Siliguri Institute of Technology
<u>Department of Electrical Engineering</u>

ENERGY STORAGE SYSTEM IN RENEWABLE INTEGRATED DEREGULATED POWER SYSTEM

A PROJECT REPORT

Submitted by

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In partial fulfilment for the award of the degree
Of

BACHELOR OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING

SILIGURI INSTITUTE OF TECHNOLOGY
SILIGURI-734009

MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY, WEST BENGAL
(Formerly known as West Bengal University of Technology)
KOLKATA - 700064

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DECLARATION

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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BONAFIDE CERTIFICATE

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ABSTRACT

The rapid growth in the usage and development of renewable energy sources in the present day electrical grid mandates the exploitation of energy storage technologies to eradicate the dissimilarities of intermittent power. The energy storage technologies provide support by stabilizing the power production and energy demand. This is achieved by storing excessive or unused energy and supplying to the grid or customers whenever it is required. Further, in future electric grid, energy storage systems can be treated as the main electricity sources. Researchers and industrial experts have worked on various energy storage technologies by integrating different renewable energy resources into energy storage systems. Due to the wide range of developments in energy storage technologies, in this article, authors have considered various types of energy storage technologies, namely battery, thermochemical, thermal, pumped energy storage, compressed air, hydrogen, chemical, magnetic energy storage, and a few others. These energy storage technologies were critically reviewed; categorized and comparative studies have been performed to understand each energy storage system's features, limitations, and advantages. Further, different energy storage system frameworks have been suggested based on its application. Therefore, this paper acts as a guide to the new researchers who work in energy storage technologies. The future scope suggests that researchers shall develop innovative energy storage systems to face challenges in power system networks, to maintain reliability and power quality, as well as to meet the energy demand

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Introduction :

Due to urbanization and the rapid growth of population, carbon emission is increasing, which leads to climate change and global warming. With an increased level of fossil fuel burning and scarcity of fossil fuel, the power industry is moving to alternative energy resources such as solar power (SP), wind power (WP), and battery energy-storage systems (BESS), among others. The electrical power infrastructures are facing significant challenges such as the scattered nature of making power, the need of autonomous microgrids to ensure reliability, and the integration of various energy resources to meet unpredictable demands of providing consistent power supply. To address these issues, the usage of the renewable energy-storage system (RESS) has increased tremendous consideration and has become an appealing option for researchers due to its promising features. The principle highlight of RESS is to consolidate at least two renewable energy sources (PV, wind), which can address outflows, reliability, efficiency, and economic impediment of a single renewable power source. However, a typical disadvantage to PV and wind is that both are dependent on climatic changes and weather, both have high initial costs. With this motivation, an array of energy storage technologies has been developed such as batteries, supercapacitors, flywheels, Compressed-Air Energy Storage (CAES), pumped hydro (PHS) and hydrogen storage systems. These technologies are mainly categorized as chemical, electrochemical, mechanical, and electrical. This paper provides a comprehensive review of the battery energy-storage system concerning optimal sizing objectives, the system constraint, various optimization models, and approaches along with their advantages and weakness. This article collates numerous functionalities of ESS. Furthermore, different ESS features and limitations are critically reviewed and highlighted in this paper. Besides, various applications of ESS are discussed together with the challenges and future direction.

CHAPTER 1 :

RENEWABLE ENERGY

1. Renewable Energy

Renewable energy is an energy which is derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, biomass for example, are such sources that are constantly being replenished.

From 2011- 2021, the share of renewable power from sun and wind increased from 2% to 10%. Biomass and geothermal energy grew from 2% to 3%. India is world's 3rd largest renewable energy producer with 40% of energy capacity installed in the year 2022 (160 GW of 400 GW) derived from renewable sources.

Present days, demand of non-renewable sources are mainly increased because we have not fully adapted towards renewable. We see that a 5 % yearly increase not only the point of view of fuel depletion, but is also a main reason for increase in pollution level and related disasters.

1.1. Why renewable energy ?

- As the name suggests, renewable energy is created from sources that naturally replenish themselves – thereby not to worry about extinction.
- During the process there are no greenhouse gasses or other pollutants created.
- Renewable energy creates no waste, or contamination risks to air and water as produced by burning of fossil fuels.
- With an increasing focus on global warming and many governments setting ambitious carbon-reduction goals, one of the major advantages of renewable energy is that it has quickly become a huge opportunity for new job growth.

