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Integrating Renewable Energy in Smart Grid: Opportunity, Challenges and Progress in India

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Abstract - *Indian power system have seen a significant growth in renewable energy specially wind and solar sector in last decade (2010-2020). Government of India have set renewable energy installing capacity target to 500GW (40 % of its total installed capacity) by 2030 from 175GW by 2022[2]. In 175 GW, 100 GW will be generated from solar 60 GW from wind 10 GW from Bio-power and 5GW from small hydro power plant (< 25MW). To integrate the same to power grid will be really a challenging task as renewable energy sources are unevenly distributed unlike conventional power plant. Variability, intermittency and fast ramping nature of these sources increases the integration challenges even more. So in this paper first we will briefly discus potential and development of renewable energy sources in India then we will study the challenges to integrate them to grid, role of storage system along with a practical case study.*

Keywords: RE- Renewable energy, GW: Giga-watts, TW-hr: Terawatt Hour, BU: Billion unit, AC: Alternate Current, GOI: Government of India, CEA: Central Electricity Authority, MNRE: Minister of New and Renewable energy, ISA: International Solar Alliance, ROK: Republic Of Korea

1. INTRODUCTION

India is one of the largest and populous country in the world with vast and fastest growing economy and a huge military power so energy need of this country is huge and growing rapidly. Total installed capacity of India is 374.2GW (as on 30 November 2020) in which 231.3 GW (61.8%) generated through thermal plant 45.7GW (12.2 %) through hydro plant (Renewable) 6.7 GW 91.8%) through Nuclear plant and 90.4GW (24.8%) through renewable particularly solar and wind[1]. To fulfill this much need of energy through conventional energy sources is tough and also not environment friendly and also the conventional energy sources are declining rapidly so shifting towards renewable energy sources is now need of the hours. And being a sunshine country India have huge potential in renewable energy specially wind solar and hydro power sources. In last decade India have harvested renewable sources satisfactorily.

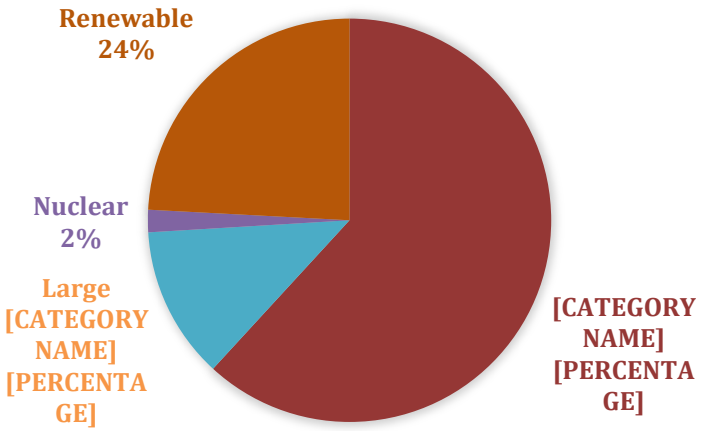

Chart - 1 Total installed capacity composition[1]

The Government of India has therefore seized energy development and security as critical policy objectives, and RE, in a country with immense solar and wind resources and falling technology costs, serves a central role in meeting these objectives. India during Paris Climate Conference have pledge to increase its target to 20GW of installed capacity of renewable energy to 175 GW of installed capacity in which 100 GW will generated through solar 60 GW through wind 10 GW through bio-plants and 5GH through small hydro plants. And by 2030 India's 40% all electricity will be generated through non fossil fuel. According to Central Electricity Authority (CEA) government have prepared a blueprint to achieve 57% of its total installed capacity through renewable energy by 2027 and as per this blueprint government is aiming to install 225GW of renewable energy capacity by 2022 (including 114 GW of solar capacity 67GW of wind capacity). As on 30 November 2020 India's installed renewable energy capacity is 90.4 GW in which wind capacity is 38.4, GW solar capacity is 38GW (including ground mounted and roof top), small hydro capacity is 4.7 GW and bio-plant capacity is 10GW[2].

