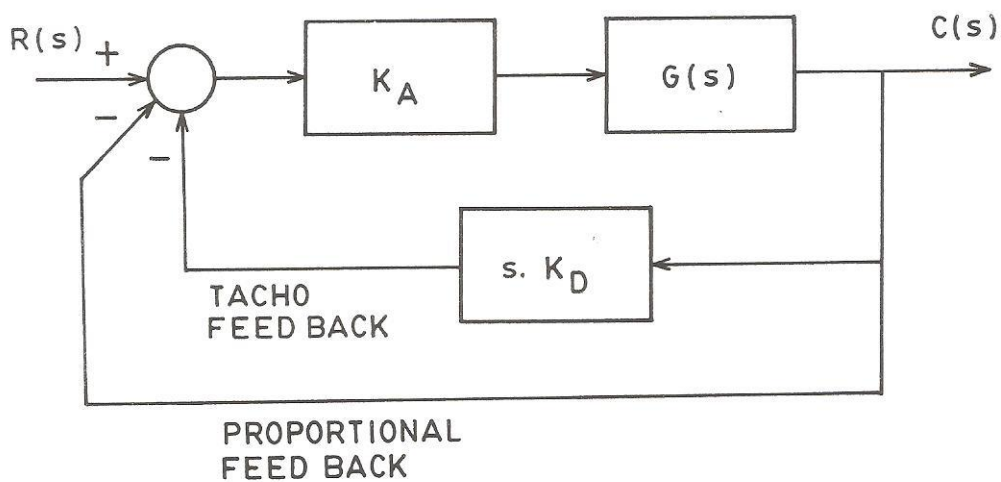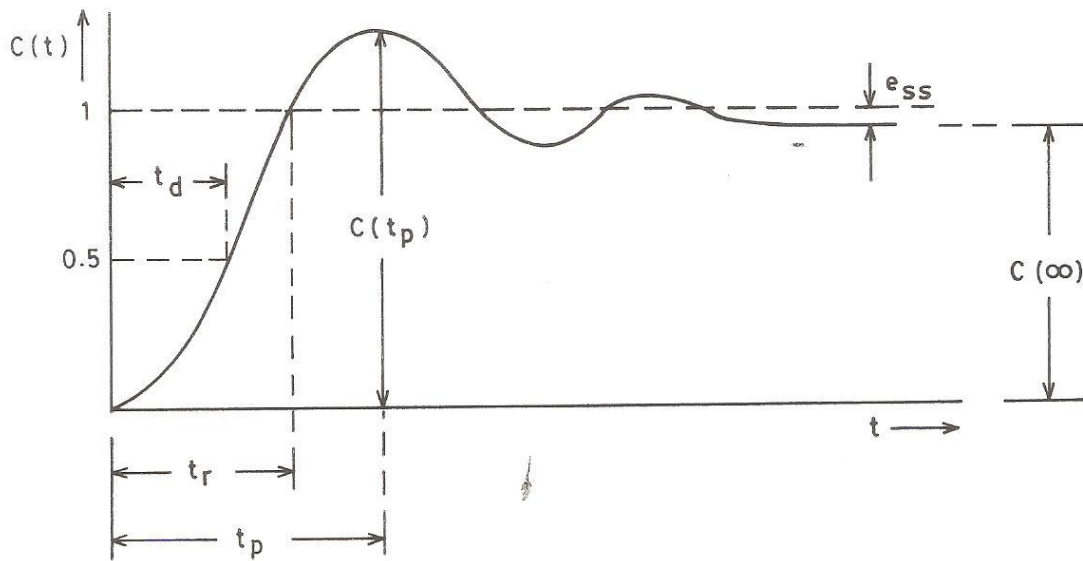

FIG. 3 SIMPLIFIED BLOCK DIAGRAM

FIG. 4   NORMALIZED STEP RESPONSE OF THE
         SECOND ORDER SYSTEM
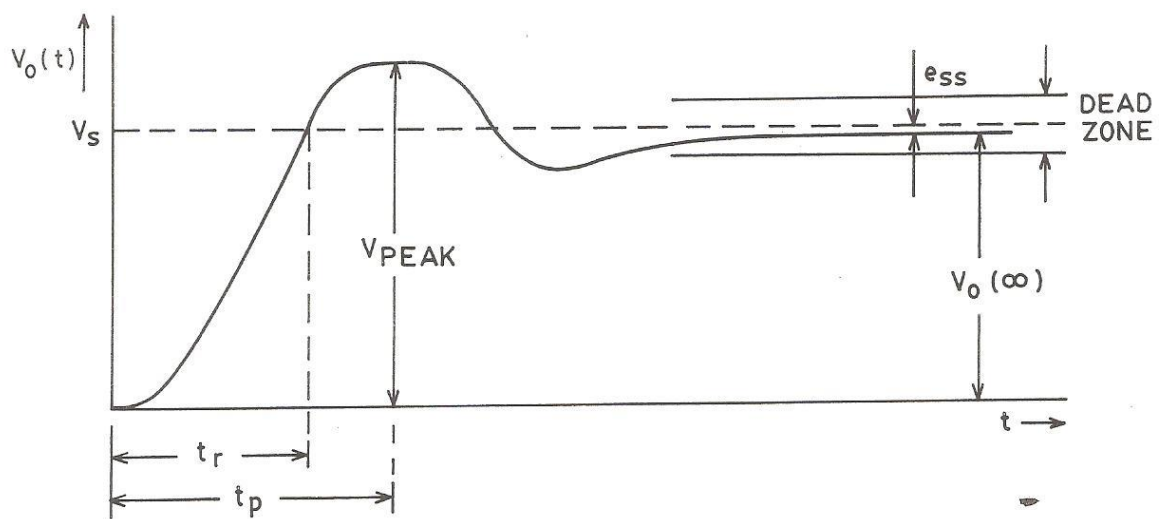

FIG. 5   TYPICAL STEP RESPONSE OF THE POSITION
         CONTROL SYSTEM

SILIGURI INSTITUTE OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL ENGINEERING

(b) Critically damped case ($\delta = 1$)

$$c(t) = 1 - e^{-\omega_n t}(1 + \omega_n t) \qquad (2)$$

(c) Overdamped case ($\delta > 1$)

$$c(t) = 1 - \frac{\omega_n}{2\sqrt{(1-\delta^2)}}\left(\frac{e^{-s_1 t}}{s_1} - \frac{e^{-s_2 t}}{s_2}\right) \qquad (3)$$

where $s_1 = (\delta + \sqrt{(\delta^2 - 1)})\omega_n$ and $s_2 = (\delta - \sqrt{(\delta^2 - 1)})\omega_n$

Referring to Fig. 2, the transfer function G(s) of an armature controlled d.c. motor may be derived as [1],

$$\frac{\theta(s)}{E(s)} = G(s) = \frac{K_m}{s(sT + 1)}$$

where K_m is Motor gain constant, and T the Mechanical time constant.

Considering proportional feedback only, the close loop transfer function of the system of Fig. 3 may be obtained as,

$$\frac{C(s)}{R(s)} = \frac{K_A G(s)}{1 + K_A G(s)} = \frac{K_A K_m / T}{(s^2 + s/T + K_A K_m / T)} \qquad (4)$$

This gives unit step response similar to equations (1), (2) or (3) depending upon the value of K_A. Thus the response of the position control system can be altered by varying the amplifier gain K_A, and a 'satisfactory' performance may usually be obtained. This leads to the concept of performance characteristics as defined on the step response of an underdamped second order system in Fig. 4 and explained in brief here.

(i) **Delay time**, t_d, is defined as the time needed for the response to reach 50% of the final value.

(ii) **Rise time**, t_r, is the time taken for the response to reach 100% of the final value for the first time. This is given by

$$t_r = \frac{\pi - \beta}{\omega_d}, \text{ where } \beta = \tan^{-1}\frac{\sqrt{(1-\delta^2)}}{\delta}$$

(iii) **Peak time**, t_p, is the time taken for the response to reach the first peak of the overshoot and is given by

$$t_p = \frac{\pi}{\omega_n\sqrt{(1-\delta^2)}}$$

(iv) **Maximum Overshoot**, M_p, is defined by

$$M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} \times 100\%$$

(v) **Settling time**, t_s, is the time required by the system response to reach and stay within a prescribed tolerance band which is usually taken as ±2% or ±5%. An approximate calculation based on the envelops of the response for a low damping ratio system yields

t_s (±5% tolerance band) = $3/\delta\omega_n$

t_s (±2% tolerance band) = $4/\delta\omega_n$

Another important characteristic of a closed loop system is the steady state error, e_{ss}. For unity feedback systems e_{ss} is defined as

$$e_{ss} = \lim_{t \to \infty} e(t) = \lim_{t \to \infty} \{r(t) - c(t)\}$$

A simpler way to calculate steady state error without actually computing the time response is available in the complex frequency domain. Application of the final value theorem of Laplace Transform to unity feedback system gives,

$$e_{ss} = \lim_{t \to \infty} e(t) = \lim_{s \to 0} sE(s) = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)}$$

CLOSED LOOP STUDY

The steps are as follows.

- Ensure that the step command is switched off
- Set $K_D = 0$.
- Set $K_A = 2$.
- Calculate $\theta_R, V_R, \theta_0, V_0$ in Table – I.
- Calculate $\Delta\theta_R, \Delta\theta_0$
- Repeat for $K_A = 4.6, 8, 10$
- Now set $K_A = 2$ and choose various values of $K_D = 0.1, 0.3, 0.5, 0.7$ and repeat the above observations in Table - II

TABLE - I

K	θ_R	$\Delta\theta_R$	θ_0	$\Delta\theta_0$	V_R	V_0

TABLE - II

K_D	θ_R	$\Delta\theta_R$	θ_0	$\Delta\theta_0$	V_R	V_0

Step response

The steps are as follows

- Set $K_D = 0$.
- Adjust reference potentiometer to get $V_R = 0$.
- Set $K_A = 5$.
- Connect the CRO, calibrate the time scale and switch to CAPTURE mode.
- Apply step input
- Trace the waveform from the CRO.
- Compute $M_P, \xi, t_p, t_r, e_{ss}$.
- Repeat for $K_A = 8, 10$
- Tabulate the results in Table - III

TABLE - III

K_A	M_P	t_p (ms)	t_r (ms)	ξ	e_{ss} (volt)	w_n

CALCULATIONS

$e_{ss} = V_s - V_o$, where V_s & V_o may be measured by DVM.

$$M_p = \frac{V_{PEAK} - V_o(\alpha)}{V_o(\alpha)} \times 100\%$$

t_p and t_r may be obtained from CRO

ξ may be calculated from M_p using the standard relation

$M_p = \exp[-\pi\xi/(\sqrt{1-\xi^2})]$

Thus,

$\xi = \text{Ln } M_p/\sqrt{\{\pi^2 + (\text{Ln } M_p)^2\}}$

ω_n is calculated from the expression of t_p which is given by $t_p = [\pi/\omega_n(\sqrt{1-\xi^2})]$

Thus

$\omega_n = \pi/t_p(\sqrt{1-\xi^2})$

LABORATORY INSTRUCTION MANUAL

CONTROL SYSTEM LAB - II
EE 691

Lab Manual version: January, 2016

DEPARTMENT OF ELECTRICAL ENGINEERING

SILIGURI INSTITUTE OF TECHNOLOGY

General Information

All assigned experiments must be performed in order to pass the class. Most of the work for an experiment should be done during class time in the laboratory. In order to allow for further analysis and graphing, the notebooks are due at the start of the laboratory the following week. Submit your completed notebook to the instructors Evaluation of laboratory performance is based on the instructor's observations of you while you are performing the experiments. Among the factors considered are your ability to construct circuits, your competency in using test equipment, your preparation prior to starting the experiment, answers given to any questions asked during the laboratory, as well as attendance, tardiness, and attitude. Keep in mind that your behaviour influences your grade; act professionally at all times.

The following guidelines should be followed when using your notebook:

- The first page should contain a table of contents.
- All pages in the notebook must bound, numbered and dated.
- Use a pen or permanent marker, never pencil.
- Write legibly and coherently. Extreme neatness is not required but anyone should be able to read and understand what you have written.
- Never erase errors or remove pages. Simply draw a line through any mistakes.
- The notebook should be a complete record of your work, i.e. what you actually do in the laboratory, and sufficiently detailed that a knowledgeable person could reconstruct what you did.
- All measurements, notes, and calculations should be directly recorded in the notebook. Never write information on scraps of paper for later transcription into the notebook.
- Do not paste the laboratory manual into your notebook
- Any graphs or printouts relevant to the experiment should be pasted into your notebook.
- Be sure to label all diagrams, schematics, graphs, and waveform printouts.
- All numbers should include appropriate units.
- Include an equipment list.

Electrical Engineering Laboratory Regulations

<u>**General**</u>

Students working the electrical laboratories should be very cautious during the lab work. The electric potentials used in many experiments are dangerous and may cause injury. Students must observe all safety precautions and must not work alone with potentials exceeding 25 V. The rotating machines used in some experiments are dangerous. Keep loose clothing, jewellery, and other objects away from any rotating parts.
Food and drinks are not permitted in the laboratories.

<u>**Equipment**</u>

All equipment must be returned to its proper storage location at the end of the lab period. Instruments and equipment are delicate and expensive. Improper use of equipment can result in instantaneous damage; check with you instructor or the equipment's manual if you are in doubt.
Damaged or faulty equipment should be given to the technicians/instructor along with a description of the problem.

Siliguri Institute of Technology

Electrical Engineering Department

Laboratory Work Book for Control System-II Lab (EE-691)

NAME:

ROLL NO.:

REGISTRATION NO.:

GROUP NO:

INDEX

Expt No.	Experiment Name	Date of Experiment	Submission Date	Page No.	Signature of Teacher

Siliguri Institute of Technology

Electrical Engineering Department

Laboratory Work Book for Control System-II Lab (EE-691)

Title Sheet

Experiment No   **:**

Experiment Name   **:**

Date of Experiment   **:**

Submission Date   **:**

Student Name   **:**

Roll No.   **:**

Group   **:**

Signature of Student:

Siliguri Institute of Technology

Electrical Engineering Department

Laboratory Work Book for Control System-II Lab (EE-691)

**NAME:**

ROLL NO.:

REGISTRATION NO.:

GROUP NO:

The Students can able to develop the following skills from Control System-II (EE-691) Laboratory:

Skill	Experiments							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. PC based simulation as well as Hardware based analysis of Practical position control system	√							
2. PC based as well as Hardware based tuning of PID controller.		√						
3. PC based design of Lag and Lead compensator			√					
4. PC based analysis of different dynamic system using State variable analysis.				√	√			
5. PC based performance analysis of discrete time system.						√	√	
6. PC based analysis the effect of Nonlinearities in a feedback controlled system.								√
7. Function effectively as an individual and as a team.	√	√	√	√	√	√	√	√
8. Improve communication Skill	√	√	√	√	√	√	√	√
9. Write effective technical reports and design documentation.	√	√	√	√	√	√	√	√

STUDY OF A PRACTICAL POSITION CONTROL SYSTEM. Obtaining closed step responses for gain setting corresponding to over-damped and under-damped responses. Determination of rise time and peak time using individualized components in SIMULINK. Determination of un-damped natural frequency and damping ratio from the experimental data.

Objectives:
a. Modeling a practical position control system using individualized components in SIMULINK.
b. Obtaining step responses for different gain settings.
c. Determination of un-damped natural frequency and damping ratio.

The practical setup of a position control system is shown in the figure below. The input and output of the system are the input shaft position and the output shaft position respectively.
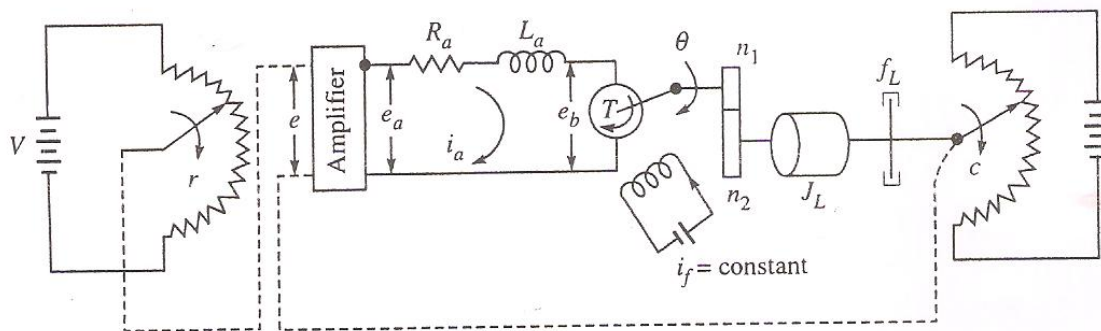
The detailed block diagram considering individual components of the system is shown in the figure below.
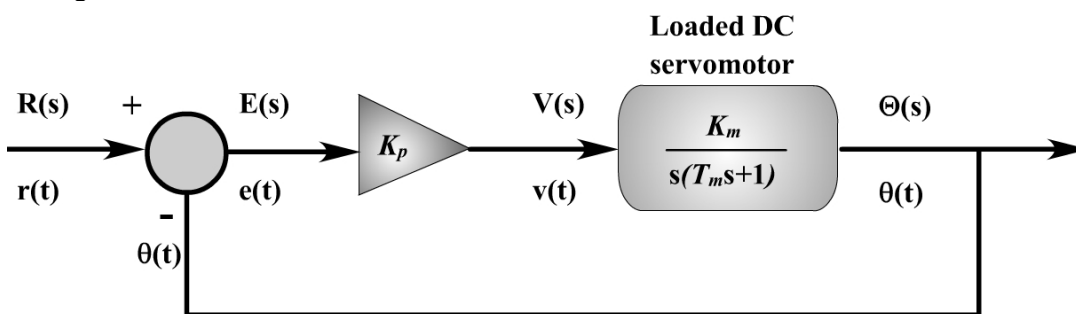
Here,

K_P= Amplifier Gain

And considering $K_m = 10$ and $T_m = 0.25$ $K_m = 10$ and T_m =0.23

The closed loop system transfer function is given by:

$$\frac{\Theta(s)}{R(s)} = \frac{K_p K_m}{s^2 T_m + s + K_p K_m}$$

Depending on system parameters and the controller gain that we use, the step response could be oscillatory (under damped), critically damped or over damped.

Critical damping condition

For critical damping, the denominator of the closed loop transfer function should have equal roots. The roots will be equal if and only if
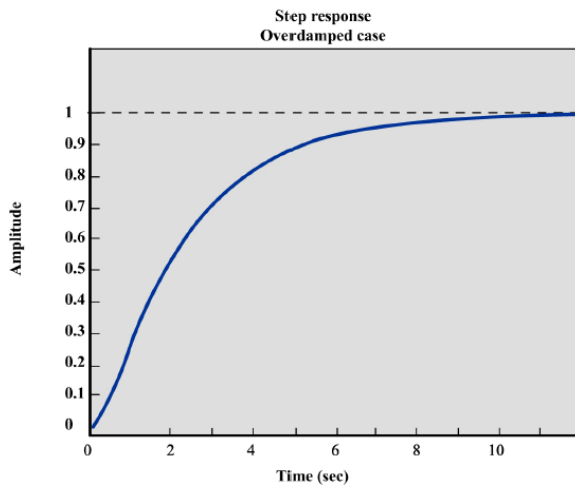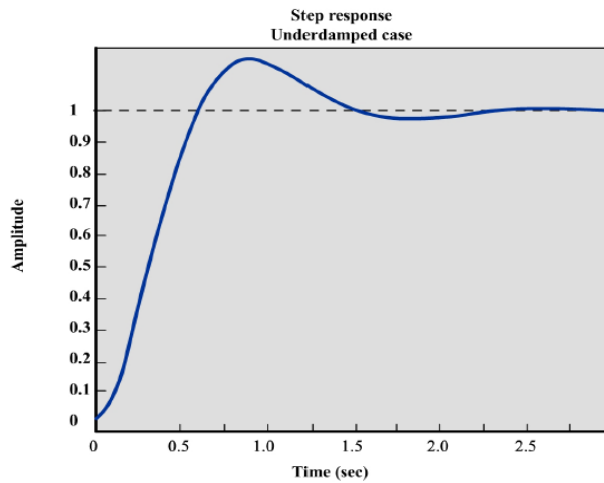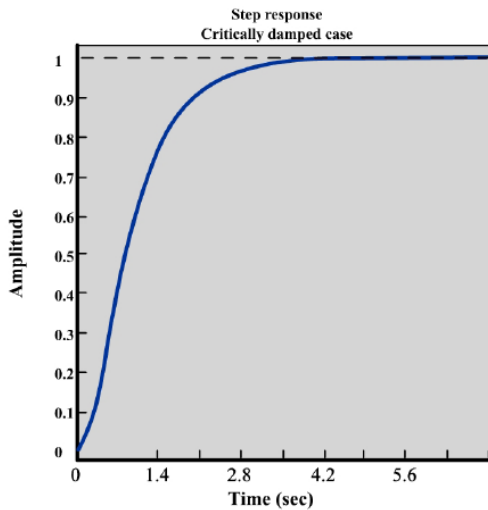
$$1 - 4K_p K_m T_m = 0$$

or

$$K_p^{cr} = K_p = \frac{1}{4K_m T_m}$$
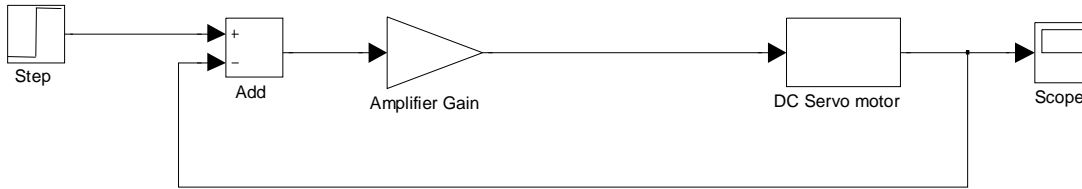
Thus the value of amplifier gain at critical damping condition is

$$K_p = \frac{1}{4K_m T_m} = \frac{1}{4(10)(0.23)} = 0.1$$

The following graphs show the step response for different gain values

Step response
Critically damped case

Step response
Underdamped case

Step response
Overdamped case

Experiment

1. Using SIMULINK develop the block diagram of the position control system.

Take T_m=0.23, K_m=Last two digits of your Roll no.

2. Determine the value of Amplifier gain to have critical damping condition.

3. Simulate the system for different value of Amplifier gain.

4. Tabulate the simulation result for different values of the amplifier gain from the output response graph.

Amplifier Gain (K_P)	Rise Time (t_r)	Delay Time (t_d)	Peak Time (t_p)	Peak Value (M_p)	Settling Time (t_{ss})

Report

Calculate the **un-damped natural frequency (ω_n)** and **damping ratio (ζ)** using the following method.
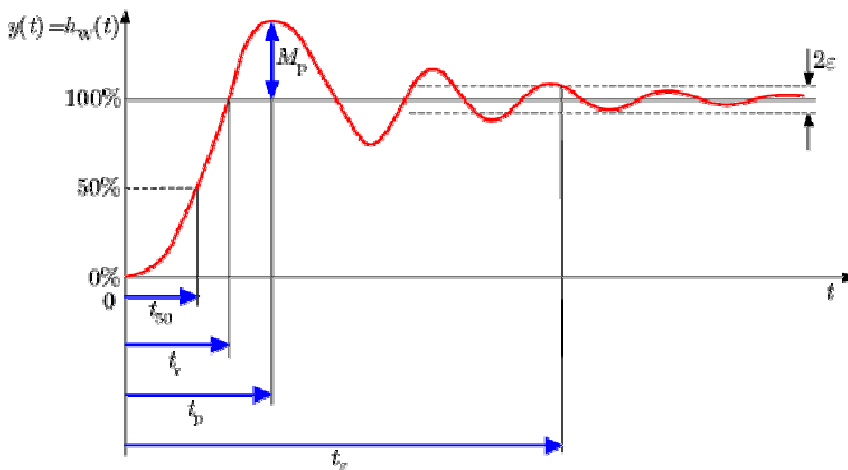
The **Peak Time (t_p)** is given by

$$t_p = \frac{\pi}{\omega_n \sqrt{(1-\xi^2)}}$$

The **Rise Time (t_r)** is given by

$$t_r = \frac{\pi - \cos^{-1} \xi}{\omega_n \sqrt{(1-\xi^2)}}$$

The **Delay Time (t_d)** is given by

$$t_d = \frac{1+0.7\xi}{\omega_n}$$

Using the above relationship and the result obtained from the experimental data determine the **un-damped natural frequency (ω_n)** and **damping ratio (ζ)** and tabulate the result.

Amplifier Gain (K_P)	Un-damped natural frequency (ω_n)	Damping ratio (ζ)

EXPERIMENT NO. 2

TUNING OF P, PI, AND PID CONTROLLER FOR FIRST ORDER PLANT WITH DEAD TIME USING Z-N METHOD. Process parameters (time constant and delay/lag) will be provided, the students would compute controller gains by using Z-N method. Steady state and transient performance of the closed loop plant with and without steady disturbances will have to be noted. Theoretical phase and gain margins will have to be manually computed for each gain settings.

Objectives:
  a. Introduction to PID controller using Z-N Method
  b. Computation of controller gain using Z-N method.
  c. Closed loop transient response for P, PI, PID controller action.

PID - Controller

The PID – Controller is the most widely used control strategy in industry. It is used for various control problems such as automated systems or plants. A PID-Controller consists of three different elements, which is why it is sometimes called a three term controller. PID stands for:

P   Proportional control
I   Integral control
D   Derivative control.
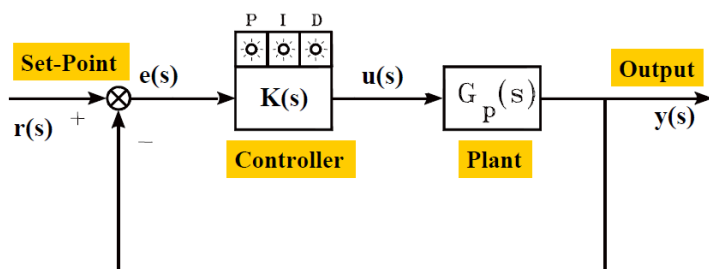
PID – control can be implemented to meet various design specifications for the system. These can include the rise and settling time as well as the overshoot and accuracy of the system step response.
To understand the operation of a PID feedback controller, the three terms should be considered separately.

Proportional Control
Proportional control is a pure gain adjustment acting on the error signal to provide the driving input to the process. The P term in the PID – controller is used to adjust the speed of the system.
Integral Control
Integral control is implemented through the introduction of an integrator. Integral control is used to provide the required accuracy for the control system.
Derivative Control
Derivative action is normally introduced to increase the damping in the system. The derivative term also amplifies the existing noise which can cause problems including instability.

PID Transfer Function

If we now look at the general transfer function of a PID-controller, the three terms can be recognised as follows:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s} + T_d s\right)$$

Where:
Kp is the proportional gain
Ti is the integral time constant
Td is the derivative time constant

If we now rearrange that a little we come up with a more conventional transfer function form:

$$U(s) = K_p E(s) + K_i \frac{1}{s} E(s) + K_d s E(s)$$

The effects of increasing each of the controller parameters K_P, K_I and K_D can be summarized as

| Response	Rise Time	Overshoot	Settling Time	S-S Error
K_P	Decrease	Increase	NT	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	NT	Decrease	Decrease	NT

NT: No definite trend. Minor change.

Ziegler-Nichols Tuning

In 1942 Ziegler and Nichols, both employees of Taylor Instruments, described simple mathematical procedures, the first and second methods respectively, for tuning PID controllers. These procedures are now accepted as standard in control systems practice. Both techniques make a priori assumptions on the system model, but do not require that these models be specifically known. Ziegler-Nichols formulae for specifying the controllers are based on plant step responses.

The First Method

The first method is applied to plants with step responses of the form displayed in Figure . This type of response is typical of a first order system with transportation delay, such as that induced by fluid flow from a tank along a pipe line. It is also typical of a plant made up of a series of first order systems. The response is characterised by two parameters, L the delay time and T the time constant. These are found by drawing a tangent to the step response at its point of inflection and noting its intersections with the time axis and the steady state value. The plant model is therefore
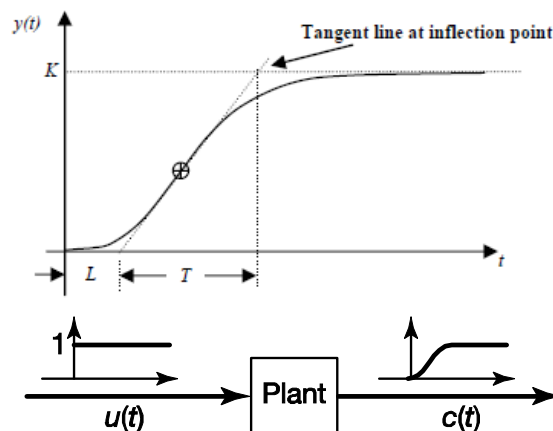
$$G(s) = \frac{Ke^{-sL}}{Ts+1}$$

Ziegler and Nichols derived the following control parameters based on this model:

| PID Type	K_p	$T_i = K_p/K_i$	$T_d = K_d/K_p$
P	$\dfrac{T}{L}$	∞	0
PI	$0.9\dfrac{T}{L}$	$\dfrac{L}{0.3}$	0
PID	$1.2\dfrac{T}{L}$	$2L$	$0.5L$

The Controller Transfer Function is given by

$$
\begin{aligned}
G_c(s) &= K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \\
&= 1.2\frac{T}{L}\left(1 + \frac{1}{2Ls} + 0.5Ls\right) \\
&= 0.6T\,\frac{\left(s + \dfrac{1}{L}\right)^2}{s}
\end{aligned}
$$

Second Method

The second method targets plants that can be rendered unstable under proportional control. The technique is designed to result in a closed loop system with 25% overshoot. This is rarely achieved as Ziegler and Nichols determined the adjustments based on a specific plant model.
The steps for tuning a PID controller via the 2nd method is as follows:

Using only proportional feedback control:

1. Reduce the integrator and derivative gains to 0.
2. Increase K_p from 0 to some critical value $K_p = K_{cr}$ at which sustained oscillations occur. If it does not occur then another method has to be applied.
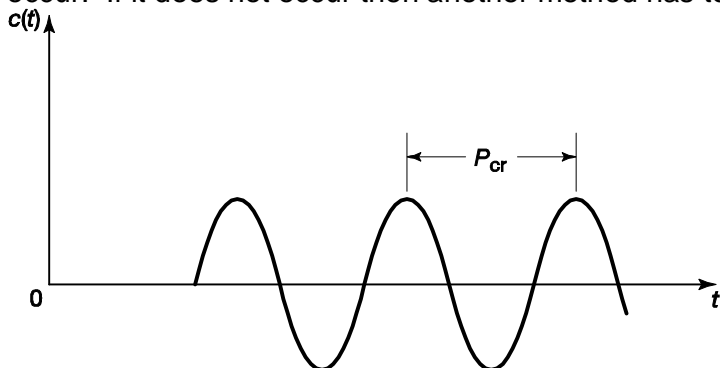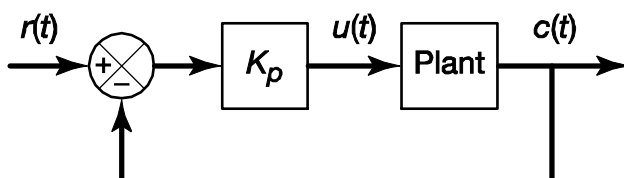
3. Note the value K_{cr} and the corresponding period of sustained oscillation, P_{cr}

The controller gains are now specified as follows:

PID Type	K_p	T_i	T_d
P	$0.5 K_{cr}$	∞	0
PI	$0.45 K_{cr}$	$\dfrac{P_{cr}}{1.2}$	0
PID	$0.6 K_{cr}$	$\dfrac{P_{cr}}{2}$	$\dfrac{P_{cr}}{8}$

The Controller Transfer Function is given by

$$G_c(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right)$$

$$= 0.6 K_{cr} \left(1 + \frac{1}{0.5 P_{cr} s} + 0.125 P_{cr} s \right)$$

$$= 0.075 K_{cr} P_{cr} \frac{\left(s + \dfrac{4}{P_{cr}} \right)^2}{s}$$

Experiment - A

1. Consider the Plant Transfer Function
    $$G(s) = \frac{K}{s^2 + 11s + 6}$$
    Take K=Last two digits of your roll no.
2. Find step response of the plant and determine delayed time**(L)** and Time Constant **(T)** of the equivalent Transfer function
    $$G(s) = \frac{K e^{-sL}}{Ts + 1}$$
3. Calculate the P, PI, & PID controller gains using Z-N First Method.
4. Tabulate the gains.
5. Compare the closed loop step response for the system with PID controller & without PID controller using SIMULINK.

Experiment - B

1. Consider the system Transfer Function
   $$G(s) = \frac{K}{s(s+1)(s+3)}$$, Take K=Last two digits of your roll no.
2. Use Routh-Hurwitz Criterion to determine the Proportional gain value to have sustained oscillation.
3. Determine the step response for the calculated proportional gain value using SIMULINK. From the response curve determine the P_{CR}
4. Calculate the P, PI, & PID controller gains using Z-N Second Method.
5. Tabulate the gains.
6. Compare the closed loop step response for the system with PID controller & without PID controller using SIMULINK.

DESIGN OF LEAD AND LAG COMPENSATION USING CACSAD TOOLS (Plant transfer function will be provided. Step response is to be obtained. (PSPICE, MATLAB, SciLab may be used).

> **Objectives:**
> a. Introduction to SISOTOOLS.
> b. Design of a Compensator for a given system and its step response.

A lead–lag compensator is a component in a control system that improves an undesirable frequency response in a feedback control system.
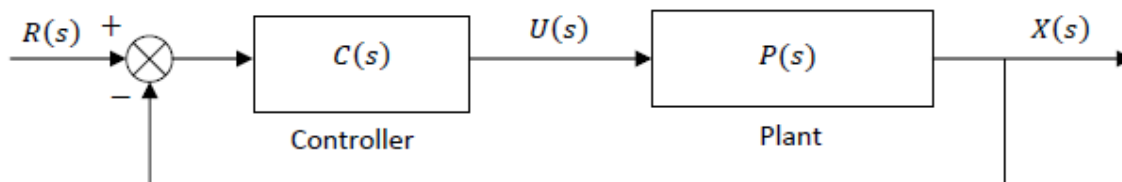We can realize lead and lag compensation by introducing a cascade compensator of the form

$$C(s) = \frac{K_c \cdot (s + z)}{(s + p)}$$

For Lag Compensator

$$C(s) = \frac{K_c \cdot (s + z)}{(s + p)} \text{ where } |z| > |p|$$

For Lead Compensator

$$C(s) = \frac{k \cdot (s + z)}{(s + p)} \text{ where } |p| > |z|$$

Introduction to Matlab 'sisotool'

Generic Unity Feedback Control System

A. Getting Started

- Enter the transfer function P(s) for the plant, in your workspace (i.e., from the Matlab command prompt).
- Type 'sisotool' at the command prompt.
- Click **Close** when the help window comes up.
- Click on **View →Open Loop Bode** to turn off the bode plot. (Whatever is checked in this list will be displayed in the window.)

B. Loading the Transfer Function

- 1. Click on **File → Import**.
- A window on the left will show you the transfer functions in your workspace, while the window on the right will let you choose the control system configuration.

- We will usually be assigning P(s) to block 'G' (the plant). Double-click the space next to 'G' and type your transfer function name and hit Enter. You must hit enter or nothing will happen.
- Once you hit enter, you should be able to click the OK button at the bottom of the window. Then the window will close.
- After you enter the transfer function, the root locus will be displayed. Double check to make sure that the open-loop poles and zeros of your plant are in the correct locations.

C. Generating the Step Response

- Click on **Analysis → Response to Step Command**.
- You will probably two curves on your step response plot. To fix this click on Analysis → Other Loop Responses... Make sure only r to y is checked, and then click OK.
- You can now click on the pink boxes on the root locus (the current closed-loop poles for the given gain) and move them along the root locus. Essentially, you are exploring different controller gain values by doing this. Note how the step response changes as you move the closed-loop pole locations.
- The values of the closed-loop poles will appear at the bottom of the root locus window as you click and hold the mouse on the pink boxes representing them. This only gives you the value of the closed-loop pole you are clicking on. If you need the other closed-loop pole locations, you will have to click on them on each of the other branches.

D. Entering the Compensator (Controller)

- Click **Compensators →Edit →C**. Click on **Add Lead** or **Add Lag** to enter Compensator. You will be able to make changes to these values later. After you are done, click **OK** to exit this window.
- Look at the form of C(s) to be sure it is correct. Then look at the root locus window and see how it changed once the compensator was added.
- You can again see how the step response changes with the compensator by clicking on the closed-loop poles (the pink squares) and dragging them along the root locus.
- You can also change the location of the poles/zeros of the compensator by clicking on them and dragging them. Be careful not to inadvertently change the poles and zeros of the plant.

E. Adding Design Constraints

- Click Edit → **Root Locus → Design Constraints** then either **New** to add new constraints or **Edit** to edit existing constraints.
- At this point you can choose from settling time, percent overshoot, damping ratio, and natural frequency constraints.

Assignment - 1

The feedback control system has

H(s)=1 and

$G(s) = \dfrac{K}{s(s+2)(s+3)}$, K is the last two digits of your roll number

Using sisotool determine

   a. The range of controller gain for the system to be stable
   b. Value of controller gain for the complex dominant-poles damping ratio of 0.6. for this value of gain obtain the frequency response GM and PM. Also obtain step response and the time-domain specifications.

Assignment - 2

For the above system design a lead-lag compensator for the following unit step response specifications.

   a. Dominant poles damping ratio ζ=0.707
   b. Settling time less than 8 seconds.
   c. Peak response less than 1.2

EXPERIMENT NO. 4

STATE VARIABLE ANALYSIS USING CACSAD COMMAND TOOL. Familiarization and use of CACSAD command for state variable analysis. Obtaining transfer function from SV model and vice versa. Obtaining step response for a SISO system given in SV form. (Using MATLAB)

Objectives:
   a. Familliarization with the MATLAB commands for state variable analysis.
   - Obtaining transfer function from a given SV model using MATLAB programming.
   b. Obtaining SV model from a given transfer function using MATLAB programming.
   c. Obtaining step response for a SISO system given in SV form using MATLAB programming

ASSIGNMENT - 1

1. Open MATLAB command window. Observe the commands
   ss2tf, tf2ss, ss2zp, eig, inv, ctrbf, obsv, lyap, canon, size, initial, rank, ,dsolve,plot

2. Write a matlab program to input the following two matrices

$$A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \qquad B = \begin{bmatrix} 5 & 6 \\ 7 & 8 \end{bmatrix}$$

Also determine the followings
   i) P=A+B   ii)   Q=transpose of B   iii)   R=inverse of A
   iv)   determinant of B

Check the results with theoretical calculations.

3. Find out the Eigen Values & Eigen Vectors of the following matrices.

   a) $A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$

   b) $A = \begin{bmatrix} 4 & -1 & 5 \\ 2 & 1 & 3 \\ 6 & -7 & 9 \end{bmatrix}$

   verify the result with theoretical calculations.

ASSIGNMENT - 2

1. Given the dynamic equation

$$\frac{d^3 y}{dt^3} + 6\frac{d^2 y}{dt^2} + 11\frac{dy}{dt} + 6y = u, \qquad t \geq 0$$

   Using MATLAB program, find

   a) x(t) when all the initial conditions are zero

   b) x(t) when x(0) = 1 & x'(0) = 2   (Hint : Use 'dsolve')

2. Obtain the state-space representation of the following system using MATLAB

   a) $\dfrac{C(s)}{R(s)} = \dfrac{12s + 7}{s^3 + 5s^2 + 32s + 7}$

   b) $\dfrac{C(s)}{R(s)} = \dfrac{s^4 + 3s^3 + 12s^2 + 7s + 8}{s^5 + 9s^4 + 5s^3 + 7s^2 + 7}$

   Draw the State Diagram of the above systems.

3. Find the Transfer Function of the following systems using MATLAB program

   a)
   $$\dot{x}(t) = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$
   $$y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} x(t)$$

   Check the result with theoretical calculation.

   b)
   $$\dot{x}(t) = \begin{vmatrix} 0 & 3 & 7 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -5 & -6 & 9 & 5 \end{vmatrix} x(t) + \begin{bmatrix} 0 \\ 5 \\ 7 \\ 2 \end{bmatrix} u(t)$$
   $$y(t) = \begin{bmatrix} 1 & 3 & 6 & 5 \end{bmatrix} x(t)$$

4. Find the Unit Step response of the following systems using MATLAB program

   a)
   $$\dot{x}(t) = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$
   $$y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} x(t)$$

b) $\dot{x}(t) = \begin{bmatrix} -5 & 2 & 0 \\ 0 & -9 & 1 \\ 0 & 0 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 2 \\ 1 \end{bmatrix} u(t)$

$y(t) = \begin{bmatrix} 0 & 1 & 1 \end{bmatrix} x(t)$

5. Obtain the Unit-Step response, unit-ramp response & unit-impulse response of the following system using MATLAB program

$$\dot{x}(t) = \begin{bmatrix} -1 & -1.5 \\ 2 & 0 \end{bmatrix} x(t) + \begin{bmatrix} 1.5 \\ 0 \end{bmatrix} u(t)$$

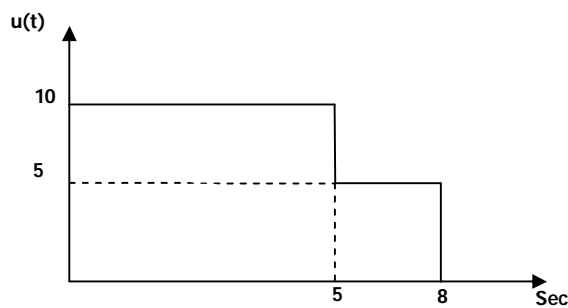$$y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} x(t)$$

Also obtain the Bode Plot & Nyquist Plot for the above system
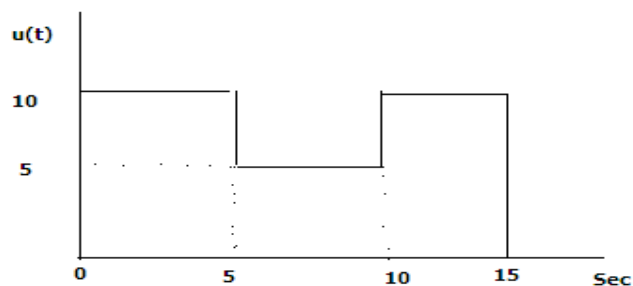
6. For the system below using SIMULINK consider:

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -2 & -3 & -4 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} u(t) \quad \text{and} \quad y(t) = [1\ 0\ 0]\ x(t)$$

find the response due to initial condition $x(0) = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}$

a. find the response due to an input u(t), shown below.

b.

EXPERIMENT NO. 5

STATE VARIABLE ANALYSIS USING CACSAD BLOCK DIAGRAM TOOL. Familiarization and use of CACSAD BLOCK DIAGRAM TOOL for state variable analysis. Obtaining step response and initial condition response for a single input, two output system given in SV form. (PSPICE, MATLAB, SciLab may be used).

Objectives:
- a. Familiarization with the MATLAB commands for state variable analysis.
- b. Obtaining step response and initial condition response for a SISO system given in SV form using MATLAB programming
- c. Obtaining step response and initial condition response for a Two input system given in SV form using MATLAB programming .

ASSIGNMENT – 1

1. Open MATLAB command window. Observe the commands
   jordan, fliplr, flipud, ctrbf, obsv, initial, kalman, acker, place.

2. Write a MATLAB program to determine the STM for the given A matrix as

   a. $A = \begin{bmatrix} 0 & -1 \\ 2 & -3 \end{bmatrix}$

   Verify the result by theoretical calculation.

   b. $A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -6 & -11 & -5 \end{bmatrix}$

ASSIGNMENT – 2

1. Find the Unit Step response of the following system using MATLAB program

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -5 & -17 & -5 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} 0 & 25 & 5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Also find out the response for the initial conditions

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 0 \end{bmatrix} \text{ and } \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 5 \\ 7 \end{bmatrix}$$

2. Solve the problem stated in 1. Using SIMULINK

3. Find the Unit Step response of the following system using MATLAB program

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ 7 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Also find out the response for the initial conditions

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 1 \\ 5 \end{bmatrix}$$

Verify the result with theoretical calculation.

ASSIGNMENT – 3

1. Test the Controllability and Observability of the following systems

a) $\dot{x}(t) = \begin{bmatrix} -0.5 & 0 \\ -0 & -2 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$

      $y(t) = \begin{bmatrix} 0 & 1 \end{bmatrix} x(t)$

b) $\dot{x}(t) = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} u(t)$

      $y(t) = \begin{bmatrix} 1 & 0 & 2 \end{bmatrix} x(t)$

2. Write a MATLAB program to determine the state feedback gain matrix so that closed loop poles are located at -2, -5 & -6

c) $\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -30 & -11 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u(t)$

      $y(t) = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} x(t)$

Verify obtained result with theoretical calculations

HINTS : Use 'place' or 'acker' command

EXPERIMENT NO. 6

PERFORMANCE ANALYSIS OF A DISCRETE TIME SYSTEM USING CACSAD TOOL. Familiarization and use of CACSAD block diagram tool for Digital Control System. Study of closed response of a continuous system with a digital controller with sample and hold. (PSPICE, MATLAB, SciLab may be used).

Objectives:
  a. Familliarization with the MATLAB commands for Digital control system analysis.
  b. Familiarization and use of SIMULINK block diagram tool for Digital Control System & Study of closed response of a continuous system with a digital controller with sample and hold.

ASSIGNMENT – 1

1. Open MATLAB command window. Observe the commands
   ZTRANS, IZTRANS , c2d, D2C, D2D, zplane, residuez, freqz

2. Determine the z-transform of the following sequences using MATLAB

   i) $x(n) = \dfrac{1}{4^n} u(n)$

   ii) $x(n) = \left(\dfrac{4}{3}\right)^n u(n)$

3. Determine the inverse Z Transform of the followings

   i) $F(Z) = \dfrac{2Z^2 + 1.5Z}{Z^2 - 1.5Z + 0.5}$

   ii) $F(Z) = \dfrac{6 - 9Z^{-1}}{1 - 2.5Z^{-1} + Z^{-2}}$

4. Use the z-transform to solve the difference equation

$$y(k) - 0.6\,y(k-1) + 0.05\,y(k-2) = 32\,u(k-1) - 3\,u(k-2)$$

$$u(k) = \begin{cases} k, & k \geq 0 \\ 0, & k < 0 \end{cases}$$

$$y(k) = 0, \quad k < 0.$$

ASSIGNMENT – 2

1. Find out the discrete transfer function of the following continuous time systems.

   i. $G(s) = \dfrac{2s}{s^2 - 1.2s + 0.5}$

   ii. $G(s) = \dfrac{s + 10}{s^2 + 2s + 0.5}$

                      [Hint : use c2d command]

2. Find out the continuous time transfer function of the following discrete time systems.

   i. $G(Z) = \dfrac{2Z^2 + 1.5Z}{Z^2 - 1.5Z + 0.5}$

   ii. $G(Z) = \dfrac{10}{Z^2 - 1.5Z + 0.5}$

3. Consider the system described by the following difference equation

   y(n) + 0.25 y(n-1) = 5 x(n) - 0.75 x(n-1) - 1.75 x(n-2)

   Determine the step & Impulse response for the system.
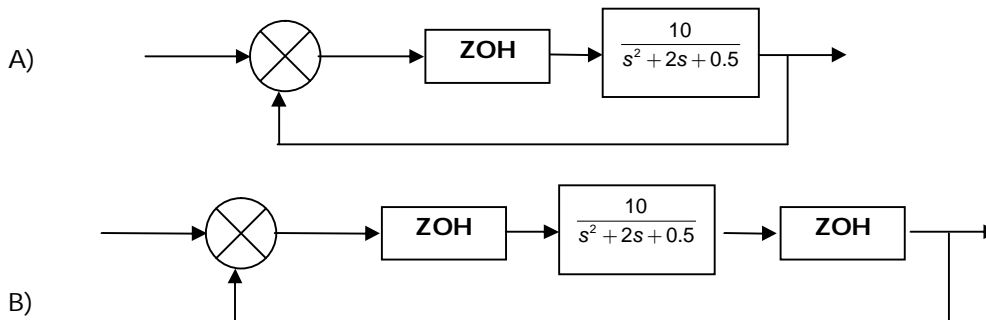
4. Write a MATLAB program to determine the pulse transfer function of the system if sampling time T=0.1 sec

   $G(Z) = \dfrac{1}{s^2 + 10s + 20}$

   Also get the step response for sampling time of 1/20 sec

ASSIGNMENT – 3

Use simulink to determine the step & ramp response of the following systems

A)

B)

Observe the responses along with all the signals of the system

EXPERIMENT NO. 7

STUDYING THE EFFECTS OF NONLINEARITY IN A FEEDBACK CONTROLLED SYSTEM USING TIME RESPONSE. Determination of step response with a limiter nonlinearity introduced into the forward path of 2nd order unity feedback control systems. The open loop plant will have one pole at the origin and the other pole will be in LHP or RHP. To verify that (i) with open loop stable pole, the response is slowed down for larger amplitude input and (ii) for unstable plant , the closed loop system may become oscillatory with large input amplitude. (PSPICE, MATLAB, SciLab may be used).

Objectives:
a. Introduction to the limiter type of nonliniearity.
b. Determination of step response of a 2nd order unity feedback system with limiter nonlinearity in the forward path having open loop stable pole.
c. Determination of step response of a 2nd order unity feedback system with limiter nonlinearity in the forward path having open loop unstable pole..

Limiter type nonlinearity

A *limiter* is a common nonlinearity in control system, it simply limits the output to a certain threshold value. This type of nonlinearity is found in almost all type of amplifiers (electronic, mechanical, electromechanical etc.) where limited output power can not follow a large input signals. Sometime a limiter is very useful for limiting the output magnitude. For example, in a design in which the error signal driving the controller can reach very large values, it might be best to limit the error magnitude at the controller input to prevent excessive controller output magnitude.
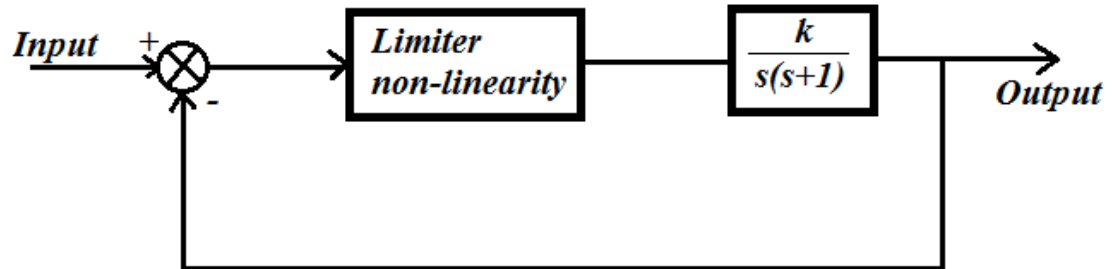
The figure shows the typical characteristic of a limiter and is described by the expression

$$Y_N = kx \qquad for \ -x_b \le x \le x_b$$
$$= -y_b \quad for \ -x_b > x$$
$$= y_b \quad for \ x > x_b$$
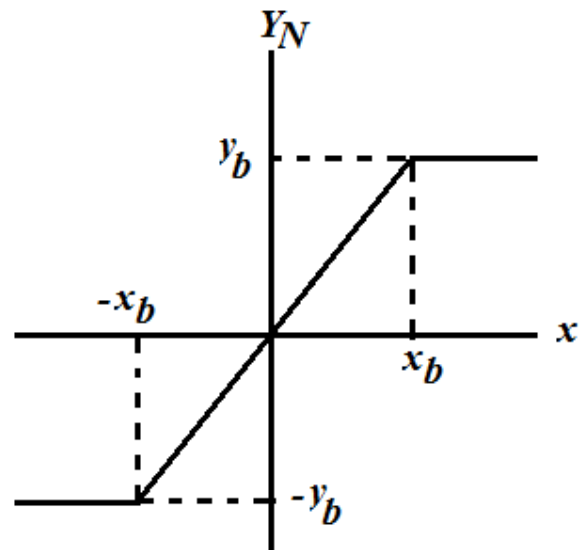
Experiment – 1

1. Consider the system represented by the block diagram

Take k as the last two digits of your roll number
2. Develop the block diagram using SIMULINK.
3. Take the input a unit step and the slew rate of the limiter as 0.5
4. Record the response.
5. Increase the step magnitude from unity to 50 and then to 100 and record the response.
6. Repeat the steps 3 to 5 for slew rate 1.0

Experiment – 2
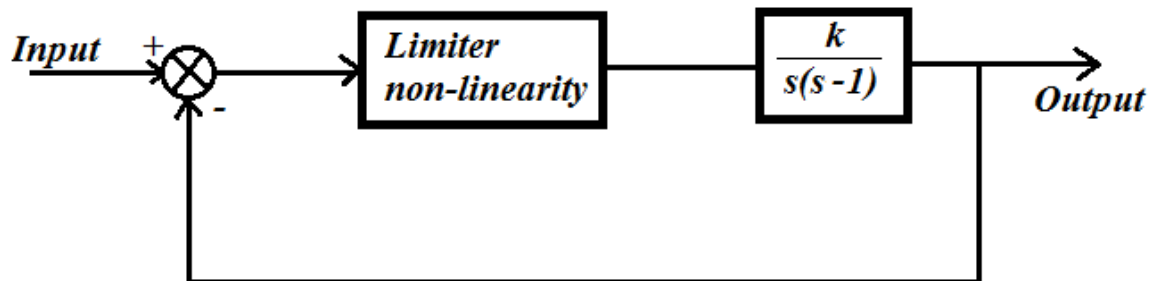
1. Consider the system represented by the block diagram

Take k as the last two digits of your roll number
2. Develop the block diagram using SIMULINK.
3. Take the input a unit step and the slew rate of the limiter as 0.5
4. Record the response.
5. Increase the step magnitude from unity to 50 and then to 100 and record the response.
6. Repeat the steps 3 to 5 for slew rate 1.0

EXPERIMENT NO. 8

STUDYING THE EFFECTS OF NONLINEARITY IN A FEEDBACK CONTROLLED SYSTEM USING PHASE PLANE PLOTS. Determination of phase plane trajectory and possibility of limit cycle of common nonlinearities. CACSAD block diagram tool will be used. (PSPICE, MATLAB, SciLab may be used).

Objectives:
- a. Introduction to Phase Plane Analysis & Phase Plane Plots.
- b. Determination of phase plane trajectory and possibility of limit cycle of common nonlinearities.

Phase Plane Analysis & Phase Plane Plots

Phase plane analysis is a graphical method for studying second-order systems.

The phase plane method is concerned with the graphical study of second-order autonomous systems described by

$$\dot{x}_1 = f_1(x_1, x_2)$$
$$\dot{x}_2 = f_2(x_1, x_2)$$

Where,

x_1, x_2 : states of the system

f_1, f_2 : nonlinear functions of the states

Geometrically, the state space of this system is a plane having x_1 , x_2 as coordinates. This plane is called phase plane. The solution of the above equations with time varies from zero to infinity can be represented as a curve in the phase plane. Such a curve is called a phase plane trajectory. A family of phase plane trajectories is called a phase portrait of a system.

Phase portrait of a mass-spring system

(a) *(b)*
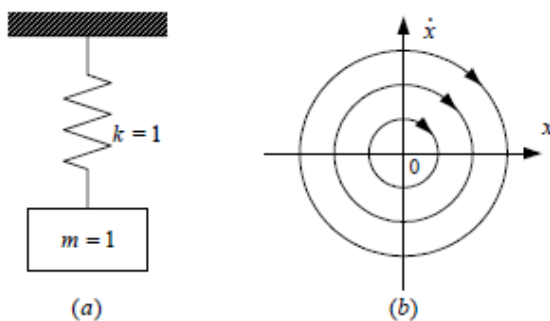
The governing equation of the mass-spring system in Fig.(a) is the familiar linear second-order differential equation

$$\ddot{x} + x = 0$$

Assume that the mass is initially at rest, at length x_0 . Then the solution of this equation is

---

$$x(t) = x_0 \cos(t)$$
$$\dot{x}(t) = -x_0 \sin(t)$$

Eliminating time t from the above equations, we obtain the equation of the trajectories

$$x^2 + \dot{x}^2 = x_0^2$$

This represents a circle in the phase plane. Its plot is given in Fig. (b).
The nature of the system response corresponding to various initial conditions is directly displayed on the phase plane. In the above example, we can easily see that the system trajectories neither converge to the origin nor diverge to infinity. They simply circle around the origin, indicating the marginal nature of the system's stability.

A major class of second-order systems can be described by the differential equations of the form

$$\ddot{x} = f(x, \dot{x})$$

In state space form, this dynamics can be represented with $x_1 = x$ & $x_2 = \dot{x}$ & as follows

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = f(x_1, x_2)$$

Phase Plane Analysis of Linear Systems

The general form of a linear second-order system is

$$\dot{x}_1 = a x_1 + b x_2 \qquad \text{------(a)}$$

$$\dot{x}_2 = c x_1 + d x_2 \qquad \text{------(b)}$$

Transform these equations into a scalar second-order differential equation in the form
$b\dot{x}_2 = bcx_1 + d(\dot{x}_1 - ax_1)$.
Consequently, differentiation of (a) and then substitution of (b) leads to
$\ddot{x}_1 = (a+d)\dot{x}_1 + (cb-ad)x_1$.
Therefore, we will simply consider the second-order linear system described by

$$\ddot{x} + a\dot{x} + bx = 0 \qquad \text{--------(c)}$$

To obtain the phase portrait of this linear system, we solve for the time history

$$x(t) = k_1 e^{\lambda_1 t} + k_2 e^{\lambda_2 t} \quad \text{for } \lambda_1 \neq \lambda_2$$
$$x(t) = k_1 e^{\lambda_1 t} + k_2 t e^{\lambda_2 t} \quad \text{for } \lambda_1 = \lambda_2$$

whre the constant λ_1, λ_2 are the solutions of the characteristic equation

$$s^2 + as + b = (s - \lambda_1)(s - \lambda_2) = 0$$

The roots λ_1, λ_2 can be explicitly represented as

$$\lambda_1 = \frac{-a + \sqrt{a^2 - 4b}}{2} \quad \text{and} \quad \lambda_2 = \frac{-a - \sqrt{a^2 - 4b}}{2}$$

For linear systems described by (c), there is only one singular point (b $\neq$ 0) , namely the origin. However, the trajectories in the vicinity of this singularity point can display quite different characteristics, depending on the values of a and b . The following cases can occur

- λ_1, λ_2 are both real and have the same sign (+ or -)
- λ_1, λ_2 are both real and have opposite sign
- λ_1, λ_2 are complex conjugates with non-zero real parts
- λ_1, λ_2 are complex conjugates with real parts equal to 0

We now briefly discuss each of the above four cases

Stable or unstable node (Fig.a -b)
The first case corresponds to a node. A node can be stable or unstable:

$\lambda_1, \lambda_2 < 0$: singularity point is called stable node.

$\lambda_1, \lambda_2 > 0$: singularity point is called unstable node.

There is no oscillation in the trajectories.

Saddle point (Fig.c)
The second case ($\lambda_1 < 0 < \lambda_2$) corresponds to a saddle point.

Because of the unstable pole λ_2 , almost all of the system trajectories diverge to infinity.

Stable or unstable locus (Fig. d-e)
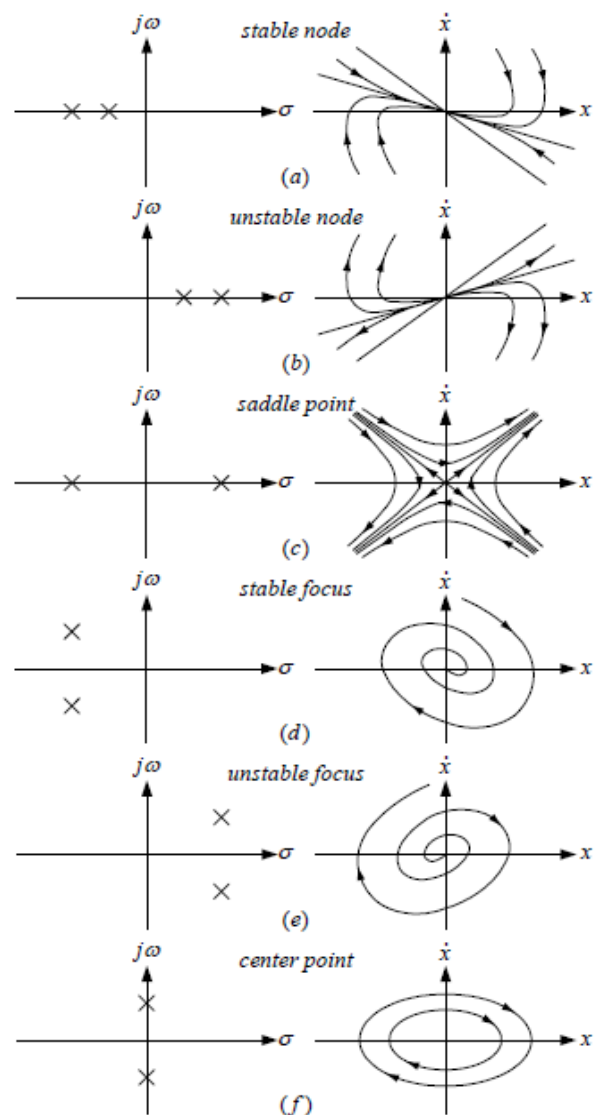The third case corresponds to a focus.

Re(λ_1, λ_2) < 0 : stable focus

Re(λ_1, λ_2) > 0 : unstable focus

Center point (Fig. f)
The last case corresponds to a certain point. All trajectories are ellipses and the singularity point is the centre of these ellipses.

Phase Plane Analysis of Nonlinear Systems

In discussing the phase plane analysis of nonlinear system, two points should be kept in mind:

• Phase plane analysis of nonlinear systems is related to that of liner systems, because the local behavior of nonlinear systems can be approximated by the behavior of a linear system.

• Nonlinear systems can display much more complicated patterns in the phase plane, such as multiple equilibrium points and limit cycles.

Local behavior of nonlinear systems

If the singular point of interest is not at the origin, by defining the difference between the original state and the singular point as a new set of state variables, we can shift the singular point to the origin. Therefore, without loss of generality, we may simply consider the equation

$$\dot{x}_1 = f_1(x_1, x_2)$$

$$\dot{x}_2 = f_2(x_1, x_2)$$

with a singular point at 0. Using Taylor expansion, Eqs. can be rewritten in the form

$$\dot{x}_1 = a x_1 + b x_2 + g_1(x_1, x_2)$$

$$\dot{x}_2 = c x_1 + d x_2 + g_2(x_1, x_2)$$

where g_1, g_2 contain higher order terms. In the vicinity of the origin, the higher order terms can be neglected, and therefore, the nonlinear system trajectories essentially satisfy the linearized equation

$$\dot{x}_1 = a x_1 + b x_2$$

$$\dot{x}_2 = c x_1 + d x_2$$

As a result, the local behavior of the nonlinear system can be approximated by the patterns shown in the previous figures..

Limit cycle

In the phase plane, a limit cycle is defined as an isolated closed curve. The trajectory has to be both closed, indicating the periodic nature of the motion, and isolated, indicating the limiting nature of the cycle (with nearby trajectories converging or diverging from it).

Depending on the motion patterns of the trajectories in the vicinity of the limit cycle, we can distinguish three kinds of limit cycles.

(a)   (b)   (c)

• **Stable Limit Cycles**: all trajectories in the vicinity of the limit cycle converge to it as $t \rightarrow \infty$ (Fig. a).

• **Unstable Limit Cycles**: all trajectories in the vicinity of the limit cycle diverge to it as $t \rightarrow \infty$ (Fig. b)

• **Semi-Stable Limit Cycles**: some of the trajectories in the vicinity of the limit cycle converge to it as $t \rightarrow \infty$ (Fig. c)
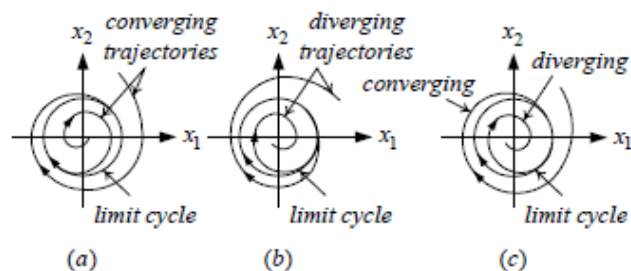
Assignment # 1

1. Develop the phase plane trajectory using SIMULINK for the system described by the dynamic equation

$$\ddot{y} + \dot{y} + 9y = 0$$

2. Consider the system represented by the state space model

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -10 & -3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} k \\ 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Take k=Last two digits of your roll no.
Develop the phase plane trajectory using SIMULINK for a unit step & unit impulse input.

Assignment # 2

1. Consider the system represented by the state space model

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = k(1 - x_1^2) - x_1$$

2. Develop the phase plane trajectory and possibility of limit cycle using SIMULINK. For k ranging from 0.1 to 10

Assignment # 3

1. Consider the system represented by the state space model

$$\dot{x}_1 = x_2 - x_1(x_1^2 + x_2^2 - 1)$$
$$\dot{x}_2 = -x_1 - x_2(x_1^2 + x_2^2 - 1)$$

2. Develop the phase plane trajectory and possibility of limit cycle using SIMULINK for r > 1 & r < 1, where

$$r = \sqrt{x_1^2 + x_2^2}$$

Siliguri Institute of Technology

Electrical Engineering Department

Laboratory Work Book for Electric Drives Lab (EE-791)

NAME:

ROLL NO.:

REGISTRATION NO.:

GROUP NO:

LAB EVALUATION SHEET

Name :

Department / Sem :

Roll No. :

Performance indicators

PI 1 : Participation & Regularity   PI 1 : Timely Submission
PI 2 : Lab Techniques   PI 2 : Organization & Preparation of report
PI 3 : Safety Procedures & Directions PI 3 : Results & Conclusions
PI 4 : Ability to work in a group

DATE	EXPERIMENT NO.	PI 1	PI 2	PI 3	PI 4	TOTAL	PI 1	PI 2	PI 3	TOTAL	SIGNATURE OF TEACHER	REMARKS

Siliguri Institute of Technology

Electrical Engineering Department

Laboratory Work Book for Electric Drives Lab (EE-791)

Title Sheet

Experiment No.   :

Experiment Name   :

Date of Experiment   :

Submission Date   :

Student Name   :

Roll No.   :

Group   :

Signature of Student:

EXPERIMENT NO. 1

STUDY OF THYSISTOR CONTROLLED DC DRIVE

> **OBJECTIVE:**
>
> To study Phase Controlled Rectified DC Motor Drive using a Full Converter.

APPARATUS REQUIRED:

1) Drive Unit.
2) 0.5 HP DC Motor.
3) C.R.O. (optional)
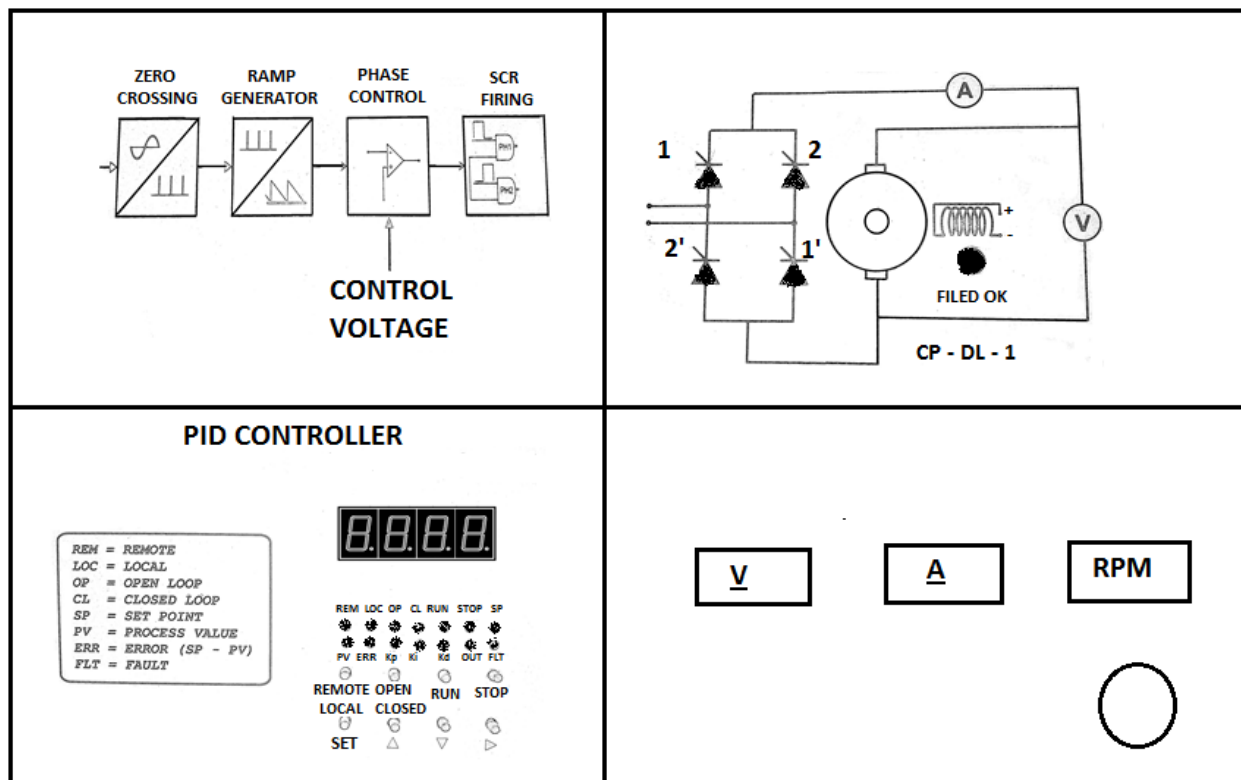4) Connecting Wires.

OPERATING PANEL LAYOUT

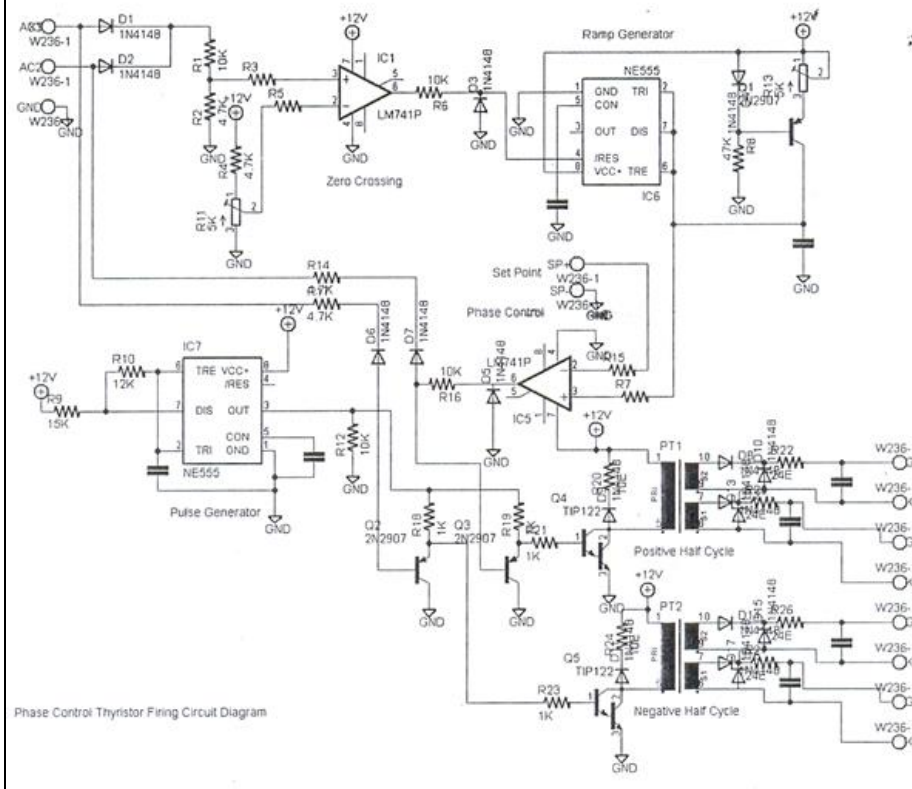**Figure 1.1: Operating Panel Layout**

Theory of Operation

Figure 1.2: Schematic Diagram of Phasor Control Thyristor Firing

THEORY:

The above diagram consists of the following blocks:

i. *Zero Crossing*

The A.C. signal from the secondary of a step-down transformers is full-wave rectified and applied to the non-inverting terminal of an op-amp configured as a comparator. The inverting terminal of the op-amp is connected to reference D.C. voltage. The resulting waveform from the comparator is a square wave of 100 Hz frequency and remains low during the zero crossing period.

ii. *Ramp Generator*

The IC 555 is used as an astable multi-vibrator in the ramp generator configuration by using a current mirror. The current mirror starts charging the capacitor towards V_{cc} at a constant rate. When the voltage across the capacitor equals to 2/3 V_{cc}, the internal capacitor turns on the internal transistor and the capacitor rapidly discharges through the

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transistor. However when the discharge voltage across the capacitor equals to 1/3 V_{cc}, the internal capacitor switches the internal transistor off, and then the capacitor starts charging up again. The charge-discharge cycle keeps on repeating.

iii. ***Phase Control***

A DC voltage is compared using a comparator, with the ramp-generator output to provide pulses for phase control. The more the DC voltage, the further away the ramp cuts from zero-crossing, thus giving an output pulse width which starts further away from the zero-crossing. The more the DC voltage, the more the phase-angle (e.g. 0 ~ 5V corresponds to 0 ~ 180 degree).

For open-loop control, a potentiometer is used to control the phase-angle. For closed-loop control, the output of the PID Controller is used to control the phase angle.

iv. ***Thyristor Firing***

An IC 555 is used to generate a 50% duty cycle, 5 KHz square wave to be used as a pulse generator for the pulse transformers. The reset terminal of the IC is connected to the output of the phase control. The resulting waveform is a 5 KHz waveform enveloped in the phase control waveform. Two transistors triggered during the positive and negative half cycles further switch this resultant waveform.

Two 1:1:1 pulse transformers are used for providing the thyristor with isolated pulses. Each pulse transformer has three isolated windings. One winding is used for input and two for output.

During the positive half cycle one pulse transformer is activated and the resulting signals trigger thyristor 1 and 1' and during the negative half cycle the other pulse transformer is activated and triggers thyristor 2 and 2'.
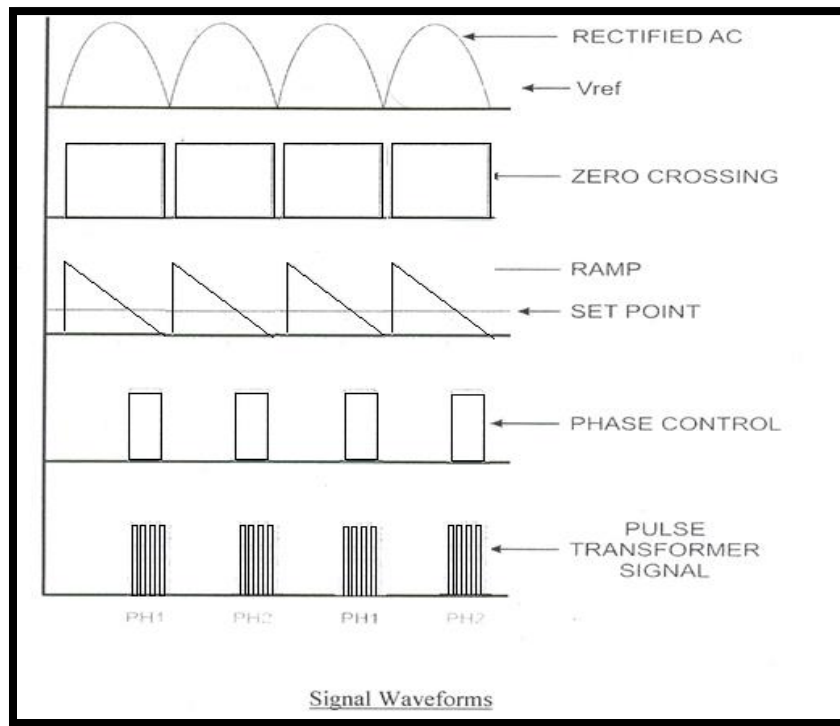
Signal Waveforms

Figure 1.3: Signal Waveforms

PID Controller

A ***Proportional-Integral-Derivative controller (PID controller)*** is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate constant parameters, the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors, and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supply of a heating element.

By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action.

Figure 1.4: Block Diagram of a PID Controller
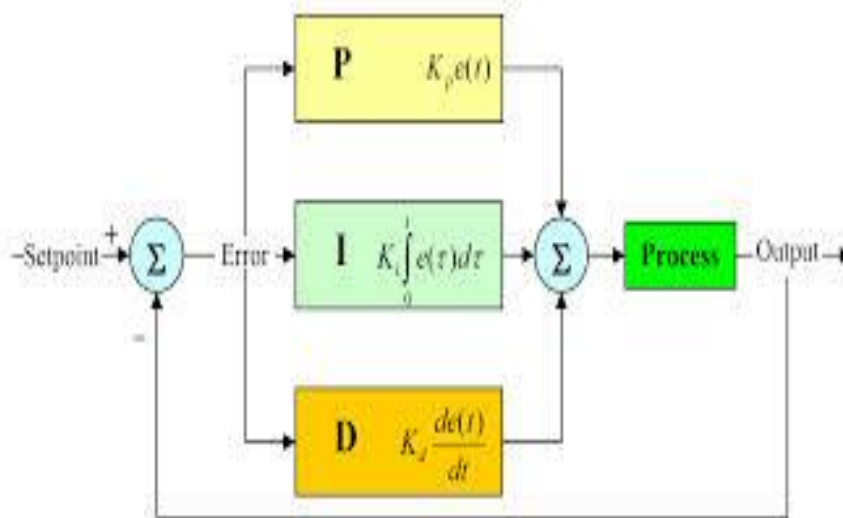
Proportional term

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain.
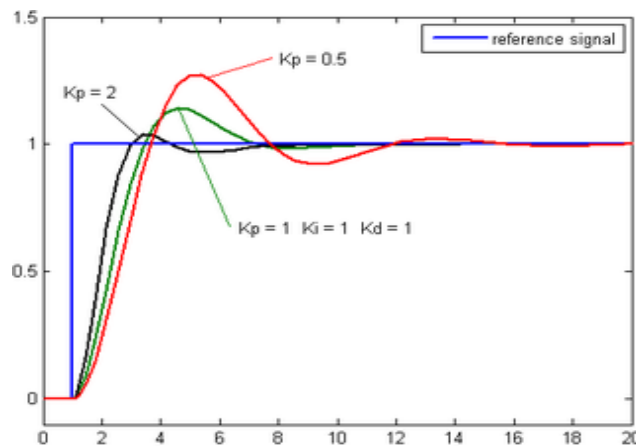

Figure 1.5: Change of response for varying K_p

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The proportional term is given by:

$$P_{out} = K_p e(t)$$

Where

P_{out} = Proportional output

K_p = Proportional gain, a tuning parameter

e = Error = SP-PV

t = Time or instantaneous time (the present)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

In the absence of disturbances, pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i.
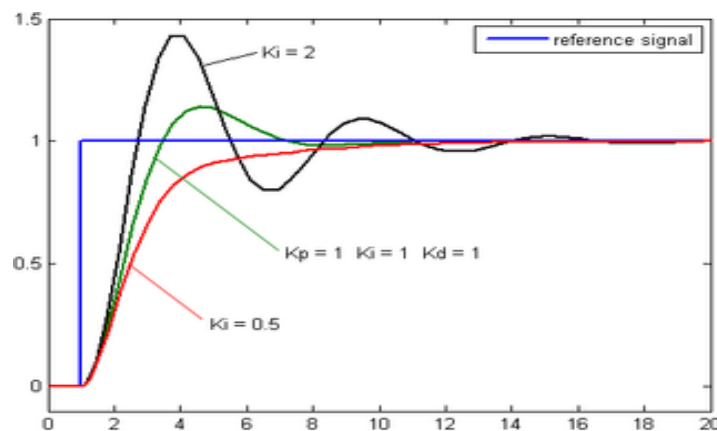

Figure 1.6: Change of response for varying K_i

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The integral term is given by:

$$I_{out} = K_i \int_0^t e(\tau)dt$$

Where

I_{out} = Integral output

K_i = Integral Gain, a tuning parameter

e =Error = SP-PV

τ =Time in the past contributing to the integral response

The integral term (when added to the proportional term) accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to overshoot the set point value (cross over the set point and then create a deviation in the other direction).

Derivative term

The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.
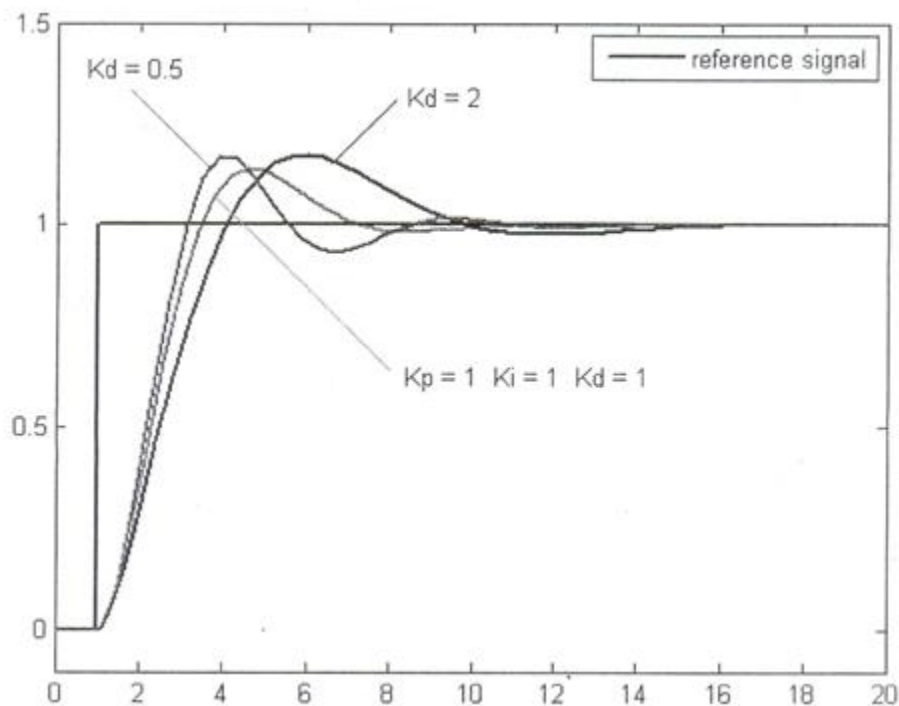

Figure1.7: Change of response for varying K_d

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The derivative term is given by:

$$D_{out} = K_d \frac{de}{dt}$$

Where

D_{out}= **D**erivative output

K_d= **D**erivative Gain, a tuning parameter

e =Error = SP-PV

t =Time or instantaneous time (the present)

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

The output from the three terms, the proportional, the integral and the derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is :

$$u(t) = Mv(t) = K_p e(t) + K_i \int_0^t e(\tau)dt + K_d \frac{de}{dt}$$

and tuning parameters are

K_p: Proportional gain

 The larger K_p typically means faster response since the larger the error, the larger the proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

K_i : Integral gain

The larger K_i implies steady state errors are eliminated quicker. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

K_d: Derivative gain

The larger K_d decreases overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

Speed measurement

The shaft of the motor is connected an optical encoder. The encoder has a circular plastic disc having 100 alternate black and transparent stripes. The disc is passed through an opto-interruptor MOC7811. Pulses are generated when the disc turns with 100 pulses per revolution.

