# Impact of Renewable Energy Sources on Indian Electricity Grid

J. Bandyopadhyay
Chief Engineer
Central Electricity Authority

Praveen Gupta
Chief Engineer
Central Electricity Authority

P.E.Kamla
Deputy Director
Central Electricity Authority

Jyotsana Kapoor
Assistant Director
Central Electricity Authority

***Abstract:*** Government of India has given a major impetus to promotion of renewable energy sources by targeting an installed capacity of 175 GW from Renewable Energy Sources by March,22. The bulk of this capacity is programmed to come from solar and wind sources which are intermittent in nature. This huge capacity from RES would pose technical, commercial and regulatory challenges. A comprehensive study covering pan India over a broad planning horizon taking into consideration the RES Capacity of 175 GW by March,2022 has not been done so far. This paper discusses the challenges involved with large scale integration of renewable energy sources with Indian electricity grid which is presently dominated by conventional energy sources. The paper also suggests possible solutions to avoid any destabilisation of electricity grid. This exercise has been carried out as a part of preparation of National Electricity Plan for Indian power sector and is based on the actual data collected from various authentic sources.

***Index Terms:*** Renewable Energy Sources, Net Load Curve, Balancing, Ramping, Duck Curve

## INTRODUCTION

**Renewable Energy is the energy which is naturally available and can be replenished from natural sources known as Renewable Energy Sources(RES). Sun is directly or indirectly linked with the RES. Thermal, photo-electric etc. are directly linked with the sun whereas wind, hydro power, energy stored in bio-mass etc. are indirectly linked with sun.**

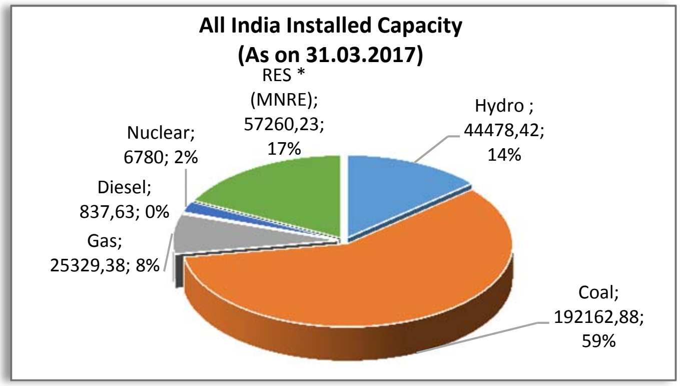
The World Energy Forum has predicted that fossil-based oil, coal and gas reserve will be exhausted in less than 10 decades [1]. This coupled with the urgent need of arresting the adverse climatic changes has forced planners and policy makers to look for alternate sources. Hence, in order to arrest the adverse climatic changes and rapid depletion of conventional energy sources and to ensure energy security and sustainable development, India is consciously taking firm steps towards development of renewable energy. India has committed in Intended Nationally Determined Contributions (INDCs) under UN Framework on Climate Change that by 2030, non-fossil fuel shall contribute 40% of the Installed capacity in Power Sector and there shall be 30-35% reduction in energy intensity with reference to 2005[2].

Now, India has significant potential of electricity generation from renewable energy sources. It has been estimated by MNRE that the solar and wind potential in India stands at 748,990 MW and 102,772 MW respectively [3] [10]. Over the years, renewable energy sector in India is emerging as a significant player in the grid connected power generation capacity. At the end of the 11th Plan i.e. as on 31st March,2012, the total installed capacity of RES stood at 24,503 MW comprising of 941.3 MW of Solar, 16,896.6 MW of Wind,3255 MW of Bio-mass and 3410.5 MW of Small Hydro. This increased to 57,260 MW (Solar: 12,289 MW, Wind: 32,280 MW, Bio-Mass: 8,312 MW and Small Hydro: 4,380 MW) as on 31.03.2017 [7]. As is evident, there has been an accelerated development in renewable energy capacity addition in the country during the last decade. Recognising that renewable energy has to play a much bigger role in achieving energy security in the years ahead and be an integral part of the energy planning process, Government of India has taken all out efforts to harness this potential. An Action Plan has been formulated by Government of India for achievement of a total capacity of 175,000 MW from Renewable Energy Sources by March, 2022.

## PRESENT SCENARIO IN INDIA

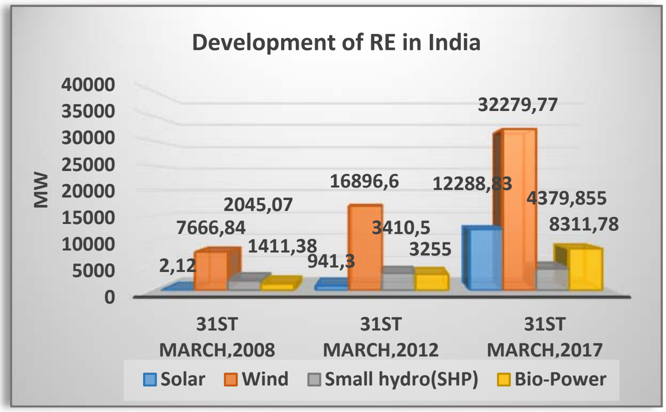
The Installed Capacity of the country as on 31st March, 2017 was 326,849 MW comprising of 218,330 MW thermal, 6,780 MW Nuclear, 44,478 MW Hydro and 57,260 MW Renewables and is depicted in Exhibit 1 [7].