The types of renewable energies available today are:

- Biomass Energy
- Wind power
- Solar Energy
- Wave energy
- Tidal power
- Geothermal heat

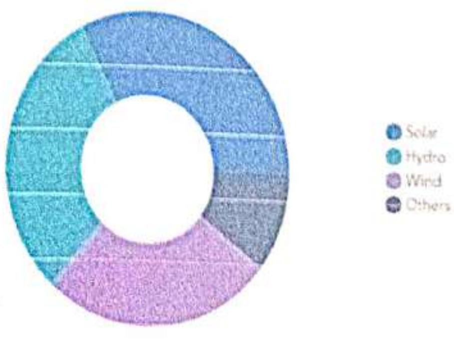

Figure 1 : RENEWABLE ENERGIES

CHAPTER 2 :
REGULATED POWER SYSTEM

2. REGULATED POWER SYSTEM

The most common utility structure is vertical integration. The traditional definition of a "vertically integrated" utility is one that owns all levels of the supply chain: generation, transmission, and distribution. Historically, all utilities were vertically integrated and had a monopoly on the production and sale of power.

Advantage

1. Monopolistic industries can create economic harm if they are not regulated. Regulation is to limit the economic harm.
2. Stable prices and long-term certainty can be achieved.

Disadvantages

1. Consumers have their limited choice.
2. In regulated states, utilities must abide by electricity rates set by state public utility commissions.

2.1. Deregulated power system

Electric deregulation is the process of changing rules to choose of electric suppliers for consumers by allowing competition. Over the last couple of decades, numerous cities within states have introduced deregulated electricity. These modifications take electricity markets from regulated to deregulated, which provides several benefits to consumers in those states.

This new type of market seems like it would be clearly understood, though there is still some confusion — especially for those homes and businesses that have recently relocated from a regulated energy market to a deregulated one.

2.2. Electricity Regulation vs Deregulation

It is often helpful to compare two concepts in order to see the differences. To help you better understand what electricity deregulation is, let's take a moment to compare the industry to energy regulation. In regulated markets, the utility holds control over the complete energy vertical. What this means is, from start to finish, from the generation of electricity all the way down to the customer's meter, the utility owns everything. Electricity deregulation takes some of this ownership away from the utility.

In a deregulated market, the utility controls distribution, maintenance of wires and poles, and invoicing of the consumer for those services. In an electricity deregulated market, companies known as REPs — Retail Electricity Providers — provide the delivery of electricity to the customer (the supply of electricity). REPs can be called a variety of different things — electric providers, electric companies, energy companies, etc., but regardless of their name their function remains the same.

Figure 2.2 : ELECTRICITY REGULATION VS DEREGULATION

2.3. Benefits of Electricity Deregulation :

The deregulation of the energy industry brought multiple benefits to the energy user, and includes the following-

- **Power to choose.** Deregulation allows energy users to choose where their energy comes from, and allows them to choose plans that are best for them.
- **Increased competition and better service.** Deregulation promotes competition among energy firms, and motivates providers to offer excellent service to their customers.
- **Encouraged energy efficiency.** Deregulation empowers users to be more energy efficient by choosing companies with more energy-efficient practices.
- **Improved energy consciousness.** Energy deregulation helps energy users understand energy costs by evaluating different plans, and providers often help their customers to save and conserve energy.
- **New and enhanced services.** By diversifying, competitive energy suppliers often offer additional services and benefits to their energy users that would otherwise have been unavailable.

CHAPTER 3 :
ENERGY STORAGE SYSTEM

3. ENERGY STORAGE SYSTEM :

Energy **storage** is the capture of energy produced at one time for use at a later time to reduce imbalances between energy demand and energy production. Some technologies provide short-term energy storage, while others can endure for much longer. The increasing share of renewables, especially wind and solar power, means that power grids are experiencing ever larger fluctuations. There are period with too much or too little green electricity, stretching base-load power plants and grid infrastructures to their limits.

Energy storage supports the energy transition Producing power from renewable sources means volatility – and energy storage is the key to matching supply to demand. Generating electricity from renewables varies greatly due to the unpredictable nature of the weather. In some cases, renewable power plants end up producing more electricity than is actually needed for current demands. Energy storage systems solve this problem by storing surplus energy and making it available at a later time as needed. Electricity can then be taken from the stored energy and fed into the grid.