The pulses from the sensor are shaped using an op-amp configures as comparator. The pulses are fed into microprocessor based display for indication of the speed in RPM.

MOC7811 has four connections, i.e. D+ & D- for detector and E+ & E- for emitter. The connections from the motor setup to the drive unit should be made one to one. On rotation of the motor, if the tachometer fails to display the speed, the connections should be checked. In case of sensor failure, do not run the drive unit in closed loop.

Load setup

The load setup for the motor is a flat pulley and friction belt breaking system. A friction belt goes around a pulley with a spring balance on one side and a nut-bolt arrangement on the other. On tightening the nut the friction between the friction belt and pulley increases to create a larger load on the motor.

DC motor field

The field coil of the DC motor is supplied with 220V DC rectified from the main supply. The current in the field coil is sensed and is used to switch on a relay. The indication FIELD OK displays the status. On field failure the relay is cut off and disconnects the armature supply.

Operation of Motor Controller

The Digital Motor Controller is PID Controller with some additional features required to operate DC/AC1/AC3 motors. The control unit consists of a four-digital display unit for displaying various parameters, some indicating LED's and some buttons for setting of parameters and running of the motor.

The motor speed is sensed using an optical encoder. The speed, set point, error and control parameters are displayed on the digital display panel one by one selecting the viewing parameter using the SET button. The parameters may be changed and saved by using the edit buttons.

The motor controller provides the facility to run the motor in open or closed loop. Different faults are indicated on the display unit.

The controller also incorporates safety features like soft-start and open/closed loop transfer through zero speed.

Speed Measurement

The motor speed is sensed using an optical encoder that generates 100 pulses per revolution. These pulses are counted and the frequency in Hz is calculated every 100 msec. the PID algorithm is executed and the output is used to drive the signal section of the specific drive.

Open Loop Operation

In the open loop operation, the output to the drive section may be varied from 0 to 100%. No feedback or control action is taken. The output and the speed or process variable may be displayed using the SET button.

Closed Loop Operation

In the closed loop, the output to the drive section is controlled using a PID algorithm. The PID section describes in detail the operation and functioning of the PID algorithm. The PID parameters may be changed while the motor is running. The set point may be varied between 0.0 to 50 Hz. The various parameters like set point, process variable (speed), error, proportional gain, integral gain, derivative gain and output are displayed on the digital display. The parameter required to be observed/modified may be selected using the SET button.

Operation

Operating panel

The front fascia consists of 4 7-segment displays, 14 LED's and 8 switches. The 7-segment display indicates the various parameters. The LED's indicate the mode of operation, motor status and parameter being viewed. The switches are used to set different parameters and switch between different modes.
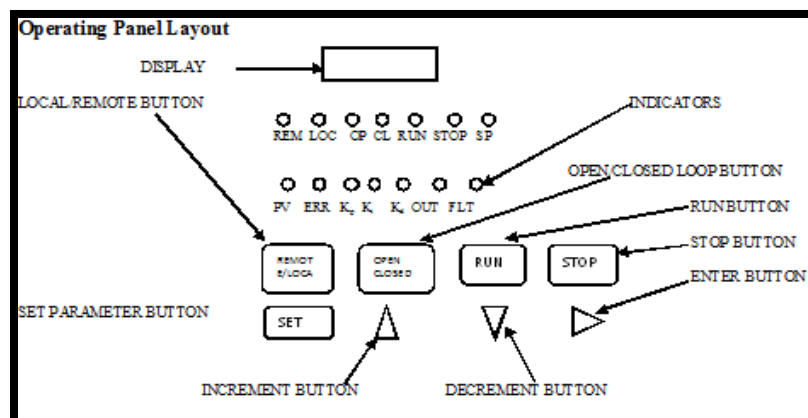

Figure 1.8: Operating Control Panel Layout

Description of Switches

REMOTE/LOCAL – Remote/Local Switch

Select between Remote / Local modes of operation. Change over only possible when the motor is stopped.

OPEN/CLOSED- Open / Closed Loop Switch

Select between Open / Closed Loop modes of operation. Change over only possible when the motor is stopped.

RUN – Motor Run Switch

Used to run the motor.

STOP - Motor Stop Switch

Used to stop the motor.

SET – Select/Exit Switch

In normal mode, it is used to select the display mode. In editing mode, it is used to quit without saving the parameter.

INC – Increment Switch

Used to increase the value of the parameter to be edited.

DEC – Decrement Switch

Used to decrease the value of the parameter to be edited.

ENT – Enter Switch

Used to save the parameter that is being edited.

Description of LED's

RE – Remote Mode Indicator

LO – Local Mode Indicator

OP – Open Loop Mode Indicator

CL – Closed Loop Mode Indicator

RUN – Run Operation Indicator

STOP – Stop Operation Indicator

SP – Set Point Indicator

PV – Process Value Indicator

ER – Error Value Indicator

KP – K_p Value Indicator

KI – K_i Value Indicator

KD – K_d Value Indicator

OU – Output Value Indicator

FA – Fault Indicator

Open-Loop Operation

When the unit is powered on, it is in the Open Loop mode by default. The motor is stopped and the set point = 0.0

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Press SET to toggle between PV and OUT displays.

Press O/C to toggle between Open Loop and Closed Loop modes.

In the Open Loop mode, only the output can be set. The value of output can be from 0.0 ~ 100.0%. Please note that the motor may not rotate below a certain minimum output. The output may be set by pressing the INC or DEC buttons and can be confirmed by pressing ENT. If the motor is on, the output value is instantaneously transferred to the soft-start algorithm so that it is slowly reflected on the output. The output value is not saved on power off.

Closed-Loop Operation
Press O/C to toggle between Open Loop and Closed Loop modes.
Press SET to display the various parameters in the following sequence.

Figure 1.9: closed-loop operation

In the Closed Loop mode, the following parameters may be set

PARAMETER	RANGE
SP - Set Point	0.0 ~ 50.0Hz
KP – Proportional Gain	0.0 ~20.0
KI – Integral Gain	0.0 ~ 70.0 s^{-1}
KD – Derivative Gain	0.0 ~20.0 s

The value of the set point can be varied from 0.0 ~ 50.0Hz. Please note that the motor may not run/rotate if adequate gain is not selected. All parameters may be set by pressing the INC or DEC buttons and can be confirmed by pressing ENT. The effect is instantaneous. The values of K_p, K_i and K_d are saved on power failure.

Additionally, the following parameters may be displayed.

PARAMETER	RANGE

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PV – Process Value	0.0 ~ 50.0Hz
ERR - Error	-50.0 ~ 50.0Hz
OUT - Output	0.0 ~ 100.0%

Fault Indications

Faults are indicated on the digital display. The various faults, their indications and sources are given below:

Fault	Display	Reason	Applicable Drives	Comments
Field failure	FFAU	Field not connected/faulty	CP-DL-1 CP-DL-2	Requires Power On.
DC Bus Not Ready	nrdy	Internal DC Bus Not Ready.	CP-DL-2 CP-DL-4	At startup only.
Over Current	oCur	Armature Current has gone above the limit.	CP-DL-1 CP-DL-2 CP-DL-3 CP-DL-4	Requires Power On.

PROCEDURE:

Figure 1.10: Connection Diagram

For Open loop operation

1) Use connecting wires to connect the motor, drive unit and mains according to the connection diagram.
2) Connect the A.C. mains cord to the power socket, but do not switch on the M.C.B.
3) Switch on the M.C.B. and see if the voltmeter, ammeter and tachometer come on. If they do not turn on or if the FIELD OK LED doesn't come on, then switch of the M.C.B. and report the problem to the instructor.

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4) Remove load from the loading arrangement.
5) Set the output to 25% using the buttons. Put the motor in RUN mode. Observe the voltage, current and speed readings on the displays. Increase the output is steps of 10% and observes the readings. If the motor does not rotate after 50V, switch of the unit and check the motor connections.
6) Note the readings in observation table.
7) Repeat the above experiment with variable load by applying different loads using the loading system in steps of 1 kg, 1.5kg, and 1.75kg.

For Closed loop operation
1) Use connecting wires to connect the motor, drive unit and mains according to the connection diagram.
2) Connect the A.C. mains cord to the power socket, but do not switch on the M.C.B.
3) Switch on the M.C.B. and see if the voltmeter, ammeter and tachometer come on. If they do not turn on or if the FIELD OK LED doesn't come on, then switch of the M.C.B. and report the problem to the instructor.
4) Apply minimum load (non-zero) using the loading arrangement.
5) Set the operation to closed loop mode.
6) Check the default settings. **(K_p=2.5 K_i=2, K_d=0).**
7) Set the set point at 5.0 Hz (300 RPM) using the buttons. Put the motor in RUN mode. Observe the voltage, current and speed readings on the displays.
8) If the motor does not rotate, switch of the drive unit and check the motor connections.
9) Note the reading in observation table.
10) Repeat the above experiment with variable load by applying different loads using the loading system in steps of 0.5kg. Please check if the motor is drawing current in excess of 90% of its rating.

OBSERVATION TABLE:

Here x = 1st speed reading, where the motor just started to rotate.

For Open loop condition

Load	Output (%)	Voltage(V)	Current(A)	Speed(rpm)
No load				

1 Kg load			
1.5 Kg			
1.75 Kg			

GRAPH:

1) Draw a graph of Voltage vs. Speed for different load values.
2) Draw a graph of Current vs. Speed for different load values.

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For Closed loop condition

Set-point (Hz)	Load(Kg)	V	I	Speed(rpm)
5Hz				
10Hz				

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15Hz				
20Hz				

 GRAPH:

1) Draw a graph of Voltage vs. Load for different speed values.
2) Draw a graph of Current vs. Load for different speed values.

CONCLUSION:

STUDY OF CHOPPER FED DC DRIVE

OBJECTIVE:

To study the operation of Chopper fed DC Drive

APPARATUS REQUIRED:

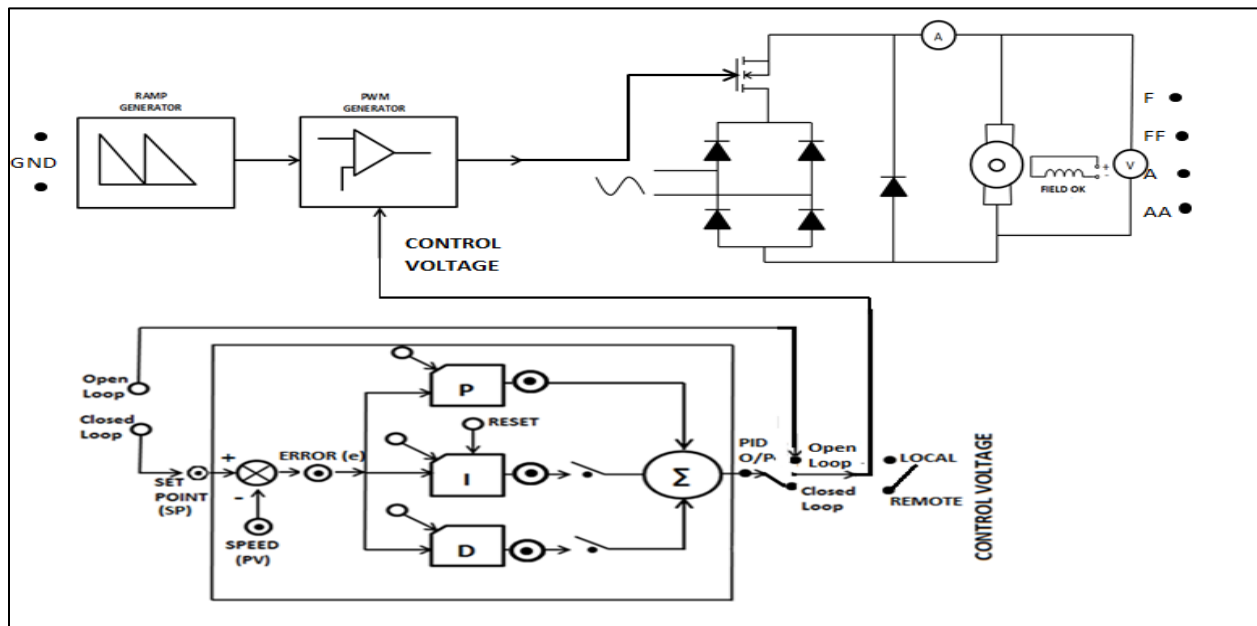1) Drive Unit
2) 0.5 HP DC Motor
3) C.R.O
4) Connecting Wire

OPERATING PANEL LAYOUT

TYPE- A
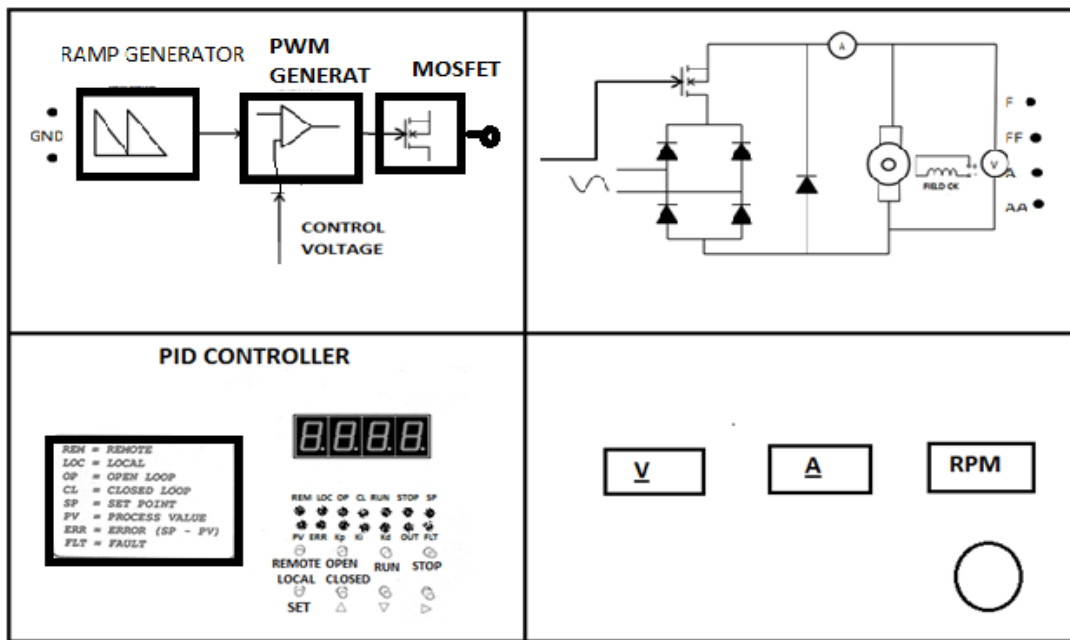

Figure 1: Operating Panel

TYPE B

Figure 2: Operating Panel
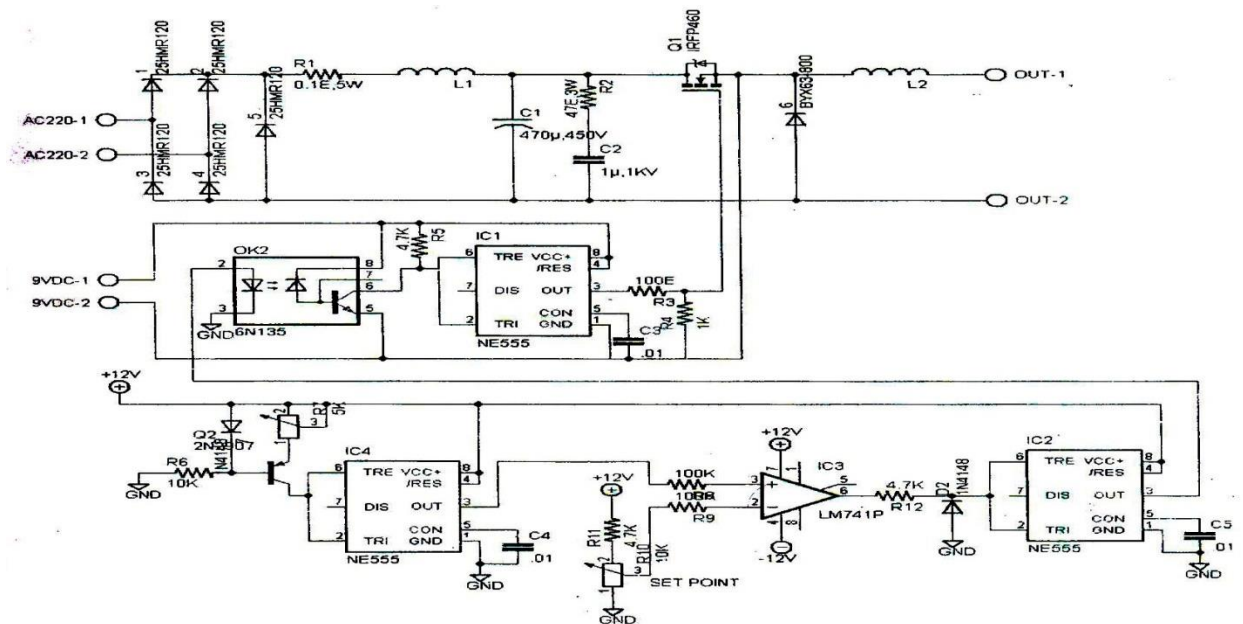
SCHEMATIC DIAGRAM

Figure 3: Schematic Diagram

THEORY:

The above diagram consists of the following blocks:

    i. ***DC bus***

The 220V AC is full wave rectifier and filtered to make a DC bus using four 25A diodes, filter capacitor, an inductor and a surge filter.

    ii. ***Ramp-Generator***

The IC 555 is used as an astable multi-vibrator in the ramp generator configuration by using a current mirror. The current mirror starts charging the capacitor towards $V_{cc\ at}$ a constant rate. When the voltage across the capacitor equals to 2/3 V_{cc}, the internal capacitor turns on the internal transistor and the capacitor rapidly discharges through the transistor. However when the discharge voltage across the capacitor equals to 1/3 V_{cc}, the internal capacitor switches the internal transistor off, and then the capacitor starts charging up again. The charge-discharge cycle keeps on repeating.
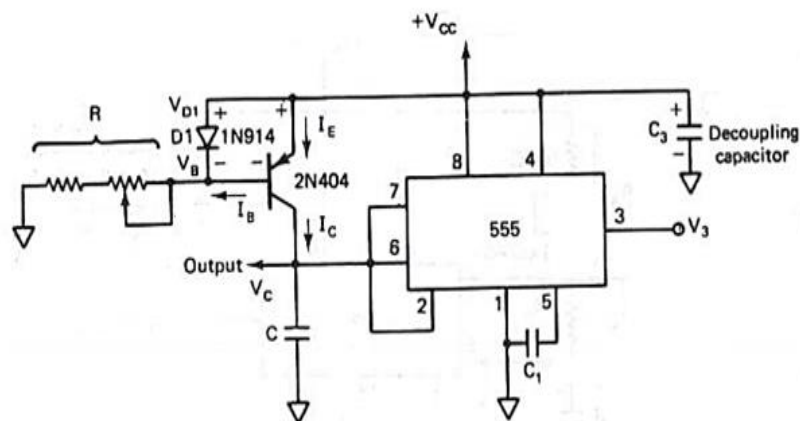
Figure 4: Ramp Generator

    iii. ***PWM Control***

A DC voltage is compared using a comparator, with the ramp- generator output to provide pulses for PWM control. The more the DC voltage, the further away the ramp cuts from start point of the ramp, thus giving an output pulse of variable width. Therefore, when the MOSFET is switched using this signal, the DC voltage from the DC bus is chopped. The output from the MOSFET is further filtered to give a DC voltage of average value inversely proportional to the DC input (e.g. 0~5V corresponds to 300~0V).

For open-loop control, a potentiometer is used to control the pulse width of the PWM. For closed-loop control, the output of the PID controller is used to control the pulse width of the PWM.

Figure 5: Signal Waveform

iv. ___MOSFET firing___

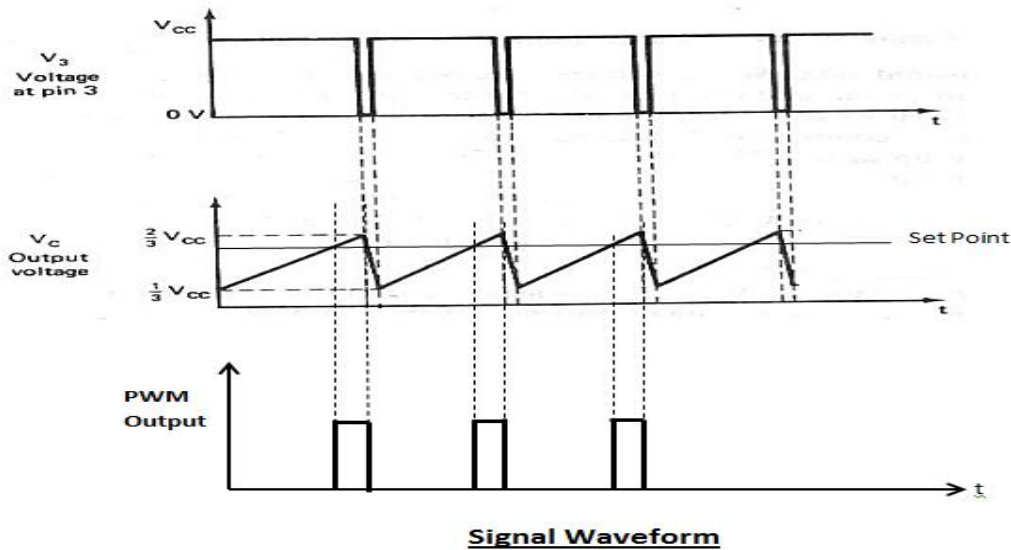The PWM output from the comparator is sent through an IC 555 configured as wave shaper. The output of the IC 555 is used to drive a high-speed opto-isolator 6N135, thereby isolating the signal side from the DC bus. The output of the opto-isolator is further sent through an IC 555 configured as a wave shaper, which triggers the gate of the MOSFET with respects to its source. The DC voltage required for powering the high voltage side of the opto-isolator and MOSFET gate comes from an isolated DC power supply of 9V. The output from the source of the MOSFET Is Connect To a high-speed diode and inductor to filter the DC output and provide a smooth DC waveform.

v. ___PID Controller___

A ___Proportional-Integral-Derivative controller (PID controller)___ is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate constant parameters, the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors, and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supply of a heating element.

By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action.
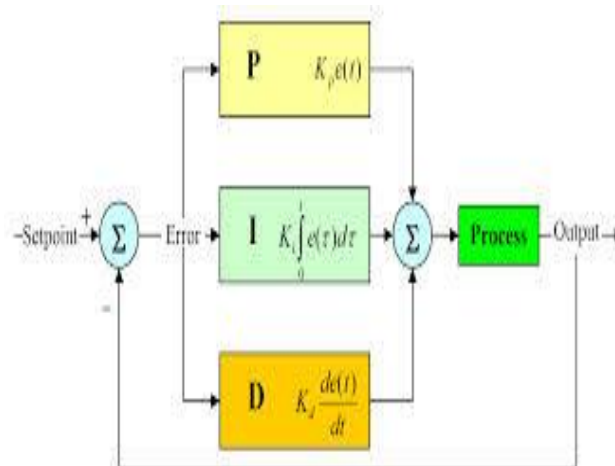

Figure 6: Block Diagram of a PID Controller

Proportional term

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain.
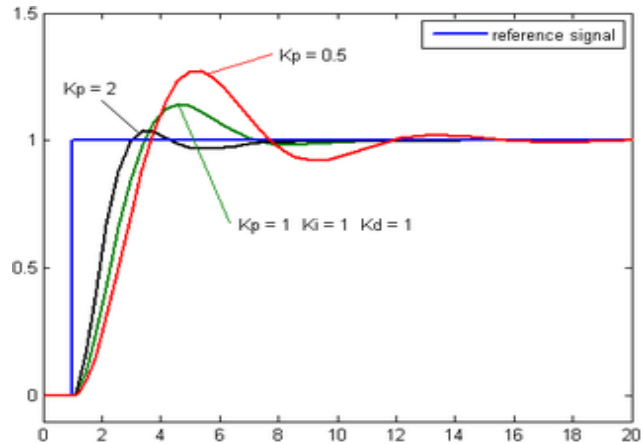
Figure 7: Change of response for varying K_p

The proportional term is given by:

$$P_{out} = K_p e(t)$$

Where

P_{out} = Proportional output

K_p= Proportional gain, a tuning parameter

e =Error = SP-PV

t =Time or instantaneous time (the present)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

In the absence of disturbances, pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i.

Figure 8: Change of response for varying Kᵢ

The integral term is given by:

$$I_{out} = K_i \int_0^t e(\tau)dt$$

Where

I_{out} = Integral output

K_i = Integral Gain, a tuning parameter

e = Error = SP-PV

τ = Time in the past contributing to the integral response

The integral term (when added to the proportional term) accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to overshoot the set point value (cross over the set point and then create a deviation in the other direction).

__Derivative term__

The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

Figure 9: Change of response for varying K$_d$

The derivative term is given by:

$$D_{out} = K_d \frac{de}{dt}$$

Where

D$_{out}$= Derivative output
K$_d$= Derivative Gain, a tuning parameter
e =Error = SP-PV
t =Time or instantaneous time (the present)

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

The output from the three terms, the proportional, the integral and the derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is :

$$u(t) = Mv(t) = K_p e(t) + K_i \int_0^t e(\tau)dt + K_d \frac{de}{dt}$$

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and tuning parameters are

K_p: Proportional gain

The larger **K_p** typically means faster response since the larger the error, the larger the proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

K_i : Integral gain

The larger **K_i** implies steady state errors are eliminated quicker. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

K_d: Derivative gain

The larger **K_d** decreases overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

Speed Measurement

The shaft of the motor is connected an optical encoder. The encoder has a circular plastic disc having 100 alternate black and transparent stripes. The disc is passed through an onto-interrupter MOC7811.Pulses is generated when the disc turns with 100 pulses per revolution. Assuming the maximum speed of the motor is 100 RPM, the maximum pulses per second shall be 2500.

The pulses from the sensor are shaped using an op-amp configures as a comparator. The pulses are fed into a microprocessor-based display for indication of the speed in RPM and an IC 555 configured as a re-trigger able moon-shot. The input pulses are varying in width and frequency. The moon-shot output gives pulses of fixed width, which is filtered to provide a voltage proportional to frequency of the pulses, there by proportional to speed.

MOC7811 has four connections, i.e. D+ & D- for detector and E+ & E- for emitter. The connections from the motor setup to the drive unit should be made one to one. On rotation of the motor, if the tachometer fails to display the speed, the connections should be checked. In case of sensor failure, do not the drive unit in closed loop.

Load setup

The load setup for the motor is pulley and rope braking system. A rope goes around a pulley with a spring balance on one side and a nut-bolt arrangement on the other. On tightening the nut the friction between the rope and pulley increases to create a larger load on the motor.

Dc motor Field

The field coil DC motor is supplied with 220V DC rectified from the main supply. The current in the field coil is sensed and is used to switch on a relay. The indication FIELD OK displays the status. On field failure the relay is cut off and disconnects the armature supply

OPERATION OF MOTOR CONTROLLER (FOR TYPE B OPERATING PANEL)

Introduction

The Digital Motor Controller is PID Controller with some additional features required to operate DC/AC 1phase /AC 3phase motors. The control unit consists of a four-digital display unit for displaying various parameters, some indicating LED's and some buttons for setting of parameters and running of the motor.
The motor speed is sensed using an optical encoder. The speed, set point, error and control parameters are displayed on the digital display panel one by one selecting the viewing parameter using the SET button. The parameters may be changed and save by using the edit buttons.
The motor controller provides the facility to run the motor in open or closed loop. Different faults are indicated on the display unit.
The controller also incorporates safety features like soft-start and open/closed loop transfer through zero speed.

Speed Measurement

The motor speed is sensed using an optical encoder that generates 100 pulses per revolution. These pulses are counted and the frequency in Hz is calculated every 100 msec. the PID algorithm is executed and the output is used to drive the signal section of the specific drive.

Open Loop Operation

In the open loop operation, the output to the drive section may be varied from 0 to 100%. No feedback or control action is taken. The output and the speed or process variable may be displayed using the SET button.

Closed Loop Operation

In the closed loop, the output to the drive section is controlled using a PID algorithm. The PID section describes in detail the operation and functioning of the PID algorithm. The PID parameters may be changed while the motor is running. The set point may be varied between 0.0 to 50 Hz. The various parameters like set point, process variable (speed), error, proportional

gain, integral gain, derivative gain and output are displayed on the digital display. The parameter required to be observed/modified may be selected using the SET button.

Operation

Operating panel

The front fascia consists of 4 7-segment displays, 14 LED's and 8 switches. The 7-segment display indicates the various parameters. The LED's indicate the mode of operation, motor status and parameter being viewed. The switches are used to set different parameters and switch between different modes.

Figure 2.10: Operating Panel Layout

Description of Switches

REMOTE/LOCAL – Remote/Local Switch
Select between Remote / Local modes of operation. Change over only possible when the motor is stopped.

OPEN/CLOSED- Open / Closed Loop Switch
Select between Open / Closed Loop modes of operation. Change over only possible when the motor is stopped.

RUN – Motor Run Switch Used to run the motor.

STOP - Motor Stop Switch Used to stop the motor.

SET – Select/Exit Switch

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In normal mode, it is used to select the display mode. In editing mode, it is used to quit without saving the parameter.

INC – Increment Switch Used to increase the value of the parameter to be edited.

DEC – Decrement Switch Used to decrease the value of the parameter to be edited.

ENT – Enter Switch Used to save the parameter that is being edited.

Description of LED's

RE – Remote Mode Indicator

LO – Local Mode Indicator

OP – Open Loop Mode Indicator

CL – Closed Loop Mode Indicator

RUN – Run Operation Indicator

STOP – Stop Operation Indicator

SP – Set Point Indicator

PV – Process Value Indicator

ER – Error Value Indicator

KP – K_p Value Indicator

KI – K_i Value Indicator

KD – K_d Value Indicator

OU – Output Value Indicator

FA – Fault Indicator

Open-Loop Operation

When the unit is powered on, it is in the Open Loop mode by default. The motor is stopped and the set point = 0.0

Press SET to toggle between PV and OUT displays.

Press O/C to toggle between Open Loop and Closed Loop modes.

In the Open Loop mode, only the output can be set. The value of output can be from 0.0 ~ 100.0%. Please note that the motor may not rotate below a certain minimum output. The output

may be set by pressing the INC or DEC buttons and can be confirmed by pressing ENT. If the motor is on, the output value is instantaneously transferred to the soft-start algorithm so that it is slowly reflected on the output. The output value is not saved on power off.

Closed-Loop Operation

Press O/C to toggle between Open Loop and Closed Loop modes.

Press SET to display the various parameters in the following sequence.

Figure 2.11: Closed Loop Operation

In the Closed Loop mode, the following parameters may be set

PARAMETER	RANGE
SP - Set Point	0.0 ~ 50.0Hz
KP – Proportional Gain	0.0 ~20.0
KI – Integral Gain	0.0 ~ 70.0 s^{-1}
KD – Derivative Gain	0.0 ~20.0 s

The value of the set point can be varied from 0.0 ~ 50.0Hz. Please note that the motor may not run/rotate if adequate gain is not selected. All parameters may be set by pressing the INC or DEC buttons and can be confirmed by pressing ENT. The effect is instantaneous. The values of K_p, K_i and K_d are saved on power failure.

Additionally, the following parameters may be displayed.

PARAMETER	RANGE

PV – Process Value	0.0 ~ 50.0Hz
ERR - Error	-50.0 ~ 50.0Hz
OUT - Output	0.0 ~ 100.0%

Fault Indications

Faults are indicated on the digital display. The various faults, their indications and sources are given below:

Fault	Display	Reason	Applicable Drives	Comments
Field failure	FFAU	Field not connected/faulty	CP-DL-1 CP-DL-2	Requires Power On.
DC Bus Not Ready	nrdy	Internal DC Bus Not Ready.	CP-DL-2 CP-DL-4	At startup only.
Over Current	oCur	Armature Current has gone above the limit.	CP-DL-1 CP-DL-2 CP-DL-3 CP-DL-4	Requires Power On.

 PROCEDURE:

Figure 102: Connection Diagram

For Open loop operation

1) Use connecting wires to connect the motor, drive unit and mains according to the connection diagram.
2) Connect the A.C. mains cord to the power socket, but do not switch on the M.C.B.

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3) Switch on the M.C.B. and see if the voltmeter, ammeter and tachometer come on. If they do not turn on or if the FIELD OK LED doesn't come on, then switch of the M.C.B. and report the problem to the instructor.
4) Remove load from the loading arrangement.
5) Set the output to 25% using the buttons. Put the motor in RUN mode. Observe the voltage, current and speed readings on the displays. Increase the output is steps of 10% and observes the readings. If the motor does not rotate after 50V, switch of the unit and check the motor connections.
6) Note the readings in observation table.
7) Repeat the above experiment with variable load by applying different loads using the loading system in steps of 1 kg, 1.5kg, and 1.75kg.

For Closed loop operation
1) Use connecting wires to connect the motor, drive unit and mains according to the connection diagram.
2) Connect the A.C. mains cord to the power socket, but do not switch on the M.C.B.
3) Switch on the M.C.B. and see if the voltmeter, ammeter and tachometer come on. If they do not turn on or if the FIELD OK LED doesn't come on, then switch of the M.C.B. and report the problem to the instructor.
4) Apply minimum load (non-zero) using the loading arrangement.
5) Set the operation to closed loop mode.
6) Check the default settings. **(K_p=2.5 K_i=2, K_d=0).**
7) Set the set point at 5.0 Hz (300 RPM) using the buttons. Put the motor in RUN mode. Observe the voltage, current and speed readings on the displays.
8) If the motor does not rotate, switch of the drive unit and check the motor connections.
9) Note the reading in observation table.
10) Repeat the above experiment with variable load by applying different loads using the loading system in steps of 0.5kg. Please check if the motor is drawing current in excess of 90% of its rating.

OBSERVATION TABLE:

Here x = 1st speed reading, where the motor just started to rotate.

For Open loop condition

For Open loop condition

Load	Output(%)	Voltage(V)	Current(A)	Speed(rpm)

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No load			
0.5 Kg load			
1 Kg			
1.5 Kg			

 GRAPH:

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1) Draw a graph of Voltage vs. Speed for different load values.
2) Draw a graph of Current vs. Speed for different load values.

For Closed loop condition

Set-point (Hz)	Load(Kg)	V	I	Speed(rpm)
5Hz				
10Hz				

15Hz				
20Hz				

GRAPH:

1) Draw a graph of Voltage vs. Load for different speed values.
2) Draw a graph of Current vs. Load for different speed values.

CONCLUSION:

STUDY OF AC SINGLE PHASE MOTOR-SPEED CONTROL USING TRIAC.

OBJECTIVE:

To Study the operation of TRIAC controlled single phase AC motor Drive.

APPARATUS REQUIRED:
1) Drive Unit
2) 0.5 HP AC (Induction) Motor
3) C.R.O
4) Connecting Wire

OPERATING PANEL LAYOUT

TYPE (A)
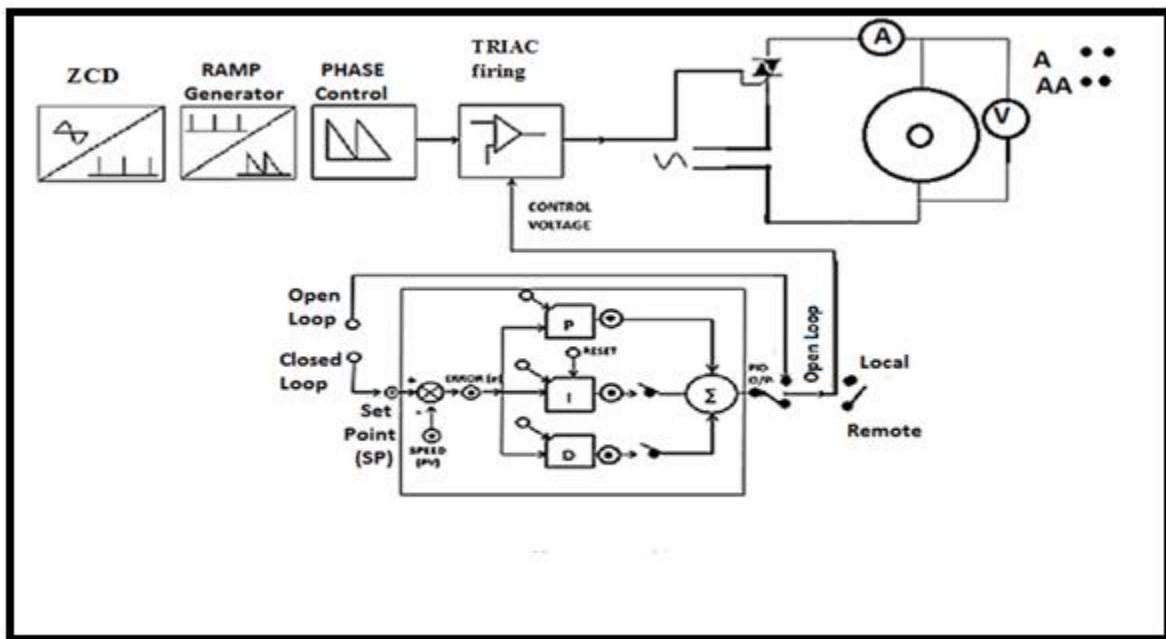
Figure 3.1: Operating Panel

TYPE(B)
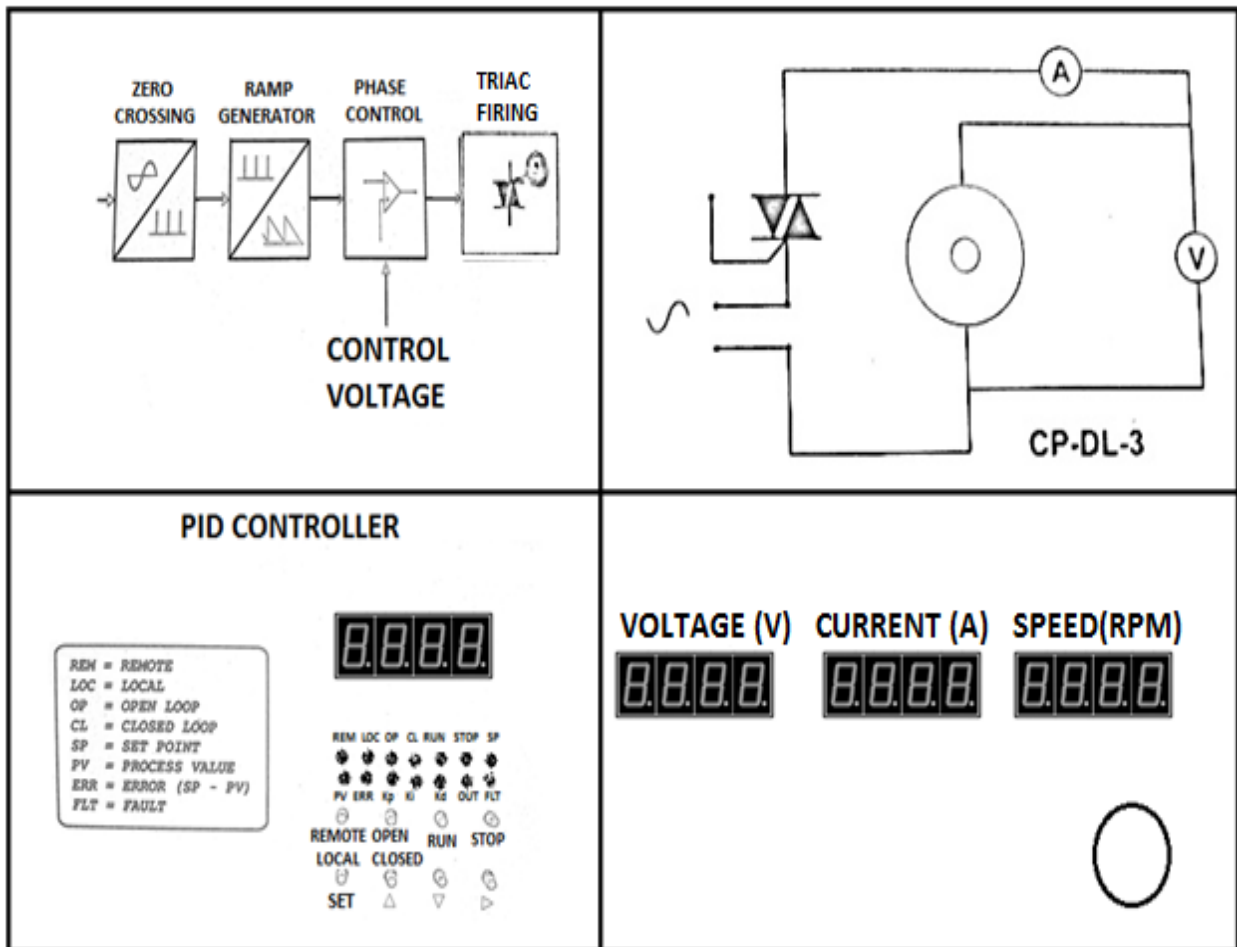
Figure 3.2: Operating panel
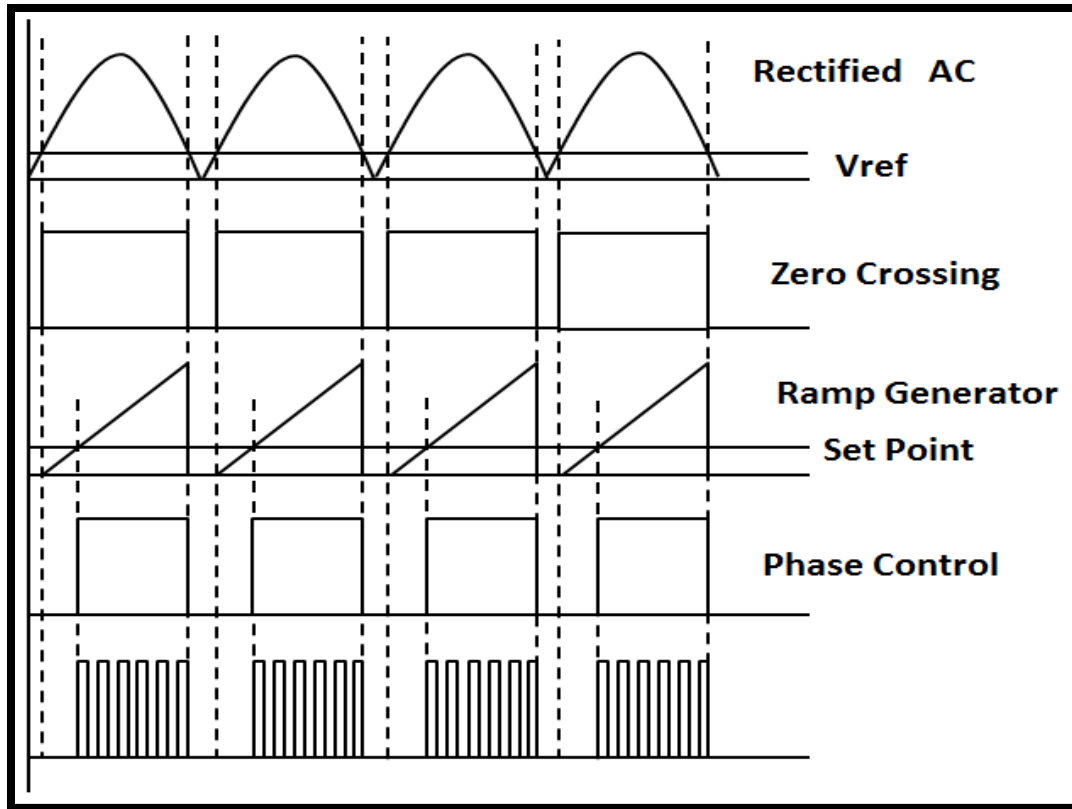
Figure 3.3: Signal Waveform

THEORY:

The above diagram consists of the following blocks:

i.   ***Zero Crossing***

The A.C. signal from the secondary of a step-down transformers is full-wave rectified and applied to the non-inverting terminal of an op-amp configured as a comparator. The inverting terminal of the op-amp is connected to reference D.C. voltage. The resulting waveform from the comparator is a square wave of 100 Hz frequency and remains low during the zero crossing period.

ii.   ***Ramp Generator***

The IC 555 is used as an astable multi-vibrator in the ramp generator configuration by using a current mirror. The current mirror starts charging the capacitor towards $V_{cc \ at}$ a constant rate. When the voltage across the capacitor equals to 2/3 V_{cc}, the internal capacitor turns on the internal transistor and the capacitor rapidly discherges through the transistor.. However when the discharge voltage

across the capacitor equals to 1/3 V_{cc}, the internal capacitor switches the internal transistor off, and then the capacitor starts charging up again. The charge-discharge cycle keeps on repeating.

iii.   *__Phase Control__*

A DC voltage is compared using a comparator, with the ramp-generator output to provide pulses for phase control. The more the DC voltage, the further away the ramp cuts from zero-crossing, thus giving an output pulse width which starts further away from the zero-crossing. The more the DC voltage, the more the phase-angle (e.g. 0 ~ 5V corresponds to 0 ~ 180 degree).

For open-loop control, a potentiometer is used to control the phase-angle. For closed-loop control, the output of the PID Controller is used to control the phase angle.

IV. **TRIAC Firing:**

An IC 555 is used to generate a 50% duty cycle, 5 KHz square wave to be used as a pulse generator for the pulse transformer. The reset terminal of the IC is connected to the output of the phase control. The resulting waveform is a 5 KHz waveform enveloped in the phase control waveform. One1:1 pulse transformer is used for providing the TRIAC with isolated pulses.

__PID Controller__

A *__Proportional-Integral-Derivative controller (PID controller)__* is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate constant parameters, the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors, and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supply of a heating element.

By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action.

Figure 3.4: Block Diagram of a PID Controller

Proportional term

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain.
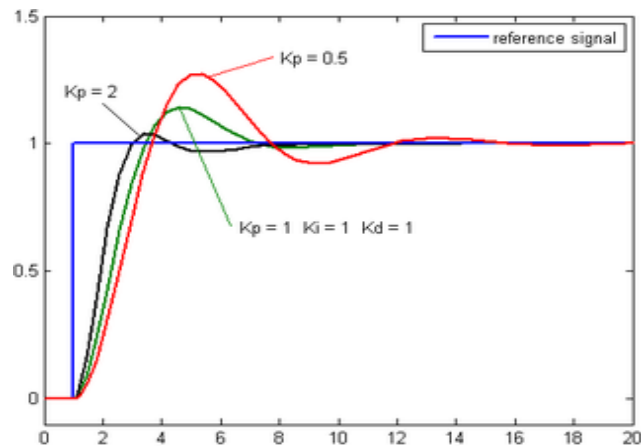
Figure 3.5: Change of response for varying K_p

The proportional term is given by:

$$P_{out} = K_p e(t)$$

Where

P_{out} = Proportional output

K_p = Proportional gain, a tuning parameter

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e =Error = SP-PV

t =Time or instantaneous time (the present)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

In the absence of disturbances, pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i.

Figure 3.6: Change of response for varying K_i

The integral term is given by:

$I_{out} = K_i \int_0^t e(\tau)dt$

Where

I_{out} = Integral output

K_i = Integral Gain, a tuning parameter

e =Error = SP-PV

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τ =Time in the past contributing to the integral response

The integral term (when added to the proportional term) accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to overshoot the set point value (cross over the set point and then create a deviation in the other direction).

Derivative term

The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

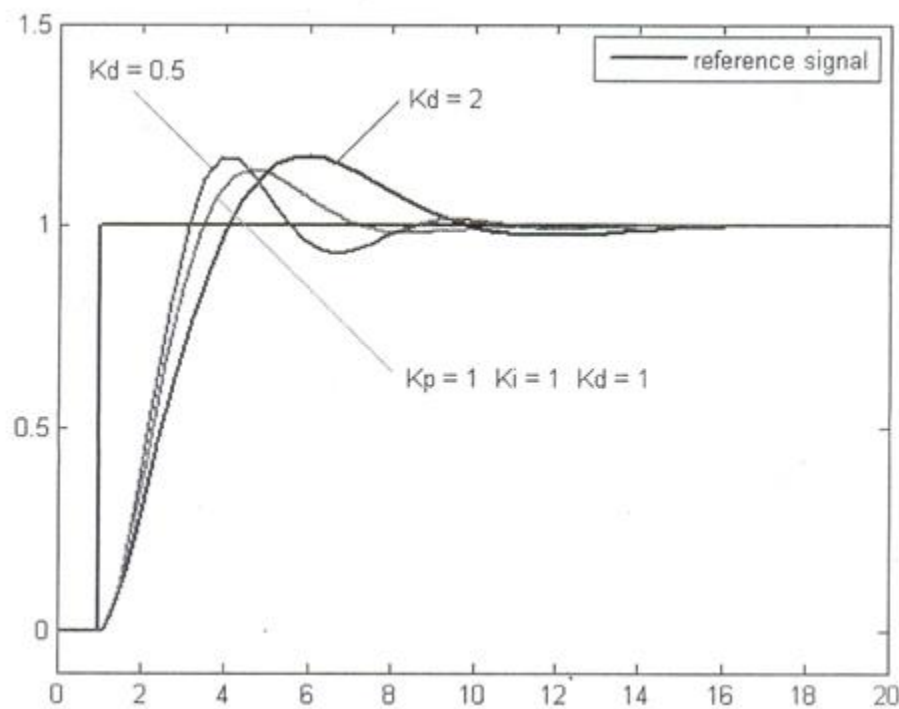**Figure 3.7: Change of response for varying Kd**

The derivative term is given by:

$$D_{out} = K_d \frac{de}{dt}$$

Where

D_{out}= Derivative output

K_d= Derivative Gain, a tuning parameter

e =Error = SP-PV

t =Time or instantaneous time (the present)

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The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

The output from the three terms, the proportional, the integral and the derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is :

$$\mathbf{u(t) = Mv(t) = K_p e(t) +\ K_i \int_0^t e(\tau)dt + K_d \frac{de}{dt}}$$

and tuning parameters are

K_p: Proportional gain

The larger $\mathbf{K_p}$ typically means faster response since the larger the error, the larger the proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

K_i : Integral gain

The larger $\mathbf{K_i}$ implies steady state errors are eliminated quicker. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

K_d: Derivative gain

The larger $\mathbf{K_d}$ decreases overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

Speed measurement

The shaft of the motor is connected an optical encoder. The encoder has a circular plastic disc having 100 alternate black and transparent stripes. The disc is passed through an opto-interruptor MOC7811. Pulses are generated when the disc turns with 100 pulses per revolution.

The pulses from the sensor are shaped using an op-amp configures as comparator. The pulses are fed into microprocessor based display for indication of the speed in RPM.

MOC7811 has four connections, i.e. D+ & D- for detector and E+ & E- for emitter. The connections from the motor setup to the drive unit should be made one to one. On rotation of the motor, if the

tachometer fails to display the speed, the connections should be checked. In case of sensor failure, do not run the drive unit in closed loop.

Load setup

The load setup for the motor is a flat pulley and friction belt breaking system. A friction belt goes around a pulley with a spring balance on one side and a nut-bolt arrangement on the other. On tightening the nut the friction between the friction belt and pulley increases to create a larger load on the motor.

DC motor field

The field coil of the DC motor is supplied with 220V DC rectified from the main supply. The current in the field coil is sensed and is used to switch on a relay. The indication FIELD OK displays the status. On field failure the relay is cut off and disconnects the armature supply.

Operation of Motor Controller

The Digital Motor Controller is PID Controller with some additional features required to operate DC/AC1/AC3 motors. The control unit consists of a four-digital display unit for displaying various parameters, some indicating LED's and some buttons for setting of parameters and running of the motor.

The motor speed is sensed using an optical encoder. The speed, set point, error and control parameters are displayed on the digital display panel one by one selecting the viewing parameter using the SET button. The parameters may be changed and saved by using the edit buttons.

The motor controller provides the facility to run the motor in open or closed loop. Different faults are indicated on the display unit.

The controller also incorporates safety features like soft-start and open/closed loop transfer through zero speed.

Speed Measurement

The motor speed is sensed using an optical encoder that generates 100 pulses per revolution. These pulses are counted and the frequency in Hz is calculated every 100 msec. the PID algorithm is executed and the output is used to drive the signal section of the specific drive.

Open Loop Operation

In the open loop operation, the output to the drive section may be varied from 0 to 100%. No feedback or control action is taken. The output and the speed or process variable may be displayed using the SET button.

Closed Loop Operation

In the closed loop, the output to the drive section is controlled using a PID algorithm. The PID section describes in detail the operation and functioning of the PID algorithm. The PID parameters may be changed while the motor is running. The set point may be varied between 0.0 to 50 Hz. The various parameters like set point, process variable (speed), error, proportional gain, integral gain, derivative gain and output are displayed on the digital display. The parameter required to be observed/modified may be selected using the SET button.

 Operation

Operating panel

The front fascia consists of 4 7-segment displays, 14 LED's and 8 switches. The 7-segment display indicates the various parameters. The LED's indicate the mode of operation, motor status and parameter being viewed. The switches are used to set different parameters and switch between different modes.

Figure 3.8: Operating Panel Layout

<u>**Description of Switches**</u>

REMOTE/LOCAL – Remote/Local Switch
Select between Remote / Local modes of operation. Change over only possible when the motor is stopped.
OPEN/CLOSED- Open / Closed Loop Switch

Select between Open / Closed Loop modes of operation. Change over only possible when the motor is stopped.

RUN – Motor Run Switch

Used to run the motor.

STOP - Motor Stop Switch

Used to stop the motor.

SET – Select/Exit Switch

In normal mode, it is used to select the display mode. In editing mode, it is used to quit without saving the parameter.

INC – Increment Switch

Used to increase the value of the parameter to be edited.

DEC – Decrement Switch

Used to decrease the value of the parameter to be edited.

ENT – Enter Switch

Used to save the parameter that is being edited.

Description of LED's

RE – Remote Mode Indicator

LO – Local Mode Indicator

OP – Open Loop Mode Indicator

CL – Closed Loop Mode Indicator

RUN – Run Operation Indicator

STOP – Stop Operation Indicator

SP – Set Point Indicator

PV – Process Value Indicator

ER – Error Value Indicator

KP – K_p Value Indicator

KI – K_i Value Indicator

KD – K_d Value Indicator

OU – Output Value Indicator

FA – Fault Indicator

Open-Loop Operation

When the unit is powered on, it is in the Open Loop mode by default. The motor is stopped and the set point = 0.0

Press SET to toggle between PV and OUT displays.

Press O/C to toggle between Open Loop and Closed Loop modes.

In the Open Loop mode, only the output can be set. The value of output can be from 0.0 ~ 100.0%. Please note that the motor may not rotate below a certain minimum output. The output may be set by pressing the INC or DEC buttons and can be confirmed by pressing ENT. If the motor is on, the output

value is instantaneously transferred to the soft-start algorithm so that it is slowly reflected on the output. The output value is not saved on power off.

Closed-Loop Operation

Press O/C to toggle between Open Loop and Closed Loop modes.

Press SET to display the various parameters in the following sequence.

Figure 3.9: Closed Loop Operation

In the Closed Loop mode, the following parameters may be set

PARAMETER	RANGE
SP - Set Point	0.0 ~ 50.0Hz
KP – Proportional Gain	0.0 ~20.0
KI – Integral Gain	0.0 ~ 70.0 s^{-1}
KD – Derivative Gain	0.0 ~20.0 s

The value of the set point can be varied from 0.0 ~ 50.0Hz. Please note that the motor may not run/rotate if adequate gain is not selected. All parameters may be set by pressing the INC or DEC buttons and can be confirmed by pressing ENT. The effect is instantaneous. The values of K_p, K_i and K_d are saved on power failure.

Additionally, the following parameters may be displayed.

PARAMETER	RANGE
PV – Process Value	0.0 ~ 50.0Hz
ERR - Error	-50.0 ~ 50.0Hz
OUT - Output	0.0 ~ 100.0%

Fault Indications

Faults are indicated on the digital display. The various faults, their indications and sources are given below:

Fault	Display	Reason	Applicable Drives	Comments
Field failure	FFAU	Field not connected/faulty	CP-DL-1 CP-DL-2	Requires Power On.
DC Bus Not Ready	nrdy	Internal DC Bus Not Ready.	CP-DL-2 CP-DL-4	At startup only.
Over Current	oCur	Armature Current has gone above the limit.	CP-DL-1 CP-DL-2 CP-DL-3 CP-DL-4	Requires Power On.

PROCEDURE:

Figure 3.10: Connection Diagram

For Open loop operation

1) Use connecting wires to connect the motor, drive unit and mains according to the connection diagram.
2) Connect the A.C. mains cord to the power socket, but do not switch on the M.C.B.
3) Switch on the M.C.B. and see if the voltmeter, ammeter and tachometer come on. If they do not turn on or if the FIELD OK LED doesn't come on, then switch of the M.C.B. and report the problem to the instructor.
4) Remove load from the loading arrangement.
5) Set the output to 25% using the buttons. Put the motor in RUN mode. Observe the voltage, current and speed readings on the displays. Increase the output is steps of 10% and observes

the readings. If the motor does not rotate after 50V, switch of the unit and check the motor connections.

6) Note the readings in observation table.
7) Repeat the above experiment with variable load by applying different loads using the loading system in steps of 1 kg, 1.5kg, and 1.75kg.

For Closed loop operation

1) Use connecting wires to connect the motor, drive unit and mains according to the connection diagram.
2) Connect the A.C. mains cord to the power socket, but do not switch on the M.C.B.
3) Switch on the M.C.B. and see if the voltmeter, ammeter and tachometer come on. If they do not turn on or if the FIELD OK LED doesn't come on, then switch of the M.C.B. and report the problem to the instructor.
4) Apply minimum load (non-zero) using the loading arrangement.
5) Set the operation to closed loop mode.
6) Check the default settings. **(K$_p$=2.5 K$_i$=2, K$_d$=0).**
7) Set the set point at 5.0 Hz (300 RPM) using the buttons. Put the motor in RUN mode. Observe the voltage, current and speed readings on the displays.
8) If the motor does not rotate, switch of the drive unit and check the motor connections.
9) Note the reading in observation table.
10) Repeat the above experiment with variable load by applying different loads using the loading system in steps of 0.5kg. Please check if the motor is drawing current in excess of 90% of its rating.

Observation Table :

❖ **For Open Loop Control-**

Load	Output(%)	Voltage(V)	Current(A)	Speed(rpm)
	25%			
No load				

1 Kg load			
1.5 Kg			
1.75 Kg			

GRAPH

1) Draw the graph of voltage vs speed for different load values.

2) Draw the graph of current vs speed for different load values

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For Closed Loop Control-

Set-point (Hz)	Load(Kg)	V	I	Speed(rpm)
5Hz	No load			
	1			
	1.25			
	1.5			
	1.75			
	2			
10Hz	No load			
	1			
	1.25			
	1.5			
	1.75			
	2			
15Hz	No load			
	1			
	1.25			
	1.5			
	1.75			
	2			
	No load			
	1			
	1.25			

20Hz	1.5			
	1.75			
	2			

GRAPH

1) Draw the graph of voltage vs load for different speed values.

2) Draw the graph of current vs load for different speed values.

Discussion & Conclusion:

Objective:

- Use electrical machines and power electronics to simulate a simple AC motor drive with variable speed control.
- Learn how to use the Universal Bridge block.
- Discretize your model and compare variable-step and fixed-step simulation methods.
- Learn how to use the Multimeter block.
- Learn how to use the FFT tool.
-

Minimum Required Software Package:

MATLAB Simulink with SIMPOWER SYSTEM tools box.

Pre-Laboratory:

Variable speed control of AC electrical machines makes use of forced-commutated electronic switches such as IGBTs, MOSFETs, and GTOs. Asynchronous machines fed by pulse width modulation (PWM) voltage sourced converters (VSC) are nowadays gradually replacing the DC motors and thyristor bridges. With PWM, combined with modern control techniques such as field-oriented control or direct torque control, you can obtain the same flexibility in speed and torque control as with DC machines. This section shows how to build a simple open loop AC drive controlling an asynchronous machine.

The Machines library contains four of the most commonly used three-phase machines: simplified and complete synchronous machines, asynchronous machine, and permanent magnet synchronous machine. Each machine can be used either in generator or motor mode. Combined with linear and nonlinear elements such as transformers, lines, loads, breakers, etc., they can be used to simulate electromechanical transients in an electrical network. They can also be combined with power electronic devices to simulate drives.

The Power Electronics library contains blocks allowing you to simulate diodes, thyristors, GTO thyristors, MOSFETs, and IGBT devices. You could interconnect several blocks together to build a three-phase bridge. For example, an IGBT inverter bridge would require six IGBTs and six anti parallel diodes.

To facilitate implementation of bridges, the Universal Bridge block automatically performs these interconnections for you.

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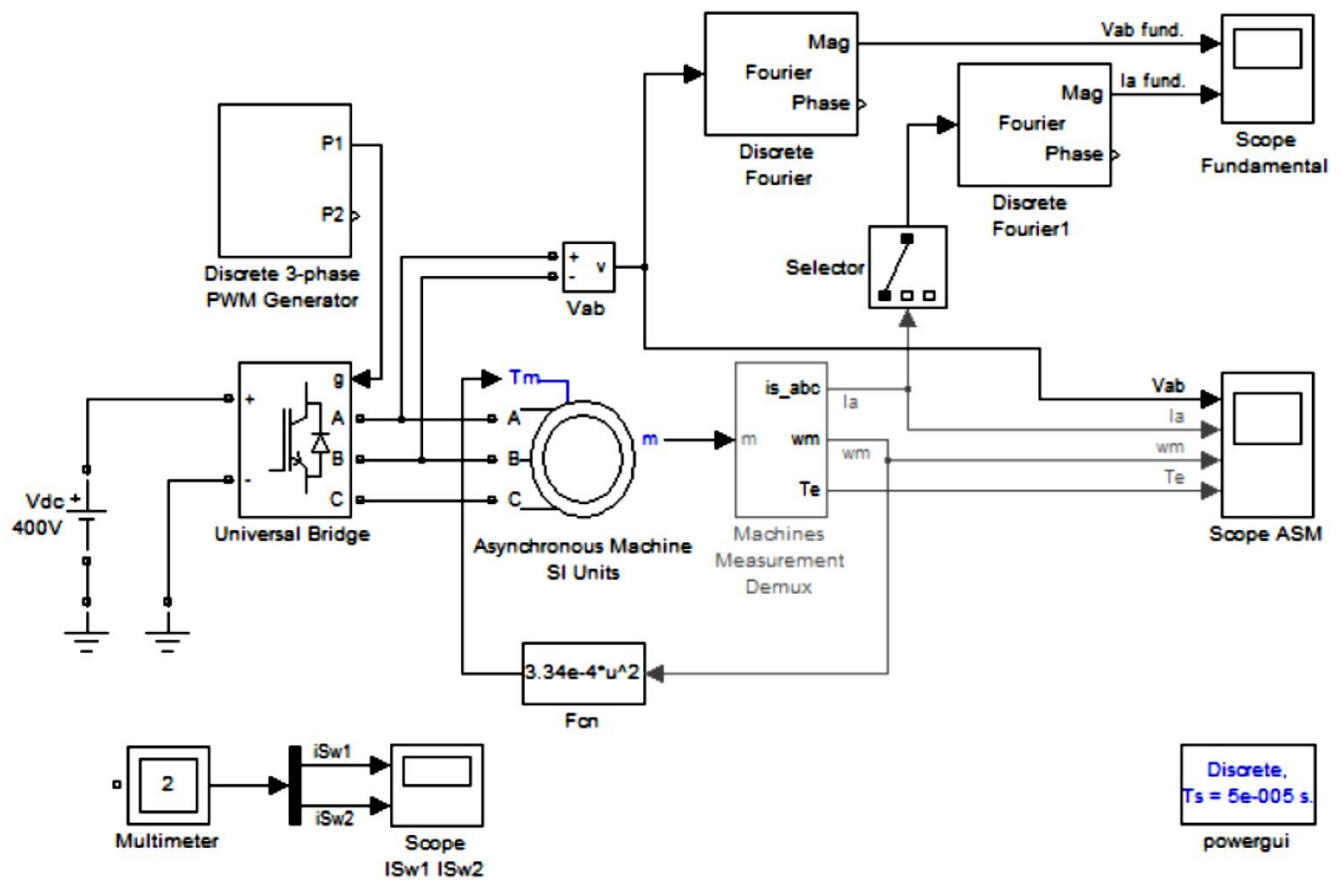**DEPARTMENT OF ELECTRICAL ENGINEERING**

Circuit Diagram:

Figure 4.1: Pulse Width Modulation (PWM) of an Induction Motor

Laboratory:

Building and Simulating the PWM Induction Motor Drive

Follow these steps to build a PWM-controlled motor.

Assembling and Configuring the Motor Blocks

In the first steps, you copy and set up the motor blocks:

1 Open a new window and save it as Exp4.

2 Open the Power Electronics library and copy the Universal Bridge block into your Exp4 model.

3 Open the Universal Bridge dialog box and set its parameters as follows:

Power electronic device   IGBT/Diodes

Snubber

      Rs   1e5 Ω

      Cs   inf

      Ron   1e-3 Ω

Forward voltages

      Vf   0 V

      Vfd   0 V

Tail

      Tf   1e-6 s

      Tt   1e-6 s

4 Open the Machines library. Copy the Asynchronous Machine SI Units block as well as the Machine Measurement Demux block into your Exp4 model.

5 Open the Asynchronous Machine menu and look at its parameters. Set the nominal power Pn parameter to 3*746 VA and the nominal line-to-line voltage Vn to 220 Vrms to implement a 3 HP, 60 Hz machine with two pairs of poles. Its nominal speed is therefore slightly lower than the synchronous speed of 1800 rpm, or ws= 188.5 rad/s.

6 Notice that the three rotor terminals a, b, and c are made accessible. During normal motor operation these terminals should be short-circuited together. In the Asynchronous Machine menu change the rotor type to Squirrel cage. Notice that after this change the rotor connections are no longer accessible.

7 Open the Machine Measurement Demux block menu. When this block is connected to a machine measurement output, it allows you to access specific internal signals of the machine. First select the Asynchronous machine type. Deselect all signals except the

following three signals: is_abc (three stator currents), wm (rotor speed), and Te (electromagnetic torque).

Loading and Driving the Motor

You now implement the torque-speed characteristic of the motor load. Assume a quadratic torque-speed characteristic (fan or pump type load). The torque T is then proportional to the square of the speed ω.

$$T = k \times \omega^2$$

The nominal torque of the motor is

$$T_n = \frac{3 \times 746}{188.5} = 11.87 \; Nm$$

Therefore, the constant k should be

$$k = \frac{T_n}{\omega^2} = \frac{11.87}{188.5} = 3.34 \times 10^{-4}$$

1 Open the User-Defined Functions library of Simulink and copy the Fcn block into your Exp4 model. Open the block menu and enter the expression of torque as a function of speed: 3.34e-4*u^2.

2 Connect the input of the Fcn block to the speed output of the Machines Measurement Demux block, labeled wm, and its output to the torque input of the motor, labeled Tm.

3 Open the Electrical Sources library and copy the DC Voltage Source block into your Exp4 model. Open the block menu and set the voltage to 400 V.

4 Open the Measurements library and copy a Voltage Measurement block into your Exp4 model. Change the block name to Vab.

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5 Using Ground blocks from the Elements library, complete the power elements and voltage sensor interconnections as shown in Circuit 5: PWM Control of an Induction Motor.

Controlling the Inverter Bridge with a Pulse Generator

To control your inverter bridge, you need a pulse generator. Such a generator is available in the Extras library of powerlib:

Open the Extras/Discrete Control blocks library and copy the Discrete 3-Phase PWM Generator block into your Exp4 model. This block can be used to generate pulses for a two-level or a three-level bridge. In addition the block generates two sets of pulses (outputs P1 and P2) that can be sent to two different three-arm bridges when the converter uses a twin bridge configuration. In this case, use it as a two-level single-bridge PWM generator. The converter operates in an open loop, and the three PWM modulating signals are generated internally. Connect the P1 output to the pulses input of the Universal Bridge block.

Displaying Signals and Measuring Fundamental Voltage and Current

1 You now add blocks measuring the fundamental component (60 Hz) embedded in the chopped Vab voltage and in the phase A current. Open the Extras/Discrete Measurements library of powerlib and copy the discrete Fourier block into your Exp4 model. Open the discrete Fourier block dialog box and check that the parameters are set as follows:

Fundamental frequency   f1   60 Hz

Harmonic number   1

Initial input   [0 0]

Sample time   10e-6 s

Connect this block to the output of the Vab voltage sensor.

2 Duplicate the Discrete Fourier block. To measure the phase A current, you need to select the first element of the is_abc output of the ASM Measurement Demux block. Copy a Selector block from the Simulink Signal Routing library. Open its menu and set Index vector (dialog) to 1. Connect the Selector output to the second Discrete Fourier block and its input to the is_abc output of the Machines Measurement Demux block as shown in Circuit 5: PWM Control of an Induction Motor.

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3 Finally, add scopes to your model. Copy one Scope block into your circuit. This scope is used to display the instantaneous motor voltage, currents, speed, and electromagnetic torque. In the Scope properties > General menu of the scope, set the following parameters:

Number of axes   4

Time range   0.05 s

Tick labels bottom axis   only

To allow further processing of the signals displayed on the oscilloscope, you have to store them in a variable. In the Scope properties > Data history menu of the scope, set the following parameters:

Limit data point to last   deselected

Save data to workspace   selected

variable name   ASM

Format   Structure with time

After simulation, the four signals displayed on the scope are available in a structure array named ASM.

4 Duplicate the four-input Scope and change its number of inputs to 2. This scope is used to display the fundamental component of Vab voltage and Ia currents.

Simulation Result:
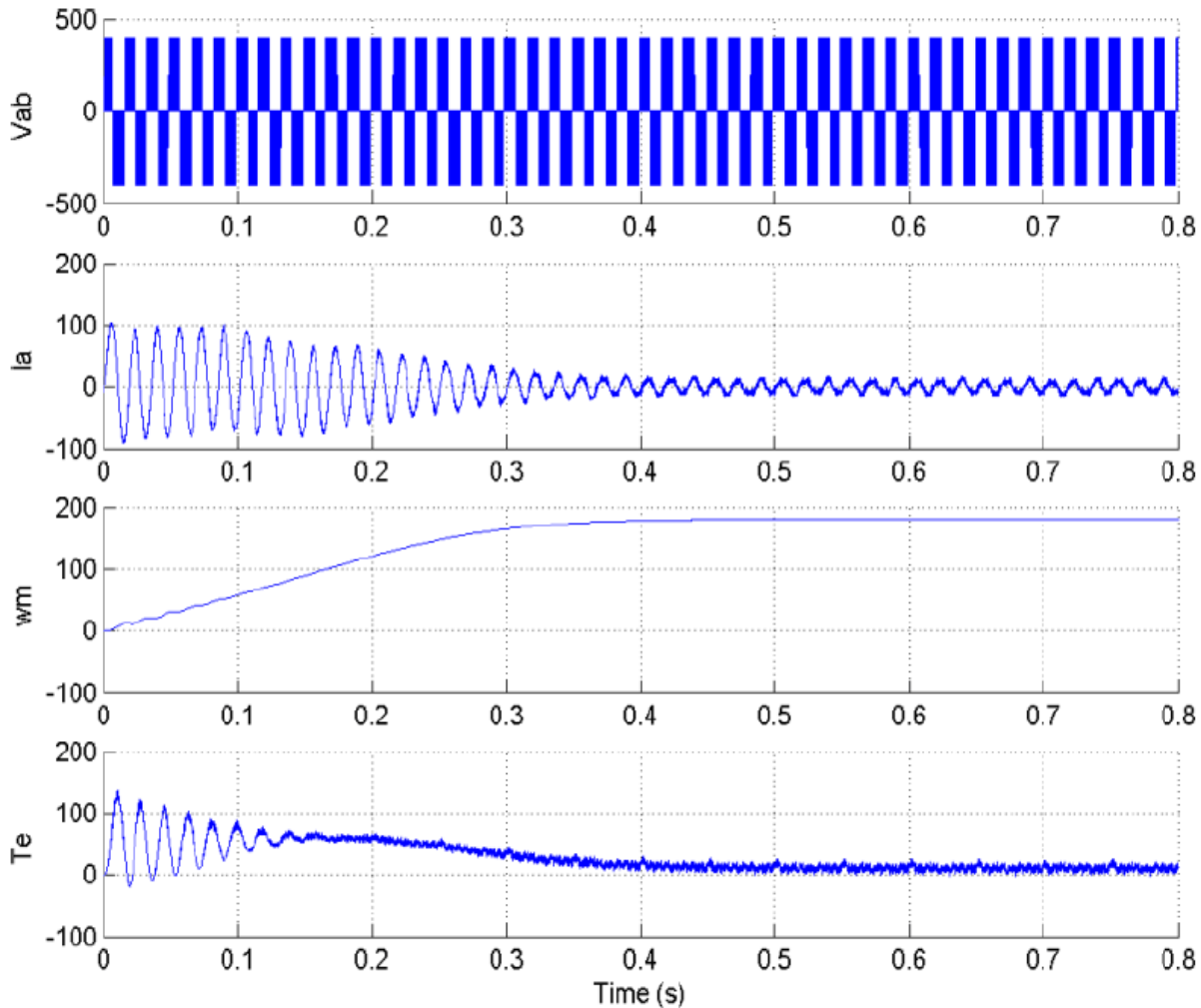
Figure 4.2: PWM Induction Motor Drive; Simulation result at motor starting at full voltage

Using the Multimeter Block

The Universal Bridge block is not a conventional subsystem where all the six individual switches are accessible. If you want to measure the switch voltages and currents, you must use the Multimeter block, which gives access to the bridge internal signals:
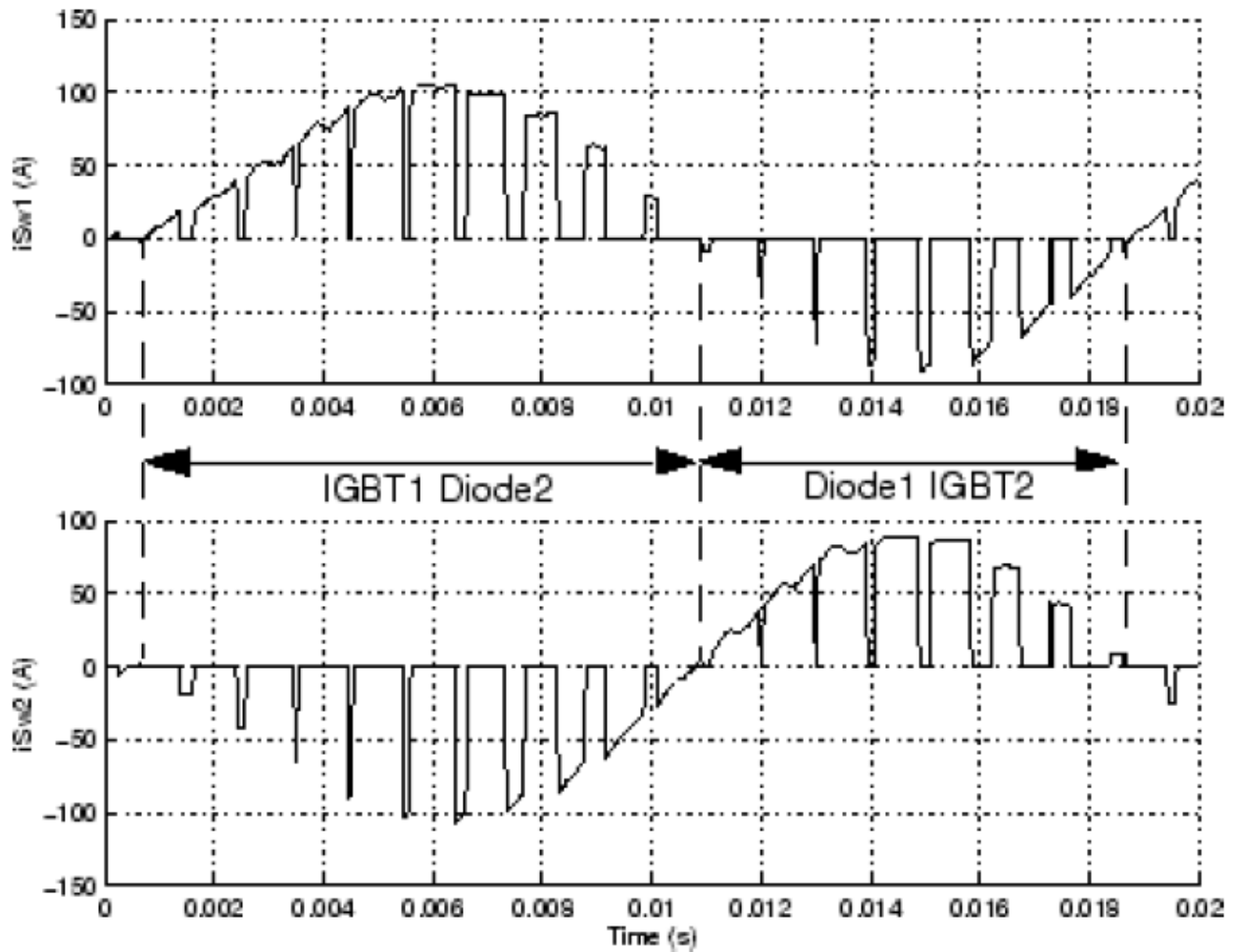
Figure 4.3:Currents in IGBT switch and Diode 1 and 2

Discretizing the PWM Motor Drive

You might have noticed that the simulation using a variable-step integration algorithm is relatively long. Depending on your computer, it might take tens of seconds to simulate one second. To shorten the simulation time, you can discretize your circuit and simulate at fixed simulation time steps.

Performing Harmonic Analysis Using the FFT Tool The two Discrete Fourier blocks allow computation of the fundamental component of voltage and current while simulation is

running. If you would like to observe harmonic components also you would need a Discrete Fourier block for each harmonic. This approach is not convenient.
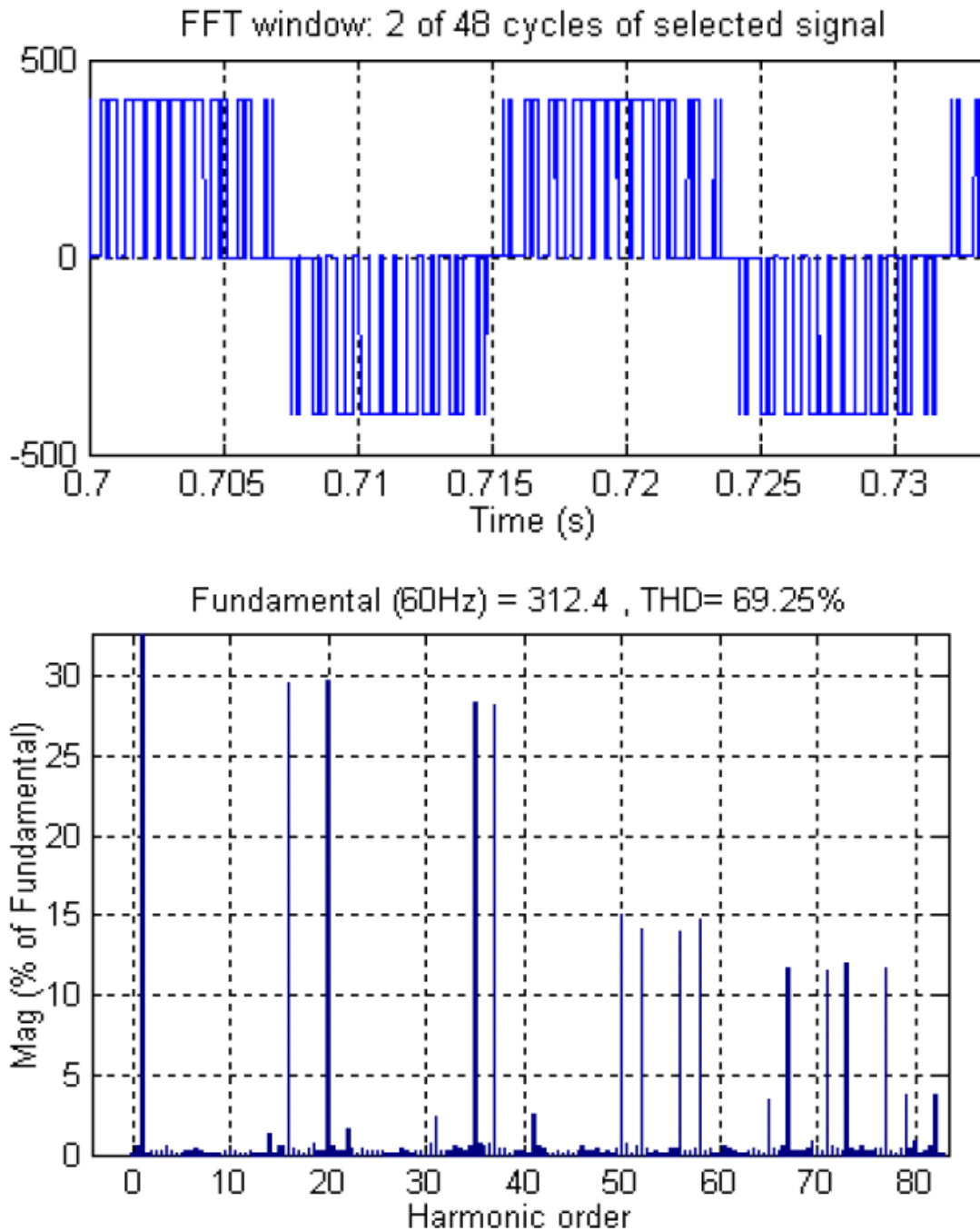
Figure 4.4: FFT analysis of motor Line-to-Line Voltage

Now use the FFT tool of Powergui to display the frequency spectrum of voltage and current waveforms. These signals are stored in your workspace in the ASM structure with time

variable generated by the Scope block. Because your model is discretized, the signal saved in this structure is sampled at a fixed step and consequently satisfies the FFT tool requirements.