**Exhibit 1**



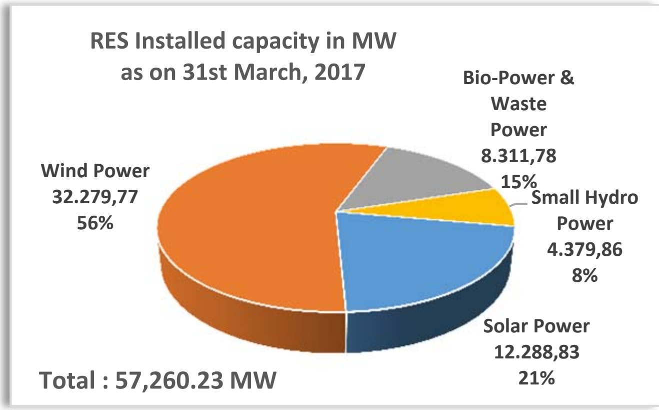
Indian electricity system has been historically dominated by thermal power. However, as mentioned earlier, there has been a significant increase in renewable energy capacity addition during the last decade. The installed capacity of renewables in India has grown from 11,125 MW in 2008 to 24,503 MW in 2012 and presently reached to 57,260 MW in 2017 [7] [8].

**Exhibit 2**



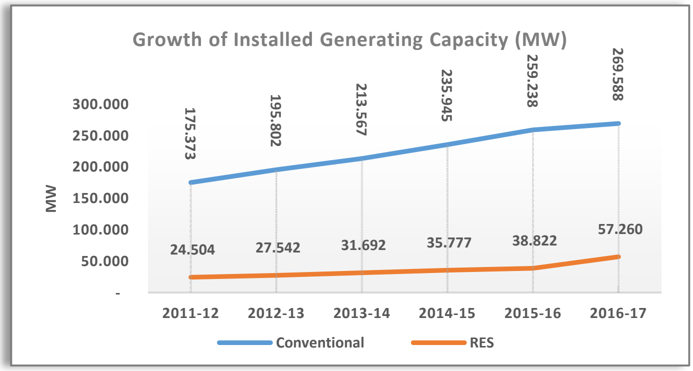

India ranks fourth in the world in terms of installed capacity of wind turbine power plants.

**Exhibit 3**




The present installed capacity of Renewables is mainly dominated by Wind power which is 56% of total Renewable Installed Capacity in India, mostly located in South, West and North regions [3]. This capacity of wind power is mainly spread across Tamil Nadu (7861.46 MW), Maharashtra (4771.33 MW), Gujarat (5340.62 MW), Rajasthan (4281.72 MW), Karnataka (3751.40 MW), Madhya Pradesh (2497.79 MW), Andhra Pradesh (3618.85 MW), Telangana (100.8 MW) and Other States (55.8 MW). Tamil Nadu state has become a leader in Wind Power in India [3]. The pace of growth of conventional energy sources as compared to that of RE sources is shown in Exhibit 4.

**Exhibit 4**




## RENEWABLE ENERGY TARGET BY 2022

Renewable Energy sector is now poised for a quantum jump as India has reset its Renewable Energy capacity addition target so as to have installed capacity of 175 GW from renewable energy sources by 2022. This includes 100 GW from solar, 60 GW from wind, 10 GW from biomass and 5 GW from small hydro power **(Exhibit 6)**. Within the target of 100 GW for solar energy, 40 GW would be from solar roof tops and the balance 60 GW would be from off the ground large and medium scale projects **[9]**.

Although wind power plants are predominant today, but in future, installed capacity of Solar Plants shall exceed the installed capacity of Wind Plants.

**Exhibit 5**

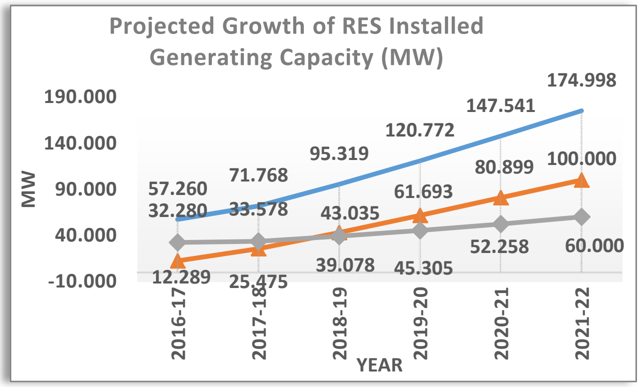
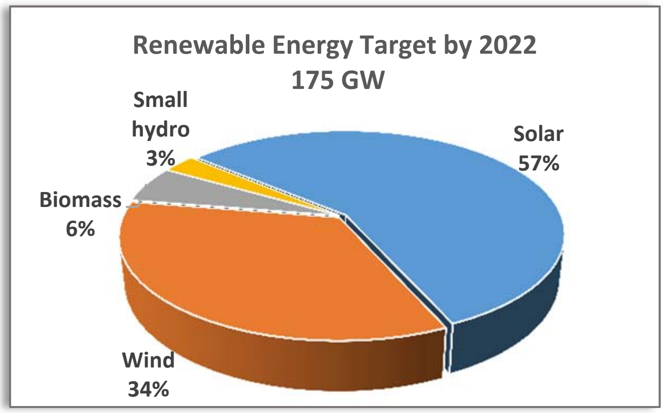
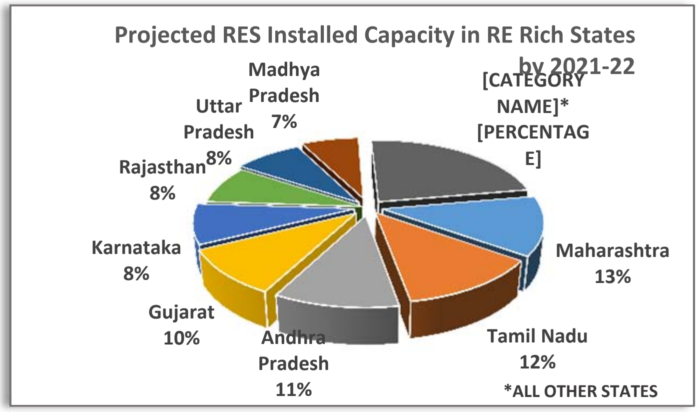