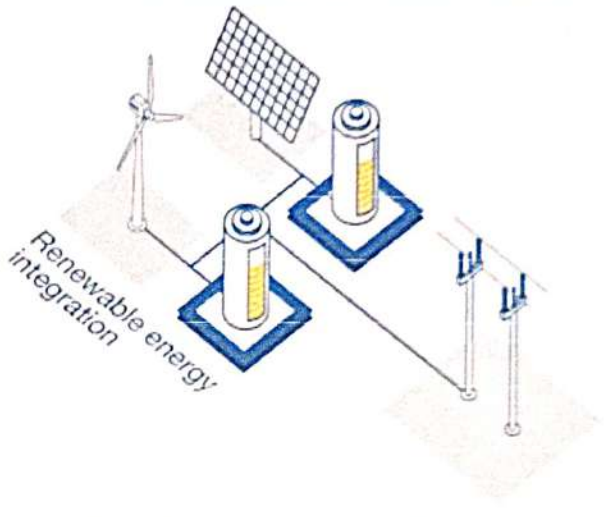

Figure 3 : ENERGY STORAGE SYSTEM

Energy storage systems can integrate renewables by shifting energy to high-demand periods, or provide grid services like frequency control or spinning reserve. It's also possible to use the stored energy in the form of heat and cold, or as synthetic fuel e.g., for transportation.

In addition to being a key component in the expansion of renewables and ensuring a sustainable, reliable, and economic power supply, energy storage systems are also an important factor in what is known as "sector coupling".

The following list includes a variety of types of energy storages are:

- Compressed air energy storage (CAES)
- Flywheel energy storage
- Battery electric energy storage (BEES)
- Pump storage hydroelectricity (PSH)
- Thermal Expansion

3.1. Battery Electric Energy Storage (BESS)

Energy can be stored in advance technological solutions for later use by BESS system. It is an important pillar for any energy strategy. With the help of solar energy system, batteries charge during whole day and deliver or releases energy during night time. Both domestic and large-scale commercial equipment work on the same principles. They use automatic battery algorithms to manage energy productions, as well as intelligent control system to determine how stored energy is used. Modern systems and control system will use stored energy during peak times when electricity cost is highest.

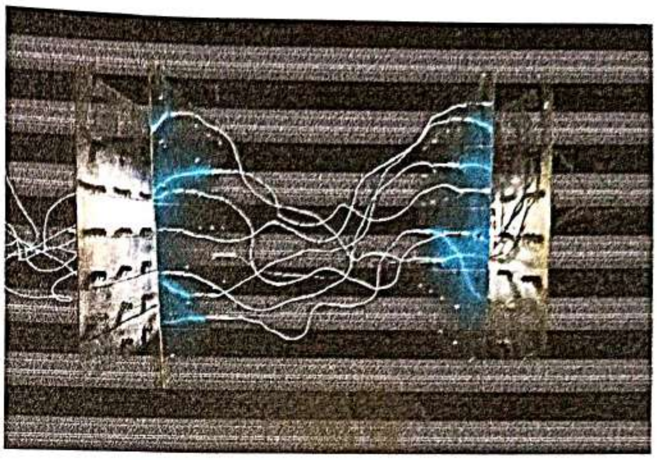

Figure 3.1 : BATTERY ELECTRIC ENERGY STORAGE

3.2. Compressed Air Energy Storage (CAES)

Compressed air energy storage (CAES) is a way to store energy generated at one time for use at another time. At utility scale, energy generated during periods of low energy demand (off-peak) can be released to meet higher demand (peak load) periods. Since the 1870's, CAES systems have been deployed to provide effective, on-demand energy for cities and industries. While many smaller applications exist, the first utility-scale CAES system was put in place in the 1970's with over 290 MW nameplate capacity. CAES offers the potential for small-scale, on-site energy storage solutions as well as larger installations that can provide immense energy reserves for the grid.

❖ Working of compressed air energy storage:

Compressed air energy storage (CAES) plants are similar with pumped-hydro power plants in terms of their applications. In a CAES plant, ambient air or another gas is compressed and stored under pressure in an underground cavern or container. When electricity is required, the pressurized air is heated and expanded in an expansion turbine driving a generator for power production.

The special thing about compressed air storage is that the air heats up strongly when being compressed from atmospheric pressure to a storage pressure of approx. 1,015 psia (70 bar). Heat of compression therefore is extracted during the compression process or removed by an intermediate cooler.