Conclusion:

EXPERIMENT NO. 7

STUDY OF PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE FED BY PWM INVERTER.

OBJECTIVE:

To Study of permanent magnet synchronous motor drive fed by PWM Inverter

SOFTWARE USED: MATLAB7.9 (R2009B)

CIRCUIT DIAGRAM:

Circuit diagram of the internal connection of Phase Controlled Rectified DC Motor Drive is shown below:
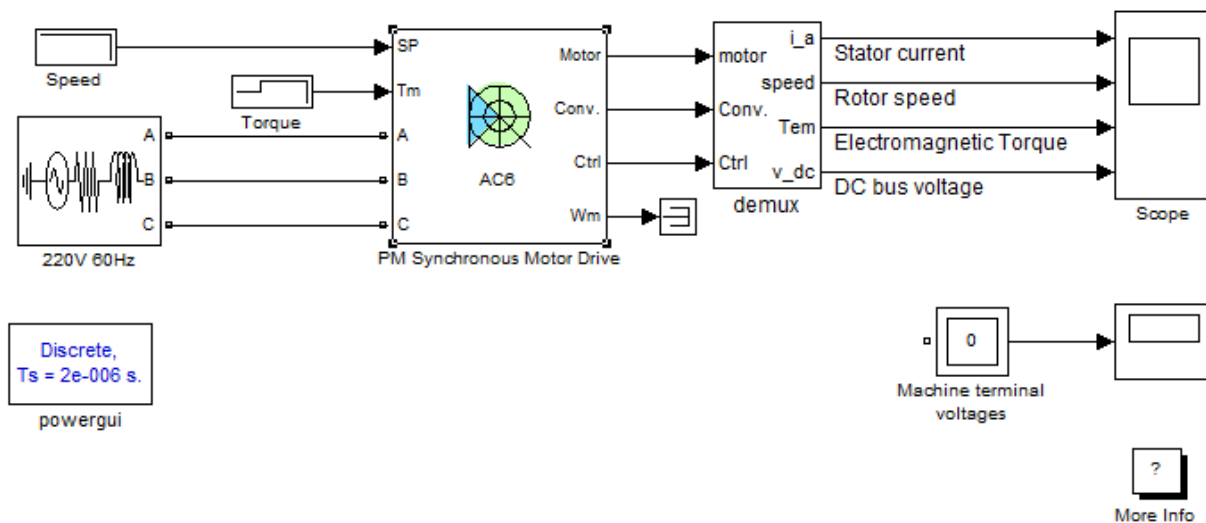
Figure 7.1: Circuit Diagram

THEORY:

This circuit uses block of Sim PowerSystems™ library. It models a permanent magnet (PM) synchronous motor drive with a braking chopper for a 3HP motor.

The PM synchronous motor is fed by a PWM voltage source inverter, which is built using a Universal Bridge Block. The speed control loop uses a PI regulator to produce the flux and torque references for the vector control block. The vector control block computes the three reference motor line currents corresponding to the flux and torque references and then feeds the motor with these currents using a three-phase current regulator.

Motor current, speed, and torque signals are available at the output of the block.

Simulink Schematic

High level Schematic
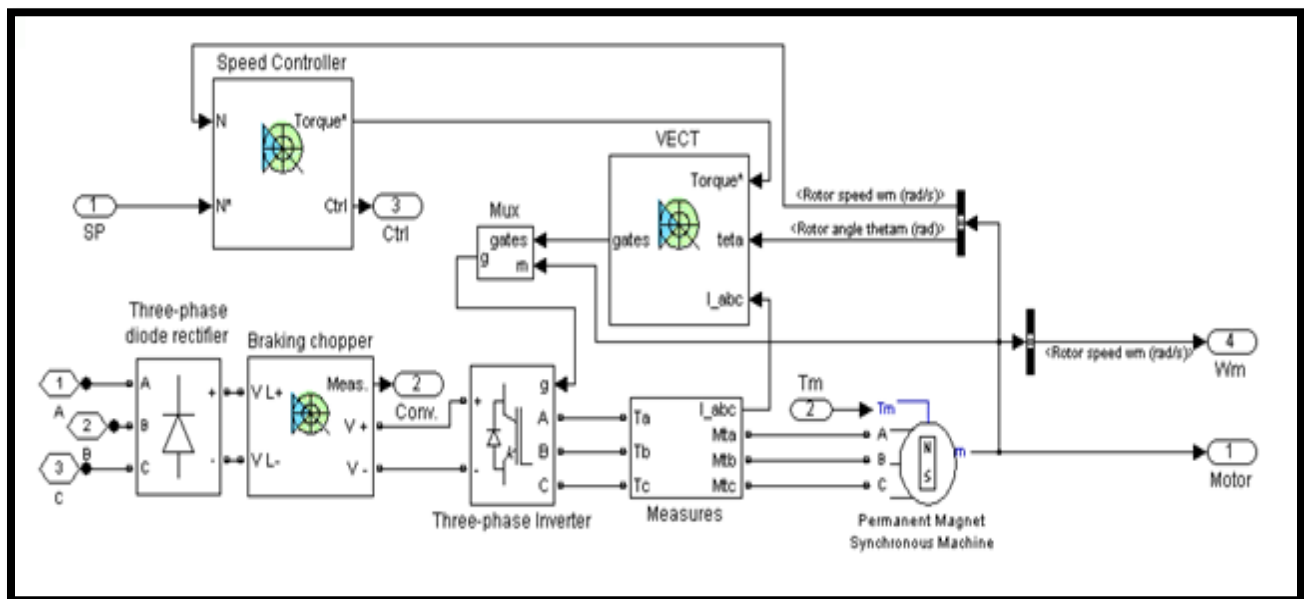
Figure7.2:
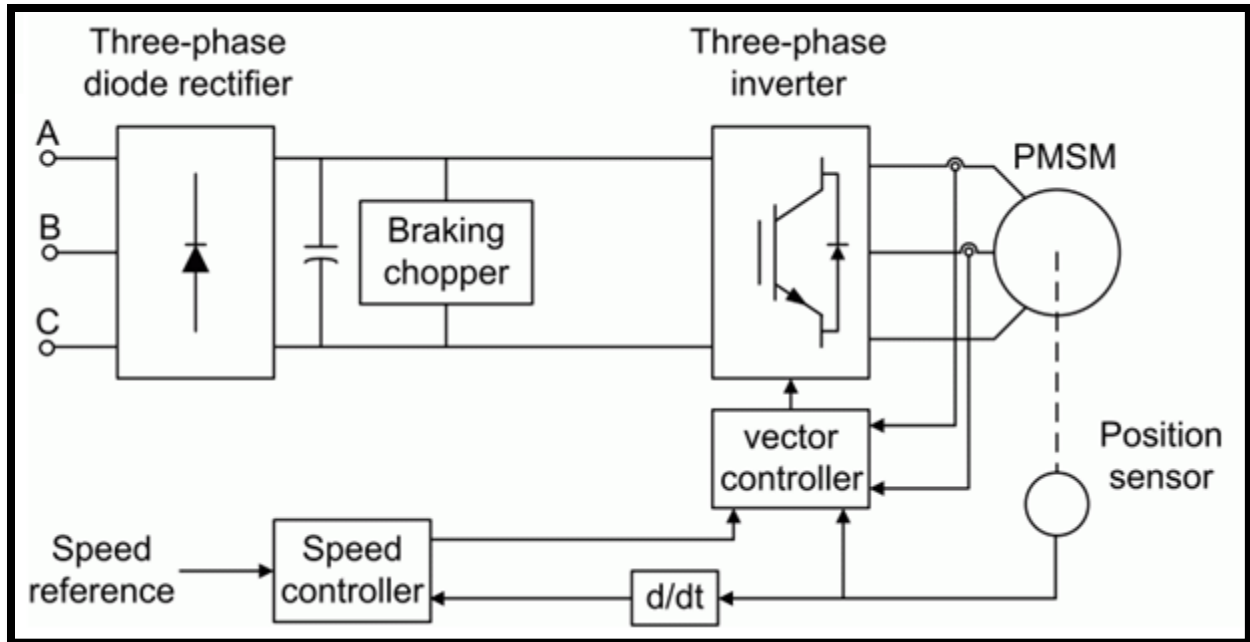
Figure 7.3:

Speed controller

The speed controller is based on a PI regulator, shown below. The output of this regulator is a torque set point applied to the vector controller block
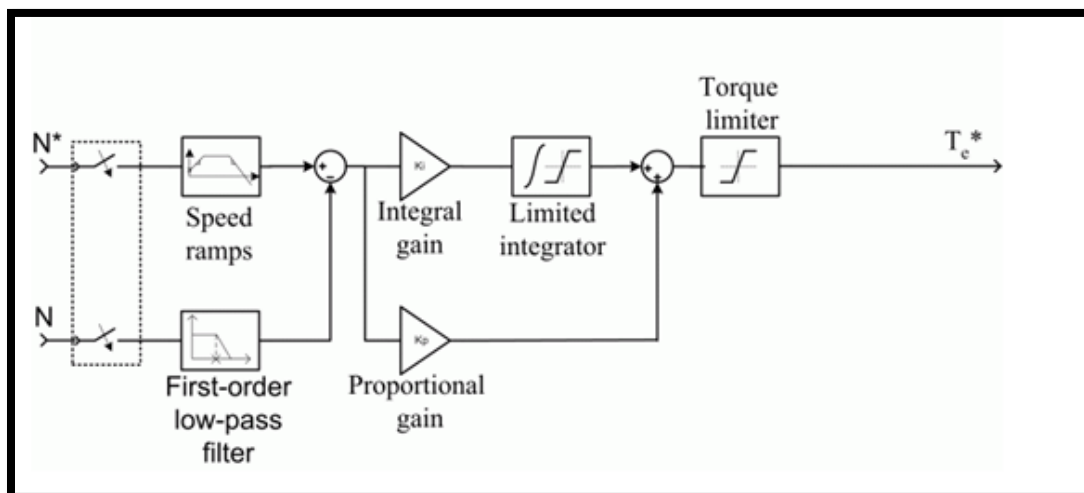
Figure 7.4: Speed controller

Vector Controller

The vector controller contains four main blocks, shown below. These blocks are described below.
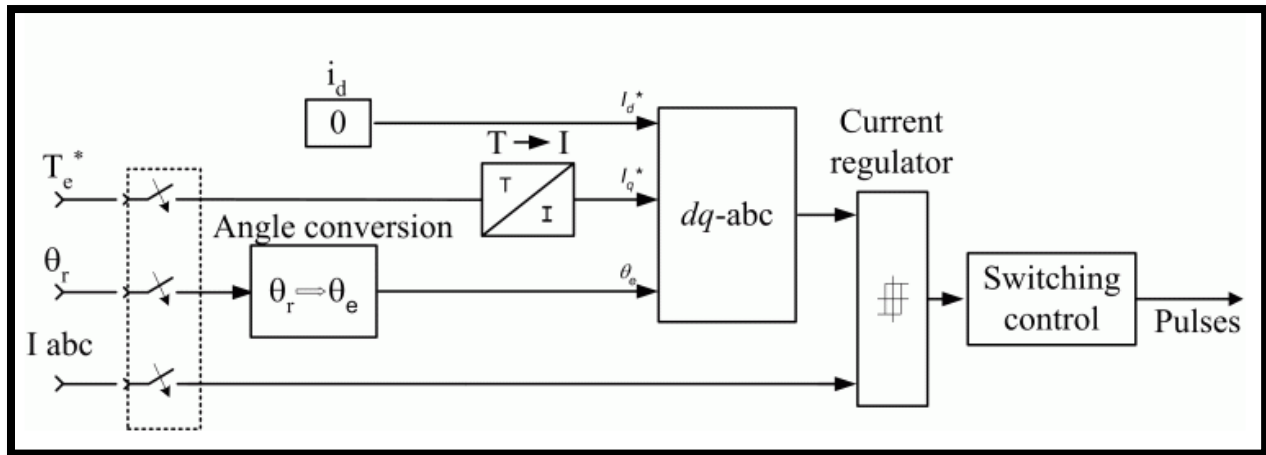
Figure7.5: Vector Controller

The *dq-abc* block performs the conversion of the *dq* current component in the rotor reference frame into *abc* phase variables.

The *current regulator* is a bang-bang current controller with adjustable hysteresis bandwidth.

The *angle conversion* block is used to compute the electrical rotor angle from the mechanical rotor angle.

The *Switching control* block is used to limit the inverter commutation frequency to a maximum value specified by the user.

When using the average-value inverter, the *ab* current references are sent to the inverter, as well as switching pulses from a slightly modified *Switching control block.*

Braking Chopper

The braking chopper block contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by a motor deceleration.

Demux schematic
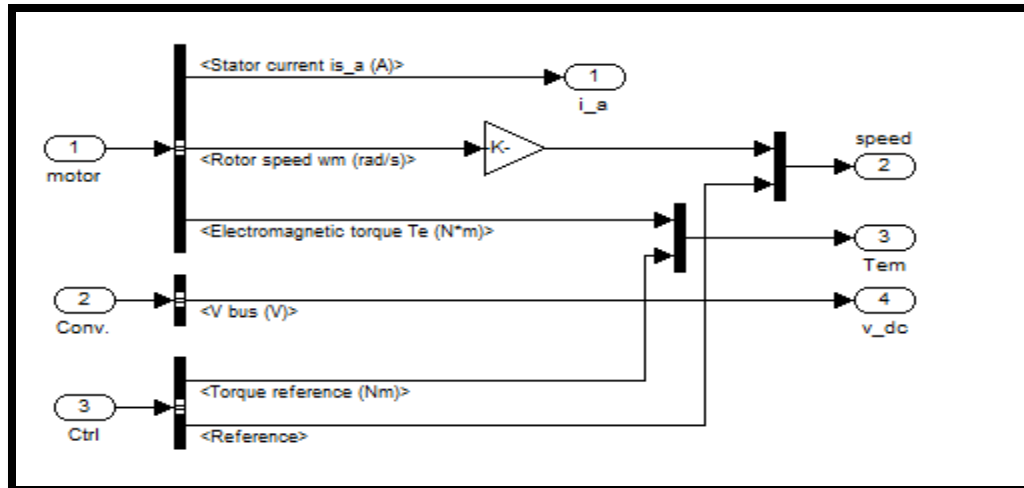
Figure 7.6: Demux schematic

Figure 7.7: Electrical & Mechanical parameters of PM Synchronous Motor Drive

Figure 7.8: Converter & DC bus parameters of PM Synchronous Motor Drive

Figure 7.9: Controller of PM Synchronous Motor Drive

Model Specifications

The library contains a 3 hp drive parameter set. The specifications of the 3 hp drive are shown in the following table

Drive Input Voltage		
	Amplitude	220 V
	Frequency	60 Hz
Motor Nominal Values		
	Power	3 hp
	Speed	1800
	Voltage	300

PROCEDURE:

Start the simulation. You can observe the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage on the scope. The speed set point and the torque set point are also shown.

At time t = 0 s, the speed set point is 300 rpm. Observe that the speed follows precisely the acceleration ramp.

At t = 0.5 s, the full load torque is applied to the motor. You can observe a small disturbance in the motor speed, which stabilizes very quickly.

At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases down to 0 rpm following precisely the deceleration ramp.

At t = 1.5 s., the mechanical load passes from 11 Nm to -11 Nm. The motor speed stabilizes very quickly after a small overshoot.

Finally, note how well the DC bus voltage is regulated during the whole simulation period.

1) The power system has been discretised with a 2 us time step. The speed controller uses a 140 us sample and the vector controller uses a 20 us sample time in order to simulate a microcontroller control device.

2) A simplified version of the model using average-value inverter can be used by selecting 'Average' in the 'Model detail level' menu of the graphical user-interface. The time step can then be increased up to 75 us. This can be done by typing 'Ts = 75e-6' in the workspace, by setting Vector control sample time to 75e-6 and by setting Speed controller sample time to 150e-6

GRAPH:

Draw graph
1.Stator current vs time.
2.Rotor speed vs time
3.Electromagnetic Torque vs time
4.DC bus voltage vs time.
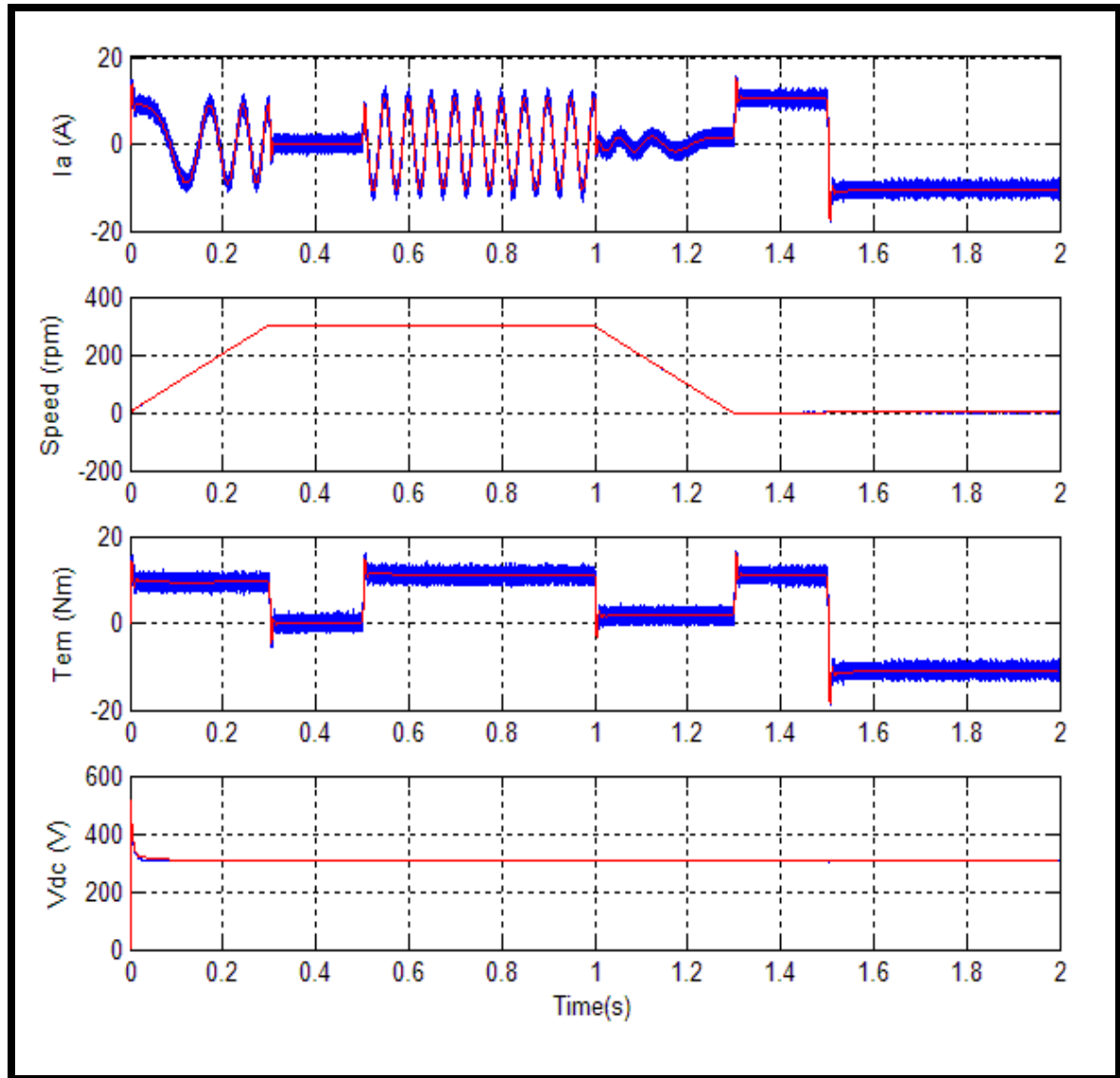
Figure 7.10: Graph

CONCLUSION:

EXPERIMENT NO. 8

TITLE   Regenerative/ Dynamic braking operation for DC Motor - Study using software.

OBJECTIVE: To study Regenerative/ Dynamic braking operation for DC Motor

SOFTWARE USED: P-SIM

CIRCUIT DIAGRAM:
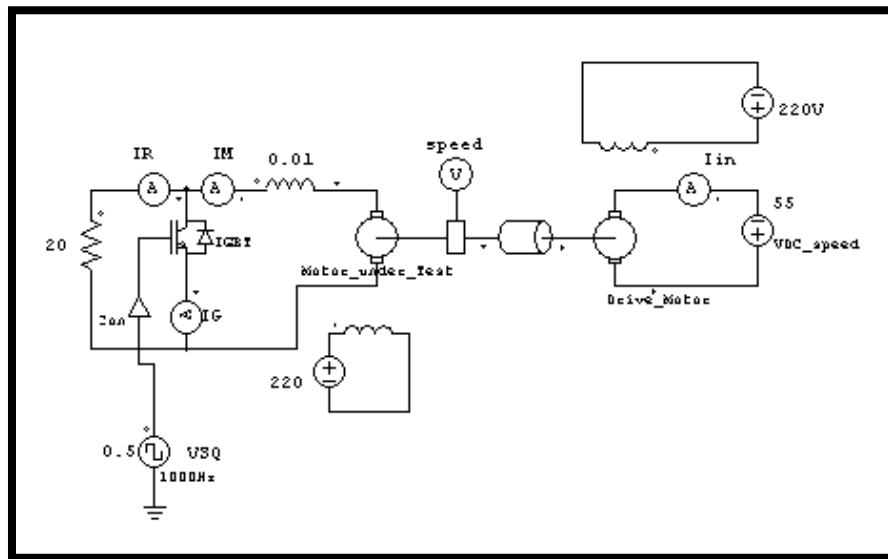
Dynamic Braking of DC Motor
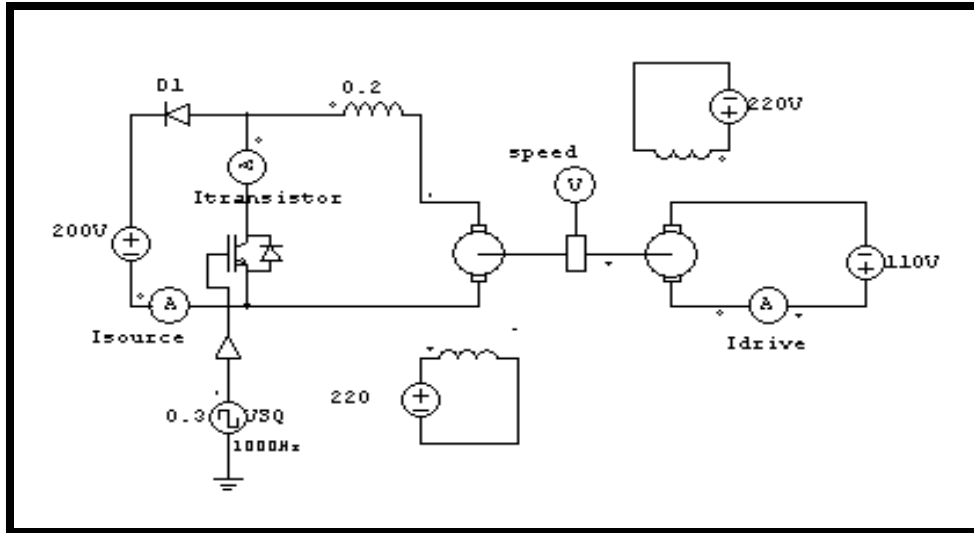
Regenerative Braking of DC Motor

THEORY:

In Chopper operated dynamic braking of a d.c. motor armature terminals are alternately shorted and closed through a braking resistance R_b. The steady state braking torque developed by the motor is

$$T_B = \frac{r_a I_{a,rms}^2 + R_b I_{b,rms}^2}{\omega}$$ where, $I_{a,rms}$ = motor rms current, $I_{b,rms}$ = Resistance rms current, ω = speed in rad/sec.

In Chopper operated regenerative braking method armature terminals are first shorted and then connected to a d.c. source. This is repetitively carried out. Steady state braking torque developed by the motor is $T_B = \dfrac{VI_0 + r_a I_{a,rms}^2}{\omega}$ where I_0 = average current through the source.

Device	*Description*	*Parameters*
Motor under Test	Separately Excited DC Motor	Ra=0.055, La=0.01, R$_f$=55, L$_f$=0.02, MI =0.2, Vt=220, Ia= 80, n(rated) = 1500, I$_f$ =4, Torque Flag=0, Master/Slave Flag=0.
Drive Motor	Separately Excited DC	Ra=0.055, La=0.01, R$_f$=55, L$_f$=0.02, MI =0.2, Vt=220, Ia= 80, n(rated) = 1500, I$_f$

	Motor	=4, Torque Flag= 1, Master/Slave Flag=1.

Procedure :

Dynamic Braking

1. Open the PSIM software and use the "element" icon to get all the relevant components/ devices.
2. Reset the parameters of different devices by double clicking over them as specified in the given Fig.1 Specify the two motor parameters as given below :
3. Set the duty cycle of the square voltage source VSQ (frequency 1000Hz) at $\delta = t_{on}/T = 0.2$
4. Vary the speed of the d.c. machine under test from 20% to 100% of rated speed in steps of 10% by adjusting the applied voltage $V_{DC-Speed}$ to the armature of the drive motor.
5. For each speed obtain the developed torque from the simulated output SIMVIEW (with final time 4/5 sec) and enter the measured average torque and speed in the result table below.
6. Repeat steps 4 through 6 for $\delta = 0.4, 0.6, 0.8$.
7. For any specific setting of δ and speed obtain the oscillographic traces of motor current, device current and braking resistor current in separate windows.

Regenerative Braking:

1. Now change the circuit as shown in Fig.2. Follow the procedure of dynamic braking 1-3.
2. Set the duty cycle of the square voltage source VSQ (frequency 100Hz), $\delta = t_{on}/T = 0.1$ and follow the procedure 5-6 of dynamic braking.
3. Repeat steps 2 for $\delta = 0.2, 0.3, 0.4$. Take the same set of readings.
   Note that at no stage average motor current exceeds its rated value.

4. For any specific setting of δ and speed obtain the oscillographic traces of motor current, device current and source input current.

Graph

1. Make the speed vs torque plots of the results for all the four δ values on a single graph paper.
2. Take the printed output of the currents mentioned in 8 of the procedure.
3. Present one sample calculation for predicted braking torque.

Discussion & Conclusion

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Experimental Results : Dynamic Braking

Sl. No.	Duty Cycle	Speed	Braking Torque (Measured)	Motor rms Current	Braking resistor rms current	Predicted Braking Torque

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Experimental Results : Regenarative Braking

Sl. No.	Duty Cycle	Speed	Braking Torque (Measured)	Average Motor Current	Braking resistor rms current	Predicted Braking Torque

EXPERIMENT NO. 9

Title: **Regenerative/ Dynamic braking operation for AC Motor**

OBJECTIVE: **To study Regenerative/ Dynamic braking operation for AC Motor**

SOFTWARE USED: **P-SIM**

THEORY

Induction motors are used at various places. Speed control of induction motors is quite difficult and that's why their use was restricted and DC motors had to be used as their speed regulation was possible. But when induction motor drives were invented and implemented, they were given preference because of many advantages over DC motors. Whenever controlling of motors is done, braking is the most important term, so as with induction motors. **Induction motor braking** can be done by different methods, which are-

1. Regenerative braking of induction motor
2. Plugging Braking of induction motor
3. Dynamic braking of induction motor is further categorized as

- AC dynamic breaking
- Self excited braking using capacitors
- DC dynamic braking
- Zero Sequence braking

We know the power (input) of an induction motor is given as.
$P_{in} = 3VI_s\cos\phi_s$

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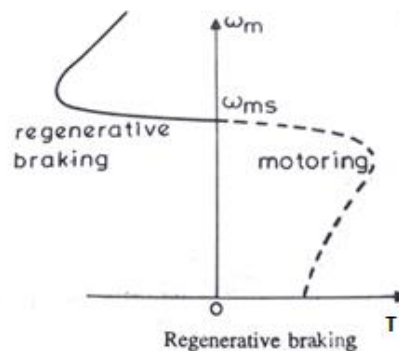
Here, φ_s the phase angle between stator phase voltage V and the stator phase current I_s. Now, for motoring operation $\varphi_s < 90°$ and for braking operation $\varphi_s > 90°$. When the speed of the motor is more than the synchronous speed, relative speed between the motor conductors and air gap rotating field reverses, as a result the phase angle because greater than 90° and the power flow reverse and thus regenerative braking takes place.

If the source frequency is fixed then the **regenerative braking of induction motor** can only take place if the speed of the motor is greater than synchronous speed, but with a variable frequency source regenerative braking of induction motor can occur for speeds lower than synchronous speed. The main advantage of this kind of braking can be said that the generated power is use fully employed and the main disadvantage of this type of braking is that for fixed frequency sources, braking cannot happen below synchronous speeds.

Dynamic Braking of Induction Motor
There are four type of **dynamic braking of induction motor** or **rheostatic braking**

AC Dynamic Braking- This type of induction motor braking is obtained when the motor is made to run on a single phase supply by disconnecting any one of the three phase from the source, and it is either left open or it is connected with another phase. When the disconnected phase is left open, it is called two lead connection and when the disconnected phase is connected to another machine phase it is known as three load connection. The braking operation can be understood easily. When the motor is running on 1-phase supply, the motor is fed by positive and negative sequence, net torque produced by the machine at that point of time is sum of torques due to positive and negative sequence voltage. At high resistance the net torque is found to be negative and braking occurs. From the figure below the two and three load connections can be understood.

Device	Description	Parameters
Motor under Test	3 phase Slip Ring Type Induction Machine	Rs=1.32, Ls=0.0136, Rr=1.23, L_r=0.0136, Lm =0.2215, Ns/Nr=1, Poles= 4, MI= 0.225, Torque Flag= 0, Master/Slave Flag=0.
Driver Motor	Separately Excited DC Motor	Ra=0.055, La=0.01, R_f=55, L_f=0.02, MI =0.154, Vt=220, Ia= 80, n(rated) = 1500, I_f =4, Torque Flag=0, Master/Slave Flag=1.

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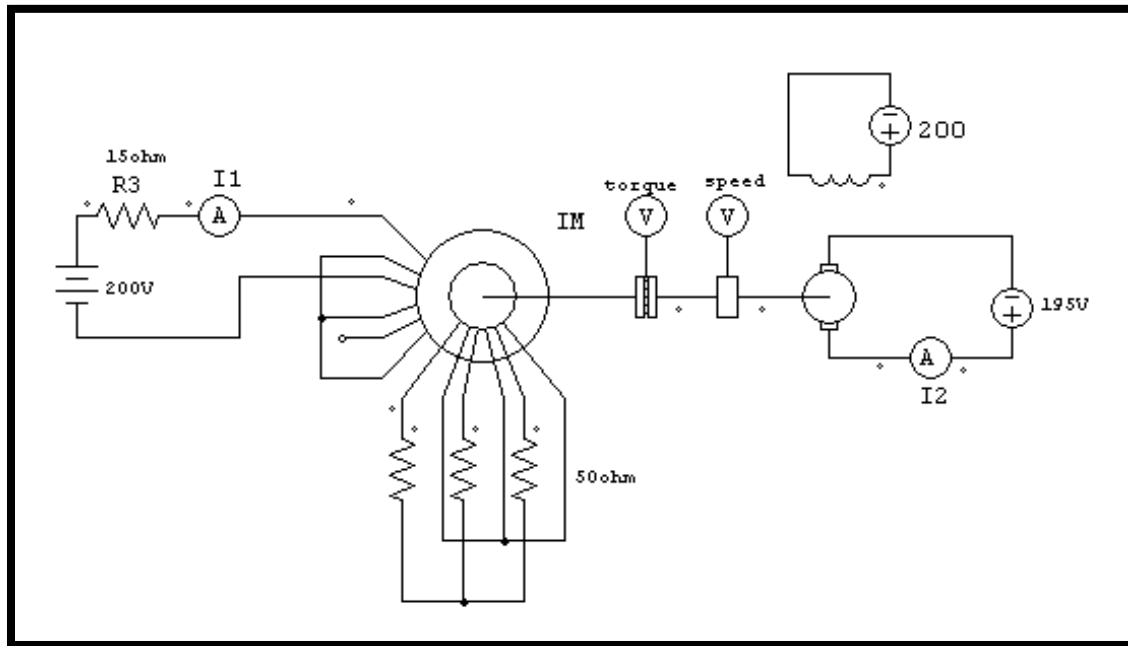
Fig. 1 : Dynamic Braking of 3 phase Induction Motor
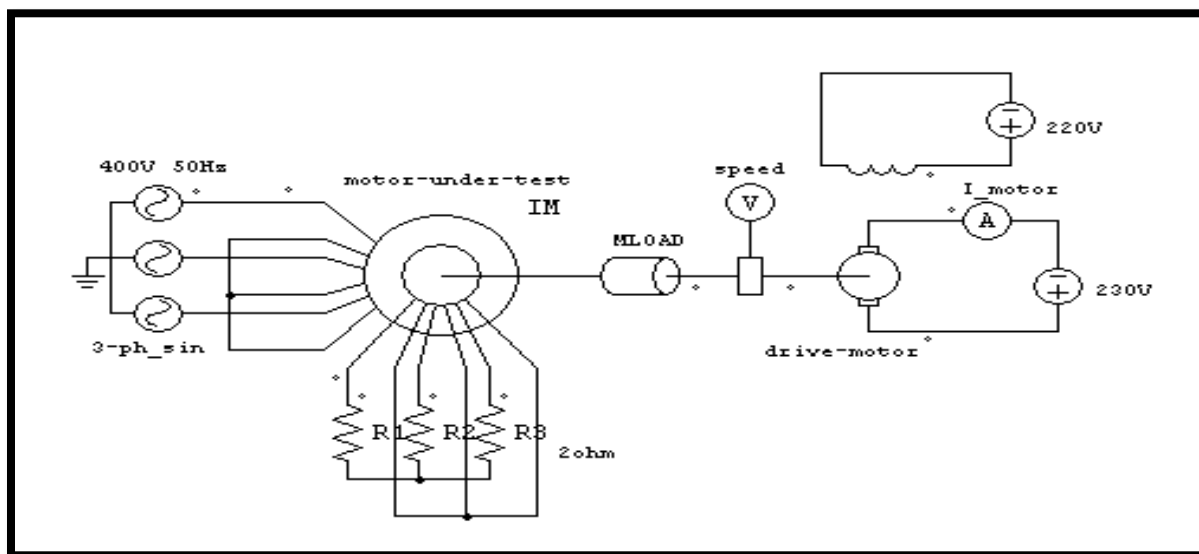
Fig.2 : Regenerative Braking 3 phase Induction Motor

Procedure:

Dynamic Braking

1. Open the PSIM software and make the circuit as shown in Fig.1 below.
2. Use the "element" icon to get all the relevant components/ devices.
3. Specify the two motor parameters as given in the table.

4. Connect rotor resistances 50 ohm with the rotor circuit of the slip ring motor.
5. Connect the two terminals of the slip ring motor to a dc supply 200V with a resistance 15 ohm as shown in fig. 1.
6. Vary the speed of the d.c. drive_motor from 20% to 100% of rated speed in steps of 10% by adjusting the armature voltage of the drive motor.
7. For each speed obtain the developed torque from the simulated output SIMVIEW (with final time 6/8 sec) and enter the measured average torque and speed in the result table below.
8. Measure the braking resistor current I1 and motor current I2 in each speed.
9. Make the speed vs torque plots with the above results.

Regenerative Braking:

1. Now change the circuit as shown in Fig.2. Follow the procedure of dynamic braking 1-3.
2. Connect rotor resistances 2 ohm with the rotor circuit of the slip ring motor.
3. Connect a mechanical load of 9 N-m with the slip ring motor.
4. Connect a 3 phase sinusoidal ac supply 400V, 50Hz with the stator of the slip ring motor as shown.
5. Vary the speed from 1510 rpm to 1650 rpm in steps of 10 or 15 rpm by adjusting the armature voltage of the drive motor. Note down the developed torque in each case. Also measure the dc motor average currents.

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Experimental Results

Dynamic Braking

Sl. No.	Speed	Braking Torque (Measured)	Average Motor Current	Average braking resistor current	Predicted Braking Torque

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Regenerative Braking

Sl. No.	Speed	Braking Torque (Measured)	Average Motor Current	Predicted Braking Torque

Graph:

1. Make the speed vs torque plots of the results on a graph paper.
2. Calculate the predicted braking torque in each case and enter them into the result table.

Discussion & Conclusion

LABORATORY INSTRUCTION MANUAL

ELECTRICAL & ELECTRONIC MEASUREMENT LAB

PC EE 493

Lab Manual version: January, 2020

DEPARTMENT OF ELECTRICAL ENGINEERING

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General Information

All assigned experiments must be performed as per the schedule. Most of the work for an experiment should be done during class time in the laboratory. In order to allow for further analysis and graphing, the notebooks are to be submitted after completing the work within the stipulated submission date. Submit your completed notebook to the instructors/class teacher for evaluation. The laboratory performance is evaluated based on the instructor's observations of you while you are performing the experiments. Among the factors considered are your ability to construct circuits, your competency in using test equipment, your preparation prior to starting the experiment, answers given to any questions asked during the laboratory, as well as attendance, tardiness, and attitude. Keep in mind that your behavior influences your grade; act professionally at all times.

The following guidelines should be followed when using your notebook:

- The first page should contain a table of contents as per the attached format.
- All pages in the notebook must bound, numbered and dated.
- Use a pen or permanent marker, never pencil.
- Write legibly and coherently. Extreme neatness is not required but anyone should be able to read and understand what you have written.
- Never erase errors or remove pages. Simply draw a line through any mistakes.
- The notebook should be a complete record of your work, i.e. what you actually do in the laboratory, and sufficiently detailed that a knowledgeable person could reconstruct what you did.
- All measurements, notes, and calculations should be directly recorded in the notebook. Never write information on scraps of paper for later transcription into the notebook.
- Do not paste the laboratory manual into your notebook
- Any graphs or printouts relevant to the experiment should be pasted into your notebook.
- Be sure to label all diagrams, schematics, graphs, and waveform printouts.
- All numbers should include appropriate units.
- Include an equipment list if any.

Keep the laboratory neat & clean;

Shut down the computers after completion of work;

Keep your mobile switched off / in silent mode while the laboratory is going on.

Electrical Engineering Laboratory Regulations

General

Students working in the electrical laboratories should be very cautious during the lab work. The electric potentials used in many experiments are dangerous and may cause injury. Students must observe all safety precautions and must not work alone with potentials exceeding 25 V. The rotating machines used in some experiments are dangerous. Keep loose clothing, jewellery, and other objects away from any rotating parts.

Food and drinks are not permitted in the laboratories.

Equipment

All equipment must be returned to its proper storage location at the end of the lab period. Instruments and equipment are delicate and expensive. Improper use of equipment can result in instantaneous damage; check with you instructor or the equipment's manual if you are in doubt.

Damaged or faulty equipment should be given to the technicians/instructor along with a description of the problem.

ELECTRICAL & ELECTRONIC MEASUREMENT LAB

Code : PC EE 493

Contacts : 3 P

Credit : 2

LIST OF EXPERIMENTS

Experiment no.	Experiment name
PC EE 493/1	Instrument workshop- Observe the construction of PMMC, Dynamometer, Electro thermal and Rectifier type of instruments, Oscilloscope and Digital multimeter.
PC EE 493/2 & PC EE 493/3	To calibrate ammeter, voltmeter & electrodynamometer type wattmeter by potentiometer.
PC EE 493/4	Calibrate AC energy meter.
PC EE 493/5	Measurement of resistance using Kelvin double bridge.
PC EE 493/6	Measurement of power using Instrument transformer.
PC EE 493/7	Measurement of power in Polyphase circuits.
PC EE 493/8	Measurement of frequency by Wien Bridge.
PC EE 493/9	Measurement of Inductance by Anderson bridge
PC EE 493/10	Measurement of capacitance by De-Sauty bridge.
PC EE 493/11	Measurement of capacitance by Schering Bridge.

NAME: _____ GROUP: _____

ROLL NO._____

LIST OF EXPERIMENTS

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PC EE 493/11	Measurement of capacitance by Schering Bridge.

EXPERIMENT NO.PC EE 493/2 & PC EE 493/3

Name: To calibrate ammeter, voltmeter & electrodynamometer type wattmeter by potentiometer.

Objective:

1. To compare the readings of a given ammeter, voltmeter & wattmeter with the corresponding calculated value of current and voltage from the observations of a DC potentiometer.
2. To draw a graph showing percentage error for different observed values of current and voltage.

Apparatus:

Sl. No.	Item	Quantity	Rating	Maker
1.	DC Potentiometer			
2.	Standard Resistance			
3.	Volt-ratio box			
4.	Variable DC power supply			
5.	Portable Wattmeter			
6.	Portable ammeter			
7.	Portable voltmeter			
8.	Change over switch			

THEORY:

DC Potentiometer: A potentiometer is an instrument designed to measure an unknown voltage by comparing it with a known voltage. The known voltage supplied by standard cell. The potentiometer can also be measure current by measuring the voltage drop produce by the unknown current passing through a known standard resistance. The potentiometer is used for a calibration of voltmeter and ammeter and has in fact become the standard for the calibration of these instruments.

Calibration of voltmeter:

Generally potentiometer measure maximum voltage is 0-1.8 volts. If higher voltage range has to be measured a volt-ratio box is required. Volt-ratio box is actually a potential divider. If we connected a high DC voltage (approx. 300volt), its output is very low voltage (about 1.8 volts) which is connected to the potentiometer.

For calibration of voltmeter a DC source is required. A potential divider is connected to the supply. Output of the potential divider is connected between common terminal and high voltage post of the volt-ratio box connected with potentiometer. *If the reading of the potentiometer is 0.975 volt, then the value of unknown voltage is 0.975*(300/1.8) =162.5 volts.*

A calibration curve indicating the errors at various scale readings of the voltmeter may be plotted.

Calibration of ammeter:

Generally potentiometer measure DC voltage. For ammeter calibration a standard resistance of suitable value and sufficient current carrying capacity is placed in series with ammeter .The voltage across the standard

resistor is measured with the help of potentiometer and the current through the standard resistance can be computed.

$$\text{Current, } I = V_s / S$$

Where V_s = voltage across the standard resistor as indicated by the potentiometer,

And S = resistance of standard resistor.

Since the resistance of the standard resistor is accurately known and the voltage across the standard resistor is measured by a potentiometer, this method of calibrating an ammeter is very accurate. A calibration curve indicating the errors at various scale readings of the ammeter may be plotted.

Calibration of wattmeter:

For wattmeter calibration two measurements are made. One across the standard resistance 'S' which connected in series with load and current coil of the wattmeter and other across at output terminals of the volt-ratio box .

The current in the circuit can be computed from the voltage drop across the standard resistance and the voltage across the load can be computed from the potentiometer reading across the output terminals of volt-ratio box.

The voltage V and current I are measured in turn with the potentiometer employing a double pole throw switch.

Let, V_s =reading of potentiometer when connected across S.

V_R=reading of potentiometer when connected across volt-ratio box.

Current through the load $I = V_s / S$

And voltage across the load $V = K\, V_R$,where K is multiplying factor of volt-ratio box.

Power consumed $P = VI = (K\, V_R) * V_s / S$

Now the power (P) and the wattmeter reading may be compared with this value.

A calibration curve indicating the errors at various scale readings of the wattmeter may be plotted.

CIRCUIT DIAGRAM:

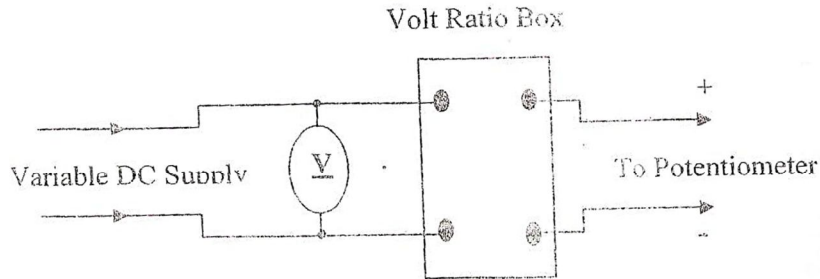- **Voltage measurement:**

Figure -1; Circuit Diagram for Calibration of Voltmeter with Potentiometer and Volt-Ratio Box.
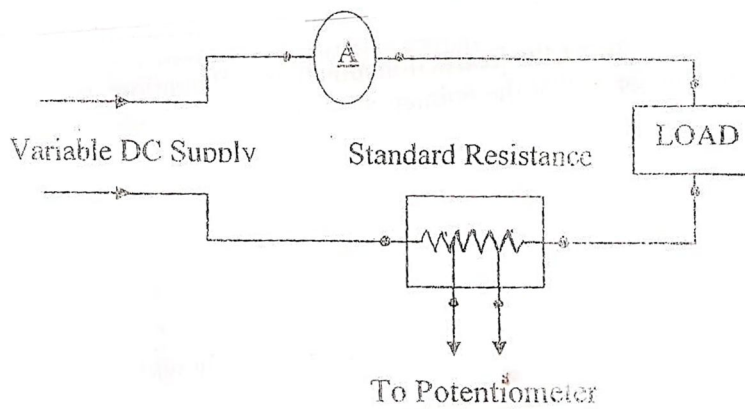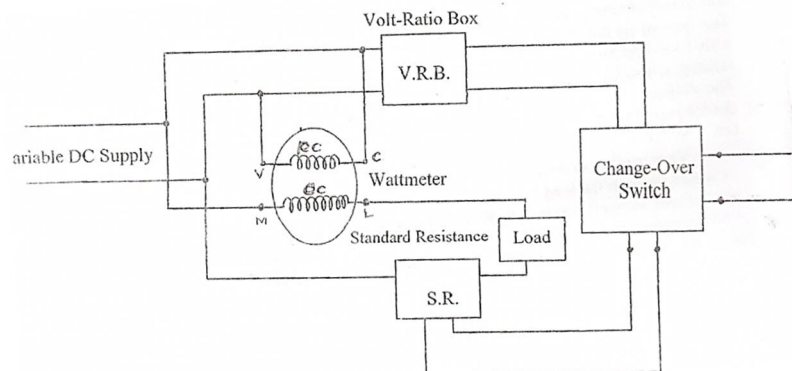
- **Current measurement:**

Figure -2; Circuit Diagram for Calibration of Ammeter with Potentiometer and Standard Resistance.

- **Power measurement:**

PROCEDURE:

1. Make connections according to fig-1
2. Standardization of the potentiometer as per the instruction attach with potentiometer.
3. Adjust the variable DC supply source at any voltage so that the pointer coincides exactly with a major division of the voltmeter.
4. Measure the low DC voltage by the potentiometer (follow instruction of the potentiometer for measuring the voltage).
5. Measure the actual voltage and calculate the error and % of error of the voltmeter.
6. Take at least five reading to change the voltage by variable DC voltage source.
7. Change the connections as per fig-2 for measure the current.
8. Adjust the variable Dc supply source at any current so that the pointer coincides exactly with a major division of the ammeter.
9. Measure the voltage drop across the standard resistance by potentiometer.
10. Calculate the actual current and the error and % of error of the ammeter.
11. Change the connection as per fig-3 for measure the power.
12. The voltage and current measured in turn with the potentiometer employing a double pole double through switch. The true power and wattmeter reading compared with this value and calculate the error of the wattmeter.

OBSERVATION TABLE:

CALIBRATION OF VOLTMETER					
Sl no.	*Voltmeter reading (V_x)volts*	*Measuring voltage by the potentiometer (V_p) volts*	*Ratio of the Volt-ratio box (K)=input/output*	*Actual calculated voltage $(V_p *K)$ volts*	*Percentage of error*

CALIBRATION OF VOLTMETER					
Sl no.	*Ammeter reading (A_x)amp*	*Measuring voltage by the potentiometer (V_s) volts*	*Value of standard resistance (S) ohm.*	*Actual calculated current $(V_s *S)$ volts*	*Percentage of error*

Electrical & Electronic Measurement LAB (PC EE 493)

				CALIBRATION OF WATTMETER					
Sl no	Wattmeter reading (W_x) watt	Potentiometer voltage across standard resistance (V_s)	Potentiometer voltage across volt-ratio box (V_R)	Value of Standard resistance (S) ohm	Multiplying Factor of volt-ratio Box (K)	Current Through load (I) amp	Voltage Across load (V) volt	Actual Power Consumed (W_s) watt	% of error

Conclusion:

Answer the following questions:

1. What is the importance of standard cell?
2. What is the value of the standard cell?
3. What do you mean by calibration?
4. Why potentiometer is used for this experiment?

EXPERIMENT NO. PC EE 493/4

Name: Calibrate AC energy meter.

OBJECTIVE:

1. To conduct short time test on a single phase energy meter to find the speed error.
2. To conduct long time test on the meter to find the registration error.
3. To compare the calibration of the meter with the help of an energy meter.

THEORY:

For short time test

If P = power in watts

t = time in sec

Then standard reading = P*t Joules…………….(1)

If no. of revolution =N

Meter constant = K rev/kwh

Then test reading = (N/K) kwh

$$= (N/K) * 360000 \text{ Joules} \ldots\ldots\ldots (2)$$

$$\text{Percentage of error} = \left(\frac{\text{test reading - standard reading}}{\text{standard reading}} \right) * 100 \ldots\ldots\ldots\ldots.(3)$$

For long time test

Test reading = Final reading - initial reading

The expression for percentage error is same as before.

CIRCUIT DIAGRAM:

Figure 1

Figure 2

PROCEDURE:

1. The circuit is connected as shown in fig.1 and supply is switched on.
2. Time required from 5 to 20 revolutions is noted down along with the voltage current and power.
3. The speed error is calculated using equations (1), (2), (3).
4. The process is repeated by changing the load resistance.
5. The energy meter near to full load is set up. The initial reading is to be noted down. Then the meter is allowed to run for 20-30 min at the end of which the final reading is noted down along with the voltmeter, ammeter and wattmeter readings to calculate the registration error.

OBSERVATION TABLE:

1. For short time test:

Sl.no	No. of rev.(N)	Voltmeter reading(V)	Ammeter reading(A)	Wattmeter reading(W)	Time taken(sec)	Standard reading(kwh)	Test reading N/K (kwh)	% of error

2. For Long time test:

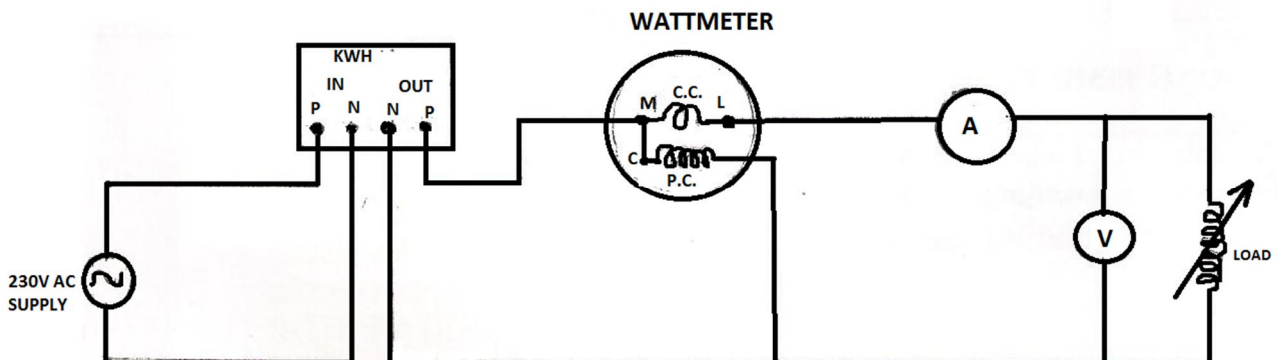| Sl.no.	Initial reading	Final reading	Wattmeter reading(W)	Time taken(sec)	Test reading N/K (kwh)	Standard reading(kwh)	% of error

3. Calibration against standard meter:

Initial reading Of the test meter(kwh)	Final reading Of the test meter(kwh	Initial reading of the Standard meter(kwh)	Final reading of the Standard meter(kwh)	Actual reading(kwh)	Standard reading(kwh)	% of error

REPORT:

1. If the meter runs slowly then the no of rev. will be less therefore the reading will be less and the consumer will be gaining and supplier will be losing. But if the meter run fast then the no. of rev. will be fast and therefore the reading will be much consumer will be affected and the supplier will be gaining.

2. CREEP: In some meter a slow but continuous rotation is obtained even when there is no current flowing through current coil and only pressure coil is energized, this is called creeping.

3. INTEGRATING METER: Integrating meter totalize events over a specified period of time. The summation which is the product of time and on electrical quantity.

4. ENERGY METER AS INTEGRATING METER: Energy meter is an integrating meter. Because in energy meter we totalize the energy specified period of time. It is measured in watt-hour. Because it has a register unit.

Conclusion:

Answer the following questions:

1. What is the use of Energy Meter?

2. What do you mean by calibration?

3. What is the revolution per hour of standard Energy Meter?

4. What do you mean by long time test?

5. What do you mean by short time test?

EXPERIMENT NO. PC EE 493/5

Name: MEASUREMENT OF RESISTANCE USING KELVIN DOUBLE BRIDGE.

Objective: To find out the resistivity of a material by using kelvin double bridge.

Apparatus:

Sl. No.	Item	Quantity	Rating	Maker
1.				
2.				
3.				
4.				
5.				

THEORY: The best and the most precise method for the measurement of low resistance is that of the kelvin double bridge. It is a modification of the wheat stone bridge by using the error due to contact and lead resistance are eliminated.

Standard resistance of low value are therefore usually of four terminal type and are measured in such a way that their point of attachment to the circuit and their lead resistance do not enter in the measurement.

The circuit diagram of the kelvin double bridge is shown here, where "x" is the unknown resistance under the test and "s" is the standard resistance of the same order of resistance. The two resistance "X" and "S" are connected in series with a short link of low resistance value as possible. 'P' & 'Q' and 'p' &'q' are four known non-inductive resistance, one pair of which (P & Q or p & q) are variable.

A current preferably the rated current of resistance under test is passed through the two resistance 'X' and 'S' from low voltage high current battery.

A regulating rheostat and an ammeter are connected in the circuit for convenience. A sensitive galvanometer is connected across the driving point of PQ and pq. The ratio P/Q is kept the same as p/q, these ratios being varied until the galvanometer read zero. i.e. no deflection of the pointer of the galvanometer.

Now, at balance condition of the bridge applying KVL we get,

$I_1P - I_2P - IX = 0$ or $IX - I_1P - I_2P = 0$ …………………… (1)

Again, $I_1Q - I_2q - IS = 0$ or $IS = I_1Q - I_2q$ ………….(2)

Now, (1) / (2) we get, $X/S = (I_1P - I_2P)/(I_1Q - I_2q) = \frac{P(I_1 - I_2\frac{p}{P})}{Q(I_1 - I_2\frac{q}{Q})}$

We know that, P/Q = p/q. therefore, P/p = Q/q, under balance condition. Therefore, X/S = P/Q or X = (P/Q)S.

Thus, the unknown resistance (we find out unknown copper wire resistance) is determining in terms of the standard resistance "S" and the ratio arms P & Q.

FIG. 1
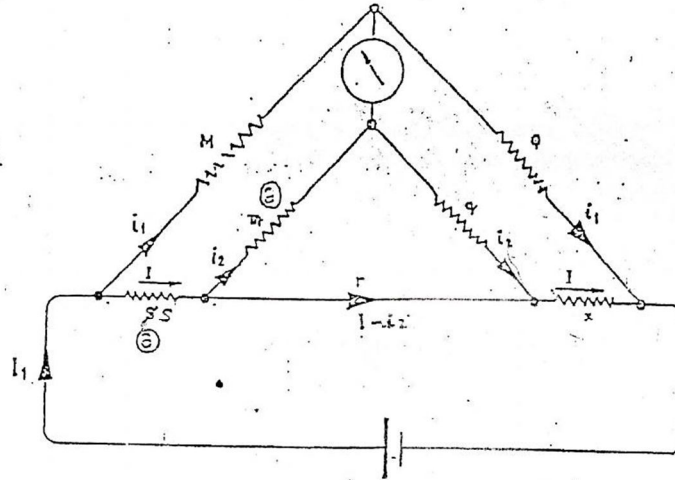
PRINCIPLE OF OPERATION

FIG. 2

CIRCUIT DIAGRAM

FIG.3

CURRENT SWITCH

CURRENT INPUT

MILLIOHMS

MILLIOHMS

RANGE MULTIPLIER

G_1

S

G_2

C   P P_1 C_1

INITIAL   FINAL

GALVANOMETER

PANEL LAYOUT

FIG.4

RANGE MULTIPLIER

G_1

S

G_2

R_3

R_1

R_2

R_g

INITIAL   FINAL

GALVANOMETER

FIG.5

RANGE MULTIPLIER

G_1

S

G_2

R_{d1}

R_g

INITIAL   FINAL

GALVANOMETER

FIG. 6

POTENTIAL TERMINATION

CURRENT TERMINATION
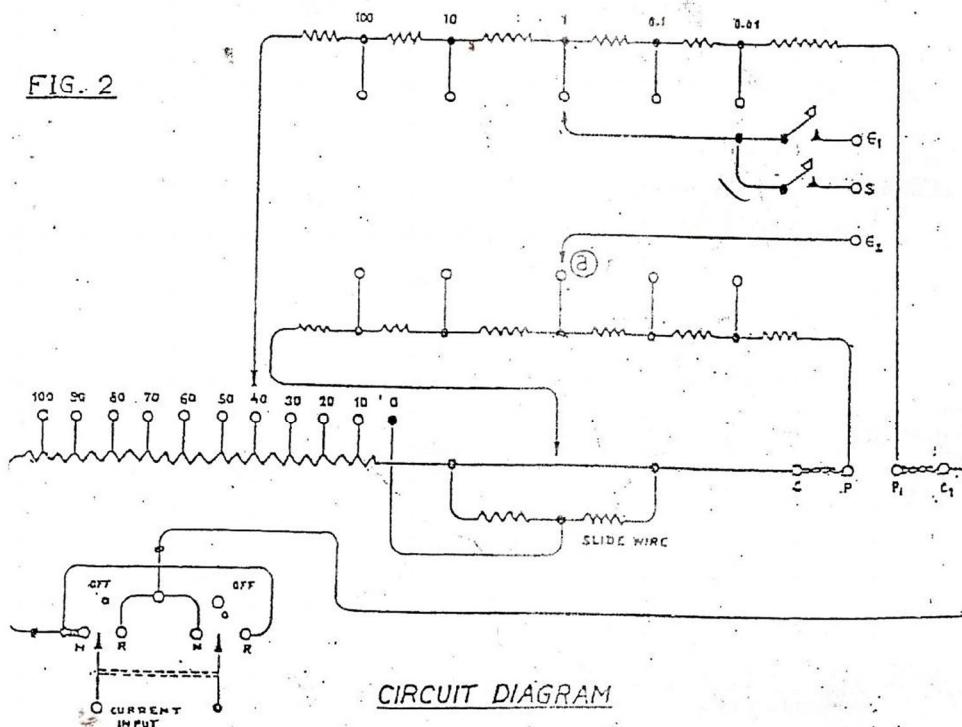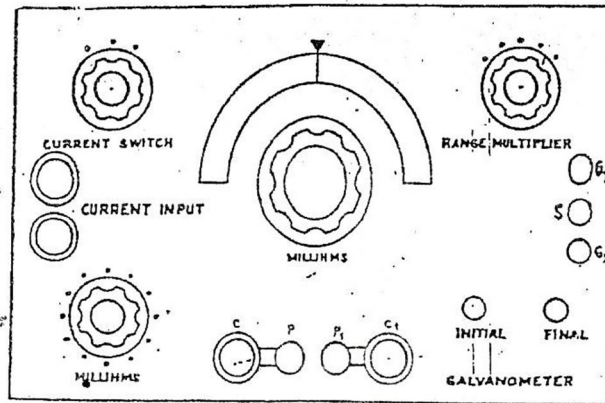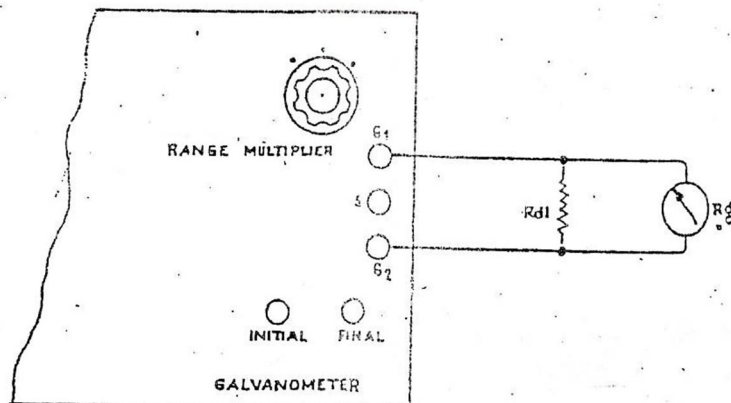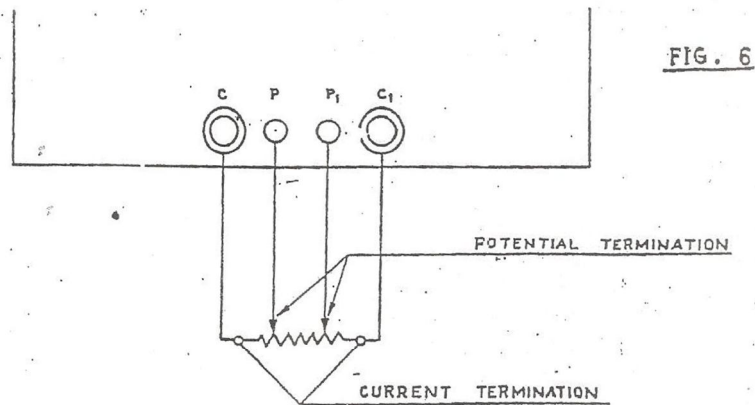
RESISTANCE MEASUREMENT OF FOUR TERMINAL RESISTANCE

FIG. 7

COMBINED CURRENT & POTENTAL TERMINATION
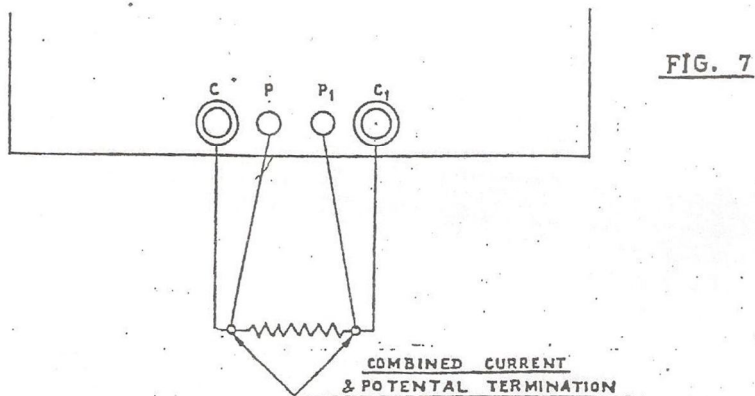
RESISTANCE MEASUREMENT OF TWO TERMINAL RESISTANCE BY FOUR TERMINAL METHOD.

Procedure:

1. Ensure that the current switch is off.
2. Connect the DC power supply with the terminal marked current input.
3. Connect galvanometer to the bridge.
4. Connect the unknown wire which is under test to the bridge terminal C, C1 and P, P1. Assuring that all connections make good contact. This is most important because dirty and insecure connections will result in unstable reading inaccuracies.
5. Set current switch to normal.
6. Set the range multiplier to "X100".
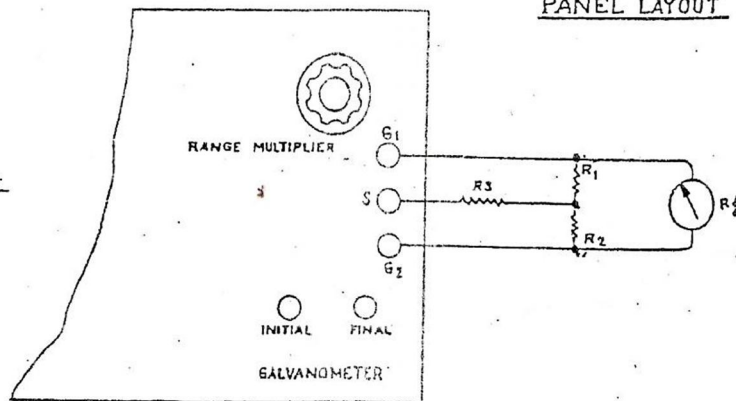7. Operate galvanometer keys by depressing the initial key intermittently; otherwise depress the final key intermittently.
8. Observe galvanometer deflection and adjust the milliohms decade, the milliohm slide wire to obtain a balance (i.e. zero current through galvanometer).

FIG. 8

CURRENT LEAD
TERMINATION
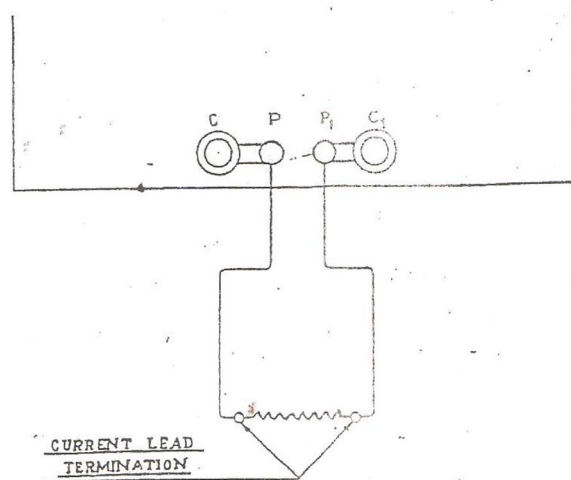
RESISTANCE MEASUREMET BY TWO TERMINAL METHOD

FIG. 9

JOIN

LEAD RESISTANCE MEASUREMENT.

Calculation: The resistance of unknown copper wire is:

Conclusion:

EXPERIMENT NO. EE 493/6

Name: Measurement of Power Using Instrument Transformer.

Objectives:

1. To study the working of current transformer and potential transformer.
2. To connect instrument transformers in electrical circuits for measurement of current voltage and power.

Apparatus:

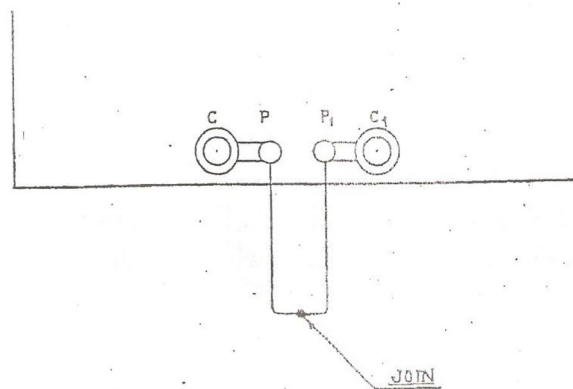| Sl. No.	Item	Quantity	Rating	Maker
1.	Current transformer			
2.	Potential transformer			
3.	Ammeter			
4.	Voltmeter			
5.	Wattmeter			
6.	Loading arrangement			
7.	Single phase Variac			

Theory:

In DC circuits, large currents can be measured with help of low range ammeters with appropriate shunts. For measuring high voltages, low range voltmeters are used in conjunction with a high series resistance. Same methods cannot be used with ac circuits because of the presence if inductance and capacitance in the circuit. For this purpose, specially designed, accurate ratio instrument transformers are used in conjunction with standard low range ac instruments. These instrument transformers are of two types:

      I)   Current transformers for measuring large alternating current.

      II)   Potential transformers for measuring high alternating voltages.

Current transformers (CT):

These transformers are used with low- range ammeters to measure current in high voltage alternating current circuits where it is practically not possible to connect instruments and meters directly to the lines. In addition to insulating from high voltage, they step down the current in a known ratio. The current transformer has a primary coil of one, two or more turns of thick wire connected in series with the line whose current is to be measured as shown fig-1. The secondary side consists of a large number of turns of fine wire and is connected across the ammeter terminals (usually of 5 ampere or 1 ampere range).

The current transformer is basically a step-up transformer and obviously the current in the secondary winding will be less than that in the primary winding. Thus the current transformer having primary to secondary voltage transformation ratio of 1:20 will have a current transformation ratio of 100:5 (20:1) .Hence if we know the current transformation ratio ($\frac{I_1}{I_2}$) Then line current is obtained by multiplying the ammeter reading i.e, I_2 by the ratio $\frac{I_1}{I_2}$.

Clip-on or clamp-on type current transformer is also very common. In such, lamp on meters the core of transformer is so arranged that it can be opened out at hinged section by pressing a handle. When the core is thus opened, it permits the admission of heavy current carrying bus bar or conductor in between the core. When core is tightly closed, the current carrying conductor or feeder acts as a single turn primary whereas the secondary is connected across the standard ammeter mounted between the handle and the arm.
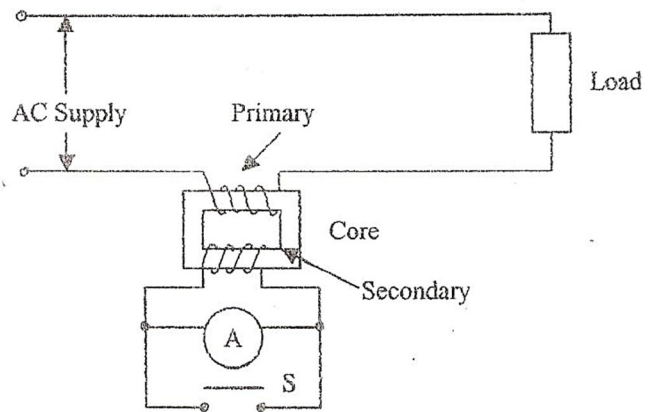
Fig. – 1. Multiple winding Current Transformer.

It should be noted that, since the ammeter resistance is very low, the CT normally works as short circuited. In case that has to be removed on an energized CT, the terminals must be short by switch S (**Fig-1**) otherwise in the absence of opposing secondary ampere turns, the primary current will produce a very high flux in the core which will result into increased iron losses and abnormally high voltage across the open secondary terminals which may become dangerous for the operating personal. In case of Two winding convectional transformer, the primary current is determined by the load on the secondary whereas in current transformer the secondary current is determined by the primary current because secondary is short circuited through a very small impedance of an ammeter. Hence as a precaution, secondary of an energized CT should never be left open under any circumstances.

Potential Transformer (PT):

These transformers are step-down transformers with known transformation ratio. PT's are used in conjunction with low range voltmeters (usually 110) whose deflection, when divided by voltage transformation ratio gives the true voltage on the high voltage side. In general, they are of shell type and do not differ much from the ordinary two winding transformers except that their power rating is extremely small. For voltage higher than

Fig.-2. Potential Transformer connection.

11kv, they are generally oil immersed .Since secondary load is either an instrument a relay or a pilot lamp, the rating of PTs is 40 to 100w.For safety secondary should be completely insulated from the high voltage primary and should be earthed. **Fig-2** shows the connection of such transformer.
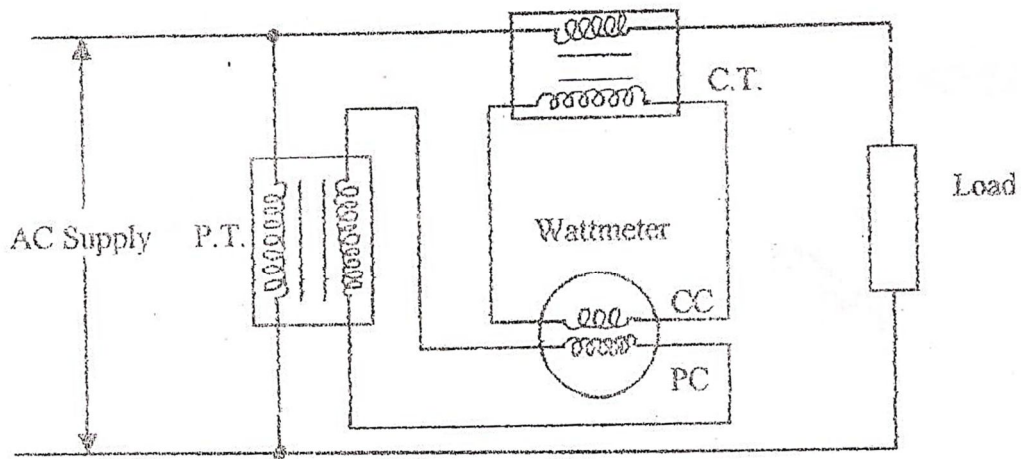
Fig.-3. The connections of instrument transformers with a wattmeter.

Fig-3 shows the connection of instrument transformer with a wattmeter. Such connections will be useful for measurement of power in a circuit having such currents and voltages which are not practically possible to apply to wattmeter current and potential coils. The wattmeter reading is to be multiplied by the current transformation ratio of CT and Voltage transformation ratio of the potential transformer respectively. If K_p and K_c are the transformation ratios of PT and CT respectively, then power in the load is given by K_p, K_c .W ,where w is the wattmeter reading.

Circuit diagram:

- Circuit of CT for measurement of current:
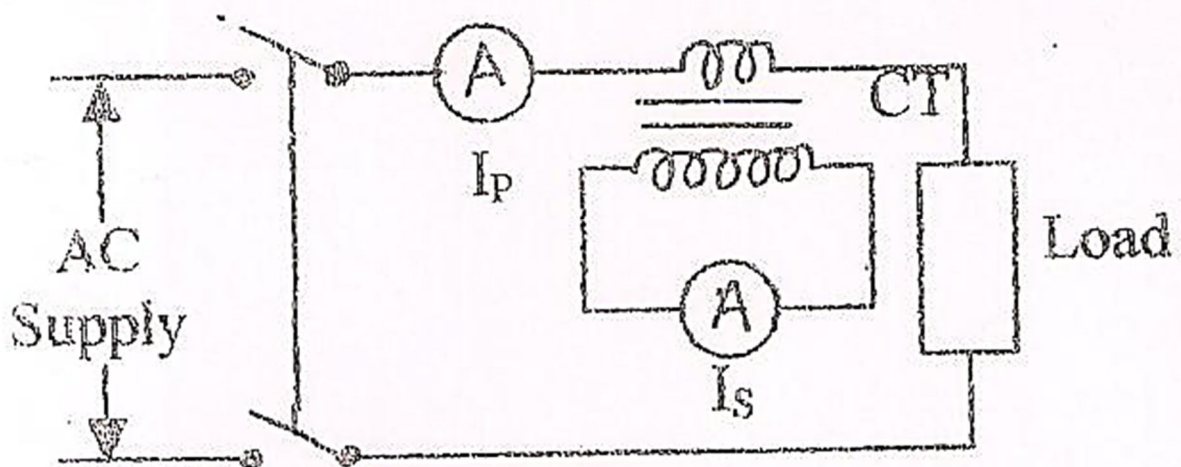
Fig. 4(a)

- Circuit of PT for measurement of voltage:
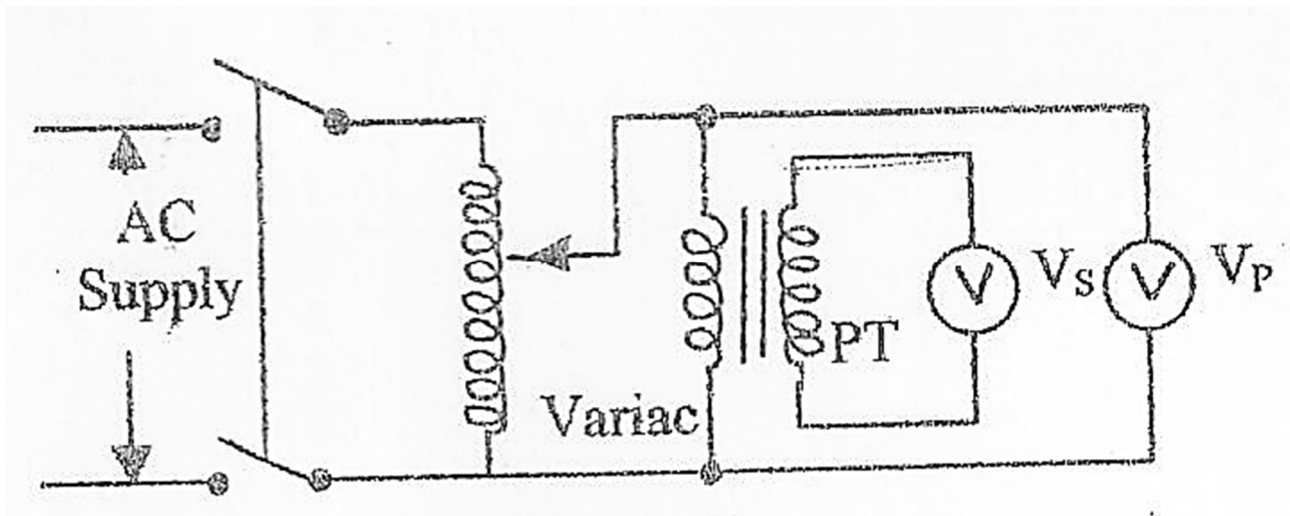
Fig. 4(b)

- Circuit diagram for measurement of power using CT & PT:
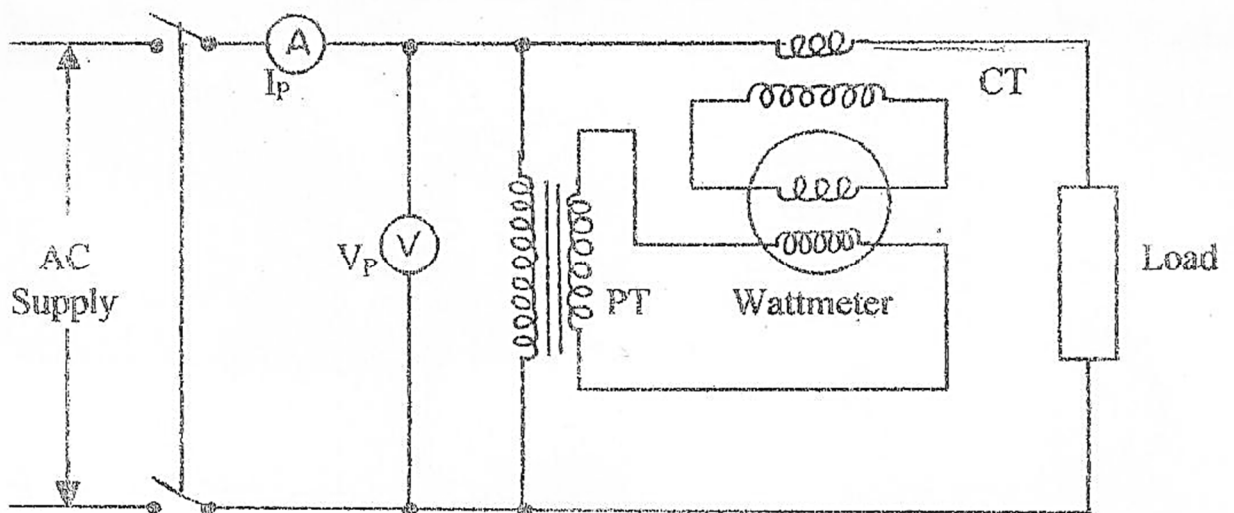
Fig. 4(c)

PROCEDURE:

A. Measurement of current using CT

1. Make connections as shown in fig 4(a). Note the current transformer ratio mentioned on the CT name plate.
2. Switch on the supply and adjust load to a suitable value. Note I_1 and I_2 and record them. Change load and take several readings of I_1 and I_2 and record them.
3. Calculate current transformation ratio of the CT and record against each set of observations.

B. Measurement of voltage using PT:

1. Make connections as shown in fig-4(b). Note the voltage transformation ratio of the PT from its name plate.
2. Switch on the supply and adjust input voltage to an appropriate value. Note V1 and V2. Change the primary voltage & Take several observations of V1 and V2.
3. Calculate voltage transformation ratio of the PT and record against each set of observations.

C. Measurement of Power using CT &PT:

1. Make connections as shown in fig-4(c). Note current transformation ratio of CT and voltage transformation ratio of PT.
2. Switch on the supply and against load such that the wattmeter shows some reading. Record ammeter, voltmeter and wattmeter readings.
3. Take several observations by changing the load and record in the observation table.
4. Calculate total power consumed by the load by multiplying the wattmeter observations with transformation ratios of CT & PT.

Observations and Results:

Measurement of current:

Sl.no.	Current transformation ratio K_c	Primary current I_p (amp)	Secondary current I_s (amp)	Ratio of I_p and I_s	Average I_p/I_s
1.					
2.					
3.					

Measurement of voltage:

Sl.no.	Potential transformation (PT) ratio K_p	Primary voltage V_p (volts)	Secondary voltage V_s (volts)	Ratio of V_p and V_s	Average V_p/V_s
1.					
2.					
3.					

Measurement of Power:

Sl.no	Current Transformation (CT) ratio K_c	Potential transformation (PT)ratio K_p	Load current (I)	Supply voltage (v)	Wattmeter reading(w)	Total Power W*K_c*K_p
1.						
2.						
3.						

Conclusion:

EXPERIMENT NO. PC EE 493/8

Name: MEASUREMENT OF FREQUENCY BY WIEN BRIDGE.

Objective:

1. To study the main features of the Wien bridge Audio Oscillator.
2. To obtain oscillation of different frequencies by varying R-C.
3. To study the frequency response of phase shift network.

