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Grid Integration of Renewable Energy Sources

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***Abstract*—**Economic growth and rising per capita energy consumption, coupled with conducive policy, regulatory framework, fiscal incentive have accelerated development of renewable energy (RE) generation in the country in past few decades. Presently, in renewable generation portfolio, wind constitutes major share and penetration of solar generation is also increasing, However, it is characterized by intermittency & variability. Increasing renewable penetration presents numerous challenges to the system planner as well as grid operator. This paper identifies challenges in grid integration of large scale renewable as well as suggests suitable measures to address them. Need for requirement of other control infrastructure like establishment of Renewable Energy Management Centers (REMC) equipped with advanced forecasting tools as well as Real time measurement/monitoring schemes through WAMS applications, dynamic reactive compensation, energy storage to provide balancing services etc. It also highlights potential of renewable generation in deserts and transmissions plan that serve as a road map up to year 2050.

***Keywords*—** Balancing; energy storage; intermittency; transmission; renewable; integration; solar; wind.

I. INTRODUCTION

Power is the most vital input for the growth of any economy. Therefore, it is considered as a core industry as it facilitates development across various sectors, such as manufacturing, agriculture, commercial, education, railways etc. to achieve economic growth. Energy needs of the country is growing at a very fast pace to meet high GDP growth rate. Present peak electricity demand of the country is above 145GW(Jun'15) which is expected to grow to about 200GW & 283GW by the end of 2016-17 (12th plan) & 2021-22 (13th plan) respectively as envisaged in the 18th EPS report of CEA. To meet growing demand and to reduce supply-demand gap, there is a need of large capacity addition through conventional as well as from renewable energy sources.

India is endowed with abundant Renewable Potential which presents an excellent solution to meet challenges like meeting long term energy requirements, attaining energy security along with affordability, addressing climate change concerns etc. Government is also promoting development of renewable generation through an attractive mix of fiscal and financial incentives as well as conducive policy environment. It is envisaged that more than 30 GW renewable generation capacity shall be added in the 12th Plan period and 20 GW solar by 2018-19. MNRE has also projected about 175 GW renewable capacity by 2022.

Renewable energy is characterized by intermittency and variability which presents various challenges in its grid integration for maintaining grid stability & security. On the other side, due to large demography, demand varies over the day/week/month as well as on seasonal/regional basis. In order to address above challenges especially in high penetration regime, there is a need to introduce more flexibility with quick ramping features in generation portfolio with mix of various fuel technologies especially Hydro & Gas as well as demand side flexibility.

Considering envisaged renewable penetration level by 12th plan and beyond as well as need of identifying challenges, infrastructure requirements etc. to facilitate RE grid integration, POWERGRID carried out studies and identified "Green Energy Corridor". It covers transmission infrastructure requirement both at Intra state, for evacuation & absorption of RE power in the host state, as well as Inter-state, for transfer of RE power out of the host state. Strong grid interconnection shall also help in enlarging power-balancing area, Intermittent/variable nature of RE sources results in wide variations in quantum and direction of power flow on the transmission corridors. This requires placement of Dynamic reactive compensation in the form of STATCOM/SVC at strategic locations to provide dynamic voltage support for smooth operation and maintaining grid security. This shall also help in addressing fault ride through issues in RE generators.

In addition, the study evolves requirement of other control infrastructure like establishment of Renewable Energy management centers (REMC) equipped with advanced forecasting tools, Real time measurement/monitoring schemes through WAMS applications, Energy Storage facilities to provide balancing etc. POWERGRID also evolved schemes to facilitate integration of ultra-mega solar power parks envisaged in various states through Green Energy Corridor-II.

