Chapter 11
Hybrid Energy Storage Systems for Renewable Energy Integration and Application

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ABSTRACT

Energy storage has an important role in integration and application of upcoming micro and smart grid network. The various environmental issues are directly related to energy generations. With the growing environmental affects, engineers, entrepreneurs, and policymakers are transforming towards energy storage solution. Hybrid energy systems carry distinct generation technology along with storage on a single system, upgrading all the benefits in contrast to a system that is dependent on a single source. The storage of energy is necessary to fulfil the demand of the consumers, thus enhancing the storage technology at distribution section of power supply. This chapter also throws deep light on different types of storage systems and their hopeful market areas. The study also aims to identifying the technical challenges facing the formation of storage systems globally. It also focuses on typical HESS-utility, energy storage integral designing, concept of energy management system and an ideal proposal for the power flow based on maximal clipping.

INTRODUCTION

Sustainable energy is the basic requirements for centuries. The environmental issues that are directly related to energy generation and distribution are emissions of greenhouse gases, climatic change, air infection and scraps dumping. The green gas emission from fossil fuel ignition is the basic cause of environment air pollution. The international troubles of a hastily growing concentration of CO_2 in the surroundings, its impact and the related changes in global warming and climatic change should be addressed and solved with immediate effects (Bocklisch, 2015). The solution of it is to achieve the goal of transitioning from fossil fuel toward sustainable green and cleaner energy. Renewable energy is a clean and green energy

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source that comes directly from sun, wind, oceanic waves, tides and geothermal. With the increase in demand of electricity, today too, people are still dependent on coal, gas and oil; therefore, required to enhance the electricity supply. So the natural sources are used today for generation of electricity. Now the era is changing from nonrenewable energy sources to renewable energy sources. The non-conventional sources are sun power, wind power, tidal power, and geothermal power. Non-conventional energy has its own application in the area such are generation of electricity, water heating or cooling and transportation (electric vehicle). Renewable power can also drive technological innovation and generate employment such as s supply demand management, grid extension or energy storage. Principles for varieties of storage innovations based on electrical, mechanical, chemical, and thermal power storage are possible with varying technical operating specifications and their features.

The irregular behaviour of renewable power resources creates hindrance in the operating performance of grid. The performance related issues with the system are stability, reliability, and irregular output power. Applying energy storage system to the smart grid can improve the operating performance by fulfilling the energy development demand (*Energy Data Explorer*, n.d.; Al-Foraih, Sreekanth, and Al-Mulla, 2018; Zakeri and Syri, 2015). Energy storage has an important action in integration and application of upcoming micro-grids and modernized grid network (Fathima and Palanisamy, 2018). One of the extraordinary features of the energy area, is the quantity of electricity produced is incredibly constant for small durations, although demand for power varies throughout day. Flourishing innovations to store power energy to fulfil the demand of electrical energy whenever required. This might constitute a prime step towards energy distribution. Assisting to fulfill this intention, electricity storage devices can regulate the energy required to supply consumers at instances of maximum load. These storage devices help the renewable energy to control the output power by grid operators (*Grand View Research,* 2022). Hybrid energy structures can enhance the quantity of dispatchable green and clean energy in addition to the reliability of rural power access.

Global Energy Consumption

Energy consumption gravitates as population increases and people are becoming prosperous. This can be balanced partially with the improvement in power energy i.e. the quantity of energy utilized per dollar (Ritchie & Roser, 2020). Utilization of global energy consumption is still growing. For the last half century, we observed that only for few years' energy utility didn't enhance. Increased energy dependency has enhanced the lifestyle of people globally, making a transition towards low-carbon energy systems. This transition has challenged the growth of clean and green energy and declining the conventional energy resources. Figure 1 shows the global consumption of primary energy till 2019 (Ritchie & Roser, 2020).

Today also more than 80% of fossil fuels contribute our energy requirement. The breakdown of consumption of primary energy via conventional and non-conventional energy sources is shown in Figure 2 (Ritchie & Roser, 2020).

Carbon emission has increased from 6% to 13% in between 1970 to 2000. Since last twenty years, progress in low carbon emission is observed. CO2 and Greenhouse Gas Emissions has only increased by 3%, trying to fulfil the targets made under the Paris Climate Agreement to control mean global temperature hike to 2°C (Ritchie & Roser, 2020). The Paris Agreement is based on the goal to get rid of climate hazards by declining worldwide temperature less than 2°C and making attempt to restrict it to 1.5 degree centigrade (Suh, 2017; Sterk et al., n.d.). Its motive is to further enhance national potential to handle the effect of environment variation and keep up them in their efforts (Suh, 2017; Sterk et al., n.d.). The agreement of Paris is flyover between present policies and climatic- non-interference policy before the end of the 100 years. Worldwide power demand is expected to enhance with 4.6% in 2021; go beyond pre-coronavirus disease in 2019 (Suh, 2017). Downfall of worldwide power demand is by 4% in 2020, which is the maximum recession since World War II (IEA, 2022; Chandel, 2022). Pandemic-19 has affected the economy globally as shown in figure 3 (IEA, 2021). The statistical analysis at the end of April 2021 highlights the effect of pandemic on the world energy demand (*Statistical Review of World Energy,* 2021) and also compares the actual energy demand with respect to the predicted energy consumption till 2019 as shown in figure 4 (*Statistical Review of World Energy,* 2021)

Figure 1. Consumption primary energy globally till 2019 (Ritchie and Roser, 2020).

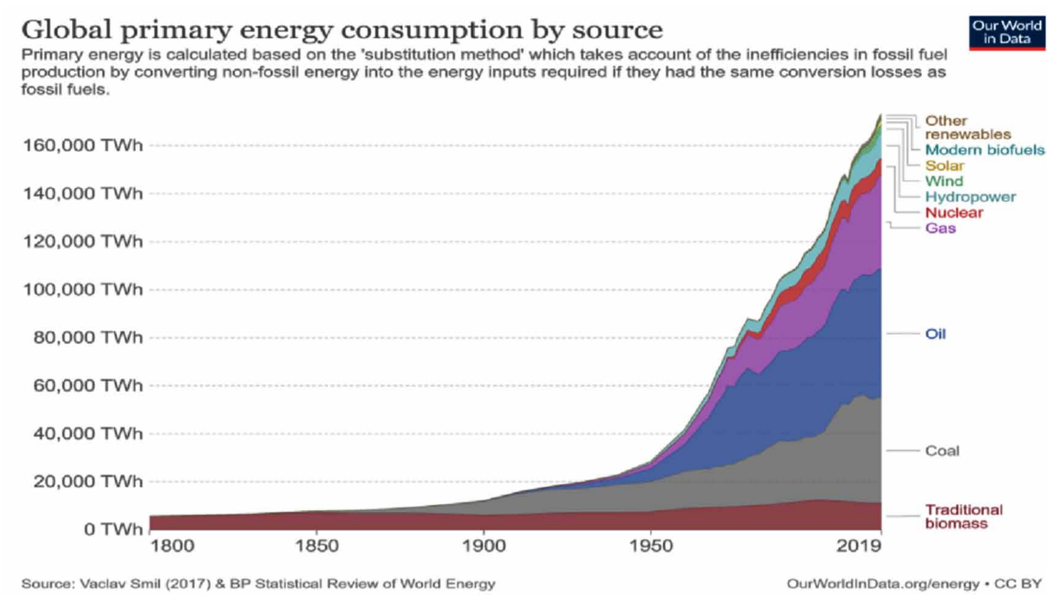
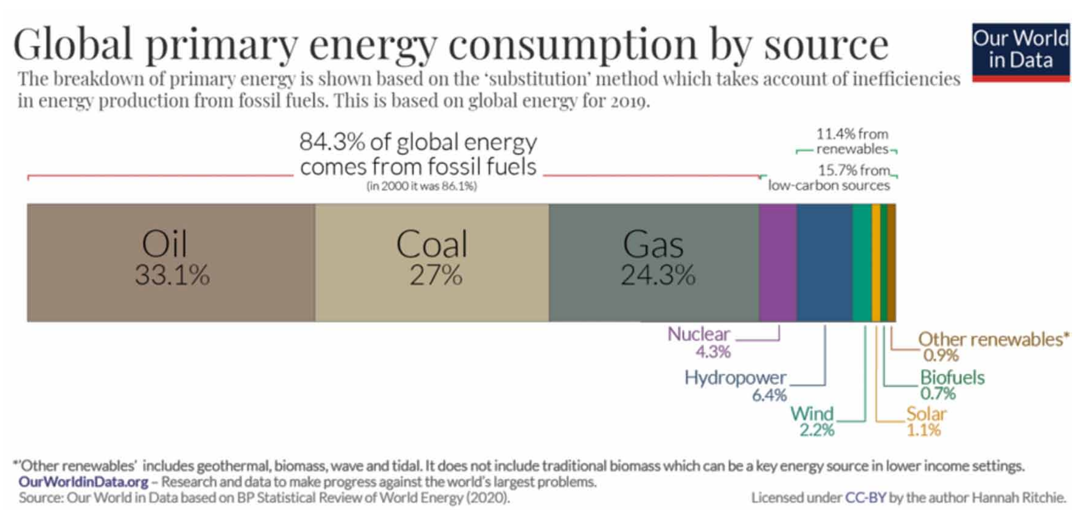
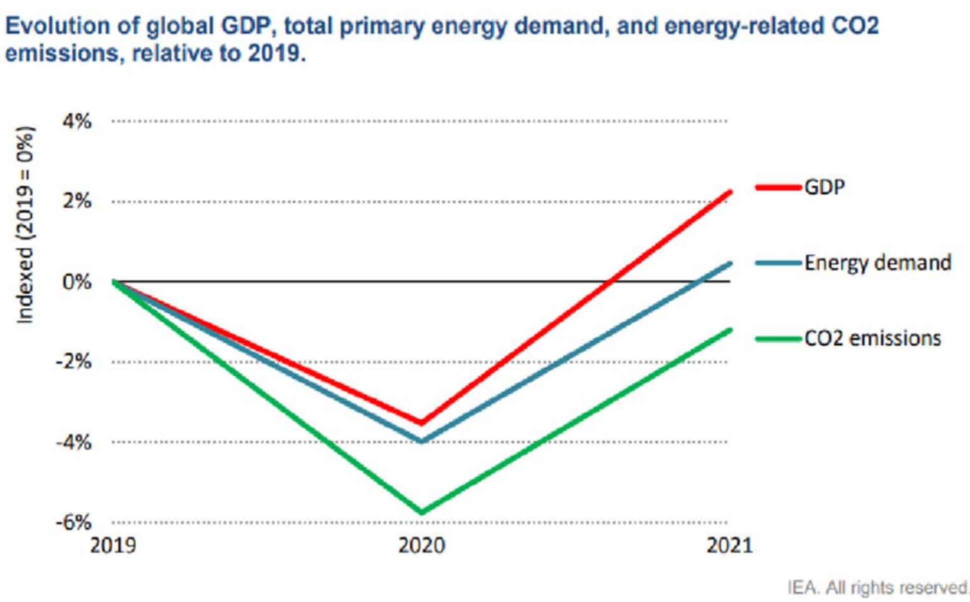