Apparatus: The board consists of the following built in parts:

1. DC power supply
2. Variable gang capacitor
3. Potentiometer
4. Two PNP Transistors
5. Adequate no. of patch cords
6. A.C. Milivoltmeter
7. Audio Frequency Generator
8. Cathode Ray Oscilloscope 20MHz

Theory: Wien Bridge is a two stage R.C coupled amplifier, in which a fraction of the output voltage is fed back to the input terminals. Oscillations are produced if the feedback voltage,E_{fb1} is equal in magnitude and in phase, with the voltage, initially assumed at the input of the 1st stage . Fig.1 shows the circuit diagram of solid state Wien Bridge Oscillator. The Oscillator is termed as a Wien Bridge Oscillator, because of the similarity of the frequency determining circuit with the basic Wien Bridge. The frequency determining network has the from as illustrated in Fig.2. The upper arm consists of resistance and capacitance in series, the lower arm of an equal resistance and an equal capacitance in parallel. In order to study the behavior of this network can be calculated as follows:

$$\frac{E_{fb}}{E_o} = \frac{Rjx}{R+jx} / [R + jx + \frac{Rjx}{R} + jx]$$

Where $x = \frac{1}{\omega c}$

$$\frac{E_{fb}}{E_o} = \frac{Rjx(R^2 - x^2) + 3R^2x^2}{(R^2 - x^2) + (3Rx)^2}$$

When there is Zero phase shift, the term 'j' vanishes and we have,

$$(R^2 - x^2) = 0$$

Or $R^2 = x^2$

Or $R^2 = \frac{1}{\omega^2 x^2}$

Or $R = \pm \frac{1}{\omega c}$

Taking the positive value,

$R = \frac{1}{\omega c}$

$\omega = \frac{1}{Rc}$

$f = \frac{1}{2\pi Rc}$

Substituting R=X in the expression (1), to find the attenuation at this frequency, we have

$\frac{E_{fb}}{E_O} = \frac{3R^2 x^2}{9R^2 x^2} = \frac{1}{3}$

Or $\frac{E_{fb}}{E_O} = 3$

The amplifier thus requires a gain just exceeding 3, to sustain oscillation. Such a low voltage gain could readily be obtained from a single amplifier, but it is difficult in such a simple amplifier to obtain the required phase shift of 360^0 (or zero phase shifts). Therefore two stage or even three stage amplifier is used, and the gain is reduced to the required value by negative feedback.

Wien bridge oscillators are frequently used for audio frequency testing purpose, the oscillator frequency can readily be adjusted if a two gang variable capacitor is used for C_1 and C_2 (giving a 10 : 1 change in frequency), the resistors R_1 and R_2 being switched in decade steps to give different frequency ranges. By this means, it is possible to design an oscillator with a frequency range say from 30 Hz to 30 KHz.

Procedure

1. Trace the circuit according to the figure shown on the panel and identity the following:

    (a)R-C coupled amplifier and

    (b)R-c phase shift net-work

2. Training board IC regulated 9v power supply is connected internally.
3. Connect the point A to H and C to F.
4. Switch on the supply
5. Adjust the variable resistance '4K7' till stable and undistorted oscillations are obtained. Observe the oscillations at the point B, on C.R.O. Vary the gang condenser and measure the frequency by comparing it with a standard audio frequency generator.

To study the frequency response of phase shift network:

Switch off the power supply; disconnect the point A to H and C to F.

Then the phase shift network will appear to be as shown in fig.2. Apply a constant signal of 5 volts between the terminals H and ground and measure the output between C and ground at

the lowest possible frequency. Increase the frequency in suitable steps until maximum frequency is reached and note the output at each steps with A.C. milivoltmeter.

Report:

1. Plot the graph between $\dfrac{E_{fb}}{E_o}$ frequency. This gives the frequency response of the phase shift network.

2. Tabulate the values of the frequency of oscillations for different positions of variable condenser from steps (2) to (5)

Circuit diagram:

FIG. 1

FIG. 2
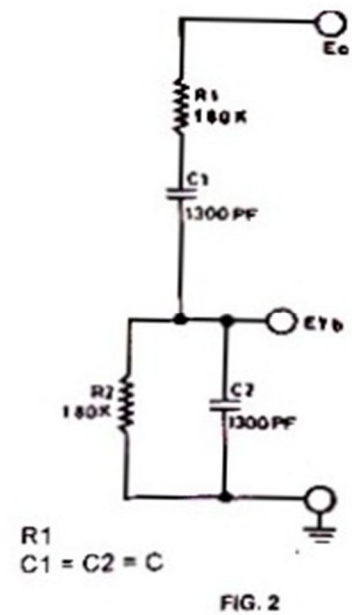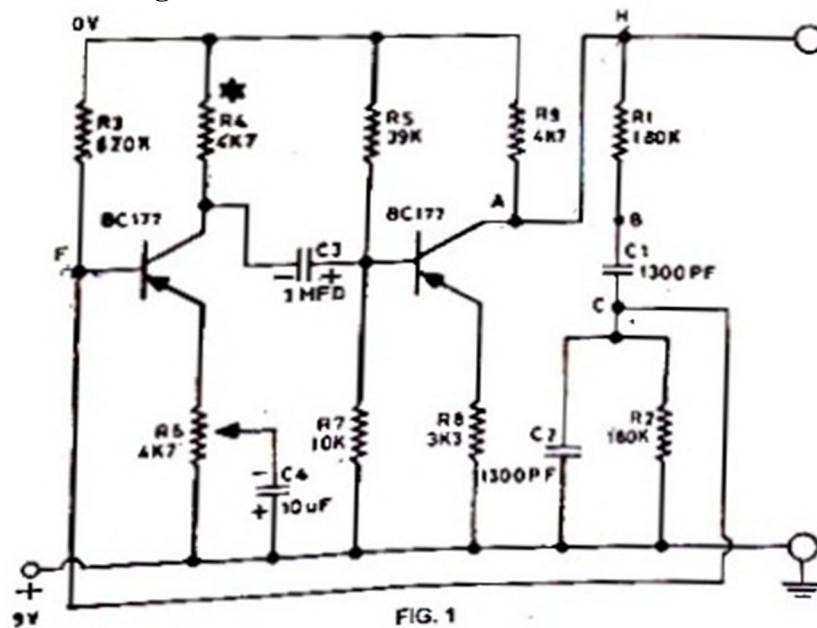
OBSERVATION TABLE:

Sl. No	Resistance (R_1)(Ω)	Capacitance(C_1)(PF)	Frequency (Hz) , $f = \dfrac{1}{2\pi Rc}$

Conclusion:

EXPERIMENT NO. PC EE 493/9

Name: MEASUREMENT OF INDUCTANCE BY ANDERSON BRIDGE

OBJECTIVE: To find unknown self-inductance of coil with the help of Anderson's bridge.

Apparatus:

Sl. No.	Item	Quantity	Rating	Maker
1.	An Anderson Bridge trainer kit			
2.	An external inductance coil			
3.	Connection probes			

Theory:

For low frequencies a practical coil can be represented by self-inductance in series with a resistance which accounts for losses in the coil. The self-inductance of a coil can be measured with help of Anderson Bridge illustrated in figure.

Let L be the self-inductance of coil and S be its resistance. A variable resistance s1 is inserted in the arm CD of bridge in which the coil is placed.

In figure, S = (s+s1) is the total resistance of the arm CD. P, Q, R are non-inductive resistances. m is variable non inductance resistance. c is a standard capacitor. D is a detector.

At balance condition, i.e., for no flow current the detector, We have

$$S = R \, Q/P \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.1$$

$$\text{And } L = CR \, [\, Q + m \, (1+P/Q)] \dots\dots\dots\dots\dots\dots\dots\dots\dots2$$

Equation (1) & (2) are respectively referred to as the DC &the AC balance conditions of the bridge.

If P = Q Equation (2) reduces to L = CR (Q+2m)……………….3

The AC balance represented by Equation (3) can achieved only when L > CR Q. Otherwise, the resistance r will be negative. If c is expressed in Farad, R, Q and r are expressed in ohms, then L will be obtained in Henry from the equation(3).

Procedure:

1. **Attainment of DC balance:**

A. Set up the circuit carefully. Supply source will be dc voltage source.
B. The resistance P, Q, R of the kit is each taken equal.
C. Vary the resistance S & test the balance condition by watching the null detector.

When the deflection changes. In the opposite direction for One ohm variation in S, insert fractional resistance to achieve exact null Detector .The total resistance in arm CD of the bridge will then be.

$$(P = Q = R) S = s + s1.$$

Therefore the coil resistance S will be   s = S - s1

By this arrangement, the resistance in all the four arms of Wheatstone bridge are made equal, e.g.1kohm.under this condition bridge is most sensitive.
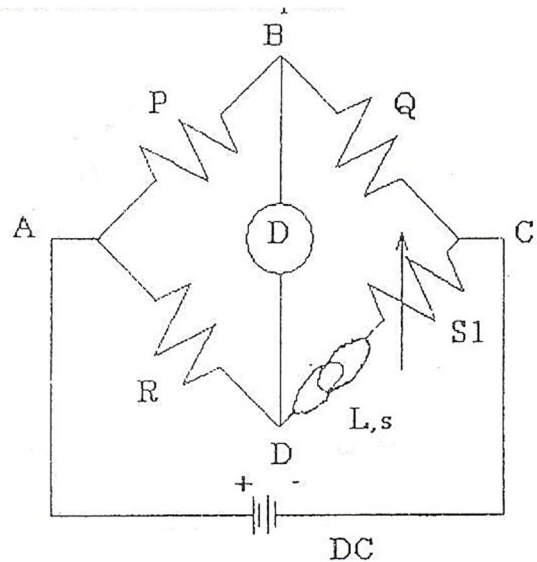
2. **Attainment of AC balance:**

A. Switch off the kit &replace the DC source by AC source. Now, insert the standard capacitor C & resistance m properly to obtain the circuit of the figure. The resistance P, Q, R & S as obtained for DC balance [operation (1) above], **are left unaltered**.

B. Vary the resistance 'm' until the Null Value will come. Note the corresponding value of 'm' when Null value will come.

Note: There may be a problem with this null value. In practical field, it is having lots of noise e.g. temperature generated noise, magnetic field & electrical field generated noise much more. That's why the actual null value cannot be obtained. How would you get this null value? The simple technique is as follows.

Let C be the connected at 0.01 micro-farad. Earlier, 'S' obtained, was nearly 960 ohms. Known L is also connected unaltered. 'S' should not be altered .Now by varying m at
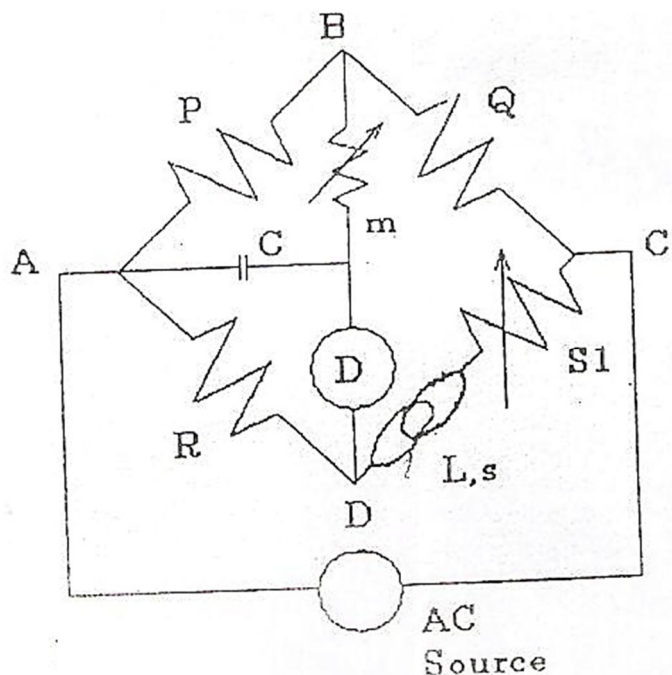
around 360 ohms we will get 003 in Null Detector. Increase m & we get 022 in Null Detector. Again we decrease m, & then we will get 006 in Null Detector. So the Null value will be in between 600 & 200. Therefore we consider we have got the Null value when we have got the Null value when choose m =360.

C. Calculate L using the equation (3)

D. Repeat steps (B) & (C) for the different values of C & calculate the mean value of L.

Table: 1

DATA FOR DC BALANCE

OBSERVATION TABLE

Resistances in ohm				Value of S at Null point	Coil resistance s = S - s1
P	**Q**	**R**	**S1**		

Table: 2

DATA FOR AC BALANCE

OBSERVATION TABLE

P = Q = R = S = s + s1

Capacitance C (µF)	Value of m (Ω)	Value of m at Null point (Ω)	L (mH)	Mean L (mH)

Discussions:

1. The value of C must be such that L>CRQ. Therefore to perform the experiment, the approximate value of L is required before hand to choose C properly. The experiment then allows an accurate determination of L.
2. Unless the bridge is sensitive, an accurate determination of the AC Null point is difficult. The bridge is made sensitive by choosing equal value resistances in the four arms.
3. In the beginning, the frequency the AC source be varied & a proper value of it should be chosen, so that it suits the ear &an accurate determination of Null point is possible.

Conclusion:

Answer the following questions:

1. What do you mean by self-inductance of a coil? What is its SI unit?

2. What is non-inductive winding?

3. Will the self-inductance of a coil be effective for a DC supply?

4. What type of oscillator are you using? What is its frequency?

5. Apart from the self –inductance, what other circuit parameters will a coil have?

6. Define self-inductance.

7. Define one henry.

EXPERIMENT NO. PC EE 493/10

Name: MEASUREMENT OF CAPACITANCE BY DE-SAUTY BRIDGE.

Objective: To study the working of a De-Sauty bridge and to determine the capacitance of an unknown capacitor.

Apparatus:

Sl. No.	Item	Quantity	Rating	Maker
1.	standard variable capacitor bank			
2.	variable non-inductive resistance bank			
3.	signal generator			
4.	null detector			
5.	connecting cords			

Formula: Capacity of an unknown capacitor $C_x = \dfrac{R_1}{R_2} \times C_1 \; \mu F$

Where, C_1 is the capacity of the known capacitor.

R_1 and R_2 are the variable non-inductive resistors.

Theory: The De-Sauty bridge is an AC bridge working on a principle of Wheatstone bridge. This bridge is used to determine the capacity of an unknown capacitor C_x in term of the capacitor C_1. Here R_1 and R_2 are non-inductive resistors. R_1, R_2, C_1 and C_2 (i.e. C_x) are connected in a Wheatstone bridge as shown in figure -1. When the bridge is balance, the ratio of impedance is equal as given below.

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$$

$$or, \frac{R_1}{R_2} = \frac{\dfrac{1}{j\omega C_1}}{\dfrac{1}{j\omega C_2}}$$

$$or, \frac{R_1}{R_2} = \frac{C_2}{C_1}$$

Procedure: The connections are made as shown in figure -1. The resistance R_1 and a condenser C_1 are in series in one branch of the bridge and a resistance R_2 and another capacitor C_x are in series in another branch. The AC signal generator frequency is a fixed value of $1KH_Z$.

Connect the unknown capacitance in C_x arm. Connect the signal generator and null detector. Set the ratio of R_1 and R_2 resistance in a fixed value. Switch on the trainer. A perfect balance is obtained by adjusting C_1 till the null detector indicates zero / a minimum value. In the balance condition the capacitance value of the C_x is calculated by using the above formula.
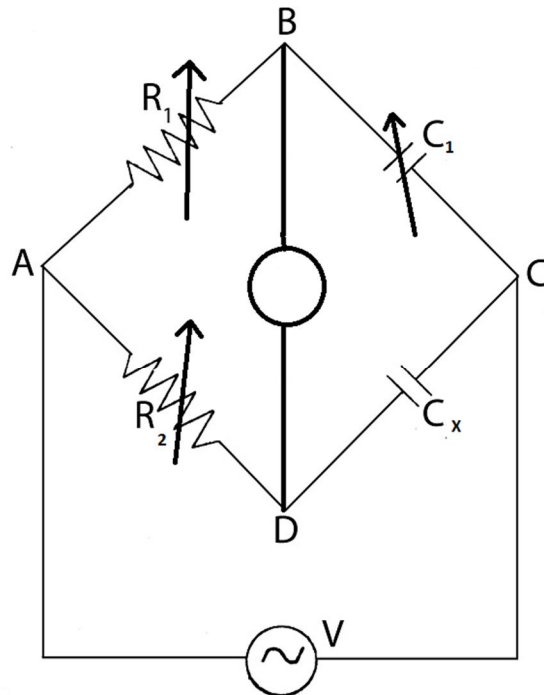
Figure 1: De sauty bridge

When the null detector is zero/ minimum then the upper and the lower branch of Wheatstone's bridge equal i.e; $C_1R_1=C_2R_2$.

OBSERVATION TABLE:

SL NO.	Capacity of unknown capacitor $C_1(\mu F)$	Resistance $R_1(\Omega)$	Resistance $R_2(\Omega)$	Capacity of a unknown capacitor $C_x = \frac{R_1}{R_2} X\ C_1(\mu F)$

Conclusion:

Answer the following question:

1. What is the main objective of using De-Sauty Bridge?
2. Why we use loudspeaker?
3. What is the use of CRO?
4. How much frequency is supplied to the circuit?
5. Why the output section is called the Imbalance Amplifier?

EXPERIMENT NO. PC EE 493/11

Name: MEASUREMENT OF CAPACITANCE BY SCHERING BRIDGE

Objective: To study the working of Schering bridge and to determine the capacitance of an unknown capacitor.

Apparatus: Trainer kit

Formula: Capacity of an unknown capacitor $C_x = \frac{R_1}{R_2} * C_3$

Where, C_3 is the capacity of the known capacitor.

R_1 and R_2 are the variable non-inductive resistors.

Theory: The Schering Bridge, one of the most important AC bridges, is used extensively for the measurement of capacitors. It is particularly useful for measuring insulating properties, i.e., for phase angles very nearly 90^0. The basic circuit arrangement is shown in Fig.1, and inspection of the circuit shows a strong resemblance to the comparison bridge. Notice that arm 1 now contains only a capacitor. The standard capacitor is usually a high quality mica capacitor for general measurement work or an air capacitor for insulation measurements. A good quality mica capacitor has very low losses (no resistance) and therefore a phase angle of approximately 90^0.
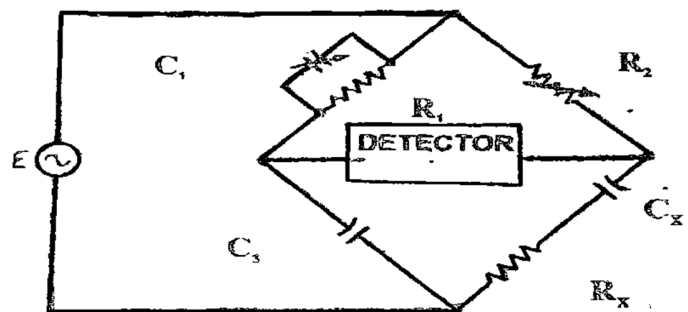
Fig. 1

The balance equations are derived in the usual manner, and by substituting the corresponding impedance and admittance values in the general equation, we obtain

$$Z_x = Z_2 * Z_3 * Y_1$$

Or $R_x - \frac{j}{\omega C_x} = R_2 * \{\frac{j}{\omega C_3}\} * \{\frac{1}{R_1} + j\omega C_1\}$

And expanding $R_x - \frac{j}{\omega C_x} = \frac{R_2 * C_1}{C_3} - \frac{j R2}{\omega * C_3 * R_1}$

Equating the real terms and the imaginary terms, we find that

$Rx = \frac{R_2 * C_1}{C_3}$

$Cx = \frac{C_3 * R_1}{R_2}$

Procedure: The connections are made as shown in fig1. The resistance R_1 and a condenser C_1 are in parallel in one branch of the bridge and a resistance R_2 and C_x are in series in another branch. Known capacitor C_3 is also connected in one branch of the bridge is in series with parallel combination of C_1 and R_1. The AC signal generator frequency is a fixed value of 1 KHz.

Connect the unknown capacitor in C_x arm. Connect the signal generator and null detector. Set the ratio of R_1 and R_2 resistance in a fixed value. Switch on the trainer. A perfect balance is obtained by adjusting C_1 till the null detector indicates zero / a minimum value. I the balance condition the capacitance value of the Cx is calculated by using the above formula.

Circuit diagram:
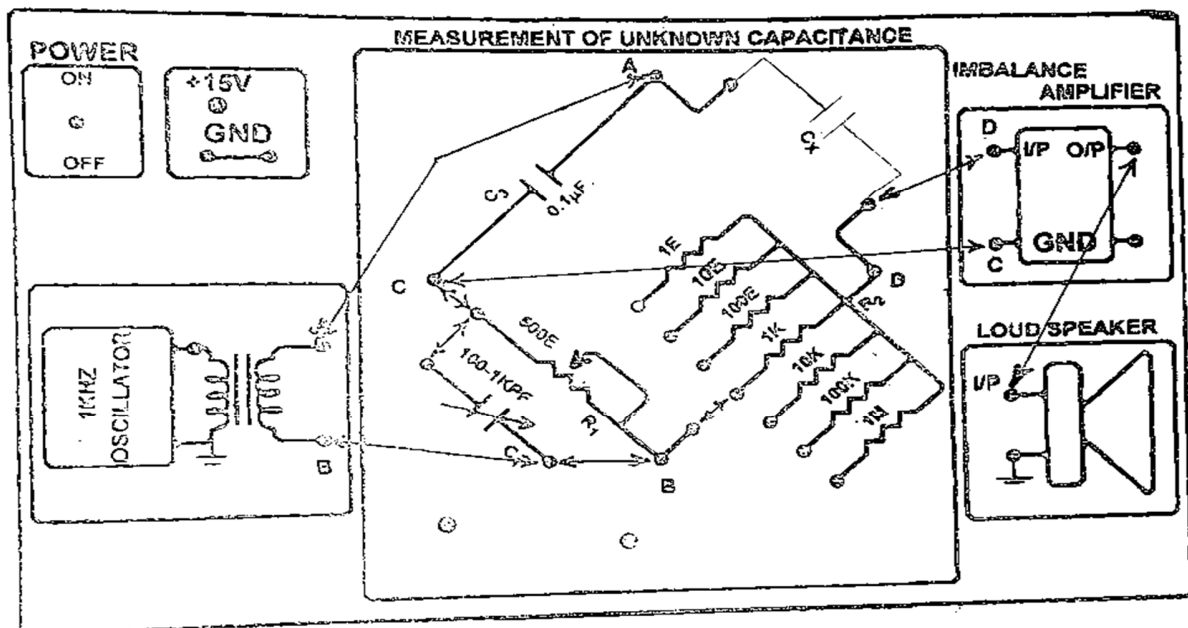
Fig. 2

OBSERVATION TABLE:

Sl No.	Capacity of known capacitor(uF)	Resistance R1(Ω)	Resistance R2(Ω)	Capacity of unknown capacitor $Cx = \frac{C3*R1}{R2}$(uF)	Mean Value

Conclusion:

Answer the following question:

1. What is the main objective of using Schering Bridge?
2. Why we use loudspeaker?
3. What is the use of CRO?
4. How much frequency is supplied to the circuit?
5. Why the output section is called the Imbalance Amplifier?

EXPERIMENT NO. 1

Determination of the characteristics of a separately excited DC generator.

Objective:
Study of the steady state characteristics of a separately excited DC generator.

Conduct OCC test and draw (i) armature voltage with field current, and (ii) armature voltage with speed.

Conduct load test at constant speed and draw (i) armature voltage with load current.

NAME PLATE DETAILS:

DC motor	DC Generator
Volts:	Volts:
Amps:	Amps:
KW:	KW:
RPM:	RPM:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

THEORY:

In spite of the advantages of ac systems, the dc machines continue to find use in a wide range of industrial applications because of their flexibility and versatility. The special features which determine the choice of a dc machine for a particular application are the torque speed characteristics of motors and the voltage-load characteristics of generators. The knowledge of the limits within which these characteristics can be varied, and of the way, in which such variations could be obtained are also important. Study of these features for a dc machine is accordingly the motivation for this experiment.

A D.C. generator is an energy converter. Mechanical power input received from a prime mover (D.C. motor in this case) is converted electromagnetically into electrical energy. This electrical energy can be changed into heat as is done by connecting load resistors across its armature terminals. It is essential that the field windings of the generator be excited with D.C. current.

In a separate excited DC Generator the armature and field circuits are separate and an external dc voltage is applied across the field.
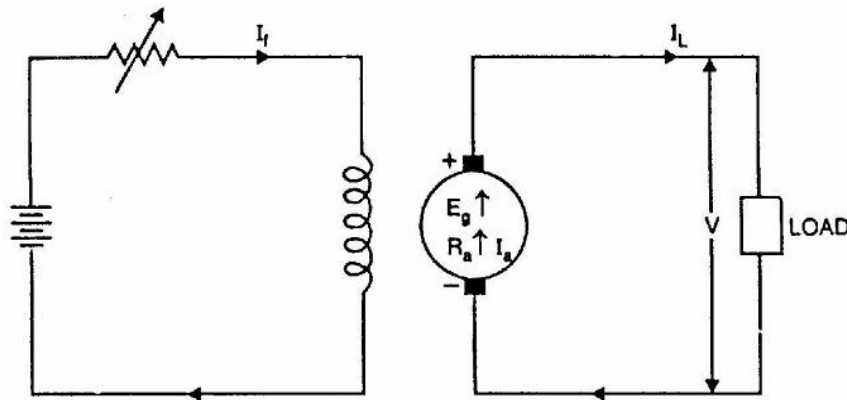
Open Circuit Characteristics

An important relation essential in the determination of dc generator performance is the relation between field current or field ampere turns and armature emf. The resulting curve at the desired speed is the magnetization characteristic or the open-circuit characteristics (OCC). The magnetization characteristics at several different speeds can be obtained from any one characteristic by recognizing that the voltage is directly proportional to speed for a fixed flux or field current.

Load Characteristics

The load characteristic of a dc generator at a particular speed is the relationship between armature voltage of the generator and its load current at that speed. It is called the external characteristic if the plot is between the terminal voltage vs load current and the internal characteristic if the plot is between the generated emf vs load current. In a separately excited dc generator, the field current is independent of armature conditions. At constant field current and constant speed, the terminal voltage in this case drops off somewhat as load current increases because of the increased armature resistance drop and reduction in flux due to armature reaction

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PRECAUTIONS:

(a) Make sure that field connections of DC shunt motor are proper and three-point starter return to its zero position before every fresh start.

(b) Use proper range of DC instruments only

PROCEDURE:

Magnetization Characteristics of a Separately Excited DC Generator

1. Connections are made as per the circuit diagram.
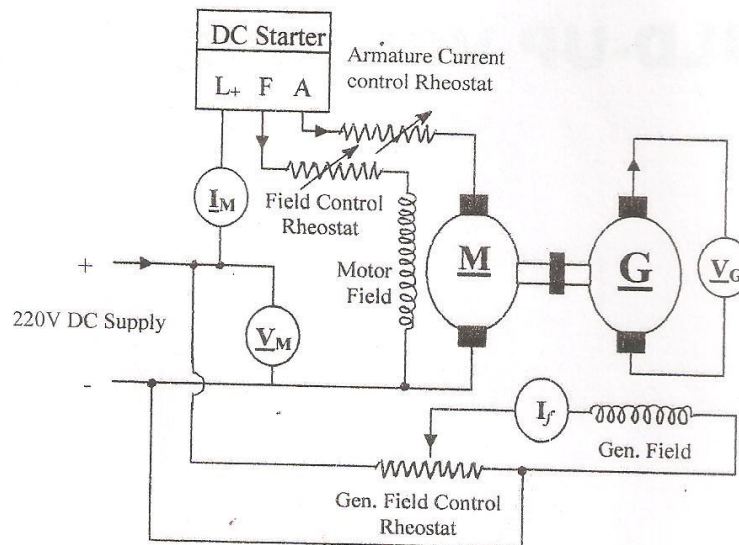
2. Set all rheostats & potential divider at minimum position.
3. Run the Motor with the help of a DC three-point starter.
4. Set the speed of the Motor-Generator Set at rated speed with the help of Armature control rheostat.
5. Note down the voltmeter reading. The generator field current is zero but voltmeter will read a few volts due to residual magnetism.
6. Increase the generator field current gradually with the help of potential divider and observe that the induced voltage also increases.
7. Record the readings of generator induced voltage for different field current keeping the speed of the machine constant.
8. Tabulate readings in Table - 1 upto 110% of the rated voltage of the DC generator.

Load Characteristics of Separately Excited DC Generator

1. Connections are made as per the circuit diagram.
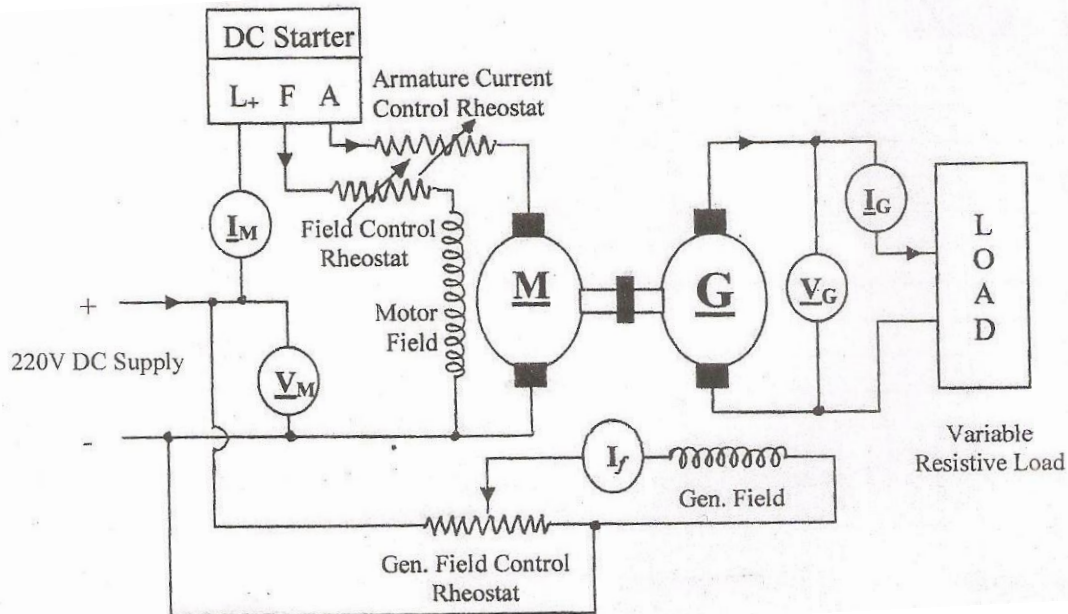
2. Set all rheostats & potential divider at minimum position.
3. Run the Motor with the help of a DC three-point starter.
4. Set the speed of the Motor-Generator Set at rated speed with the help of Armature control rheostat.
5. Adjust the field resistance to obtain 220V DC at no-load at rated speed of the DC generator.
6. Connect resistive load as shown in the connection diagram through the 2-pole switch.
7. Vary the load keeping the Motor-Generator set speed and generator field current constant.
8. While adjusting the speed foirst adjust the armature control rheostat and then field control rheostat.
9. Tabulate readings of the load current and terminal voltage for various loading conditions in Table – 2.

RESULT:

TABLE - 1				
Speed of the Motor-Generator set:				
S.no	**Increasing Field current from zero to maximum value**		**Decreasing Field current from maximum value to zero**	
	Field current (I_f) (Amps)	**Induced voltage (V_G) (Volts)**	**Field current (I_f) (Amps)**	**Induced voltage (V_G) (Volts)**

TABLE - 2						
S.no	**Motor**		**Generator**			**Speed**
	Terminal voltage (Volts)	**Current (Amps)**	**Terminal voltage (Volts)**	**Load Current (Amps)**	**Field Current (Amps)**	

REPORT:

1. Using the experimental data obtain the following characteristics.

    i)   armature voltage with field current
    ii)   armature voltage with speed.
    iii)   armature voltage with load current.

2. Explain why does terminal voltage decrease with increasing load current.

EXPERIMENT NO. 2

Determination of the characteristics of a DC motor

Objective:

To determine the basic characteristics of DC shunt motor.

NAME PLATE DETAILS:

DC motor
Volts:
Amps:
KW:
RPM:

APPARATUS USED:

SL NO	NAME OF THE INSTRUMENT	RANGE/ RATING	MAKERS NAME
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			

.

THEORY:

There are three characteristics for any DC motor
1. speed vs. armature current characteristics
2. torque vs. armature current characteristics
3. speed vs. torque characteristics.

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The following three fundamental equations pertaining to DC machine are known:

$$V = E \pm I_a R_a \qquad (1)$$

$$E = \frac{\phi Z \omega P}{2\pi A} \qquad (2)$$

$$\omega = f(T)\frac{V\phi}{K_e} - \frac{R_a T K_1 \phi^2}{K_e} \qquad (3)$$

The speed vs. armature current characteristics can be determined from equations (1) & (2)

$$\omega = \frac{V - I_a R_a}{K_e \phi} \qquad (4)$$

Where K_e is constant for the machine .when ϕ is constant , $\Box$ can be expressed in the form $A - BI_a$, where $A = \frac{V\phi}{K_e}$ and $B = \frac{R_a \phi}{K_e}$ are also constants for the machine under study. Hence $\omega = f(I_a)$ should be straight line .however , due to the armature reaction ,the effect of which increases with increase in armature current ,the magnitude of denominator of equations(4) reduces with increase in I$_a$. but to a less extent then the numerator and therefore ,has the shape shown in fig-1.
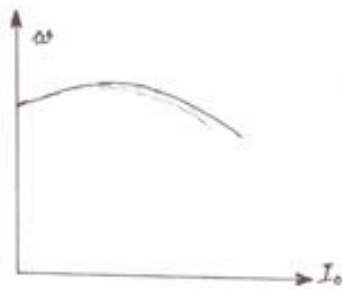
Fig-1 Speed-Current Curve of DC Shunt Motor. Fig-2 Torque-Current Curve of DC Shunt Motor. Fig-3 Speed-torque Curve of DC Shunt Motor
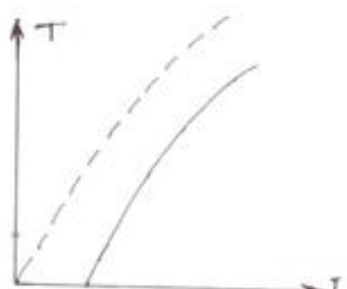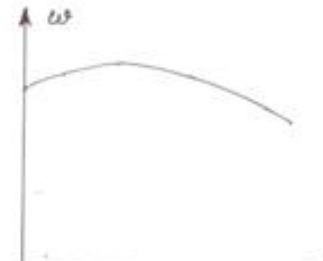
The torque vs. armature current characteristic can be obtained from equation (3),i.e, $T = K_1 I_a$, where K$_1$ is a constant for the machine, the curve with dotted line in fig-2 represent this relationship ,the deviation from an ideal straight line, especially at higher value of I$_a$,being due to the effect of armature reaction ,viz, the reduction in the magnitude of flux per pole .since $I_a = I_{load} - I_f$, the actual curve will be as shown by firm line in fig-2. This curve has an interception in the X axis given by the magnitude of the no load current of the motor.

The relationship between speed and torque can be determined by using the above two characteristics or alternatively, from equations (3) & (4), which gives

$$\omega = \frac{V\phi}{K_e} - \frac{R_a T K_1 \phi^2}{K_e} = A_1 - B_1 T \qquad (5)$$

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Where A_1 and B_1 are constant.

Neglecting the effect of armature reaction, $\omega = f(T)$ will be linear. due to armature reaction,φ no longer remains constant for different values of I_a and hence speed –torque characteristics attains the shape shown in fig-3.

Procedure :

1. make connection as per circuit diagram.
2. start the dc motor with the help of starter.
3. record the voltage, current and speed of the motor at no load condition.
4. load the machine by left pulley arrangement gradually and record the load current ,speed ,applied voltage at different load condition .take at least 5 reading.
5. the applied voltage of the machine must be constant.
6. measure the armature resistance of the DC motor by ammeter –voltmeter method.

Connection diagram :
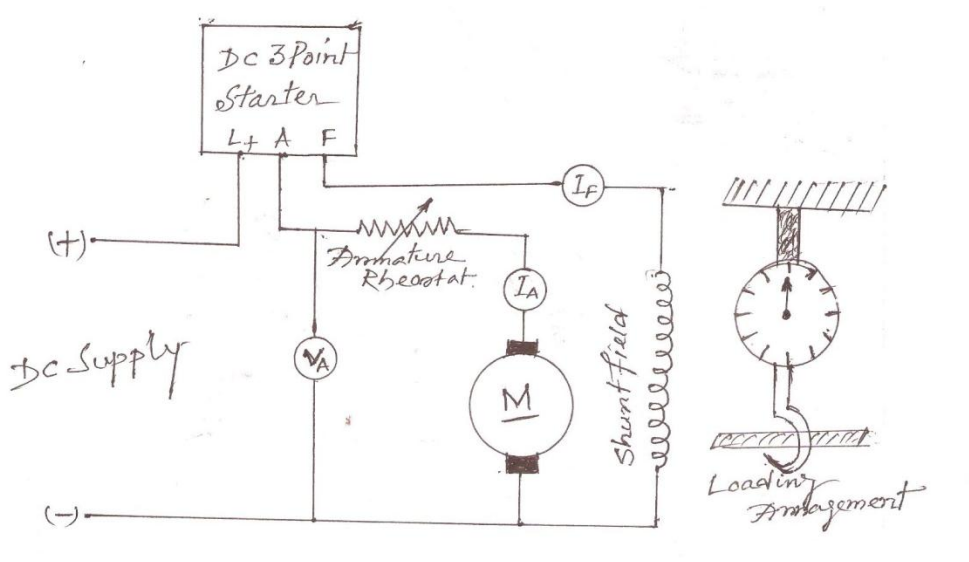
Fig 4 : DC shunt motor connection diagram
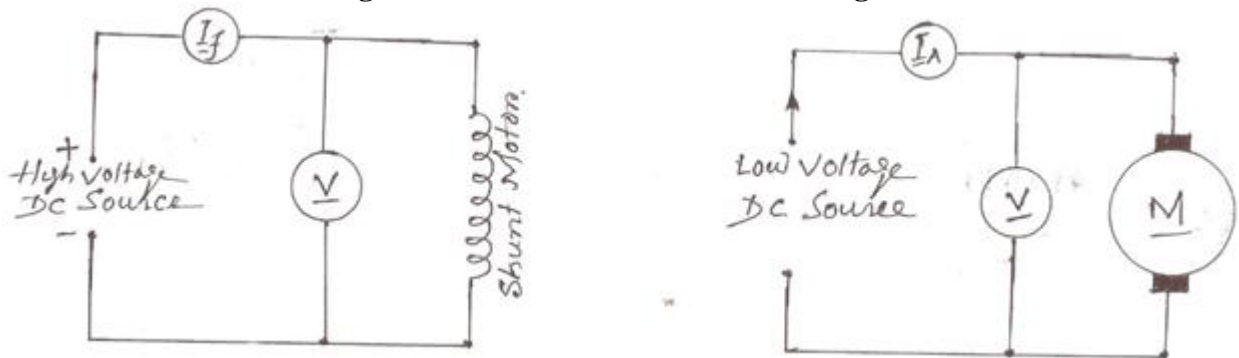
Fig 5 : Connection diagram for measurement of Field & Armature resistance

Observation table and result:

Armature resistance R_a=………………………….ohms.

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Sl no.	Speed in R.P.M	Applied voltage	Load current	S₁	S₂	$T = (S1 - S2)X\dfrac{D}{2}X9.8$

REPORT:

3. Using the experimental data obtain the following characteristics.

   a) speed vs. armature current characteristics
   b) torque vs. armature current characteristics
   c) speed vs. torque characteristics.

EXPERIMENT NO. 3

Study of methods of speed control of DC motor.

Objective:

To study the speed control of a DC shunt motor by
1. varying the armature voltage.
2. varying the armature resistance.
3. varying the field resistance.

NAME PLATE DETAILS:

DC motor
Volts:
Amps:
KW:
RPM:

APPARATUS USED:

SL NO	NAME OF THE INSTRUMENT	RANGE/ RATING	MAKERS NAME
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			

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THEORY:

The speed of a DC motor is given as-

$$N = \frac{(V - I_a(R_a + R_e))}{K\phi}$$

Where,

V=armature voltage

I_a=armature current

R_a=armature resistance

R_e=external resistance in armature circuit

φ =flux/pole

K=machine constant

It is evident from this expression that the speed will rise if the flux, φ is reduced. It can achieved by inserting external resistance in the field circuit to reduce the field current . This method is called field control and is used if the speed is to be raised above the rated speed. The speed can also be reduced either by reducing the armature voltage V or by inserting an external resistance R_e in the armature circuit to increase the armature voltage drop. The former method is called armature voltage control and is popularly used. The later method involves large amount of ohomic losses in the external resistance placed in the armature circuit, hence this method is not preferred. This armature voltage control has been made by using variable voltage source or by using potential divider or by using a variac and a rectifier bridge which has also been used for starting the motor.

Precautions:

(c) Make sure that field connections of DC shunt motor are proper and three-point starter return to its zero position before every fresh start.

(d) Use proper range of DC instruments only

Procedure:

For armature voltage control :

1. connect DC shunt motor, voltmeter, ammeters, DC supply, resistance as per circuit diagram.

2. initially the resistance is minimum position i.e the applied voltage of the armature is minimum that is zero.

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3. increase the voltage by varying the potential divider and take the reading of the voltmeter ,ammeter and RPM meter.

4. take at least 5 readings from minimum to maximum position and tabulate it.

5. draw the graph between terminal voltage vs. speed and armature current vs. speed.

For armature resistance control :

1. connect DC shunt motor, voltmeter, ammeters, DC supply, resistance as per circuit diagram.

2. initially the resistance is maximum position

3. on the Dc supply and start the motor.

4. decrease the resistance and take the reading of the voltmeter ,ammeter and RPM meter.

5. take at least 5 readings from minimum to maximum position and tabulate it.

6. draw the graph between terminal voltage vs. speed and armature current vs. speed.

For field current control :

1. connect DC shunt motor, voltmeter, ammeters, DC supply, resistance as per circuit diagram.

2. Initially the resistance is minimum position

3. increase the external field resistance in steps and note the speed and field current .

4. take at least 5 readings to change the field resistance .follow that the speed is not exceed 130% of the rated speed.

5. similarly decrease the field resistance and take the readings.

6. draw the graph between field current vs. speed

Connection diagram :

Armature Voltage Control

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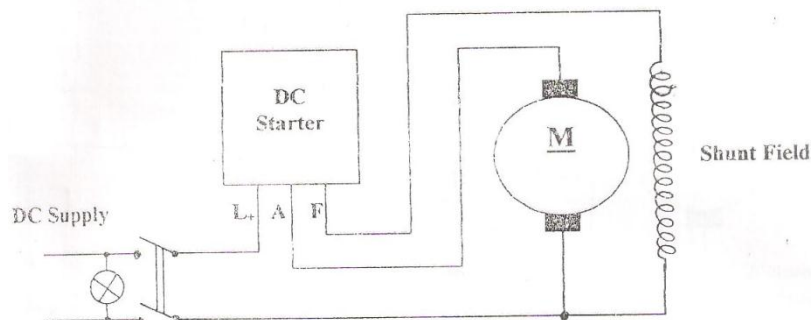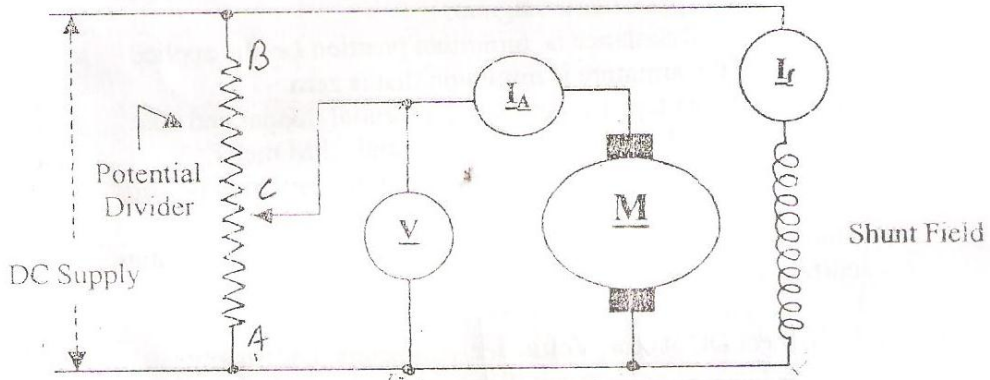
Armature resistance Control
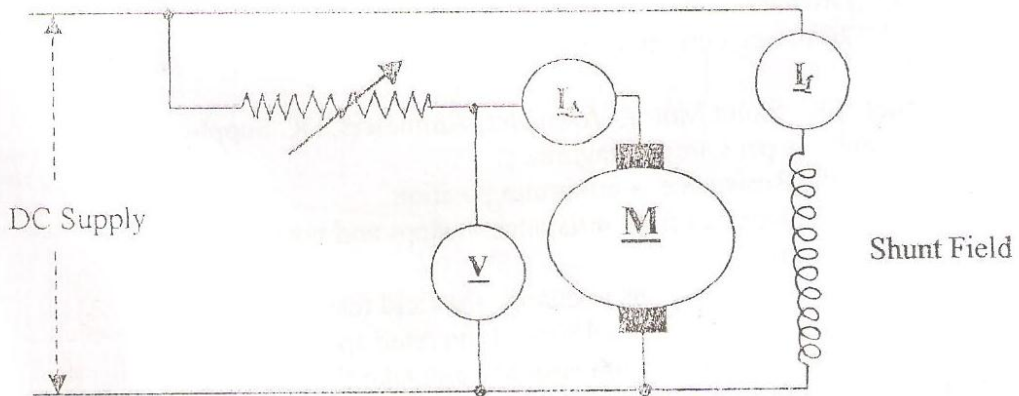
Field Current Control
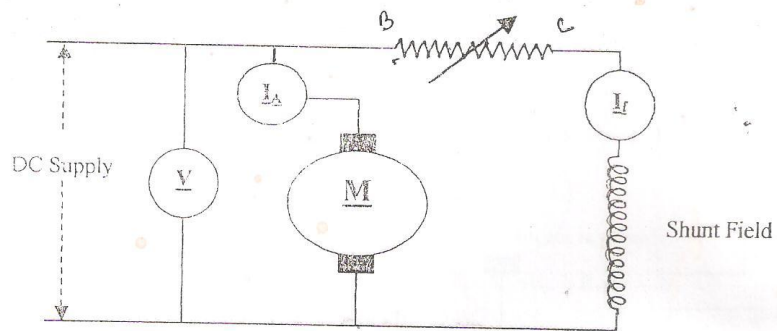
Observation table:

For Armature Voltage Control

SL.NO	ARMATURE VOLTAGE(volts)	ARMATURE CURRENT(amps)	FIELD CURRENT(amps)	SPEED(RPM)	REMARK
					Armature voltage increasing
					Armature voltage decreasing

For Armature Resistance control

SL.NO	ARMATURE VOLTAGE(volts)	ARMATURE CURRENT(amps)	FIELD CURRENT(amps)	SPEED(RPM)	REMARK
					Armature voltage increasing
					Armature voltage decreasing

For field Current control

SL.NO	ARMATURE VOLTAGE(volts)	ARMATURE CURRENT(amps)	FIELD CURRENT(amps)	SPEED(RPM)	REMARK
					Armature voltage increasing
					Armature voltage decreasing

Study of the characteristics of a compound DC generator (short shunt).

Objective:
Study of the steady state performance of a DC compound generator.

Conduct load test to get the external characteristic of the generator and hence the voltage regulation of the generator.

NAME PLATE DETAILS:

DC motor	DC Generator
Volts:	Volts:
Amps:	Amps:
KW:	KW:
RPM:	RPM:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

THEORY:

In a compound generator, both series and shunt excitation are combined as shown in Fig. The shunt winding can be connected either across the armature only (short-shunt connection S) or across armature plus series field (long-shunt connection G). The compound generator can be cumulatively compounded or differentially compounded generator. The latter is rarely used in practice. It may be noted that external characteristics of long and short shunt compound generators are almost identical.

Short Shunt Compound
(a)

Long Shunt Compound
(b)
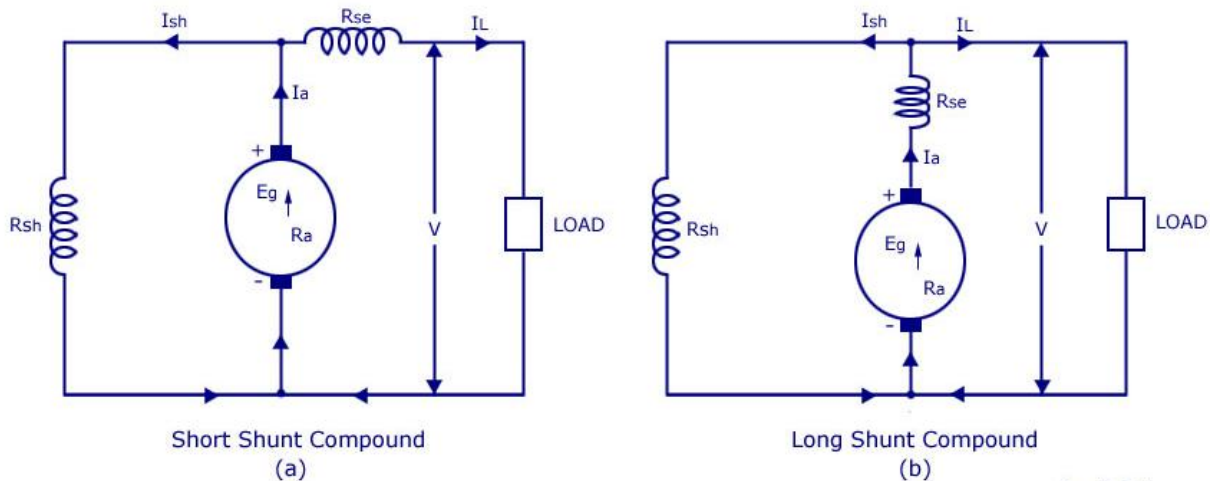
In case of short shunt compound generators

Series field current, $I_{se} = I_L$

Shunt field current, $I_{sh} = \dfrac{V + I_{se}R_{se}}{R_{sh}}$

Terminal voltage, $V = E_g - I_aR_a - I_{se}R_{se}$
Power developed in armature $= E_gI_a$
Power delivered to load $= VI_L$

External characteristic

Fig. shows the external characteristics of a cumulatively compounded generator. The series excitation aids the shunt excitation. The degree of compounding depends upon the increase in series excitation with the increase in load current.

A. If series winding turns are so adjusted that with the increase in load current the terminal voltage increases, it is called over-compounded generator. In such a case, as the load current increases, the series field m.m.f.

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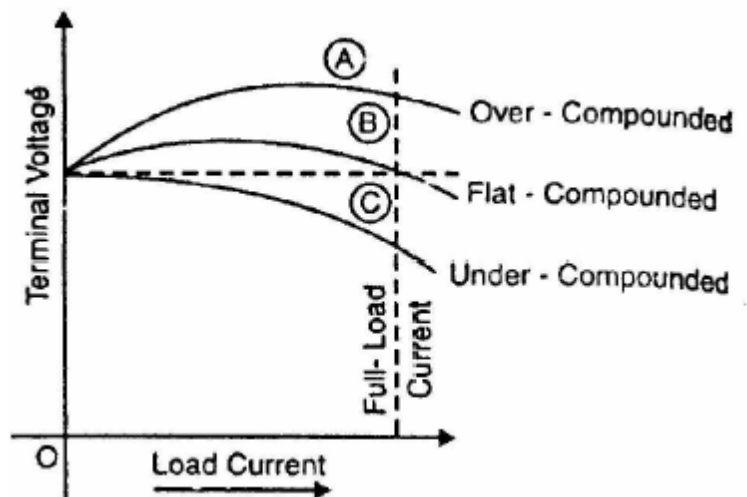
increases and tends to increase the flux and hence the generated voltage. The increase in generated voltage is greater than the I_aR_a drop so that instead of decreasing, the terminal voltage increases as shown by curve A in Fig.

B. If series winding turns are so adjusted that with the increase in load current, the terminal voltage substantially remains constant, it is called flat-compounded generator. The series winding of such a machine has lesser number of turns than the one in over-compounded machine and, therefore, does not increase the flux as much for a given load current. Consequently, the full-load voltage is nearly equal to the no-load voltage as indicated by curve B.

C. If series field winding has lesser number of turns than for a flat compounded machine, the terminal voltage falls with increase in load

Voltage Regulation

The change in terminal voltage of a generator between full and no load (at constant speed) is called the voltage regulation, usually expressed as a percentage of the voltage at full-load.

$$\% \text{ Voltage regulation} = [\,(V_{NL}-V_{FL})/V_{FL}\,] \times 100$$

where V_{NL} = Terminal voltage of generator at no load

V_{FL} = Terminal voltage of generator at full load

PRECAUTIONS:

(e) Make sure that field connections of DC shunt motor are proper and three-point starter return to its zero position before every fresh start.

(f) Use proper range of DC instruments only

PROCEDURE:

10. Connections are made as per the circuit diagram.

11. Set all rheostats & potential divider at minimum position.

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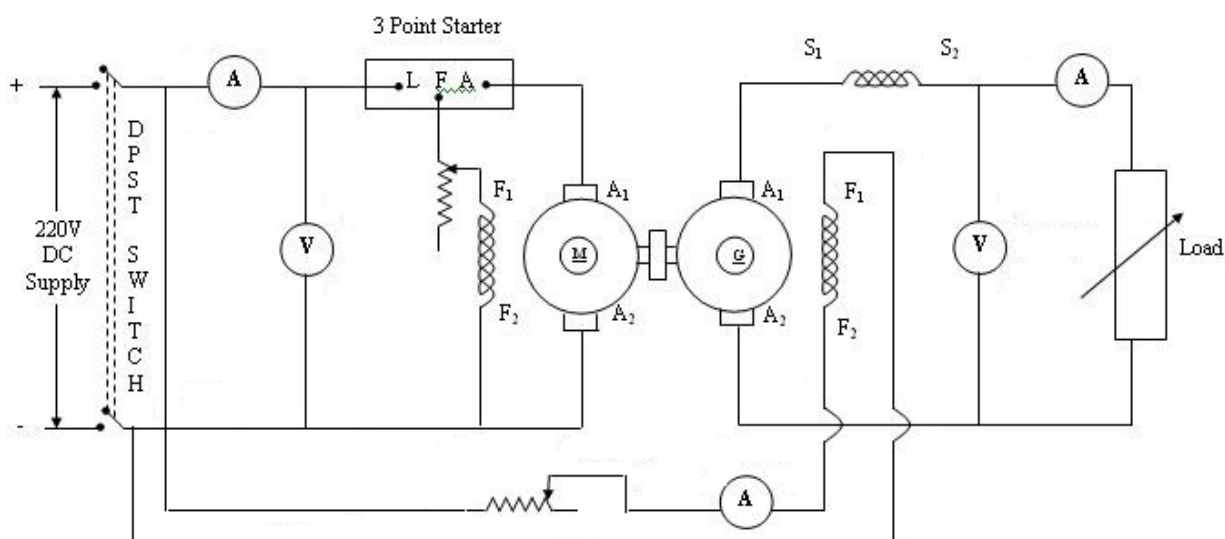
12. Run the Motor with the help of a DC three-point starter.
13. Set the speed of the Motor-Generator Set at rated speed with the help of Armature control rheostat.
14. Adjust the field resistance to obtain 220V DC at no-load at rated speed of the DC generator.
15. Connect resistive load as shown in the connection diagram through the 2-pole switch.
16. Vary the load keeping the Motor-Generator set speed.
17. While adjusting the speed first adjust the armature control rheostat and then field control rheostat.
18. Tabulate readings of the load current and terminal voltage for various loading conditions in Table.
19. The connections of series field windings are reversed the above steps are repeated.
20. The values of voltage for the particular currents are compared and then the differential and cumulative compounded DC generator is concluded accordingly.

RESULT:

TABLE - 1						
S.no	**Motor**		**Generator**			**Speed**
	Terminal voltage (Volts)	**Current (Amps)**	**Terminal voltage (Volts)**	**Load Current (Amps)**	**Field Current (Amps)**	

S.no	Motor		Generator			Speed
	Terminal voltage (Volts)	Current (Amps)	Terminal voltage (Volts)	Load Current (Amps)	Field Current (Amps)	

TABLE – 2 (Series field reversed)

REPORT:

4. Using the experimental data obtain the following characteristics.

        iv)   Generator terminal voltage with speed.

        v)   Generator terminal voltage with load current.

EXPERIMENT NO. 05

DETERMINATION OF SPEED OF DC SERIES MOTOR AS A FUNCTION OF LOAD TORQUE.

Objective

1. To plot the Torque- Speed characteristic of a DC Series Motor.
2. To determine the efficiency of the motor.

NAME PLATE DETAILS:

DC Series Motor	DC Shunt Generator
Volts:	Volts:
Amps:	Amps:
KW:	KW:
RPM:	RPM:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

Theory :

The speed and torque of a DC motor is given by the following expressions

$$N = \frac{V - I_a r_a}{K\phi} \qquad \text{(i)}$$

$$T = K_t I_a \phi \qquad \text{(ii)}$$

Now for a series motor, flux is proportional to the armature current. Therefore, the above expressions can be re-written as

$$N = \frac{V - I_a r_a}{K_1 I_a} \qquad \text{(iii)}$$

$$T = K_2 I_a^2 \qquad \text{(iv)}$$

Present experiment will determine how the speed and torque of a DC series motor are related to each other.

From equation (iii), it can be seen that speed N is inversely proportional to the armature current I_a (= load current). The equation can be re-written as

$$N.I_a = \frac{V - I_a r_a}{K_1}$$

With increase in armature current, the term $(V - I_a r_a)$ does not change very much as $I_a r_a$ drop is small compared to V. So the above equation is of the form $XY = Constant$. Which is the equation for a rectangular hyperbola. The speed vs. armature current characteristic will be approximately a rectangular hyperbola as shown in figure – 1.

Figure – 1   Figure – 2   Figure – 3
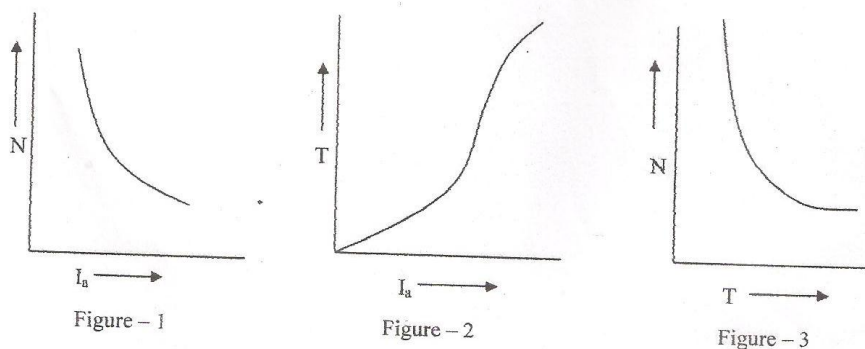
From equation (iv) it is seen that Torque, T is proportional to the square of the armature current. Hence the torque vs. armature characteristic will be a parabola as shown in figure - 2. (It may be noted that after saturation, flux will be constant and torque will then be directly proportional to the armature current.)

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From the graphs shown in figure 1 & 2, we can arrive at the speed – torque characteristic as shown in figure – 3. (Note that if *T vs I$_a$* characteristic was linear then the shape of *N vs. T* characteristic would be same as *N vs I$_a$* characteristic. But as the *T vs I$_a$* characteristic ia parabolic, the *N vs. T* characteristic will be much more curved.)

PRECAUTIONS:

The DC series motor should never be started on no load condition.

PROCEDURE:

1. Make connection according to the circuit diagram shown in figure- 4

2. Connect the generator as a shunt generator. This is important because a series motor should not be run on no load.

3. Start the series motor with help of a starting resistance (series motor starter) . The generator will act as a load on the series motor.

4. Apply rated voltage to the motor. Record the input voltage , input current, speed of the motor and output voltage and current of the generator.

5. Increase the load on the DC generator step by and record for each step the speed , current taken by the motor and the output voltage and current of the generator. Keep the voltage constant for all the steps.

6. Measure the armature and field resistance of the DC generator by ammeter – voltmeter method (as fig-5)

Connection diagram :
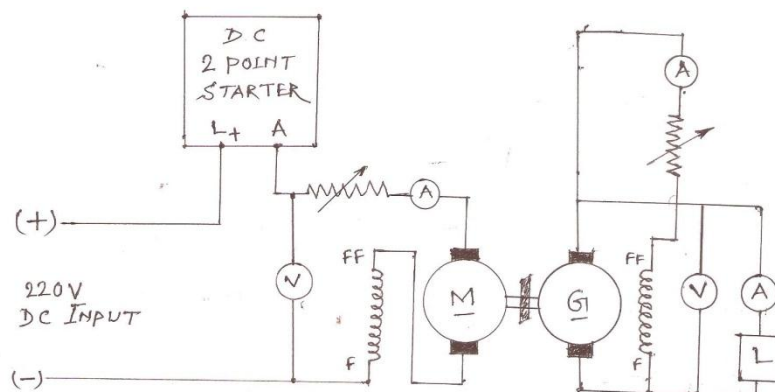
Figure 4
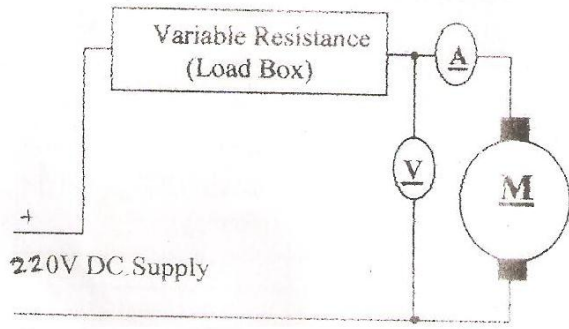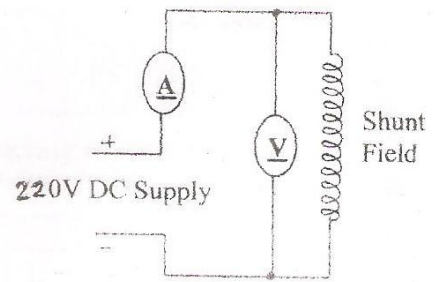
Figure 5

Observations & results :

SL NO.	MOTOR		GENERATOR			Speed of the set (rpm)	Calculated values of	
	Terminal voltage (volts)	current (amps)	Terminal voltage (volts)	Field current (amps)	Load current (amps)		Torque (N-M)	Efficiency

Calculations

Copper loss of the DC generator $= I_a^2 R + V_f . I_f$

Where,

I_a = load current of the generator
R = Armature resistance of the generator
V_f = Aplied voltage of the shunt field and
I_f = Shunt field current of the generator

Input power of generator = Output of generator + Copper loss

Windage, friction and iron losses are neglected.

Output torque of the Series motor , T is : $T = \dfrac{Input\ power\ of\ generator}{w}$

Where , w = angular speed in radians / sec. of the DC series motor. $= \dfrac{2\pi N}{60}$

N is the speed of the DC series motor.

Thus for each speed , T can be calculated.

For each value of input to the DC series motor , its effiency can be calculated thus :

$$Efficiency = \dfrac{Output\ of\ the\ motor\ (=\ input\ of\ the\ DC\ generator)}{Input\ to\ the\ motor}$$

REPORT:

5. Using the experimental data plot the following characteristics

   a) Load torque and speed.

   b) Load torque and armature current.

   c) Speed and armature current .

   d) Efficiency and armature current.

EXPERIMENT NO. 6

Polarity test on a single phase transformer

Objective:
The aim of the experiment is to conduct polarity test to determine polarity of single phase transformer.
Study of different connections of three phase transformers using three single phase transformers.

NAME PLATE DETAILS:

1Φ Transformer
Volts:
Amps:
KVA:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

Polarity test :

The polarity of any given terminal of any primary winding is determined by the supply voltage and change after every half-cycle. The instantaneous polarity of the terminals of secondary is determined by the direction of flux relative to that of primary terminals. For single – phase working of transformer it is not necessary to find out the polarity, but when two or more single-

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phase transformers are to be connected in parallel or for poly phase operation, it is essential to find the relative polarities of the winding and terminals and mark them.

Fig. 1.   Polarity Connection.

Procedure:

1. Connect the circuit diagram as shown in the fig .1
2. Note the voltmeter reading.

Observations:

At no load the induced voltages are equal to terminal voltages. If the voltmeter is Connected between the same polarities of primary and secondary, it will read $(E_1 - E_2)$, else it will read $(E_1 + E_2)$ [Fig. 2]

$E1 - E2 \Rightarrow$ Subtractive Polarity.

$E_1 + E_2 \Rightarrow$ Additive Polarity

Fig. 2. Primary and Secondary Polarities.

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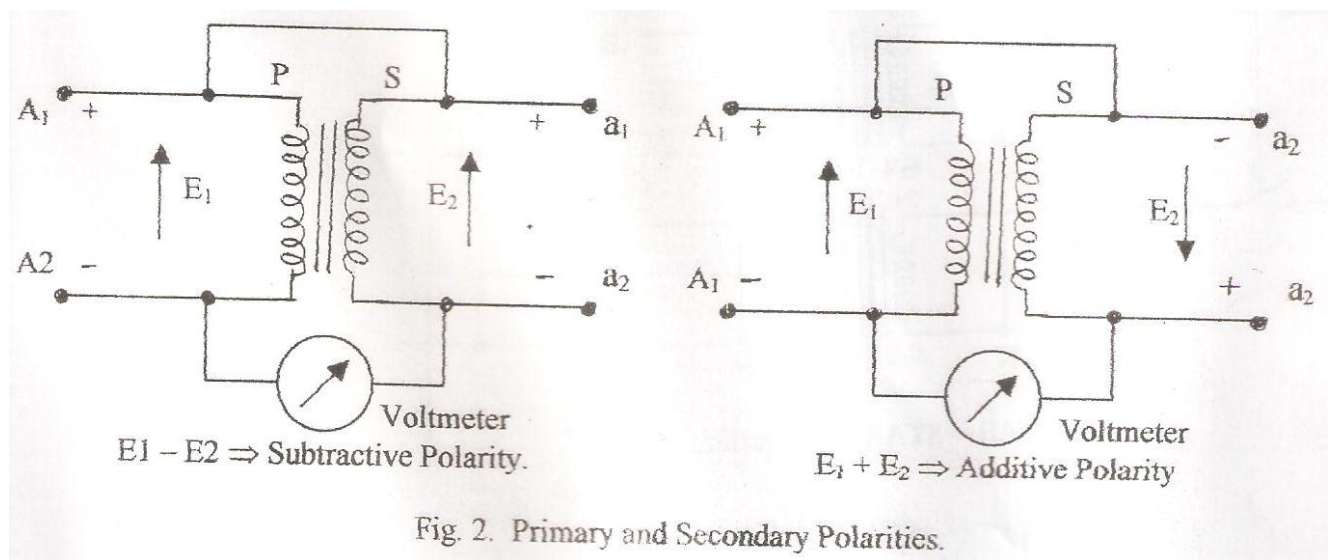
3-phase transformer connections.

When it is necessary to raise or to lower the voltage of a three-phase power supply, by means of three transformers, any one of the four combinations of connections may be used:

1. *Primary in Star and secondary in Star.*
2. *Primary in Star and secondary in Delta.*
3. *Primary in Delta and secondary in Delta.*
4. *Primary in Delta and secondary in Star.*

Theoretically, all four combinations may be made to give correct results; but in practice, in a given case, one particular combination usually has some advantages.

Windings of three-phase transformers may be connected in star or delta. Depending on the primary and secondary connections, phase shifts of 0°, +30° and 180° can be produced between the primary and secondary phase-to-neutral voltages.

Procedure:

1. Connect the circuit diagrams as shown in the connection diagram.
2. Measure the line voltages and phase voltages and tabulate as shown in Table 1(b). For a ratio '*n*' and primary line voltage V, the various phase and line voltages will be as shown in the Table 1(a).

Connection diagrams:

STAR – STAR Connection.

STAR – DELTA Connection

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DELTA – DELTA Connection

DELTA – STAR Connection.

Result:

Table 1(a) : Various Line & Phase Voltages													
		Primary Voltages						**Secondary Voltages**					
Primary connection	**Secondary connection**	V_{12}	V_{23}	V_{31}	V_{1N}	V_{2N}	V_{3N}	V_{ab}	V_{bc}	V_{ca}	V_{aN}	V_{bN}	V_{cN}
Star	*Star*	V	V	V	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$
Star	*Delta*	V	V	V	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$			
Delta	*Delta*	V	V	V				$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$			
Delta	*Star*	V	V	V				$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$

Table 1(b) : Various Line & Phase Voltages (Experimental Data)													
		Primary Voltages						**Secondary Voltages**					
Primary connection	**Secondary connection**	V_{12}	V_{23}	V_{31}	V_{1N}	V_{2N}	V_{3N}	V_{ab}	V_{bc}	V_{ca}	V_{aN}	V_{bN}	V_{cN}
Star	*Star*												
Star	*Delta*												
Delta	*Delta*												
Delta	*Star*												

REPORT:

6. Tabulate the possible Phase displacements & corresponding vector groups for Star/Delta, Star/Star, Delta/ Delta & Delta/Star connections

EXPERIMENT NO. 07

Determination of equivalent circuit of a single phase transformer and efficiency

Objective:

1. To conduct Open circuit & Short circuit test on a single phase transformer.
2. Determination of the equivalent circuit parameters and efficiency of the transformer using the test data.

NAME PLATE DETAILS:

1 φ Transformer
Volts:
Amps:
KVA:

APPARATUS USED:

SL. NO.	DESCRIPTION	RANGE/ RATING	MAKERS NAME	TAG NO/SERIAL NO
1				
2				
3				
4				
5				

.

Open circuit test

The purpose of this test is to determine the core of iron loss (w_0), no load current (I_0) and there by the parameters of the shunt branch R_0 and X_0 of the equivalent circuit .

The core loss and iron loss i.e.the no load loss in a transformer is determined by performing the no load test at normal sine wave impressed voltage . through the iron loss in a transformer is not governed by the supply being connected to primary or secondary side but when measuring this no load loss ,it is more convenient and safer from the testing personnel . to determine the shunt branch, parameter of the equivalent circuit , the primary side (L.V) is connected to a normal supply voltage and rated frequency and secondary side (H.V) terminal are kept open. The wattmeter connected in the primary , will then read the total hysteresis and eddy current loss (W_0) in the single phase transformer. Since
$VI_0\cos\phi_0=W_0$ the primary no load current is small ,the copper loss due to it can be neglected . if the supply voltage is V volts.
Where $\cos\phi$=no load power factor ,I_0=no load current
$\phi_0 = \cos^{-1}(W_0/VI)$
No load Current energy component $I_e=I_0\cos\phi_0=W_0/V$
No load Current magnetizing component $I_M=\sqrt{(I_0^2-I_e^2)}=I_0\sin\phi_0$

$R_0=V/\ I_0\cos\phi_0$
$G_0=I_0\cos\phi_0/V$
$X_0=V/I_0\sin\phi_0$
$B_0=I_0\sin\phi_0/V$

Where, R_0=shunt branch resistance
$\qquad X_0$=shunt branch reactance
B_0=shunt branch susceptance
$\qquad G_0$=shunt branch conductance
In no load test ,the shunt branch parameters (B_0=shunt branch susceptance,G_0=shunt branch conductance) are known.

Procedure

1.   Connect the circuit diagram as shown in fig. 1.
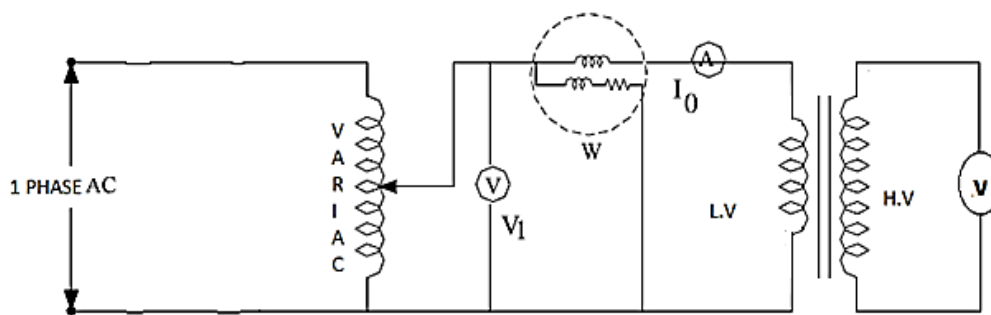
2. Figure 1 Circuit Diagram for Open – Circuit test.

3.   Set the to its minimum value and switch on the supply.

---

4.   Vary the applied voltage to the primary winding from zero to 120 % of its rated value.

5.   Record at each step the readings of all the meters.

6.   Reduce the applied voltage to zero value.

7.   Switch of the supply.

Short circuit test

The purpose of this test is to determine the full load copper loss and equivalent resistance and equivalent referred to metering side.

This test is done on a single –phase transformer to find out the series parameters of the equivalent as well as to obtained the full load copper loss. For this test fig. below terminals of the low voltage side of the transformer are short circuit and adjust the voltage (by a factor of 5 to 20 lower than the rated voltage , depending on the type of transformer) on the other side so that full load current flows , It is preferable to short circuit the voltage side (as the current rating of the side is higher). This loss during this circuit will be full load copper losses in both the primary and secondary windings , the core loss being very small and is quit negligible. Precaution is to be taken about the magnitude of applied voltage at the H.T side such that full load current is not exceeded.

Therefore , if a wattmeter (U.P.F) is connect in the supply side it will read full load copper loss of the single- phase transformer.

If ,W_s = wattmeter reading   = short circuit power . V_p = supply voltage at short circuit ,I_p= Primary current . Full load copper loss $P_c = I_S^2 R_{eq} = W_s$

Then equivalent impedance referred to the primary side is

$Z_{eq} = V_P / I_P$

Equivalent resistance referred to the primary side is

$R_{eq} = W / I_p^2$

While the equivalent reactance referred to the primary side is given by

$X_{eq}^2 = Z_{eq}^2 - R_{eq}^2$

Procedure

1. Connect the circuit diagram as shown in fig. 2. Here the low – voltage winding is short – circuited by a having negligible resistance and good contacts. Preferable by an ammeter .
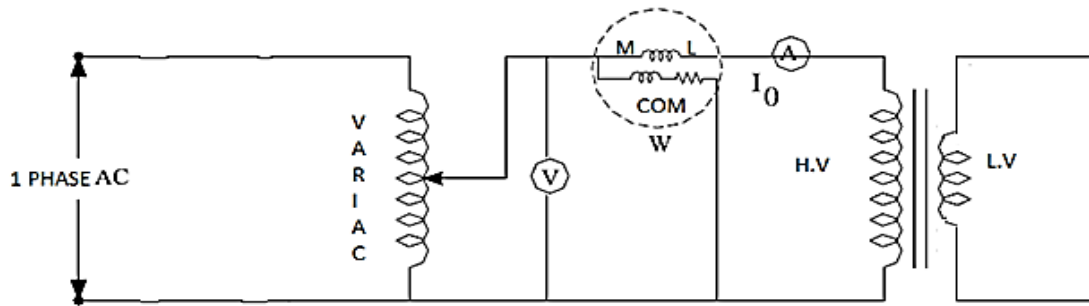
Figure : 2 Circuit Diagram for Short – circuit test.

2. Set the to its minimum value and switch on the supply.

3. Maintain the supply frequency constant ; increase the variable supply voltage from zero, in small step to a value until the rated primary current (this will imply rated secondary current as well) is reached.

4. Note the reading of all the meters.

5. Reduce the applied voltage to zero value.

6. Switch off the supply.

Observation table:

TABLE -1 (FOR OPEN CIRCUIT TEST)

Primary voltage(V)	Input current (I_0)	Input power (W_0)	Active current (I_e)	Magnetizing current (I_m)	R_0	X_0	Secondary voltage (V)

TABLE -2 (FOR SHORT CIRCUIT TEST)

Primary Voltage (V_p)	Primary Current (I_p)	Short circuit power (W_S)	Req. $= W/ I_p^{\,2}$	Xeq $= \sqrt{Z_{eq}^2 - R_{eq}^2}$	Zeq $= V_P / I_P$

REPORT :-

1. Using test data determine the equivalent circuit parameters. Draw the equivalent circuit diagram.

2. Plot the variation of no load power with primary voltage and hence find the core loss at rated voltage.

EXPERIMENT NO. 8

Study of different connections of three phase transformer

Objective:
Study of different connections of three phase transformers using three single phase transformers.

NAME PLATE DETAILS:

1Φ Transformer
Volts:
Amps:
KVA:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

Polarity test:

The polarity of any given terminal of any primary winding is determined by the supply voltage and change after every half-cycle. The instantaneous polarity of the terminals of secondary is determined by the direction of flux relative to that of primary terminals. For single – phase working of transformer it is not necessary to find out the polarity, but when two or more single-phase transformers are to be connected in parallel or for poly phase operation, it is essential to find the relative polarities of the winding and terminals and mark them.
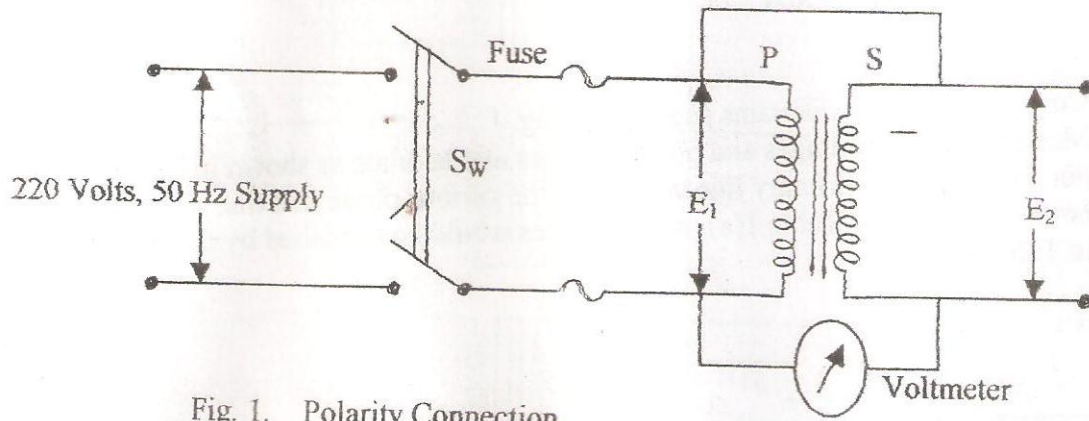
Fig. 1.   Polarity Connection.

Procedure:

3. Connect the circuit diagram as shown in the fig .1
4. Note the voltmeter reading.

Observations:

At no load the induced voltages are equal to terminal voltages. If the voltmeter is Connected between the same polarities of primary and secondary, it will read $(E_1 - E_2)$, else it will read $(E_1 + E_2)$ [Fig. 2]
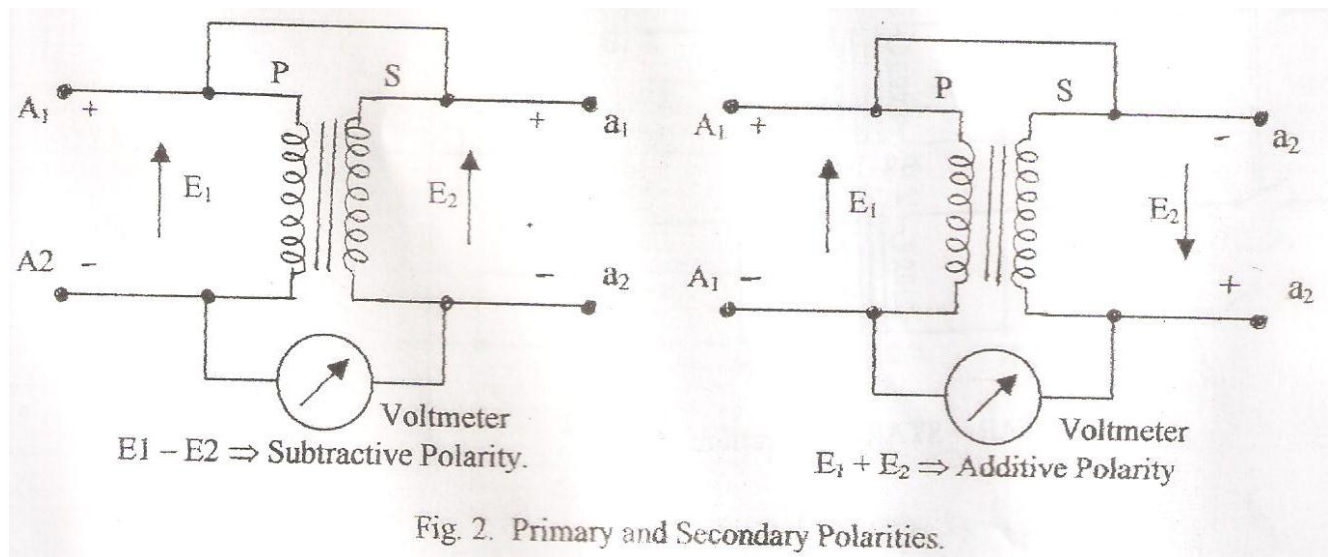
Fig. 2. Primary and Secondary Polarities.

3-phase transformer connections.

When it is necessary to raise or to lower the voltage of a three-phase power supply, by means of three transformers, any one of the four combinations of connections may be used:

5. *Primary in Star and secondary in Star.*
6. *Primary in Star and secondary in Delta.*
7. *Primary in Delta and secondary in Delta.*
8. *Primary in Delta and secondary in Star.*

Theoretically, all four combinations may be made to give correct results; but in practice, in a given case, one particular combination usually has some advantages.

Windings of three-phase transformers may be connected in star or delta. Depending on the primary and secondary connections, phase shifts of 0°, +30° and 180° can be produced between the primary and secondary phase-to-neutral voltages.

Procedure:

3. Connect the circuit diagrams as shown in the connection diagram.
4. Measure the line voltages and phase voltages and tabulate as shown in Table 1(b). For a ratio '*n*' and primary line voltage V, the various phase and line voltages will be as shown in the Table 1(a).