**Exhibit 6**



The tentative State-wise break-up of Renewable Power target corresponding to installed capacity of 175 GW set by Ministry of New and Renewable Energy sources, to be achieved by the year 2022 is shown in Exhibit 7 [9].

**Exhibit 7**



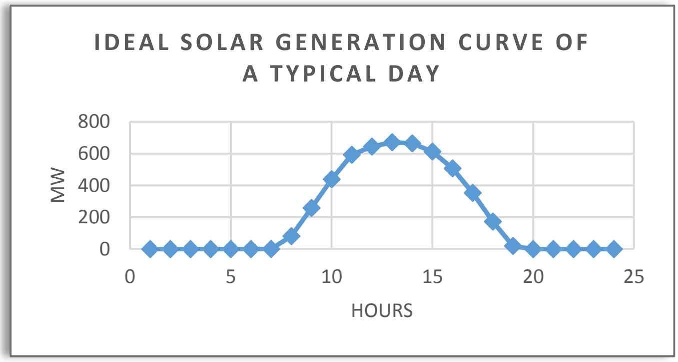

It is seen from the Exhibit 7 that 9 States in India shall contribute almost 77% of the RE installed capacity by 2022.

## GENERATION PROFILE OF RES

As the RES derive energy from natural sources, their availability may be highly variable. For this reason, these generation sources are called Variable Renewable Energy Sources(VRE). Generation from the VRE cannot be scheduled with the same accuracy as that from conventional sources. The variability occurring is both diurnal and seasonal, as is the case of generation from solar plants. The other reason for variation is attributed to the uncertainty associated with natural phenomenon like sudden movement of clouds etc. To account for such intermittency of RES sources, it is critical to study the generation pattern of different types of sources over both micro and macro periods of time as well as dispersed geographical locations so that both short term and long term variability can be well understood and taken care of. Variation of different RE sources over time is discussed below:

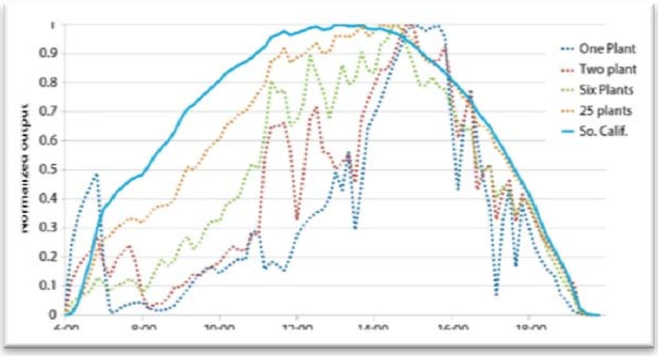
**Solar:** Solar energy generation involves the use of the sun's energy to provide electricity via solar photovoltaic (PV) and concentrated solar power (CSP) systems. The amount of energy produced directly depends on the sunshine intensity. Thus, the output varies both seasonally and daily. Also there are short term variations due to weather conditions like clouds or rainfall. Normally generation from a solar plant gradually increases after dawn and reaches a maximum around noon and then gradually decreases and becomes "Zero" with the advent of evening. An ideal Generation Profile of a solar plant is shown Exhibit 8.

**Exhibit 8**




However, due to various uncertainties associated with solar generation, the generation profile is not as smooth as shown in Exhibit 8.