II. PRESENT POWER SCENERIO

The Indian power sector is one of the most diversified in the world. The Sector has been continuously progressing in generation capacity addition through conventional viz. coal, lignite, gas, hydro and nuclear power as well as non-conventional/renewable sources viz. wind, solar, small hydro, Biomass etc. Presently total installed generation capacity in the country is about 275 GW (Jun'15) which constitute capacity from conventional sources (87%) viz. Coal (167GW), Gas(23GW), Nuclear (5.8GW) and large hydro (42GW)[7]. Balance 35.8 GW (13%) contribution is from renewable generation capacity contribution Wind(23.4GW), Solar(4GW), SHP(4GW) and biomass/biogas (4.4GW) generation[9]. Present generation capacity along with their resource composition is shown in 0

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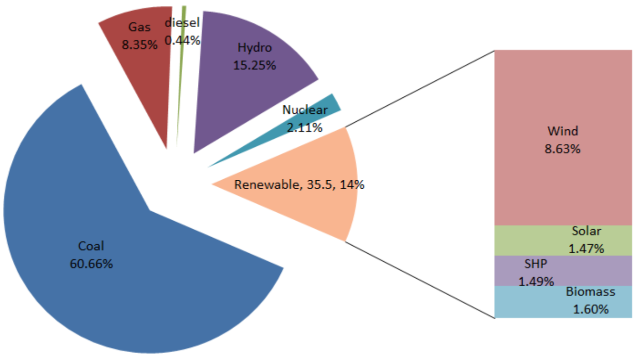

Fig. 1. Installed capacity (Conventional & Non conventional).

Electricity generation due to renewable has increased to about 6% in overall electricity generation mix. As per the projections of 12th plan, renewable capacity & energy penetration shall increase to 21% & 13% respectively. Further share of renewable capacity will rise to 50% by 2022. The trend of increasing renewable penetration from present to 2022 is shown in 0.

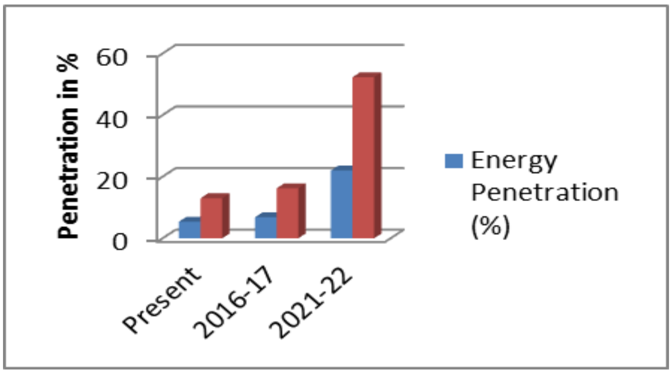

Fig. 2. Renewable Capacity penetration in India (Present & envisaged).

III. Envisaged RE Capacity Addition in 12th &13thPlan (2012-22)

In the 12th plan period, about 33GW renewable capacity addition is envisaged in eight(8) RE resource rich states viz. Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Maharashtra, Rajasthan, Himachal Pradesh and Jammu & Kashmir. Out of 33GW, about 65% capacity (20.5 GW) is envisaged to be contributed from Wind, about 30% from (10 GW) from Solar, and balance 2.5GW is to be contributed from small hydro. Above renewable capacity assessment has been carried out by the respective State Nodal Agency (SNA)/State Transmission Utility (STU).

Government of India has an ambitious plan to establish 1,00,000 MW Solar and 65,000 MW Wind generation in next five years. Solar capacity targets of 1,00,000 MW by 2021-22 includes setting up of 25 solar parks in various States, each with a capacity of 500 to 1000 MW (as ultra-mega solar power projects) thereby targeting around 20,000 MW solar generation installed capacity. These solar parks will be put in place in a span of 5 years (2014-15 to 2018-19). Balance Solar capacity comprises 40,000 MW Roof top Solar PV and 40,000 MW through distributed solar generation.

POWERGRID has carried out studies to identify transmission and other control infrastructure requirement for grid integration of RE capacity addition envisaged in 12th plan period (2017) as a part of "Green energy corridor". The work also evolves mitigating measures to address various challenges faced on account of grid integration of large scale renewable generation. In addition, to facilitate integration of ultra mega solar parks, Green Energy Corridor-II has been evolved.