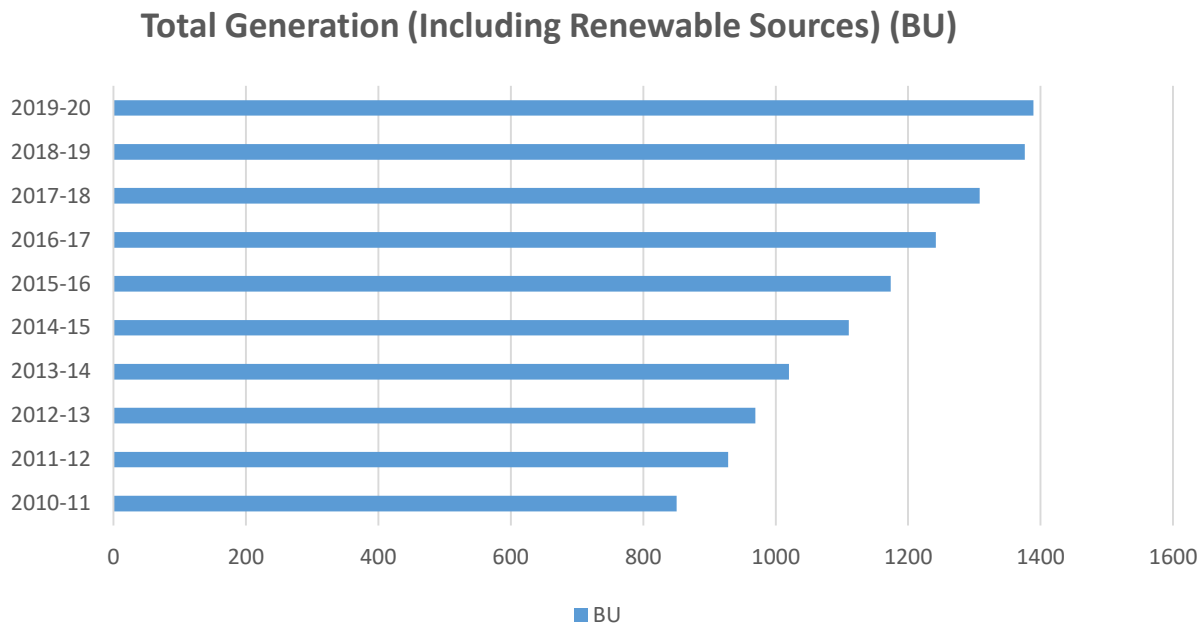

Chart - 2: Total Generation in BU over Last decade in the country during 2010-11 to 2019-20[1]

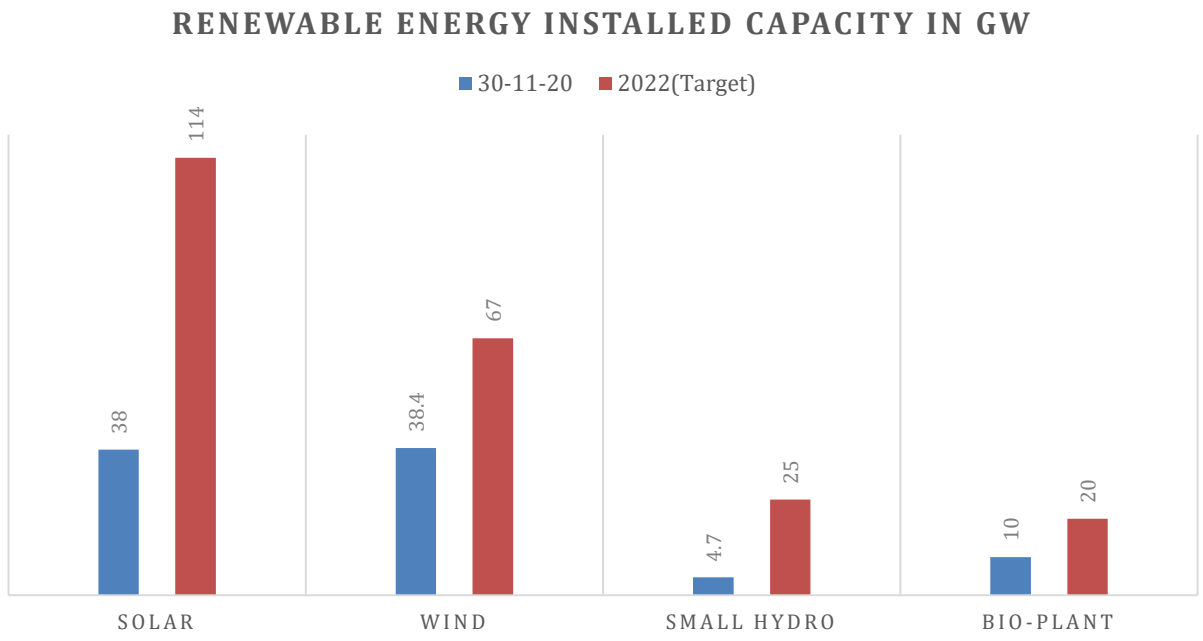

Chart -3: Renewable Energy installed capacity and government's target for 2022[2]

Integrate this amount of renewable energy into grid is really a challenging task as the renewable energy sources are distributive and constantly varies according to weather unlike conventional sources which are centrally located and are not depend on whether so we can control supply according to demand and load forecasting data. And control of this type of plant are easy as compare to widely distributive sources like renewable energy sources like wind and hydro. As they introduces more variability in power network other than demand variability. So when we will be unable to forecast generation power so balancing the demand and supply will be deteriorate which can cause even grid failure and blackout in entire country. So intermittency and fast ramming down nature of solar and wind energy are one of the most promising challenge in the way to integrate them into the grid. Effective control and management of the system further adds the challenge. Cost of equipment and land requirement for renewable energy are also big challenge.