Connection diagrams:
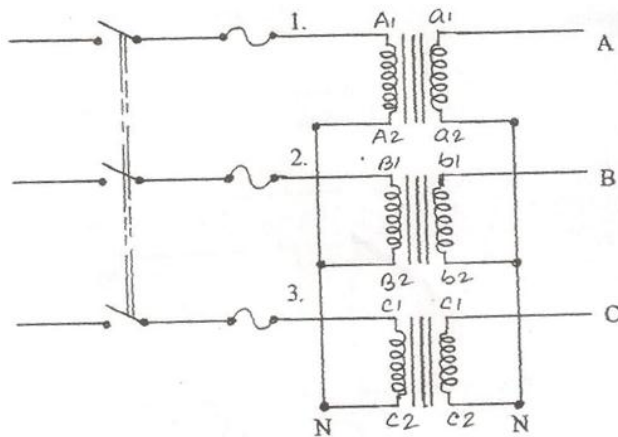
STAR – STAR Connection.
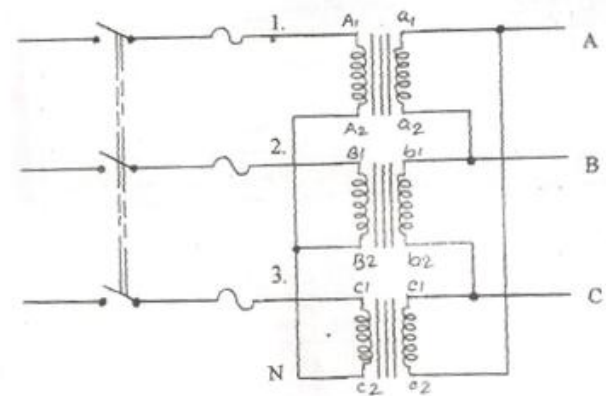
STAR – DELTA Connection

DELTA – DELTA Connection

DELTA – STAR Connection.

Result:

Table 1(a) : Various Line & Phase Voltages													
		Primary Voltages						Secondary Voltages					
Primary connection	Secondary connection	V_{12}	V_{23}	V_{31}	V_{1N}	V_{2N}	V_{3N}	V_{ab}	V_{bc}	V_{ca}	V_{aN}	V_{bN}	V_{cN}
Star	*Star*	V	V	V	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$
Star	*Delta*	V	V	V	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$			
Delta	*Delta*	V	V	V				$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$			
Delta	*Star*	V	V	V				$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$	$\dfrac{V}{n\sqrt{3}}$

Table 1(b) : Various Line & Phase Voltages (Experimental Data)													
		Primary Voltages						Secondary Voltages					
Primary connection	Secondary connection	V_{12}	V_{23}	V_{31}	V_{1N}	V_{2N}	V_{3N}	V_{ab}	V_{bc}	V_{ca}	V_{aN}	V_{bN}	V_{cN}
Star	*Star*												
Star	*Delta*												
Delta	*Delta*												
Delta	*Star*												

REPORT:

7. Tabulate the possible Phase displacements & corresponding vector groups for Star/Delta, Star/Star, Delta/ Delta & Delta/Star connections

EXPERIMENT NO. 9

Study of Parallel operation of a single phase transformers

Objective:
To understand the operation of transformers in parallel

NAME PLATE DETAILS:

1Φ Transformers
Volts:
Amps:
KVA:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

<u>Theory:</u>

A power transformer is one of the most vital and an equally expensive component in a power system. It may so happen that, over time, due to load growth in its service area, an existing transformer may not be able to withstand the demand during peak-hours without exceeding its long-term MVA rating. Operating a transformer in such a fashion would cause overheating and degrade its expected life. In most cases, instead of commissioning an entirely new higher capacity unit, a more viable alternative exists in adding a smaller unit in parallel to complement the existing one. In other words, a new smaller capacity transformer can now be connected in parallel to the existing one such that the two shares a large peak load in a specific proportion and the one

operating near limits is relieved of the burden. Also, during light load conditions, the additive capacity can be kept offline, if desired.
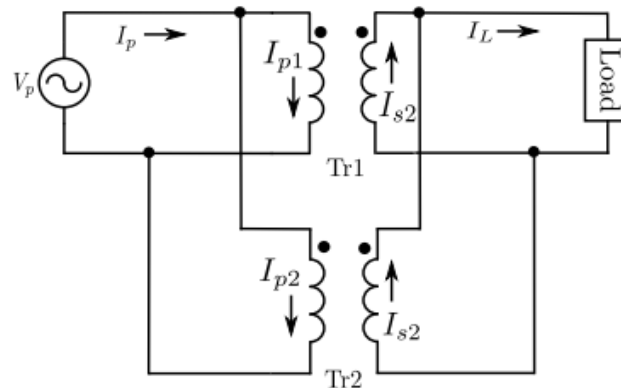
Fig. 1: Two single-phase Transformers in Parallel

Necessary Conditions:

- *The polarities of corresponding primary and secondary terminals of the two transformers must be same*

Referring to Fig.1, if the said condition is not satisfied and the back emfs at the secondary windings have opposite polarities at the dots, the windings form a closed electric circuit with two voltage sources of equal magnitude connected in series additively. This results in a very high circulating current limited only by the winding resistance which is very small. Hence it is imperative to conduct a polarity test on the two transformers to establish identical winding polarities

- *The no-load primary and secondary voltages of the two transformers should match closely in magnitude as well as in phase*

On similar lines with the previous condition, if the no-load transformer voltages are not equal in magnitude and phase, a closed electric circuit with a voltage source equal to the difference of instantaneous secondary voltages is formed and circulating currents are established even before loads are connected. The circulating currents get reflected on the primary side as well. The more the phasor difference, more is the circulating current. Hence it is advisable to conduct a test to verify the no-load rated voltages of the two transformers.

- *The per unit impedances of two transformers on their respective Z_{bases} must be equal if the transformers have to share the load in proportion to their ratings*

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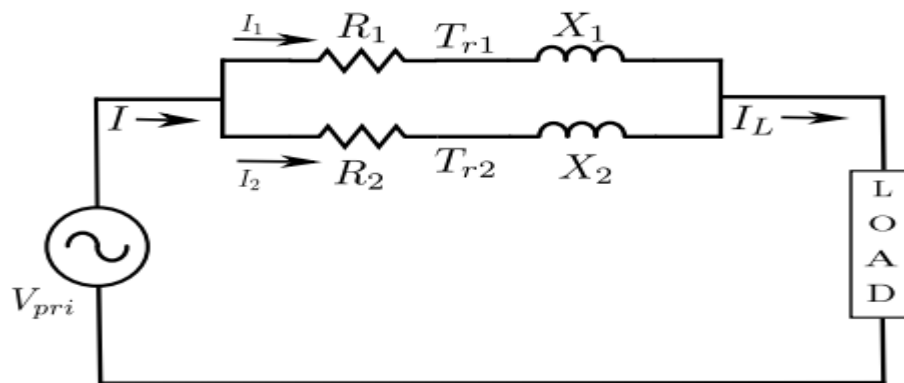
Fig. 2: Equivalent Circuit of Two Single-phase Transformers in Parallel

Fig.2. In this figure, the equivalent circuit of transformer is shown with all quantities referred to the primary side. Also note that all quantities are in complex numbers unless specified otherwise.
$I_L = I_1 + I_2$

$I_1 = Z_2 / Z_1 + Z2 * I_L$

$I_2 = Z_1 / Z_1 + Z_2 * I_L$ where, $Z = R + jX$

Consider two transformers of different KVA ratings connected in parallel with the same voltage ratings. It is desirable that they share the load in proportion of their MVA ratings. Hence we have in absolute scale (not in per unit),

$S_1 */S_2 *=V_1*I_1/V_2*I_2$

Procedure:

For each of the transformers, note down the name plate ratings and determine the rated currents for both the windings. The two units must have identical voltage ratings or the same transformation ratio. Also, it is assumed that we have the leakage impedance parameters determined for each unit through short-circuit tests already performed. A. First, perform the polarity test on each of the units and label or note down terminals with the same polarity B. Also, confirm that no-load secondary voltages of both transformers match in magnitude. If possible, also check the respective instantaneous phase angles. Note: It is important to perform both these tests before attempting the parallel operation. C. Perform the SC test to find out leakage impedance parameters of the two transformers. Attempt to calculate the power sharing analytically using equivalent circuit of transformer. D. With the primaries in unenergized state, connect a common load across the transformer secondaries, with the load kVA rating not exceeding the total kVA rating of the two units. E. Slowly increase the autotransformer voltage until rated voltage appears across the primaries of each transformer.

Observation:

Sl. No	Primary current		Secondary current		Load current	Load voltage
	T1	T2	T1	T2		

- **Calculation of active, reactive and apparent power delivered to the load by each unit**
- **Determination of power sharing between the two units**

REPORT:

1. Calculate the circulating current in two paralleled single-phase transformers with leakage impedance 5% each and no-load voltage difference of 1%. Express in percentage of full load current.

EXPERIMENT NO. 10

DETERMINATION OF TEMPARATURE RISE AND EFFICIENCY OF THE TRANSFORMER(BACK TO BACK TEST)

OBJECTIVE: To conduct the Sumpner's test, or Back to Back test on two identical transformers to predetermine their efficiency.

APPARATUS REQUIRED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

NOTE: Use 2 similar rating transformers.

PROCEDURE:

1.Connections are made as shown in the circuit diagram (9).

2.By keeping the 1-Φ auto-transformers (1) and (2) in zero out-put positions, SPST switch (S_3) and DPST switch (S_2) in open positions, the supply switch (S_1) is closed.

3. Vary the 1-Φ auto-transformer no-(1) gradually and apply the rated voltage of the transformer. [say 230V]

4. The reading of voltmeter (V_2) connected across the SPST switch (S_3) is observed. It should read zero; if not, the auto-transformer is brought back to its initial zero out-put position, open the supply switch (S_1) and interchange one of the transformer's secondary terminals.

5.Close the supply switch (S_1), repeat step no-3. Close SPST switch (S_3). (By ensuring voltmeter (V_2) reads zero). The watt-meter (W_0), voltmeter (V_1) and ammeter (I_1) readings are noted down.

6.Switch (S_2) is closed and by operating the auto-transformer (2) very slowly, a low voltage is applied such that rated current flows through the transformer. The wattmeter (W_{CU}) and ammeter (I_2) readings are noted down.

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7. The auto-transformers (2) and then (1) are brought back to their initial zero out- put positions, the DPST switch (S_2), SPST switch (S_3), and supply switch (S_1) are opened.

TABULAR COLUMN:

Sl. No	V_1 (Volts)	I_1 (Amps)	W_o (Watt)	I_2 (Amps)	W_{cu} (Watt)

NOTE: $W_0 = (K_1 \times$ Wattmeter Reading$)$

Where, $K_1 = \dfrac{Vsol \; x \; Isol \; x \; COS\emptyset}{Full \; Scale \; Deflection}$

$W_{cu} = (K_2 \times$ Wattmeter Reading$)$

Where, $K_2 = \dfrac{Vsol \; x \; Isol \; x \; COS\emptyset}{Full \; Scale \; Deflection}$

MODEL GRAPH:

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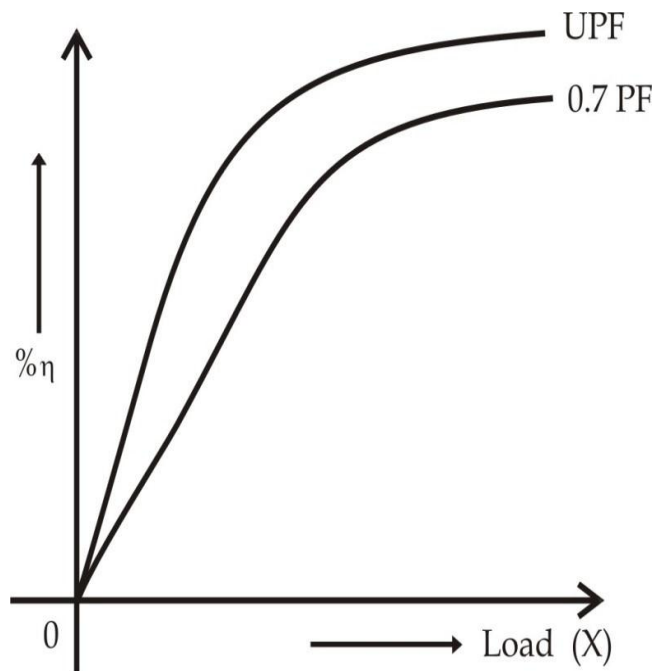
CALCULATION:

Rated current of Transformer $= \dfrac{KVA\,X1000}{Rated\,Voltage}$

Total Iron loss in both transformers = W_i = _____ Watt

Iron loss in each transformer = $W_{i/2}$ = $\dfrac{Wi}{2}$

Full load total Copper loss of both transformers = W_{cu} = _____ Watt

Full load Copper loss of each transformer = $W_{CU/2}$ = $\dfrac{Wcu}{2}$ = _____ Watt

a. For combined efficiency (ŋ)

% η= $\left(\dfrac{SXCOSøX1000}{SXCOSøX1000+Wi+x^2Wcu}\right)$

Then, % η= $\left(\dfrac{Output}{Output+Total\,LOsses}\right)$

NOTE: S = Rating of the transformer in KVA (i.e., 2 KVA is used here)

{S = 4:-for combined efficiency of transformers.

S = 2:-for efficiency of each transformer.}

b. For individual efficiency (ŋ)

$$\% \; \eta = \left(\frac{SXCOS\phi X1000}{SXCOS\phi X1000 + W_{i/2} + x^2 W_{Cu/2}} \right)$$

Therefore, $\% \; \eta = \left(\frac{Output}{Output + Total\;LOsses} \right)$

Combined efficiency (ŋ)

Sl. No	x (Load)	pf	% ŋ
01.	1		
02.	¾	UPF	
03.	½		
04.	¼		
05.	1		
06.	¾	0.7	
07.	½		
08.	¼		

Individual efficiency(ŋ)

Sl. No	x (Load)	pf	% ŋ
01.	1		
02.	¾	UPF	
03.	½		
04.	¼		
05.	1		
06.	¾	0.7	
07.	½		
08.	¼		

Circuit Diagram (9)
SUMPNER'S TEST

LABORATORY INSTRUCTION MANUAL

ELECTRICAL MACHINES-II LAB PC-EE- 591

DEPARTMENT OF ELECTRICAL ENGINEERING

SILIGURI INSTITUTE OF TECHNOLOGY

General Information

All assigned experiments must be performed in order to pass the class. Most of the work for an experiment should be done during class time in the laboratory. In order to allow for further analysis and graphing, the notebooks are due at the start of the laboratory the following week. Submit your completed notebook to the instructors Evaluation of laboratory performance is based on the instructor's observations of you while you are performing the experiments. Among the factors considered are your ability to construct circuits, your competency in using test equipment, your preparation prior to starting the experiment, answers given to any questions asked during the laboratory, as well as attendance, tardiness, and attitude. Keep in mind that your behaviour influences your grade; act professionally at all times.

The following guidelines should be followed when using your notebook:

- The first page should contain a table of contents.
- All pages in the notebook must bound, numbered and dated.
- Use a pen or permanent marker, never pencil.
- Write legibly and coherently. Extreme neatness is not required but anyone should be able to read and understand what you have written.
- Never erase errors or remove pages. Simply draw a line through any mistakes.
- The notebook should be a complete record of your work, i.e. what you actually do in the laboratory, and sufficiently detailed that a knowledgeable person could reconstruct what you did.
- All measurements, notes, and calculations should be directly recorded in the notebook. Never write information on scraps of paper for later transcription into the notebook.
- Do not paste the laboratory manual into your notebook
- Any graphs or printouts relevant to the experiment should be pasted into your notebook.
- Be sure to label all diagrams, schematics, graphs, and waveform printouts.
- All numbers should include appropriate units.
- Include an equipment list.

Electrical Engineering Laboratory Regulations

General

Students working the electrical laboratories should be very cautious during the lab work. The electric potentials used in many experiments are dangerous and may cause injury. Students must observe all safety precautions and must not work alone with potentials exceeding 25 V. The rotating machines used in some experiments are dangerous. Keep loose clothing, jewellery, and other objects away from any rotating parts.

Food and drinks are not permitted in the laboratories.

Equipment

All equipment must be returned to its proper storage location at the end of the lab period. Instruments and equipment are delicate and expensive. Improper use of equipment can result in instantaneous damage; check with you instructor or the equipment's manual if you are in doubt.

Damaged or faulty equipment should be given to the technicians/instructor along with a description of the problem.

Vision of Institute

To be a recognized institution offering high quality education, opportunities to students to become globally employable Engineers/Professionals in best ranked industries and research organization.

Mission of Institute

To impart quality technical education for holistic development of students who will fulfil the needs of the industry/society and be actively engaged in making successful career in industry/research/higher education in India & abroad.

Vision of the Department

To emerge as a leading Department of Electrical Engineering that caters to the latest needs of power sector, electrical & allied industry in the region.

Mission of the Department

To evolve as an innovative & globally competent Electrical Engineering department that contributes to the socio - economic growth of region by utilizing the advancement in Electrical Engineering by providing conducive learning and interactive environment to students and faculty.

LAB PEROFRMANCE RUBRICS

Lab performance for each experiment is done in the following way:

```
Lab Performance Evaluation
├── Lab Report (30/3=10
│   ├── PI 1(10)
│   ├── PI 2 (10)
│   └── PI 3 (10)
├── Lab Performance
│   ├── PI 1(10)
│   ├── PI 2 (10)
│   ├── PI 3 (10)
│   └── PI 4 (10)
└── Attendance (10
```

PI stands for Performance Indicators.

Performance Indicators for Evaluation of Lab Report		Inadequate (0 -4)	Average (5-6)	Admirable (7-8)	Outstanding (9-10)
		1	2	3	4
PI 1	Timely Submission	Student is not disciplined at all in submitting the lab report	Student is fairly disciplined in submitting the lab report in time to time	Student is disciplined in submitting the lab report in time to time	Student is very much disciplined regarding the submission of lab report in time to time.
PI 2	Organization and Preparation of Report	Organization and Preparation of report is not good at all.	Organization and preparation of report is not up to the mark.	Organization and preparation of report is good.	Organization and preparation of report is very good.
PI 3	Results and Conclusions	Result and conclusion obtained by the student is wrong.	Result and conclusion obtained by the student is satisfactory.	Result and conclusion obtained by the student is good.	Result and conclusion obtained by the student is very good.

Performance Indicators for Lab Performance monitoring		Inadequate (0 -4)	Average (5-6)	Admirable (7-8)	Outstanding (9-10)
		1	2	3	4
PI 1	Participation and regularity	The attendance record of the student in the lab is poor.	The attendance record of the student in the lab is average.	The attendance record of the student in the lab is good.	The attendance record of the student in the lab is very good.
PI 2	Safety Procedures and direction	Demonstration of safety procedure and direction is poor.	Demonstration of safety procedure and direction is average.	Demonstration of safety procedure and direction is good.	Demonstration of Safety procedure and direction is very good.
PI 3	Ability to Work in a Group	Ability to work in a group is poor.	Ability to work in a group is average.	Ability to work in a group is good.	Ability to work in a group is very good.
PI 4	Lab Techniques	The way and approach of demonstration of lab techniques is poor.	The way and approach of demonstration of lab techniques is average.	The way and approach of demonstration of lab techniques is good.	The way and approach of demonstration of lab techniques is very good.

LIST OF EXPERIMENTS WITH CONTACT HOURS
Subject with code: ELECTRIC MACHINE LABORATORY-I (PC-EE 591)
Semester : 5th
Discipline :- Electrical Engineering

Exp. No.	Details of Experiment(s)	Hours allotted
1	Different methods of starting of a 3 phase Cage Induction Motor & their comparison [DOL, Auto transformer & Star-Delta]	3
2	Study of equivalent Circuit of 3 Phase Induction Motor by no load and blocked rotor test.	3
3	Study of performance of wound rotor Induction motor under load.	3
4	Study of performance of 3 phase squirrel cage induction motor – determination of iron loss, friction & windage loss.	3
5	Speed control of 3 phase squirrel cage induction motor by different methods & their comparison [voltage control & frequency control]	3
6	Speed control of 3 phase slip ring Induction motor by rotor resistance Control.	3
7	Determination of regulation of Synchronous machine a. Potier reactance method. b. Synchronous Impedance method.	3
8	Determination of equivalent circuit parameters of a single phase Induction motor.	3
9	Load test on single phase Induction motor to obtain the performance characteristics.	3
10	To determine the direct axis resistance [Xd] & quadrature axis reactance [Xq] of a 3 phase synchronous machine by slip test	3
11	Load test on wound rotor Induction motor to obtain the performance characteristics.	3
12	To make connection diagram to full pitch & fractional slot winding of 18 slot squirrel cage Induction motor for 6 poles & 4 pole operation .	3
13	To study the performance of Induction generator.	3
14	Parallel Operation of 3 Phase Synchronous Generator.	3
15	V-curve of Synchronous motor.	3

Expt. No.	Experiment Name	Schedule	Marks
1.	Different methods of starting of a 3 phase Cage Induction Motor & their comparison [DOL, Auto transformer & Star-Delta]	3 hours	40 marks
2.	Study of equivalent Circuit of 3 Phase Induction Motor by no load and blocked rotor test.	3 hours	
3.	Study of performance of wound rotor Induction motor under load.	3 hours	
4.	Study of performance of 3 phase squirrel cage induction motor – determination of iron loss, friction & windage loss.	3 hours	
5.	Speed control of 3 phase squirrel cage induction motor by different methods & their comparison [voltage control & frequency control]	3 hours	
6.	Speed control of 3 phase slip ring Induction motor by rotor resistance Control.	3 hours	
7.	Determination of regulation of Synchronous machine a. Potier reactance method. b. Synchronous Impedance method.	3 hours	
8.	Determination of equivalent circuit parameters of a single phase Induction motor.	3 hours	
9.	Load test on single phase Induction motor to obtain the performance characteristics.	3 hours	
10.	To determine the direct axis resistance [Xd] & quadrature axis reactance [Xq] of a 3 phase synchronous machine by slip test	3 hours	
11.	Load test on wound rotor Induction motor to obtain the performance characteristics.	3 hours	
12.	To make connection diagram to full pitch & fractional slot winding of 18 slot squirrel cage Induction motor for 6 poles & 4 pole operation .	3 hours	
13.	To study the performance of Induction generator.	3 hours	
14.	Parallel Operation of 3 Phase Synchronous Generator.	3 hours	
15.	V-curve of Synchronous motor.	3 hours	
	University Exams		60 marks

Name   :

Department / Sem   :

Roll No.   :

<u>Performance indicators</u>

PI 1 : Participation & Regularity
PI 2 : Lab Techniques
PI 3 : Safety Procedures & Directions
PI 4 : Ability to work in a group

PI 1 : Timely Submission
PI 2 : Organization & Preparation of report
PI 3 : Results & Conclusions

DATE	EXPERIMENT NO.	PI 1	PI 2	PI 3	PI 4	TOTAL	PI 1	PI 2	PI 3	TOTAL	SIGNATURE OF TEACHER	REMARKS

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Utech

LIST OF CONDUCTED EXPERIMENTS

i.   Different methods of starting of a 3 phase Cage Induction Motor & their comparison [DOL, auto transformer & Star-Delta]

ii.   Study of equivalent circuit of 3 phase Induction Motor by no load and blocked rotor test.

iii. Study of performance of wound rotor induction motor under load.

iv.   Study of performance of 3 phase squirrel cage Induction Motor – determination of iron loss, friction & windage loss.

v.   Speed control of 3 phase squirrel cage induction motor by different methods & their comparison [voltage control & frequency control].

vi.   Speed control of 3-Φ Slip ring Induction Motor by rotor resistance control

vii. Determination of regulation of Synchronous Machine by:
       a. Potier reactance method.
       b. Synchronous Impedance method.

viii. Determination of equivalent circuit parameters of a 1-Φ Induction Motor.

ix.   Load test on 1-Φ Induction Motor to obtain the performance characteristics.

x.   To determine the direct axis reactance [X_d] & quadrature reactance [X_q] of a 3-Φ synchronous machine by slip test.

xi.   Load test on 3-Φ Wound Induction Motor to obtain the performance characteristics.

xii. To make connection diagram for full pitch & fractional slot winding of 18 slot 3-Φ Squirrel Cage Induction Motor for 6-pole & 4-pole

operation.
xiii. To study the performance of Induction generator.
xiv. Parallel operation of 3-Φ synchronous generators.
xv. V-curve & Inverted V-curve of synchronous motors.

The Students can able to develop the following skills from Electrical Machines-II Lab (PC-EE-591) Laboratory:

Skills	Experiments											
	1	2	3	4	5	6	7	8	9	10	11	12
Acquire sound knowledge of different types of starting of 3-phase induction motor and a comparative performance study.	√			√								
The students will be able to demonstrate different kinds of speed control (voltage and frequency control) arrangement of 3-phase squirrel-cage induction motor.		√	√		√							
The students will be able to demonstrate the speed control arrangement of 3-phase slip ring induction motor.			√		√							
The students will be able to determine the voltage regulation of an alternator by various methods (EMF method, ZPF method) and justify the performance.						√	√					
The students will be able to analyze the equivalent circuit of a single Phase induction motor and identify the different losses of the machine.							√					
The students should demonstrate the process of synchronization of alternators.								√		√		
The students acquire the skill to verify the performance of an induction generator.									√			
The students should monitor the performance of a synchronous motor by the representation of V-curve and inverted V-curve.										√		
Can work in a team and improve communication skills.	√	√	√	√	√	√	√	√	√	√	√	√
Improves technical report writing skill.	√	√	√	√	√	√	√	√	√	√	√	√

Siliguri Institute of Technology

Department of Electrical Engineering

Contributions to the Electrical Machines Lab

Mid 2017	Mr. Niladri Chakraborty, Ms. Shreya Shree Das and Prof. C. Sain jointly upgraded the lab manuals and tested all the experiments related with Electrical Machines-II Lab.
Early 2017	Prof. C. Sain, Mr. Niladri Chakraborty, Prof. M. Basu Das taken care about the annual maintenance of the entire laboratories, tested some faulty machines and initiated to repair the same. Mr. Niladri Chakraborty also upgraded the stock registrar of all the machineries. Prof. C. Sain and Mr. N. Chakraborty jointly developed one experimental set-up of Universal Motor beyond the syllabus.
Mid 2016	Mr. Ananta Biswas, Mr. Niladri Chakraborty and Prof. Chiranjit Sain jointly upgraded the lab manuals and taken care about some maintenance.
Early 2016	Prof. Dipak Bhattacharjee, Prof. Chiranjit Sain and Mr. Ananta Biswas upgraded and restructured some of the lab manuals and tested some faulty machines.
Mid 2015	Mr. Souvik Das maintained the detailed stock register of the laboratory and time to time provides feedback. Mr. Nilkamal Das maintained some necessary documentations regarding procurement/purchase of laboratory and also updated students' performance evaluation report.
Early 2015	Mr. Ananta Biswas, Mr. Niladri Chakraborty, Prof. Dipak Bhattacharjee and Prof. Chiranjit Sain provided assistance during the annual maintenance of the laboratory.
Mid 2014	Prof. Dipak Bhattacharjee gave valuable feedback and encouragement from his stint as a tutor for this lab.
Early 2013	Mr. Ananta Biswas and Mr. Niladri Chakraborty tested some faulty machines and repaired.
Mid 2012	Mr. Jayanta Bhsan Basu and Mrs. Moushumi Basu Das designed and upgraded all the necessary lab manuals as per the upgraded machinery.
Early 2011	Prof. Dipak Bhattacharjee and Prof. Chiranjit Sain upgraded two experimental set-ups of DC Machines.
Early 2010	Mr. Chiranjit Sain and Mr. Niladri Chakraborty jointly participated for the throughout maintenance of this laboratory.

Siliguri Institute Of Technology

Department of Electrical Engineering

Laboratory Workbook for Electrical Machines-II Laboratory (PC-EE 591)

INDEX

Expt. no.	Title of the experiment	Date of experiment	Date of report submission	Page no.	Signature of Teacher

Title Sheet

Laboratory workbook for Electrical Machines-II Lab (PC-EE 591)

Experiment no.   :

Description   :

Date of Performance   :

Date of Submission   :

Name   :

Department / Sem:

Roll No.   :

Signature of the Student

Siliguri Institute of Technology

Department of Electrical Engineering

REPORT ON

Electrical Machines-II Lab (PC-EE 591)

Name   :

Department   :

Semester   :

Roll No.   :

ELECTRICAL MACHINES LAB- II

Code: PC-EE-591

<u>List of Experiments</u>

1. Different methods of starting of 3-Φ Squirrel Cage Induction Motor & their comparison (DOL, Auto-Transformer & Star-Delta).
2. Study of equivalent Circuit of 3 phase Induction Motor by no load and blocked rotor test.
3. Study of performance of wound rotor Induction Motor under load.
4. Study of performance of 3 phase squirrel cage Induction Motor – determination of iron loss , friction loss, friction & windage loss.
5. Speed control of 3-Φ Squirrel Cage Induction Motor by different methods & their comparison(Voltage Control& Frequency Control).
6. Speed control of 3-Φ Slip ring Induction Motor by rotor resistance control.
7. Determination of regulation of Synchronous Machines by:
    a. Potier reactance method
    b. Synchronous Impedance method
8. Determination of equivalent circuit parameters of a 1-Φ Induction Motor.
9. Load test on 1-Φ Induction Motor to obtain the performance characteristics.
10. To determine the direct axis reactance & quadrature reactance of a 3-Φ synchronous machine by slip test.
11. Load test on3-Φ Wound Induction Motor to obtain the performance characteristics.
12. To make connection diagram for full pitch & fractional slot winding of 18 slot 3-Φ Squirrel Cage Induction Motor for 6-pole & 4-pole operation.
13. To study the performance of Induction generators.
14. Parallel operation of 3-Φ synchronous generators.
15. V-curve of synchronous motors.

Experiment No. 1

EXPERIMENT:DIFFERENT METHODS OF STARTING OF A 3 PHASE CAGE INDUCTION MOTOR & THEIR CONPARISON[DOL, AUTO TRANSFORMER]

Objective: To study the different types of starting & running procedure of a 3-Φ Squirrel Cage Induction Motor using:

    i.   Star- Delta Starter
   ii.   D.O.L. Starter
  iii.   Auto- Transformer Starter

NAME PLATE DETAILS:

APPARATUSUSED:

Sl. No.	Description	Range/ Rating	Maker's Name	Tag No./ Serial No.

THEORY

In order to limit the high inrush of current in a 3-Φ Squirrel Cage Induction Motor at the starting, several methods are employed. The method includes:

   a.   D.O.L. starting
   b.   Star- Delta starting
   c.   Auto-transformer starting

D.O.L. Starting

This is the simplest type of starting method where full line voltage is imposed across the stator & are generally employed for small motors (output of nearly 1.5kW). The Direct on Line Motor Starter (DOL) consist a MCCB or Circuit Breaker, Contactor and an overload relay for

protection. The Electromagnetic contactor can be opened by the thermal overload relay under fault conditions.

Typically, the contactor will be controlled by separate start and stop buttons, and an auxiliary contact on the contactor is used, across the start button, as a hold in contact, i.e. the contactor is electrically latched closed while the motor is operating.

Star Delta Starting

In this case, at the starting instant stator winding are connected in star so that the voltage across it is 0.577 times the line voltage& thus lower will be the starting current. But after it starts running, a mechanism is such developed that stator winding are now connected in delta so that the voltage across it is equals the line voltage. With this type of starting, starting torque reduces to 1/3 of that obtained from direct switching. This method is employed for starting 3-Φ Squirrel Cage Induction Motor of rating between 4-20kW.

Auto-transformer starting

In this method of starting, reduced voltage is obtained by taking tapping at suitable points from 3-Φ autotransformer operating either manually or magnetically which results the decreased starting current. With this type of starting, starting torque reduces as square of transformation ratio that is obtained from direct switching. This method is employed for starting 3-Φ Squirrel Cage Induction Motor of large rating (output greater than 20kW).

PROCEDURE

For D.O.L. Starter:

  i.   Connection is done as shown in the wiring diagram.
  ii.   Connect the motor terminal (i.e. the stator terminals) to the 3-Φ supply.
  iii.   Switch on the supply & press START (Green) Button to start the motor.
  iv.   All the readings are recorded in the table.

For Star-Delta starter:

  i.   Connection is done as shown in the wiring diagram.
  ii.   Throw the handle to 'Start' position& switch on the supply to start the motor with star-connected stator.
  iii.   Note the readings in the table.
  iv.   Now throw the handle to 'Run' position as the motor gains speed so that stator becomes delta-connected.
  v.   Note the readings in the table.

For Auto-transformer starter:

i.   Connection is done as shown in the wiring diagram.
ii.   Throw the handle to 'Start' position & switch on the supply to start the motor with reduced voltage provided through the tapping of auto-transformer.
iii. Note the readings in the table.
iv.   Throw the handle to 'Run' position so that the motor can be provided with full line voltage across its stator.
v.   Note the readings in the table.

CONNECTION DIAGRAM

Wiring diagram of DOL Starter for 3-Φ Squirrel Cage Induction Motor
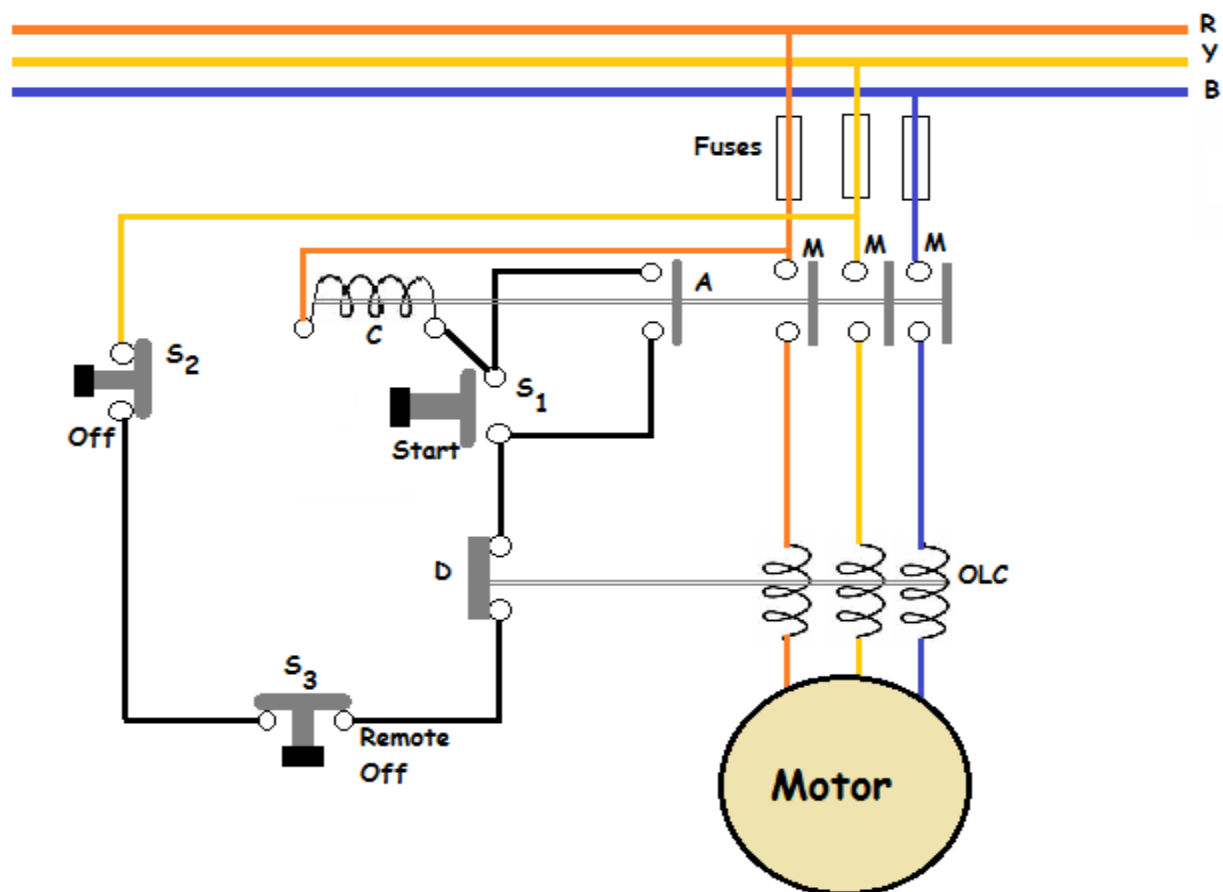
Direct On Line (DOL) Starter Wiring Diagram

Wiring diagram of Star-Delta Starter for 3-Φ Squirrel Cage Induction Motor
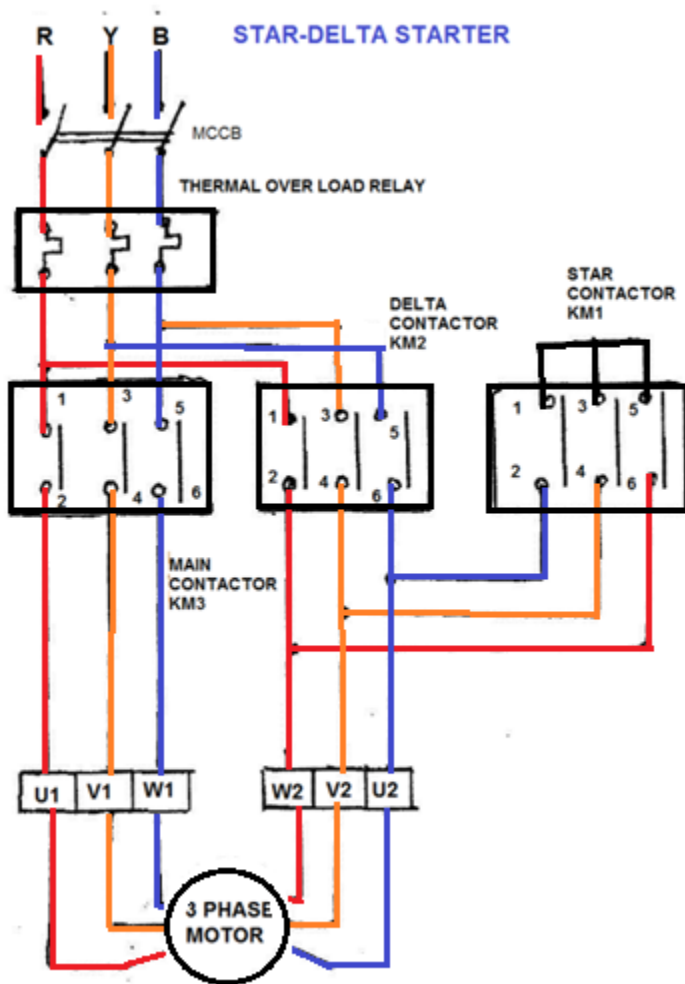
Wiring diagram of Auto-Transformer Starter for 3-Φ Squirrel Cage Induction Motor
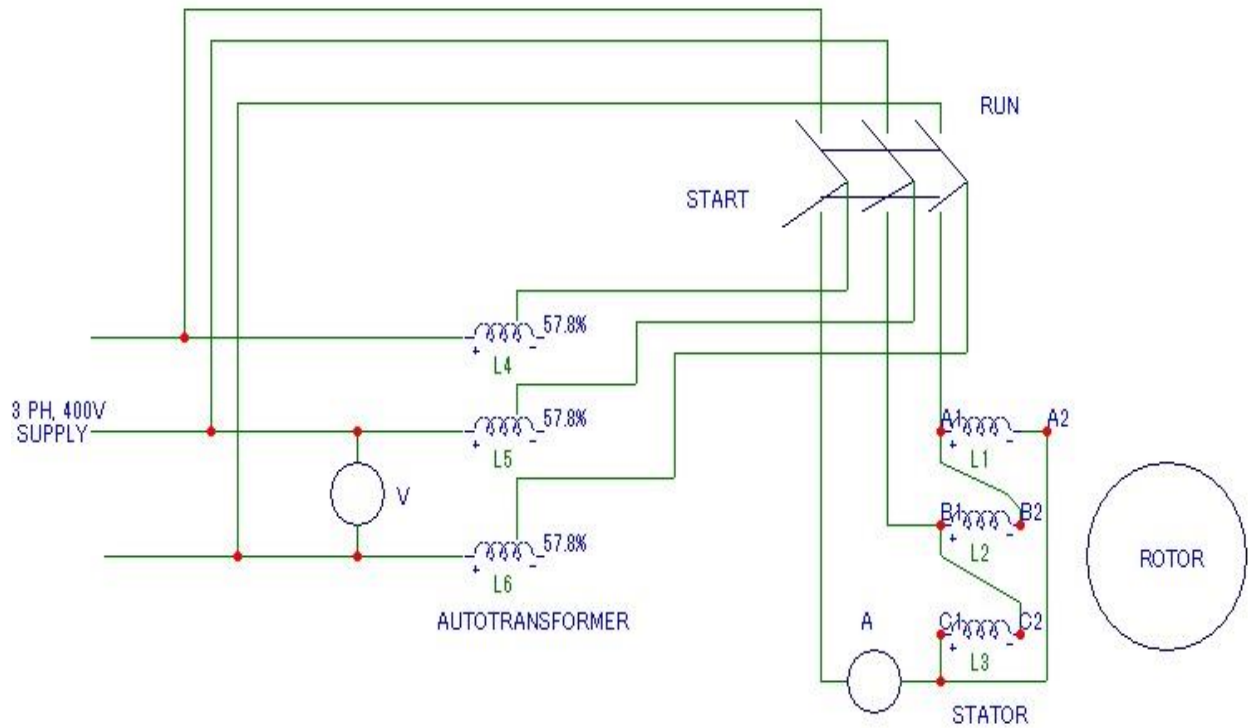
OBSERVATION TABLE

TABLE-1.D.O.L. STARTER

Obs. No.	Line Voltage				Line Current				Speed (N$_{DOL}$)	Remarks
	Starting		Running		Starting		Running			
	R-Y	Y-B	R-Y	Y-B	R	B	R	B		

TABLE-2.STAR-DELTA STARTER

Starter position	Obs. No.	Line Voltage				Line Current				Speed (N$_{S-D}$)	Remarks
		Starting		Running		Starting		Running			
		R-Y	Y-B	R-Y	Y-B	R	B	R	B		
Star											
Star to Delta											

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TABLE-3.AUTO-TRANSFORMER STARTER

Obs. No.	Supply Voltage		Applied Voltage		Voltage Ratio (x)	Line Current				Speed (N_{AUTO})	Remarks
						Starting		Running			
	R-Y	Y-B	R-Y	Y-B		R	B	R	B		

CALCULATION: Using the experimental data, determine the ratio of currents with Star-Delta Starting & D.O.L. Starting.

Starting line current by connecting the stator windings in star at the starting instant = starting motor current per phase= $I_{sc}/\sqrt{3}$.

Starting line current by direct switching (D.O.L starting)with stator windings connected in delta= $\sqrt{3}$ I.

$$\frac{\text{Line Current with star-delta starting}}{\text{Line Current with direct switching}\sqrt{3}\ I} = \frac{I_{sc}/\sqrt{3}}{3} = \frac{1}{3}$$

CONCLUSION:

EXPERIMENT NO.2

STUDY OF EQUIVALENT CIRCUIT OF THREE PHASE INDUCTION MOTOR BY NO LOAD AND BLOCKED ROTOR TEST.

Objective:
The aim of the experiment is to conduct the no load and blocked rotor test on three phase squirrel cage induction motor and to draw the equivalent circuit

NAME PLATE DETAILS:

3Φ Induction motor
Volts:
Amps:
KW:
RPM:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

THEORY:

An induction motor is simply an electric transformer whose magnetic circuit is separated by an air gap into two relatively movable portions, one carrying the primary and the other the secondary winding. Alternating current supplied to the primary winding induces an opposing current in the secondary winding, when later is short circuited or closed through an external

impedance. Relative motion between the primary and secondary ie, stator and rotor is produced by the electromagnetic forces corresponding to the power thus transferred across the air gap by induction.

The equivalent circuit of an induction motor referred to stator is as shown in the figure below
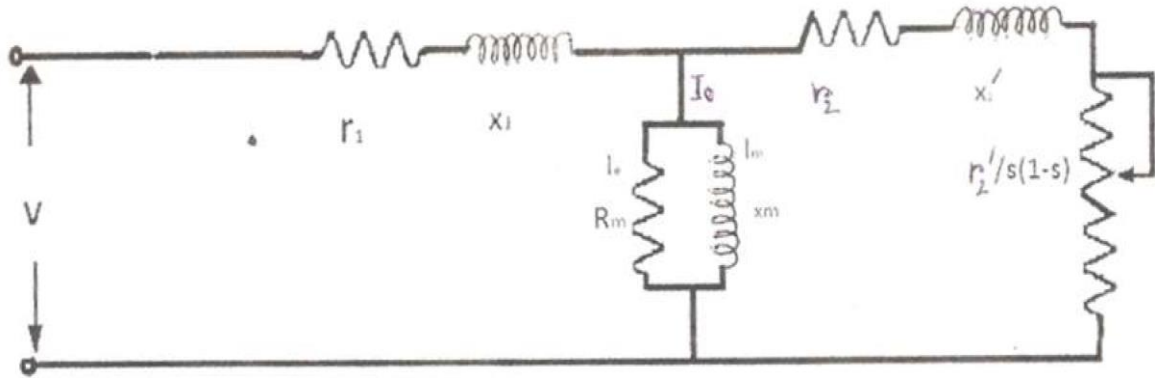
To determine the above parameters following tests are conducted on the motor.

NO LOAD TEST OR OPEN CIRCUIT TEST:

No load test is performed to determine the no load current, no load power factor, windage and friction losses, no load input and no load resistance and reactance.

Since there is no power output on no load, the power supplied to the stator furnishes its core loss and the friction and windage losses in the rotor.

BLOCKED ROTOR TEST OR SHORT CIRCUIT TEST:

It is also known as locked rotor or short circuit test. This test is used to find the short circuit current with normal voltage applied to stator, power factor on short circuit, total leakage reactance and resistance of the motor as referred to stator and full load copper loss.

PRECAUTIONS:

1. The auto transformer should be kept at minimum voltage position.

PROCEDURE:

1. Connections are made as per the circuit diagram.

2. For no load test by adjusting autotransformer apply rated voltage and note down the ammeter, voltmeter and wattmeter readings. In this test the rotor is free to rotate.

3. For blocked rotor test by adjusting autotransformer apply rated current and note down the ammeter, voltmeter and wattmeter readings. In this test the rotor is blocked.

4. After that make the connections to measure the stator resistance as per the circuit diagram.

CONNECTION DIAGRAM :
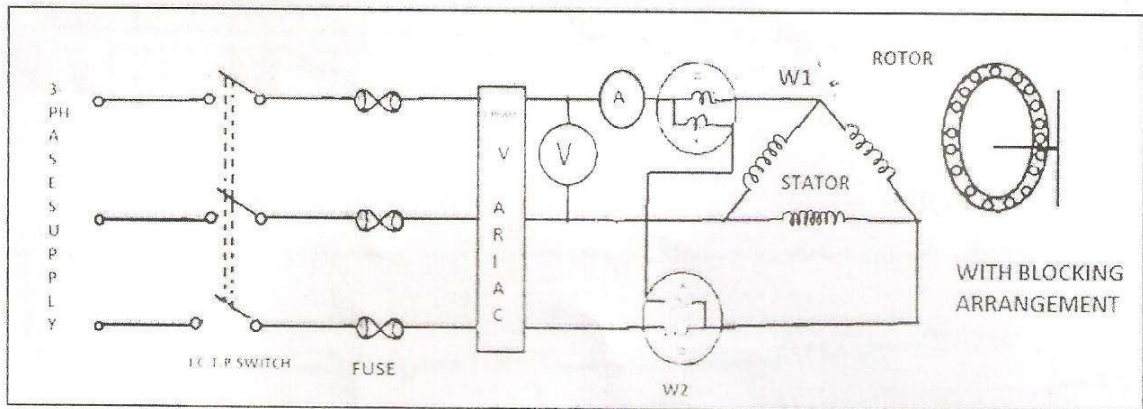
RESULT:

TABULAR COLUMN:

NO LOAD TEST:

Speed of the induction motor:

Multiplication Factor:

S.no	No load current (Io)	No Load Voltage (Vo)	No load Power		Total No load Power W_1+W_2
			W_1	W_2	
	(Amps)	(Volts)	(Watts)		(Watts)

BLOCKED ROTOR TEST:

Speed of the induction motor:

Multiplication Factor:

S.no	Short circuit current (Isc)	Short circuit Voltage (Vsc)	Short circuit Power W₁ W₂	Total Power W₁+W₂
	(Amps)	(Volts)	(Watts)	(Watts)

The resistance of the stator winding per phase is given by $r_1 = 7.5$ ohm

CALCULATION: (STATOR DELTA CONNECTED)

From No-load test:

P_{i0} = Total power input

I_{OL} = Line current

V_{OL} = Rated line voltage

Thus

Phase voltage $= V_i = V_{OL}$

Phase current $= I_0 = \dfrac{I_{OL}}{\sqrt{3}}$

The stator resistance, $r_1 = 7.5$ ohm
Stator copper loss, $p_c = 3I_0^2 r_1$

Windage and friction loss, $p_{wf} = \Box Watt$ (Determine from no-load test)

No-load power, $p_i = p_{i0} - p_c - p_{wf}$

No-load power factor, $\cos\phi_0 = \dfrac{p_i}{3V_i I_0}$

In-phase current component, $I_e = I_0 \cos\phi_0$

Magnetising current component, $I_m = I_0 \sin\phi_0$

So,

$$R_m = \frac{V_i}{I_e}$$

$$X_m = \frac{V_i}{I_m}$$

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From Blocked rotor test:

P_{ib} = Total power input

I_{bL} = Line current

V_{bL} = Line voltage

Thus

Phase voltage $= V_b = V_{bL}$

Phase current $= I_b = \dfrac{I_{bL}}{\sqrt{3}}$

Power factor, $\cos\phi_b = \dfrac{p_{ib}}{3V_b I_b}$

$Z_{br} = \dfrac{V_b}{I_b}$ ohm/phase

$R_{br} = \dfrac{P_{ib}}{3I_b^2} = Z_{br}\cos\phi_b$ ohm/phase

$X_{br} = \sqrt{Z_{br}^2 - R_{br}^2} = Z_{br}\sin\phi_b$ ohm/phase

Now $X_{br} = X_1 + X_2'$

Considering $X_1 = X_2'$

$$\boxed{X_1 = X_2' = \dfrac{X_{br}}{2}}$$

Also $R_{br} = r_1 + r_2$

$$\boxed{r_2' = R_{br} - r_1}$$

REPORT:

1. Using the experimental data determine the equivalent circuit parameters and draw the equivalent circuit diagram.

2. Enumerate the possible reasons if a three phase motor fails to start?

3. What happens if single phasing occurs when the motor is running? And when it is stationary?

EXPERIMENT NO.03

STUDY OF PERFORMANCE OF WOUND ROTOR INDUCTION MOTOR UNDER LOAD.

Objective

To perform load test on three-phase induction motor and:
  A) Compute torque, output power, input power, efficiency, input power factor
     and slip for various load settings.
  B) To plot the different performance characteristics from the data obtained.

NAME PLATE DETAILS:

Induction motor
Volts:
Amps:
KW:
RPM:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

THEORY :

The result of a load test on induction motor helps us to compute the complete performance of induction motor. The complete performance of induction motor means to calculate the various quantities at different loading of the induction motor. These quantities are torque , slip, efficiency , power factor etc. During this test electricity at normal voltage and normal frequency is supplied to the motor and a variable mechanical load is applied to the shaft of the motor. Mechanical loading can be provided by break and pulley arrangement. The quantities like input current ,input voltage input power and the speed of the speed of the motor are observed from the experiment and the various performance quantities are calculated explained below.

SLIP :- Due to the three phase supply given to the starter of an induction motor a rotating magnetic field of constant magnitude is set up in the stator of the motor. The speed with which this rotating magnetic field rotate is knows as synchronous speed Ns is given by Ns = 120f/P

r.p.m , Where f = frequency of supply voltage, P = No. of poles on the stator on the motor.

The actual speed of the motor of an induction, N2 is always less than the synchronous speed. This rotor speed decrease slowly as the mechanical load motor increases. The difference between the synchronous speed Ns and the rotor speed Nr is known as slip ,and be mathematically defined as follows slip, S = (Ns – Nr / Ns) × 100 . The value of slip at full load lies between 2 to 5%.

Torque : - Mechanical loading is applied on induction motor by means of a drum coupled to the shaft of the motor . A belt is provided on this drum (brake drum) . The belt can be tightened or loosened by means of threaded rods with handles fixed on a frame. Two spring balance are provided at the ends of the belt. The net force exerted at the break drum can be obtained from the reading of the two spring balances i.e – S1 and S2.

Net force exerted on the drum W = (S1 – S2) kgf, Torque , T = W (d / 2) 9.8 N-m, Where d = effective diameter of the break in meter.

Output power : - The output power of the motor P0 can be calculated as 2 watts , where N = speed of the motor in r.p.m.

Input power:- Input power pi , can be calculated from the readings of two wattmeter's connected in the circuit , W1 and W2 , P_i = W1 + W2 .

It is important to note that one of the wattmeter may read negative . This happens at low power factor , under no load condition . In that case the connection of one coil should be reversed. Then the wattmeter will start giving positive reading however such a reading should be recorded as negative reading.

Input power factor :- The power factor angle can be calculated from the reading of two wattmeter's using the following relation tan

Once the angle Ph i($\emptyset$) is known, the power factor cos$\emptyset$ can be

easily known, Efficiency can be calculated using,

η = [Output power / input power] × 100

The variation of above mentioned quantities with O/P power are shown in figure below.
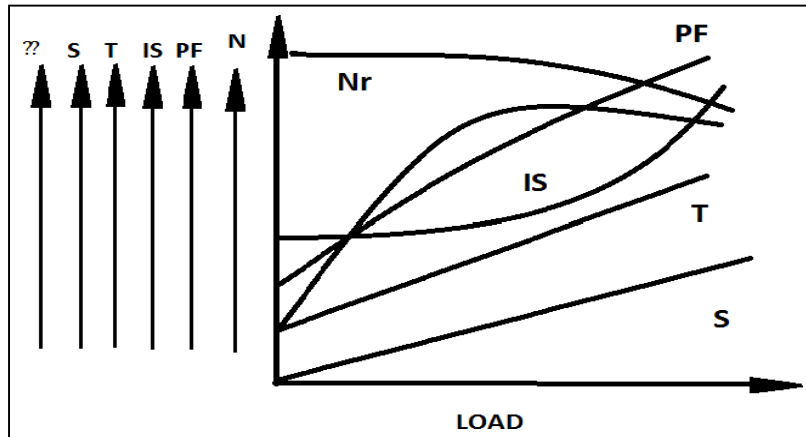
CIRCUIT DIAGRAM:-
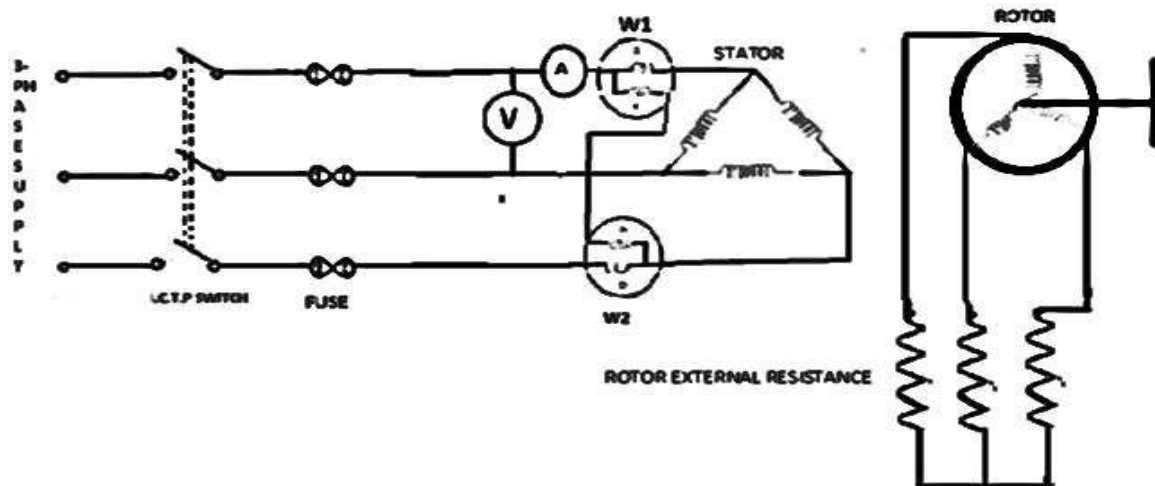
PROCEDURE :-
  i)   Make connection according to circuit diagram.
  ii) The phase variac is set for zero value , and break pulley arrangement is the set for no load.
  iii) Three phase supply is given to the motor.
  iv) The three phase variac setting is increased slowly. The direction of deflection in wattmeter should be noted. At this stage one of the watt-meters may read negative if is So, the switch off, the 3phase variac setting is a gain brought to its minimum.
  v)   Increase the voltage applied to its rated value.
  vi) Note down the reading . This is no load readings.
  vii) Increase the mechanical on the motor and the readings . Repeat this for varies load setting (Stator current cannot exceed the rated value 5 Amps)
  viii) At some stage one of the wattmeter may again start reading negative , then repeat the step (4).

RESULT:

Table :- 1 (for load test on three- phase induction motor)

Sl no.	Supply Voltage (V$_L$) in volts	Line current (I$_L$) in amps	Wattmeter readings in watt		Mechanical Load		Speed N$_r$ in r.p.m
			w$_1$	w$_2$	Balances1(kgf)	Balance S2(kgf)	

D=… .... m

Table-2 (Calculation of the performance of three-phase motor)

Sl. No.	Mechanical Torque (N-M) $T = \dfrac{(S1-S2)D \times 9.8}{2}$	Output power (W) $P_0 = \dfrac{2\pi NT}{60}$	Input Power (W) $W = W_1 + W_2$	Slip $s = \dfrac{N_S - N_r}{N_S}$	Power factor $pf = \dfrac{W}{\sqrt{3}V_L I_L}$	Efficiency $\eta = \dfrac{P_0}{W}$

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REPORT:

1. Using the experimental data obtain the following characteristics.

       i) Efficiency vs output power.
      ii) Torque vs output power.
     iii) Line current vs output power.
     iv) Power factor vs output power.
      v) Slip vs output power.
     vi) Torque vs speed.

STUDY OF PERFORMANCE OF THREE PHASE SQUIRREL-CAGE INDUCTION MOTOR – DETERMINATION OF IRON-LOSS, FRICTION & WINDAGE LOSS.

Objective:
The aim of the experiment is to conduct no-load test on three phase squirrel-cage Induction motor and separate the no load losses of the motor as core loss and mechanical loss.

NAME PLATE DETAILS:

3Φ Induction motor
Volts:
Amps:
KW:
RPM:

APPARATUS USED:

S.NO	NAME OF THE APPARATUS	RANGE	TYPE	QUANTITY

FORMULA USED:

1. Input Power $W = (W_1 + W_2)$ watts

2. Stator cu loss $= 3 I_o^2 R_a$ watts

---

3. Constant loss / phase $Wc = (W - 3Io^2Ra)/3$watts

4. Core loss/phase Wi = Constant loss/phase – Mechanical loss

Here the mechanical loss Wm will be the distance from the origin to the point at where the constant loss/phase Vs voltage curve cuts the y axis.

THEORY:

The no load losses are the constant losses which include core loss and friction and windage loss. The separation between the two can be carried out by the no load test conducted from variable voltage, rated frequency supply.

When the voltage is decreased below the rated value, the core loss reduces as nearly square of voltage. The slip does not increase significantly he friction and windage loss almost remains constant. The voltage is continuously decreased, till the machine slip suddenly begins to increase and the motor tends to stall. At no load this takes place at a sufficiently reduced voltage.
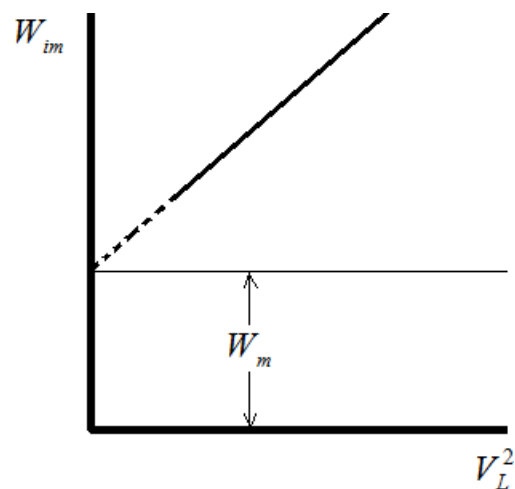
For separation of losses a graph V_L^2 in X-axis and W_{im} in Y-axis is plotted as shown in the figure. The graph will be almost rectilinear. The graph is extrapolated towards Y-axis and an intercept is obtained. Here $V_L = 0$ and hence the intercept corresponds to voltage independent loss i.e. the mechanical loss W_m. When this loss is subtracted from W_{im} at rated voltage, the remaining value give the value of iron loss W_i at rated voltage.

PRECAUTIONS:

1. The auto transformer should be kept at minimum voltage position.

PROCEDURE:

1. Connections are given as per the circuit diagram.

2. Set the variac at zero value. Switch on the main and increase voltage in the stator with the help of the variac. At about 20% of the rated voltage the rotor will start rotating and will pick up speed near to its rated speed. Increase the voltage in steps and record the readings.

3. Go upto 110% of the rated voltage.

4. Tabulate the readings.

5. Draw the suitable graph to find the mechanical loss.

6. Obtain the core loss by separating the mechanical loss from the constant loss.

Connection diagram :
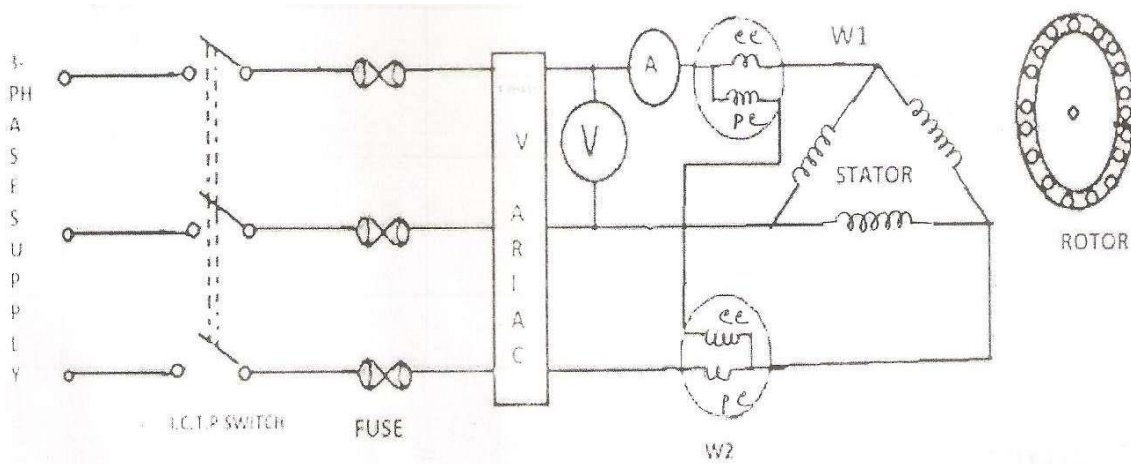
RESULT:

Sl. No.	Supply voltage (V_L)	Supply current (I_L)	Speed	Wattmeter's reading		Power input	Power factor	V_L^2	Stator copper loss	W_{im}
				W_1	W_2	$P=W_1+W_2$	$\cos\varphi= \dfrac{p}{\sqrt{3}V_L I_L}$		$P_s = 3I_p^2 R_s$	$=P-P_s$

REPORT:

1. Draw the graph between constant loss and input voltage.

2. Using the experimental data determine different no-load losses of the motor.

3. Mention the losses that occur in induction motor.

4. What are the no load losses?

5. In which type of induction motor can resistance be introduced in the rotor circuit?

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Experiment No. 5

EXPERIMENT: SPEED CONTROL OF 3 PHASE SQUIRREL CAGE INDUCTION MOTOR BY DIFFERENT METHODS AND THEIR COMPARISON[VOLTAGE CONTROL & FREQUENCY CONTROL]

Objective: To study the different types of speed control of a 3-Φ Squirrel Cage Induction Motor using:

   i.   Voltage control
  ii.   Frequency control

APPARATUS USED

Sl. No.	Description	Range/ Rating	Maker's Name	Tag No./ Serial No.

THEORY

Methods of speed control may either from stator or rotor side. From the stator side, various methods of speed control are:

   i.   Variation of supply frequency
  ii.   Variation of applied voltage
 iii.   By changing the no. of poles

But if speed is controlled from rotor side (for wound rotor motor), then different methods are:

   i.   Changing rotor circuit resistance
  ii.   Introducing an emf of same frequency as the fundamental emf of rotor in the rotor circuit

Of all the above said methods, we are going to confine our discussion with speed control by variation of voltage& variation of frequency being employed in the experiment.

Speed control by variation of voltage

$T = (KsE_2^2) / R_2$ (for low value of slip, s)

Thus, torque is directly proportional the product of s & E_2^2. This E_2varies with input voltage (V) & hence torque is directly proportional the product of s & V^2.

i.e. $T= K_1sV^2$, where $K_1$is any constant

So, for constant torque (fixed load) operation, variation in V results corresponding change in s (& hence N_r).

This method of speed control is simple, low in first cost, & has low maintenance cost but it suffers from few disadvantages which are:

  i.   Voltage beyond certain value can cause saturation
 ii.   Large change in voltage results small change in speed
iii.   Load torque reduces greatly with reduced voltage & the motor will come to standstill if load torque exceeds motor's pull-out torque corresponding to reduced supply voltage
 iv.   Range of speed control is from rated speed to lower speeds

This method of speed control is used where torque requirement is low at reduced speeds like small squirrel cage motors driving fans.

Speed control by variation of frequency

By this method of speed control, wide range of speed can be obtained by varying the supply frequency. In order to maintain constant flux, (V/f) ratio must be kept constant. So, if we are varying frequency over a wide range, we must have vary the voltage suitably.

PROCEDURE:

1. Connect the system as per circuit diagram show in fig. below.

2. Switch ON the system to ON the Three-Phase MCB.

3. Start the system using DOL starter.

4. The display of the VVVF drive show "STOP"

5. Push the "INCREASE" Push button. The motor start to rotate slowly.

6. Press the INCREASE push button to reach the frequency upto 8 Hz to 10 Hz & take the reading of output Voltage, Output Current, Output Frequency and speed.

7. Take at least 10 reading upto maximum limit.

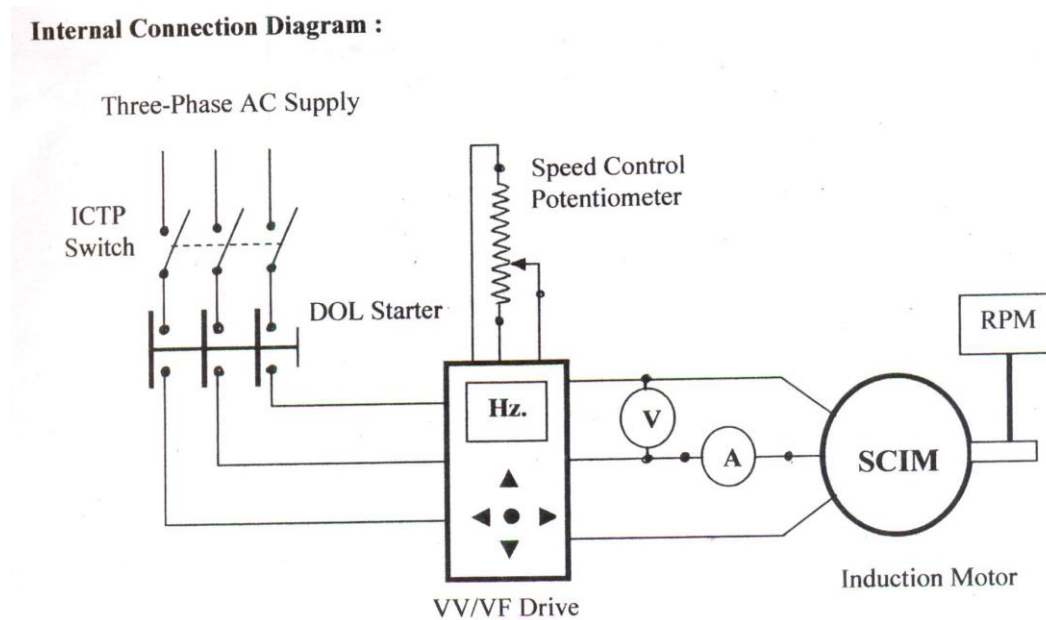8. Measure the ratio of Voltage and Frequency in every reading.

CONNECTION DIAGRAM:

Fig: Internal connection diagram of VV/VF drive of Sq. Cage Induction Motor.

OBSERVATION TABLE:

Sl. No.	Output Voltage (in V)	Output frequency(Hz.)	Output Current(A)	Speed(RPM)

REPORT:

Plot the graph between Voltage vs. Frequency, Voltage vs. Speed and Frequency vs. Speed in graph paper.

CONCLUSION:

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EXPERIMENT NO. 06

NAME OF THE EXPERIMENT: SPEED CONTROL OF THREE PHASE SLIP RING INDUCTION MOTOR BY ROTOR RESISTANCE CONTROL

APPARATUS REQUIRED:

SL. NO	NAME OF THE APPARATUS	TYPE	RANGE	QUANTITY
01	Ammeter			
02	Voltmeter			
03	Rotor Resistance Starter			
04	Auto Transformer			
05	Tachometer			
06	Wattmeter			
07	Connecting Leads			

THEORY:

Rotor Rheostat Control:

In this method, which is applicable to slip ring induction motors alone, the motor speed is reduced by introducing an external resistance in the rotor circuit. For this purpose, the rotor starter may be used provided it is continuously rated. This method is in fact similar to the armature rheostat control method of D.C shunt motors.

NAME PLATE DETAILS:

3ø Induction Motor

Rated Voltage   :
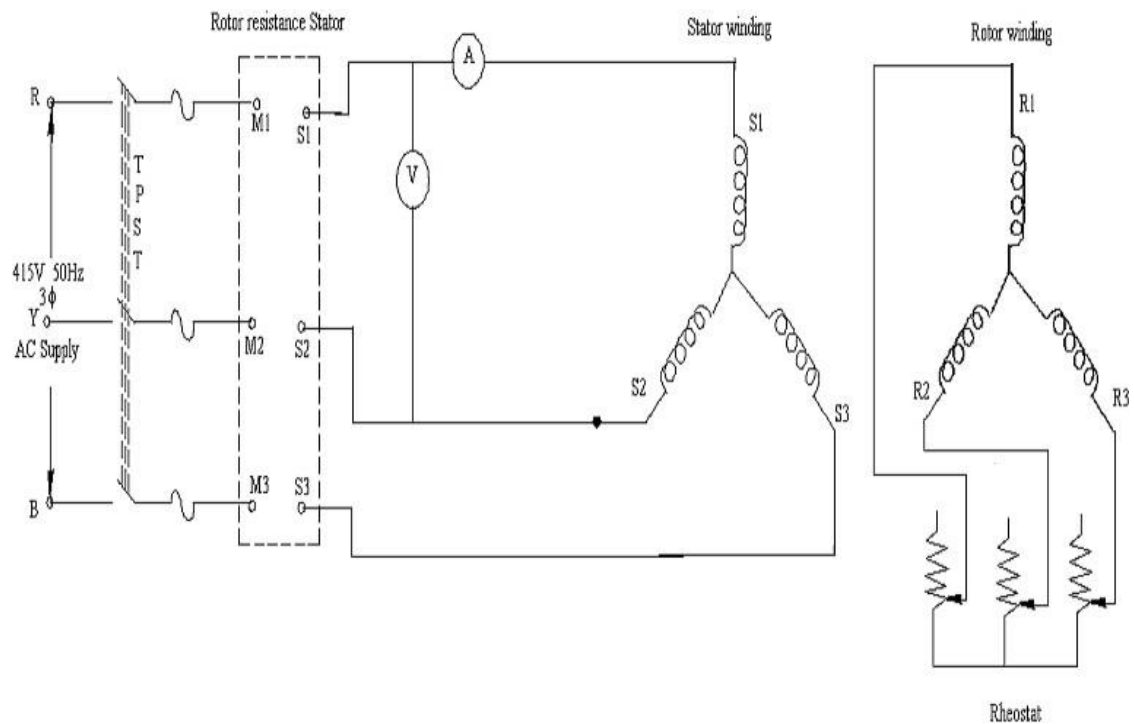
Rated Current   :

Rated Speed   :

Rated Power   :

Rated Frequency   :

CIRCUIT DIAGRAM:

PRECAUTION:

The motor input current should not exceed its rated value.

PROCEDURE:

1. Connections are given as per circuit diagram.

2. Keep the rotor resistance stator output as zero voltage & the external rotor resistance at minimum resistance position.

3. Switch ON the supply & increase the input voltage to stator winding upto its rated value.

4. Measure the speed.

5. Now increase the rotor resistance in steps & note the corresponding values of speed.

6. Draw a graph of rotor resistance Vs. Speed.

OBSERVATION TABLE:

SL. NO	EXTERNAL ROTOR RESISTANCE IN OHMS	SPEED(RPM)

GRAPH:

Draw a graph of rotor external resistance vs. speed

RESULT:

Thus the speed of 3 phase slip ring induction motor was controlled by rotor resistance control method.

VIVA QUESTIONS:

1. What will happen if the rotor circuit of a slip ring I.M. is open & electric supply is given to its stator winding?

2. What is the constructional difference between a slip-ring & a squirrel cage I.M ?

3. Draw & explain the Torque-speed characteristics of a slip ring I.M. for different values of rotor resistance.

4. What is the effect of changing the rotor resistance on the slip ring at max torque SMT?

5. Can an I.M. rotate at synchronous speed? Justify your answer.

EXPERIMENT NO. 7(a)

EXPERIMENT: Determination of regulation of synchronous machine by Potier reactance method.

OBJECTIVE: To determine regulation of an alternator by Potier reactance method (ZPF method).

THEORY: The variation of terminal voltage of an alternator between full - load and no-load expressed in percentage of full-load voltage is called the percentage voltage regulation of synchronous machine.

Phasor diagram of an alternator at lagging power factor is as follows.
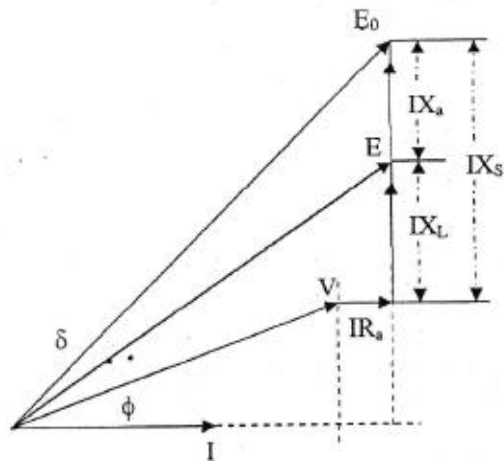
Regulation is found by the following expression:

$$\% \text{ regulation} = \frac{Eo - V}{V} \times 100$$

Where, V is the terminal voltage and E_o is the induced voltage.

Regulation of alternator can be determined by measuring the voltage of the alternator when loaded and also when the load is taken off. In actual practice it will be difficult to load a big synchronous machine in the testing laboratory. Due to this reason regulation of large alternators are not determined by direct loading method.

Regulation of a synchronous machine can alternatively be determined by the Piotier reactance method. (Zero Power Factor method).

For this method the following three tests are required:

Potier Reactance Method.

        a)   Open Circuit Test (OCC upto rated voltage or above)

        b)   Short Circuit (SCC upto rated current)

        c)   Zero Power Factor (ZPF for rated Voltage & Rated Current)

        d)   Armature Resistance.

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Apparatus Required:

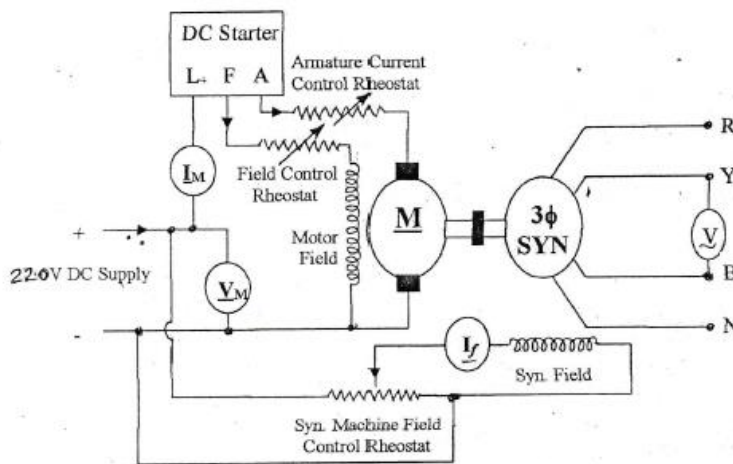| Sl no.	Apparatus	Rating	Makers
1.	DC Shunt Motor in Synchronous Machine Set		
2	DC Starter		
3	Moving Coil type Ammeter		
4	Moving Coil type Voltmeter		
5	Moving Iron type Ammeter		
6	Moving Iron type Voltmeter		
7	3Phase Inductive Load		
8	Motor Armature & Field Control Rheostat		
9	Alternator Field Exciter		

Circuit Diagram:

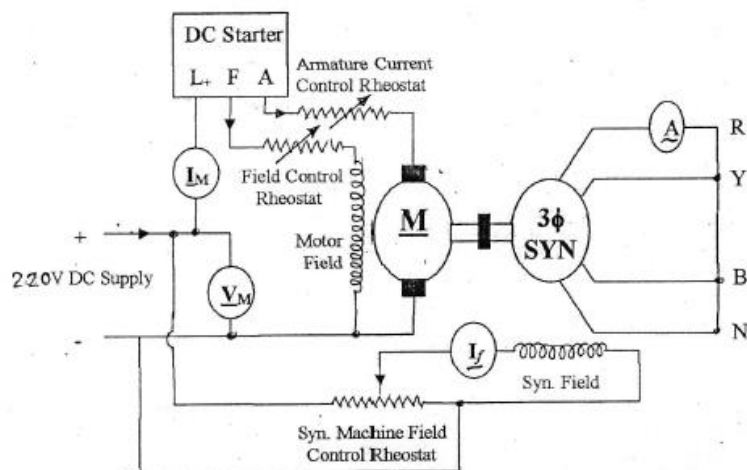Fig-1 Connection diagram for Open Circuit Test (OCC) of synchronous machine

Fig-2 Connection diagram for Short Circuit Test (SCC) of synchronous machine

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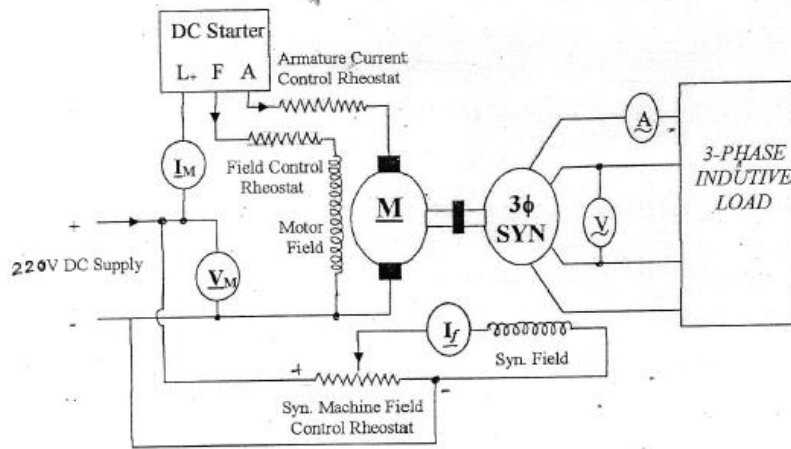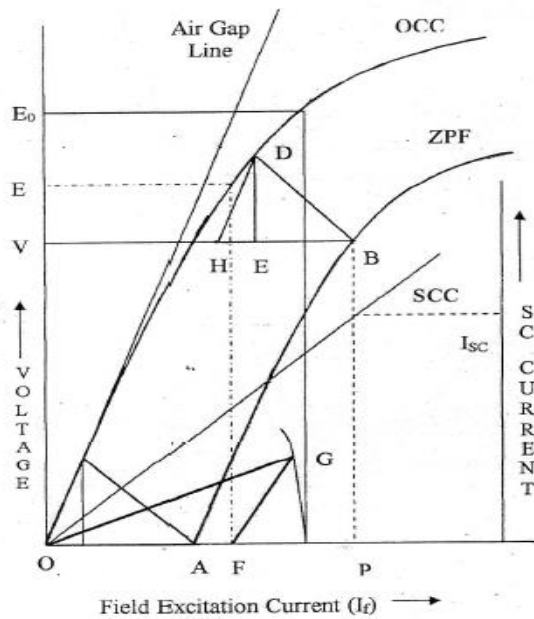**DEPARTMENT OF ELECTRICAL ENGINEERING**

Fig-3 Connection diagram of regulation test of synchronous machine by Potier reactance method.

PROCEDURE:

1. Make connections as per circuit diagram shown infigure-1. Start the DC motor with help of DC starter. Bring the speed of the set to the rated speed of the alternator.
2. Excite the alternator gradually and record the induced emf of the alternator for various values of its field current at constant speed up to 110% of the rated Voltage.
3. Record the data as per table and draw the curve between excitation current and induced voltage.
4. Reduced the excitation of the synchronous machine and adjust the speed of the set at rated speed.
5. Short circuit the armature terminals of the synchronous machine as per fig-2.
6. Increase the field current of the synchronous machine in steps till rated full-load current flows through the armature winding of the synchronous machine.
7. Record the data as per table indicated.
8. Draw the curve between excitation current and short circuit current
9. Draw tangent to OCC (air gap line)
10. Reduced the excitation of the synchronous machine and adjust the speed of the set at rated speed.
11. Connect the inductive load with synchronous machine. Increase the excitation. In all steps the synchronous machine speed & Load current is constant.
12. Conduct ZPF test at full load for rated voltage and draw curve between excitation current and induced Voltage and fix the point B.
13. Draw the line BH with length equal O.'A to the field current required to produce full load current at short circuit.
14. Draw HD parallel to the air gap line so as to touch the OCC.
15. Draw DE parallel to voltage axis. Now DE represents the voltage drop IXL and BE represents the field current required to overcome the effect of armature reaction.
16. Triangle BDE is called Potier Triangle and XL is the Potier Reactance.
17. Find E from V, IXL and Φ (Φ is the phase angle of current from voltage, if the load is purely inductive the Φ= 90°). Consider Ra also. The expression to use is

$$E_O = \sqrt{(V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_L)^2}$$

18. Draw F G with magnitude equal to BE at angle (90 + Ψ) from field current axis, where Ψ is the phase angle of current from voltage vector E (internal phase angle).
19. The resultant field current is given by OG. Mark this length on field current axis.