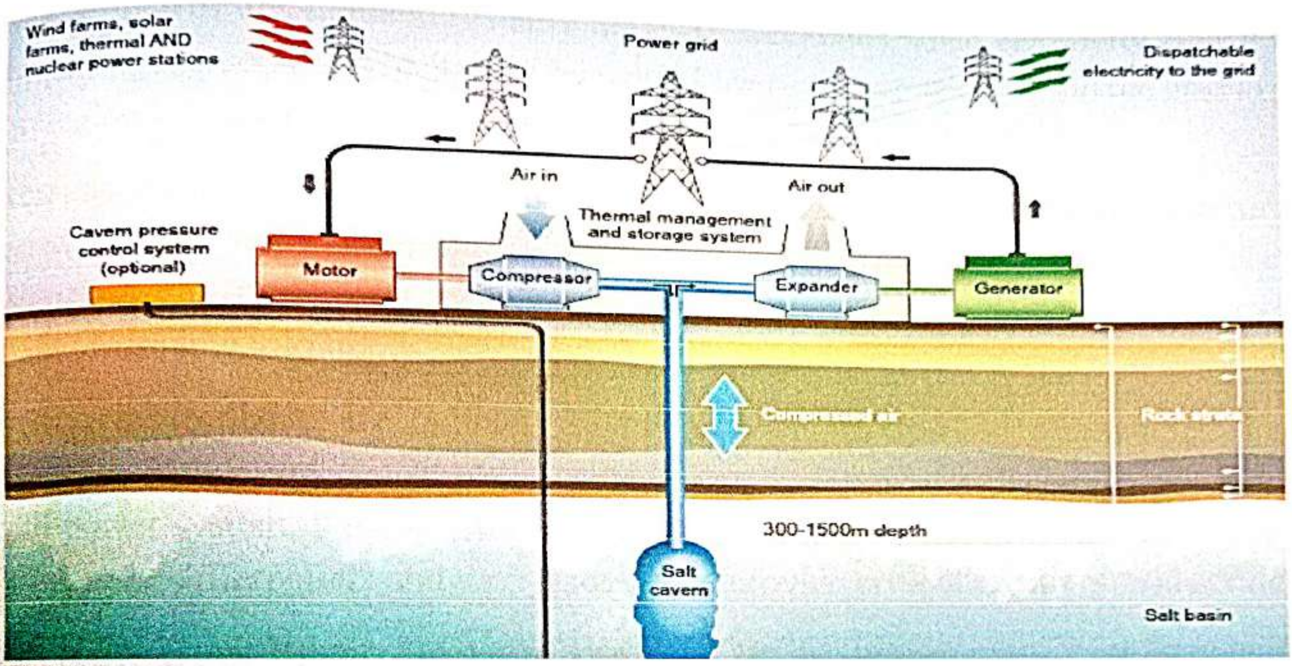

Figure 3.2 : WORKING OF COMPRESSED AIR ENERGY STORAGE

3.3. Pump Hydroelectric storage (PHS)

Gravity is a powerful, inescapable force that always surrounds us – and it also underpins one of the most established energy storage technologies, pumped hydro-power. Currently the most common type of energy storage is pumped hydroelectric facilities, and we have employed this utility-scale gravity storage technology for the better part of the last century in the United States and around the world. Pumped storage hydropower (PSH) is a type of hydroelectric energy storage.

A hydroelectric dam relies on water flowing through a turbine to create electricity to be used on the grid. In order to store energy for use at a later time, there are a number of different projects that use pumps to elevate water into a retained pool behind a dam – creating an on-demand energy source that can be unleashed rapidly. When more energy is needed on the grid, water from that pool is run through turbines to produce electricity.

Because of the immense scale achieved through these applications, this is the most common type of grid-level energy storage based on megawatts installed today.

Pumped hydroelectric storage facilities store energy in the form of water in an upper reservoir, pumped from another reservoir at a lower elevation. During periods of high electricity demand, power is generated by releasing the stored water through turbines in the same manner as a conventional hydropower station.

During periods of low demand (usually nights or weekends when electricity is also lower cost), the upper reservoir is recharged by using lower-cost electricity from the grid to pump the water back to the upper reservoir.

Reversible pump-turbine/motor-generator assemblies can act as both pumps and turbines. Pumped storage stations are unlike traditional hydroelectric stations in that they are a net consumer of electricity, due to hydraulic and electrical losses incurred in the cycle of pumping from lower to upper reservoirs.

However, these plants are typically highly efficient (round-trip efficiencies reaching greater than 80%), and can prove very beneficial in terms of balancing load within the overall power system. Pumped-storage facilities can be very economical due to peak and off-peak price differentials and their potential to provide critical ancillary grid services.

❖ How Does Pump Storage Works:

• Upper Reservoir

When power from the plant is needed, water stored in an upper reservoir is released into an underground tunnel.

• Intake tunnel

The water rushes down the intake tunnel.

• Turbines

The force of the water drives huge turbines, which are underground at the base of dam. The spinning turbines are connected to large generators, which produce the electricity.