Figure 2. Breakup of consumption of primary energy globally (Ritchie and Roser, 2020).



Due to pandemic, globally huge financial loss occurred. World-wide GDP is assessed to decline by 3.5% in the year 2020 – becoming the immense peacetime recession ever since the great misery/ on the other hand shows the control over carbon emission. Comparative analysis was done showing improvement in green gas emission, shown in figure 5 (*Statistical Review of World Energy,* 2021). The average green gas emission per unit power used has decreased by 1.8%, showing the maximum ever fall after war history (*Statistical Review of World Energy,* 2021). From the last ten to twenty years, declination of fossil fuel has affected the climatic change, resulting in transformation toward RES, thus satisfying the power demand worldwide (Babu et al., 2016). Eco-friendly environment, flexibility and other substantial qualities of renewable energy system has fascinated its placements in business, manufacturing, and residential sectors. Moreover, this is assisted by using the short development in power electronics (Ellabban, Abu-Rub, & Blaabjerg, 2014), which support complete control of non-conventional energy sources limited by stochastic natural conditions (Blaabjerg et al., 2006). Furthermore, non-conventional energy sources have various restrictions like poor load backup, irregular energy production and non-dispatchable behaviour. Because of such reasons, their regulation in the grid system is very difficult for efficient working, especially for high capacity systems (Zhu et al, 2017).

Figure 3. Effect of pandemic-19 on energy demand (IEA, 2021).

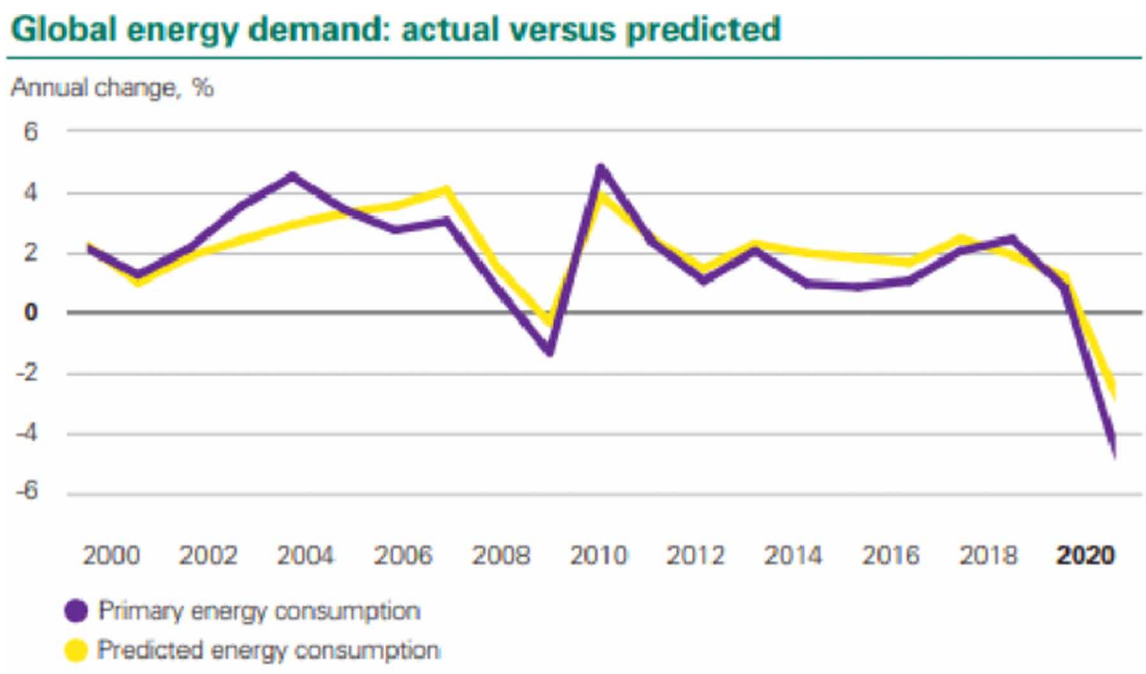


The remarkable challenges seen at the time of integration of non-conventional energy sources are voltage and frequency fluctuation, load deviation and low-quality power (Kyritsis et al., 2017). The integration of energy storage system is an encouraging solution to control these restrictions and to ease the balance working of grid. The unification of energy storage system with renewable energy sources into the smart grid can overcome power fluctuations, low quality power, frequency adjustment and many other services (Chong et al, 2016). Therefore, different ESS technologies are arriving in the coming years which can be electrical, electrochemical, chemical, and mechanical storage systems. The commonly utilized energy storage system innovations are super capacitors, SMES, flywheel, pumped hydro storage, batteries, CAES and hydrogen tanks. . Among the above mentioned technologies, batteries storage technology is considered as best energy storage system for keeping the consistency of power system networks (May, Davidson, & Monahov, 2018).

The cumulative energy storage globally from 2015 till 2030 is shown in Figure 6 (Niclas, 2021).

Furthermore, HESS performs a remarkable role in controlling the irregular and quality of power.

Figure 4. Comparison of actual energy demand with respect to predicted energy demand globally (Statistical Review of World Energy, 2021).



Hybrid Energy Storage System

A hybrid energy storage system link different forms of electricity production and store it (Liu et al., 2018) as shown in Figure 7. It is a precious method of transitioning from fossil fuel economics towards sustainable energy economics. It also shows innovation towards higher integrated sustainable power assets promoting latest sustainable technology with renewable photovoltaic electric energy generation, Wind power production along with fossil fuel electric generation assisting the expansion of the utility of renewable electricity sources (Liu et al., 2018).

A Hybrid power storage system is mostly established by two different storage appliances which is connected by different topologies and these two devices have to be synchronized by an Energy Management System (EMS).

Figure 5. Comparison of primary energy consumption with green gas emitted from energy (Statistical Review of World Energy, 2021).