In this paper we will first observe the potential and development of renewable energy sources, challenges to integrate them into power grid and how we can address these challenges, advantage and need of energy storage system, and then we will see some case study of renewable energy plants.

2. PROGRESS OF POWER DEVELOPMENT IN INDIA

2.1 Generation

India have seen significant growth in power generation since 1947. In 1947-48 India's installed capacity was 1362 MW in which 856 MW was thermal Power installed capacity and 508 MW was hydro power installed capacity and the power generated in that year was 4073 GW-hr and in 2020 total installed was grown to 374.2 GW in which 231.3GW is thermal power capacity 45.7GW is the hydro power capacity 6.7GW is nuclear power capacity and 90.4GW is renewable power capacity and the gross power generated in 30th March 2019 to 30th March 2020 was 1383.4 TW-hr in which 10% (138.34TW-hr) power was generated through renewable energy. In the year 2019-20 only renewable energy generation have seen increment and the power generated by fossil fuel have decreased[3].

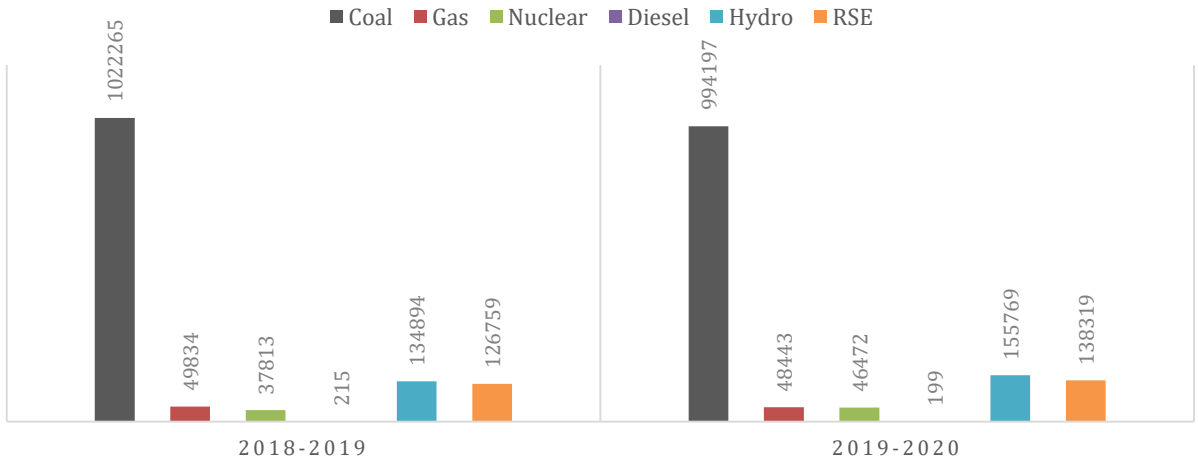

Chart - 4: Gross electricity generation in india mode wise-utilities 2018-19 & 2019-20 in GW-hr

2.2 Transmission

The natural resources for electricity generation in India are unevenly dispersed and concentrated in a few pockets. Transmission, an important element in electricity supply chain, facilitates evacuation of power from generating stations and its delivery to the load centers. For efficient dispersal of power to deficit regions, strengthening the transmission system network, enhancing the Inter-State power transmission system and augmentation the National Grid by connecting all 5 regional grids gradually and enhancement of the transmission system network are required. An extensive network of transmission lines has been developed over the years for evacuating power produced by different electricity generating stations and distributing the same to the consumers. The nominal Extra High Voltage lines in vogue are ± 800 kV HVDC & 765 kV, 400 kV, 230/220 kV, 110 kV and 66 kV AC lines.

2.3 Distribution

Distribution network has a great significance in electrical supply system**.** It is a crucial link between transmission network and consumer. Initially distribution network was not given adequate attention due to this distribution companies have faced huge lose. But in last 2 decades government have taken some good initiative to reduce aggregate technical and commercial (AT&C) losses along with a definitive regulatory framework. GOI have made huge investment through RGGVY (Rajiv Gandhi Grameen Vidyutikaran Yojana) and APDRP (Accelerated Power Development and Reform Program) programs and also introduced some policy and regulation to increase competitiveness and to attract participation of private players. But with renewable energy integration it needs some IT and AI based smart and innovative solution so that we can make network more reliable with bidirectional power flow and reduce AT&C losses so that it could able to smartly account, audit and manage power demand and supply and can comply with distributive generation more reliably.

2.4 Co-generation

Particularly in heavy industries, though it was not uncommon earlier due to their specific needs, due to change in regulation more and more participation is taking place. With adequate protection and advancement of technology, in fact renewable energy or green energy sources are finding path to penetrate power sector in a big way.