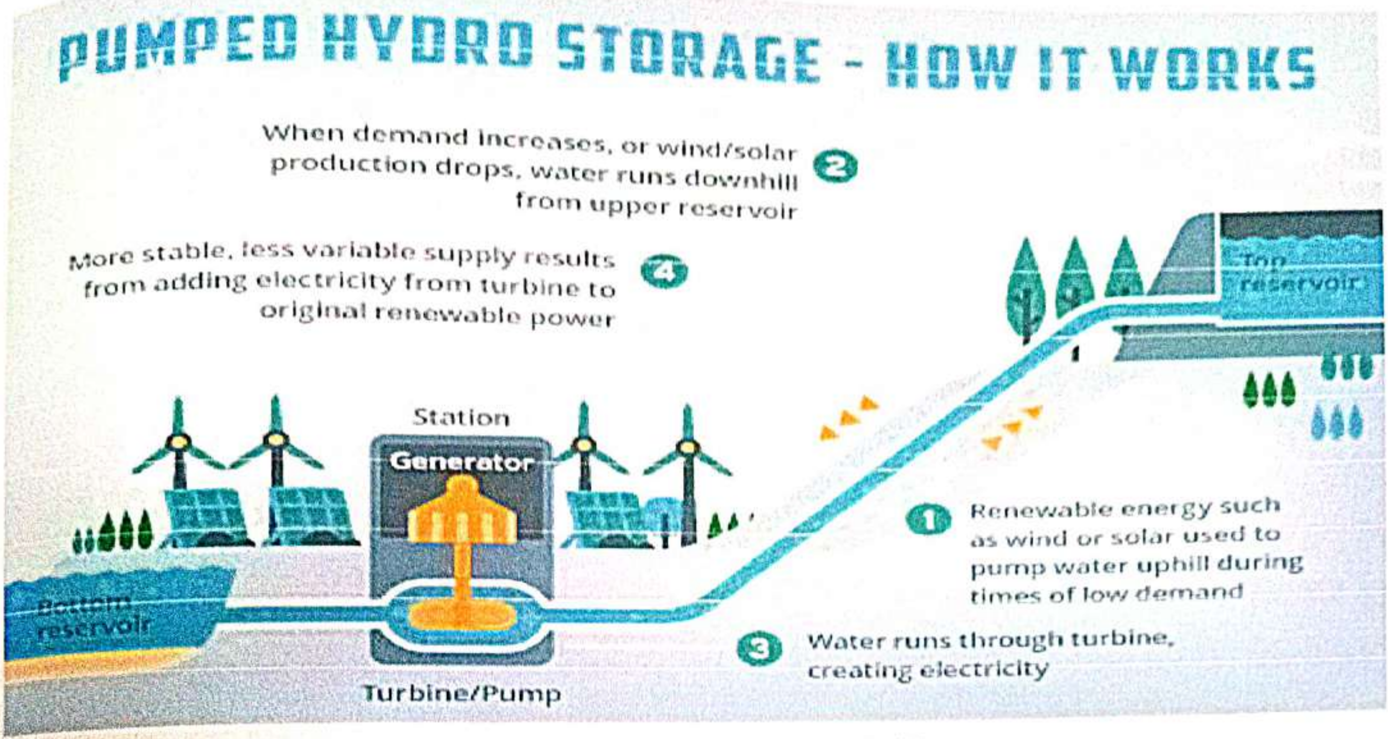

Figure 3.3 : WORKING OF PUMP HYDRO STORAGE

• Discharge tunnel

The water then flows through a discharge tunnel into a lower reservoir.

• Recharging

When demand for electricity is low, the turbines spin backward and pump the water back up into the upper reservoir to make it available to generate electricity when it's needed.

CHAPTER 4 :
CHALLENGES AND FUTURE PROSPECT

4. CHALLENGES AND FUTURE PROSPECT :

In the modern power network, Energy storage system provides reliability and sustainability for maintaining the power grid. Although, the integration of ESS to the power grid can be challenging. Hence, to success the ESS integration, the following challenges shall be encountered.

4.1. Battery Degradation:

Battery is mostly used energy storage type and it suffers degradation problem which reduces its life span. Due to rapid cycling of battery by charging and discharging, the temperature inside the battery changes and aging factor also effects on battery performance. Aging of battery depends on frequency of operation, depth of discharge and operating temperature.

The author introduced a strategy to control this phenomenon and goal to enhance the life span. In battery, two terms State Of Charge(SOC) and State Of Health(SOH) are main factors. SOC is percentage of charge available in bank. Maximum capacity and charge level stored in battery decides if the battery has adequate energy for supplying the load. Most common technology used for SOC estimation is Terminal Voltage Measurement.