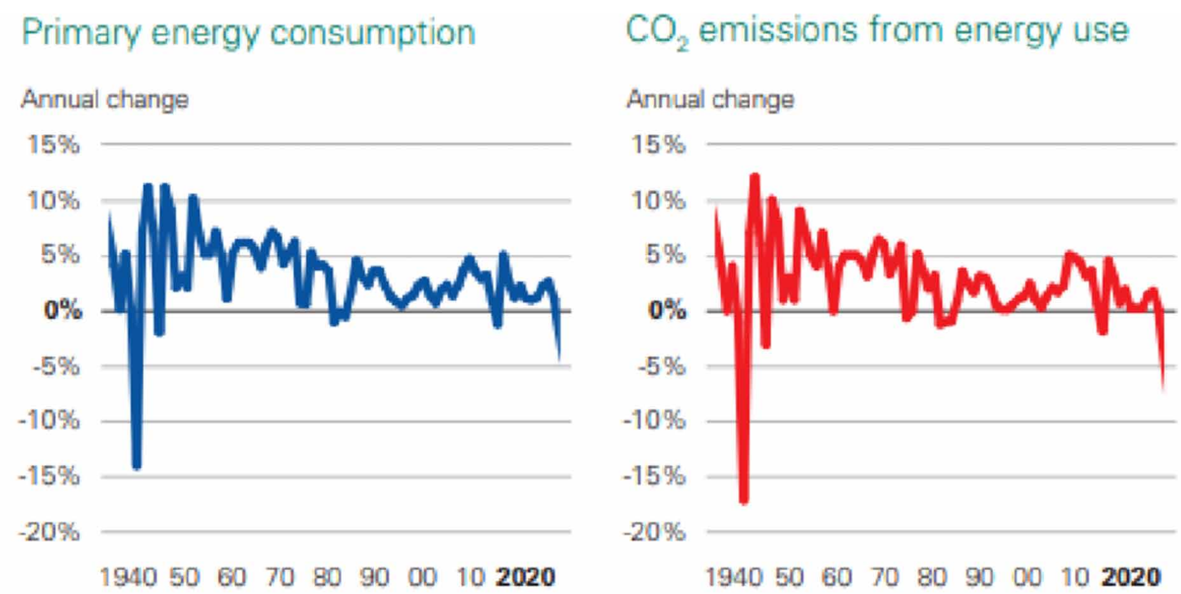


Figure 6. Cumulative energy storage globally from 2015 till 2030 (Niclas, 2021).

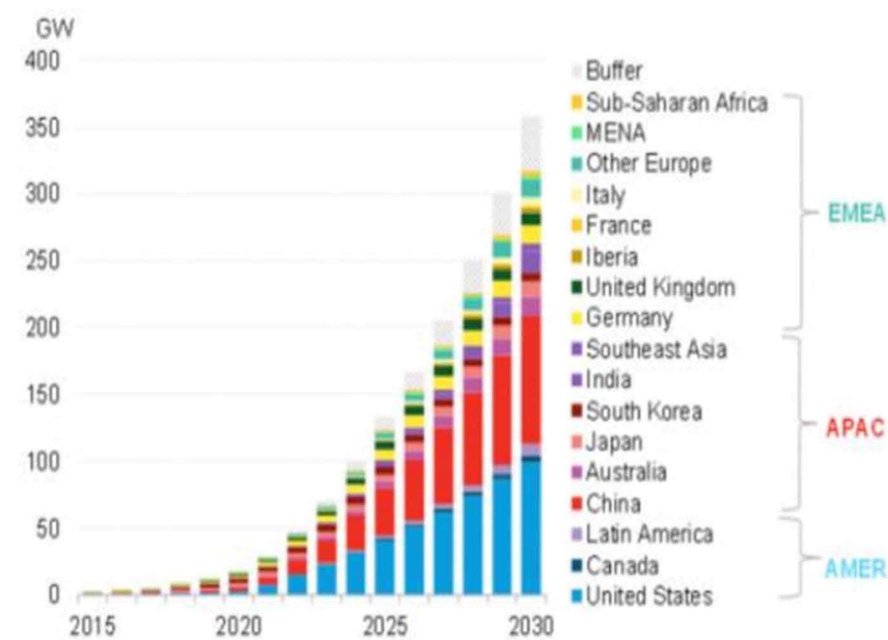


Figure 7. Hybrid Energy storage system with distributed power system (Liu et al., 2018).

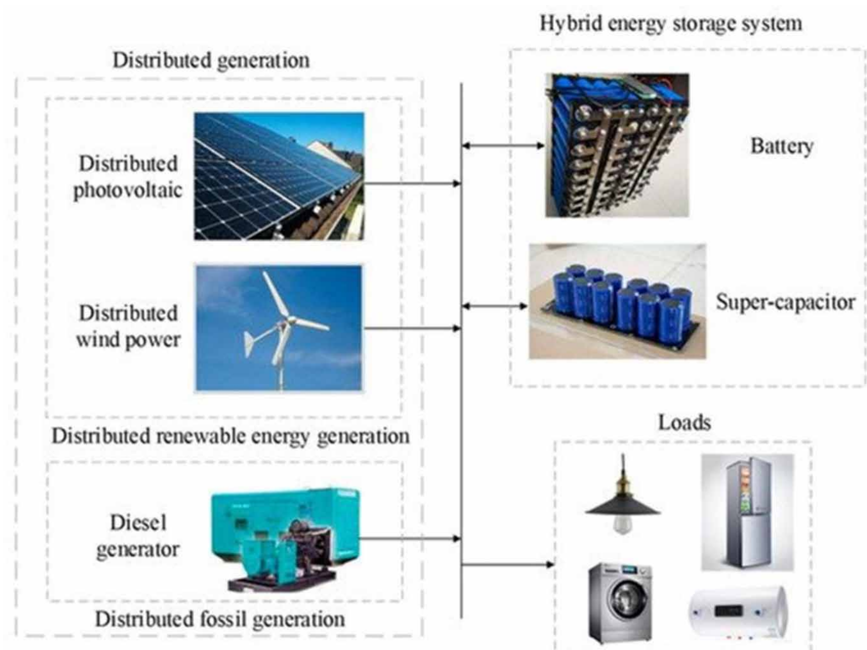
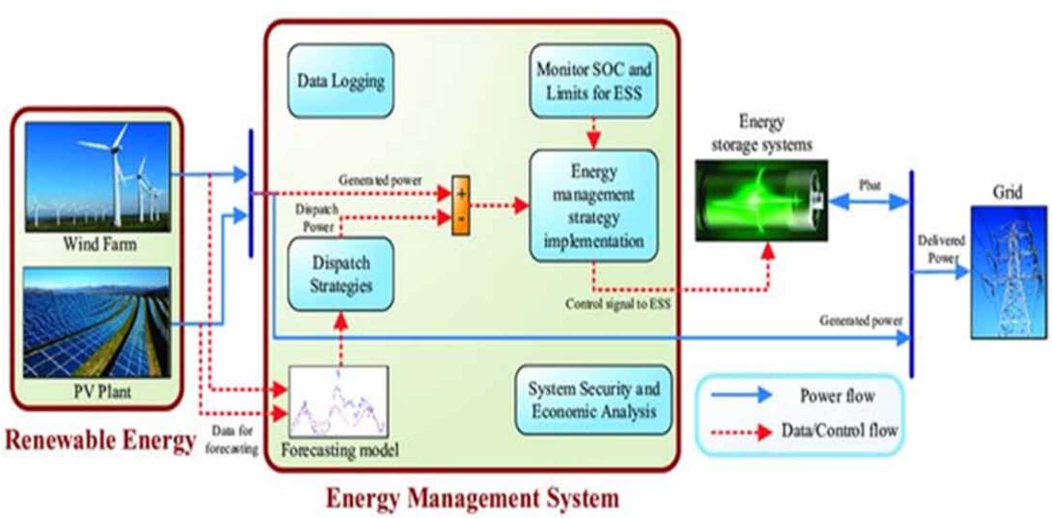


Figure 8. Energy Management System (Babu et al., 2016).

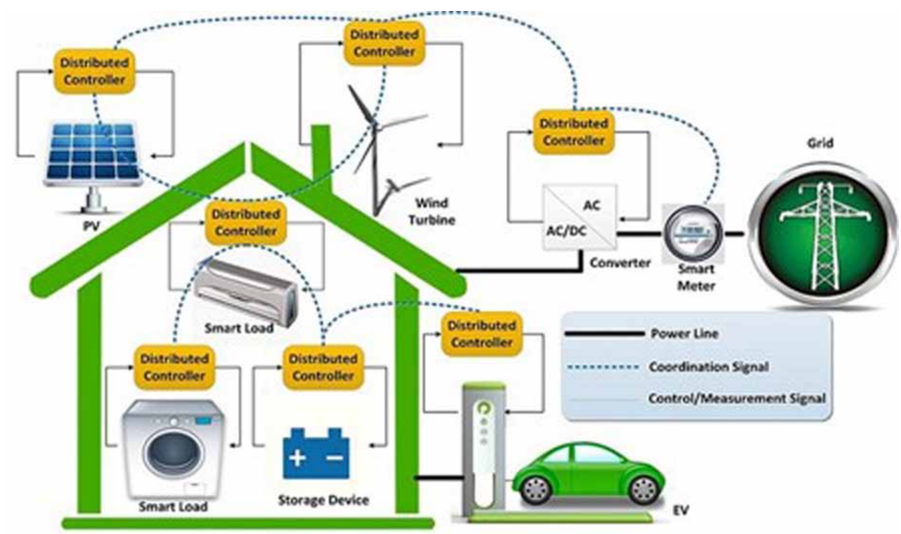


Energy Management System (EMS)

Efficient utility of energy, now a day is becoming essential to prevent global warming. This responds to power generation and distribution situation and bearing the enhanced cost of electricity. Dynamic use of energy, especially in establishment of energy management system is upgraded in various sectors. These sectors include corporate sector, residential and marketing sector.