3. POTENTIAL OF RENEWABLE ENERGY IN INDIA

Renewable energy sector has grown rapidly in last decade and emerged as a significant player in electricity generation. As of November 2020, 37% (Including large hydropower plant) of India's total installed capacity (374GW) generated through renewable energy sources. In Paris climate summit 2025 India committed that it will increased its installed renewable capacity to 175GW by 2022 in which 100GW will be of solar capacity 60GW of wind power, 10GW of Bio-energy, 5GW of small hydro power capacity[2].

India lies between tropic of cancer and tropic of Capricorn, in this region the solar irradiation is high and that's why the country which lie partially or completely between regions are known as sunshine countries. These countries have formed a formal alliance known as International Solar Alliance (ISA) for promotion and development of solar power internationally. So having a sunshine and geographically diverse country India has huge potential in renewable energy. India's estimated renewable energy potential is approximately 900GW. In which wind potential is 102GW, Bio-energy potential is 25GW, Small hydro power potential is approximately 20GW, and solar power potential is 750GW[4].

India's renewable energy capacity growth in last decade was quite impressing as at the beginning of 2009 India's renewable energy installed capacity was 14.4GW and by the end of November 2020 it increased to 90.4GW[2]. Ministry of New and Renewable Energy have played proactive role in promoting the adoption of renewable energy sources by offering generation incentive, capital and interest subsidies, concessional finance, viability gap funding, fiscal incentive etc. with the help of these incentive the renewable energy became cost competitive as compare to fossil fuel based generation. Advancement of technologies and investment have reduced unit generation cost of renewable energy further.

Having a geographically diversified country India have diversified non-conventional sources such as wind, hydro, solar, nuclear, tidal, bio-energy, Geo-thermal etc. which are classified below-

3.1 Hydro Power

Hydroelectric power plants uses potential energy of water to convert into electric water. Hydroelectric plant requires dependable water flow so dam or reservoir is constructed on the water head then this water is fed through channel or pen stoke to turbine and the pressure of water rotates the turbine and convert the potential of water into mechanical energy and then mechanical energy is converted to electrical energy through generator which is connected to turbine through shaft.

India has 80GW of hydro power capacity which can be economically exploited. As of 31 March 2020 India's installed utility scaled hydroelectric capacity was 46GW (12% of total utility power generation) which is 5th largest in the world. In addition 4.38GW of small hydroelectric plant(less than 25MW of name plate capacity) have installed[2]. Small and micro hydro power plant comes under minister of new and renewable energy capacity while large hydro plants more than 25MW of nameplate capacity comes under ministry of power.

3.2 Wind Power

Electricity can be generated through wind power by converting kinetic energy of wind into mechanical energy through wind turbine then mechanical energy could be converted to electrical energy through electrical generator coupled to wind turbine through shaft and finally this electrical energy can be supplied to power grid or can be store to pumped hydro plant or into battery storage system.

The estimated potential of wind power in India is 102GW assessed at 80m hub height. India's Installed capacity of wind power as on 31 March 2020 was 35.6GW which is 4th largest installed capacity in the world. Government have set ambitious target to increase nation's total installed capacity to 60GW by 2022. In 2018 Ministry of new and renewable energy have announced hybrid wind and solar policy means same piece of land will be used to house both wind form and solar plant[2].