State Of Health(SOH) used to measure health of battery. It is measures in terms of number of cycles i.e. number of charge-discharge occurred during its operational lifetime. Keeping track of battery is needed to prevent system failure and timely maintenance and also used to distribute load Optimizely among different battery bank based on health of batteries.

$$C(k) = C(s) - E(k).(Cs - Cr)$$
$$C(k) = C(k-1) \qquad k = J*T$$

Where,

- T denotes one half cycle time period i.e. either charging from zero level to full capacity or discharging from full capacity to zero level.
- Cs denotes maximum energy storage capacity of battery at beginning of its operational life.
- E represent aging of battery
- Cr denotes maximum energy storage capacity of battery after m number of cycles.
- J is the constant multiplier of T and J = 1,2,3…

- k represents lifecycle of battery

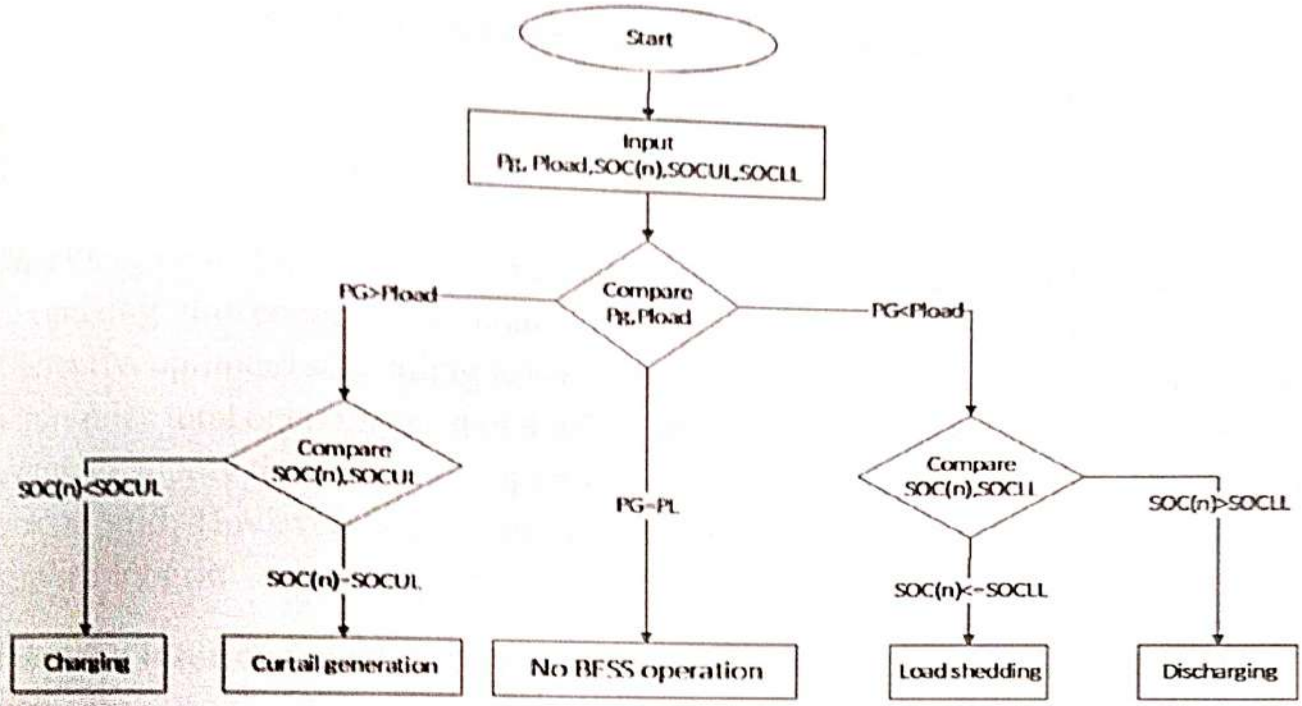

Figure 4.1 : POWER BALANCE ALGORITHM

Fig.4.1 shows power balance algorithm which monitors loads, generation, and variation of active power balance

The algorithm takes input such as load, generation, and state of charge (SOS) of BESS. There will be five possible cases after proceeding the algorithm

- If generated power is more than load, (Pg>Pm) and battery storage are not fully charged, then control system will call for charging operation. BESS will charge fully with the excess power.
- If generated power is more than load, (Pg>Pm) and BESS are fully charged, then control system will reduce the generator power output to prevent excess delivery.
- If generated power is equal to load power drawn, (Pg=Pm) and then BESS is not required, thereby it is disconnected from system.
- If generated power is less than load, (Pg<Pm) and BESS is not fully charged, then control system will call to draw rest amount of energy also from BESS to meet the demand.