As the global warming became one of the issues, utility of clean and green energy is promoted as government policy and framework has been designed in terms of tariff scheme for non-conventional energy. This policy came into existence in 2012. Energy management system is a combo of computer-aided engineering tool (CAET), consisting of software and hardware control systems as shown in figure 8 (Babu et al., 2016).

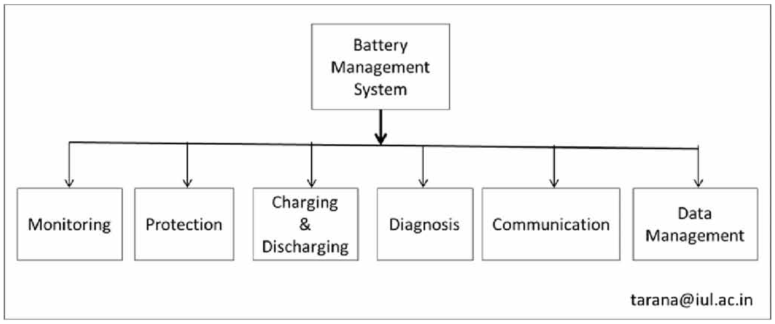
Figure 9. Energy Management System globally (Gupta, 2020).



Software and hardware provides designing and implementation of information systems along with monitoring or managing energy consumption and its utility in buildings (Babu et al., 2016). Its main aim is to optimize the whole energy consumption process in buildings, reduce utility costs and improve the utilization of electrical system and. It includes power, security systems and fire. The energy management system goals are system reliability, performance and economic feasibility (Gupta, 2020).

As per global energy management system study shown in figure 9 (Gupta, 2020) include appliances such as Smart thermostats, residential array, output control relays and smart plugs whereas software includes Industrial energy management system (IEMS), Service Energy management system (SEMS), Residential energy management system (REMS) and many more. According to applications: Building (commercial and residential) EMS, Vertical (Telecom and IT), Power & Energy production and solutions such as demand response management, carbon management system and utility billing and customer information system (Gupta, 2020). The future predicted of 2018-2025, companies or organization operating in energy management system market will be Siemens AG, Electrical corporate sector, International Business Machine Corporation, Emerson Electric Company, Tendrill Networks Inc., Asea Brown Boveri (ABB) Ltd., Cisco Systems, Inc., Schneider Electric SE, CA Technologies, Honeywell International, Inc., Eaton Corporation PLC (Gupta, 2020).

Figure 10. Features of Battery Management (Gabbar, Othman, and Abdussami, 2021).



Renewable Energy Integration (REI)

Renewable energy produces 22% of worldwide electricity generation. It is expected to double in next fifteen years via variable renewable energy from SPV and wind energy (IEA, 2015). The purpose of REI is to integrate non-conventional energy production/generation, their storage, heat activated innovations, and supply demand into the power transmission and distribution system. An integrated system has been generated to manage integrated developments and direct technical issues, finance, regulate the problems and institutional barriers for using variable renewable energy and distributed systems. These issues can be fully addressed developing business strategies and incorporating innovative technologies in enhancing grid installation, its operations and demand supply administration.The motive of renewable energy integration is to

1. Modernize system designing and planning for generation and distribution system and use electric grid to fulfil supply on demand.
2. Reduce green gas emission
3. Reduce the cost of electricity
4. To attain the standard of RE and improve efficiency of energy
5. Maintain accuracy, security and flexibility in micro-grid applications within crucial infrastructure and highly constrained grid area
6. Expansion in utility of plug in EV working with electrical power grid by reducing the use of oil

Technology Adoption

From IEA-Energy Technology Systems Analysis Programme (IEA-ETSAP, 2015) report, we can observe the performance and cost of technology which support renewable energy grid integration (IEA, 2015). ETSAP is an Agreement of the International Energy Agency (IEA), first established in 1976 for implementation in renewable energy integration (IEA, 2015). The purpose of it was to invite country members for active participation in establishing, maintaining and expanding a constant multi-country energy/economy/environment/engineering (4E) analytical capability (IEA,2015).

Dispatchable renewables powers are hydro power (ETSAP E06, E18), geothermal power (ETSAP E07) and biomass power (ETSAP P09, P11, E05, E21), and non-dispatchable renewables that are also referred to as “variable” or “irregular” renewables, such as wind power (ETSAP E09), solar photovoltaic

(ETSAP E10), concentrating solar power (ETSAP E11) and wave and tidal power (ETSAP 08) (IEA, 2015). These dispatchable RE powers can be grouped together with innovative energy technologies for generation of electricity. Such types of generation of electricity are referred as source ability. This source ability is controlled in regard to system requirement i.e. the variation of supply demand. These power energies are available all time

In general, dispatchable renewables are constantly available excluding the period when maintenance is required.

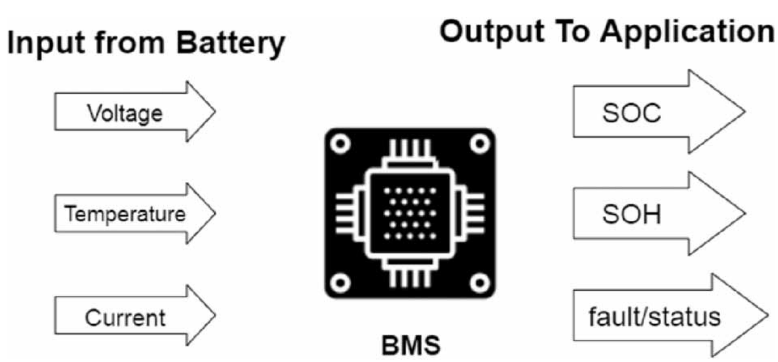
Battery Management System

Battery management system (BMS) consist of innovations that gives the overview of battery package consisting of multiple battery cells organised in series and parallel connection to provide the required value of voltage and current for the desired load for a particular time span. The financial merits of BMS are enhancement of battery life, increasing the precision and lowering its cost (Gabbar, Othman, and Abdussami, 2021). The performance and operation of battery has great on management system, reducing the environmental hazards.

The battery management system provides the following features as shown in figure 10 (Gabbar, Othman, and Abdussami, 2021).

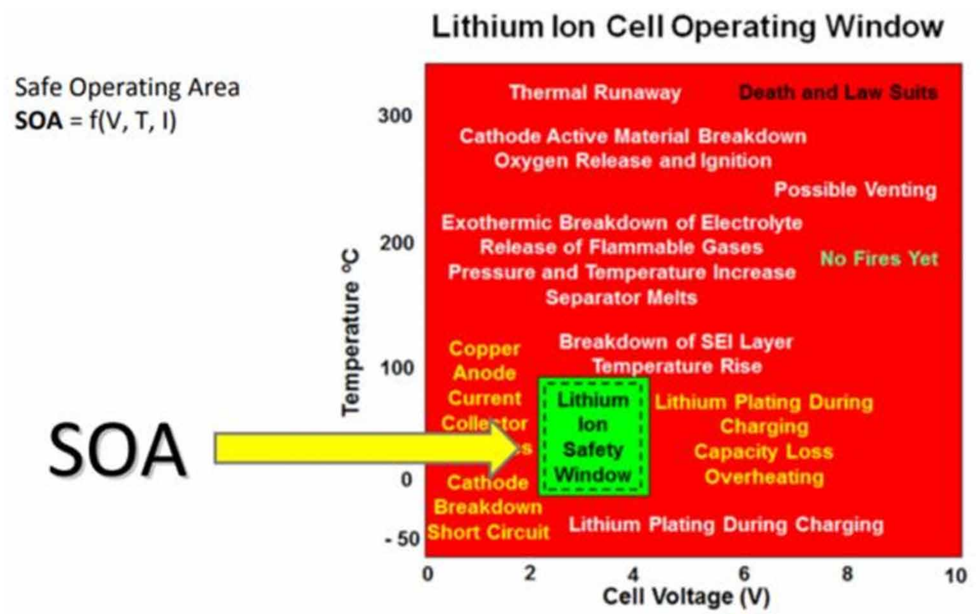
1. Battery monitoring
2. Gives protection to battery
3. Evaluate the operation of battery i.e charging and discharging
4. Diagnosis/ Improving the performance of battery continuously
5. Communicating the status of operation to the external appliances
6. Data Management

Figure 11. Input and output parameters of BMS (Jain, 2010).