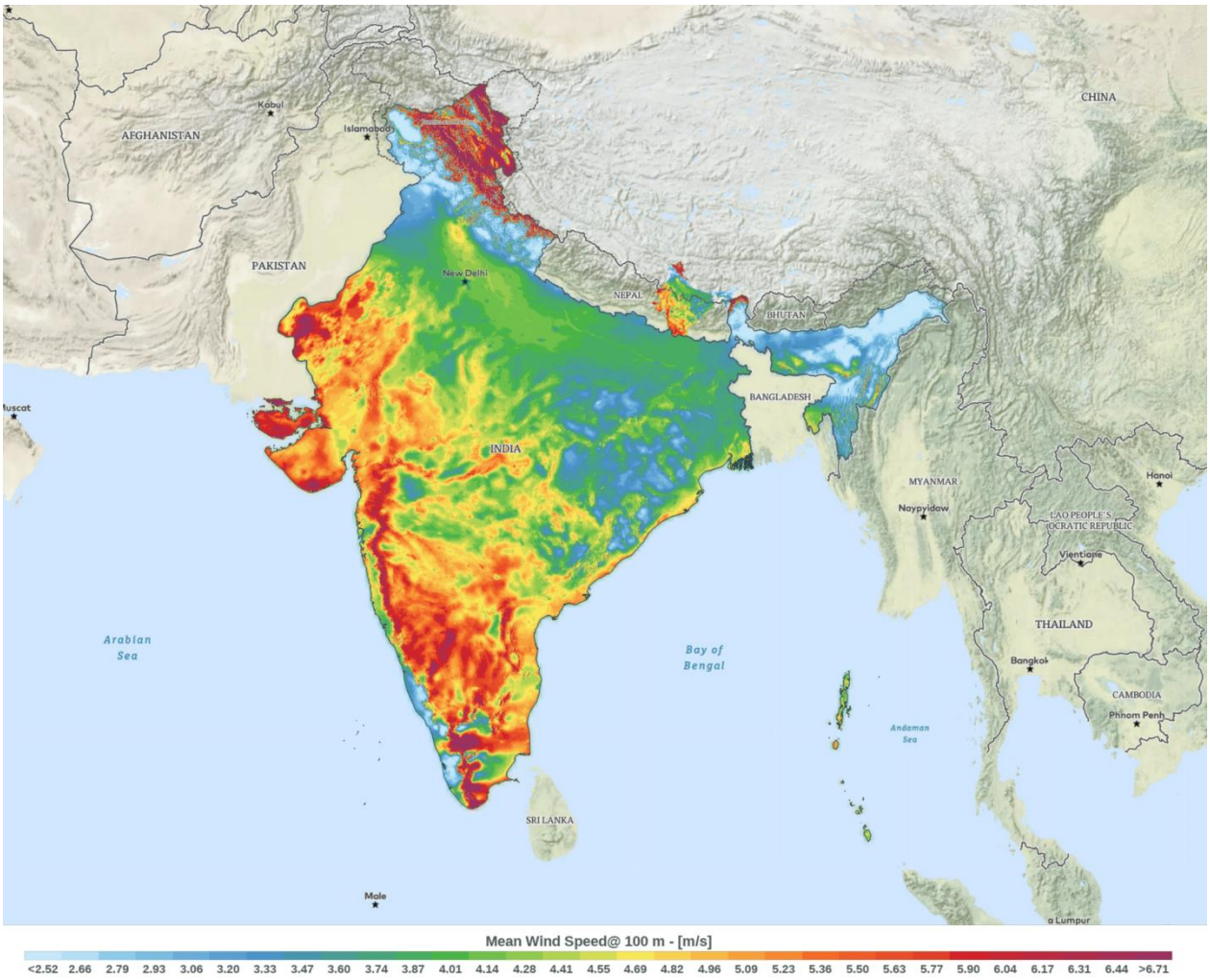

Fig - 1: Mean wind speed map of India[5]

3.3 Solar Power

Solar energy is utilized directly as solar thermal energy by solar appliances as water heating, drying, cooking and space heating and indirectly as solar electric application. Electricity can be generated through solar photovoltaic (PV) panels. It is made up of semiconductor cells which are connected in series and parallel connection to form panel of required specification. When the solar radiation falls on solar cells it starts conducting and the generated DC power can be stored in battery storage system or converting it into AC and after synchronizing to grid frequency it can be integrated to power grid.

India is endowed a huge solar potential. About 4-5 kW-hr per m^2 per day indented on India's land and in a year nearly 5000 trillion kWhr. Nation Institute of solar energy has estimated that solar potential in India is approximately 750GW by assuming 3% of waste land coved through PV modules. Government of India have targeted to install 100GW of grid connected installed solar capacity by 2022 to achieving this target government of India have taken many generation incentive, capital and interest subsidies and policy framework to accelerate the mission under national solar mission program. As on 30 June 2020 country's total installed solar capacity is 35.74GW.