**Exhibit 9**



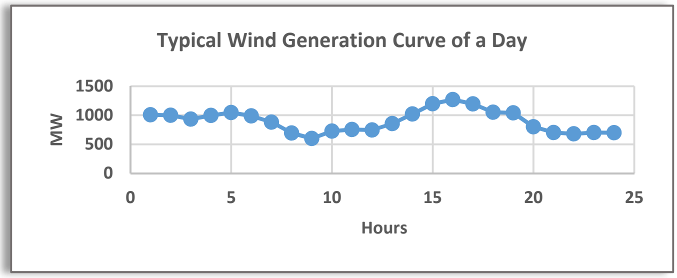

The uncertainty associated with the output of a single PV system can be smoothened out in two ways-

i) aggregating a large no. of PV systems and

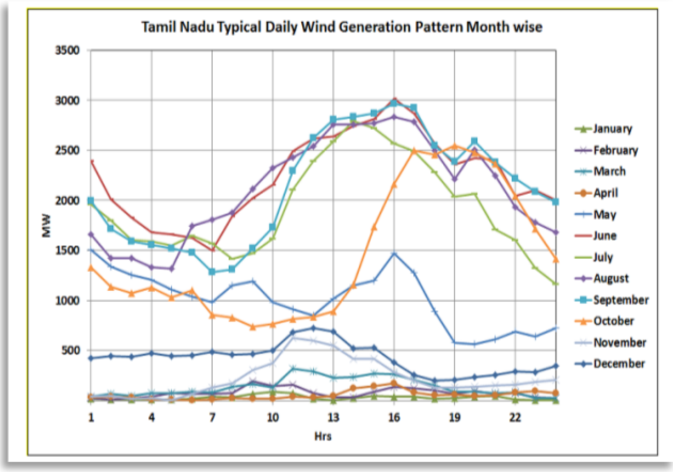
ii) aggregating the output of different PV systems scattered at dispersed geographic locations. As the number of PV plants increases, their normalized, aggregate output becomes smoother as shown in Exhibit 9. [11]

**Wind:** As the wind turbine output is directly proportional to cube of the wind speed, wind power becomes unavailable at both very low and very high speed. This is different from the solar generation where changes occur rapidly and variation may be from second to second due to cloud cover. A typical daily wind generation curve is shown in Exhibit 10.

**Exhibit 10**

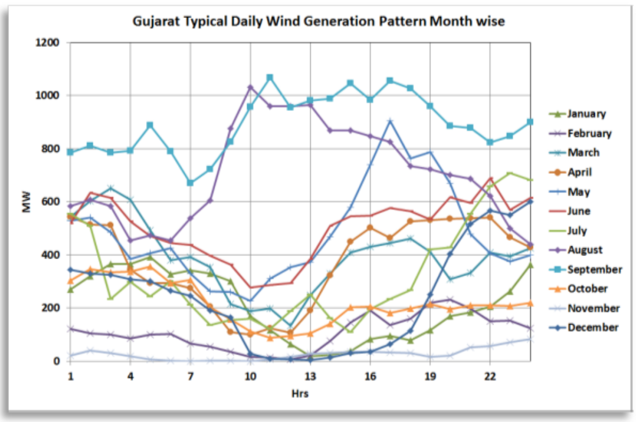



However, there are wide variations in wind generation during different hours of the day and in different seasons. Tamil Nadu's typical daily Wind Generation Pattern Month wise (Source-TAN SLDC) is depicted below:




(Source: TAN SLDC/ NLDC)

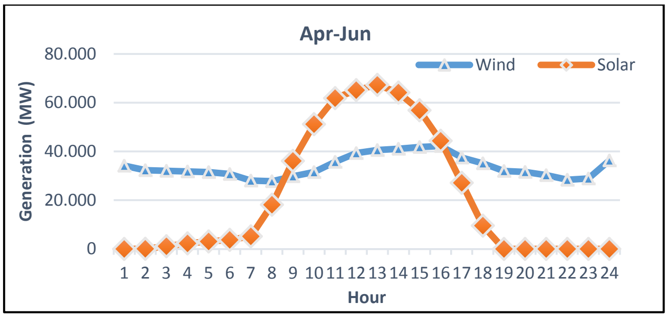
The profile of wind generation of Gujrat is as follows:



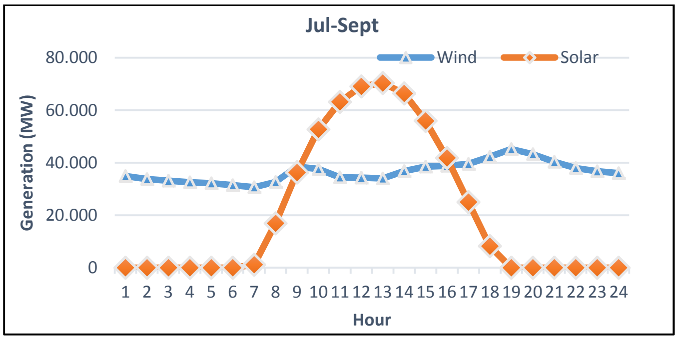

(Source: Gujrat SLDC/ NLDC)

**Combined wind and Solar Profile of the country:** The combined generation profile of solar and wind varies largely on seasonal basis. This variation can be attributed to different factors like location, season etc. Typical generation patterns of solar and wind for different seasons on all India basis during 2021-22 as computed as a part of the study are shown in Exhibit 11(a) to (e).