Monitoring and control are applied to all individual cells known as modules. Lithium-ion batteries are rechargeable having maximum energy density. These batteries are considered as standard choice for many appliances such as laptop, mobiles, electric vehicles etc. Their operations are in safe mode but it is critical during charging and discharging mode. If the voltage and current of any battery goes beyond its limit, its operation becomes dangerous. Furthermore, voltage reaching below threshold voltage is also monitored for the operational and life safety of the battery. For example if lithium-ion battery reaches the lower threshold voltage then copper crystal is developed at the anode resulting in higher discharge rate. The battery management system monitors the received voltage current and temperature from the battery processes it via algorithm and gives its output. The output indicates the state of change, state of health, faults and also the signal status. Figure 11 shows the input and output parameters of BMS (Jain, 2010).

Figure 12. Lithium-ion safe operating area.



Performance of battery is an important parameter in a battery management system (BMS). The battery protection management involves two specifics protection parameters i.e. electrical and thermal protection. The electrical protection helps the battery from getting damage i.e. its use outside the surface operating area, while the thermal protection helps to control the passive/active temperature and maintain its surface of operating area.

Electrical Protection Management: Current and Voltage

Monitoring current and voltage of battery is a roadway towards electrical protection. Figure 12 shows lithium-ion safe operating area. The lithium cells are current limited toward charging and discharging modes for a particular time period. A current protection BMS will certainly apply a continuous peak current. However, this condition may be applicable for the changing load condition as in case of electric vehicle sudden acceleration. Thus BMS may include maximum current monitoring mechanism by incorporating current and delta time. This will help to monitor the sensitivity of current

Figure 13. Current-Voltage range of lithium-ion cells.

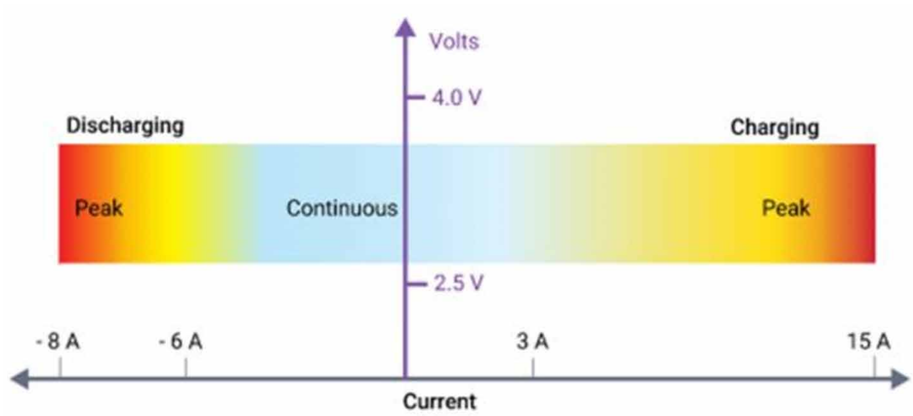


Figure 13 shows the current-voltage range for the operation of lithium-ion cells i.e., charging and discharging of current. The SOA its own constraint depending upon the intrinsic chemistry of cell and its temperature. The discharging cycle is dependent upon the load demand while charging is dependent on the type of energy sources. Therefore, voltages are limited to optimize the life of the battery. Hence BMS works on these constraints making its decision on these threshold values. For example, as the cell reaches its maximum value of voltage, BMS demands for gradual declination of the charging current/ termination of the charging current. On other side, when the voltage goes below the minimum values, BMS requests the active load to reduce the demand of current. For example, in an electric vehicle, this may be achieved by decreasing the torque in the tractor motor. BMS take safety caution for the vehicle drivers by protecting the battery from permanent damage. Battery management system controls the charging and discharging cycles to prevent overloading the electric power and heat, reducing the carbon emission from the power plants and grid utility. These are safeguards toward environmental hazards and human health issues.

Thermal Protection Management: Temperature

Battery management system protects the battery from over charging/ discharging, below/excess temperature, hence safe and reliable for reliable for battery use. If the temperature of battery exceeds 55^{o}C, the poly-isolation becomes soft and starts melting and explodes as battery temperature exceeds 60^o C (Jain, 2010). Figure 14 shows safe operating area of the battery with over-charging & under-charging, over-temperature, and under-temperature (Jain, 2010).

Lithium-ion batteries are much better than lead-acid. Temperature management of the battery is completely dependent on its size. Operating temperature of the battery is 20^o C. If the temperature increases above 30^o C, its efficiency decreases. If the battery pack is overcharged and discharged at 45^o C, causing 50% loss in its performance. This will directly affect the battery life and suffers from premature aging. Figure 15 shows the temperature range for charging/ discharging of the battery.

Figure 14. Safe Operating area of the battery (Jain, 2010).

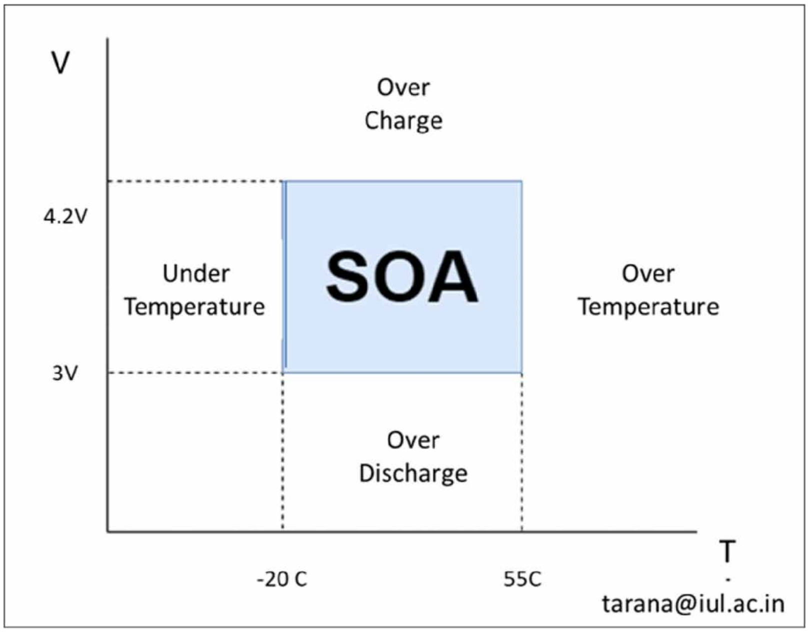
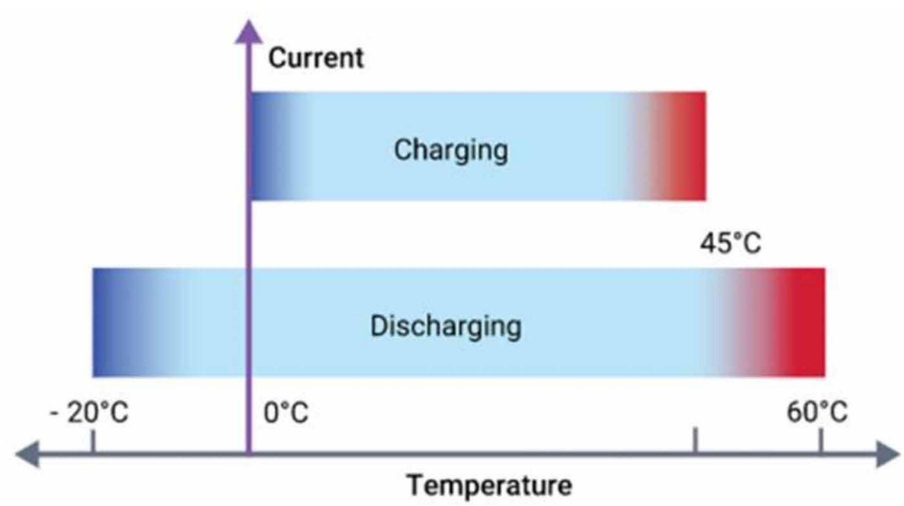


Figure 15. Temperature range for charging/discharging of battery.