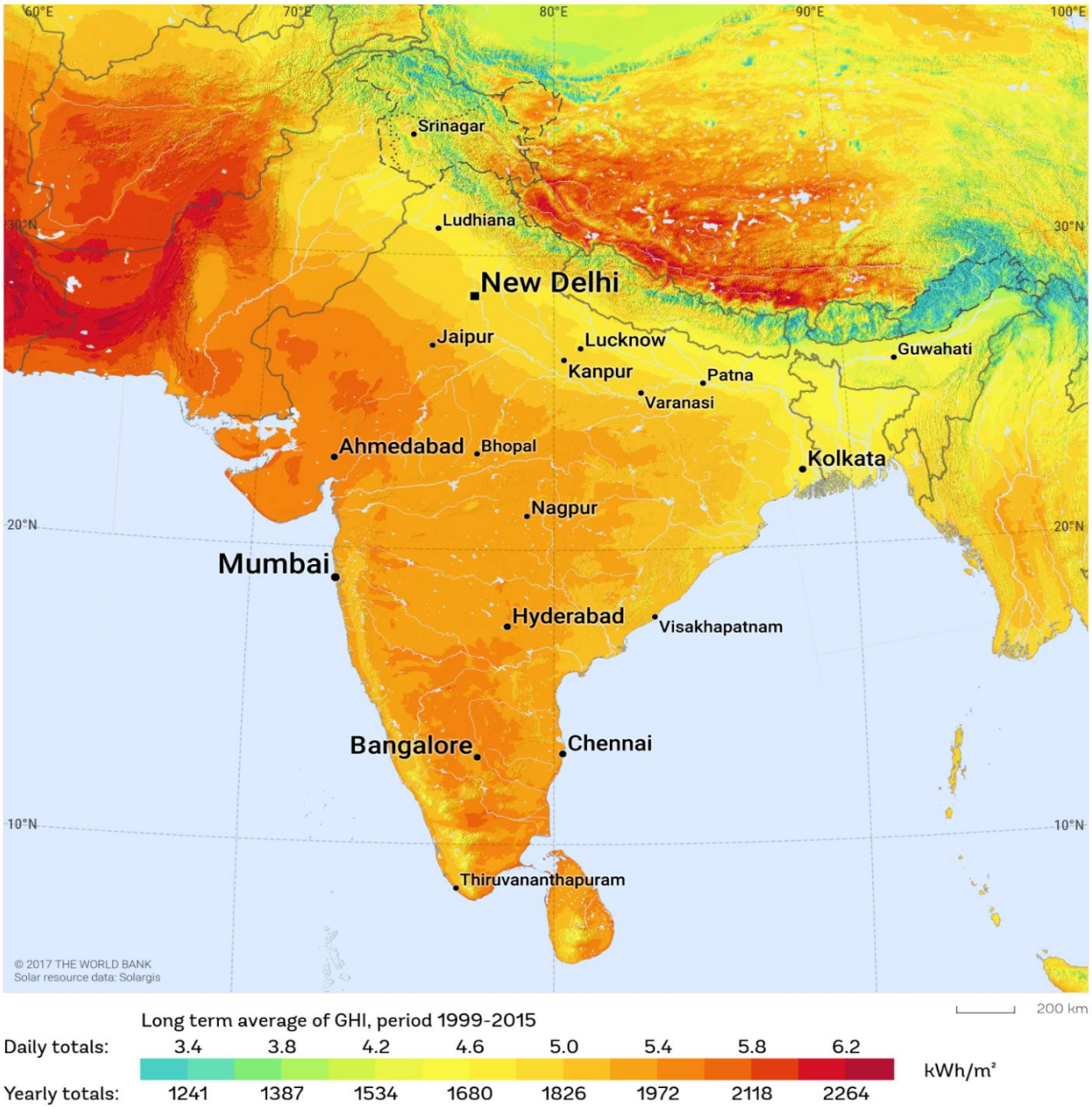

Fig - 2: Global Horizontal Irradiance in India[6]

3.4 Biomass Power / Bagasse Based Co-generation

Biomass is biological material derived from forest, agricultural residue, rice husk, straw, plant and animal manure etc. biomass can be use directly as energy source by combusting to produce heat or indirectly, biomass can be converted into fuel like methanol and ethanol which can be used in engine. By anaerobic fermentation biomass can also be converted into bio-gas. Then through combustion of these bio-fuels we can produce heat of electric power. As of now total installed capacity of biomass power is 2.66GW which will be increased to 10GW by 2022[2].

3.5 Geothermal

The thermal energy stored in earth's interior is known as geothermal energy. The steam and hot water at high temperature and pressure come at earth's surface naturally at some places which can be harvest to generate electric power.

According to estimation India have 10GW of geothermal capacity. Government in phase-1 is intended to utilize 1GW of geothermal energy by 2022[2].

4. INTEGRATION RENEWABLE ENERGY TO GRID

We have observed above that India has huge and widely dispersed renewable energy capacity. In order to take benefit of these sources we have to integrate them to grid. Integration of low level wind and solar energy sources to the grid in an effective manner can be achieved relatively easily. But at higher levels, wind and solar generation can present some challenges to grid operations because of the additional variability and uncertainty they bring to the power system. As power system routinely experiences variability in load due to different electricity usage pattern by residential, commercial and industrial consumer and due to changing weather power usage varies. Power system are also subjected to uncertainty as load forecasting can be done with a marginal error and electrical and mechanical fault can occur at generation station, transmission network and distribution station without warning. Power system operators have developed some methods and technique to manage these variability and uncertainty in an effective manner[15].

Generation of electricity by non-conventional (like thermal, diesel, nuclear and gas power plants) sources are constant and controllable in nature means they do not depend on weather conditions and we can change generation according to power demand. While Renewable sources particularly wind and solar are variable in nature and depends on weather conditions. On the other hand hydroelectric and biomass sources are controllable and geothermal sources are relatively constant. But we produces most of the power through solar and wind sources so variability, intermittency and fast rampaging nature of renewable sources are challenge in the way to integrate them into power grid. Other issues to integrate them into grid are reliability and affordability, integration cost.