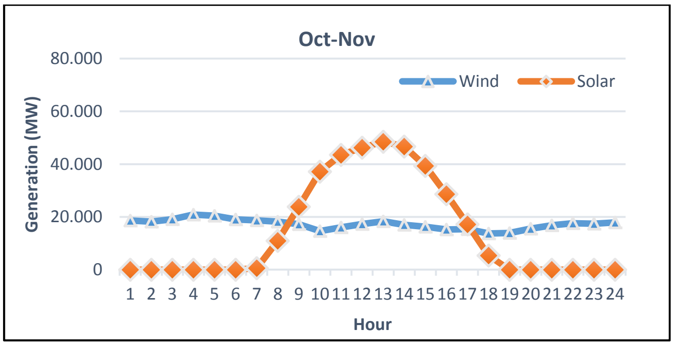
**Exhibit 11(a)**



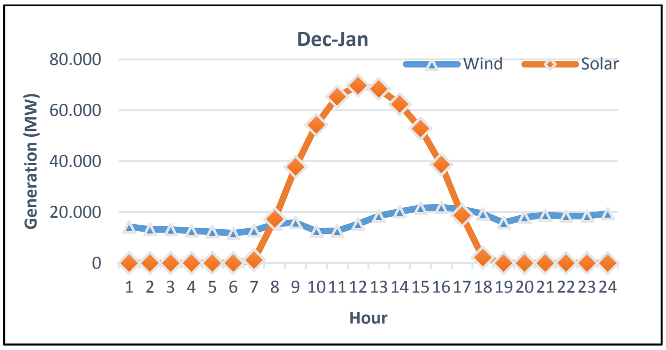

**(b)**



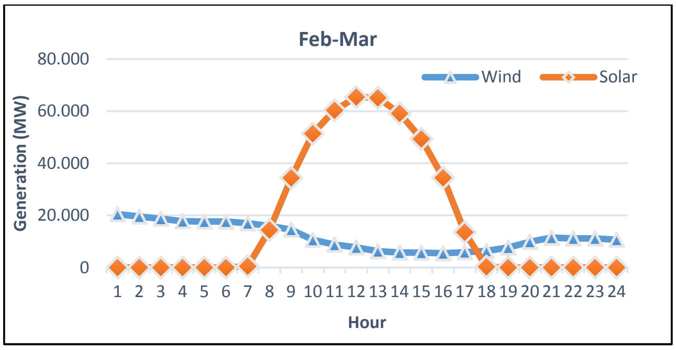

**(c)**




**(d)**




**(e)**




It can be seen that the maximum generation from Solar sources would be available during the months of April to June and wind generation is maximum during the month of July to September i.e. mainly in monsoon season.

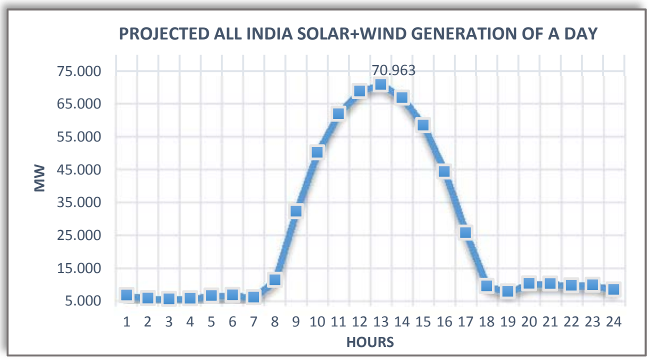
## STUDY AND ANALYSIS

Integration of renewables and challenges therein have been discussed in the past by many authors in India. Debrase and Ramchandran [12] have carried out a study for Kolar District of Karnataka. Mercados [15] have highlighted the lessons learnt from the integration of renewables in the Southern Regional grid in India. Shakti [16] in its Report on "Integrating Variable Energy with the Grid" have highlighted the short term and long-term issues to be addressed. Niti Aayog [14] in its "**Report on India's Renewable Electricity Roadmap 2030: Towards Accelerated Renewable Electricity Deployment"** have identified the new policies and programs that would be useful for RE integration into the Indian electricity grid. But comprehensive study based on different scenario covering pan India for future basis has not been done so far. In this paper, a detailed study based on future demand projection has been made for integration of 175 GW of RES into the grid. The effects of RES and challenges of integration into the grid are being discussed in detail.

**Projected All India RES Generation:** A study has been carried out to estimate the amount of total generation available from projected installed capacity of RES in the target year 2021-22. For this, latest available hourly generation profile data for 8760 hours (24 hrsX365days=8760 hours) from existing solar and wind power projects of various States of India was collected. For such states where said data was not available, the hourly generation profile was estimated from various studies carried out by Ministry of New and Renewable Energy, Government of India. Consequently, each of the hourly profile for Solar and Wind projects were normalized and scaled up by proposed Capacity addition of each state/UT by the year 2021-22. Appropriate diversity factors were assumed and applied. Finally, by aggregating the hourly generation profile of all the States where Solar and Wind power capacity addition is envisaged, the All India RE generation profile for the year 2021-22 was obtained.

The likely combined generation pattern for Solar and Wind for a typical day in March,2022 is shown in Exhibit 12.

**Exhibit 12**




Based on the estimated hourly generation profile (8760 hours), the expected generation available from RE sources (Wind and Solar) in the year 2021-22 are shown in Table 1.