IV. Operational Characteristics of Renewable

In power system, impact of renewable capacity not only depends on its penetration level but also on the power system size (inertia), mix of generation capacities, robustness of interconnections, load variation etc. Amongst various RE resources, wind being the major contributor as well as its virtue of variability and intermittency, plays a dominant role in defining the renewable penetration level. Annual profile of wind based electricity generation in RE potential rich regions and a typical day variation of wind generation pattern in each month of a year for a single state is shown in 0 & 0 respectively.

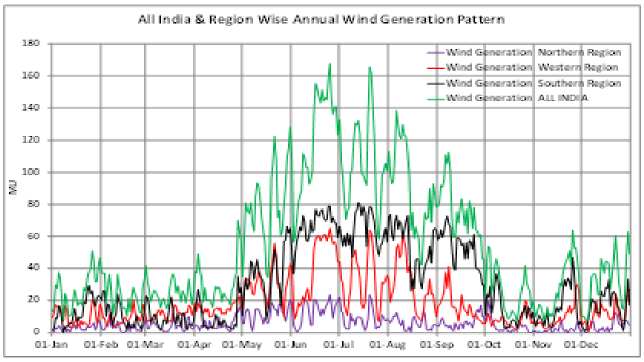

Fig. 3. Region wise annual wind generation pattern for RE Rich Regions.

Typical day wind generation pattern in each month of a year for one state shown in 0 below

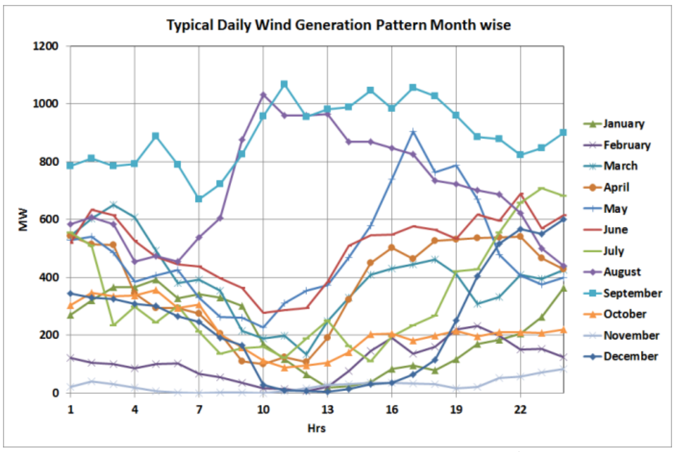

Fig. 4. Typical day wind generation pattern in each month of a year.

From above characteristics as well as other state's wind generation pattern, it is observed that wind generation is mostly available during other than the peak demand hours and

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doesn't support the peak demand. Similarly a typical day variation of solar generation is also shown in 0 as under.

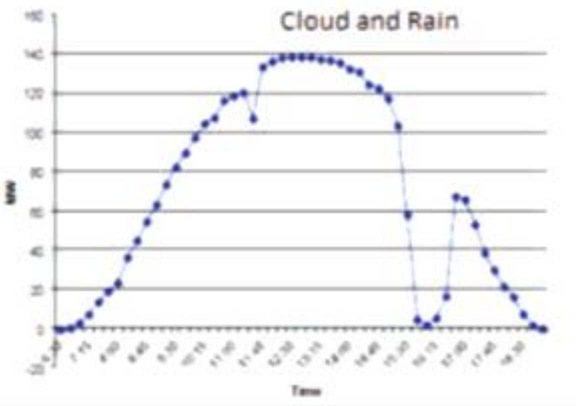

Fig. 5. Typical day variation of solar generation.

Presently, the variability and intermittency of wind energy generation is being addressed by the varying output of hydro plants whereas thermal plants are being operated as meeting the base load.

Considering increasing renewable penetration and limited hydro/gas generation in the country, various system operation challenges are envisaged to be faced which requires deployment of various measures in order to integrate variable energy resources.

V. Challenges in Planning & Operation of Large Scale Renewables

Large scale renewable integration leads to new requirements in the Power System to meet system security and stability. As part of the comprehensive analysis, challenges on this account were first identified in Grid Planning as well as Operation domains, which are described as under.