So before integrating these sources to grid we have to focus of following areas-

- Latest technology and innovation can increase affordability as the prices of PV Panels and wind turbines are drastically fall in last decade. But we have to focus other renewable sources and have to integrate then in grid so that we can enhance reliability.
- Frequency is one of the key indicator of demand and supply mismatch. If frequency deviation become too wide then system operation can deteriorate which can case even grid failure and black out in the very entire region. So we have to focus on frequency response, system stability and system balancing to avoid such incidents.
- Generation forecasting is very essential for renewable sources as they are highly dependable on variable weather conditions and shall lead to power fluctuation in power system so we have to develop new and advance tools and mechanism for better generation and weather forecasting load and we have to insure resource adequacy during operation and grid security.
- We have to improve and invent more advanced and efficient scheduling and dispatch mechanism in order to improve system reliability.
- Adequate spinning reserve and balancing reserve are required for respond to grid fluctuation and demand supply mismatch. In order to integrating 175GW of installed renewable power, requires significantly large quantum of reserve capacity. Pumped hydro and gas based plants are not sufficient for this purpose so we have to focus on other storage system too.
- With increasing the portion of renewable power in total installed capacity we need to modify the existing power system as they are incapable to respond fast ramping up.
- Ancillary services are required for maintaining acceptable frequency and voltage level in the system. Ancillary services are implemented at inter-state level but it should be implemented at the state level for better and efficient operation.

Until now India's transmission grid and distribution system had worked for convention sources, these sources are concentrated on few location and large in size so scheduling and management of plant was easy task. But with increasing the integration of various distributive renewable sources it is becoming a challenging task. It is needed to modify and expand

transmission capacity to accommodate renewable sources. In order to integrate 175GW of renewable power we have to integrate all 5 regional grid into one grid so that it can reduce generation variability impact. In 2015 government of India have announced National smart grid mission of the very purpose. It is needed to work on bidirectional distribution system and metering system in order to integrate rooftop solar panels into grid. AI (artificial intelligent) and ML (machine learning) technology should be employed for better load forecasting and dispatching purposes so the we can make smart and more responsive distribution network and energy management and audit can be done in more efficient manner.

5. ENERGY STORAGE TECHNOLOGY

We have noticed above that the main issue of integration of renewable energy into grid are variability, intermittence and fast ramping nature of these sources. For sustainable and reliable grid operation we have to address these issue. Variability can be reduced by interconnecting regional grid in order to form national grid and availability of adequate electricity reserve can offset the impact of intermittence problem of Renewable energy sources by storing the generated intermittent energy and then making it accessible upon demand which can improve grid reliability. So before integrating such 175GW or more amount of renewable installed capacity, we have to insure adequate reserve capacity. In this section we are going to review various electric energy store technologies, India's current storage capacity and potential and advantages of have sufficient storage.

Due to technology advancement renewable energy sources are emerging as a viable solution of sustainable and reliable grid operation. Adequate availability of conventional storage such as pumped hydro storage and non-conventional storage such as battery storage improving power quality and availability. Power system operator have to keep balance between demand and supply and frequency should be kept between 48HZ to 52HZ so for this need fast response storage such as batteries and fly wheels are best suitable technologies. For grid stabilization services we operate power plant at sub-optimal or insufficient way which is cost ineffective so we can use battery storage for grid stabilization and conventional power plant will be used for power generation purpose which will be more efficient and cost effective and generation can be optimized. Seasonal variability on the supply or demand side can be compensated by storing energy for longer time so for this purpose reservoir hydro plants can be taken into account[11]. Storage facility can be utilized for storing generation output to maintain power flow over tie-line which will be useful to handling congestion situation in the transmission system. For handling contingencies adequate generation reserve are to be maintained in the system and should be segregated into primary secondary and tertiary for balancing purposes[14]. In 2019 ministry of power have amended it "Hybrid wind-solar with storage policy". Initially it was only battery storage but with amendment it included any form of storage could be used in hybrid projects like pumped storage, compressed storage and flywheel etc.