Renewable Energy Integration into Power Grid

Integrating large portion of variable renewable energy (VRE) into electrical grid needs a complete modification of the present electrical networks (IEA, 2015) so as to:

1. Permit bidirectional energy flow i.e., from top to bottom (from production to consumer) and bottom to top (with consumer end coming up with the utility to power generation) focussing on the stability of grid while installing distribution section.
2. Setting up an effective power-demand and grid management system focussing to decline maximum loads and enhancing reliable flexible grid thus increasing versatility of systemic.
3. Refining grids interconnections at the local, country and globally level, focusing to enhance grid control capabilities, security, accuracy and consistency.
4. Technical applications are enhanced, plan of action are made to guarantee proper working of grid steadiness, controlling frequency, voltage and balancing power in the presence of a large contribution of VRE.
5. Adding energy storage capacity to accumulate electricity to fulfil the demand of electricity supply with security.

Execution of smart grid technologies plays a prominent role in integrating grid elements for smart working of electricity demand and balanced supply along with two way data signalling and communication technologies, to upgrade security, flexibility and its output. The operation of smart grid system and its building blocks are as follows.

Smart Grid

The idea of modernized grid is related to digital technology along with electric power network. It involves electricity network, digitally controlled appliance and intelligent monitoring system providing bidirectional information of energy generation/transmission, distribution to consumer. It controls energy flow and declines power losses, making system under control and reliable. In other words we can say that smart grid operate more effectively, making affordable electric tariff with less effect on environment (*European Smart Grids Technology Platform,* 2006, Ma, 2010).

Function of Smart Grid

As per US department of energy, smart grid must have following features (Ma, 2010).

1. **Self-healing from power disturbance events**: Digitally controlled, intelligent system and automatic analysis of problem, enhances the fault detection power and making it easy to manage the problem. The automatic switching machines are very much aware of Internet. Therefore, the workers/executives can utilize real time information received from the embedded system having sensors to detect and respond to the system faults such as disturbance in quality and quantity of power automatically (Ma, 2010; Battaglini et al., 2008).
2. **Quality power and optimizing asset**: In US, an annual cost of electricity is $100 billion due to power quality and outage issues. But modernized grid technology can provide stable power and high cost reduction (Battaglini, 2008 ; US DOE, 2008).
    a. Modernized grid can enhance the capital by reducing operation and maintenance cost reducing grid jam and saving the users money. Smart grid coordinate transmission and distribution of energy flow at regional level, reducing grid jam and thereby saving customers money.

3. **Allowing participation of active customer and operating without permanent deformation or rupture**: Smart grid can recognise the hacker and counter it. Actual-time information allows grid workers and executives both to cut off affected areas and redirect power flows towards fault areas.
4. **Accommodating all Innovations and permitting new merchandise, utility, and markets:** Modernized grid will hold conventional power load. These smart grids connects micro-turbines, renewable energy, fuel cells and other production transmission and distribution technologies at all levels. Integration of small scale electric power will allow commercial and residential power to create self-production of power and selling the power to market. Because of this interconnection it enhances power quality and quantity with reduced electricity cost attracting more consumers

Salient Features of Smart Grid

The modernized grid has excellent performance due to following salient features.

1. **Alleviate Load**: the overall load connected between the grids is not constant, thus variable energy consumption. The increase of power consumption takes large time to respond rather than start up time of generator. To overcome this time respond, surplus generators are used as energy-saver mode. The smart grid restrain all devices in order to reduce load for short time or continuously. With computational analysis it is easy to compute the number of standby grid required to reach the rate of failure.

Generally, replying time of fast increase in energy consumption should be more than the start-up time of a huge generator, some extra generators are put on a dissipative energy-saver mode. If there is a smart grid, it may restrict all individual devices, or another larger customer, to reduce the load temporarily (to allow time to start up a larger generator) or continuously (in the case of limited resources). With mathematical prediction algorithms' help, it is possible for us to figure out how many standby generators need to be used to reach a certain failure rate. In the traditional grid, the failure rate can only be reduced at the cost of more standby generators. In a smart grid, the load reduction by even a small portion of the clients may eliminate the problem.

2. **Eradication of the demand fraction**: The IoTs, intelligent system with automatic control system have different levels of communication. These are generation section, transmission section, distribution section along with substation and energy users. Basically the information's are received frons users and load, and they are controlled backed to the utilities. The utilities try their best to fulfil the supply demand or face failure such as blackout (rolling or uncontrolled). The supply demand permits real time interaction between generator and load. The smart grid amplifies our existent electric grid with by giving utilities, the flexibility to respond to fluctuations in electric demand. It focuses on decreasing the power usage cost, reducing the maximum demand, improving the power ratio ratio, minimizing the user inconvenience through modification in working patterns of the devices, and increasing usage of power obtained through local production sources.
3. **Power Generation Distribution (PGD):** the power generation and distribution permits the users to develop power at the respective place. This helps the consumers to control their own power production to their load making them self-dependent from government electricity grid, avoiding them from electricity failure. Traditional grids are unidirectional in energy flow. Since smart grids

are bidirectional, it manages the excess energy generated at substation than it is consumed by the reverse flow.

Energy Storage

The energy demand fluctuates from maximum to minimum due to personal needs and climatic effects. Storing the excess power during off-peak hours might be an urgent need as production may surpass the total power demand. The inconsistence energy challenges between production and supply becomes more appropriate because of the intermittency of the RES (Zablocki, 2021; Georgious et al., 2021; Hargreaves and Jones, 2020; Koohi-Fayegh and Rosen, 2020). The conventional grid reliability is affected by the large scale integration of renewable energy sources. It is generally agreed that more than 20% penetration from intermittent renewables can greatly destabilize the grid system. Large scale ESSs can alleviate many inherent inefficiencies and deficiencies of the conventional grid and facilitate the full scale integration of renewable energy source. It is generally agreed that more than 20% penetration from intermittent renewables can greatly destabilize the grid system (Loveless, 2019; Bindra and Revankar, 2019; Hossain et al., 2020; Poullikkas, 2013; Luo et al., 2015; Alkafaji, Al-Samawi, and Trabelsi, 2021). Generally, ESSs can balance supply and demand, reduce power fluctuations, decrease environmental pollution, and increase grid reliability and efficiency.

The energy storage deals with ETSAP E18 in technology. In power grids, major part variable renewable energy are stored and allowed to be retained. On supply demand, this stored energy is supplied even when renewable energy generation is not available. HES involve multiple energy technologies that are location wise /or operationally linked. The energy storage workshop also helps in guarantee stable frequency and voltage for grid at different operating situations. Since electricity cannot be stored, it involves transducers to convert electricity into other form of energy using different technological operation with different characteristic and its performance. These different technologies (ETSAP E10 and ATSAP E17) (IEA, 2015) are

1. pumped-storage hydro
2. compressed air energy storage
3. Electric batteries (e.g. lead-acid, lithium- and nickel-based, flowbatteries, etc.)
4. superconducting magnets
5. flywheels; super-capacitors;
6. chemical storage (e.g. electricity conversion into hydrogen by electrolysis);
7. Thermal storage (e.g. heat storage in concentrating solar power plants.

Electricity storage is also done from end-use technologies, such as plug-in electric vehicles (EV) batteries. These batteries can be charged during night using excess electricity and are used throughout the day. These technologies are feasible and fulfil the supply demand. Among all storage technologies, “pumped-storage hydro” is the commercially available for high capacity electricity storage. Now we can say that electricity storage plays a key role for renewable integration in power grids.

Grid Interconnection Globally

Flexibility in energy transmission is available with enhanced grid interconnection at regional, national and international level. This helps in fulfilling the electricity supply demand at all levels. The global grid interconnect require framework for infrastructure and operation, involving political deal and understanding between the two countries for trading. At the same time, the presence and operation of an international power line can provide both political benefits, ranging from enhanced potential for international cooperation to increased democratization at home, and liabilities, ranging from dependency on another country to internal squabbles over power line benefits.