- Variability & intermittency may cause severe stresses on the system
- Low gestation period of renewable generation as compare to development of transmission strengthening, constraints may arise on account of large difference of gestations periods without integrated planning approach
- Wind/Solar plants are generally located in remote/concentrated locations. The probability of such area not being a load center is quite high. In addition, resource concentration to few pockets may cause supply management issues in case of sudden drop in such generation
- Wind/Solar plants are known to be providing lesser grid support in terms of ancillary services during system disturbances/exigencies than the conventional generation.
- At present most of the wind plants are not capable to operate during severe voltage sags (Ride through capabilities) caused by system faults. In case this happens and large amount of wind generation trips in certain pocket, the system will be adversely affected magnifying the effect of fault.
- Some of the Wind turbines consume reactive power from the systems, which can adversely impact the system during disturbances/high loadings unless suitable mitigating measures are taken.

VI. Mitigating Measures to Address Challenges of Renewable Integration

In order to accommodate large scale renewable generation into the grid and address above associated challenges, following measures were identified:

- Strong Grid interconnections to enlarge power balancing areas
- Forecasting of Renewable generation on different time scale
- Flexible generation, Ancillary Services etc. for supply-balancing
- Pocket wise RE generation development should be prioritized in such a manner so that transmission infrastructure available in the pocket can be utilized optimally.
- Establishment of Renewable Energy Management Centers (REMC) equipped with advanced forecasting tools
- Smart Grid Application: Demand Side management, Demand Response and Storage for load balancing
- Deployment of Synchrophasor technology i.e. PMUs/WAMS on pooling stations and interconnection with centralized control centre through Fiber Optic Communication for real time information, monitoring and control

VII. Interconnection of Renewable

Small size Renewable energy generating stations, located scatteredly, are generally connected with grid at 33/66kV level. The EHV transmission system beyond first connection point is either at 132/220/400kV depending on the quantum of power being pooled at EHV Substations. Some of the generating stations with large capacities are also connected directly at higher voltage level i.e. 132/220kV level. Typical Schematic of RE station connectivity at various voltage levels is shown at 0.

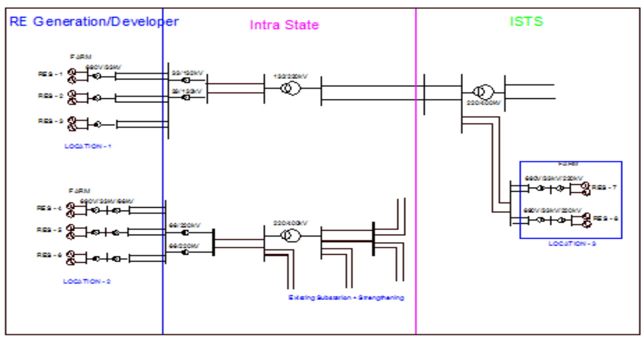

Fig. 6. Typical connection arrangement of RE generation farm with grid.

Therefore to integrate large scale renewable generation at the grid level, there is requirement for Intra State

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strengthening which is from Point of common coupling (PCC) to grid network for absorption of power within same area or host state including Connectivity Transmission system from RE Generation switchyard (beyond first step up voltage level) to Point of common coupling (PCC) in STU network.

In addition, there is a need of Interstate transmission system (ISTS) for transfer of power from RE rich state to other states.

VIII. Renewable Energy Management Centre (REMC)

Renewable energy management center, for the specially supervised large scale renewable grid integration, equipped with advanced forecasting tools, smart dispatching solutions & real time monitoring of RE generation, can closely coordinate with the existing SCADA system for efficient and reliable operations of the overall grid. Typical architecture of REMC is shown in 0. Some of the functions are described as under.

- Real time Acquisition and monitoring of Renewable energy Generation data from pooling Stations
- Exchange RE generation data with partner load dispatch center.
- Forecasting-day ahead, now casting, ramp etc.
- Enable RE developers to provide proposed generation schedules as per their own forecast
- Data repository for analysis, trends, reports and analytics in area of responsibility.