20. Calculate the Voltage relation of the alternator.

OBSERVATION AND RESULT:

For OCC test

Sl no	Excitation current If in Amp	Terminal Voltage (V) in volt	Speed in rpm

For SC test:

Sl no	Excitation current If in Amp	Short Circuit Current(Amps)	Speed in rpm

For Zero Power Factor Test:

Sl no.	Excitation current If in Amp	Load Current(Amps)	Terminal Voltage (V) in volt	Speed in rpm

Measurement of Armature resistance of Alternator:

Sl no	Applied DC volt	Armature current amp	Resistance

Find the regulation using   % regulation = $\dfrac{Eo - V}{V}$ x 100

CONCLUSION:

Experiment No. 7(b)

EXPERIMENT: Determination of regulation of Synchronous Machine by Synchronous Impedance method.

Objective: To determine the regulation of a 3-Φ Alternator by Synchronous Impedance method / O.C. & S.C. Test.

NAME PLATE DETAILS

APPARATUS USED

Sl. No.	Description	Range/ Rating	Maker's Name	Tag No./ Serial No.

THEORY

In synchronous impedance method, following tests are performed:

i. Open Circuit Test- To determine the Open Circuit Characteristics (O.C.C.) of the alternator.
ii. Short Circuit Test- To determine the Short Circuit Characteristics (S.C.C.) of the alternator.
iii. Test for determining the effective armature resistance/ phase (R_a).

In the characteristics shown below,

V- Rated phase voltage

I_{SC}- Short Circuit Current corresponds to field current producing the rated voltage.

Synchronous Impedance/phase, $Z_S = V/I_{SC}$

$X_S = (Z_S^2 - R_a^2)^{1/2}$

Voltage Regulation$= (E_O - V)/V$

Voltage Regulation $(\%) = [(E_O - V)/V]*100$

Here E_O is obtained by Synchronous Impedance method.

For lagging pf,
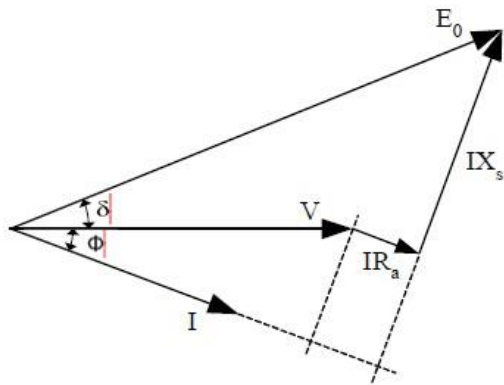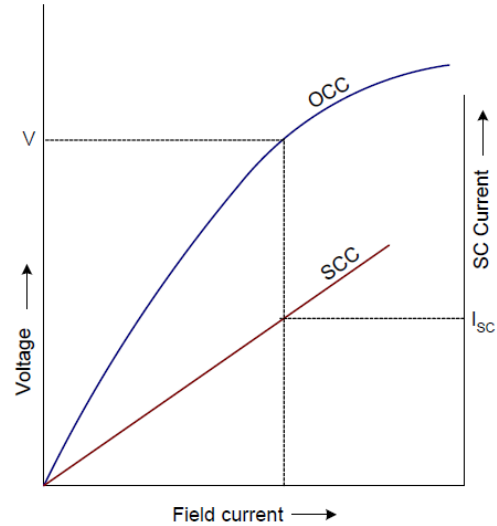
$$E_0 = \sqrt{(V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_s)^2}$$

For unity pf,

$$E_0 = \sqrt{(V + IR_a)^2 + (IX_s)^2}$$

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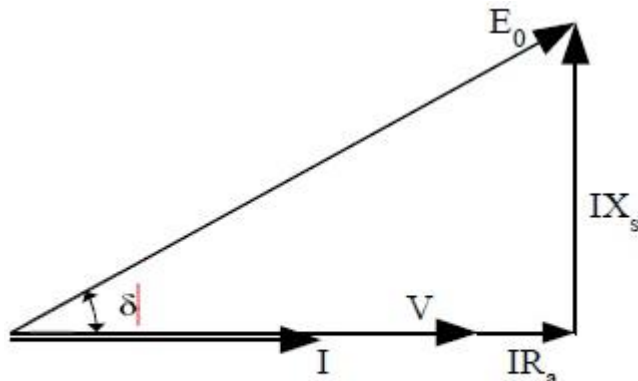
For leading pf,
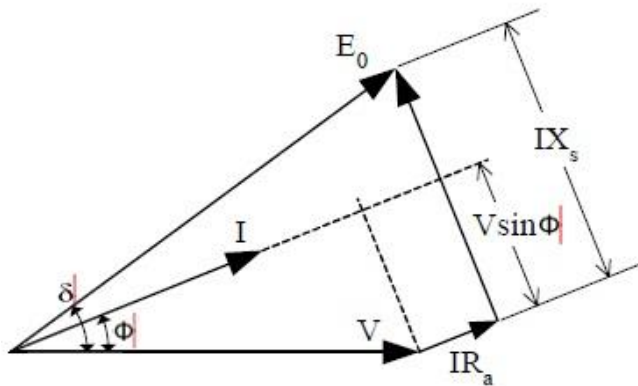
$$E_0 = \sqrt{(V \cos \Phi + IR_a)^2 + (V \sin \Phi - IX_s)^2}$$

PROCEDURE

Open Circuit Test

i.   Arrange the circuit as shown in the connection diagram.
ii.   Set potential divider to zero o/p position & motor field resistance to minimum value.
iii.   Switch on DC supply to start the DC Motor.
iv.   Increase motor speed so that it reaches synchronous value by varying motor field rheostat. Note the meter readings.
v.   Increase the field excitation of alternator & note the meter readings.
vi.   Repeat the above step (Step 5) up to 120% of rated alternator voltage.
vii.   Maintain constant rotor speed for all readings.

Short Circuit Test

i.   Arrange the circuit as shown in the connection diagram.
ii.   Set potential divider to zero o/p position & motor field resistance to minimum value.
iii.   Switch on DC supply to start the DC Motor.
iv.   Increase motor speed so that it reaches synchronous value by varying motor field rheostat.
v.   Increase the field excitation of alternator & note the ammeter readings.
vi.   Repeat the above step (Step 5) up to 25-50% of rated armature current.
vii.   Maintain constant rotor speed for all readings.
viii.   Determine armature resistance/phase R_a by multimeter or ammeter-voltmeter method & convert it to ac resistance.
ix.   Plot the characteristics to determine the synchronous impedance.

CONNECTION DIAGRAM

Open Circuit Test
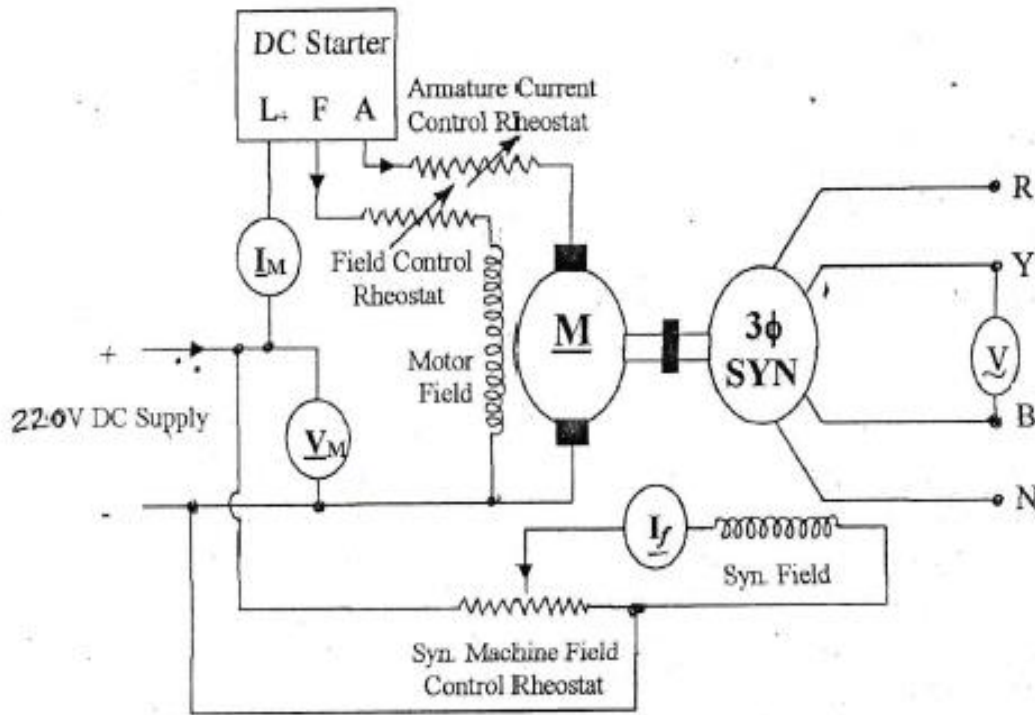
Fig-1 Connection diagram for Open Circuit Test(OCC) of synchronous machine

OBSERVATION TABLE:

Open circuit circuit

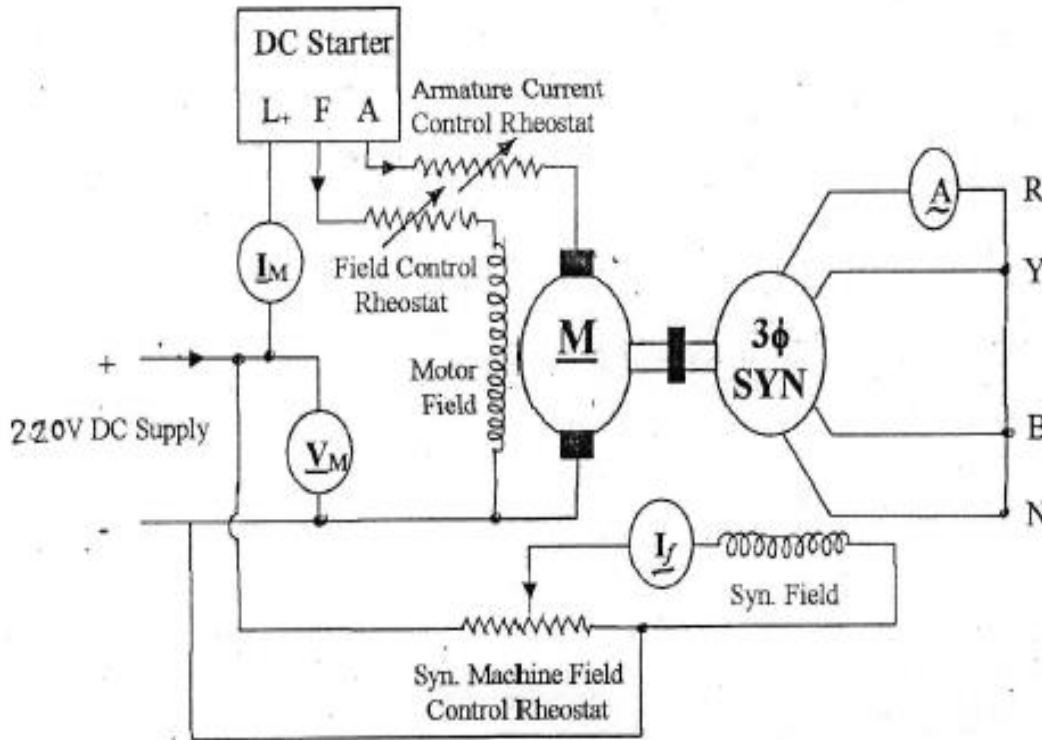| Sl no	Excitation current (I_f) in Amp	Terminal Voltage (V_O) in volt	Speed in rpm

Short Circuit Test

Fig-2 Connection diagram for Short Circuit Test(SCC) of synchronous machine

OBSERVATION TABLE

Short circuit Test

Sl no	Excitation current(I_f)	Short Circuit Current(I_{SC})	Speed in rpm

OBSERVATION TABLE

Measurement of Armature resistance of Alternator (R$_a$)

Sl no	Applied DC volt	Armature current amp	Resistance(R$_a$)

CALCULATION:

Calculate the excitation emf, Eo& voltage regulation for full-load &

    i.   0.8 lagging p.f.
   ii.   Unity p.f.
  iii.   0.8 leading p.f.

Find the regulation using   % regulation = Eo — V x 100

                                         V

REPORT:

Graph:

Plot the readings to draw the following graphs on the same graph paper:

    i.   I$_f$ verses V$_o$ (From OC Test)
   ii.   I$_f$ verses I$_{sc}$ (From SC Test)

CONSCLUSION:

Experiment No-8

EXPERIMENT: Determination the equivalent circuit parameters of a 1-Φ Induction Motor.

Objective: To determine the equivalent circuit parameters of a 1-Φ Induction Motor by:

   i.   Measurement of stator winding resistance
   ii.   No-load test
   iii. Blocked rotor test

NAME PLATE DETAILS:

APPARATUS USED:

Sl. No.	Description	Range/ Rating	Maker's Name	Tag No./ Serial No.

THEORY

For determining the machine constants, following tests are performed:

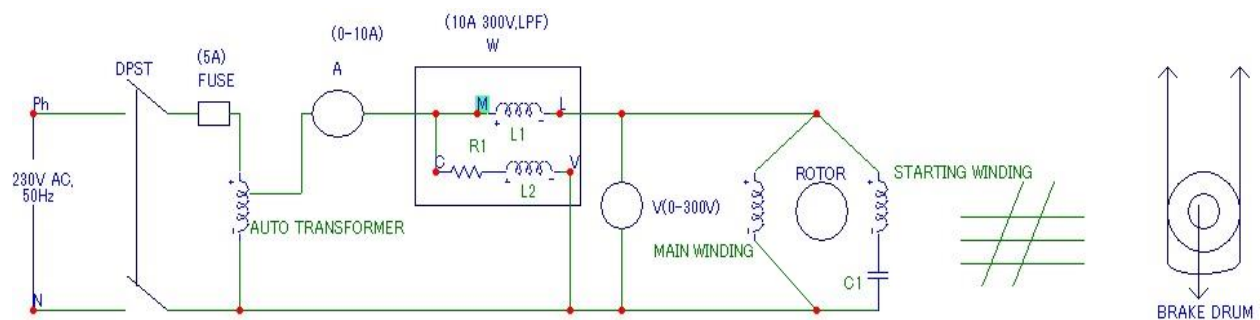   i.   Measurement of stator winding resistance
   ii.   Blocked rotor test
   iii. No-load test

Measurement of stator winding resistance

In this test, the dc resistance of stator winding (R_{dc}) is measured separately either by multimeter or voltmeter-ammeter method from stator side omitting the auxiliary winding capacitor (if any).

AC Resistance, R_1= Multiplying factor* R_{dc}

Blocked rotor test

The rotor is blocked to prevent rotation and voltage is applied to the stator terminals& input voltage current, power loss &speed are measured. Using these data we can obtain rotor resistance (R_2), leakage reactance of stator & rotor (X_1& $X_2^{'}$) respectively.

Let P, V, I be the meter readings of wattmeter, voltmeter & ammeter respectively. Then,

$R_1+R_2^{'}=P/I^2$

We can measure R_1 by the previous method.

$R_2^{'}=P/I^2-R_1$

Now, $Z_{eq}=V/I= [(R_1+R_2^{'})^{2}+ (X_1+X_2^{'})^{2}]^{1/2}$

$X_1+X_2^{'}= [Z_{eq}^2-(R_1+R_2^{'})^{2}]^{1/2}$

Assuming $X_1=X_2^{'}=(X_1+X_2^{'})/2$

No-load test

It is performed at rated voltage, exciting the main winding only &input voltage current, power loss &speed are measured. Using these data we can obtain stray power loss & magnetizing reactance (X_m).

Let P, V, I be the meter readings of wattmeter, voltmeter & ammeter respectively. Then,

Stray power loss $P_s= P-I^2*[R_1+ (R_2^{'}/4)]$

$Z_{eq}=V/I= [(R_1+R_2^{'}/4)^2+ (X_1+X_2^{'}/2+X_m/2)^2]^{1/2}$

$X_1+(X_2^{'}/2) + (X_m/2) = [Z_{eq}^2-(R_1+R_2^{'}/4)^2]^{1/2}$

$X_m= 2* [Z_{eq}^2-(R_1+R_2^{'}/4)^2]^{1/2} – 2[X_1+(X_2^{'}/2)]$

PROCEDURE

Measurement of stator winding resistance:

  i.   DC resistance is measured by ammeter-voltmeter method after deactivating the condenser. The ratio of voltmeter reading & ammeter reading gives the net resistance.
  ii. The effective ac resistance of stator can be calculated by considering skin effect.

Blocked rotor test:

  i.   The connection is made as shown in the circuit diagram & the rotor is blocked by braking arrangement.
  ii. Variable voltage is applied to stator winding till the rated current flow.
  iii. Voltmeter, Ammeter & Wattmeter readings are noted.

No-load test

    i.   The connection is made as shown in the circuit diagram.
    ii.   The auto transformer is kept at minimum voltage position.
    iii.   Run the motor without any external load.
    iv.   By applying the stator voltage to the stator corresponding readings of ammeter, voltmeter & wattmeter are noted.

CONNECTION DIAGRAM

Measurement of stator winding resistance
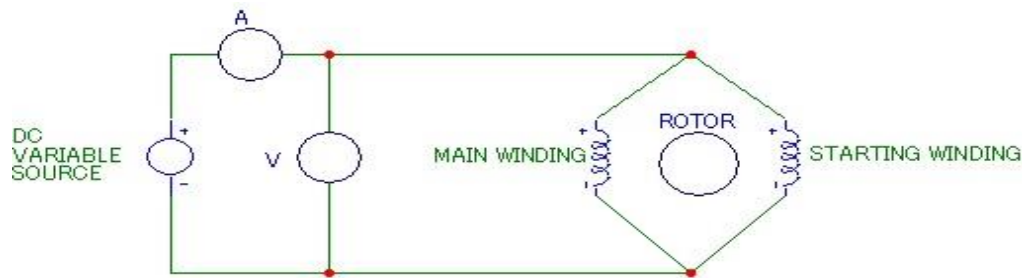
Blocked rotor test
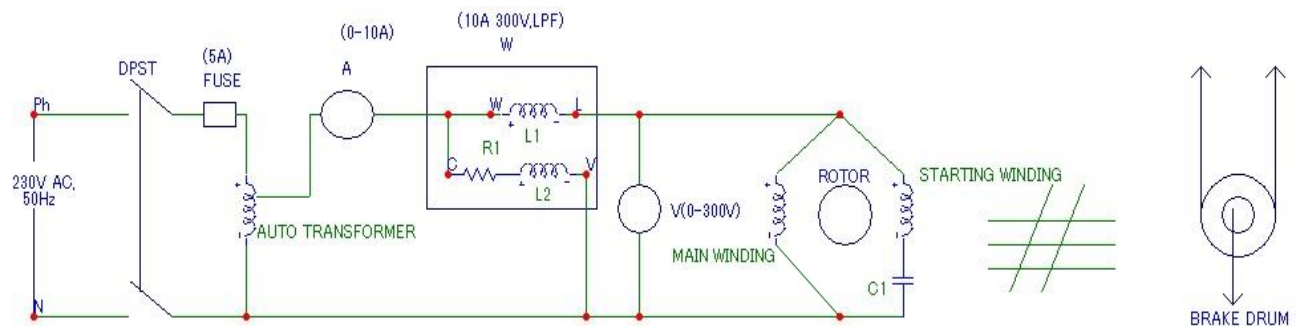
No-load test

OBSERVATION TABLE

Measurement of stator winding resistance

Sl. No.	DC Voltage V_{dc} (in V)	Stator current I_s (in A)	Resistance $R= V_{dc}/ I_s$	Mean Resistance	AC Resistance

Blocked rotor test

Sl. No.	Input Voltage V (in V)	Input Current I (in A)	Input Power P (in W)	Speed N (in rpm)

No-load test

Sl. No.	Input Voltage V (in V)	Input Current I (in A)	Input Power P (in W)	Speed N (in rpm)

REPORT

From the tests performed determine:

i.   Stator & rotor resistance (R1 & R2)
ii.   Stator & rotor leakage reactance (X1 & X2')
iii. Magnetizing reactance (X_m).

Finally develop the equivalent circuit of a 1-Φ Induction Motor.

CONCLUSION:

EXPERIMENT NO-9

EXPERIMENT NAME: LOAD TEST ON A SINGLE PHASE INDUCTION MOTOR TO OBTAIN PERFORMANCE CHARACTERISTICS

OBJECTIVE: TO PERFORM LOAD TEST ON SINGLE PHASE INDUCTION MOTOR &

1. **COMPUTE TORQUE , OUTPUT POWER, INPUT POWER FACTOR & SLIP FOR VARIOUS LOAD SETTING.**

2. **TO PLOT THE FOLLOWING CURVES FROM THE DATA OBTAINED**

   A. EFFICIENCY Vs OUTPUT POWER.
   B. TORQUE Vs OUTPUT POWER.
   C. CURRENT Vs OUTPUT POWER.
   D. POWER FACTOR Vs OUTPUT POWER.
   E. TORQUE Vs SPEED

APPARATUS USED:

SL NO.	DESCRIPTION	RANGE/ RATING	QUANTITY	TYPE	MAKERS NAME	TYPE

THEORY:

The load test on induction motor is performed to compute its complete performance i.e. torque, slip, efficiency, power factor etc. During this test, the motor is operated at rated voltage and frequency and normally loaded mechanically by brake and pulley arrangement from the observed data, the performance can be calculated, following the steps given below.

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SLIP: The speed of rotor, Nr droops slightly as the load on the motor is increased. The synchronous speed, Ns of the rotating magnetic field is calculated, based on the number of poles, P and the supply frequency, f i.e.

Synchronous speed Ns = $\frac{120f}{P}$ r.p.m

Then, slip, S = $\frac{Ns - Nr}{N_S}$ x 100 Percent

Normally, the range of slip at full load is from 2 to 5 percent.

TORQUE: Mechanical loading is the most common type of method employed in laboratories, a brake drum is coupled to the shaft of the motor and the load is applied by tightening the belt, provided on the brake drum. The net force exerted at the brake drum in kg is obtained from the readings S1 and S2 of the spring balances i.e.

Output = Torque x Speed

Thus as the speed of motor does not vary appreciably with load torque will increase with increasing load.

Net force exerted, W = (S1 – S2) kg

Then, load torque, T = W x d/2 kg – m

 = W x d/2 x 9.8 Nw– m

Where, d – effective diameter of the brake drum in meters.

INPUT POWER: Input power is measured by the two wattmeters, properly connected in the circuit i.e.

Input power = (W1 + W2) watts

Where, W1 and W2 are the readings of the two wattmeters.

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POWER FACTOR: Power factor of induction motor on NO-LOAD is very low because of the high value of magnetising current. With the increase in load the power factor increases because the power component of the current is increased. Low power factor operation is one of the disadvantages of induction motor. An induction motor draws heavy amount of magnetising current due to presence of air gap between the stator and rotor. Thus to reduce the magnetising current in induction motor the air-gap is kept as small is possible.

Input power factor can also be calculated from the readings of two wattmeters for balanced load. If p is the power factor angle, then

Tan p = √ 3 $\frac{(W1 – W2)}{W1 + W2}$

Knowing the power factor angle, p, from the above, power factor, cos p can be calculated. It may be noted clearly at this stage, that the power factor of the induction motor is very low at no load, hardly 0.1 to 0.25 lagging. As such, one of the wattmeter will record a negative reading, till the power factor is less than 0.5, which may be measured by revering the connection of either the current coil or pressure coil of this wattmeter.

EFFICIENCY:

Percentage efficiency of the motor, n = $\frac{\text{Output power}}{\text{Input power}}$ x 100

Full load efficiency of 3 phase induction motor lies in the range of 72 % (for small motors) to 82 % (for very large motors)

SPEED: When the induction motor is on NO-LOAD speed is slightly below the synchronous speed. The current due to induced emf in the rotor winding is responsible for production of torque required at NO-LOAD. As the load is increased the rotor speed is slightly reduced. The emf induced in the rotor causes the current increased to produce higher torque, untill the torque developed is equal to torque required by load on motor.

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PROCEDURE

1. The circuit is connected as sown in circuit diagram.
2. The auto transformer should be kept at minimum voltage position.
3. Break pulley arrangement is set for no load
4. Supply is given to the motor & increase the voltage applied to the rated value.
5. Note down the corresponding reading of ammeter, voltmeter and wattmeter.
6. Increase the mechanical load on the motor & note the reading. Repeat this for various load setting. (Sector current cannot exceed the load value.)

CIRCUIT DIAGRAM:
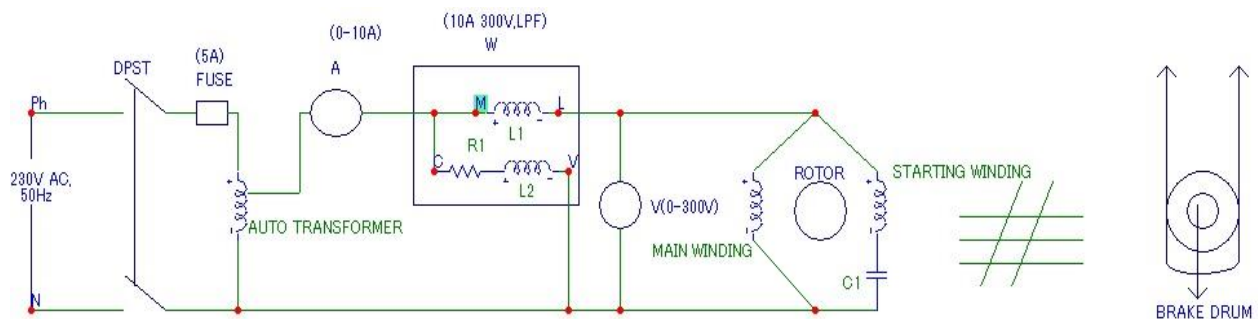
OBSERVATION TABLE
Diameter of the break drum:

Sl no.	Supply Voltage (V) in volts.	Input current(I) in Amps	Input Power (W) in Watt.	Speed (N) in R.P.M	Output Balance.		Torque in N-M (T)=(S1-S2)(D/2)^{x}9.8	Output Power(PO) in Watt 2PiNT/60	Power factor W/VI=COS$_\varphi$	Efficiency (PO/W) ^{x}100%
					S1 kgf	S2 kgf				

Calculation:

Torque in N-M (T) = (S1-S2)*(D/2)*9.8

Output Power in Watt (P_O) = 2PiNT/60

Power Factor (Cos $_\varphi$) = W/VI

Efficiency= (P_O/W)*100%

Report:

1. EFFICIENCY Vs OUTPUT POWER
2. TORQUE Vs OUTPUT POWER
3. CURRENT Vs OUTPUT POWER
4. CURRENT Vs OUTPUT POWER
5. TORQUE Vs SPEED

Conclusion :

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EXPERIMENT: To determine the direct axis reactance (Xd) and quadrature axis reactance (Xq) of a 3 Phase Synchronous Machine by Slip Test.

THEORY: From Open-circuit test and short circuit test of an alternator we can measure the d-axis Synchronous reactance (Xd).

Synchrous Impedance $Z_f = E_f/I_{sc}$

$$= \frac{\text{Open circuit terminal Voltage for a certain field current}}{\text{Short-circuit current for the same field current}}$$

The DC resistance of the stator winding can be calculated by ammeter-voltmeter method. The effective armature AC resistance per phase r_a is higher than the DC resistance. The value of DC resistance r_{dc} of one phase measured by voltmeter-ammeter and it may be multiplied by a factor of 1.3 to calculate the AC resistance r_a.

Now, $Z_s = \sqrt{(r_a^2 + X_d^2)}$

The synchronous reactance can thus be calculated as $Xd = \sqrt{(Z_s^2 - r_a^2)}$

The q-axis synchronous reactance can be measured by Slip test. The synchronous machine is driven a separate prime-mover (DC motor) at a speed slightly different from synchronous speed. The field winding is left open and positive sequence balance voltages of reduced magnitude (around 25% of rated values) and of rated frequency impressed across the armature terminals. Under this condition, the relative velocity between the field poles and the rotating armature m.m.f. waves is equal to difference between synchronous speed and the rotor speed, i.e. the slip speed. A small AC voltage across the open field winding indicates that the field poles and rotating m.m.f. wave, are revolving in the same direction and this is what is required in slip test. If field poles revolve in a direction opposite to the rotating m.m.f. wave, negative sequence reactance would be measured.

At one instant, when the peak of armature m.m.f. wave is in line with the field pole direct axis, the reluctance offered by the small air gap is minimum as shown in fig-l (a)
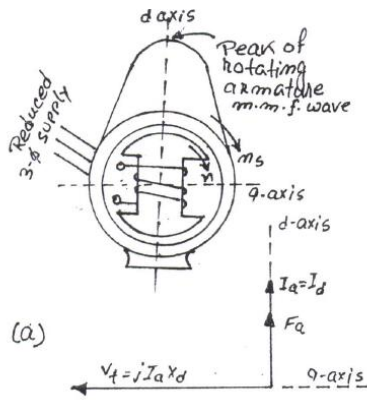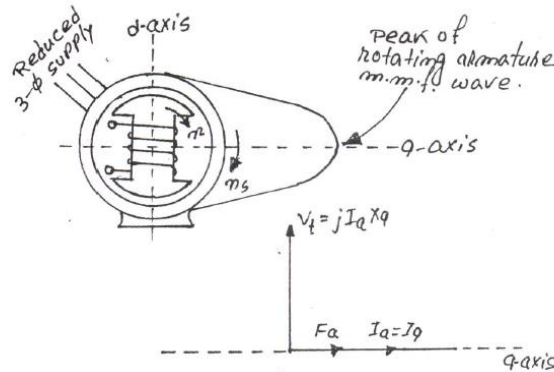
Fig 1(a)   **Fig 1(b)**

At this instant the impressed terminal voltage per phase divided by the corresponding armature current per phase, gives d-axis synchronous reactance (X_d). After one-quarter of slip cycle, the peak of armature m.m.f. wave acts on the interpolar or q-axis of the magnetic circuit. Figure-l (b) and the reluctance offered by long air gap is maximum. At this instant, the ratio of armature terminal voltage per phase to the corresponding armature current per phase, gives q-axis synchronous reactance Xq.

An Ammeter and a Voltmeter are used to measure the d-axis synchronous reactance and the q-axis synchronous reactance. The connection diagram shown in figure 3. The prime-mover (DC motor) speed is adjusted till ammeter and voltmeter pointers swing slowly between maximum and minimum value. Readings of both ammeter and voltmeter are recorded in order to determine Xd and Xq . Since the applied voltage is constant, the air- gap flux would be constant. When the rotating m.m.f.. Wave is in line with the field pole axis, figure-1(a), minimum air-gap offers minimum reluctance, consequently the armature current, required for the establishment of constant air-gap flux, must be minimum. Constant applied voltage minus the minimum impedance voltage drop in the leads and 3phase variac gives maximum armature terminal voltage. Thus the d-axis synchronous reactance is given by,

X_d = <u>Maximum armature terminal Voltage per phase</u>
        Minimun armature current per phase.

X_q = <u>Minimum armature terminal voltage per phase</u>
         Maximum armature current per phase.

During slip test, it would be observed that swing of the ammeter pointer is very wide, whereas the voltmeter has only small swing because of the low impedance voltage drop in the leads and 3phase variac. Since low armature terminal voltages are used, values of reactance's obtained are unsaturated values.

CIRCUIT DIAGRAM:
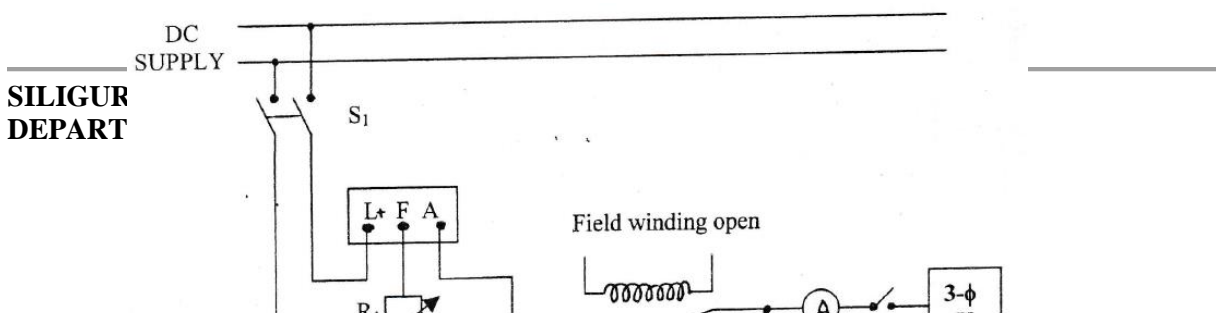
Fig 2. Connection diagram for determining the magnetization characteristic of an alternator.

APPARATUS REQUIRED:

Slno.	Name of Apparatus	Range	Make
1.	Synchronous Generator coupled with a DC motor.		
2.	3Point starter for DC motor		
3.	Field regulating resistance for the DC motor.		
4.	Tachometer.		
5.	Voltmeter, Moving iron type.		
6.	Ammeter, Moving iron type		
7.	Three-phase variac		

PROCEDURE:

1. Make connections as shown in figure-2. Start the DC motor with the help of starter and bring the speed of the set slightly different from synchronous speed. A little adjustment with the help of field regulating rheostat R1 may be necessary. The switch S2 of the alternator field circuit should remain open. Measure the value of induced emf when If = 0. The lowest range of the voltmeter should be used as the value of induced emf will be a few volts only.

2. Switch on the three phase AC supply for three phases variac. Apply a small balance three phase AC voltage (around 25%) across the armature terminal. Slightly adjust the speed of the prime mover so that the ammeter and voltmeter pointers swing slowly between maximum and minimum positions. Under this condition, maximum and minimum reading of both ammeter and voltmeter are recorded.

3. During this test, it would be observed that swing of the ammeter pointer is very wide whereas the voltmeter has only small swing.

4. From the readings of voltmeter and ammeter calculate the value of d-axis synchronous reactance and q-axis synchronous reactance.

OBSERVATIONS:

Sl no.	Reduced 3 phase supply(volts)	Voltmeter reading Max	Min	Ammeter reading Max	Min

CONCLUSIONS:

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EXPERIMENT NO. 11

NAME OF THE EXPERIMENT: LOAD TEST OF 3 PHASE WOUND ROTOR INDUCTION MOTOR TO OBTAIN PERFORMANCE CHARACTERISTICS

OBJECTIVE: To perform load test on three-phase induction motor and:

A) Compute torque, output power, input power and efficiency. Input power factor and

Slip for various load settings.

B) To plot the following curves from the data obtained part(a)

I) Efficiency Vs. output power

II) Torque Vs. output power

III) Line current Vs. output power

IV) Power factor Vs. output power

V) Slip Vs. output power

VI) Slip Vs. Torque

THEORY:

The result of a load test on induction motor helps us to compute the complete performance of induction motor. The complete performance of induction motor means to calculate the various quantities at different loading of the induction motor. These quantities are torque, slip, efficiency, power factor etc. During this test electricity at normal voltage and normal frequency is supplied to the motor and a variable mechanical load is applied to the shaft of the motor. Mechanical loading can be provided by break and pulley arrangement. The quantities like input current, input voltage, input power and the speed of the motor are observed from the experiment and the various performance quantities are calculated explained below.

Slip: Due to the three phases supply given to the starter of an induction motor a rotating magnetic field of constant magnitude is set up in the stator of the motor. The speed with

which this rotating magnetic field rotate is knows as synchronous speed N_S and the rotor speed N_R is known as slip and be mathematically defined as follows slip,
S= $[(N_S - N_R)/N_S]$ x 100 . The value of slip at full load lies between 2 to 5.

Torque: Mechanical loading is applied on induction motor by means of a drum coupled to the shaft of the motor. A belt is provided on this drum (break drum). The belt can be tightened or loosened by means of threaded rods with handles fixed on a frame. Two spring balance are provided at the ends of the belt. The net force exerted at the break drum can be obtained from the reading of the two spring balances i.e. S1 and S2.

Net force exerted on the drum W= (S1-S2) kgf, Torque, T=W x (D/2) x 9.8 N-m, where D= effective diameter of the break in meter.

Output power: The output power of the motor P_O can be calculated as $2\pi NT/60$ watts, where N= Speed of the motor in r.p.m.

Input Power: Input power P_i, can be calculated from the readings of two wattmeter's connected in the circuit, W1 and W2, $P_i = W1 + W2$.

It is important to note that one of the wattmeter may read negative. This happens at low power factor, under no load condition. In that case the connection of one coil should be reversed. Then the wattmeter will start giving positive reading however such a reading should be recorded as negative reading.

Input power factor: The power factor angle can be calculated from the reading of two wattmeter's using the following relation.

Once the angle phi (∅) is known, the power factor cos (∅) can be easily known,

Efficiency can be calculated using,

Efficiency= [Output power/Input power] x 100

The variation of above mentioned quantities with O/P power are shown in figure below.

APPARATUS:

SL NO.	DESCRIPTION OF ITEM	QTY	RANGE/RATING	MAKERS NAME	TAG NO/SERIAL NO.

CIRCUIT DIAGRAM:

LOAD TEST ON 3 PHASE INDUCTION MOTOR

PROCEDURE:-

i)   Make connection according to circuit diagram.
ii)   The phase variac is set for zero value, and break pulley arrangement is the set for no load.
iii) Three phase supply is given to the motor.
iv)   The three phase variac setting is increased slowly. The direction of deflection in wattmeter should be noted. At this stage one of the watt-meters may read negative is so, the switch off, the 3 phase variac setting is again brought to its minimum.
v)   Increase the voltage applied to its rated value.
vi)   Note down the reading. This is no load readings.
vii) Increase the mechanical on the motor and the readings. Repeat this for varies load setting (Stator current exceed the rated value 5 Amps).

viii)   At some stage one of the wattmeter may again start reading negative, and then repeat the step (4).

Table: - (for load test on three-phase induction motor)

Sl No.	Supply Voltage(V_L) In volts	Line Current $I_{L\,in}$ amps	Wattmeter Reading in watt		Output		Speed N_r in r.p.m
			W1	W2	Balance $S_{1(kgf)}$	Balance $S_{2(kgf)}$	

D=….............................m

Table-2(calculation of the performance of three- phase motor)

Sl. No.	Torque in power(W) T=(S1-S2)*D/2*9.8	Output power po= $2\Pi nt/60$ watt.	Slip(S)=(N_S - Nr)/N_s	Power factor	Efficiency(P_O/W)	Input Power (W)=W1+W2)Watt

CONCLUSION:

EXPERIMENT: To make connection diagram to full pitch & fractional slot winding of 18 slot squirrel cage Induction Motor for 6 pole & 4 pole operation

OBJECTIVE:

1. To study the connection diagrams of Squirrel Cage Induction Motor for 6 Pole & 4 Pole Operation.
2. To study the fractional slot winding of Squirrel Cage Induction Motor.
3. Speed Control of Squirrel Cage Induction Motor by Pole-changing method.

THEORY:

The speed of an induction motor $N = 120f/P$. If supply frequency is constant then the speed of the motor is inversely proportional to the number of poles. Therefore we can change the rotor speed of an induction motor by changing the number of pole. Here we attached different winding diagram for a' "three-phase 18 slots induction machine. Hence this is a double layer winding, therefore total numbers-of coil are 18 (i.e. number of slots is equal to number of coils). In double layer winding, all coils are of the same shape and size. Each coil has its one side in top half of one slot and other coil side in the bottom half of some other slot. Two end of each coil bought-out at a top Bakelite panel board for flexible connection.

The winding arrangement of different poles shown by a simple method, called *clock-diagram* method. The clock diagram, the arrangement of the coil-sides in both layers is illustrated.

The winding arrangement for N poles the phase belt = [S/PXN]

Where,   S = Number of slots
          P = Number of phase
          N = Number of poles.

Therefore winding arrangement of a 6 pole machine,

Phase belt = [18/3x6]
            = 1 (Therefore one coil makes a batch).

CONNECTION PROCEDURE:

For 6 pole connection:

Connect 1st phase in clockwise direction in such way that 1st coil bottom, connected with 4th coil bottom; 4th coil top, connected with 7th coil top. 7th coil bottom connected with 10th coil bottom; 10th coil top connected with 13th coil top. 13th coil bottom connected with 16th coil bottom. These six coils make of 1st phase group and make 1st coil top-end is A_1 and 16th coil Top End is A_2.

2nd phase connect in anticlockwise direction i.e. 2nd coil bottom connected with 17th coil bottom; 17th coil top connected 14th coil top. 14th coil bottom connect with 11th coil bottom; 11th coil top connected with 8th coil top. 8th coil bottom connected with 5th coil bottom and make 2nd phase group and make - : 2nd coil top is B_2 and 17th coil top is B_1.

Similarly, for 3rd phase connect in clockwise like as 1st phase group. 3rd, 6th, 9th, 12th, 15th and 18th coil connected in clockwise direction and make 3rd phase group and making 3rd top is C_1; and 18th coil top is C_2. Now short A_1, B_1 and C_1 for star connection.

Connect A_2, B_2 and C_2; with the output DOL starter at 400 volts supply, switch on the supply. Push the 'START' button of DOL starter. The machine runs at its rated rotor speed. Measure the speed by tachometer. Draw the connection diagram and note the rotor speed and calculate the slip of the motor.

For 4 pole connection:

Winding arrangement of a 4 poles machine,

Phase belt = [18/ (3x4)]

= 1.5(one and half coil make a batch.)

But practically l.5 coil is not possible. Therefore in each phase first batch make by two coils and second batch make by one coil then third batch make by two coils or vice-versa etc. This type of connection is called fractional slot winding.

Connect 1st phase in clockwise direction in such way that 1st coil bottom connect with 2nd coil top. 2nd coil bottom connect with 6th coil bottom. 6th coil top connect with 10th coil top.10th coil bottom connect with 11th coil top. 11th coil bottom connect with 15th coil bottom. These four coils batch make of 1st phase group and make 1st coil Top-End is A_1 and 15th coil Top- End is A_2.

2nd phase connect in anti clockwise direction i.e. 3rd coil bottom connected with 17th coil bottom. 17th coil top connected 16th coil bottom. 16th coil top connect with 12th coil top.12th coil bottom connect with 8th coil bottom. 8th coil top connect with 7th coil bottom. These four coil batch make 2nd phase group and make 3rd coil Top-End is B_2 and 7th coil Top-End is B_1.

Similarly, for 3rd phase connect in clockwise direction like in 1st phase group i.e 4th, 5th, 9th, 13th, 14th & 18th coil connected in clockwise direction and make 3rd phase group and making 4th top is C_1; and 18th coil top is C_2.

Now, short A_1, B_1 and C_1. For star connection. Connect A2, B2 and C2 with the output DOL starter at 400 volts supply. Switch on the supply. Push the 'START' button of DOL starter. The machine runs at its rated speed. Measure the speed by tachometer. Draw the connection diagram and note the rotor speed and calculate the slip of the motor.

OBSERVATION AND RESULT:

4 POLE OPERATION: Calculated synchronous of the rotor (N) =
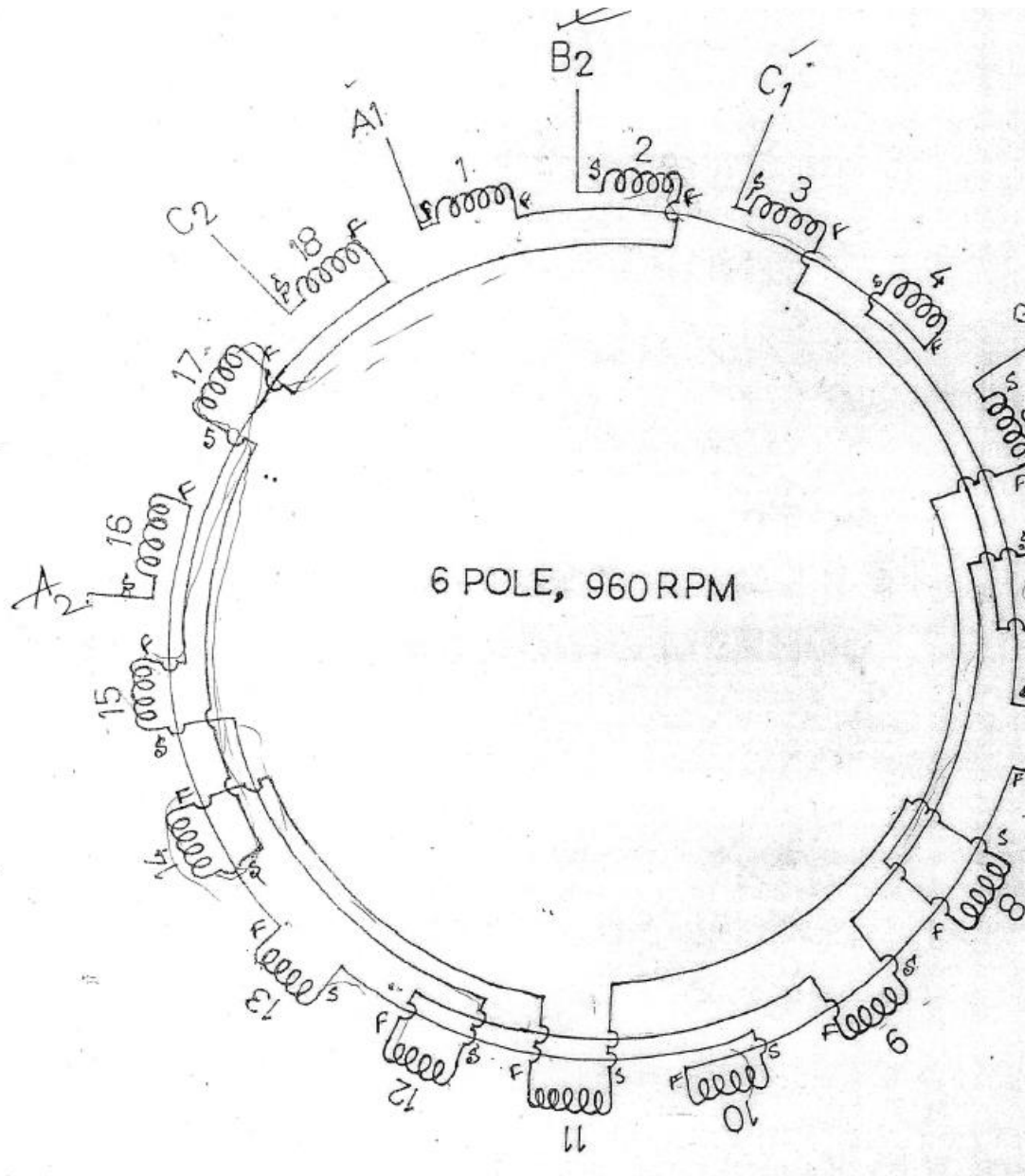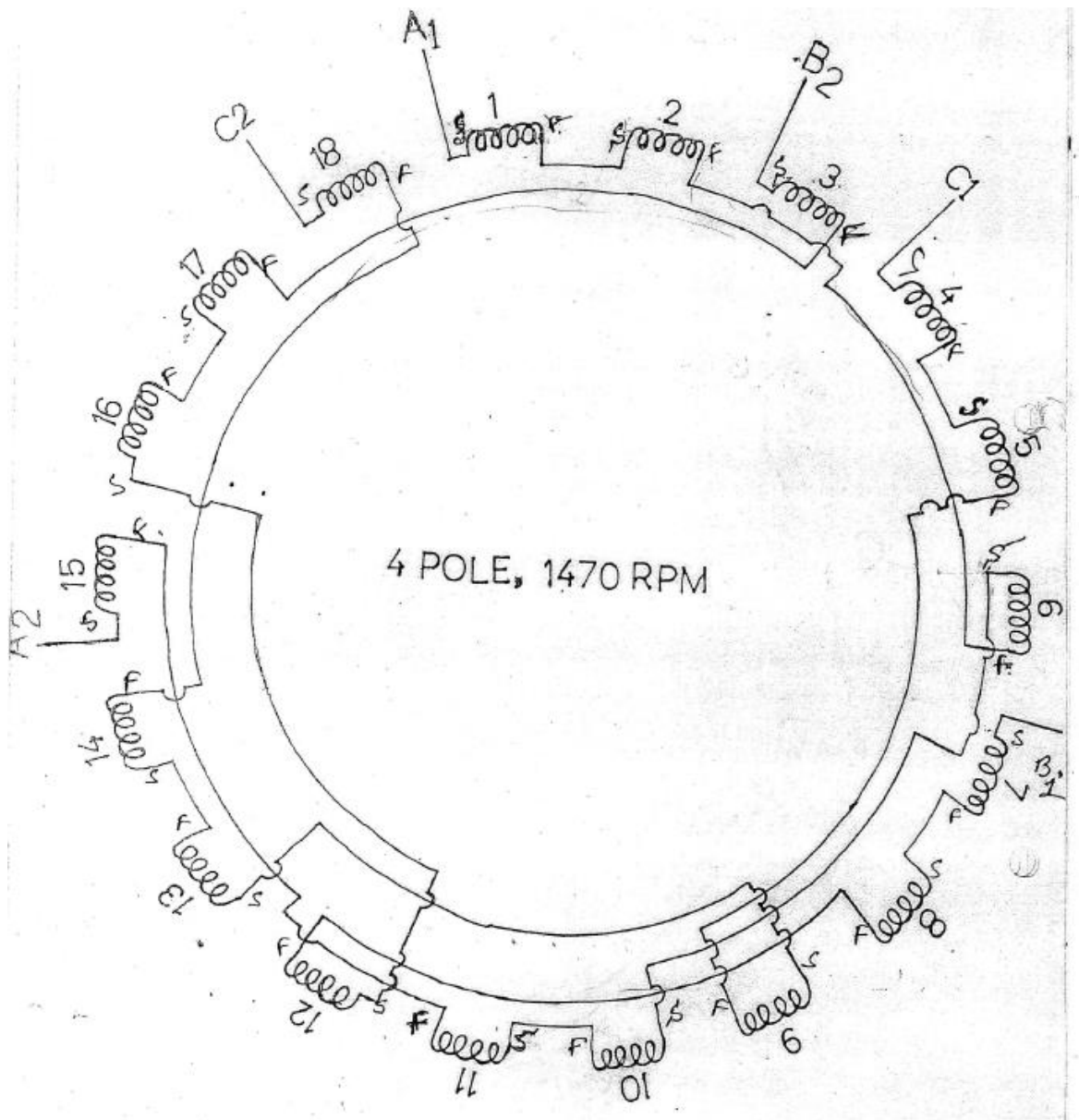
Measured speed of the rotor (R) =

Slip = (N-R)/N

6 POLE OPERATION:: Calculated synchronous of the rotor(N) =

Measured speed of the rotor (R) =

Slip = (N-R)/N

CONNCTION DIAGRAM OF 6 POLE AND 4 POLE OPERATIONS:

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6 POLE, 960 RPM

4 POLE, 1470 RPM

CONCLUSION:

NAME OF THE EXPERIMENT: **To study the performance of Induction Generator**

OBJECTIVE:
1. To study how an Induction motor operating as an induction generator.
2. To study how an Induction generator run in stand-alone mode and Grid connection mode.
3. To study the performance of induction generator.

THEORY:
An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor faster than the synchronous speed, giving negative slip. A regular AC asynchronous motor usually can be used as a generator, without any internal modifications. Induction generators are useful in applications such as mini-hydro power plants, wind turbines, or in reducing high-pressure gas streams to lower pressure, because they can recover energy with relatively simple controls.

Induction generators are often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying rotor speeds. Induction generators are mechanically and electrically simpler than other generator types. They are also more rugged, requiring no brushes or commutators

Induction generators are particularly suitable and usually used for wind generating stations as in this case speed is always a variable factor, and the generator is easy on the gearbox.

An induction generator must be excited with a leading voltage. This is usually done by connection to an electrical grid; sometimes, however, they are self-excited by using phase correcting capacitors.

Induction generators and motors produce electrical power when their rotor is turned faster than the synchronous speed. For a typical four pole motor (two pairs of poles on stator) operating on a 50 Hz electrical grid, the synchronous speed is 1500 rotations per minute.

PRINCIPLE OF OPERATION:
In normal motor operation, stator flux rotation is faster than the rotor rotation. This causes the stator flux to induce rotor currents, which create a rotor flux with magnetic polarity opposite to stator. In this way, the rotor is dragged along behind stator flux, at a value equal to the slip.

In generator operation, a prime mover (turbine, engine or DC Motor) drives the rotor above the synchronous speed. The stator flux still induces currents in the rotor, but since the opposing rotor flux is I now cutting the stator coils, an active current is produced in stator coils and the motor now operates as a generator, sending power back to the electrical grid.

EXCITATION:
Note that a source of excitation current for magnetizing flux (reactive power) for stator is still required, to induce rotor current. Induction generators are not, in general, self-exciting, meaning they require an electrical supply, at least initially, to produce the rotating magnetic flux (although in practice an induction generator will often self start due to residual magnetism). The electrical supply can be supplied from the electrical grid or, once it starts producing power, from the generator itself. The rotating magnetic flux from the stator induces currents in the rotor, which also produces a magnetic field. If the rotor turns slower than the rate of the rotating flux, the machine acts like an induction motor. If the rotor is turned faster; it acts like a generator, producing power.

ACTIVE POWER:
Active power delivered to the line is proportional to slip above the synchronous speed. Full rated power of the generator is reached at very small slip values (motor dependent typically 3%). At synchronous speed of 1500 rpm, generator will produce no power. When the driving speed is increased to 1560 rpm, full output power is produced.

A capacitor bank must supply reactive power to the motor when used in stand-alone mode. The reactive power supplied should be equal or greater than the reactive power that the machine normally draws when operating as a motor. Terminal voltage will increase with capacitance, but is limited by iron

saturation. In induction generators, the magnetizing flux is established by a capacitor bank connected to the machine in case of stand-alone system and in case of grid connection it draws magnetizing current from the grid. For a grid connected system, frequency and voltage at the machine will be dictated by the electric grid, since it is very small compared to the whole system. For stand-alone systems frequency and voltage are complex function of machine parameters, capacitance used for excitation, and load value and type.

OPERATING PROCEDURE:

1. Operating in stand-alone mode:

a) Connect DC Motor (As prime mover) and induction motor as per circuit diagram.

b) Start the DC motor with help of DC motor starter and run the motor 1500 RPM or slight below the l500 RPM with help of armature control rheostat.

c) Connect the three-phase Capacitor bank which is connecting parallel with the induction motor.

d) Observe that the induction generator induced the voltage which indicates the AC voltmeter.

e) Connect the three-phase resistive load step by step.

f) Record the reading of different parameter in observation table.

2. Operating in grid connection mode:

a) Connect DC Motor (As prime mover) and induction motor as per circuit diagram.

b) Start the DC motor with help of DC motor starter and run the motor 1500 RPM or slight below the 1500 RPM with help of armature control rheostat and observe the direction of rotation of the motor.

c) Stop the DC motor and run the induction motor with help of DOL starter and observe the direction of rotation. If direction of rotation of induction motor are same as DC motor then it is OK otherwise stop the motor and change any two phase of the motor.

d) Be careful that both of the motors (i.e. DC Shunt Motor and induction Motor) rotate in same Direction.

e) Start both of the motor and observe the resultant speed of the set.

f) Record different reading with help of the connecting meters.

g) Increase the speed of the DC motor (i.e. Prime mover) with help of rheostats (First control Armature connecting rheostat after that field control rheostat).

h) Record different reading in observation table.

INSTRUMENTS / APPARATUS REQUIRED:

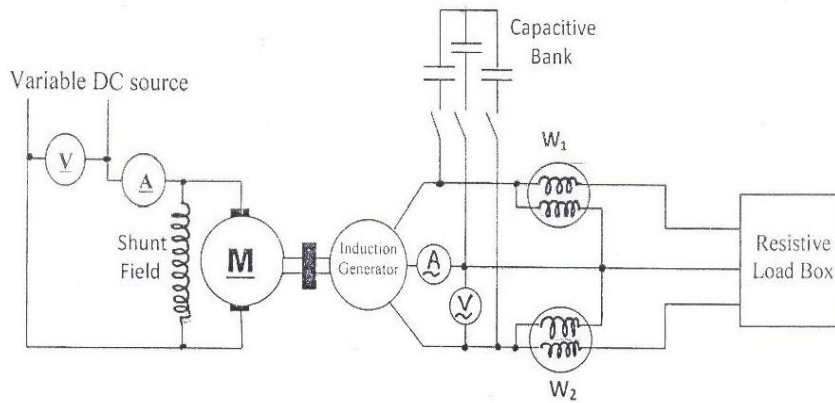| Sl. no	Name of the Instruments / Apparatus	Range/rating	quantity
1.	Dc shunt motor-Induction generator set		
2.	Variable Dc source for dc motor drive		
3.	Ac Voltmeter		
4.	DC Voltmeter		
5.	DC Ammeter		
6.	AC Ammeter		
7.	Digital Wattmeter		
8.	Three-Phase Ca active Bank		
9.	Three-Phase Resistive Load Bank		

INDUCTION GENERATOR RUNS IN STAND ALONE MODE:

Figure.1. Circuit diagram for induction generator run in standalone mode.
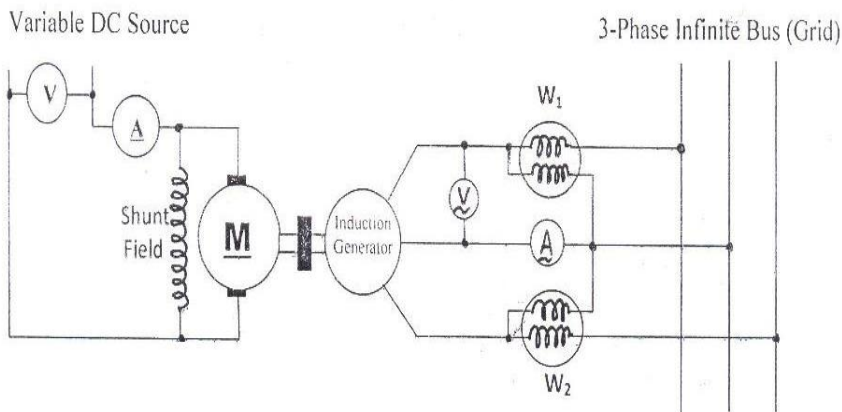
INDUCTION GENERATOR CONNECTS IN GRID:

Figure.2. Circuit diagram for induction generator run to connect in 3 phase grid

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OBSERVATION AND RESULT:

Table-1 (for standalone operation):

SL NO	For DC Motor (Prime Mover)			For Induction Generator				
	Dc voltage	Dc current	speed	Ac voltage	Ac current	Wattmeter reading		Capacitor reading
						W₁	W₂	

Table-2 (for grid connection operation):

SLNO	For DC Motor (Prime Mover)			For Induction Generator			
	Dc voltage	Dc current	speed	Ac voltage	Ac current	Wattmeter reading	
						W1	W2

CONCLUSION:

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EXPERIMENT NO. 14

NAME OF THE EXPERIMENT: **Parallel operation of three-phase synchronous generators.**

OBJECTIVE:
- i)   To synchronize a three-phase alternator with another three-phase alternator by Using Three-lamp method and synchroscope.
- ii)   To Study load sharing between the two three-phase alternators.

THEORY:

In power stations a number of alternators run in parallel. All the alternators are synchronized with a common bus-bar. The load is connected with the common bus-bar. The alternators running in parallel share the total load proportionate to their ratings. In the event of increased demand of load on a power station, additional generating sets are required to be connected in parallel with the bus-bar. Before an alternator can be connected in parallel with the bus-bar, it should be synchronized with the bus-bar. Synchronization can be done by using a synchroscope or by three-lamp method. The following conditions are to be fulfilled before connecting an alternator in parallel with others.

1. The phase sequence of the 'three phase alternator to be connected in parallel should be the same as that of the other alternators.
2. The voltage of the alternator should be the same as the other alternator voltage.
3. The frequency of induced emf of the alternator should be the same as the other alternator voltage frequency.
4. At the instant when the paralleling switch is enclosed, the voltage of the alternator should _ be in phase opposition to the other alternator voltage.

Three lamps method of synchronization:

Three pairs of lamps are connected between the alternator and bus-bar as shown in figure—l
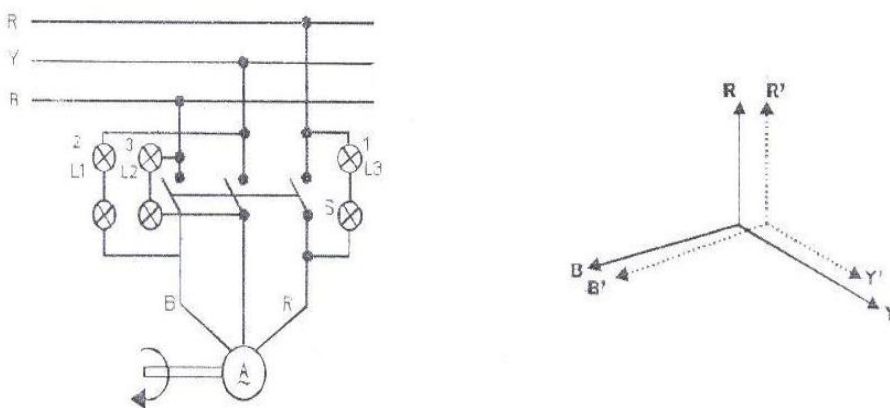
Fig 1: Synchronization of two 3-phase alternators

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Note that one pair of lamps are connected between the R-phase of the alternator and the R-phase ofthe bus-bar. Another pair of lamps is connected between the Y-phase ofthe alternator and the B- phase of the bus-bar. Two lamps of 230 volts rating are connected in series as the maximum voltage which will appear across the lamps will be the line voltage i.e. 400 volts. As each lamp is rated for 230 volts for safety reasons we need to, connect two lamps in series. When the alternator is brought to rated speed and provided with -excitation, voltages will be induced across the alternator terminals which can be made equal to the alternator voltage by adjusting the field excitation of the alternator. The three voltages of the two alternators to be paralleled are shown in figure. Phasors down in thick lines indicate the three phase voltage of the alternator. If all conditions of synchronization are fulfilled then the two sets of phasors will be at a particular instant of time. In positions as shown in figure-l at that instant the synchronizing switch can be closed and the alternator will run in parallel with the other alternator. To enable the incoming alternator to share load, however, the input to the alternator must be increased.

In the three lamp method of synchronization the lamps connected in phases RR will be dark whereas others two pairs of lamps YB & BY will bright as full line voltage will be appearing across them. Now, suppose the frequency of the incoming alternator is more than the bus-bar frequency. The lamps will darken in sequence 1 3 2 1 3 2---------- This will indicate that the speed of the alternator should be reduced. On the other hand if the frequency of the alternator is less than the bus-bar voltages than the lamps will darken is sequence 1 2 3 1 2 3---------- This will indicate that the speed of the alternator should be increased. The above is explained through series of phasor diagrams as shown in figure-2.
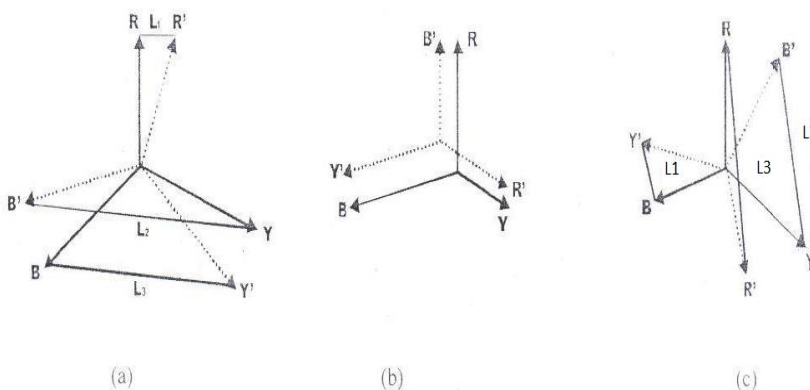
Figure-2.Phasor diagrams showing synchronization of a 3-phase alternator by three lamps method.

In figure-2(a) as voltages R' Y' B' are revolving faster than voltage R Y B, the voltages across lamps L1 and L2 are increasing whereas across L3 is decreasing. Therefore, lamp L3 will be becoming dark as shown in figure-2(b). In 2(c) voltages across L1 and L3, are increasing whereas voltage across L2 is decreasing. Thus, after lamp L3, lamp L2 will be dark. From the above it is seen that if the frequency of incoming alternator is higher than the bus-bar frequency then lamps will darken in the sequential 3 2 1 3 2-------. If the pointer of synchroscope is rotate first direction, it is indicate that the speed of the machine is high (i.e. frequency is high), If the rotate slow direction then the speed of the machine is slow (i.e. Frequency is slow). If the synchroscope's pointer is stand at 0 positions this is indicate that the frequency of the alternator is same as bus-bar frequency.

 After synchronizing an alternator, It is floating on the other alternator i.e. it if is neither delivering any power in the load/1st alternator nor neither receiving any power from the load/1stalternator.

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For sharing the load the excitation of the prime mover (i.e. D.C. Machine) may be increased slowly. In this condition the alternator shares the load. The total power share between the two alternators
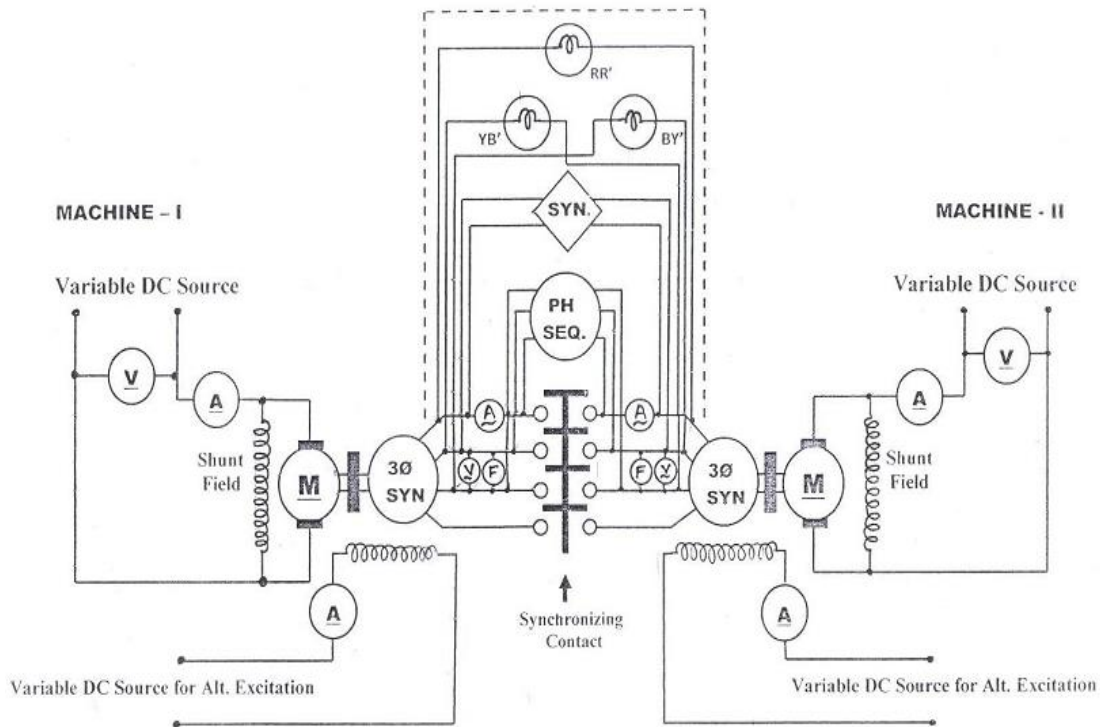
CONNECTION DIAGRAM:

Figure 3: Connection diagram for Parallel operation of two 3-phase Synchronous Machine

OBSERVATIONS &RESULTS:

BEFORE SYNCHRONIZTION:

Alternator - I			Alternator -II		
Voltage (LL)	Speed (RPM)	F1equency(Hz)	Voltage (LL)	Speed (RPM)	F1equency(Hz)

AFTER SYNCHRONIZING THE SHARING OF LOAD:

	SLNO	Load current (amps)	Current of alternator-I (amps)	Current of alternator-II (amps)
Increase the Speed of Machine-I	1. 2. 3. 4. 5.			
decrease the Speed of Machine-I	1. 2. 3. 4. 5.			
Increase the Speed of Machine-II	1. 2. 3. 4. 5.			
decrease the Speed of Machine-II	1. 2. 3. 4. 5.			

PROCEDURE:

1. Connect the DC Motor-Alternator Set-I & DC Motor-Alternator Set-ll and synchronizing panel as per circuit diagram.
2. Connect three-phase Load with load bus at synchronizing panel and all switches of load box at OFF position.
3. Switch ON the DC source of Set-I & Set the Variac knob at minimum position, Minimum indicator glow. Press the push bottom. The DC supplies are activating.
4. Increase the DC voltage slowly and run the DC motor at I500 RPM.
5. Increase the Excitation current of Alternator and set the voltage at 400V (LL).
6. Similar way starts the machine -II and set the speed at 1500 RPM and voltage 400V (LL).
7. Switch ON both three-phase AC with help of three-phase MCB on synchronizing panel.
8. Check the phase sequence of the both of the Alternators with help of the phase sequence meter (i.e Select the toggle switch as Alternator—l position and press the push button and observe the direction of Rotation. Either it clockwise or anticlockwise. Change the toggle switch at Alternator-ll position and Press the push button and observe the direction of rotation. Either it clockwise or anticlockwise. ll' both of the direction of rotation is same then phase sequence are same, if direction is reverse then there Sequence is not match. ln

this case change any two phases (re. R & Y or Y & B) of the Alternator-ll.

9. Switch ON the Synchroscope.
10. Now Adjust the speed of the Machine—ll so that the pair of lamps between RR' Connected to the identical phases will be dark and the other two pairs of lamps will be bright and the pointer of y the synchroscope is stand zero position.
11. This time also check the Voltage of two Alternators. These two voltages to be same.
12. Push the Synchronizing Push Bottom. Both of the Alternators is now synchronized.
13. Loading both of the alternators with help of loading Bus.
14. For sharing the load, increase the speed of the DC motor-l to increase the DC voltage of the motor.
15. Observe that the current of the Alternator-l increase and current of alternator-ll decrease but total load of the load-bus almost same.
16. Similarly decrease the speed of the DC motor-l to decrease the DC voltage of the motor.
17. Observe that the current of the Alternator-l decrease and current of alternator-ll increase but total load of the load-bus almost same.
18. Similarly sharing the load to change the speed of machine-ll.

CONSCLUSION:

EXPERIMENT NO. 15

NAME OF THE EXPERIMENT: V CURVE OF A SYNCHRONOUS MOTOR.

OBJECTIVE:
i)   To determine how armature current and power factor of a synchronous machine varies with change the excitation current.
ii)   ii) To draw the V curve & inverted V curve of a synchronous motor at various loads.

BRIEF THEORY: A Synchronous motor is a double-excited machine; its armature winding is energized from an AC source and its field winding from DC source. When synchronous motor is working at constant applied voltage, the resultant air gap flux demanded by applied voltage remains constant. This resultant air gap flux is established by both AC in armature winding and DC in the field winding. If the field current is sufficient enough to set up the air-gap flux, as demanded by constant applied voltage then magnetizing current or lagging reactive VA required from the AC source is zero and therefore motor operates at unity power factor. This field current, which causes unity power factor operation of the synchronous motor; is called normal excitation or normal field current. If the current less than the normal excitation, i.e. the motor is under excited, then the deficiency in flux must be made up by the armature winding m.m.f In order to do the needful, the armature winding draws a magnetizing current or lagging reactive VA from the AC source and as a result of it, the motor operates at a lagging power factor.

In case the field current is made more than its normal excitation, i.e. the motor is over-excited, operates at leading power factor.

Excitation can be increased by increasing the field current passing through the field winding of synchronous motor. If graph of armature current drawn by the motor (I,) against field current (If) is plotted, then its shape looks like an English alphabet V. If such graphs are obtained at various load conditions we get family of curves, all looking like V. Such curves are called V-curves of synchronous motor.

As against this, if the power factor (cos (φ)) is plotted against field current (I_f), then the shape of the graph looks like ... nditions are called In...
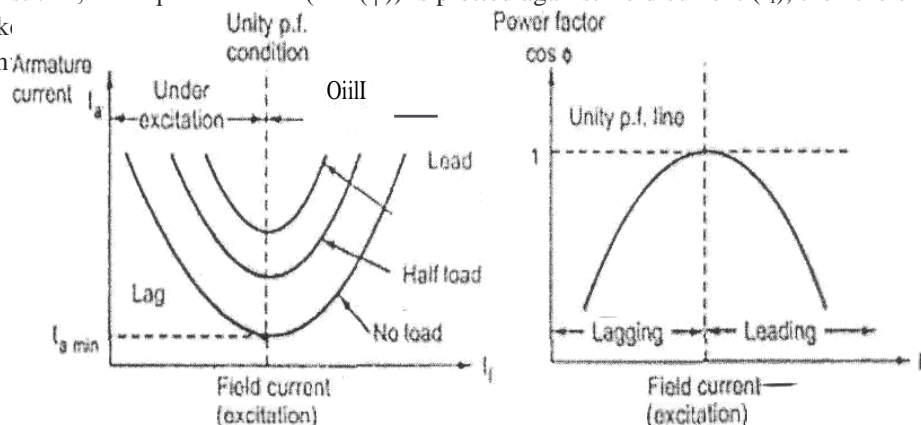
Figure -1. V Curve & Inverted V curve of Synchronous motor.

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APPARATUS USED:

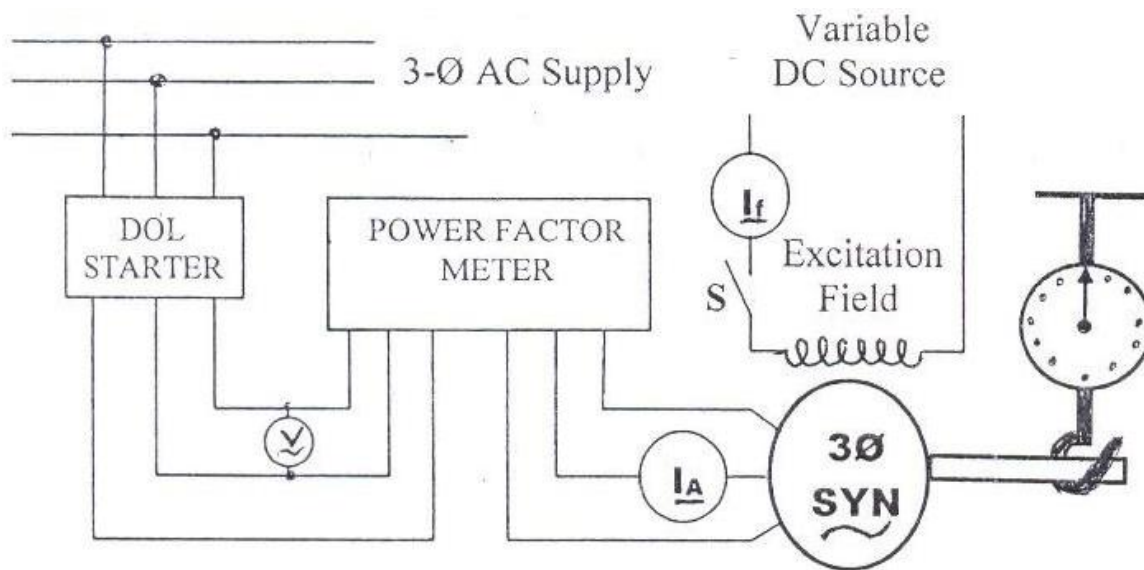| SLNO.	NAME OF THE INSTRUMENTS/APPARATUS	RANGE/RATING	MAKERS
1	3-Phase Synchronous Motor with Load		
2	DOL Starter		
3	Digital AC Ammeter		
4	Digital AC Voltmeter		
5	Digital DC Ammeter		
6	Digital Power-Factor Meter		
7	Digital RPM Meter		

CIRCUIT DIAGRAM:

Figure-2; Circuit Diagram to draw the V curve & inverted V curve of a synchronous motor.

PROCEDURE:

1. Make connections as per circuit diagram shown in figure -2.
2. Start the synchronous machine as an induction motor. (I.e. Field circuit is open).
3. Closed the Field circuit of the synchronous machine. The motor will now running as synchronous speed.
4. Increase the field current to its maximum permissible value by varying the field control DC supply.

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5. Reduce the, field current, If step by step and record value of I_f and I_A in a tabular form. While reducing I_f from its maximum value it would be observed that the value of armature current Ia will be decreasing and come to a minimum value and then again increasing. The range of variation of excitation current should be such that it does not cause excessive current.

6. Take the reading of Excitation current, Synchronous motor current, Power Factor and put in on observation table.

7. Load the Generator and the entire procedure can be repeated for various load conditions.

OBSERVATION AND RESULT:

SL NO.	Excitation Current (If) Amp.	Motor Armature Current (I_A)	Power Factor (Cosφ)
1			
2			
3			
4			
5			
6			

The graph can be plotted from this result table:

1) Ia VS I_f V-curve

2) cos (I) VS I_f Inverted V-curve

CONCLUSION:

EXPERIMENT NO. 1

STUDY OF THE CHARACTERISTICS OF AN SCR

Objectives:
- To study the output and gate characteristics of SCR and to determine the holding current.

APPARATUS USED: CT-PEL-1

THEORY:

Silicon Controlled Rectifier (SCR) is a unidirectional power switch which has three P-N junctions (P-N-P-N). It has three electrodes: Cathode (K), Anode (A) and Gate (G).

In the forward biased condition, (i.e., positive V_{AK}) if positive current is applied to the gate (i.e., positive I_G) the SCR is turned on. Once it starts conducting the gate loses control and even if the gate voltage is removed, the Anode current (I_{AK}) does not fall. The only way to stop conduction is to reduce the applied voltage (V_{AK}) to zero.

In the reverse biased condition, (i.e., negative V_{AK}) no current flows between the Anode   and Cathode except for the leakage current. This is known as reverse blocking.

Holding current is the minimum value of Anode current, necessary to keep the SCR conducting without any gate current.

CIRCUIT DIAGRAM:
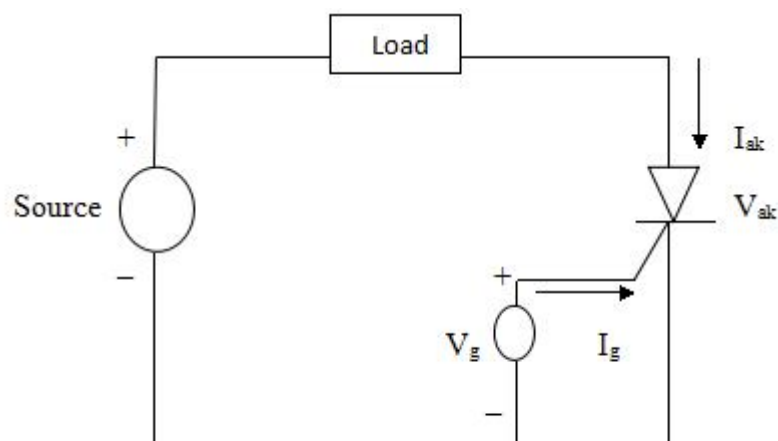
Fig.1.1: Circuit Diagram for Output Characteristics of SCR

PROCEDURE :

Experiment 1: Gate Characteristics.

1. Turn the Low Voltage Power Supply (10V) Knob to minimum.
2. Switch on the power to the kit.
3. Connect Low Voltage Power Supply (+) to the Gate (G) of SCR.
4. Connect Low Voltage Power Supply (-) to the Cathode (K) of SCR.
5. Increase the gate current I_G in steps of 0.5mA and note V_{GK} for different values of I_G.

Sl No.	I_G(mA)	V_{GK}(V)

Experiment 2: Output Characteristics.

1. Turn on High Voltage Power Supply (300V) Knob to minimum.
2. Turn on Low Voltage Power Supply (10V) Knob to minimum.
3. Switch on the power to the kit.
4. Switch the V_{AK} Voltmeter to Normal.
5. Switch the I_{AK} Ammeter to μA.
6. Connect High Voltage Power Supply (+) to one end of the resistance load.
7. Connect High Voltage Power Supply (-) to the Cathode of SCR.
8. Connect Anode (A) of SCR to other end of the Resistance load.
9. Connect the Gate of SCR to Cathode (K) of the SCR.
10. Increase the High Voltage Power Supply in steps of 20V (V_{AK}) and note the reading of I_{AK}. Switch the I_{AK} Ammeter to mA when the value goes out of range.
11. Turn the High Voltage Power Supply (300V) Knob to zero and wait for the voltage to reach zero.
12. Remove Gate (G) and Cathode (K) connection.
13. Connect Low Voltage Power Supply (+) to the Gate (G) of SCR.
14. Connect Low Voltage Power Supply (-) to the Cathode (K) of SCR.
15. Set the Gate current I_G to 1mA.
16. Repeat Step 10 for I_G = 1, 2, 3, 3.1, 3.2, 3.3, 3.4 & 3.5 mA.
17. Repeat the experiment for reverse biased condition by exchanging the High Voltage Power Supply terminals.

Sl No.	I_G(mA)	V_{AK}(V)	I_{AK}(mA)

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Experiment 3: Determination of Holding Current(I_H).

1. Turn on High Voltage Power Supply (300V) Knob to minimum.
2. Turn on Low Voltage Power Supply (10V) Knob to minimum.
3. Switch on the power to the kit.
4. Switch the V_{AK} Voltmeter to Normal.
5. Switch the I_{AK} Ammeter to µA.
6. Connect High Voltage Power Supply (+) to one end of the resistance load.
7. Connect High Voltage Power Supply (-) to the Cathode of SCR.
8. Connect Anode (A) of SCR to other end of the Resistance load.
9. Connect Low Voltage Power Supply (+) to the Gate (G) of SCR.
10. Connect Low Voltage Power Supply (-) to the Cathode (K) of SCR.
11. Set the Gate current I_G to 4mA.
12. Increase the High Voltage Power Supply V_{AK} (V) so that SCR turns on (i.e. I_{AK} shall be a few mA).
13. Remove the Low Voltage Power Supply from the Gate circuit.
14. Slowly decrease V_{AK} till the SCR turns off and not the last value of I_{AK} while the SCR was in the on state.
15. Holding Current (I_H) is the value of I_{AK}.