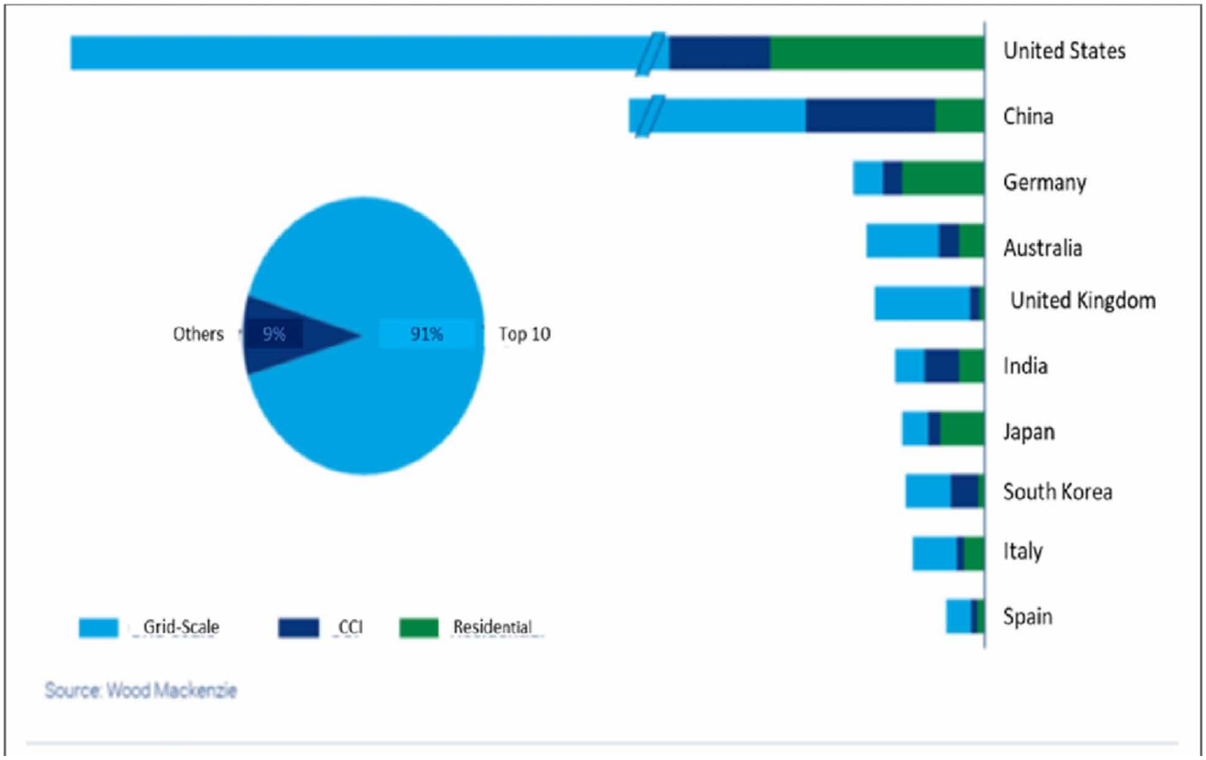
Application in Green Energy Systems

Hybrid energy storage system plays an important role in the development of high efficiency government and private sector, providing green and clean energy, pollution free transport system and smart cities with low green gas emission (Fang and Zhang, 2022). Environment and climatic issues are becoming prominent day by day. Therefore, renewable energy sources and electric vehicle are used to resolve the above mentioned issues. Basically, generation of power with renewable energy resources are intermittent in behaviour. This is due to effect of temperature and weather condition, thus electric vehicle driving cycle face instability in power supply demand. These important characteristic of renewable energy resources and electric vehicles necessitate hybrid energy storage system as a safety plug to restrain the inconsistency of the power.

Global Energy Storage System Market

The renewable energy resources perform an essential role in the smart grid, while power storage system chasing behind it. According to Wood Mackenzie (Kennedy, 2022), expectation of global energy storage capacity is 500 GW by the end of 2031 (*Advanced energy storage systems market size was valued cumulatively at nearly US$ 145 Bn in 2018 and is projected to reach US$ 211 Bn by 2026, exhibiting a CAGR of 4.82%,* 2019). in which 75% of global demand is contributed by China and United States. Wood Mackenzie further says that United State will cover the energy storage capacity of 27 GW by the end of 2031 making 83% of commercial scale storage. The market of energy storage system will expand with tremendous speed in the next coming decades. The forecasting of top ten countries is likely to portray approximately 91% global electricity demand with commercial smart grid energy storage system (Kennedy, 2022) as shown in figure 16. The European market is likely to expand 5 times in the coming decades. In Europe the amplification in making marketing strategies and policy are hindered just because of lack in finance. However, the European power commission has option to rationalize the process for generation and storage of solar energy and further targeting renewable energies which will further fulfil the supply demand and storage. The worldwide power storage systems market is segmented into innovation, consumer, application, and area. Depending upon innovations, the trade is categorized into pumped hydro storage, battery energy storage, compressed air energy storage, and flywheel energy storage. The end users covered in the study include residential, non-residential, and utilities. By application, the market is fragmented into stationary and transportation.

Figure 16. Forecasting of top 10 countries in grid energy storage market from 2021-2031 (Kennedy, 2022).



Energy Storage Systems Market, By Technology

With the innovation in technology, the maximum energy storage system market in 2020 was the pumped hydro storage (PHS) sector and widespread globally. It is an advanced energy storage system and fulfils high electricity demand (*Advanced energy storage systems market size was valued cumulatively at nearly US$ 145 Bn in 2018 and is projected to reach US$ 211 Bn by 2026, exhibiting a CAGR of 4.82%,* 2019). In addition, as time moved on the government took initiative toward renewable energy production hoping that RESS may take its place in the market globally. Figure 17 shows the energy storage system market by technology. This figure highlights pumped hydro storage sector is the most profitable sector among all energy storage system. The worldwide energy storage system claims the value of 211.24 GW, with an improvement at the progress rate of 11.0% annually from 2022 to 2030 (*Advanced energy storage systems market size was valued cumulatively at nearly US$ 145 Bn in 2018 and is projected to reach US$ 211 Bn by 2026, exhibiting a CAGR of 4.82%,* 2019).

Green and clean energy are an alternative to conventional energy, reducing carbon di oxide and broadening power supply. According to survey report ID: GVR-3-68038-057-6(Grand View Research, 2022)., the US energy storage system has the capacity of 25.9 GW in 2021 and assumed to reach 65.32 GW by the end of 2030. The US Electricity board is focussing on enhancing electrical applications following energy efficiency standards, also declining the electricity cost and taking the advantage of renewable energy innovations. US Energy storage market by technology from 2020-2030(Grand View Research, 2022).is shown in Figure 18.

Figure 17. Global energy storage system market by technology(Grand View Research, 2022).

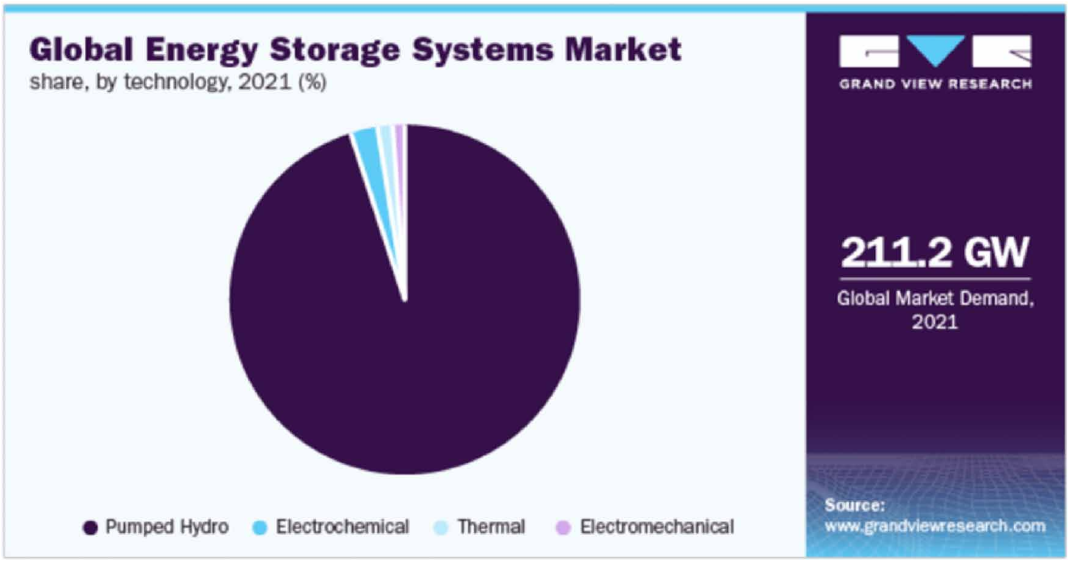
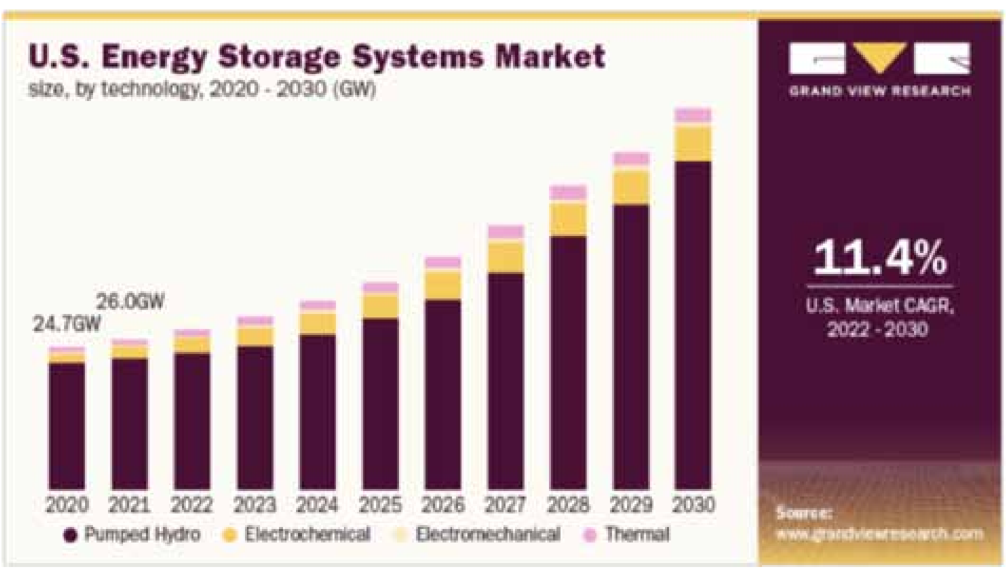