IX. Green Energy corridor

As part of Green Energy Corridor study & analysis, following infrastructure and other associated requirements were identified to facilitate integration of large scale renewable envisaged in 12th & 13th plan period:

i. Transmission system strengthening to foster grid interconnection
   - Intra state strengthening (STU)- from Point of common coupling (PCC) to grid network for evacuation & absorption of power within same area or host state
   - Inter state transmission system (ISTS) - For transfer of power from RE rich state to other states

ii. Provision of Dynamic Reactive Compensation (STATCOM/SVC etc.) at strategic locations to provide dynamic voltage support as well as address voltage ride through issues

iii. Installation of synchrophasor technology i.e. PMU/PDC and fibre optic communication links between PCC and control centres to facilitate Real time monitoring/measurement

iv. Energy Storage technology to provide supply side balancing

v. Renewable Energy Management Centres (REMCs) at State and Regional level to be co-located with respective Load dispatch centers (LDC). REMC to coordinate with SLDC/RLDC for discharging various functionalities related to management of renewable energy generation including forecasting of RE generation as well as real time monitoring of RE generation.

vi. Development of Smart Grid with Demand Side Management (DSM) functionality to introduce flexibility in consumption/demand.

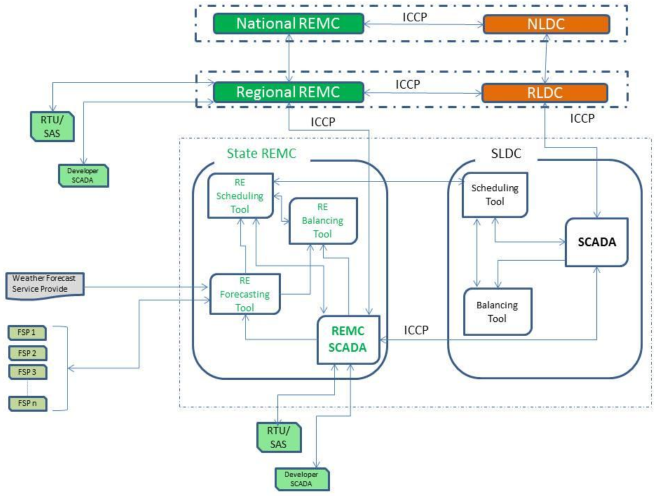

Fig. 7. Proposed architecture of REMC and communication links with the existing load dispatch centres.

Several initiatives have been taken by MOP/MNRE/CEA to expedite the implementation of Green Energy Corridors for integration of large scale renewable in 12th plan. In view of the low capacity utilization factor of renewable as well as relatively lesser utilization of last stretch of Intra state system which interconnects renewable generation, it was needed to rationalize transmission charges. An Innovative funding mechanism was devised with 40% grant from NCEF, 40% soft loan and 20% state equity for development of intra state transmission system, similarly 70% soft loan and 30% equity for development of interstate transmission system. Scheme is being taken up for expeditious implementation by respective states as well as POWERGRID.

In order to facilitate integration of various ultra-mega solar parks, capacity of 20,000 MW is envisaged in different states and Green Energy Corridor-II has been evolved. Implementation of Green Energy Corridor-II for some of the solar parks has already been started.

X. Study on Balancing

All India Generation patterns of 2014 are considered as base case to this study. The fuel mix is maintained the same while extrapolating to future generation of 2017 and 2022. If the renewable capacity addition increases certain limits the generation balancing is difficult as it breaches lower limit or upper limit of generation. The lower (or upper) limit of generation is decided by the minimum (or maximum) limit of all the generators in India including the consideration of availability of generators. If the renewable penetration is increased with double, triple of current mix, then balancing generation is not possible without extra ancillary services.

'Net load' is defined as the resultant of total generation required minus actual renewable generation. This 'Net load' is to be met by conventional generation. Among conventional

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generators hydro, gas and some coal plants are flexible to change the generation within their individual limits. As the renewable capacity addition is doubled or tripled by 2017, it is breaching the lower limit of the generation as shown in 0. As the renewable capacity addition is doubled or tripled by 2022, it is again breaching the lower limit of the generation as shown in 0.