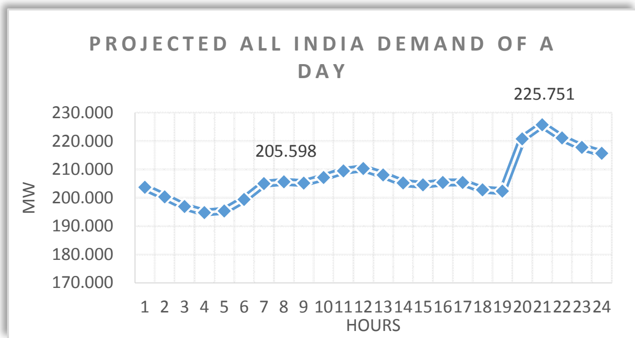
**Table 1**

| Year | Installed Capacity of RES | Expected Generation(BU) | | |
|---|---|---|---|---|
| | | Solar | Wind | Total |
| 2021-22 | 175 GW | 162 | 112 | 274 |

**RES generation Profile vis-à-vis Electricity Demand of the Grid:** To study the impact of integration of RES generation into the Indian Electricity Grid dominated by conventional energy sources, the present load pattern of the country was studied.

**Projected All India Demand Curve:** To study the projected hourly demand profile for the year 2021-22, the hourly demand data (24 hrsX365=8760 hours) was collected for past three years (2012-13, 2013-14 and 2014-15) from various Regional Load Dispatch Centres. The hourly data was analysed and corrected for any discrepancies in terms of load shedding, frequency correction, scheduled power cuts and any data errors. Projected All India hourly load profile for the year 2021-22 was generated by relevant software model based on the above data and projected Peak Demand and Electricity Energy Requirement in the year 2021-22 [I] were obtained. The projected demand pattern for a typical day in March,2022 has been shown in Exhibit 13.

**Exhibit 13**

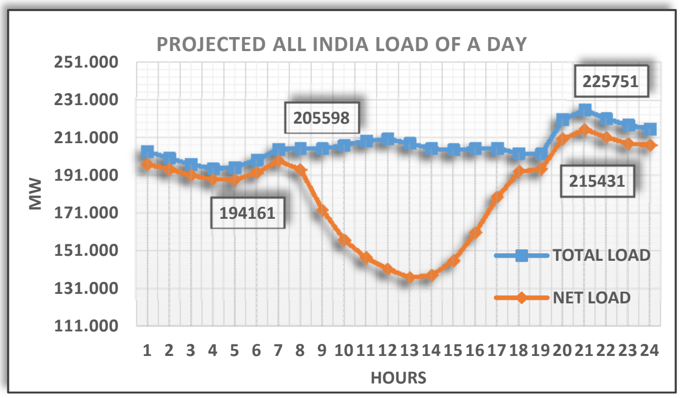


ł Separate Study was carried out by Central Electricity Authority in the purview of 19th Electric Power Survey (EPS) to estimate the peak demand and electricity requirement in the year 2021-22.

In India, normally, the peak demand occurs in the evening and is considerably higher than the morning peak. These peaks shift relatively in different seasons, on weekends, holidays etc.

**Projected All India Net Load Curve**: From the projected hourly All India Demand profile and the All India hourly Renewable Generation pattern for the year 2021-22, the All India Net Load profile was arrived at by treating generation from renewable energy sources as negative load. An example of the All India Net load profile thus obtained is shown in Exhibit 14 and is generally known as "Duck Curve" owing to its shape.

**Exhibit 14**



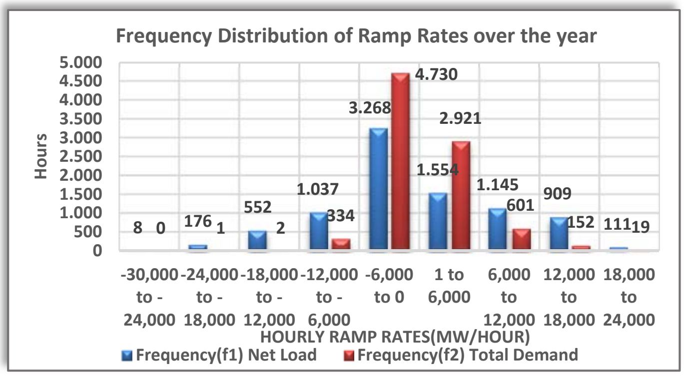

As evident, the maximum generation from RE sources is available during the day at noon time when the system demand is very low. Also, during evening when system peak demand occurs, limited generation from RE is available. This would make the Net Demand Curve very steep. Such fluctuations in the outputs, if not accounted for, can lead to destabilization of the grid. This poses serious challenges in integrating such energy sources into the grid.

## MAJOR CHALLENGES

**Increased Ramping Requirements:** The renewable energy sources are treated as must run. After absorbing generation from VRE, Net Demand is obtained. This Net Demand is to be met from conventional energy sources. As a result, the conventional energy sources need to keep pace with the variability of generation from Renewable Energy Sources. Now, generation from solar plants would normally register a maximum value at noon when the system demand is quite low. Therefore, absorbing full quantum of available generation from solar plants and wind plants would further reduce the requirement of generation from other sources. Similarly, when the evening peak approaches, the generation from the solar plants starts decreasing and becomes almost "NIL" at evening peak. This makes the net demand curve very steep. The gradient of the Net Demand represents the ramping rate.

Therefore, to assess this ramping requirement, the hourly ramping requirement in 2021-22 for 8760 hours(24X365) has been studied. The frequency and quantum of ramping have increased significantly due to increased penetration of RES into the Grid and is evident from Exhibit 15.