- If generated power is less than load, (Pg<Pm) and BESS is fully discharged, in that case Diesel generator will provide power to load. If such provision is also not available, then load shedding operation will be done.

4.2. Optimum Scheduling:

The objective of the work is to minimize the cost of energy drawn from the grid while maximizing the energy sold under TOU tariff scheme. To run any energy storage efficiently, optimum scheduling is very much important aspect. Optimum scheduling helps to minimize total operating cost of the day. When there is more than enough water available in tank to supply the load, the surplus of water is used to generate electricity which is fed back to grid. However, when there is insufficient energy in PHS, then extra energy is supplied by grid

'Fmincon interior point' method gives the solution of this problem by using MATLAB.

By using this method, non-liner optimization problem can be solved. It has been selected for the following reason:

- It can solve larger scale constrained optimization problem
- It has the ability to supply Hessian information
- Interior point algorithm improves the robustness of solver

Fmincon solves problem in the form of :

$$\text{Min } f(x)\text{ , s.t: } \begin{cases} C(x) \leq 0 \\ Ceq(x) = 0 \\ A\,.\,x \leq b \\ Aeq\,.\,x = b \\ L \leq x \leq u \end{cases}$$

In this case, at the beginning we are assuming that volume of tank is its minimum level.

- During first off-peak time period

Initial water level in the tank is shown in fig. 4 at its minimum. Thereby during that time, small load demands are is meet by grid as shown in Fig.6 and PHS remain off. To keep the cost minimal, grid power is not used to feed motor-pump set.

- During first standard time period

  In this period, grid power is used to supply the load demand Fig.6 and also to prepare for peak demand period, power is drawn to pump water in upper reservoir shown in Fig. 7. Thereby water level in tank increases shown in Fig.4.

- During first peak time period

  In peak pricing period, Load is mainly supplied by PHS and state of volume decreases as shown in fig. 4 and fig.5 . Grid is used to balance deficit amount of power needed shown fig. 6. The power stored in reservoir could be sold to grid at that time period.

- During second standard time period

  During second standard load time period, load demand is low, therefore grid power supply the load demand shown in fig. 6 and same time to pump water in upper reservoir fig.7 and fig. 4.

- During second peak time period

  As for the first peak time period, in this case also load is mainly supplied by PHS and grid is used to deliver rest of the power shown in fig.4 and fig.6 .

- During second standard time period
- At this time period, the reservoir becomes empty shown in fig.4 .In this time demand is also low which can be supplied by grid shown fig.6. Power from grid is not used pump water at that time shown in fig.7 .