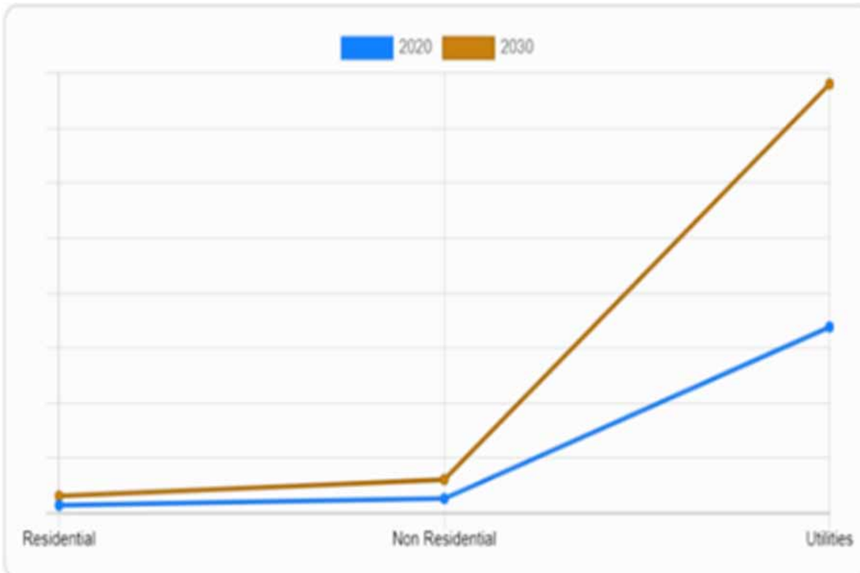
Figure 18. US Energy storage market by technology from 2020-2030(Grand View Research, 2022).



Energy Storage System Market, by end user

On behalf of electric power used in residence, non-residence and commercial places, the electricity services dominated the market worldwide in 2020 by investments in share for constructing utility scale power plant. Besides it, construction projects i.e., decentralized renewable power plant, electricity project increased rapidly. Figure 19 shows the energy storage system market by end user from 2020 to 2030 (Saurabh & Prasad, 2022).

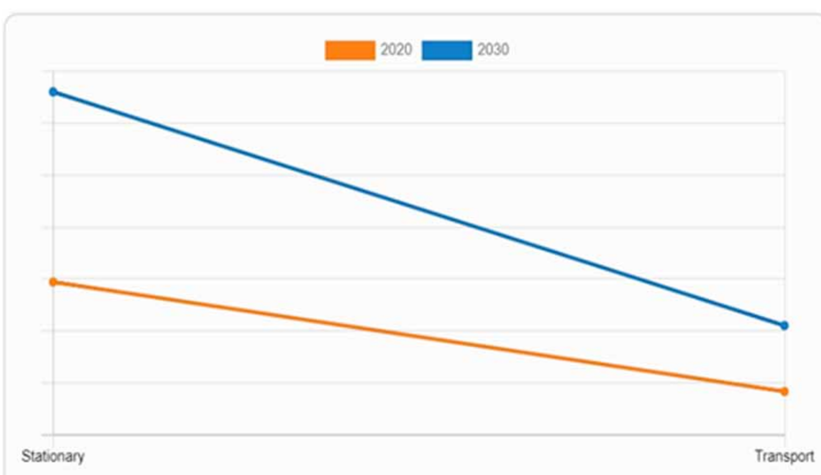
Figure 19. Energy storage system market by end user from 2020 to 2030 (Saurabh and Prasad, 2022).



Energy Storage System by Application

The stationary section guaranteed the largest market share by application in 2020. This was the fastest growth of heavy commercials and government and private projects. The projects include energy plants, smart grids, manufacturing companies and many more. A part of it, increased hydropower proposals globally act as agenda for stationary energy storage system market in the coming decades. Figure 20 shows the energy storage market by applications (Saurabh & Prasad, 2022).

Figure 20. Energy storage system market by application from 2020 to 2030 (Saurabh & Prasad, 2022).



Energy Storage System by Region

Forecasting of market of energy storage system is on peak Asia-Pacific region in 2020 in regard to economics. This is due to presence fast developments of renewable energy segments, existence of large customers. In Asia Pacific, countries such as China, Japan, India, Australia and south are expected to come up towards the growth of the market in European region. In European region; UK, France, Germany, Italy and Spain and in North America; US, Canada, Mexico (Saurabh and Prasad, 2022, *Grand View Research*, 2022) are fast capturing energy storage system market.

COVID-19 Impacts

The coronavirus is an exceptional pandemic globally spreading over 180 countries and causing major deaths and financial losses. Johns Hopkins University (JHU) did the statistical analysis of the COVID-19 as of June 28, 2021 and observed 181 102 393 infected peoples and 3923132 deaths globally (Lu, Ma, & Ma, 2021). Due to COVID-19, transient ban everywhere on transport, production, industries that directly affected electrical utilities declining the power demand from consumer (Chandel, 2022; Mohd & Yerukola, 2022). Maximum disaster occurred in United States, India and Brazil among all countries worldwide (Prasad, 2020). Many nations have announced constraint to slow down the fast spreading of the coronavirus disease, such as the closing the educational institutions, partial or full lockdowns, and remote working, therefore drastic decline in energy demand. In addition to it, current projects such as construction for infrastructure of renewable energy power plant, smart grid networking, unavailability of labours for these works, gap in demand of electricity and many more projects were hampered the energy generation throughout and after covid-19 pandemic duration. These results in declination of energy market throughout the year 2020. However, the energy market came into existence, or we can say that recovery of energy market started from the early beginning of the year 2021. This was because of the sale vaccination for coronavirus infected people globally, enhancing growth toward economic globally. Major advantage of COVID-19 pandemic is that it has positive affect on environment having lowest green gas emission with 29% declination in fossil fuel for electricity production due to less demand of electricity. With due effects, rate of declination in green gas emission reached 20% with respect to renewable energy growth rate enhanced with 46% in 2020 (Lu, Ma, and Ma, 2021) and gradually grew in 2021.

Impacts on Micro-Mobility

In April 2020, the impact of coronavirus pandemic was on peak due to which public transport was not in use i.e.60% decrease in public transport. The rate of work from home was increased, and public opted alternative of public transport. One of alternative of public transport is micro-mobility, much safer during pandemics. This was carried out in major cities globally. It was found more than 20% individuals preferred micro-mobility devices to keep themselves safe from COVID-19. The average percentage of micro-mobility devices used is 21%. These cities are Paris, Athens, Saint Petersburg, Barcelona, Madrid, Ankara, London, Los Angeles, New York City with 16.4%, 28.10%, 13.80%, 21.30%, 17.70%, 30.65%, 19.60%, 19.10%, 21.40% respectively (Catalbas, 2021). Mostly single user vehicle was used for transportation during COVID-19 such as electric bicycle, motorbike and mini EV. After pandemic also people prefer alternative to public transport.

CONCLUSION

This chapter provides qualitative and quantitative measures of the current scenario of energy storage system market with future global market estimation from 2021 TO 2030 and its future aspect. Hybrid energy storage system provides flexible innovation that helps to cover short as well as long term fluctuation in smart grid for sustainable green and clean energy involving renewable systems. This chapter describes the architecture and networking of power management system, non-conventional energy integration. Market analysis of power storage system was done and highlighted the operation and restriction towards its growth. Forecasting of ESS market growth is done on the basis of its financial value. The chapter includes application, analysis at regional as well as worldwide energy market trends, policies framework, strategies based the market growth. Is has also highlighted the impact of COVID-19 in energy demand and its utilities

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