GRAPHS:

1. Plot I_G vs. V_{GK}.
2. Plot V_{AK} vs. I_{AK}.

CONCLUSION:

QUESTIONS:

1. Why is V_{bo} greater than V_{BR}?

2. Differentiate between holding and latching currents?

3. Why should the gate signal be removed after turn on?

4. What is latching and holding current?

EXPERIMENT NO. 2

STUDY OF THE CHARACTERISTICS OF A TRIAC

Objectives:
- To study the output and gate characteristics of TRIAC and to determine the holding current.

APPARATUS USED: CT-PEL-2

THEORY:

TRIAC is a bi-directional bilateral switching device, which has four P-N junctions (N-P-N-P-N). It has three electrodes: Main Terminal 1 (MT_1), Main Terminal 2 (MT_2) & Control Electrode/Gate (**G**).

A TRIAC can be turned on at any biasing condition (i.e., both positive V_T and negative V_T) by a positive or negative voltage or trigger pulse applied to **G** with respect to MT_1. Once the TRIAC starts conducting the gate loses all control and even if the Gate voltage is removed, the TRIAC current (I_T) does not decrease. The only way to stop conduction is to reduce the applied voltage (V_T) to less than or equal to zero.

Holding current is the minimum value of TRIAC current, necessary in the TRIAC circuit to keep the TRIAC conducting with gate open.

CIRCUIT DIAGRAM:
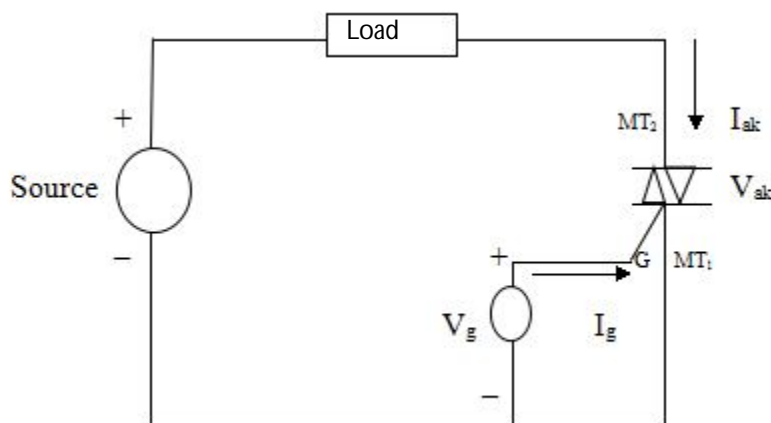
Fig.2.1: Circuit Diagram for Output Characteristics of TRIAC

PROCEDURE :

Experiment 1: Gate Characteristics.

1. Turn the High Voltage Power Supply (300V) Knob to zero.
2. Turn the Low Voltage Power Supply (10V) Knob to minimum.
3. Switch on the power to the kit.

4.Connect Low Voltage Power Supply (+) to the Gate (G) of TRIAC.

5. Connect Low Voltage Power Supply (-) to MT_1 of TRIAC.

6. Increase the gate current I_G in steps of 0.5mA and note V_{GT1} for different values of I_G.

Sl No.	I_G(mA)	V_{GT1} (V)

Experiment 2: Output Characteristics.

1. Turn on High Voltage Power Supply (300V) knob to zero.
2. Turn on Low Voltage Power Supply (10V) knob to minimum.
3. Switch on the power to the kit.
4. Switch the V_T Voltmeter to Normal.
5. Switch the I_T Ammeter to µA.
6. Connect High Voltage Power Supply (+) to one end of the resistance load.
7. Connect High Voltage Power Supply (-) to the MT_1 of TRIAC.
8. Connect MT_2 of TRIAC to other end of the Resistance load (i.e., +ve V_T).
9. Connect the Gate (G) of the TRIAC to MT_1 of TRIAC.
10. Increase the High Voltage Power Supply in steps of 20V (V_T) and note the reading of I_T. Switch the I_T Ammeter to mA when the value goes out of range.
11. Turn the High Voltage Power Supply (300V) Knob to zero and wait for the voltage to reach zero.
12. Remove Gate (G) and MT_1 connection.
13. Connect Low Voltage Power Supply (+) to the Gate (G) of TRIAC.
14. Connect Low Voltage Power Supply (-) to the MT_1 of TRIAC (i.e., positive I_G).
15. Set the Gate current I_G to 1mA.
16. Repeat Step 10 for I_G = 1, 2, 3, 3.1, 3.2, 3.3, 3.4 & 3.5 mA.
17. Repeat the experiment by exchanging the High Voltage Power Supply terminals and Gate power supply unchanged (i.e. negative V_T & positive I_G).
18. Repeat the experiment by exchanging the High Voltage Power Supply terminals and Gate power supply unchanged (i.e. positive V_T & negative I_G).
19. Repeat the experiment by exchanging the High Voltage Power Supply terminals and Gate power supply unchanged (i.e. negative V_T & negative I_G).
20. Switch off the supply.

Sl No.	I_G(mA)	V_T(V)	I_T(mA)

Experiment 3: Determination of Holding Current(I_H).

1. Turn on High Voltage Power Supply (300V) Knob to zero.
2. Turn on Low Voltage Power Supply (10V) Knob to minimum.
3. Switch on the power to the kit.
4. Switch the V_T Voltmeter to Normal.
5. Switch the I_T Ammeter to μA.
6. Connect High Voltage Power Supply (+) to one end of the resistance load.
7. Connect High Voltage Power Supply (-) to the **MT₁** of TRIAC.
8. Connect the **MT₂** of TRIAC to other end of the Resistance load.
9. Connect Low Voltage Power Supply (+) to the Gate (G) of TRIAC.
10. Connect Low Voltage Power Supply (-) to the **MT₁** of TRIAC.
11. Set the Gate current I_G to 4mA.
12. Increase the High Voltage Power Supply V_T so that TRIAC turns on (i.e. I_T shall be a few mA).
13. Remove the Low Voltage Power Supply from the Gate circuit.
14. Slowly decrease V_T till the TRIAC turns off and not the last value of I_T while the TRIAC was in the on state.
15. Holding Current (I_H) is the value of I_T.
16. Repeat the experiment by exchanging the High Voltage Power Supply terminals (i.e. –ve V_T) to determine the value of the Holding Current (I_H) for reverse I_T.
17. Switch off the supply.

GRAPHS:

3. Plot **I_G** vs. **V_{GT1}**.
4. Plot **V_T** vs. **I_T** (for **MT₂** +ve and –ve)

QUESTIONS:

1. What is power electronics?

2. What are the types of converter in power electronics?

3. What is break over voltage?

4. What is forward bias and reverse bias?

5. What is firing angle?

CONCLUSION:

EXPERIMENT NO. 8

STUDY OF PERFORMANCE OF SINGLE PHASE CONTROLLED CONVERTER WITH AND WITHOUT SOURCE INDUCTANCE (SIMULATION).

Objectives:
- To verify the full-controlled converter operation with and without source inductances and its different waveforms.

SOFTWARE USED: OrCAD 16.6 LITE

APPARATUS USED: Personal Computer.

THEORY: Rectification is a process of converting an alternating current or voltage into a direct current or voltage. The 1-phase fully controlled bridge circuit with R-L load is discussed here.

Without Source Inductance

Mode 1: During the positive half cycle of the supply voltage, the thyristors XT1 and XT3 are in the forward biased condition and the thyristors XT2 and XT4 are in the reverse biased condition. To ensure simultaneous firing of XT1, XT3 pair and XT2, XT4 pair during positive and negative half cycles of the supply voltage respectively they should be triggered from same firing circuit.

In this mode, XT1 and XT3 conduct. The load current follows the direction as shown below.

$$VIN^{+}\text{-}XT1\text{-}L1\text{-}R1\text{-}VIN^{-}$$

At the instant the supply voltage gets reversed but to the presence of larger value of lode inductance, the current (load) is maintained in the same direction with a constant magnitude. Hence, the thyristors XT1 and XT3 are in the conducting state though the supply voltage reaches zero.

Mode 2: During the negative half cycle of the supply voltage, the thyristors XT2 and XT4 are triggered simultaneously at an instant the thyristors XT1 and XT3 are commutated by the negative line voltage which reverse biases them through the thyristors XT2 and XT4 respectively. In this mode, the current follows the path as shown.

N-T3-P-load-R-T4-L

At the instant the thyristors XT2 and XT4 are still in the conducting state due to the presence of load inductance as described above.

With Source Inductance

The commutation of the conducting thyristors XT3 and XT4 stars when the thyristors XT1, XT2 are triggered at a firing angle ''. Due to the presence of source inductance, the load current flowing through thyristors XT3, XT4 reduces gradually to a zero value from the initial value I_0

and the load current through thyristors XT1, XT2 increases gradually to 'I_0' from zero value. During this process, there occurs an overlapping period.

Source Inductance:

Actually, in practice, inductance and resistance must be present in the supply source, and time is required for a current change to take place. The net result is that the current commutation is delayed, as it takes a finite time for the current to decay to zero in the outgoing thyristors, while the current will rise at the same rate in the incoming thyristors. Thus the commutation process may occupy a quite significant time, during which both the incoming and outgoing thyristors are simultaneous in conduction. This period at which both the thyristors is in conduction, is known as the overlap period and the angle for which both devices share conduction is known as the overlap angle or commutation angle.

CIRCUIT DIAGRAM:
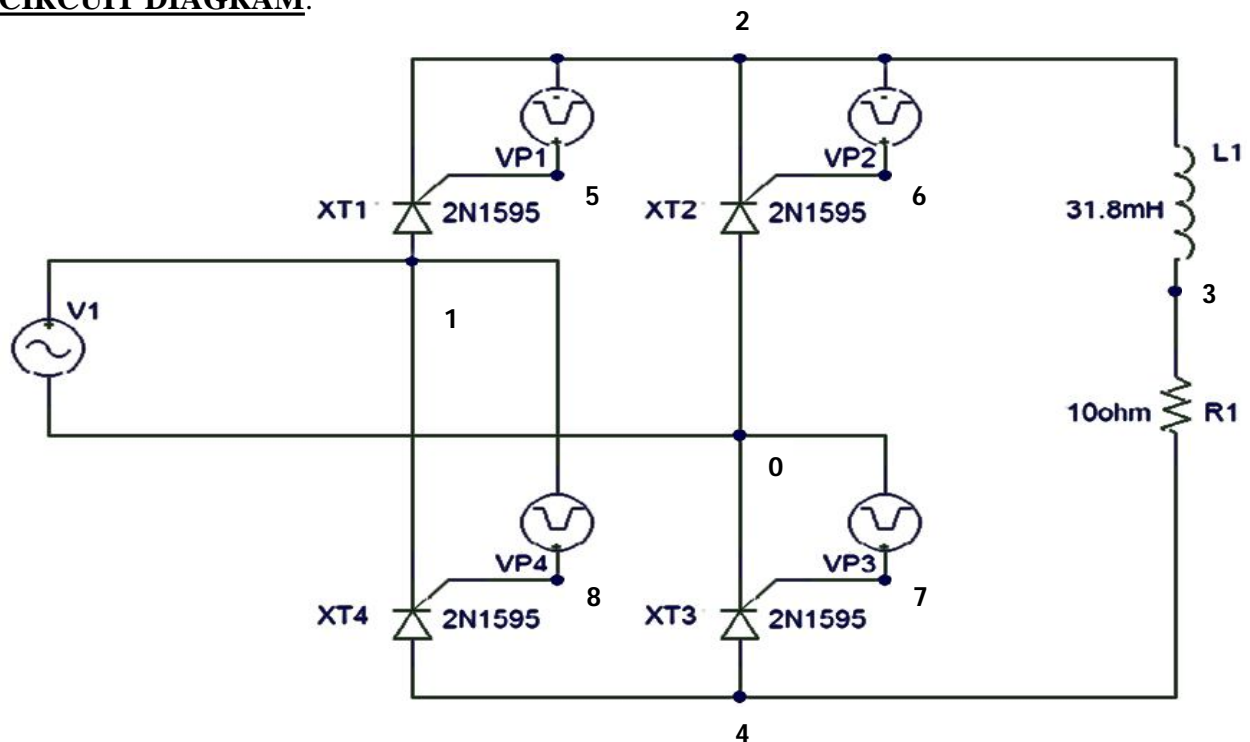
Fig. 8.1: Full wave bridge rectifier without source inductance

```
* Full-wave Bridge Rectifier with a resistive inductive load
VIN 1 0 SIN(0 340V 50Hz)
XT1 1 2 5 2 SCR
XT2 0 2 6 2 SCR
XT3 4 0 7 0 SCR
XT4 4 1 8 1 SCR
VP1 5 2 PULSE(0 10 1667U 1N 1N 100U 20M)
```

```
VP2 6 2 PULSE(0 10 11667U 1N 1N 100U 20M)
VP3 7 0 PULSE(0 10 1667U 1N 1N 100U 20M)
VP4 8 1 PULSE(0 10 11667U 1N 1N 100U 20M)
L1 2 3 31.8M
R1 3 4 10
* Subcircuit for SCR
.SUBCKT SCR 101 102 103 102
S1 101 105 106 102 SMOD
RG 103 104 50
VX 104 102 DC 0
VY 105 107 DC 0
DT 107 102 DMOD
RT 106 102 1
CT 106 102 10U
F1 102 106 POLY(2) VX VY 0 50 11
.MODEL SMOD VSWITCH(RON=0.0105 ROFF=10E+5 VON=0.5 VOFF=0)
.MODEL DMOD D(IS=2.2E-15 BV=1200 TT=0 CJO=0)
.ENDS SCR
.TRAN 10US 60.0MS 0.0MS 10US
.FOUR 50 V(2,4) I(VIN)
.PROBE
.OPTIONS(ABSTOL=1N RELTOL=.01 VNTOL=1MV)
.END
```

PROCEDURE :

1. Open PSPICE AD Student.
2. Click File-New-Text File.
3. Write down the simulation program.
4. Save the program as Circuit File (.cir).
5. Run.
6. Click Add Trace.
7. Trace the required waveform.
8. Click on View Simulation Output File.
9. Write down the results.
   - i)   V(2,4), The waveform of voltage at the output of bridge
   - ii)   I(L1), The waveform of load current

The waveform of voltage at the output of bridge
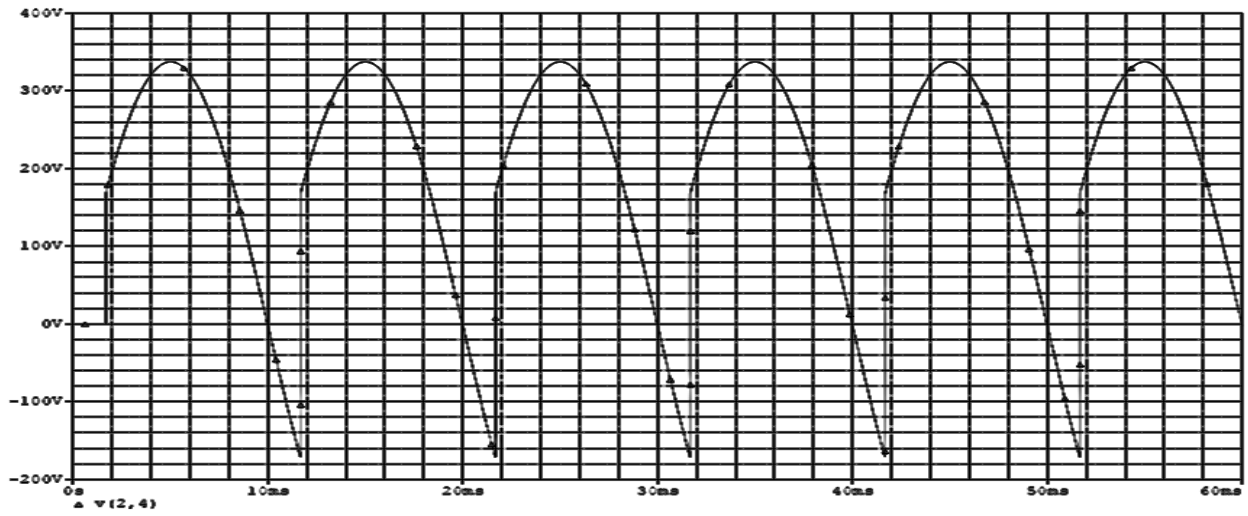
I(L1), The waveform of load current
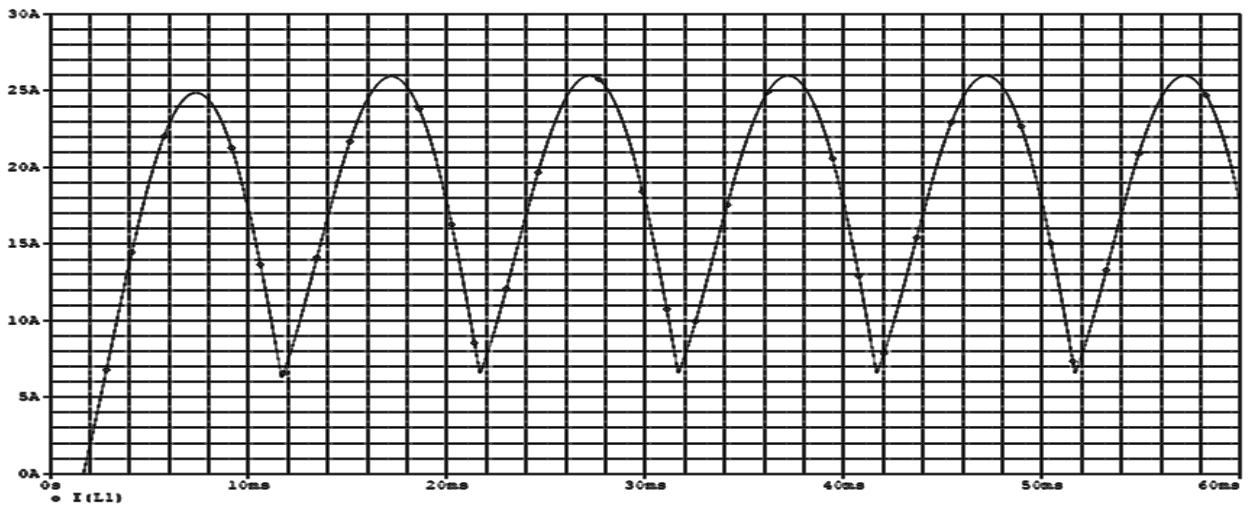
With Source Inductance circuit diagram
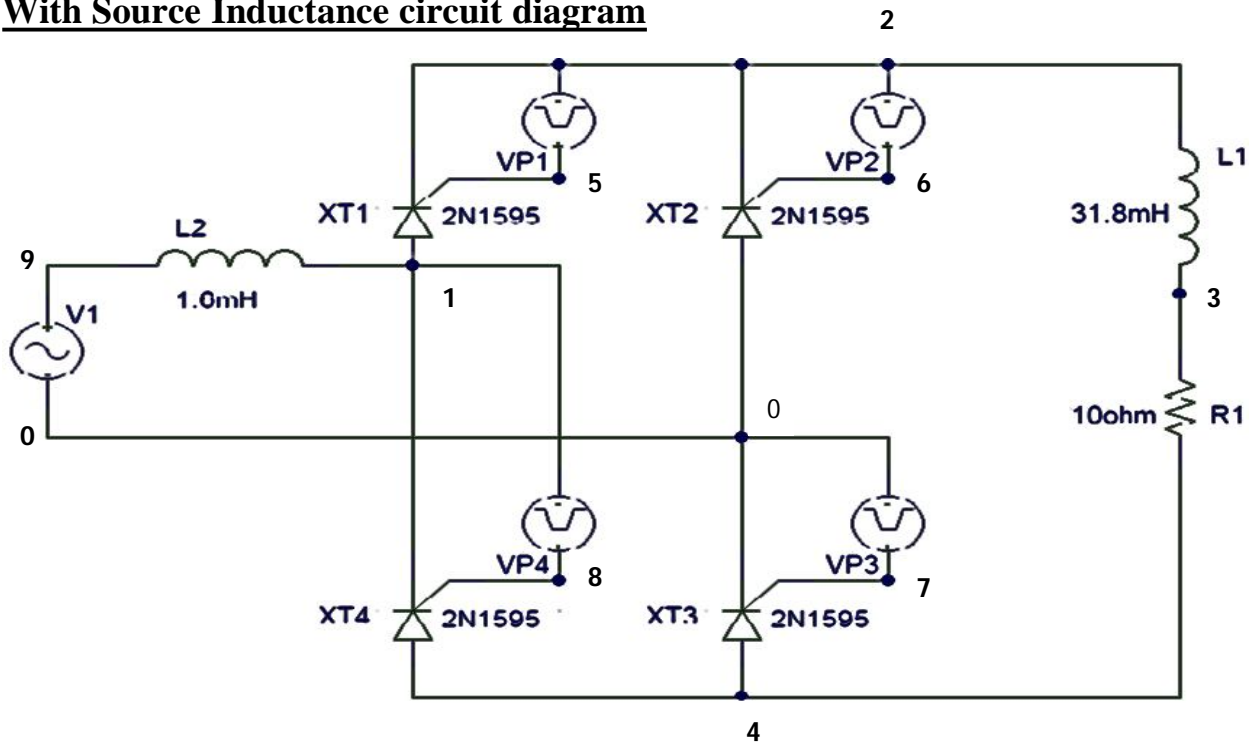
Fig.8.2: Full bridge rectifier with source inductance

* Full-wave Bridge Rectifier with RL Load and source Inductance

VIN 9 0 SIN(0 340V 50Hz)

XT1 1 2 5 2 SCR

XT2 0 2 6 2 SCR

XT3 4 0 7 0 SCR

XT4 4 1 8 1 SCR

VP1 5 2 PULSE(0 10 1667U 1N 1N 100U 20M)

VP2 6 2 PULSE(0 10 11667U 1N 1N 100U 20M)

VP3 7 0 PULSE(0 10 1667U 1N 1N 100U 20M)

VP4 8 1 PULSE(0 10 11667U 1N 1N 100U 20M)

L1 2 3 31.8M

L2 1 9 1.6M

R1 3 4 10

* Subcircuit for SCR

.SUBCKT SCR 101 102 103 102

S1 101 105 106 102 SMOD

RG 103 104 50

VX 104 102 DC 0

VY 105 107 DC 0

DT 107 102 DMOD

RT 106 102 1

CT 106 102 10U

F1 102 106 POLY(2) VX VY 0 50 11

.MODEL SMOD VSWITCH(RON=0.0105 ROFF=10E+5 VON=0.5 VOFF=0)

.MODEL DMOD D (IS=2.2E-15 BV=1200 TT=0 CJO=0)

.ENDS SCR

.TRAN 10US 60.0MS 0.0MS 10US

.FOUR 50 V(2,4) I(VIN)

.PROBE

.OPTIONS(ABSTOL=1N RELTOL=.01 VNTOL=1MV)

.END

PROCEDURE :

10. Open PSPICE AD Student.
11. Click File-New-Text File.
12. Write down the simulation program.
13. Save the program as Circuit File (.cir).
14. Run.
15. Click Add Trace.
16. Trace the required waveform.
17. Click on View Simulation Output File.
18. Write down the results.
    i)   V(2,4), The voltage output of the bridge
    ii)   I(L1), The waveform of load current

The voltage output of the bridge
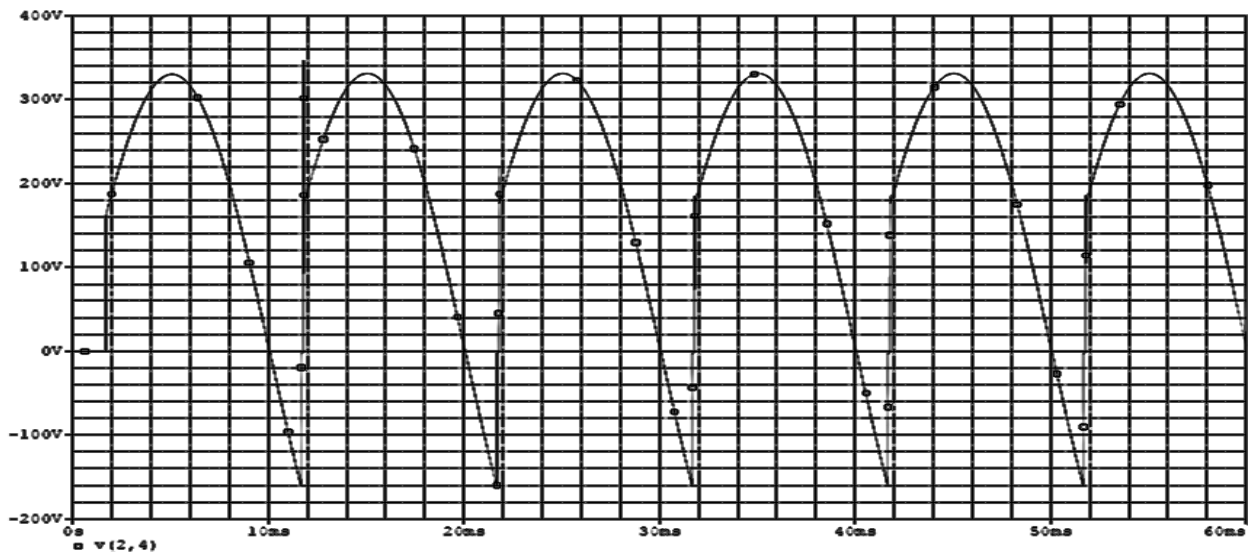
The waveform of load current
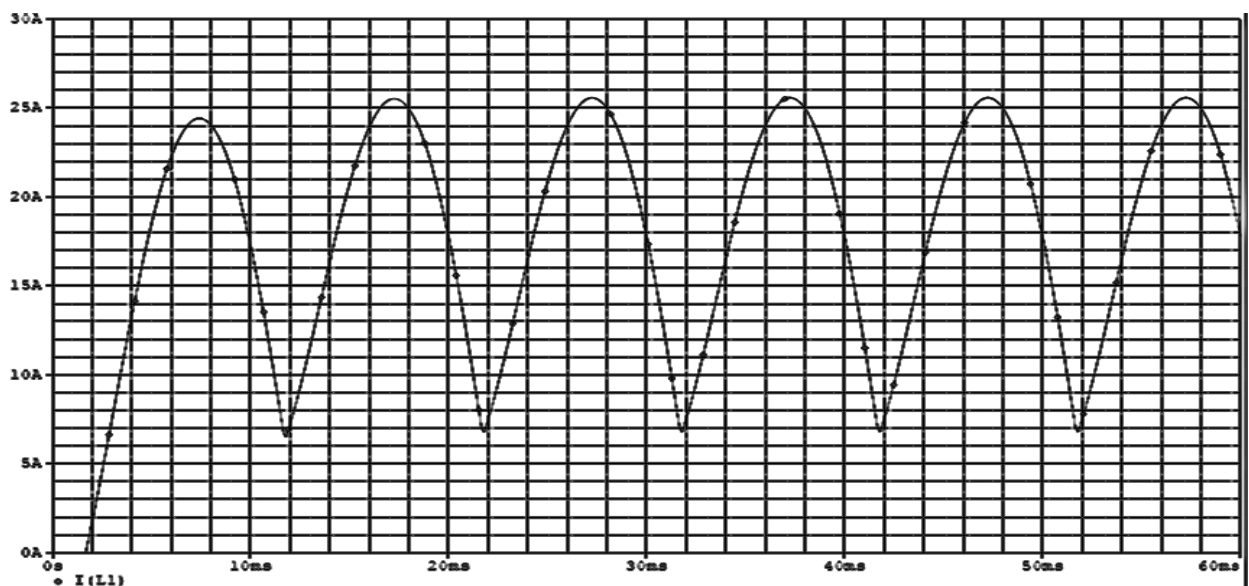
RESULTS:

CONCLUSION:

QUESTIONS:

1. What is bidirectional device?

2. What is bipolar device?

3. What type of firing is used here?

4. How do you change the firing angle?

5. Draw the symbol of Triac.

EXPERIMENT NO. 10

STUDY OF PERFORMANCE OF SINGLE PHASE HALF CONTROLLED SYMMETRICAL AND ASYMMETRICAL BRIDGE CONVERTER. (SIMULATION)

Objectives:
- To verify the half-controlled converter operation in symmetrical & asymmetrical configuration and its different waveforms.

SOFTWARE USED: OrCAD 16.6 LITE

APPARATUS USED: Personal Computer

THEORY:

When a pair of thyristors are replaced by uncontrolled devices i.e., diodes in the single phase full wave controlled rectifiers, a single phase Half controlled bridge rectifier is formed. They are two different versions of single phase half bridge rectifiers. They are

1. Symmetrical
2. Asymmetrical

1. Symmetrical configuration-

In symmetrical configuration of single phase half controlled bridge rectifier, the cathodes of the two thyristors are at the same potential as shown in circuit diagram. Hence, their gates can be connected and only a single gate pulse is required to trigger these SCRs. Its operation may be explained as follows.

The loads current is assumed continuous and ripple free. During the positive half-cycle, thyristor XT_1 is forward biased. When thyristor XT1 is fired at the load is connected to the input supply through XT_1 and D_2 during the period During the period from the input voltage is negative and the freewheeling diode D_m is forward biased. D_m conducts to provide the continuity of current in the inductive load. The load current is transferred from XT_1 and D_2 to D_m; and thyristor XT_1 and diode D_2 are turned off.

 During the negative half-cycle of input voltage, thyristor XT_2 is forward biased, and the firing of thyristor XT_2 at reverse biases D_m. The diode D_m is turned off and the load is connected to the supply through XT_2 and D_1. The output voltage is obtained for negative half cycle also.

CIRCUIT DIAGRAM:
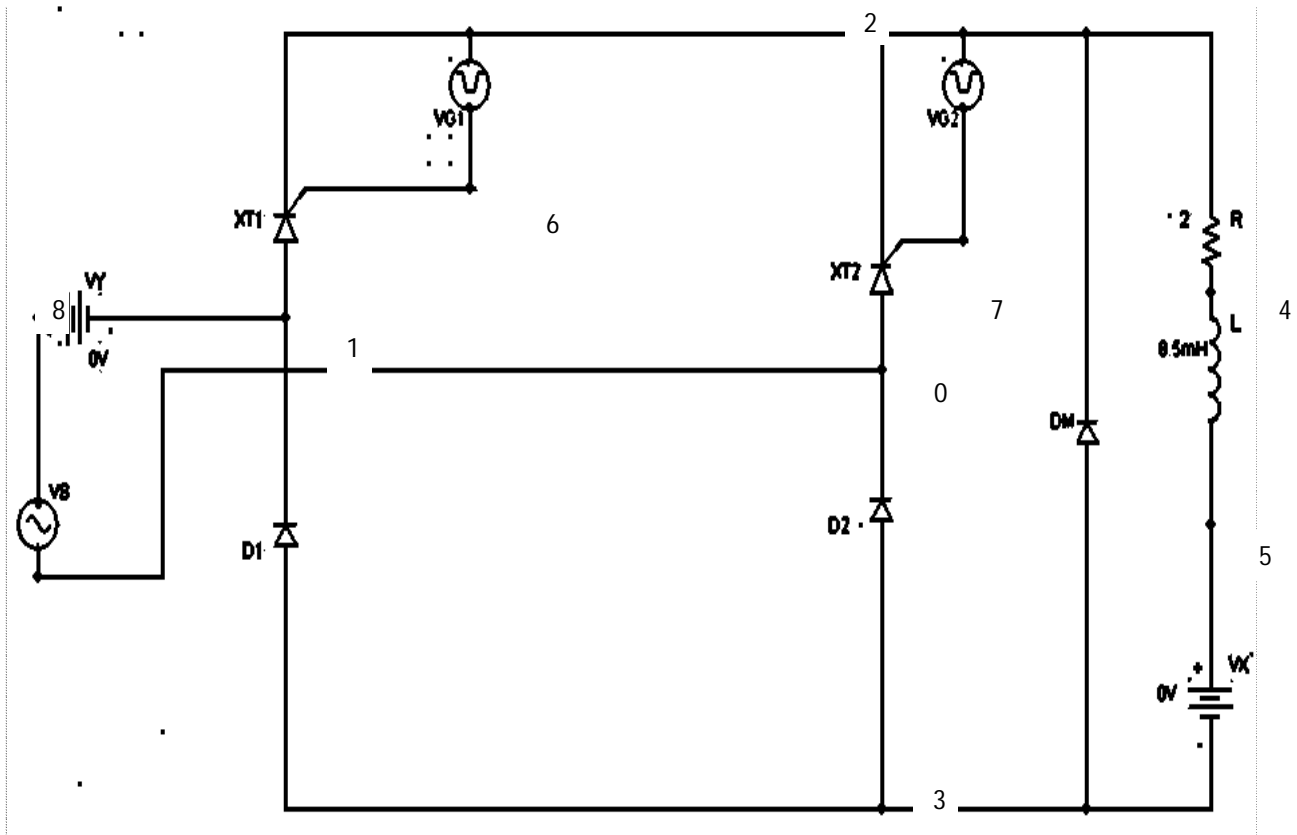
Fig.10.1: Half controlled bridge rectifier in symmetrical configuration

PROCEDURE :

19. Open PSPICE AD Student.
20. Click File-New-Text File.
21. Write down the simulation program.
22. Save the program as Circuit File (.cir).
23. Run.
24. Click Add Trace.
25. Trace the required waveform.
26. Click on View Simulation Output File.
27. Write down the results.

Simulation Program

```
* Single phase semi-converter bridge(symmetrical)
VS 8 0 SIN (0 325V 50HZ)
VG1 6 2 PULSE (0 10V 7500US 1NS 1NS 100US 20000US)
VG2 7 2 PULSE (0 10V 17500US 1NS 1NS 100US 20000US)
XT1 1 2 6 2 SCR
XT2 0 2 7 2 SCR
R 2 4 2
L 4 5 8.5MH
VX 5 3 DC 0V
VY 8 1 DC 0V
D1 3 1 DMOD
D2 3 0 DMOD
DM 3 2 DMOD
.MODEL DMOD D(IS=2.2E-15 BV=1200V TT=0 CJO=0)
.SUBCKT SCR 101 102 103 102
S1 101 105 106 102 SMOD
RG 103 104 50
VX 104 102 DC 0V
VY 105 107 DC 0V
DT 107 102 DMOD
RT 106 102 1
CT 106 102 10UF
F1 102 106 POLY(2) VX VY 0 50 11
.MODEL SMOD VSWITCH (RON=0.0105 ROFF=10E+5 VON=0.5V
VOFF=0V)
.MODEL DMOD D(IS=2.2E-15 BV=1200V TT=0 CJO=0)
.ENDS SCR
.TRAN 50US 100MS 50MS 50US
.PROBE
.FOUR 50HZ I(VX)
.END
```
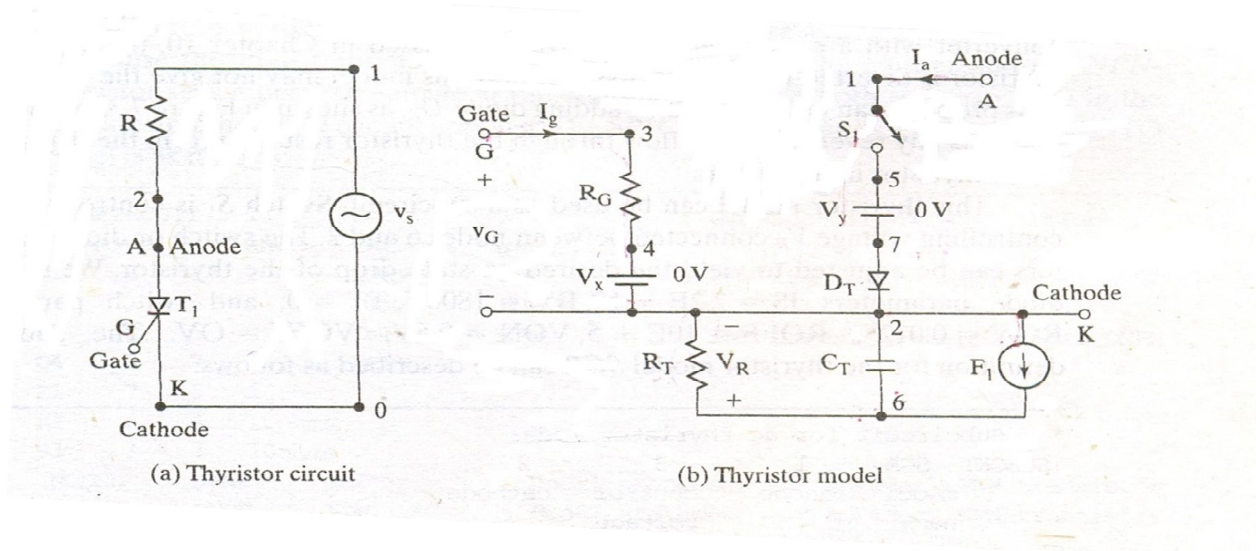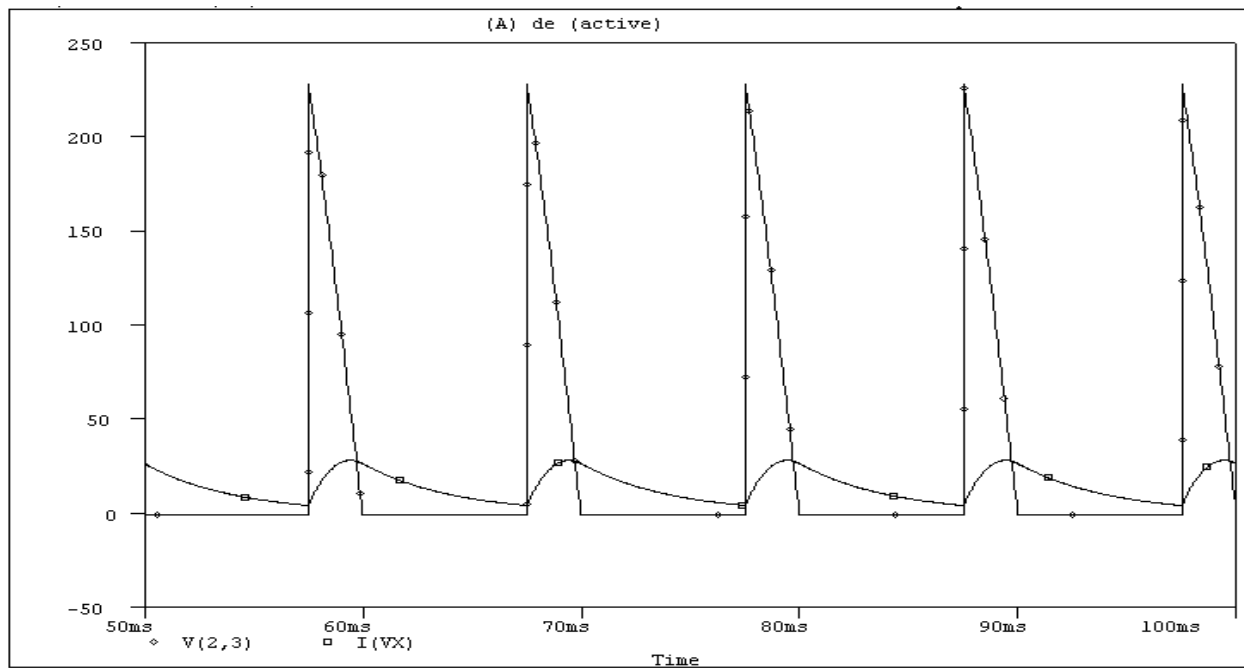
Fig.10.2: SCR subcircuit model
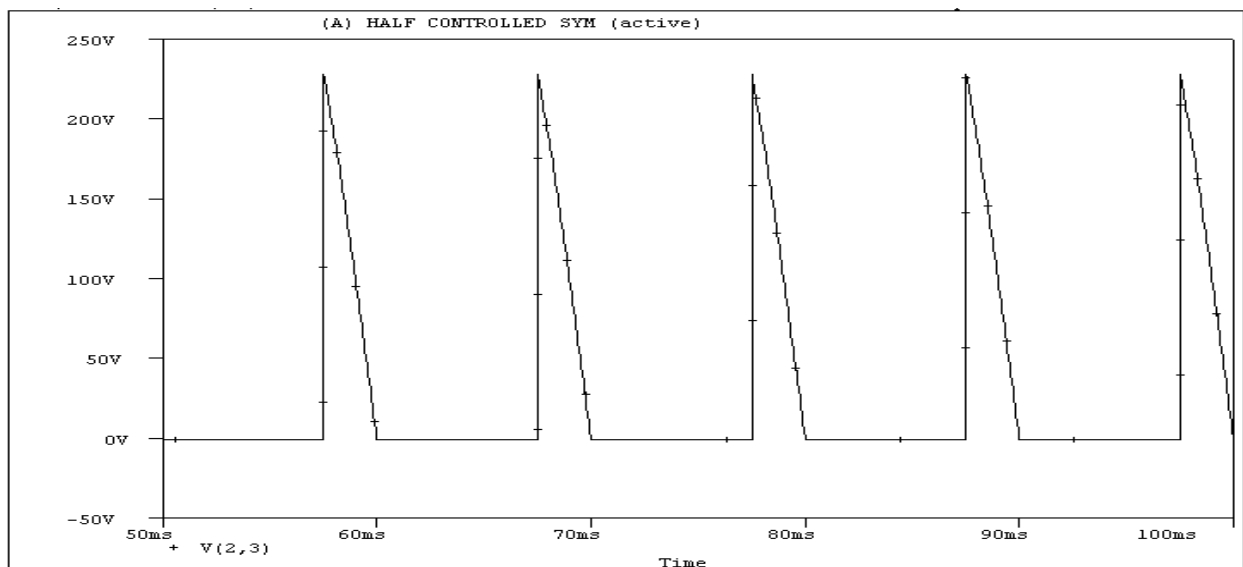
**Output voltage waveform**
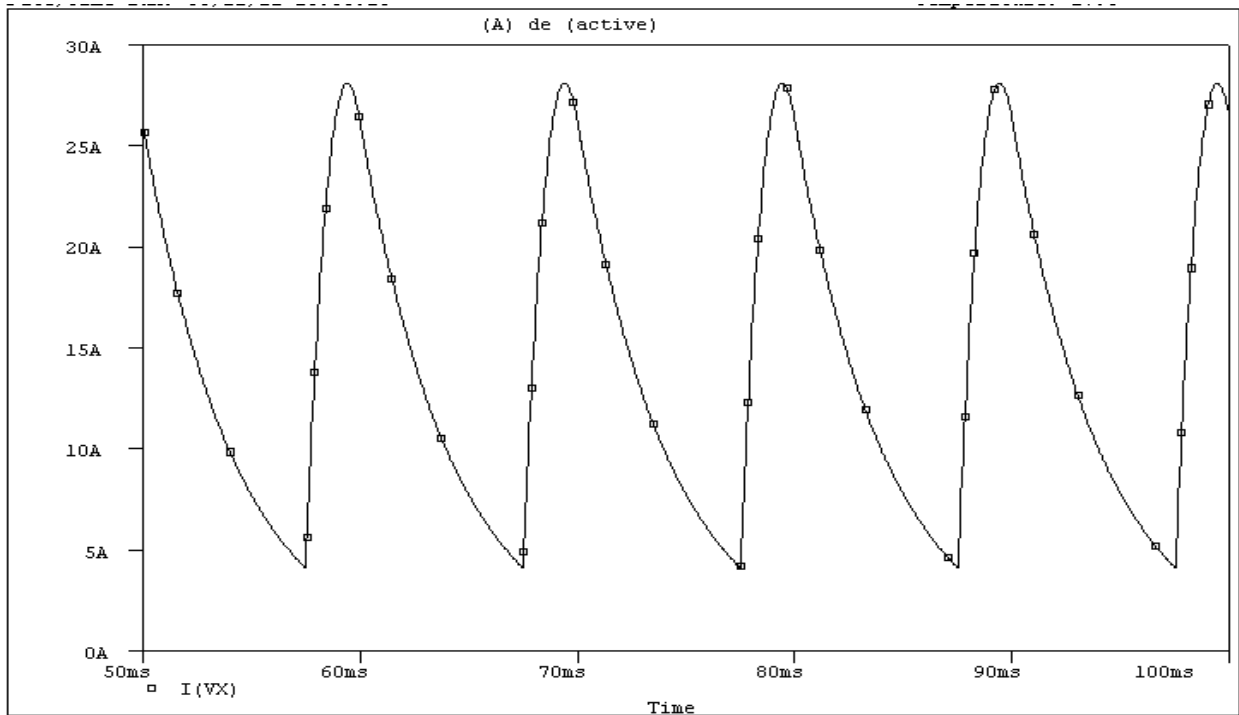
Output current waveform

Output Voltage & Current waveform

2. Asymmetrical configuration-

In asymmetrical semi-converter two separate triggering circuits is required for two SCRs. In positive half cycle, current flows through XT_1 and D_2 at . During the period from the input voltage is negative and the freewheeling diode D_m is forward biased.

In the next half cycle, thyristor XT_2 is forward biased due to forward biased D_1, and the firing of thyristor XT_2 at reverse biases D_m. The diode D_m is turned off and the load is connected to the supply through D_1 and XT_2.
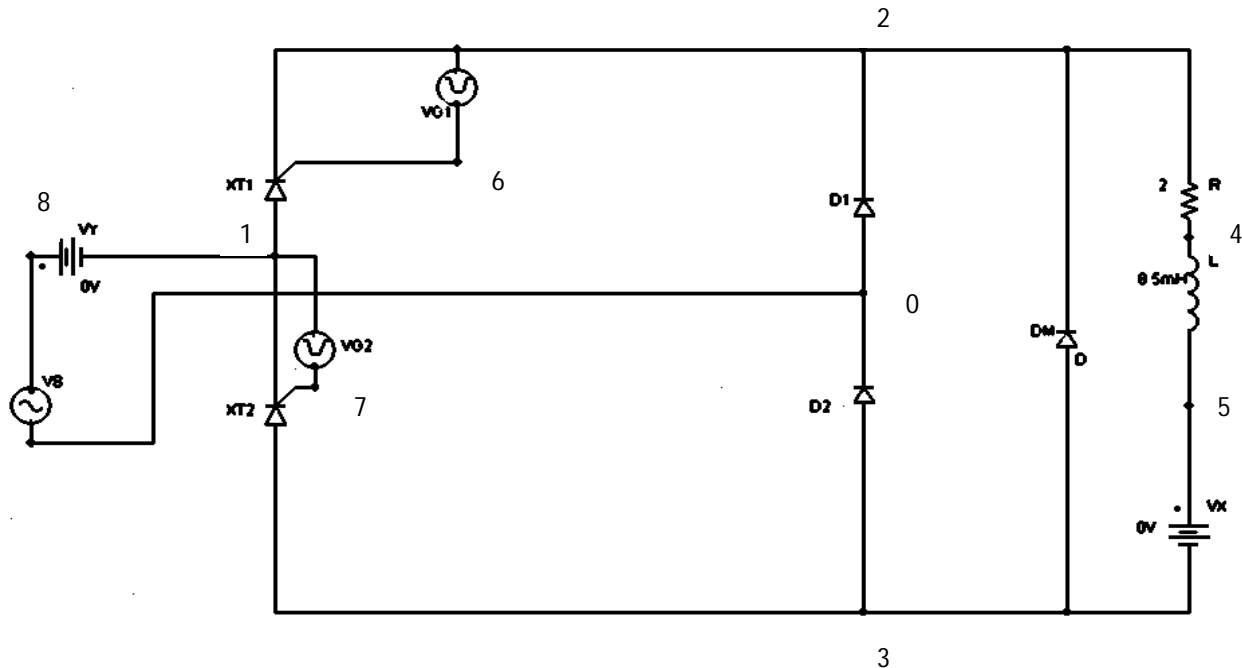
Fig.10.3: Half controlled bridge rectifier in asymmetrical configuration

Simulation Program

* Single phase semi-converter bridge(asymmetrical)

VS 8 0 SIN (0 325V 50HZ)

VG1 6 2 PULSE (0 10V 7500US 1NS 1NS 100US 20000US)

VG2 7 1 PULSE (0 10V 17500US 1NS 1NS 100US 20000US)

XT1 1 2 6 2 SCR

XT2 3 1 7 1 SCR

R 2 4 2

L 4 5 8.5MH

VX 5 3 DC 0V

VY 8 1 DC 0V

D1 0 2 DMOD

D2 3 0 DMOD

DM 3 2 DMOD

.MODEL DMOD D(IS=2.2E-15 BV=1200V TT=0 CJO=0)

.SUBCKT SCR 101 102 103 102

S1 101 105 106 102 SMOD

RG 103 104 50

VX 104 102 DC 0V

VY 105 107 DC 0V

DT 107 102 DMOD

RT 106 102 1

CT 106 102 10UF

F1 102 106 POLY(2) VX VY 0 50 11

.MODEL SMOD VSWITCH (RON=0.0105 ROFF=10E+5 VON=0.5V VOFF=0V)
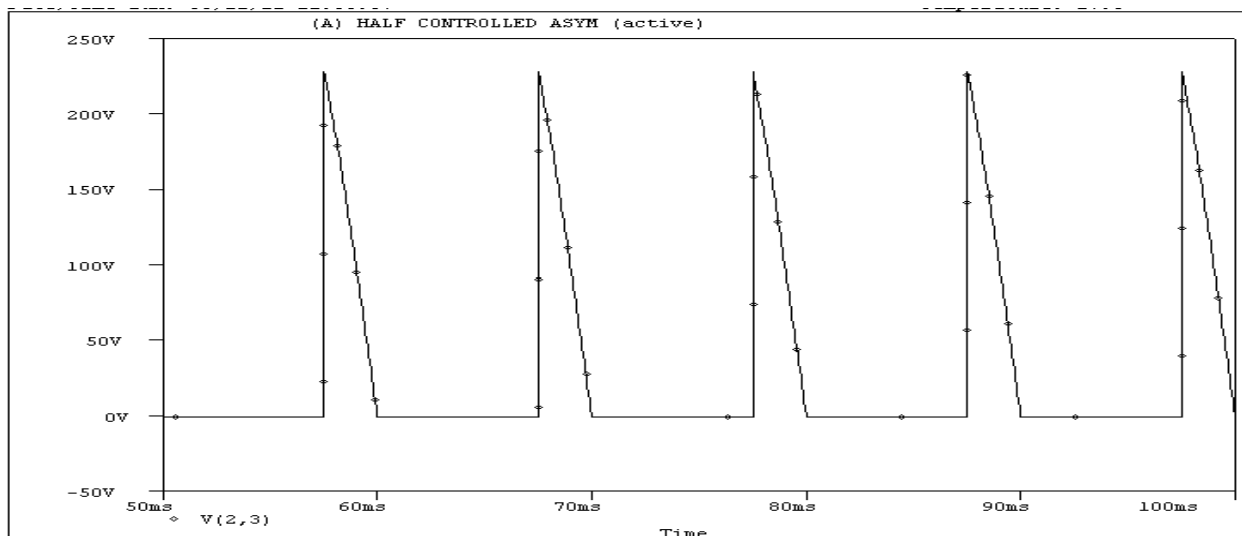
.MODEL DMOD D(IS=2.2E-15 BV=1200V TT=0 CJO=0)
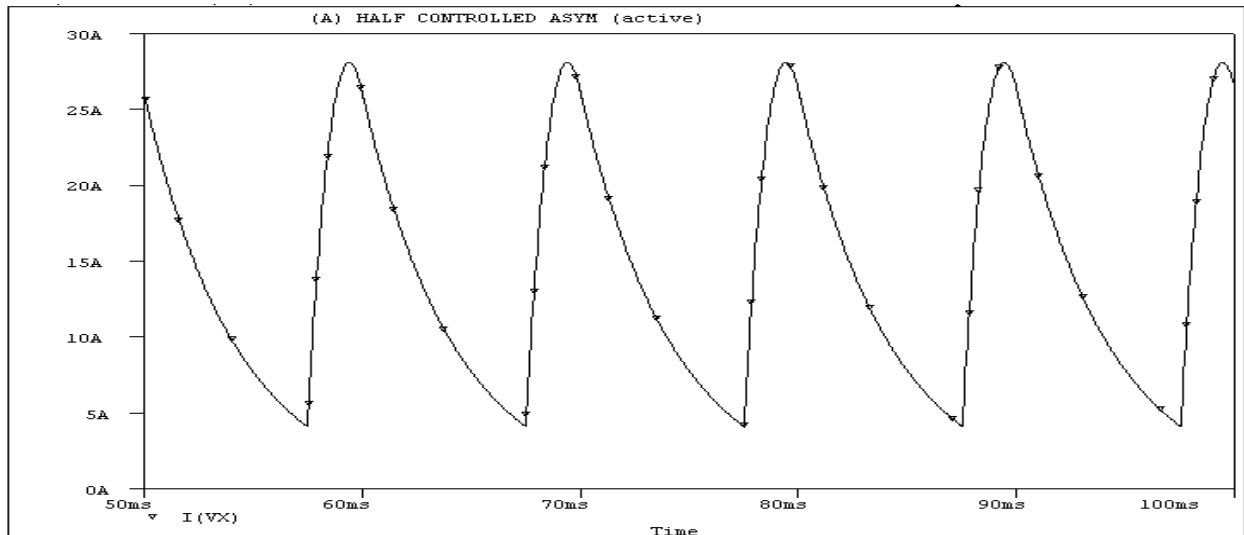
.ENDS SCR

.TRAN 50US 100MS 50MS 50US
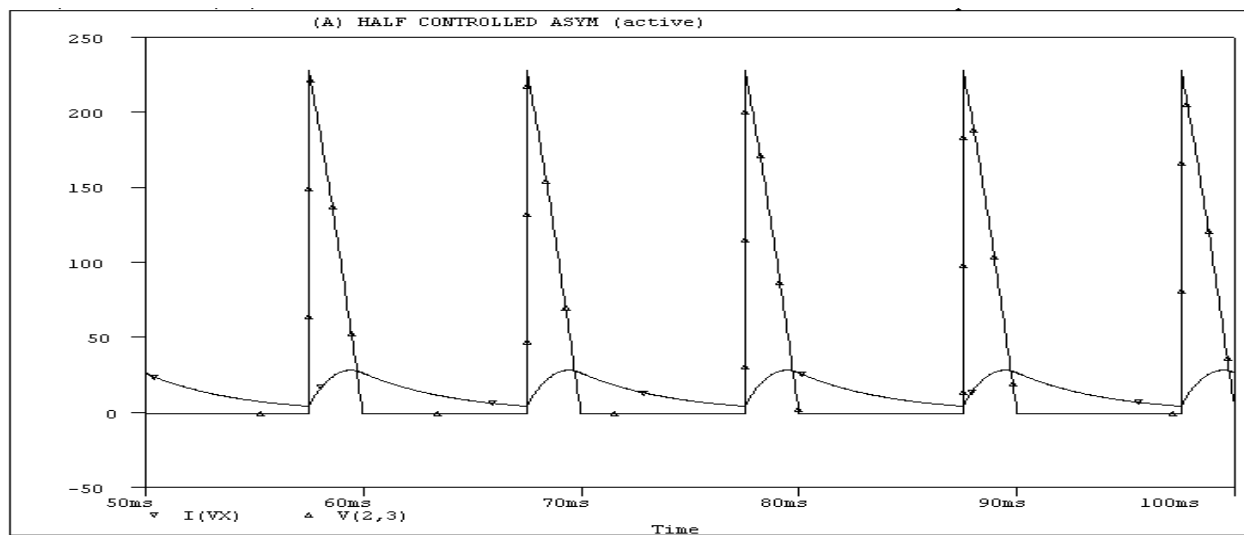
.PROBE

.FOUR 50HZ I(VX)

.END

Output voltage waveform

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Output current waveform

Output Voltage & Current waveform

RESULTS:

REMARKS:

QUESTIONS:

1. Why the negative voltage is not possible in semi converter?

2.. What is freewheeling diode?

3. Is a separate freewheeling diode necessary for semi converter? Justify your answer.

4. What is the difference between symmetrical and asymmetrical configuration of half controlled converter?

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EXPERIMENT NO. 11

STUDY OF PERFORMANCE OF THREE PHASE CONTROLLED CONVERTER WITH R-L LOAD. (simulation)

Objectives:
- To study the performance of three phase controlled converter with R-L load.

SOFTWARE USED: OrCAD 16.6 LITE

APPARATUS USED: Personal Computer

THEORY: The three-phase bridge rectifier circuit has three-legs, each phase connected to one of the three phase voltages. Alternatively, it can be seen that the bridge circuit has two halves, the positive half consisting of the SCRs XT_1, XT_3 and XT_5 and the negative half consisting of the SCRs XT_2, XT_4 and XT_6. At any time, one SCR from each half conducts when there is current flow. If the phase sequence of the source be ABC, the SCRs are triggered in the sequence XT_1, XT_2, XT_3, XT_4, XT_5, XT_6 and XT_1 and so on.

Initially, XT_1 is triggered with a firing angle 'α'. When XT_1 is conducting, the voltage between A and C reverse biases thyristorXT_5, as the voltage of phase A is more than that of phase C. So, XT_5 get turned off. Now, the voltage between the lines A and B appears across output terminals 4 and 5 through the thyristorsXT_1 and XT_6. The current follows the path A – XT_1 – load –XT_6 – B as shown in fig.- 1.

Next, A – C phase becomes much more positive when compared to A – B the return path shifts from XT_6 to XT_2. Now, voltage between the lines B and C reverse biasesXT_6. The load current follows the path A – XT_1– load – XT_2– C and so on.
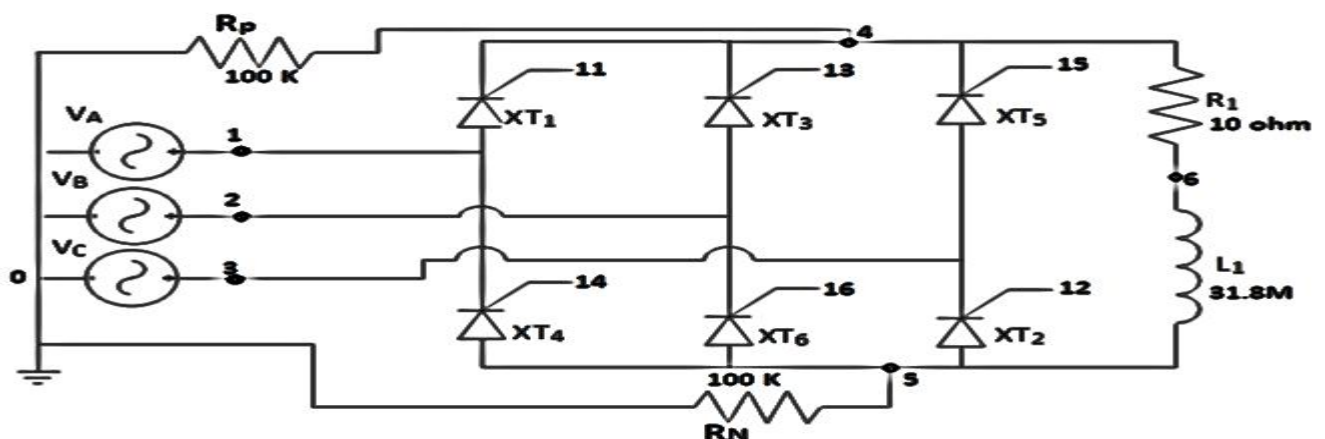
Fig.11.1: Three phase controlled rectifier with R-L load

PROCEDURE:

1. Open PSPICE AD Student.
2. Click File-New-Text File.
3. Write down the simulation program.
4. Save the program as Circuit File(.cir).
5. Run.
6. Click Add Trace.
7. Trace the required waveform.
8. Click on View Simulation Output File.
9. Write down the results.

Simulation Program

* Three-phase Full-wave Fully-Controlled Bridge Rectifier

VA 1 0 SIN(0 340V 50Hz)

VB 2 0 SIN(0 340V 50Hz 0 0 -120)

VC 3 0 SIN(0 340V 50Hz 0 0 -240)

XT1 1 4 11 4 SCR

XT3 2 4 13 4 SCR

XT5 3 4 15 4 SCR

XT4 5 1 14 1 SCR

XT6 5 2 16 2 SCR

XT2 5 3 12 3 SCR

RP 4 0 100K

RN 5 0 100K

R1 4 6 10

L1 6 5 31.8M

VP1 21 0 PULSE(0 10 3333.3U 1N 1N 100U 20M)

VP2 22 0 PULSE(0 10 6666.7U 1N 1N 100U 20M)

VP3 23 0 PULSE(0 10 10M 1N 1N 100U 20M)

VP4 24 0 PULSE(0 10 13333.3U 1N 1N 100U 20M)

VP5 25 0 PULSE(0 10 16666.7U 1N 1N 100U 20M)

VP6 26 0 PULSE(0 10 20M 1N 1N 100U 20M)

RP1 21 0 100K

RP2 22 0 100K

RP3 23 0 100K

RP4 24 0 100K

RP5 25 0 100K

RP6 26 0 100K

EP1 11 4 POLY(2) (21,0) (22,0) 0 1 1

EP2 12 3 POLY(2) (22,0) (23,0) 0 1 1

EP3 13 4 POLY(2) (23,0) (24,0) 0 1 1

EP4 14 1 POLY(2) (24,0) (25,0) 0 1 1

EP5 15 4 POLY(2) (25,0) (26,0) 0 1 1

EP6 16 2 POLY(2) (26,0) (21,0) 0 1 1

* Subcircuit for SCR

.SUBCKT SCR 101 102 103 102

S1 101 105 106 102 SMOD

RG 103 104 50

VX 104 102 DC 0

VY 105 107 DC 0

DT 107 102 DMOD

RT 106 102 1

CT 106 102 10U

F1 102 106 POLY(2) VX VY 0 50 11

.MODEL SMOD VSWITCH(RON=0.0105 ROFF=10E+5 VON=0.5 VOFF=0)

.MODEL DMOD D((IS=2.2E-15 BV=1200 TT=0 CJO=0)

.ENDS SCR

.TRAN 10US 60.0MS 0.0MS 10US

.PROBE

.FOUR 50 V(4,5) I(VA) I(L1)

.OPTIONS(ABSTOL=1N RELTOL=.01 VNTOL=1MV)

.END

RESULTS:
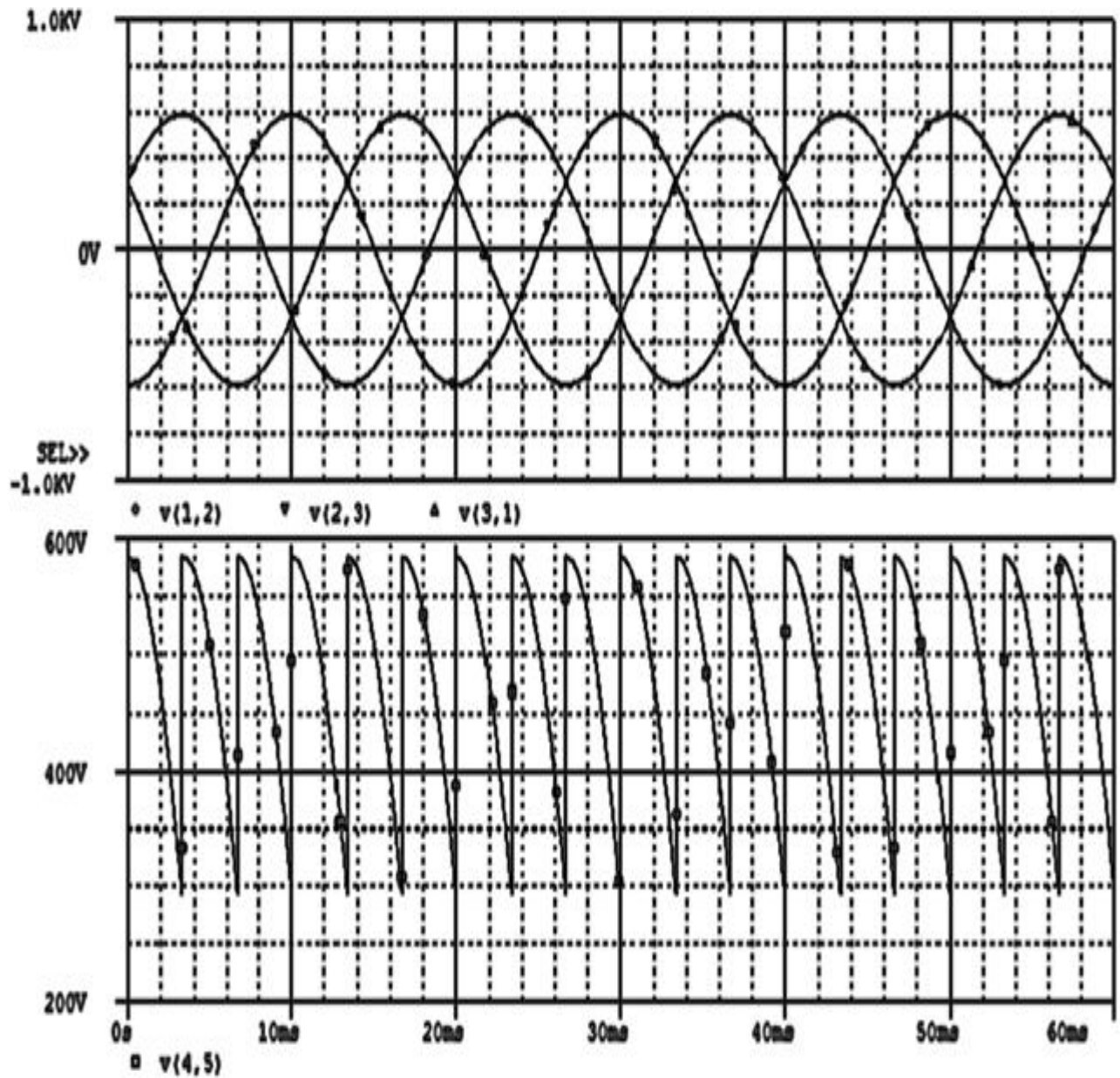
Line Voltage and Output voltage waveform

Also draw Phase voltage waveforms.

CONCLUSION:

QUESTIONS:

1. What is 6 pulse converter?

2. Discuss the effect of source impedance in a 3 phase full wave rectifier circuit.

EXPERIMENT NO. 12

STUDY OF PERFORMANCE OF PWM BRIDGE INVERTER USING MOSFET AS SWITCH WITH R AND R-L LOAD

Objectives:
- To study and analyze the working of a single phase inverter with a PWM control and plot the output voltage at different load conditions.

SOFTWARE USED: OrCAD 16.6 LITE

APPARATUS USED: Personal Computer

THEORY:

An inverter converts a fixed a fixed dc voltage to an ac voltage of variable frequency and of fixed or variable magnitude. A practical inverter has either a battery, a solar powered dc voltage source or a line frequency (50Hz) derived dc voltage source (often unregulated).

PWM inverter is gradually taking over types of inverter induced applications PWM techniques are characterized by constant amplitude pulses. The width of these pulses is however, modulated to obtained inverter output voltage control and to reduce harmonic content.

This method of pulse modulator is an extension of single phase pulse modulator. In multipulse modulation (MPM) several equidistant pulses per help cycle are used for simplicity the effect utility two symmetrical special pulses per half cycle.

CIRCUIT DIAGRAM :
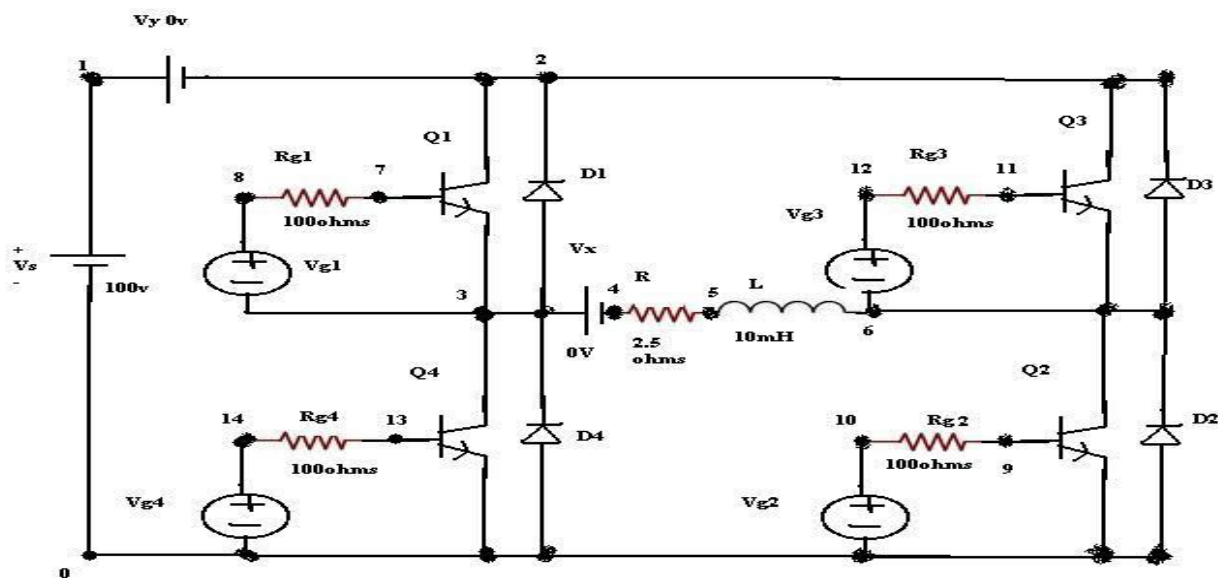
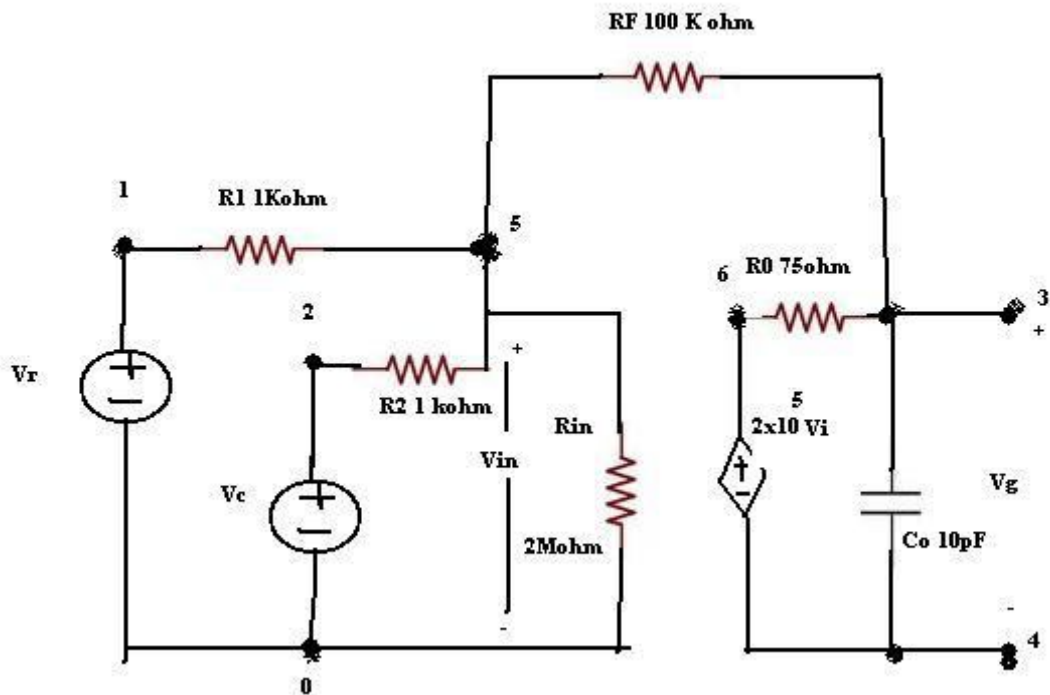*Fig.12.1: Circuit of PWM bridge inverter using R-L load*
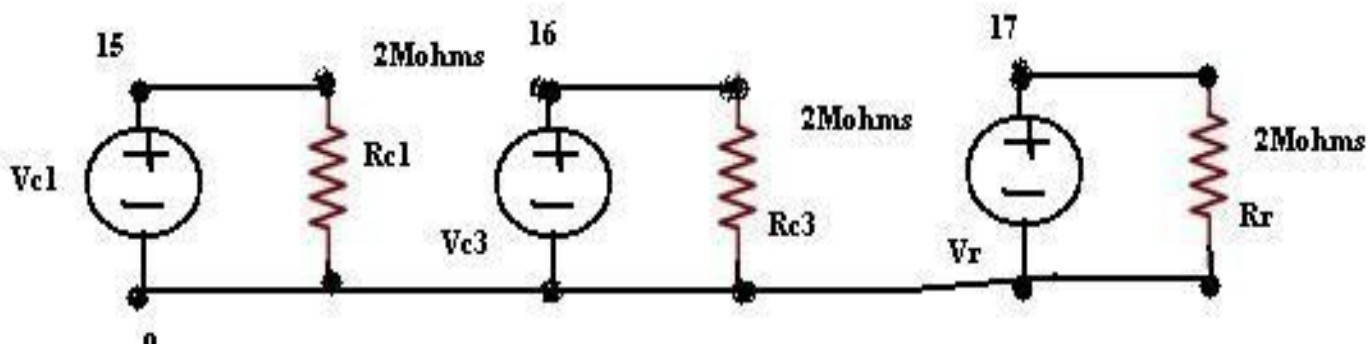
Fig.12.2: PWM Generator

Fig.12.3: Subcircuit for PWM control

PROCEDURE :

28. Open PSPICE AD Student.
29. Click File-New-Text File.
30. Write down the simulation program.
31. Save the program as Circuit File (.cir).
32. Run.
33. Click Add Trace.
34. Trace the required waveform.

35. Click on View Simulation Output File.
36. Write down the results.
    iii)   The waveform carrier and reference signal V(17),V(0,15).
    iv)   The waveform carrier and reference signal V(17),V(0,16).
    v)   The waveform of output voltage V(3,6).

Simulation Program

```
*SINGLE PHASE INVERTER WITH PWM CONTROL
VS 1 0 DC 100V
VR 17 0 PULSE(50V 0V 0 833.33US 833.33US 1NS 1666.667US)
RR 17 0 2MEG
VC1 15 0 PULSE(0V -30V 0 1NS 1NS 8333.33US 16666.67US)
RC1 15 0 2MEG
VC3 16 0 PULSE(0V -30V 8333.33US 1NS 1NS 8333.33US 16666.67US)
RC3 16 0 2MEG
R 4 5 8
L 5 6 1UH
VX 3 4 DC 0V
VY 1 2 DC 0V
D1 3 2 DMOD
D2 0 6 DMOD
D3 6 2 DMOD
D4 0 3 DMOD
.MODEL DMOD D(IS=2.2E-15 BV=1800 TT=0)
Q1 2 7 3 QMOD
Q2 6 9 0 QMOD
Q3 2 11 6 QMOD
Q4 3 13 0 QMOD
.MODEL QMOD NPN(IS=6.73µF BF=416.4 CJC=3.638P CJE=4.493P)
RG1 8 7 100
RG2 10 9 100
RG3 12 11 100
RG4 14 13 100
*SUBCKT CALL FOR PWM CONTROL
XPWM1 17 15 8 3 PWM
XPWM2 17 15 10 0 PWM
XPWM3 17 16 12 6 PWM
XPWM4 17 16 14 0 PWM
.SUBCKT PWM 1 2 3 4
*MODEL REF CARRIER +CONTROL -CONTROL
*NAME INPUT INPUT VOLTAGE VOLTAGE
R1 1 5 1K
R2 2 5 1K
RIN 5 0 2MEG
RF 5 3 100K
RO 6 3 75
CO 3 4 10PF
E1 6 4 0 5 2E+5
```

.ENDS PWM
.TRAN 100US 16.67MS 0 10US
.PROBE
.OPTIONS ABSTOL=1.00N RELTOL=0.01 VNTOL=0.1 ITL5=20000
.FOUR 60 V(3,6)
.END

WAVEFORMS:
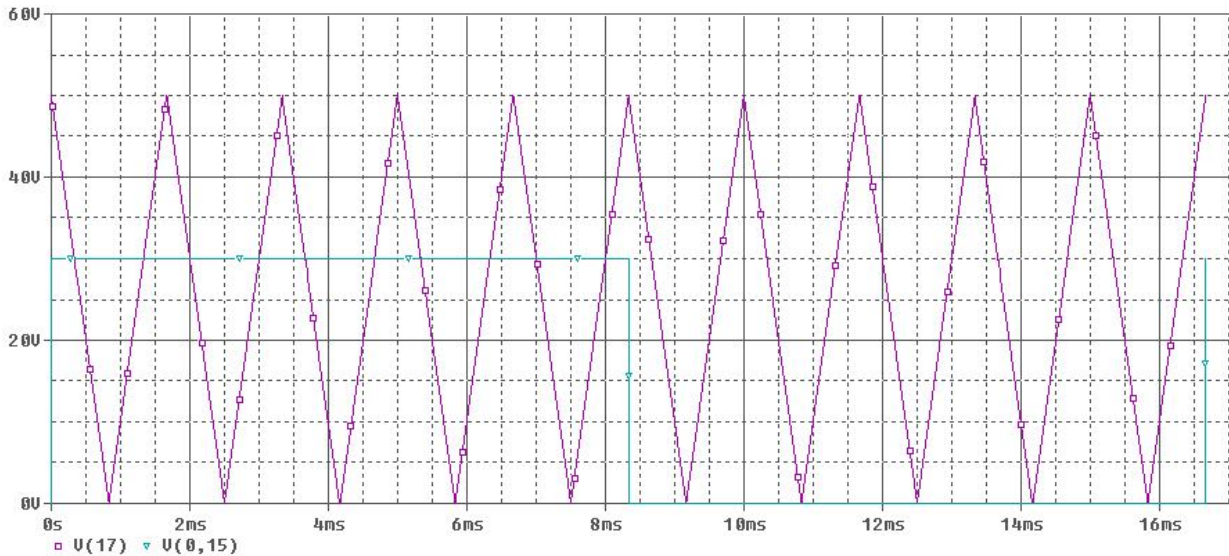
Career and Reference signal waveform
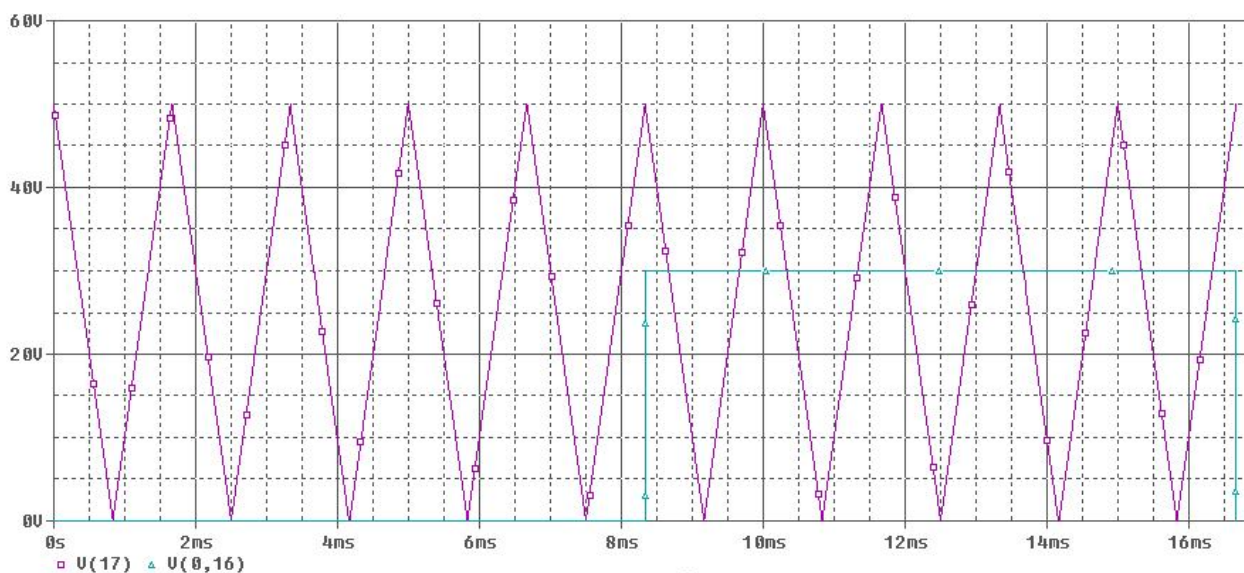
Career and Reference signal waveform
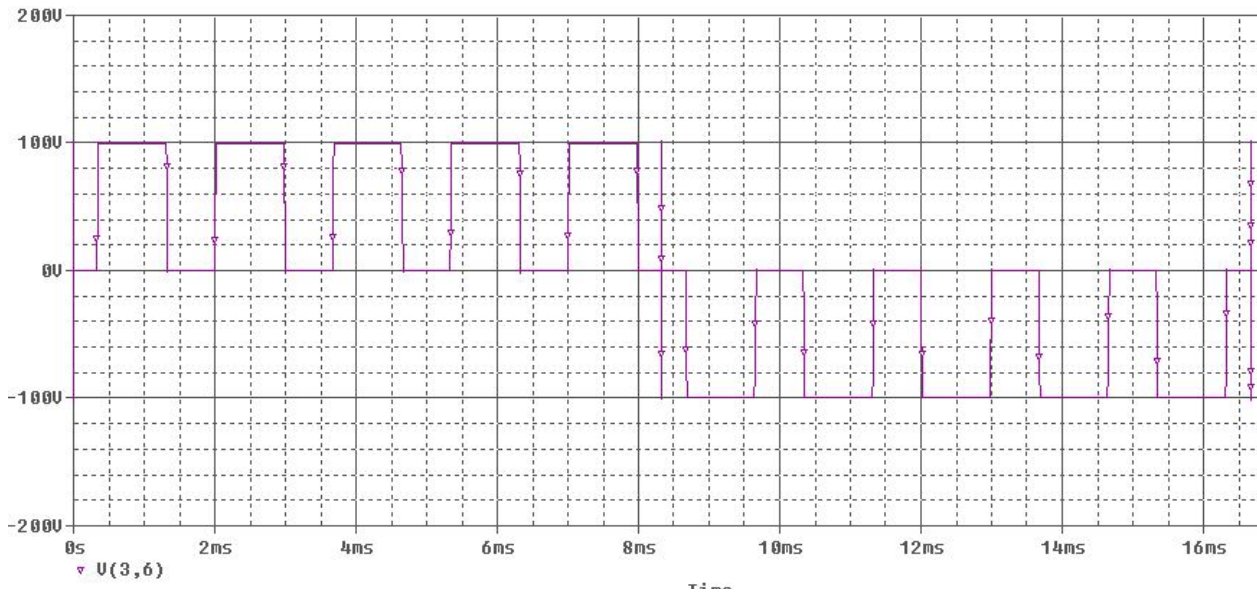
Output voltage waveform

GRAPHS:

5. Plot carrier and reference signal.
6. Plot output voltage

CONCLUSION:

QUESTIONS:

1. What is inverter?

2. Why we go for PWM?

3. What are the different types of PWM?

4. What is modulation index and what are the types?

LABORATORY INSTRUCTION MANUAL

POWER SYSTEM-I LAB
PC-EE 592

DEPARTMENT OF ELECTRICAL ENGINEERING

SILIGURI INSTITUTE OF TECHNOLOGY

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DEPARTMENT OF ELECTRICAL ENGINEERING

General Information

All assigned experiments must be performed as per the schedule. Most of the work for an experiment should be done during class time in the laboratory. In order to allow for further analysis and graphing, the notebooks are to be submitted after completing the work within the stipulated submission date. Submit your completed notebook to the instructors/class teacher for evaluation. The laboratory performance is evaluated based on the instructor's observations of you while you are performing the experiments. Among the factors considered are your ability to construct circuits, your competency in using test equipment, your preparation prior to starting the experiment, answers given to any questions asked during the laboratory, as well as attendance, tardiness, and attitude. Keep in mind that your behaviour influences your grade; act professionally at all times.