**Exhibit 15**




For example, Exhibit 15 shows that number of hourly ramping required in the range of 18000 – 24000 MW has increased from 19 to 111 Nos when renewable energy sources are integrated into Indian Electricity Grid. To accommodate the variability and uncertainty of generation from RES, the conventional generating plants need to be flexible. The flexibility of generating plants refers to its ability (i) to cycle on and off including its lead time required; (ii) the ramping rate at which it can vary the generation; and (iii) maximum and minimum output while it is in operation. In terms of flexibility, hydro plants, Pump Storage Plants, Open Cycle gas turbines, Gas Engines etc. are best suited.

Hydro Plants are one of the best suited for meeting the ramping requirements. However, in India, many hydro plants are designed as multi-purpose projects i.e. for power generation, irrigational requirement, drinking water requirement etc. Further, some plants are of pondage type and offer limited flexibility. So there is a limit to which of the existing hydro plants may provide ramping support. Open Cycle Gas based plants provide a quick ramping support. As on 31st March,2017, India has achieved a gas based generation capacity of 25,329 MW. But only 350 MW is Open Cycle. Close Cycle Gas plants have considerable less ramping capability than open cycle Gas plants. However, through retrofitting, the limitations imposed by the closed cycle plants can be overcome to a great extent. Shortage of gas supply to the gas based plants is a matter of great concern. Adequate supply of gas to the gas based plants needs to be ensured as the portfolio available for meeting the ramping requirement is very limited in India. Now Coal plants are classified as constant output or baseload plants and are rarely turned down or off frequently. Essentially, they are considered as inflexible. These plants experience reduced efficiency, more maintenance, lower equipment lifetime and reduced cost etc. if subjected to cycling or frequent ramp up and ramp down. However, existing coal based plant can be redesigned/retrofitted to enable quick start-ups and ramping. Further, any new coal-based plants coming up in future need to demonstrate its ramping capability before being allowed to be commercially integrated with the grid.

Successfully meeting the ramping requirement would pose a challenge in future. This calls for concerted efforts for optimal utilization of the existing portfolio of generators by addressing the problem technically, commercially and through regulatory mechanism.

**Transmission System Strengthening:** Requirement of strengthening of Transmission System has been stressed by many authors like S. Mukhopadhyay et al [17], Ministry of Power, Govt. of India [13], Mercodos [15] etc. Solar and wind map of India indicates that the potential of solar and wind power is concentrated mostly in few solar and wind rich states. The solar and wind power generated by these states may not be consumed fully by these states. Power generated from RES in these states needs to the transmitted to the load centers through transmission networks. This requires strengthening of existing networks of the grid. Government of India has already taken up the works relating to construction of Green Corridor for this purpose. Further strengthening of networks arises from the need of balancing a broader geographical diversity of resources to reduce flexibility needs.

**Advanced Forecasting:** Wind and solar power forecasting can help reduce the uncertainty of variable renewable generation. The use of forecasts helps grid operators to commit or de-commit more efficiently to the generators in accommodating to changes in wind and solar generation and prepare for extreme events in which renewable generation is unusually high or low. Forecasts can help reduce the amount of operating reserves needed for the system, reducing costs of balancing the system. RE generators/aggregators, Load Despatch Centres at the State/Regional/National level need to integrate with Indian Metrological Department to have live data of weather forecasts. Internationally, improvements have been made in recent years toward reducing mean average forecast errors. Today, forecast errors typically range from 3% to 6% of rated capacity one hour ahead and 6% to 8% a day ahead on a regional basis (as opposed to for a single plant). In comparison, errors for forecasting load typically range from 1% to 3% day-ahead. Day-ahead forecasts can be used to make day-ahead unit commitment decisions and thus drive operational efficiency and cost savings. Short-term forecasts can be used to determine the need for a quick-start generator, demand response, or other mitigating option and thus drive reliability.

**Market Design:** The flexibility needs of the variable renewables need to be addressed in a variety of ways including pricing, schedule/dispatch interval, ancillary service market and requirement, capacity market, other forms of resource adequacy, ramping etc. Market design affects the quantity of flexible resources. Through proper market design the roles of capacity and ramping market, the roles of distributed generation, storage and demand response into wholesale and ancillary market, economic curtailment of renewables, resource aggregators etc. are clearly spelt out.

**Balancing requirement:** Due to variability and uncertainty associated with VRE generation, provision of balancing power is to be made to ensure that system demand at any instant of time is fully met. Normally, conventional generating plants provide balancing. Balancing requirement is expressed as a percentage of total VRE installed capacity. Using different methodologies, this varies from 4% to 20%. In India, present RE penetration is moderate. But by March, 2022, RES is expected to contribute to the extent of about 35% of the likely installed capacity and shall be contributing about 18-20% of the total electrical energy requirement of the country. Therefore, there is a need to assess the country-wise, region-wise and state-wise balancing requirements for India. There are different approaches to compute balancing requirement. One of the methods is the stochastic method. It requires detailed data of deviation from schedule w.r.t. the VRE generators. In India, such detailed data is generally not available. Therefore, a different approach has been adopted to compute the balancing requirement. Pessimistic scenario analysis has been carried out for each region/state. For a RES rich states, the worst scenario may happen when the total VRE generation gets reduced to “ZERO” due to some natural calamity or some other reasons. The distribution of VRE generation is assumed to be normal over the year. Then the value corresponding to which there would be 95% probability that the VRE generation would be within this value has been computed. This would denote the quantum of balancing power in the worst case scenario. This quantum of balancing power will ensure that, in the event of extreme conditions, there is 95% chance that the system shall remain unaffected. The balancing requirement of the country as a whole is estimated to be 34.5 GW in the year 2021-22. By keeping provision of this balancing capacity, it can be ensured that in the event of extreme emergency arising out of non-availability of VRE generation, there is 95% chance that the system shall remain unaffected.