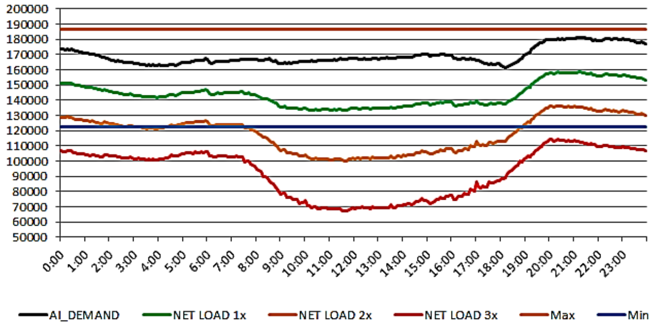

Fig. 8. Projected net load variation in single day in Summer 2017.

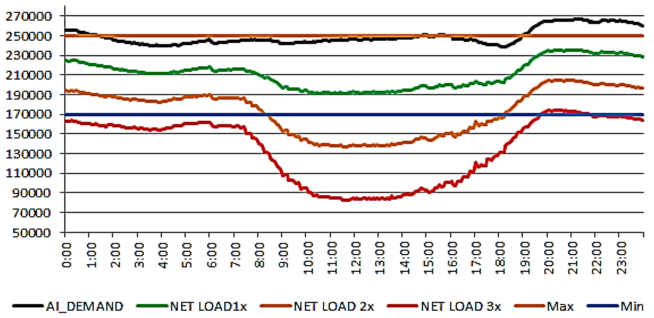

Fig. 9. Projected net load variation in single day in summer 2022.

XI. Desert Power India—2050

India has large deserts (both Hot & Cold) viz. the Thar (Rajasthan), Rann of Kutch (Gujarat), Ladakh (Jammu & Kashmir) and Lahul & Sipti valley (Himachal Pradesh) having total geographic area (TGA) of over 330,000 Sq km out of which total wasteland area is over 148,000 Sq km[10].

An assessment has been carried out for renewable generation potential in India's above four desert regions. It is estimated that with just 5-15% desert wasteland utilization, about 315 GW potential (primarily Solar) can be developed, which can contribute significantly towards energy security.

However, considering challenges arising out of integration of renewable, broad contours of transmission plan has been prepared with following approach:

1. Development of Hybrid EHV AC/ HVDC (VSC based) Transmission system for flexibility and regulation of power flow.
2. Interconnection of desert regions as well as with major load centres as touch points
3. Transmission corridors passing through conventional generation complexes like from hydro rich areas with NER/Bhutan to achieve supply balancing
4. Assessment of balancing/flexible capacity requirement using storage technologies i.e Concentrate solar plants with storage, large scale battery, pumped storage plants (PSP) etc. towards facilitating balancing in the high renewable penetration scenario as well as to take care of deficit scenario of peak hours.

XII. Conclusion

To address issues on integration of large scale renewables which are intermittent and variable, balancing requirement are the primary needs. For this, strong grid interconnections, forecasting of renewable generation, flexible generation & load, ancillary services, dynamic compensation, energy storage, smart grid applications are the solution. Renewable Energy Management Centers along with reliable communication infrastructure at all the load dispatch centers of RE resource rich states having the required tools such as scheduling, monitoring, forecasting, balancing etc. will help to achieve the grid stability. Development of Green Energy Corridors shall enable integration of large scale renewable energy sources. In addition roadmap along with control infrastructure for developing solar/wind capacity in desert area shall also facilitate increased penetration of RES.

India has large deserts (both Hot & Cold). Utilization of desert wasteland by 5-15%, can yield about 315 GW potential (primarily Solar), which can contribute significantly towards energy security. A Perspective Transmission plan which includes high capacity hybrid UHV/EHV AC & HVDC transmission system to be implemented in phased development has also been chalked out (2050).

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