Electric Energy storage can be classified as following[7]-

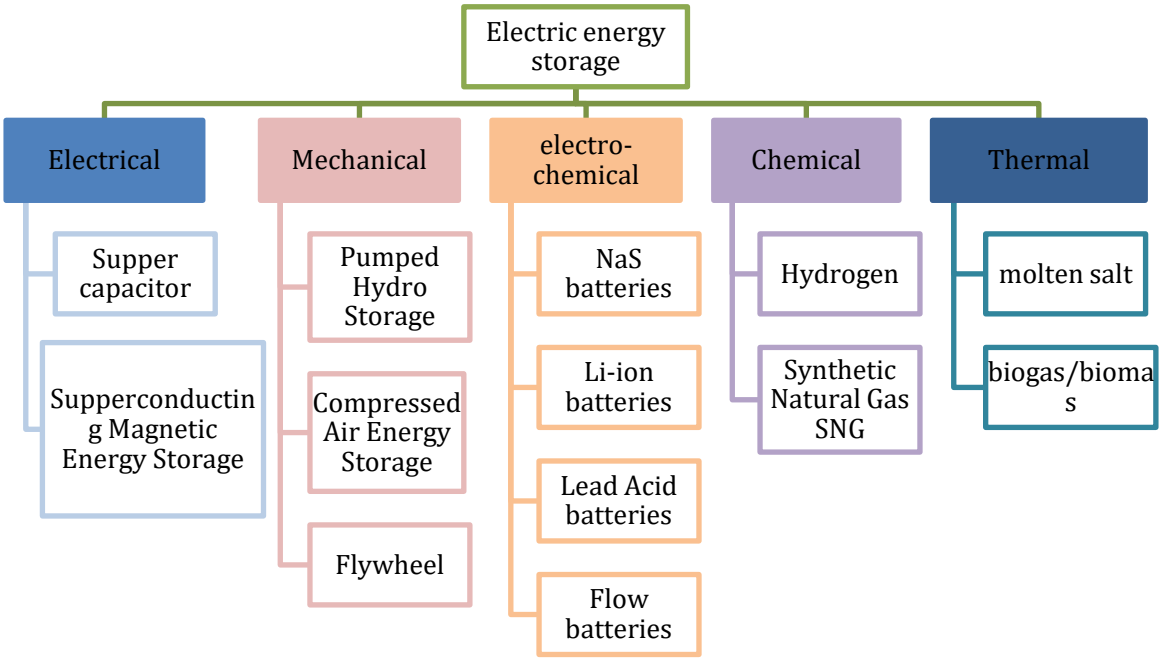

Fig - 3: Types of energy storage technologies[7]

In which pumped storage are in mature phase, fly-Wheel is in demonstration to deployment phase and compressed storage, lead acid and lithium-ion batteries are in demonstration phase. Rest of the storage technologies are in research to development phase.

Till 2018 approximately 1650 grid connected energy storage project were installed of accumulated capacity of 200GW more than 95% of it was of pumped hydro storage plant other are electro chemical and electro mechanical and thermal storage. In India also grid connected store majority is of pumped hydro storage plants that is 6 pumped storage project are operational and 4 are partially operational and under construction accumulating capacity is of 2.66GW are operational and 3.1 GW are under construction. 7 electrochemical project with overall capacity of 1.25GW are under construction[8]. India's first grid connected battery storage capacity of 10MW is operated by Tata Power Delhi Distribution Ltd.

6. CASE STUDY

Gapa or Gapado is an Island of 0.9 km^2 area with population of 245 under the administration of Republic of Korea (ROK). This island was developed as energy self-sufficient smart grid model by ROK government. Initially this island was fulfilling its energy need through three 150kW of diesel generator and was emitting 750 tons of co_2 and expending US$ 415K annually. Then ROK Government have installed two 250kW of installed capacity wind turbine and 48 household solar generator module of 111kW of aggregate capacity. The generated power supplied to load through two 500kVA and one 250kVA power converter and the remaining power above the need was stored to a 3.85MW-hr Lithium-ion battery to manage renewable energy variability and uncertainty. All this connected to a smart micro-grid through automated power management and the three 150kw diesel engine were remain connected to grid as contingency reserve. After success of this model Korean government have decided to roll-out this micro-grid self-sufficient model on all small islands. In 2018 this island have operated for 7 days only with solar wind and battery. In 2016 Korean have signed an agreement with Dubai power authority to share micro-grid and business model of this island[13]. So this magnificent model have suggested us that we can make those untouched or unreached areas as energy self-sufficient and carbon positive and we can work on larger self-sufficient model.

7. CONCLUSIONS

India have huge potential in the field of renewable energy, particularly in wind and solar areas. Indian government have taken many steps to harvest these sources like national solar mission, wind-solar hybrid policy and many RE based frameworks, amendments and incentives based schemes in last decades and as result now Renewable energy become a

sizable part of generation feeding the grid[9]. Variability, intermittency and fast-ramping nature of these sources can cause problem of fluctuation and unpredictability into grid thus energy storage can play important role and in this paper we have seen some storage technologies and there uses to curve these problems. Integrating the regional grid into a national grid under the umbrella project One Nation One Grid in phase manner can solve the variability issue of renewable energy. Our transmission and distribution network were constructed for conventional and concentrated sources so for integrating distributed non-conventional sources into the network, we can employ latest technologies like we can use data science based tools for load and weather forecasting, audit and management purposes. Machine learning (ML) and artificial Intelligence (AI) base technologies for quick fault response, better control, economic dispatching and smart load scheduling so that we can reduce losses and manage the system automatically as we have observed in Gapa Island case study.

Smart grid technologies can improve flexibility and reliability of grid. So we will be able to utilize the existing power system infrastructure in more efficient manner and can improve cost effectiveness of power system operation. So we will be able to integrate more renewable sources and thus reduce the CO_2 emission and insure reliable system operation. So in order to improve effectiveness of grid, advanced distributive network and better and efficient storage system, power operators and policy makers have need to brig latest technologies, best practices, supportive policies and institutional arrangements. Supportive policies and regulation can turn "Greening the Grid" and "Net zero emission" Dream into reality by 2050.

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