## IMPACT ON CARBON EMISSIONS

Based on the projections of capacity addition by 2021-22 given by Ministry of New and Renewable Energy, it is estimated that a generation of about 274 BU will be available from renewable energy sources (Solar and Wind) in 2021-22. Assuming the present weighted average emission rate of 0.82 kg$CO_2$/KWh of Indian Grid, it is estimated that about 225 Million tonnes of $CO_2$ will be avoided annually by the end of 2021-22 from renewable energy sources (Solar and Wind). However, the net reduction of $CO_2$ emissions will be less as emissions from thermal power stations will increase due to frequent cycling and ramping of the plants than during steady state operation affecting the efficiency of coal based power stations.However, India’s INDC commitment of 40% of cumulative installed capacity from non-fossil fuel by 2030 shall be fulfilled much earlier if the pace of capacity addition from RES is maintained as per schedule as given in Table 2 below.

**Table 2**

| Year | Likely Installed Capacity (GW) | Likely IC of Fossil Fuel (GW) | Likely IC of Non-Fossil Fuel (GW) | % of Non-Fossil Fuel in Installed Capacity |
|---|---|---|---|---|
| March 2022 | 515.1 | 270.2 | 244.9 | 47.5% |
| March 2027 | 602.9 | 241.1 | 361.7 | 60.0% |

* India's Intended Nationally Determined Contribution (INDC):40 % cumulative power installed capacity from non-fossil fuels by 2030.

## IMPACT ON PLF OF THE COAL BASED PLANTS

To accommodate the generation available from VRE, the requirement of generation from the other sources would be correspondingly getting reduced. As Indian power sector is dominated by Coal based generation, the impact would be largely felt by these plants. In fact, the study results indicate that the generation from VRE and Coal based plants are almost perfectly negatively co-related. As a result, the Plant Load Factors(PLF) of the coal based plants would be gradually coming down with the increased penetration of VRE and is expected to hover around 50-52% in 2021-22. Exhibit 16 below depicts the likely average PLF of coal based plants in different scenarios based on the extent of RES based capacity addition (RES Installed Capacity of 175 GW,150GW and 125 GW) till 2021-22 and different rate of growth (6.18%,7.18% and 8.18 %) of Annual Electricity Demand by 2021-22. Exhibit 16(a) considers higher Hydro based capacity addition till 2022 as compared to Exhibit 16(b).

**Exhibit 16(a)**

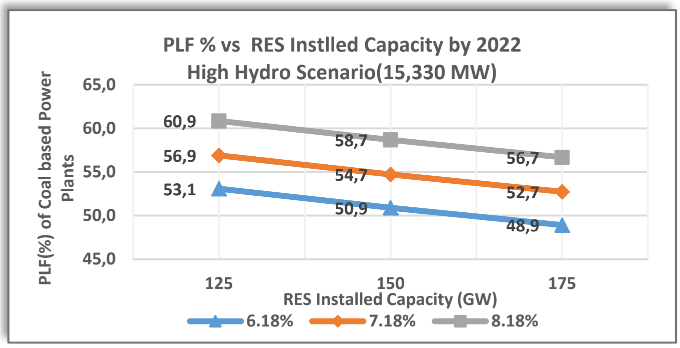
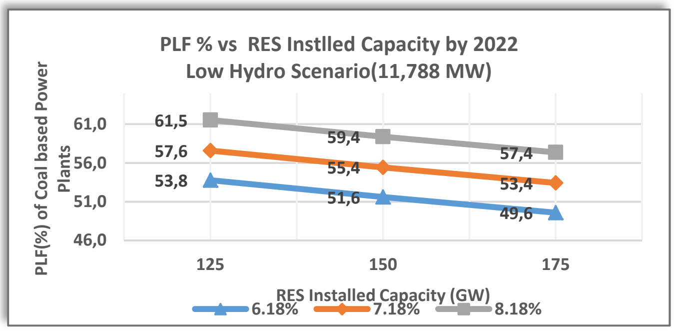



**Exhibit 16(b)**




*PLF is based on expected coal based capacity addition of 50,550 MW by 2022.

## CONCLUSIONS

This paper has discussed the challenges to Indian Electricity Grid system in view of the revised target set by Government of India to have 175 GW of installed capacity from Renewable energy sources. It is concluded that the share of energy generation from Renewable energy sources is going to increase from 7 % at present to around 20% of the total energy requirement by the year 2022. However, this increase in generation from RE sources will lead to conventional generating plants to be more flexible to cater to the increased ramping requirements due to variability associated with RE generating sources. Advanced forecasting techniques need to be adopted to accurately predict the output generation from Renewable Energy sources. The Transmission system needs to be strengthened to evacuate renewable energy from rich RE states to other parts of the country.

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