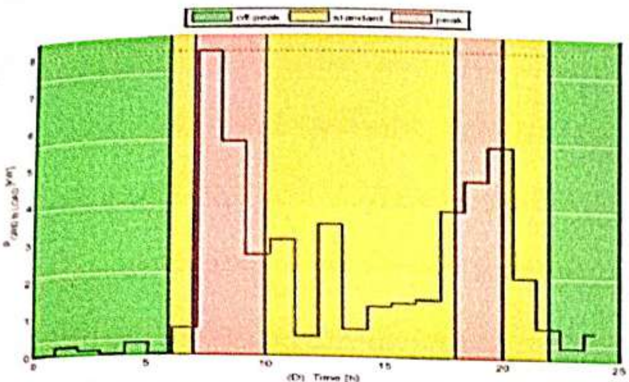

Fig 3: Load exclusively supplied by the grid

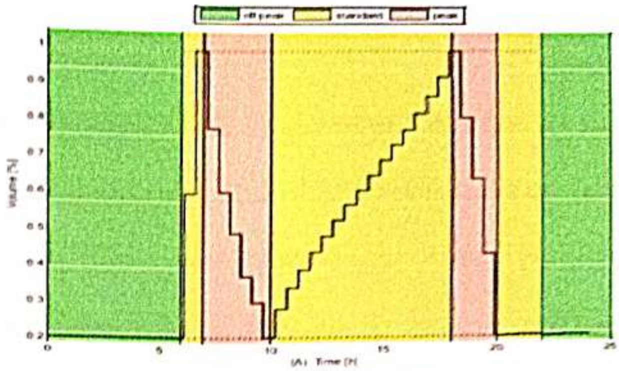

Fig 4: State of water level

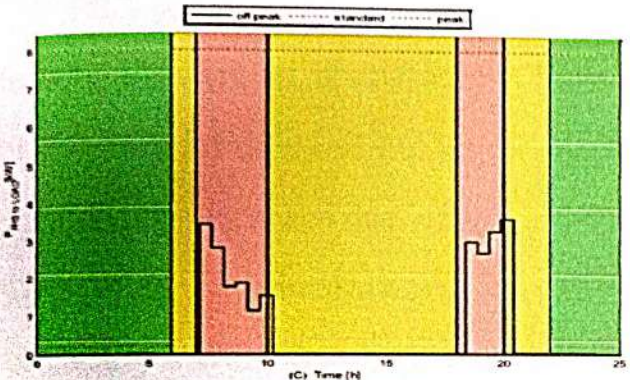

Fig 5: PHS to Load power flow

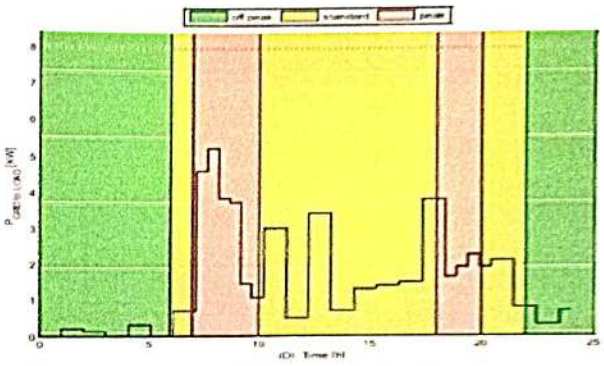

Fig 6: Grid to Load power flow

4.3. Demand Side Management :

(A state-of-the-art techno-economic review of distributed and embedded energy storage for energy systems)

In power sector, electricity demand fluctuates widely because sudden weather change, emerging growth of load in consumer side, damage in line etc. Sometimes harsh fluctuation can cause power blackouts. The impact of renewable energy plays a vital role because demand of power may peak at the time when renewable energy is low. Thereby a powerful approach is needed to control the peak demand and ensure guarantee of service.

Demand side management is a strategy used to manage the demand and electricity usage pattern by encouraging consumers at their level. **Smart Meter** plays an important role for the demand side management. This is a measuring hardware in the form of meter which is fitted in electricity network that communicate the data associated with the usage of electricity to be monitored. The data is used to deliver sustainable and economic power flow. For example, system operator can use data to send signals to consumer for reducing electricity usage during peak load hours. This can improve the efficiency of plant and avoid the requirement of extra fossil fuels.

In Traditional grid system , electricity is measured from transmission end to determine generator output for auditing and heat measurement and distribution end for billing purpose. A smart meter can record consumer usage at particular time interval after. Integration of smart meter, smart sensors and switching device in power system forms smart grid.

Heart of the system is software which combines and analyse energy storage, renewable generation, and demand management. Demand side management program takes place at user side premises and encourage consumers to reduce their energy usage at peak demand by providing them incentives. Consumer with smart meter can check their electricity usage from utility's website which can given provision to them to adjust their usage in response to change in prices. In near future it may be possible that customer will receive automatic alert message in their registered phone number when electricity consumption will go beyond threshold limit.

	Strength	Weakness	Opportunities	Threats
Battery	portable ,light Weight and good Efficiency	Developing technologies related to subsidiary items at distribution level	Quickest and cheapest storage system	Raw material supply and possibilities of price enhancement
Compressed Air storage	Proven technology, Grid scale storage	Costly, response is not fast enough for frequent services	New generation tech-nology using above Ground tanks	Underground fire or explosion can happen
Pump Hydro	Proven technology, grid scale storage	Costly, restriction of geographical area	renovation of existing plant	Difficulties due to environmental concern
Smart Meter	Provides data for control and Analysis	Dependencies on communication network	Demand side management	Accuracy of the data, privacy threat

Conclusion:

This article is intended to enhance understanding of the overall deployment of ESS technology. The purpose of the study is to elaborate classification and comparison of various ESS. This review also includes to carry out analysis of strength, weakness, opportunities, and threats of enabling technologies to inform technology choice. In general, ESS is utilized to support the power grid operation as well as Renewable energy integration in power grid by solving frequency regulation, voltage regulation, prevent back feeding, improve system flexibility and efficiency. This needs to be carefully planned with consideration given to the supply chain and the total life cycle costs including recycling of materials and disposal. The key finding of the solution will vary regionally, economy, grid, renewable generation level, government policy and willingness to change. In addition, smart grid and smart metering will be a key enabler for the growth of energy storages at retail level and demand side management. This will require several rectifications in both transmission and distribution level. Some challenges and future prospects were also discussed to inspire future research and development of technology.