The following guidelines should be followed when using your notebook:

- The first page should contain a table of contents as per the attached format.
- All pages in the notebook must bound, numbered and dated.
- Use a pen or permanent marker, never pencil.
- Write legibly and coherently. Extreme neatness is not required but anyone should be able to read and understand what you have written.
- Never erase errors or remove pages. Simply draw a line through any mistakes.
- The notebook should be a complete record of your work, i.e. what you actually do in the laboratory, and sufficiently detailed that a knowledgeable person could reconstruct what you did.
- All measurements, notes, and calculations should be directly recorded in the notebook. Never write information on scraps of paper for later transcription into the notebook.
- Do not paste the laboratory manual into your notebook
- Any graphs or printouts relevant to the experiment should be pasted into your notebook.
- Be sure to label all diagrams, schematics, graphs, and waveform printouts.
- All numbers should include appropriate units.
- Include an equipment list if any.

Electrical Engineering Laboratory Regulations

General

Students working in the electrical laboratories should be very cautious during the lab work. The electric potentials used in many experiments are dangerous and may cause injury. Students must observe all safety precautions and must not work alone with potentials exceeding 25 V. The rotating machines used in some experiments are dangerous. Keep loose clothing, jewellery, and other objects away from any rotating parts.
Food and drinks are not permitted in the laboratories.

Equipment

All equipment must be returned to its proper storage location at the end of the lab period. Instruments and equipment are delicate and expensive. Improper use of equipment can result in instantaneous damage; check with you instructor or the equipment's manual if you are in doubt.
Damaged or faulty equipment should be given to the technicians/instructor along with a description of the problem.

Keep the laboratory neat & clean

Shut down the computers after completion of work

Keep your mobile switched off / in silent mode while

the laboratory is going on

POWER SYSTEM-I LAB
Code : EE 592
Contacts : 3P
Credit : 2

LIST OF EXPERIMENTS

1. Determination of the Generalized constants A,B,C,D of Long Transmission Line.

2. Simulation of D.C distribution by Network Analyser.

3. Measurement of earth resistance by Earth Tester.

4. Dielectric strength test of Insulating Oil.

5. Determination of Breakdown Strength Test of Solid Insulating Material.

6. Different Parameters calculation by Power Circle Diagram.

7. Study of different types of insulator.

8. Active and Reactive power control of Alternator.

9. Dielectric constant, Tan Delta, Resistivity test of Transformer oil.

Siliguri Institute Of Technology
Department of Electrical Engineering

REPORT ON

_____ Lab

Name   :

Department   :

Semester   :

Roll No.   :

INDEX

Expt. no.	Title of the experiment	Date of experiment	Date of report submission	Page no.	Signature of Teacher

Title Sheet

Laboratory workbook for _____ Lab (   )

Experiment no.   :

Description   :

Date of Performance :

Date of Submission   :

Name   :

Department / Sem   :

Roll No.   :

Signature of the Student

EXPERIMENT NO.1

Experiment Name: Measurement of generalized constants ABCD of a long transmission line

Objectives:

1. To measure voltages and currents along with the phase angle between them at two ends of transmission line under open circuit and short circuit conditions.

2. To compute ABCD constants of the transmission line under open circuit and short circuit conditions.

THEORY: Depending on the length and voltage in the transmission lines it can be classified as

- **Short line** with length not more than 80 km long. (Line voltage < 20 kV)
- **Medium line** with length between 80 km to 250 km. (20 kV < Line voltage < 100 kV)
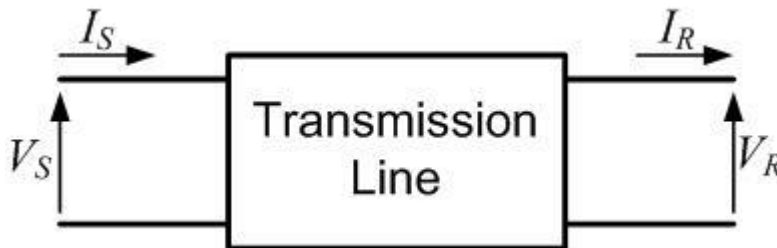- **Long line** with length more than 250 km. (Line voltage > 100 kV)

$$\begin{vmatrix} V_S \\ I_S \end{vmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{vmatrix} V_R \\ I_R \end{vmatrix}$$

Figure 1

By rigorous method solution we find the expressions for sending end voltage and sending end current are –

$$V_S = V_R \cosh \sqrt{yz} + I_R \sqrt{\frac{z}{y}} \sinh \sqrt{yz}$$

$$I_S = V_R \sqrt{\frac{y}{z}} \sinh \sqrt{yz} + I_R \cosh \sqrt{yz}$$

ABCD parameters of a transmission line should be determined by performing open circuit test and short circuit test on both sending end and receiving end.

Let,

Z_{so} = Line impedance measured at sending end with receiving end open-circuited.
Z_{ss} = Line impedance measured at sending end with receiving end short-circuited.
Z_{ro} = Line impedance measured at receiving end with sending end open-circuited.
Z_{rs} = Line impedance measured at sending end with sending end short-circuited.

After performing the tests mentioned the parameters are determined with the help of the following equations:

$$A = \sqrt{\frac{Z_{so}}{Z_{ro} - Z_{rs}}}$$

$$B = Z_{rs}\sqrt{\frac{Z_{so}}{Z_{ro} - Z_{rs}}}$$

$$C = \frac{1}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro} - Z_{rs}}}$$

$$D = \frac{Z_{ro}}{Z_{so}}\sqrt{\frac{Z_{so}}{Z_{ro} - Z_{rs}}}$$

Please note that impedances are complex quantities – the magnitudes are obtained from the reading of voltmeter and ammeter whereas the angle is obtained with the help of wattmeter reading.
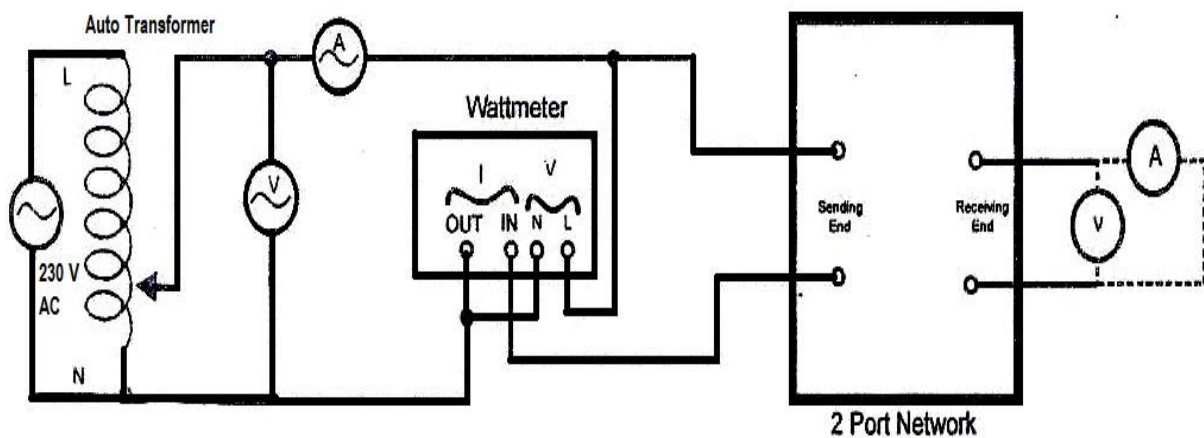
CIRCUIT DIAGRAM:

Figure 2

PROCEDURE:

1. Build a two port network (either π or T) using trainer kit to represent a long transmission line.
2. Connect instruments to this network as per circuit diagram.(Connect the wattmeter carefully; please note that it is connected with the return path; maintain proper polarity).
3. Now connect a voltmeter at the output (receiving) end **to perform open circuit test**.
4. Adjust the auto-transformer in such a way so that not more than 5 amp current flows through the circuit.
5. Now note down the input (sending) end voltmeter reading (V), ammeter reading (A), power factor, phase angle and wattmeter reading (W). (Please take care of 'sign' LED).

6. Calculate the magnitude and angle of Z_{so} using the relations –

$$|Z_{so}| = \sqrt{\frac{V}{A}}$$

$$\angle Z_{so} = \cos^{-1}\frac{|W|}{|V||A|}$$

7. Now connect an ammeter at the output (receiving) end **to perform short-circuit test**.

8. Adjust the auto-transformer in such a way so that not more than 5 amp current flows through the circuit.

9. Now note down the meter readings again as before.

10. Calculate the magnitude and angle of Z_{so} using the relations –

$$|Z_{ss}| = \sqrt{\frac{V}{A}}$$

$$\angle Z_{ss} = \cos^{-1}\frac{|W|}{|V||A|}$$

11. Now perform the above tests similarly withinput (sending) side open-circuited and short-circuited to determine Z_{ro} and Z_{rs}.

12. Now find the ABCD parameters of the line with the help of the values found above.

13. Repeat the above tests with other network configuration i.e. T-network if you have done π-network and vice-versa.

OBSERVATION TABLE:

PARAMETERS MEASURED AT RECEIVING END WITH SENDING END OPEN CIRCUITED:

Sl. No.	Driving End Voltage (V_{S1})	Receiving End Voltage (V_{R1})	Driving End Current (I_{S1})	Receiving End Current (I_{R1})	Reading of Wattmeter (W_S)	Phase angle Calculated Value (θ_{CS1})	Phase angle Observed Value (θ_{OS1})	Power Factor (Cos θ_{S1})

PARAMETERS MEASURED AT RECEIVING END WITH SENDING END SHORT CIRCUITED:

Sl. No.	Driving End Voltage (V_{S2})	Receiving End Voltage (V_{R2})	Driving End Current (I_{S2})	Receiving End Current (I_{R2})	Reading of Wattmeter (W_{S2})	Phase angle Calculated Value (θ_{CS2})	Phase angle Observed Value (θ_{OS2})	Power Factor (Cos θ_{S2})

PARAMETERS MEASURED AT RECEIVING END WITH SENDING END OPEN CIRCUITED:

Sl. No.	Driving End Voltage (V_{S3})	Receiving End Voltage (V_{R3})	Driving End Current (I_{S3})	Receiving End Current (I_{R3})	Reading of Wattmeter (W_{S3})	Phase angle Calculated Value (θ_{CS3})	Phase angle Observed Value (θ_{OS3})	Power Factor (Cos θ_{S3})

PARAMETERS MEASURED AT RECEIVING END WITH SENDING END SHORTCIRCUITED:

Sl. No.	Driving End Voltage (V_{S4})	Receiving End Voltage (V_{R4})	Driving End Current (I_{S4})	Receiving End Current (I_{R4})	Reading of Wattmeter (W_{S4})	Phase angle Calculated Value (θ_{CS4})	Phase angle Observed Value (θ_{OS4})	Power Factor (Cos θ_{S4})

CALCULATION:

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DEPARTMENT OF ELECTRICAL ENGINEERING

$Z_{so} = \dfrac{V_{s1}}{I_{s1}}$ (from first observation table)

$Z_{ss} = \dfrac{V_{s2}}{I_{s2}}$ (from second observation table)

$Z_{ro} = \dfrac{V_{r3}}{I_{r3}}$ (from third observation table)

$Z_{rs} = \dfrac{V_{r4}}{I_{r4}}$ (from fourth observation table)

$A = \sqrt{\dfrac{Z_{so}}{Z_{ro} - Z_{rs}}}$

$B = Z_{rs}.A$

$C = \dfrac{A}{Z_{so}}$

$D = Z_{ro}.C$

Also check if AD – BC = 1

**Conclusion:**Write in your own words what you have learnt after performing this experi

EXPERIMENT NO.2(a)

Experiment Name: Simulation of DC distribution by network analyser

Objectives:

To study the 2-wire D.C. distribution fed at one end and calculate the various load currents

THEORY: In figure 1 the single line diagram of a 2-wire D.C. distribution AB fed at one end A is shown. Concentrated loads I_1, I_2, I_3 and I_4 are tapped off at points C, D, E and F respectively.
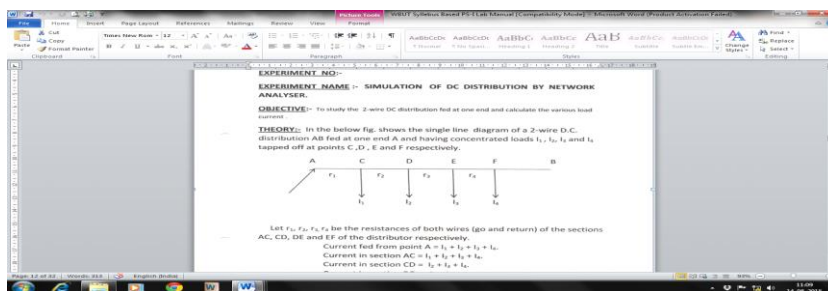
Let, r_1, r_2, r_3 and r_4 be the resistances of both wires (go and return) of the sections AC, CD, DE and EF of the distributor respectively.

Current fed from point A	=	$I_1 + I_2 + I_3 + I_4$
Current in section AC	=	$I_1 + I_2 + I_3 + I_4$
Current in section CD	=	$I_2 + I_3 + I_4$
Current in section DE	=	$I_3 + I_4$
Current in section EF	=	I_4

Voltage drop in section AC	=	$(I_1 + I_2 + I_3 + I_4) \, r_1$
Voltage drop in section CD	=	$(I_2 + I_3 + I_4) \, r_2$
Voltage drop in section DE	=	$(I_3 + I_4) \, r_3$
Voltage drop in section EF	=	$I_4 \, r_4$

So, total voltage drop in the distributor $= (I_1 + I_2 + I_3 + I_4) \, r_1 + (I_2 + I_3 + I_4) \, r_2 + (I_3 + I_4) \, r_3 + I_4 \, r_4$

It is to see that the minimum potential will occur at point F which is farthest from the feeding point A.

A long DC distribution system with single end fed and various loads connected at different locations can be represented by the circuit as shown in figure 2:
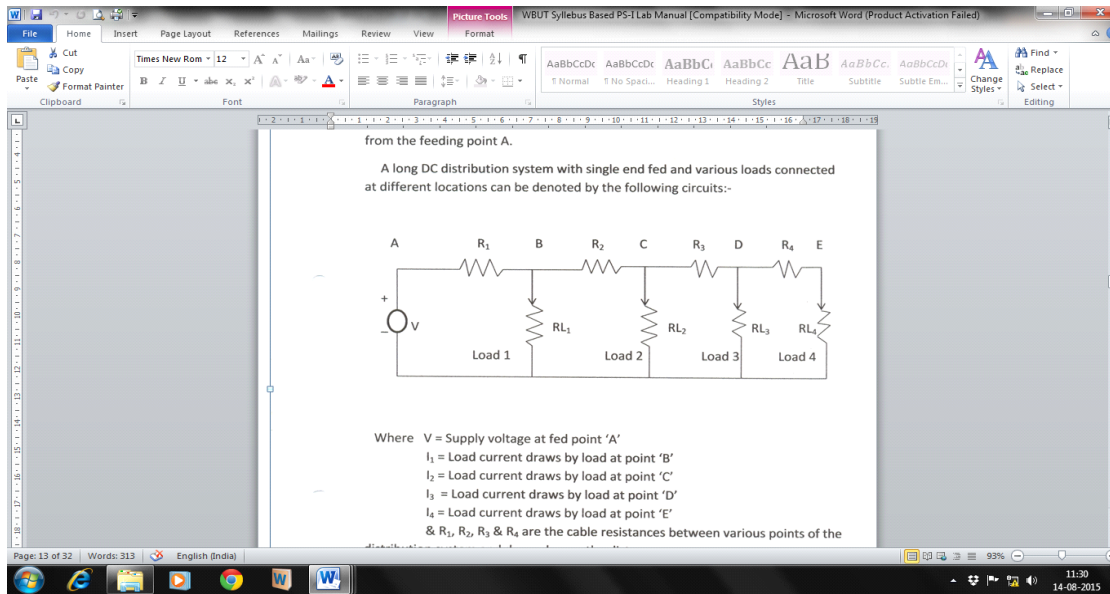
Figure 2

Where,   V   =   supply voltage at fed point A

I_1 =   load current drawn by load at point B

I_2 =   load current drawn by load at point C

I_3 =   load current drawn by load at point D

I_4 =   load current drawn by load at point E

R_1, R_2, R_3 and R_4 are the cable resistances between various points of the distribution system and depend on the distance.

CIRCUIT DIAGRAM:

Let, loads at different points are simulated with resistances RL_1, RL_2, RL_3 and RL_4. Now construct the circuit as per figure 3.
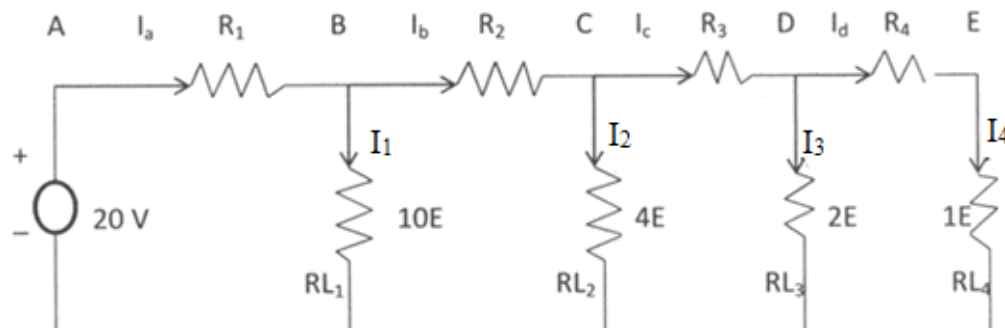
Figure 3

PROCEDURE:

- Switch on the power supply.
- Set 20V dc as supply voltage using variac.
- Note down various ammeter readings and tabulate it.
- Next find out various potential drops between the feeder terminals using voltmeter.
- Calculate the voltage drop of the feeder B, C, D and E by using line currents I_a, I_b, I_c and I_d and it can be seen that they decrease gradually as the distance from the feeding point (A) increases.
- The voltages at points A, B, C and D are observed and it can be seen that they decrease gradually as the distance from the feeding point (A) increases.
- The cable resistance values are so chosen that for every 10 km run of the line the cable resistance is 10 Ω i.e. cable resistance is 1 Ω / km. Distance between A & B is 10 km, B & C is 20 km, C & D is 40 km and D & E is 100 km.
- Verify the measured and calculated values.

OBSERVATION TABLE:

Sl. No.	Load current				Distributor current			
	I_1	I_2	I_3	I_4	I_a	I_b	I_c	I_d

	Potential drop between			
	A & B	**B & C**	**C & D**	**D & E**
Experimentally				
Theoretically				

Potential at point	Theoretically	Practically

CALCULATION:

Show your calculations.

Conclusion:

Write in your own words what you have learnt after performing this experiment.

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EXPERIMENT NO.2(b)

Experiment Name: Simulation of DC distribution by network analyser

Objectives:

To study the Ring Distribution and calculate the various load current.

THEORY: A distributor arranged to form a closed loop and fed at one or more points is called a ring distributor. Such a distributor starts from one point, makes a loop through the area to be served, and returns to the original point. For the purpose of calculating voltage distribution, the distributor can be considered as consisting of a series of open distributors fed at both ends. The principal advantage of ring distributor is that by proper choice in the number of feeding points, great economy in copper can be affected.

The most simple case of a ring distributor is the one having one feeding point as in fig below.
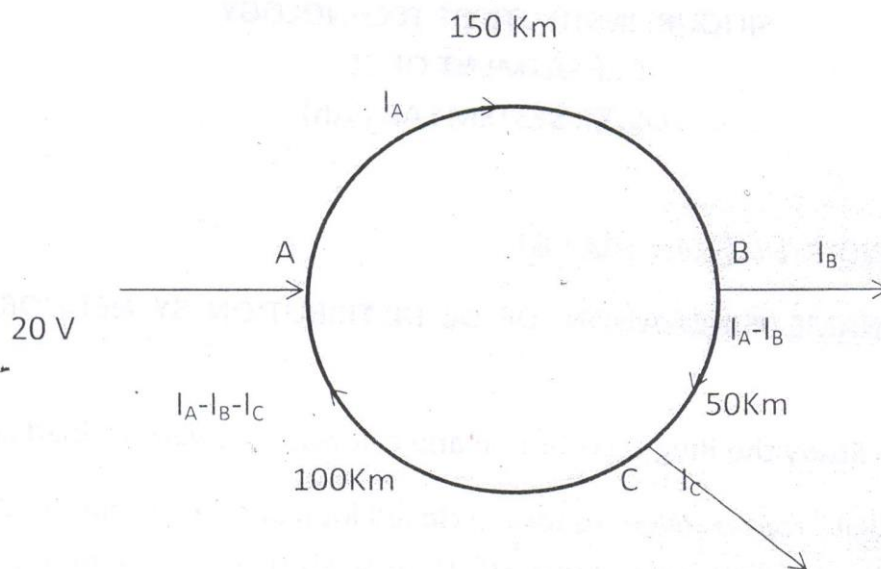

Here A is the feeding point and tappings are taken from points B and C. For the purpose of calculations, it is equivalent to a straight distributor fed at both ends equal voltages.

RING DISTRIBUTION:

1. Construct a circuit with suitable values for R_1, R_2, R_3, -------- RL1, RL2, etc.
2. Observe the following : $I_1R_1+I_2R_2+I_3R_3+I_4R_4 = 0$ (Kirchhoff's voltage law)

Measure the values and compare them with observation.

Similarly Ring distribution with interconnection, both end fed distribution etc. can be analyzed with help of Thevinin's Theorem, Super position theorem etc.
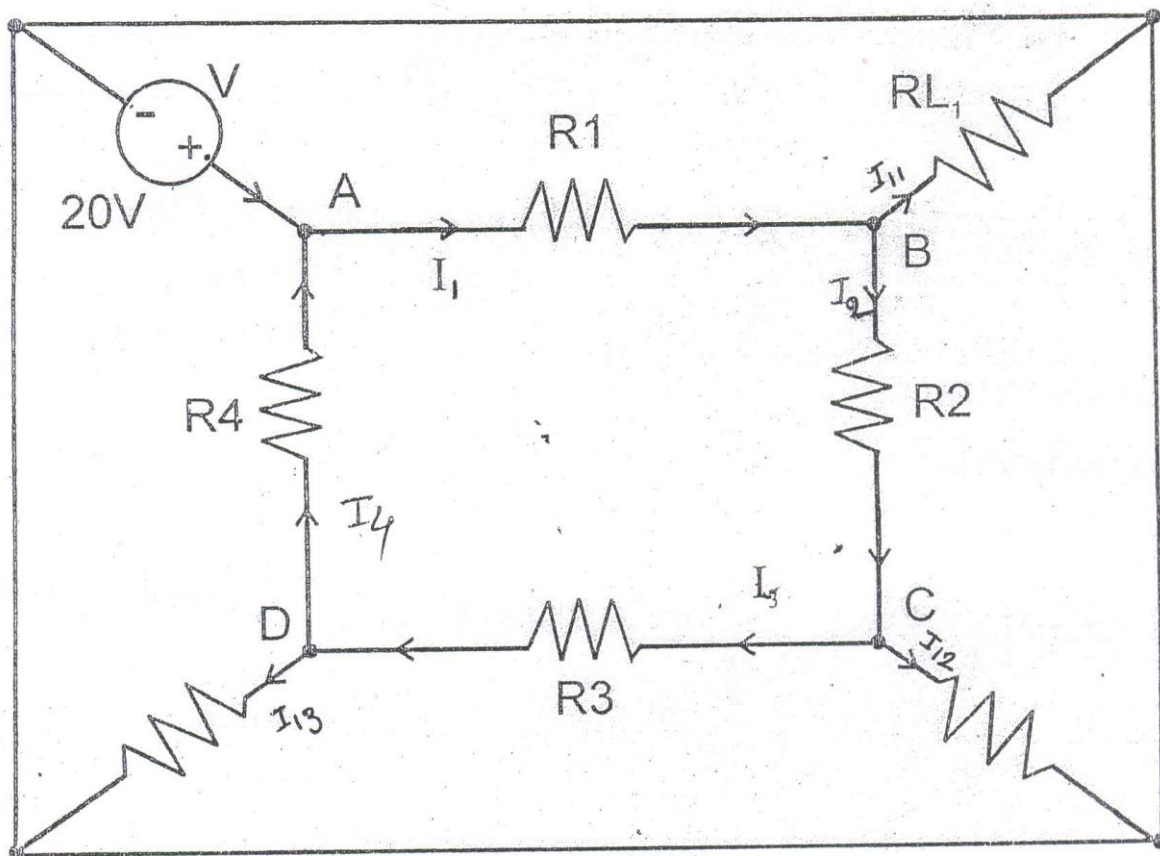
OBSERVATION TABLE:

SL NO	AT LOAD CURRENT				AT DISTRIBUTOR CURRENT			
	I_{11}	I_{12}	I_{13}		I_1	I_2	I_3	I_4

SL NO	POTENTIAL DROP BETWEEN			
	A & B	B & C	C & D	D & A
EXPERIMENTALLY				
THEORITICALLY				

POTENTIAL AT POINT	THEORITICALLY	EXPERIMENTALLY
B		
C		
D		

CALCULATION:

CONCLUSION:

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DEPARTMENT OF ELECTRICAL ENGINEERING
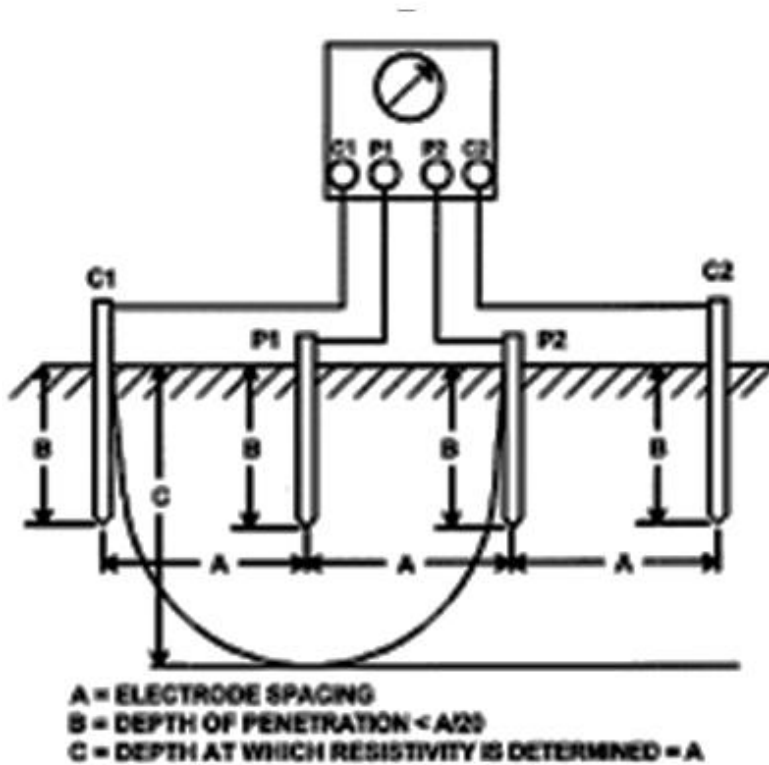
EXPERIMENT NAME: MEASUREMENT OF EARTH RESISTANCE BY EARTH TESTER

Objectives:

a) To get familiar with the working of an earth tester

b) To measure earth resistance of an installation with the help of an earth tester

THEORY: The determination of resistance between the earthing plate and the surrounding ground in distribution systems is of utmost importance. This measurement is made by the potential fall method. The use of alternating current source is necessary to eliminate electrolytic effect. The earth tester is a special type of meggar which send AC through earth and DC through the measurement instrument. It has got four terminals P_1, C_1, P_2, C_2 outside. Two terminals P_1 and C_1 are connected to P_1 and C_1 electrodes respectively. The other two terminals C_2 and P_2 are connected to the electrode C_2 and P_2. The value of the earth resistance is indicated by the instrument directly when its handle is turned at uniform speed. The distance between each electrode is 10 ft.

CIRCUIT DIAGRAM:

A = ELECTRODE SPACING
B = DEPTH OF PENETRATION < A/20
C = DEPTH AT WHICH RESISTIVITY IS DETERMINED = A

APPARATUS USED:

| SL NO	NAME OF THE INSTRUMENTS/ACCESORIES	RATING/RANGE	MAKE

PROCEDURE:

1. Connected the earth tester as shown in fig.
2. Rotate the handle continuously at a moderate speed and observe the earth resistance.
3. Change the position of electrode by 1ft on either side and observe the earth resistance.
4. Take the mean of three observation of earth resistance.

OBSERVATION TABLE:

SL NO.	POSITION OF ELECTRODEP_1	POSITION OF ELECTRODE P_2	EARTH RESISTANCE	MEAN EARTH RESISTANCE

CONCLUSION:
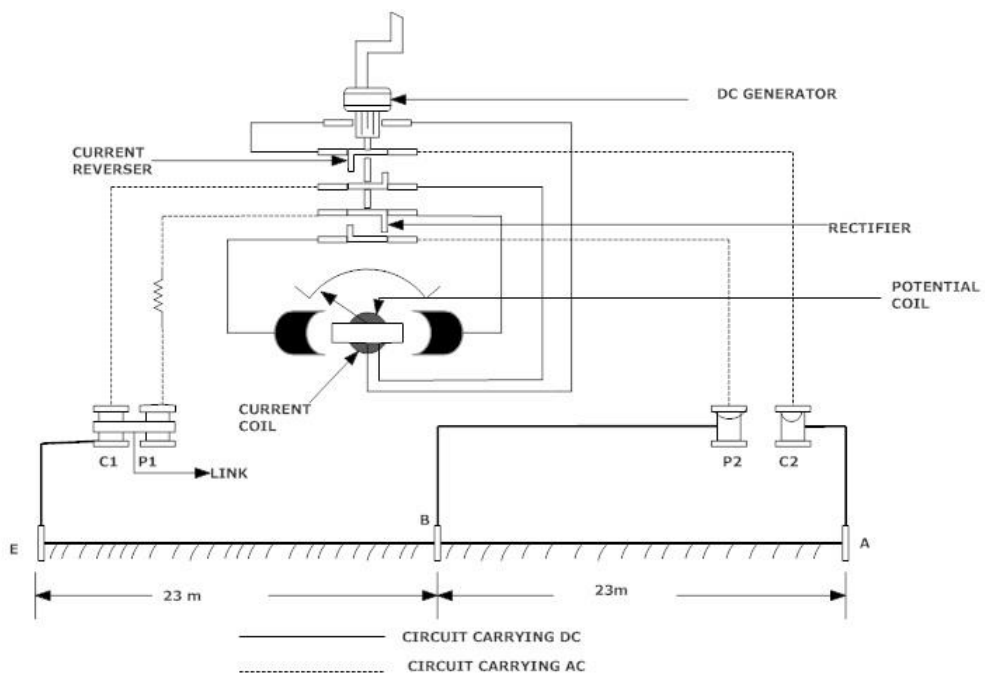
EARTH RESISTANCE MEASUREMENT BY EARTH TESTER

EXPERIMENT NAME: To find the dielectric strength of insulating oil (transformer oil)

Objectives:

- To know the operation of transformer oil test set.
- To measure the dielectric strength of given specimen of transformer oil.

THEORY: As per ISS, the breakdown strength oil when treated must be at least 50 KV_{rms} when measured with the help of two spherical electrodes of 12.5 mm diameter and with a gap spacing of 2.5 mm. However, the breakdown strength is greatly reduced due to the presence at impurities live moisture, gap bubbles solid particles etc.

CIRCUIT DIAGRAM:

Methyl Methacrylate
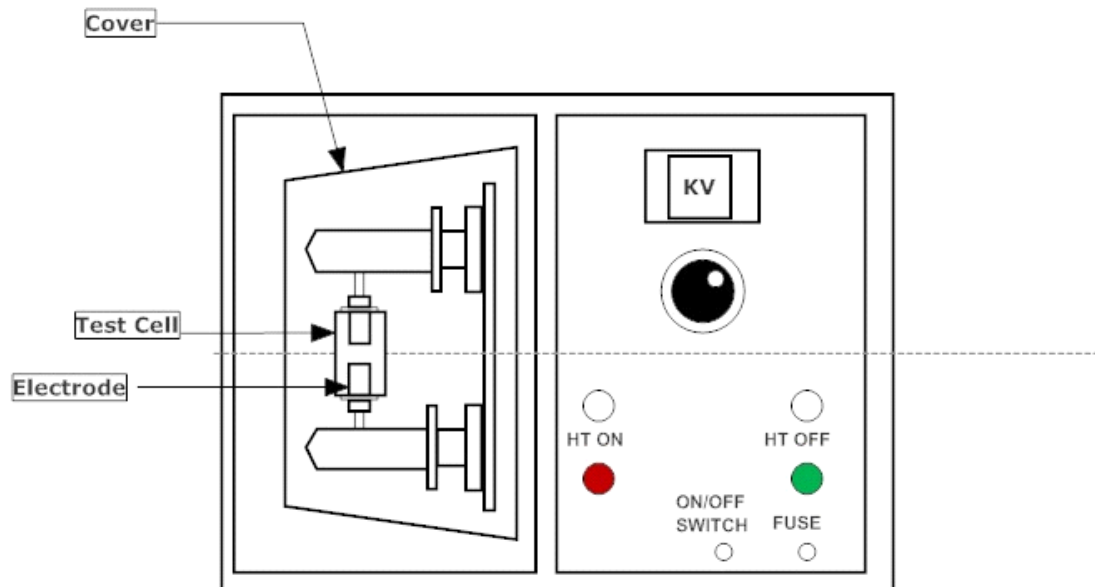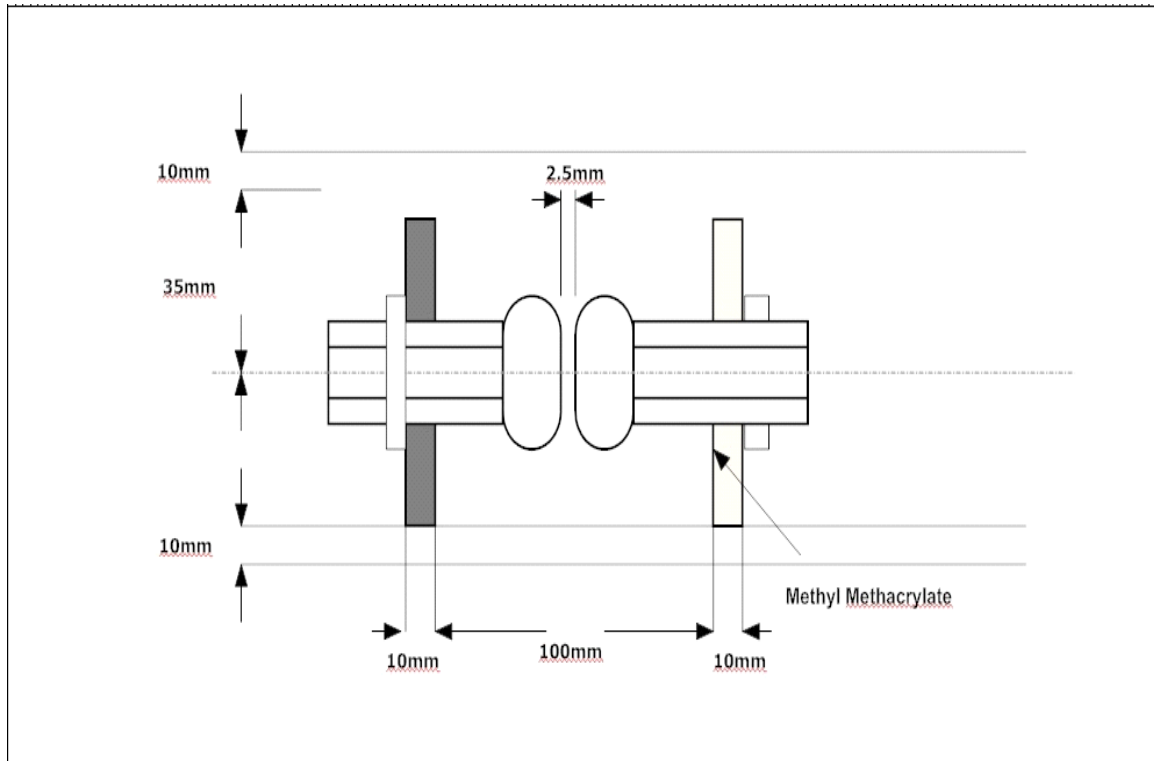
APPARATUS USED:

Sl. No.	Name of the Instruments / Accessories	Range/Rating	Make
1.	Portable oil testing set		
2.	Oil sample		

PROCEDURE:

- Clean the test cell by rising with the test oil (at least twice) before the final filling.
- Fill the cell by sample oil up to the mark and place the cell in place in the test set. Clouse the lid and switch on the supply AC mains.
- Check whether the voltmeter gives reading zero at this stage.

- Press the HT ON push button and turn the knob for measuring the HT voltage across the electrodes keep the rate of increase the voltage uniform and equal to approximately 2KV/Sec, starting from zero up the value producing breakdown. Stop moving the knob anymore as soon as breakdown occurs.
- Record the voltmeter reading and reset the knob and the voltmeter for next observation.

- Repeat the same test six times on the cell filling. After each breakdown the oil is gently stirred so as to keep away the carbon particles formed between the productions of air bubbles. Approximately a gap of 5 mints. Is recommended before two consecutive breakdowns.
- Calculate the arithmetic mean of six results, which is dielectric strength of the given sample.

OBSERVATION TABLE AND RESULT:

Sl. No.	Break down voltage	Mean Value
1.		
2.		
3.		

Conclusion:

Write in your own words what you have learnt after performing this experiment.

EXPERIMENT NO.5

**EXPERIMENT NAME: Determination of breakdown strength of solid insulating material**

Objectives:
To measure the dielectric strength of the given specimen of solid insulating material.

THEORY: When line conductors are bare and not covered with any insulating covering / coating, they may prove to be dangerous to human beings and other living things.The conductors are therefore secured by the application of insulating materials e.g. PVC, glass, porcelain etc for safety.

Power frequency dry flashover test: This test is performed to determine dry flashover voltage by applying gradually increasing voltage between the electrodes of the insulating material in a manner in which it is to be used, till the breakdown of insulation with formation of a sustained arc occurs. This test is repeated 5 to 10 times.

CIRCUIT DIAGRAM:
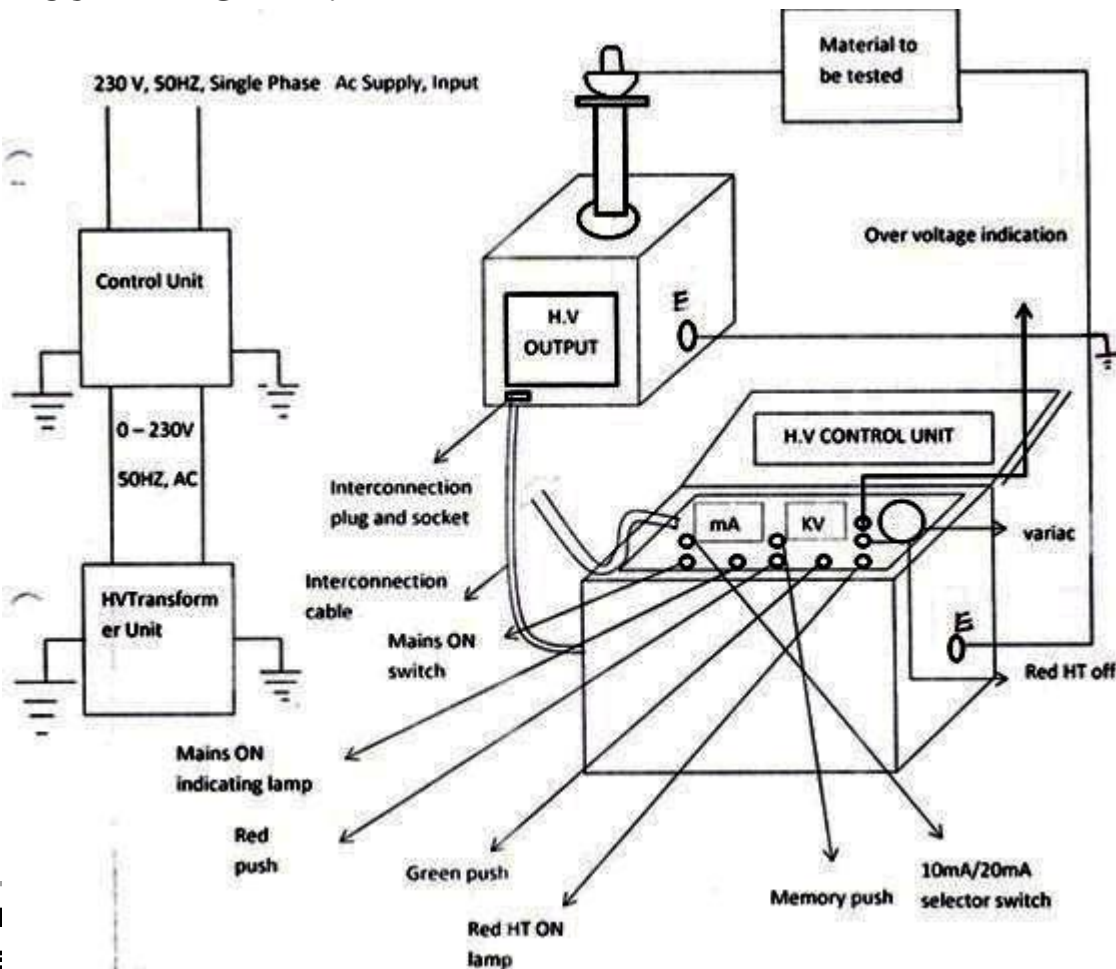
APPARATUS USED:

Sl. No.	Name of the Instruments/Accessories	Range/Rating	Make

PROCEDURE:

1. Connect the two units as given in the diagram.
2. Make the two units earthed properly; it is **very important**.
3. Connect the specimen provided between the H.V. terminal and earth.
4. Connect the main power supply cord to the nearest 230 V ac supply.
5. Make the set ON by ON switch which is indicated by glowing mains lamp in the panel.
6. Do zero interlocking i.e. bring back the variac to zero position before energizing H.V. circuit. It is **very important**.
7. Keep the overloading switch at 10 or 20 mA as per requirement. Do not disturb this switch while H.V. circuit is operating; it is indicated by red H.T. lamp. Consult with the lab supervisor in case of any doubt.
8. Now switch on the H.T. circuit.
9. Slowly increase the output voltage (which is shown by the set kV meter) to the test voltage.
10. If the sample breaks down below the test voltage, the H.T. circuit is automatically tripped OFF and exact voltage can be seen by pressing the memory push button switch without disturbing the voltage regulator.
11. **In case of any emergency**, if you need to switch off the H.T. circuit, press the red H.T. OFF push switch.
12. If raised voltage crosses the maximum voltage i.e. 50 kV, over voltage indication red lamp starts glowing and buzzer starts sound.

CAUTION

1. Ensure proper earthing of two units.
2. Connect two units properly.
3. Don't change tripping switch position during H.T. circuit operation i.e. when H.T. circuit is ON.
4. Don't touch H.V. bushing when H.T. circuit is under operationi.e. when H.T. circuit is ON.

OBSERVATION TABLE AND RESULT:

Sl. No.	Type of insulating material under test	Break down voltage
1.		
2.		
3.		

Conclusion: Write in your own words what you have learnt after performing this experiment.

EXPERIMENT NO.8

EXPERIMENT NAME: ACTIVE AND REACTIVE POWER CONTROL OF AN ALTERNATOR

Objectives:

Measurement of active and reactive power

THEORY: In an A.C circuit, no power is absorbed by either a pure inductor or capacitor, all real power is dissipated by the resister i.e. by the component of current in phase with the applied voltage= I CosØ . The ratio of CosØ of real or the true power to apparent power =VI, is known as power factor. The reactive power which is delivered to and returned by inductor and capacitor is obtained by multiplying the applied voltage with the out of phase component I SinØ i.e. P(reactive)= VI SinØ; its unit is volt ampere-reactive(VAR).

Therefore, for a single phase circuit, the expression for volt-ampes, reactive power and active power are given below.

Apparent power (VA)= voltage across the circuit X current flowing through it

Reactive Power = VI SinØ

Active Power= VI CosØ

For a three phase circuit the expression for active power, reactive power and apparent power as.

P 3 Ø = $\sqrt{3}V_L I_L$ Cos Ø

Where V_L = line voltage

I_L = line current

Q 3 Ø = $\sqrt{3} V_L I_L$ Sin Ø

S 3Q = $\sqrt{(P^2+Q^2)}$ = $\sqrt{3} V_L I_L$

The current coil of the two wattmeter are inserted in any two lines and their potential coils joined to the third line. It can be proved that the sum of the instantaneous power indicated by W1, W2 gives the three phase active power. *N case of balanced three phase circuits, it is simple to use a single wattmeter to react the reactive power. The current coil of the Wattmeter is connected in one line and the preserve coil is connected across the other two lines. Q3Q = -($\sqrt{3}$) X READING OF Wattmeter = (-$\sqrt{3} W_3$)*
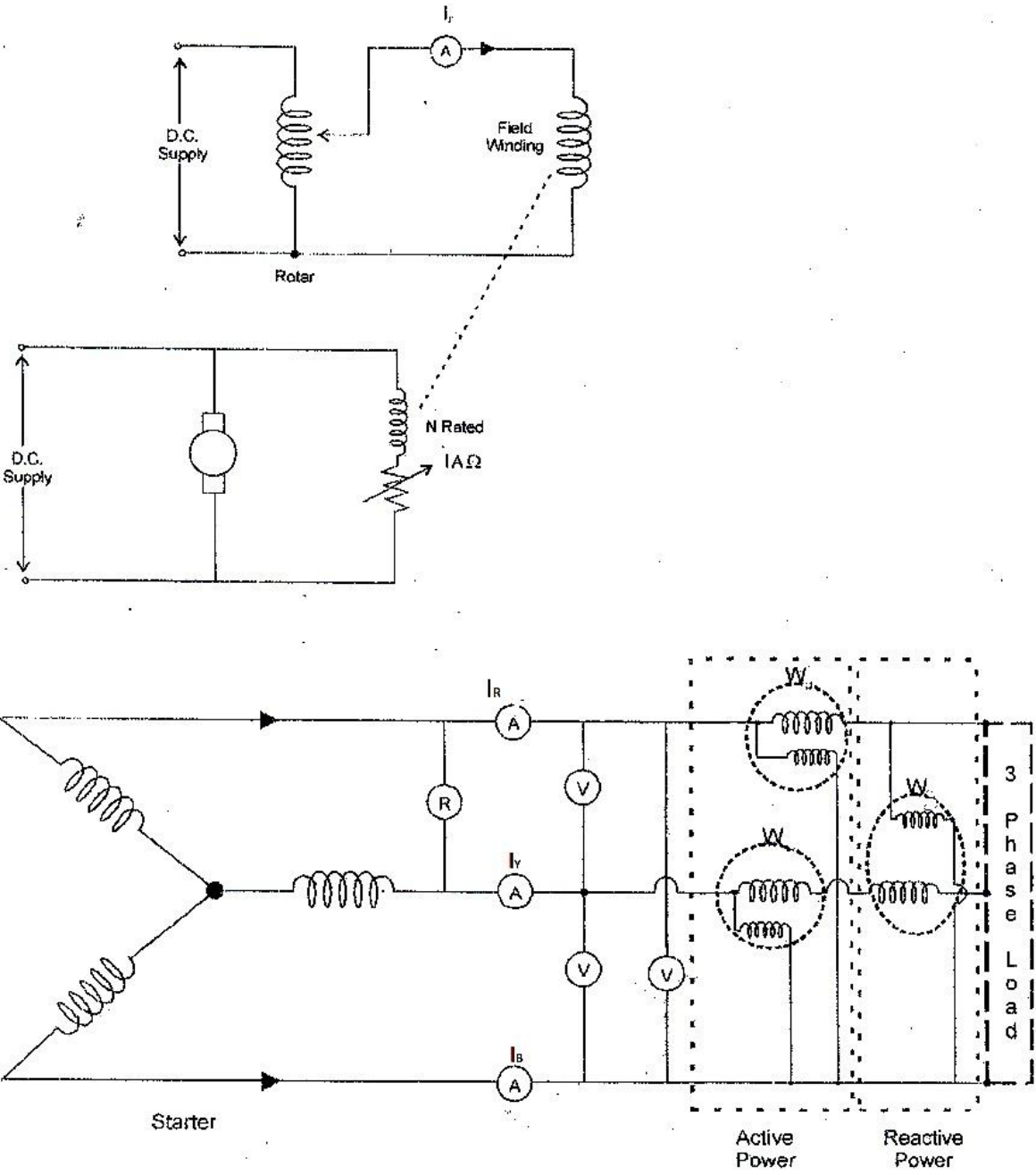
APPARATUS USED:

Sl. No.	Items	Quantity	Range/Rating	Makers Name	Makers No.
1	D.C. Ammeter	1			
2	A.C. Ammeter	3			
3	A.C. Voltmeter	3			
4	Wattmeter	3			
5	Alternator	1			
6	D.C. Motor	1			
7	Resistive Load	1			
8	Capacitive Load	1			
9					

PROCEDURE:

1. **Connect two Wattmeter (W_1 & W_2) to measure total power taken by three phase star and delta connected resistive, inductive and capacitive load.**

2. **Connect one Wattmeter (W_3) to measure total reactive power taken by the three phase star and delta connected resistive, inductive and capacitive load.**

3. **Set the line voltage at 100 volts adjust the resistance so that the reading of three Ammeter slightly less than 1 Amps.**

4. **Take down voltmeter(V_{RY},V_{BR},V_{YB}) , ammeters(I_R,I_Y,I_B) and watt meters W_1, W_2,W_3. Reading and recording table.**

5. **Change resistance values so that the Ammeter show the different readings and correspondings taken the three volt meter, watt meter readings.**

6. **Repeat the procedures for inductive and capacitive loads and tabulated in Table.**

Supply frequency = 50 Hz.

OBSERVATION TABLE:

SL NO	AMMETER READERS			VOLTMETER READERS			ACTIVE POWER MEASUREMENT			REACTIVE POWER MEASUREMENT		APPRENT POWER	TYPES OF LOAD
	I_R	I_Y	I_B	V_{RY}	V_{YB}	V_{BR}	W_1 (Watt)	W_2 (Watt)	$W_1+W_2=P_{3Q}$ (watt)	W_3 (Watt)	$Q_{3Q}=\sqrt{3}\,W_3$ (VAR)	$S_{3Q}=\sqrt{(P_{3Q}^2+Q_{3Q}^2)}$ (VA)	
1													Resistor
2													
3													
4													
1													Inductor
2													
3													
4													
1													Capacitor
2													
3													
4													

SAFETY:

- Do not ware loose garments inside the laboratory.

- Do not enter in the laboratory with bare foots.

- Do not switch on the circuit without permission of the concerned teacher.

- Do not touch the circuit rapidly.

- 5. Make sure that the circuit is switched off before leaving the lab.

REPORT WRITING :

Calculate Active, Reactive Power and power factors for Resistive, Inductive, Capacitive loads.

Draw the phasor diagram for different loads.

Draw the characteristics of the following

- V_L versus P_{3Q} for three types of load.

- I_L versus P_{3Q} for three types of load.

- V_L versus Q_{3Q} for three types of load.

- I_L versus Q_{3Q} for three types of load.

Experiment Name: Dielectric constant, tan delta, resistivity test of transformer oil.

Objectives:

To measure Dielectric constant, Tan Delta and Resistivity of transformer oil.

THEORY:
Tan Delta (tan δ) Test |Loss Angle Test | Dissipation Factor Test

<u>**Principle of Tan Delta(tan δ)Test:**</u>

A pure insulator when connected across line and earth, it behaves as a capacitor. In an ideal insulator the insulating material which acts as dielectric too is 100 % pure. The electric current passing through the insulator, only have capacitive component. There is no resistive component of the current which flows from line to earth through insulator, as in ideal insulating material, there is zero percent impurity.

In a pure capacitor, the current leads the voltage by an angle of 90°. But in general practice, the insulator cannot be made 100% pure. Also due to the ageing of insulator the impurities like dirt and moisture enter into it. These impurities provide a conductive path for the current.

Consequently, leakage current flowing from line earth through the insulator also has a resistive component. Hence, it is needless to say that, for good insulator, this resistive component of leakage current is quite low. In other way the healthiness of an electrical insulator can be determined by the ratio of Resistive component to the Capacitive component. For good insulator this ratio would be quite low. This ratio is commonly known as **tanδ**(tan delta). Sometimes it is also referred as Dissipation Factor.
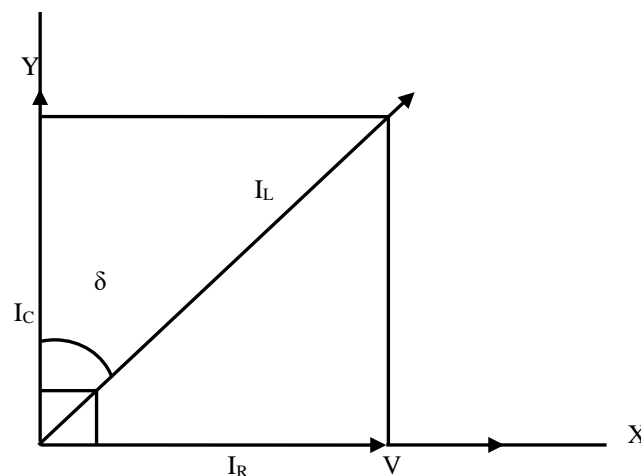
In the above vector diagram, the system voltage is drawn along x-axis. Conductive electric current i.e. resistive component of leakage current, I_R is also along x-axis. As the capacitive component of leakage electric current I_C leads the system voltage by 90°, it is drawn along y-axis.

Now, total leakage current $I_L(I_C + I_R)$ makes an angle δ (say) with y-axis.

Now, from the above diagram it is cleared that the ratio of I_R to I_C is nothing but tan δ.

Thus, tan δ = I_R / I_C .

N.B: This δ angle is known as loss angle.

Method of Tan Delta Test:

The Cable, Winding, Current Transformer, Potential Transformer, Transformer Bushing on which the Tan Delta test or Dissipation factor test to be conducted, is first isolated from the system. A very low frequency test voltage is applied across the equipment whose insulation to be tested. First the normal voltage is applied, if the value of tan delta appears good enough, the applied voltage is raised to 1.5 - 2 times of the normal voltage of the equipment. The tan delta controller unit takes measurement of tan delta values. A loss angle analyser is connected with tan delta measurement unit to compare the tan delta values at normal voltage and higher voltages and to analyse the results. During the test it is essential to apply test voltage at a very low frequency.

Reason for applying Very Low Frequency

If frequency of applied voltage is high, then capacitive reactance of the insulator becomes low, hence capacitive component of electric current is high. The resistive component is nearly fixed, it depends upon applied voltage and conductivity of the insulator. At high frequency as capacitive current, is large, hence, the amplitude of vector sum of capacitive and resistive components of electric current becomes large too.
Therefore, required apparent power for tan delta test would become high enough which is not practical. So to keep the power requirement for this dissipation factor test, very low frequency test voltage is required. The frequency range for tan delta test is generally from 0.1 to 0.01 Hz depending upon size and nature of insulation.
There is another reason for which it is essential to keep the input frequency of the test as low as possible.
As we know,

Dissipation factor $= I_R / I_C = \dfrac{V/R}{V \times 2\pi f C} = \dfrac{1}{2\pi f c R}$

That means, dissipation factor tan δ $\propto$ 1/f.
Hence, at low frequency, the tan delta number is high, the measurement becomes easier.

How to Predict the Result of Tan Delta Testing

There are two ways to predict the condition of an insulation system during tan delta or dissipation factor test.
First, one is, comparing the results of previous tests to determine, the deterioration of the condition of insulation due ageing effect.

The second one is, determining the condition of insulation from the value of tanδ, directly. No requirement of comparing previous results of tan delta test.

If the insulation is perfect, the loss factor will be approximately same for all range of test voltages. But if the insulation is not sufficient, the value of tan delta increases in the higher range of test voltage.
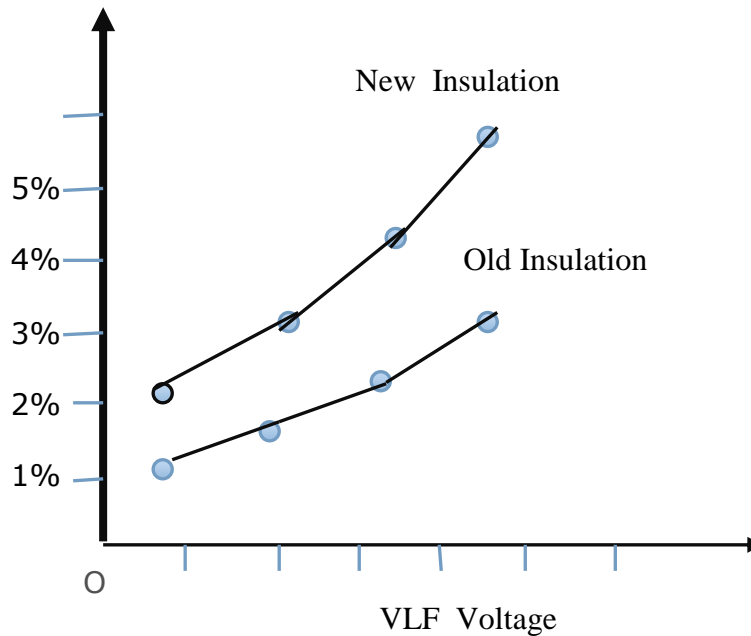
From the graph, it is clear that the tan and delta number nonlinearly increases with increasing test very low-frequency voltage. The increasing tan&delta, means, high resistive electric current component, in the insulation. These results can be compared with the results of previously tested insulators, to take the proper decision whether the equipment would be replaced or not.

The Dielectric Constant, Tan Delta & Resistivity Test set has been specially designed to determine the Tan Delta, Dielectric Constant and Resistivity of transformer oil and other electrical insulating liquids using a guarded three terminal test cell. This may also be used for measurement of the above parameters of solid insulating materials using a guarded three terminal solid test cell.

There are built in features which include zero start on voltage adjustment, auto trip with LED indication if two grounds are not connected, auto trip with LED indication if safety interlock is opened and built in protection should the test sample flash over.

The $\in$(Epsilon)- DF portion of the instrument operates as a manually balanced capacitance bridge. Since $\in$ is the ratio of the full cell capacitance to the empty cell Capacitance (in cm) must be dialed in or be balanced out by using the balancing procedure. The cell constant (in cm) equals $3.6 \times \pi \times 1 \times C$, where C is the cell Capacitance in pF. The bridge balance is accomplished with the aid of synchronous and phase sensitive null detector which allows easy and independent balancing of the and DF components. The DF $\in$ tests are carried out w.r.t line frequency.

The Resistivity meter is autoranging with the reading displayed on $3\frac{1}{2}$ digit DPM. Once the cell constant is balanced with the cm dial, the Resistivity meter reads volume Resistivity

directly in ohm-centimeters. With the cm dial set to 1000, the Resistivity meter reads resistance in ohms multiplied by a factor of 1000. The autoranging feature eliminates the need for selecting the right range manually.

APPARATUS USED:

1. Oil Loss Angle Meter.

2. Million Megohm Meter.

3. Three Terminal Oil Test Cell (Stainless Steel: SS 316)

4. Heating Chamber for three terminal oil test cell with protection device, thermostat & temperature indicator.

5. Calibrator.

CLEANING PROCEDURE FOR THE TEST CELL:

1. Use Carbon tetra chloride or distilled benzene for cleaning the oil test cell.

2. Separate the component parts of three terminal oil test cell i.e. outer case and inner electrode & keep them on the clean plate or ceramic tile.

3. Fill the outer case, partially, with cleaning agent.

4. Assemble the component parts with solvent contained in outer case.

5. Shake the cell assembly vigorously and separate the parts and throw the cleaning agent.

6. Repeat the above procedure twice or thrice with fresh solvent.

7. Dry the cell around 60°C.

8. The cleaned dry empty cell should resistance above 10^9 megohm. If not, repeat the above cleaning process again.

9. The cleaning of the cell should be done before and after every test.

MEASUREMENT PROCEDURES:

PROCEDURE FOR MEASUREMENT OF DIELECRIC CONSTANT:

1. Connect the oil test system to 230 V AC, 50 Hz power supply.

2. Switch ON the equipment.

3. Keep mode selector band switch in discharge mode.

4. In the Tan d & Discharge mode AC & Tan d% marked Led glow.

5. Keep Voltage at zero.

6. Place empty oil cell in heating chamber. The connection should be made as follows:

   a. Red Connector (HV) should be connected to outer terminal of oil cell.

   b. Black connector (LV) should be connected to the inner terminal of oil cell.

   c. Green connector (GUARD) should be connected to the middle terminal of oil cell.

7. Now select Volts/Null switch to volts position, and set voltage 500 V AC by set volts Potentiometer.

8. Select mode selector Bandswitch to Tan d mode & Volts/Null switch to Null position.

9. Set 1.00 on the DPM with the help of the potentiometer marked as Set Null at 5.00 & select Discharge mode by the mode selector.

10. Do not alter or disturb the voltage or null control knob.

11. Pour required quantity of oil in the cell (60 ml app.)

12. Now select the mode selector to Tan d mode.

13. Null DPM will show a different reading . This new reading directly shows the Dielectric Constant of the sample under test.

14. Note that meter gives the Dielectric Constant in the range 0.10 to 10.00

15. Also note that in this measurement tan d meter is not used at all.

16. Select Discharge mode after nothing the reading.

PROCEDURE FOR MEASUREMENT OF TAN D:

Tan d for oils is normally measured at 90°C as recommended by I.S.I, but for R&D purpose it can be measured any temperature upto 150°C.

1. Clean the oil cell thoroughly. This can be ensured by measuring insulation resistance on oil test system in IR range which should be practically infinite.

2. Pour oil to be tested in then oil cell gradually, the oil enters the space cavity in between the two electrodes of cell through holes provided.

3. Keep oil cell in heating chamber.

4. Connect heating chamber to 230 V AC, 50 Hz supply.

5. Switch ON the heating chamber with the help of switch self illuminating Mains ON.

6.   Switch ON the Heater ON switch.

7.   Insert sensing probe in the oil cell carefully.

8.   The DPM on heating chamber will indicate the temperature of the oil in cell.

9.   Connect oil test system to 230 V AC, 50 Hz supply.

10.   Switch ON the instrument.

11.   Keep mode selector bandswitch in Discharge mode.

12.   Keep voltage zero.

13.   Connect HV, LV & Guard terminals from oil test system to heating chamber back panel respectively. Connect the coaxial lead from the heating chamber to the oil cell black to LV & green to Guard & red to HV cover the oil cell by the acrylic box, "HV ON" led will get ON.

14.   When the temperature of Oil cell in heating chamber reach to 90°C or desired temperature, then heater supply will cut of automatically and 'Trip ON' indication lamp will get 'ON' & temperature will rise 1 to 2 degree. The trip setting may be changed if required by adjusting the 'TRIP SET' control potentiometer.

15.   Select Volts/Null switch to volts position & set AC voltage 500 VAC on the DPMA AC/DC or desired value with the help of potentiometer marked as set volts.

16.   Select mode to discharge position check zero on the Tan d% DPM, if not adjust zero on Tan d% meter carefully with the help of SET ZERO pot.

17.   When the temperature is 90°C while cooling, switch mode selector to Tan d mode & with the help of Set Null at 5.00 pot adjust the null meter to read 5.00. Read the reading on the DPM Tan d% it display the Tan delta in % directly & note down the reading.

18.   Repeat steps 16 & 17 for verification.

19.   If the tan d is more than 19.99%, select 199.9% range & use correction chart vide.

20.   To measured tan d at room temperature, repeat steps 1 to 17 when the oil indicates room temperature.

PROCEDURE FOR MEASUREMENTS OF RESISTIVITY:

As per the I.S: 6103-1971 the resistivity measurement should be made while the temperature of the inner electrode is within ± 0.5°C of the desired test temperature. If a power factor tests has been made on the test specimen short circuit the cell electrodes for one minute, then start the Resistivity measurements immediately thereafter.
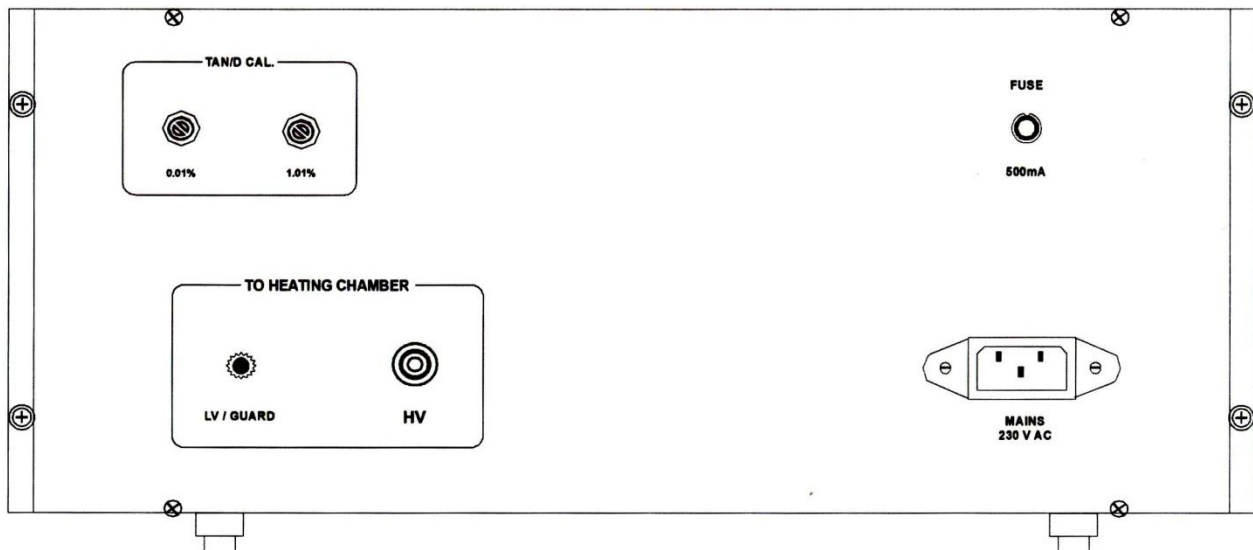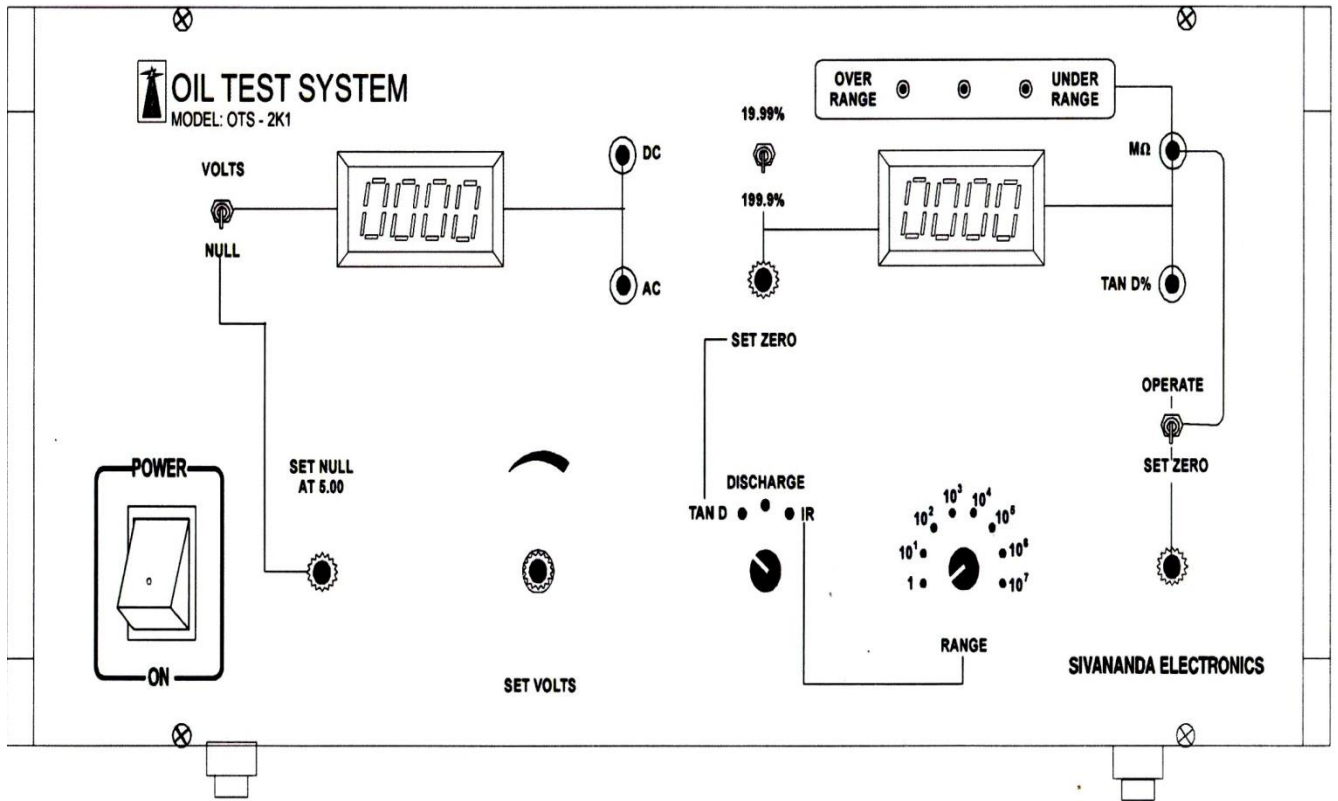
 Resistivity of the oil normally measured at room temperature as well as at 90°C.
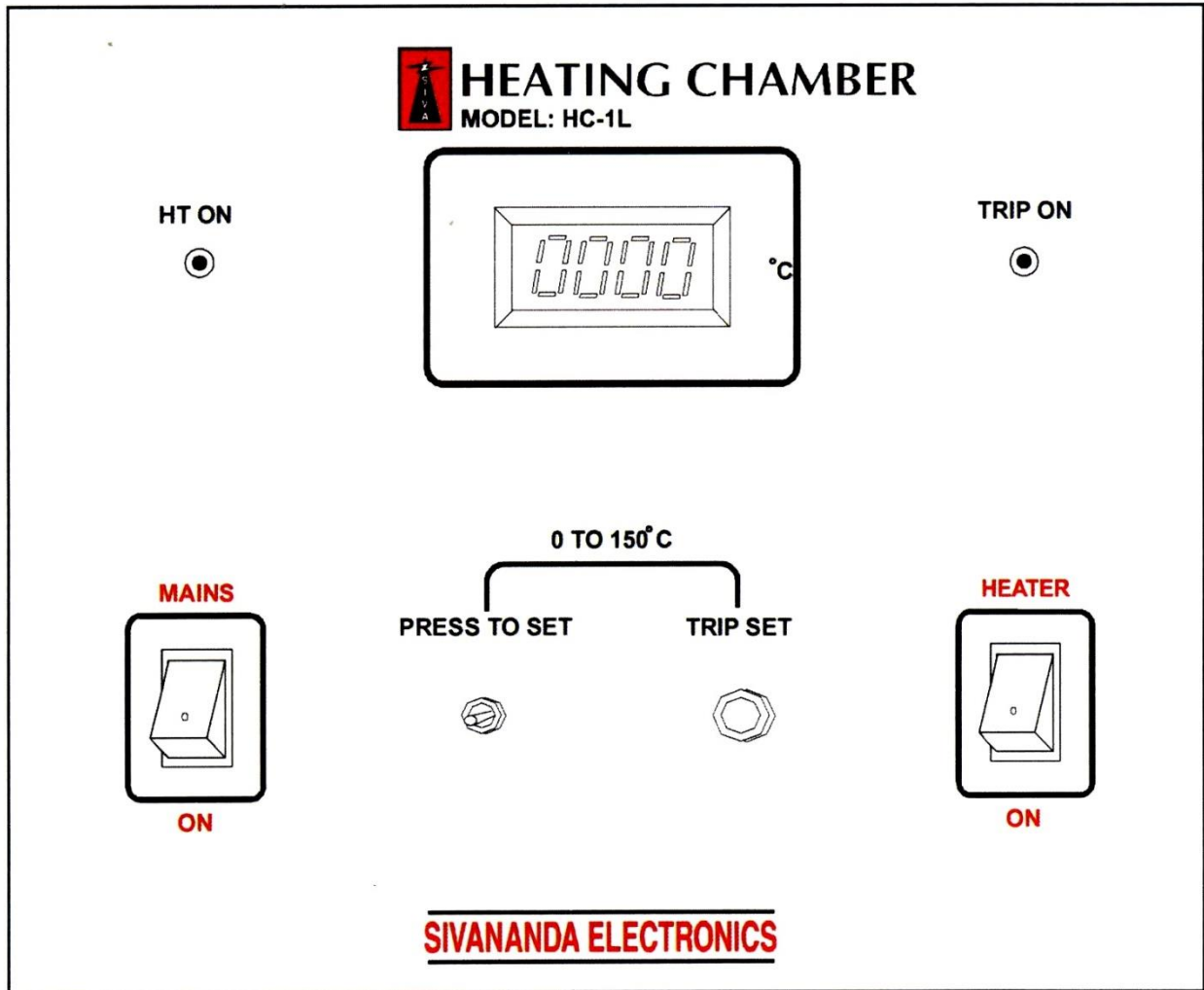
1. Clean the oil cell thoroughly as explained and place it on insulation base plate such as glass or Pyrexsheet. For measurement at room temperature proceed as follows:

2. Connect the oil test system to the mains supply 230 VAC, ±10%, 50 Hz.

3. Switch 'ON' the instrument.

4. Select mode selector to Discharge mode.

5. Select Volts/Null switch to Volts position.

6. Set Range selector Bandswitch to range 1.

7. Select mode selector to Discharge mode & connect the HV, LV & Guard leads from oil test system to heating chamber back panel respectively. Connect the coaxial lead from the heating chamber to the oil cell black to LV & green to Guard & red to HV cover the oil cell by the acrylic box, "HV ON" led will get ON.

8. Select IR mode and read the value of resistance by changing the range from 1 to 10^6, The display should show blank. If not remove the test cell after selecting DISCHARGE mode. Then clean the cell again and repeat the procedure till you get infinity reading at the highest range of interest.

CONNECT OR DISCONNECT THE OIL CELL ONLY WHEN INSTRUMENT IS IN DISCHARGE MODE.

9. Pour the required quantity of oil in the cell.

10. Keep the oil cell in Heating Chamber and connect the leads from oil test system.

11. Select IR range after 1 minute of charging note down the insulation resistance shown of the material by selecting the range of 1 to 10^7 were the reading on DPM is in between 10 to 100 note down the reading & multiplier & select Discharge mode.

12. Total Insulation Resistance is: Meter reading x Range Megohms.

13. Calculate the resistivity.

Resistivity = Resistance show in Ohm x Cell constant.

14. After taking the measurement at room temperature heat the oil cell with oil in it to the desired temperature in Heating Chamber.

15. Take measurement of resistance as explained above in this section.

OIL TEST SYSTEM
MODEL: OTS - 2K1

VOLTS
NULL
DC
AC

19.99%
199.9%

OVER RANGE
UNDER RANGE
MΩ
TAN D%

SET ZERO

POWER
ON

SET NULL AT 5.00

SET ZERO

DISCHARGE
TAN D
IR

OPERATE
SET ZERO

SET VOLTS

10² 10³ 10⁴
10¹ 10⁵
1 10⁶
10⁷

RANGE

SIVANANDA ELECTRONICS

TAN/D CAL.
0.01%   1.01%

FUSE
500mA

TO HEATING CHAMBER
LV / GUARD   HV

MAINS
230 V AC

HEATING CHAMBER
MODEL: HC-1L

HT ON

⊙

°C

TRIP ON

⊙

0 TO 150°C

MAINS

PRESS TO SET   TRIP SET

HEATER

ON

ON

SIVANANDA ELECTRONICS

HV   LV

GUARD

230 V AC

FUSE 1 Amp

SIVANANDA ELECTRONICS
DEEPAK MAHAL, LAM ROAD,
DEVLALI - 422 401
DIST. NASIK, (INDIA)

SINGLE CORE
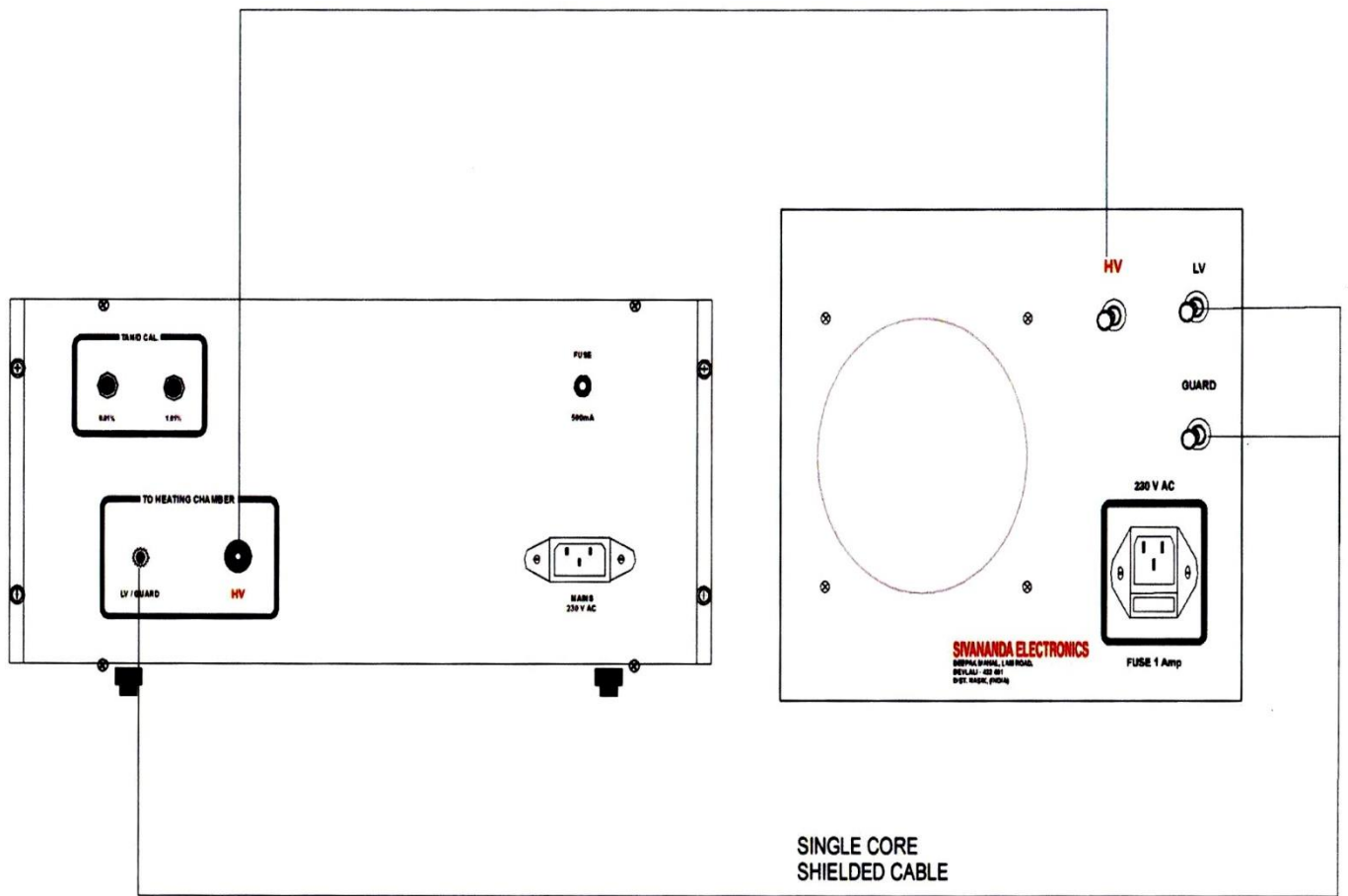SHIELDED CABLE

SINGLE CORE
SHIELDED CABLE

OBSERVATION TABLE:

Measurement of Dielectric Constant:

Sl. No	Supply Voltage	Test Voltage	Mode	Volts/Null Switch Position	Dielectric Constant	Measurement of Tan D%

Measurement of Tan D% :

Sl. No	Supply Voltage	Temp(°C)	Test Voltage	Mode	Volts/Null Switch Position	Tan D% DPM	Range Switch

Measurement of Resistivity:

Cell Constant(K) = 3.6 x π x 1 x C = 3.6 x π x 1 x 55.2pF = 623.76

Sl. No	Supply Voltage	Test Voltage	Temp .(°C)	Mode	Volts/Null Switch Position	Range selector Bandswitch position	Meter Reading(Mohm)	Insulation Resistance(Mohm)=	Cell Constant(K)	Resistivity

Insulation Resistance(M ohm) = Meter Reading X Range Meg Ohms.

Resistivity= Resistance in Ohms X Cell Constant

CONCLUSION: