Indian Wind Power

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Grid Management Special

IWTMA
INDIAN WIND TURBINE MANUFACTURERS ASSOCIATION

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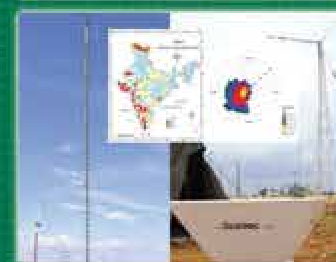

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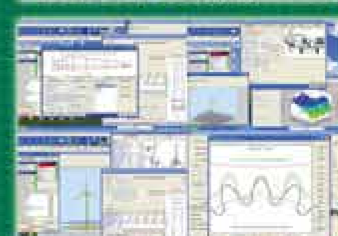

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IWTMA
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(For Internal Circulation only)

From the Desk of the Chairman - IWTMA

Dear Readers,

Greetings from IWTMA!

The Indian Power Sector is at the threshold of a transformation with a growing impetus on renewable energy, smart grids, round the clock power and power connectivity to the last mile.

The modernisation of India's infrastructure is bound to gather up speed and new policies like e-mobility that are being introduced will unleash the further growth, which directly shall set the tone for capacity addition for power generation, transmission and distribution. This clearly suggests that the country is providing ample opportunity in the value chain and market participation. The evolving dynamics of demand-supply and policy enforcement may see the power scenario tending towards consolidation.

In the recently concluded RE-Invest, the focus was on wind power procurement through bids in all the states which is now restricted to Gujarat and Tamil Nadu. There was also a consensus that the transition from FiT to Competitive Bidding was not carried in a seamless manner. An upper cap in Competitive Bidding (Reverse Action) is neither required nor tenable.

While the target of 60GW is to be completed by March 2022, the bid size must be 2500 to 3000MW on a quarterly basis, which would act as a confidence measure to the lending community and investors; while OEMs gear up to manufacture turbines and sub-component procured from a very large component base.

The industry is dependent on the value chain primarily from the SME sector. IWTMA is also working with the Ministry of New and Renewable Energy to promote a special dispensation for projects below 25 MW considering small investors are unable to take part in state/SECI bids.

Indian wind turbines are globally competitive by both—cost and technology. The Association has made representation to the Government to increase the export incentive from 2 to 10% and thereby ease the disadvantage of freight logistics and give the much-needed exposure to the line of credit.

Land and connectivity are critical to bidding irrespective of the tariff. IWTMA is working with MNRE and concerned wind states for the successful implementation and commissioning of wind projects under SECI and other state bids.

The power transmission sector in India acts a pivotal role in supplying electricity to the end consumers. The growth of the power sector is dependent on the development of a strong transmission infrastructure. India is witnessing a robust growth in renewable energy capacity addition and a shift to power generation mix with renewable energy reaching 20% of the total installed capacity.

The industry assures commercial grid discipline and grid security. Grid loading shall be optimized with higher penetration of wind power for round the clock power at an affordable tariff.

Let us fight climate change with more green energy in the grid.

Tulsi Tanti
Chairman

Strategic Grid Operation with Renewable Energy: An Effective Smart Control Approach

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Abstract

Indian Energy Sector is in evolving era which is continuously expanding with upcoming renewable energy mix in existing power network. The existing working professionals of power utilities/industries need regular upgradation regarding developing technology for better asset management and improved operational efficiency. Therefore, it is required to have better understanding on operational flexibility, which in turn ensures overall improved performance of entire system. The infrastructure expansion with upcoming renewable energy penetration at larger scale of 175 GW plus will have inclusion of new technology such as Intelligent Monitoring Devices (IMD) and Smart Controls (SC) in layered mode with decentralized architecture. It may be starting from distribution system, transmission system and generating systems. It is expected with smart controls the entire classical distribution, transmission and generation systems will be smart systems responding in real time with fast communication and controlled precisely to have reliable operational scenario. The operational coordination is aimed for better efficiency and 24x7 power delivery as envisioned by Government of India. Existing power sector personnel has to understand upcoming fully transformed power sector which is combination of thermal, hydro, renewables and various interface devices using Information and Communication Technologies (ICT).

In order to provide an efficient power network operation, the technology integration will also have renewable energy mix which includes solar, solar thermal, wind, hydro, bio-mass and bio-fuel. In the existing infrastructure, system planning with upcoming RE must be included depending upon the capacity of substations and associated infrastructure in order to ensure the effective operational criterion for power flow as India is having One Grid and One Frequency system. Also, the design issues of renewable energy need to be addressed modularly so as to have better power evacuation in existing grid structure without any instability/outage. The design of Hybrid Renewable Energy System has to be taken up in modular framework for a specific real-life system which can be replicated based upon the existing infrastructure. It is also aimed to have Internet of Thing (IoT) based control to have real time monitoring and maximum utilization of the Renewable Energy Mix in the power network existing with advance intelligent control technologies. The work involves development of Smart Control Architecture (SCA) employing Information and Communication Technology (ICT) which ensures the real time information flow for maximum utilization of renewable energy infrastructure in existing conventional power system by effective load balancing and load management. It is also proposed to develop technology of Smart Distribution System including Micro Grid in decentralized mode of control in power network including self-healing modes which ensures no interruption, i.e., 24x7 power supply to consumers and ensuring all existing Thermal Power Plants (TPPs) to operate without thermal backing as solar energy is maximum in day time. A Hybrid Architecture of Wind Energy integration with Solar Power Park/ Roof Top Solar need to be developed which employs IoT and ICT in layered structure mode.

An innovative technology solution proposed in layered hierarchical IoT smart control mode will directly benefit the system planners and power utilities at both state and central sector by regulated power flow with focus on energy market.

Introduction

The power system operation has been a major concern for all system operators. It is well known that distribution system has been an integral part of National Grid and any casual operation may deteriorate overall performance not only at point of connectivity but also back of various components in grid as well. Since all distribution systems are, in general, operating in classical way even as on date with set protection mechanism of breaker operation, the upcoming large Renewable Energy (RE) penetration at respective distribution system/sub-transmission network may affect the overall operational scenario. This may be understood with fundamentals of power engineering in which the distribution transformers are feeding load centres in general, whereas with upcoming RE at load centres/sub-transmission network, the power flow dynamics might change depending upon the RE share of power injection intermittently during day hours. However, the further percentage addition of RE at respective distribution system may affect the power sharing ratio with classical Grid and local RE source, which might be reflected at secondary of transformer in varying mode that too intermittently. Therefore, an operational strategy/system planning of existing distribution system must be reviewed in changing/varying RE injection pattern.

The concept of distribution system (DS) planning and design may change with RE penetration crossing 60% and above as the load centric DS may now become generation centric, and local loads operation may be affected, if an intelligent control architecture is not designed and developed within time. The integration of the proposed new architecture in existing DS has to be customised and accordingly power management and load management will become an integral part of Grid and distribution management respectively. Since as on date both Roof Top Solar (RTS) and Land Based Solar (LBS) are being installed in all parts of the world, a robust approach might be required, especially for Grid connected mode system architecture.

In case of off Grid RE integration, a rigorous system study and associated planning has to be done for ensuring the capacity of energy storage devices being integrated to meet intermittency and variability. It is well known that any off Grid RE system may be having both solar and wind systems, and even the bio energy can be integrated depending on the site involved. Under such a situation, off Grid control architecture need to be very location specific that may include local load dynamics and variability. It is to record that an off Grid system may be in due course grid connected to have better power exchange features including market dynamics. Thus, point of connectivity (PoC) flexibility has to be kept at design stage itself to have better flexibility in system integration. The PoC interface devices may be selected based on the size of off Grid capacity. This may include VSC HVDC technology which can be from 400 MW to 2000 MW.

Looking into upcoming micro hydel systems around the world and also good capacity hydro power projects, it may be a scenario that hydro power may also be a part of off Grid structure and then the entire operational strategy has to change depending on the mix of RE (solar, wind and hydro). Under such situations, the entire planning and control strategy may change depending of respective percentage of share at site specific.

Also, the tail end load dynamics might affect Solar Power Inverter tripping circuit and same may be viewed as reduced Performance Ratio (PR), which in turn, leads to revenue loss to the owner organizations. Sometimes, the tripping may be frequent and unnoticed without intelligent automation. Therefore, the planning, design and development of RE specially with Roof Top Solar (RTS) and Land Based Solar (LBS), wind, hydro and bio energy with energy storage has to be carefully undertaken by technical experts who have complete in-depth insight of each sub-system operational situations.

During the recent Roof Top Solar (RTS) and Land Based Solar (LBS) system operation, it has been noticed that mere installation of RE with classical mindset may result into existing system operational performance deterioration/adverse interaction and may be detrimental if technically not analysed and supported with intelligent controllers. The paper covers from the fundamentals of power flow in distribution systems to Grid management with upcoming large RE perpetration with both classical and intelligent architecture & will address professionally the various unnoticed points in global framework. The technology solution in a generalized framework is presented which may be a guide line to all power system stake holders viz. Generation, Transmission and Distribution systems. Some novel concept is given with focussed and modular strategic plan.

The paper has been arranged in following sections: Large Interconnected Power System Network Operational Complexity-Hybrid Power Generation Era, Ancillary Services- As Controller in Renewable Era, Smart Grid Layered Architecture in IoT framework.

Large Interconnected Power System Network Operational Complexity-Hybrid Power Generation Era

The operational complexity of national Grid is dependent on the power injection pattern and load connectivity in general. The evolving power network with massive hybrid energy penetration (Fig.1) need to be equipped with components which can mitigate the intermittency related power swing. Also, the connection of local load may be varying due to requirements in undefined way, which may further need regulation with smart controls appropriately in layered mode (Figs 1-3). The smart control design and location has to be properly studied and the optimal placement may be done for effective operational improvements. The existing distribution systems need full automation with smart meters and efficient communication highways for appropriate signalling and related control activation. In upcoming era of electric vehicles (EV) large penetration, charging stations are likely to be embedded in existing distribution may be 11KV and 33KV most predominantly. Since the system planning either for upcoming RE systems and EV penetration has not been taken in existing infrastructure of power system, the operational scenario need to be assessed in different distribution systems based on upcoming RE and EV charging station requirements. In case of inadequate study and analysis, adverse impact may be seen not only at respective distribution systems but also interface sub transmission as well which may in turn impact the Grid operation and existing generator specifically thermal power generators will be heavily stressed in operational domain and may lose operational range and thus life of the components of plants may be affected adding additional maintenance as such. This may be further viewed as improper plant management. In

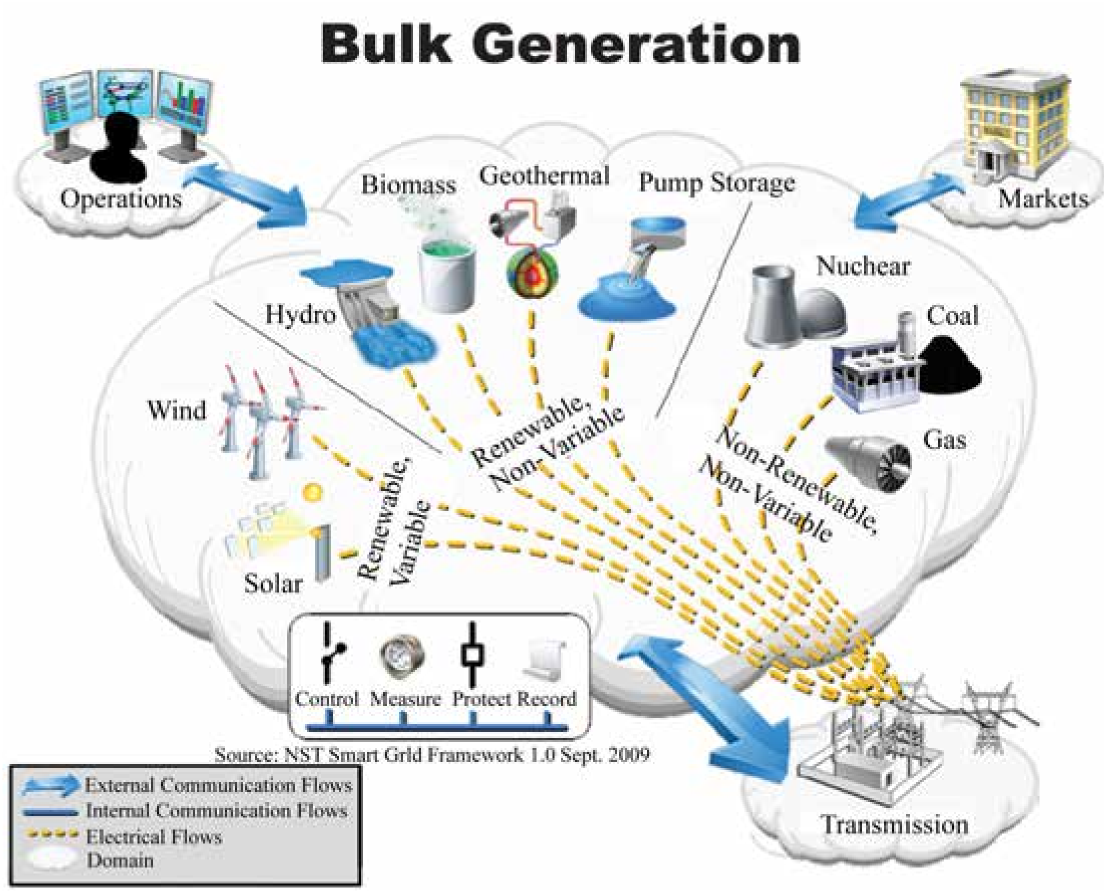


Figure 1: Hybrid power generation concept

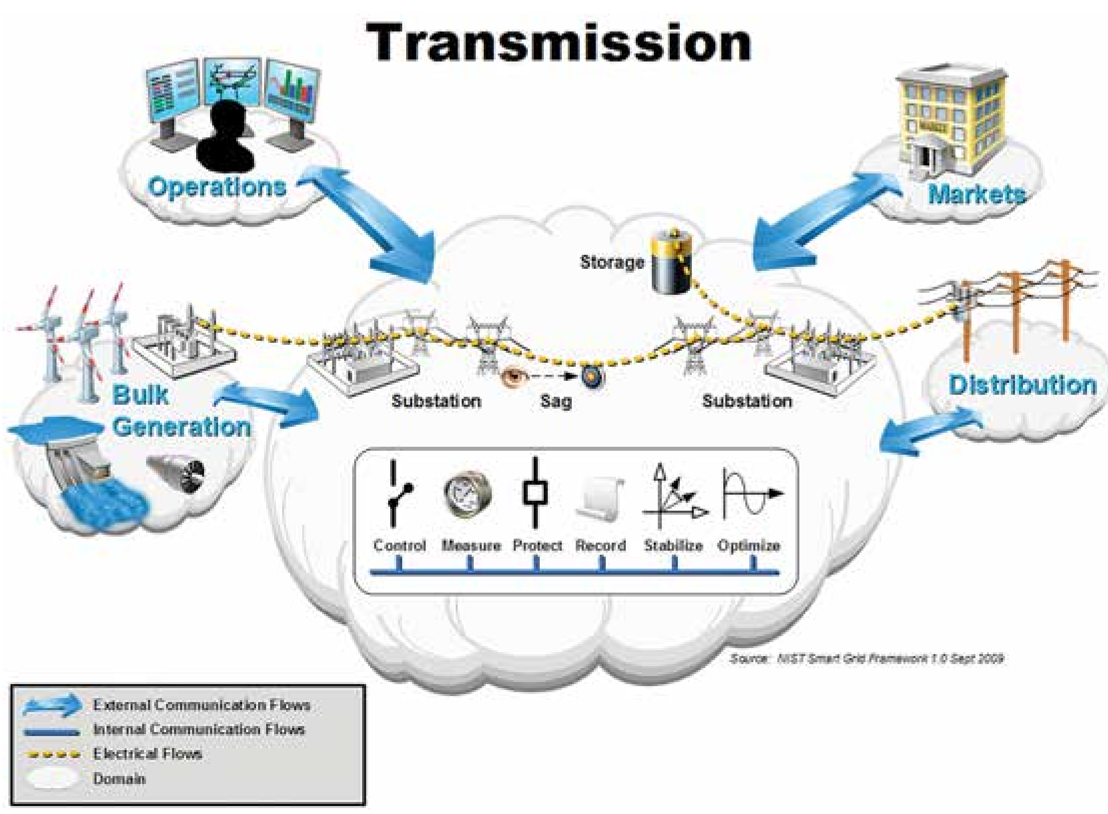


Figure 2: Evolving power system operation and market management

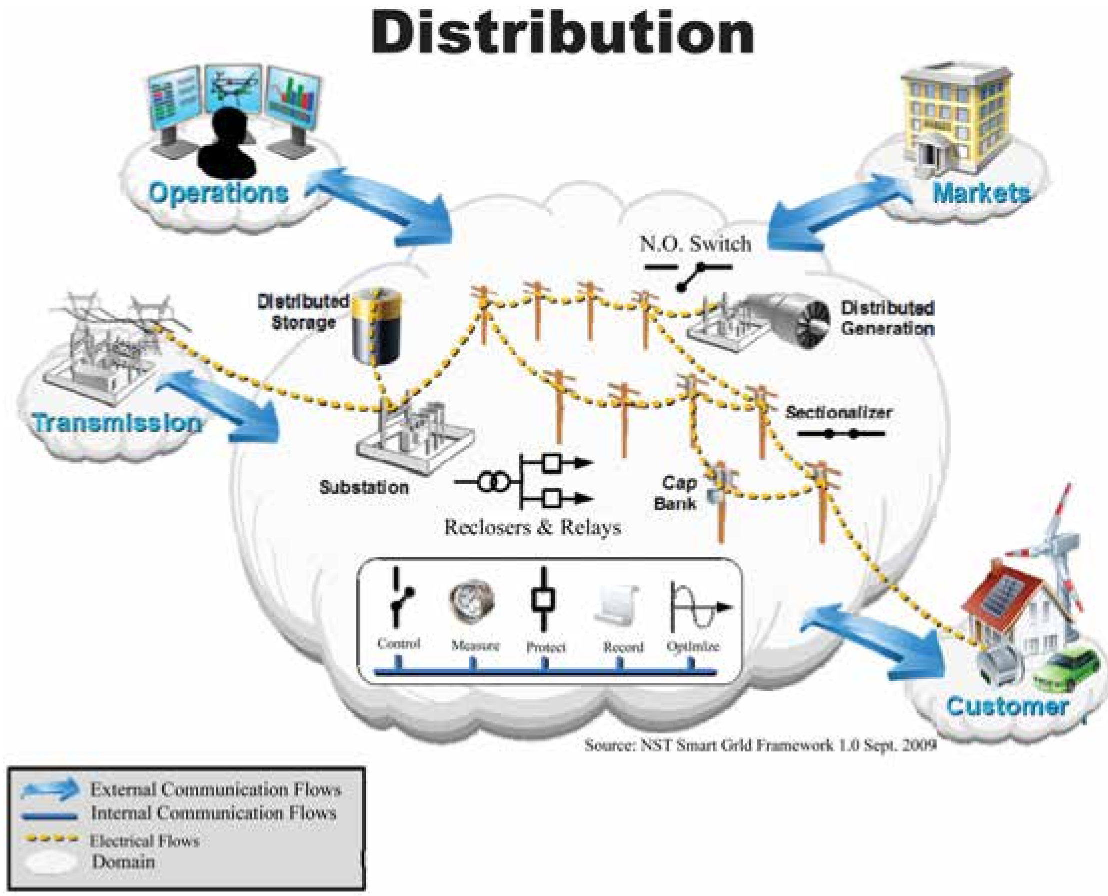


Figure 3: Distribution system interface in hybrid energy era

order to resolve such operational issues, it is necessary to start system planning in following hierarchical way:

1. Adequate System Studies need to be conducted starting from each Distribution, Sub-Transmission and Transmission Systems
2. Capacity of Existing Infrastructure needs Re-evaluation with % of Renewable Penetration and upcoming requirements of charging stations for EV.
3. Sectoral System Planning becomes an essential requirement for sustainable power network
4. Intelligent Power Controllers with Internet of Thing (IoT) becomes a Prerequisite for Coordinated Power Exchange
5. System Security with Intelligent Layered Architecture is only way to resolve upcoming challenges in overall system stability as per Grid code.

Decentralized Ancillary Services - As Controller in Renewable Era

In upcoming hybrid energy era of power system, the operational issues may be predominant in case of unnoticed variations in load and power injection pattern. In such situations, ancillary services in decentralized structure may be beneficial for local control and thus re-establishing more smooth controlled power flow depending on the variability either due to load pattern or intermittency of RE and upcoming EV charging points in distribution/sub transmission network. The hierarchical controller structure thus evolved may have energy storage in form of NaS battery for distribution system and pumped hydro for transmission system to facilitate the sub transmission power flow control in order to improve the distribution system optimal and uninterrupted operation.

In case of upcoming large renewable energy in local distribution system, the existing substation transformer need to be reassessed in terms of local power delivery and in case of excess power by RE the power flow controllers may be employed in sub transmission systems for redirecting power flow dynamically. In such situations, the system planning hierarchically has to be reviewed with % of RE penetration and EV charging points in respective systems. The smart systems need to be evolved for real time monitoring of all devices/ components such as roof top solar plants, EV charging points, energy storage battery status at distribution systems and also, the net capacity of pumped hydro and classical hydro in existing power network along with delivery time of response.

It can be noticed that adequate energy reserves need to be kept in an interconnected large power network along with the islanding mechanism incorporating special protection schemes, again in layered architecture failing which a chaotic scenario may be observed. The dynamical behaviour of all existing thermal power plants, hydro power stations, gas based power plants and nuclear power plants will depend upon the optimal location and fastest response time. Thus, the efficiency of these plants may play an important role in re-establishing power flow pattern both locally and globally.

In order to understand the power injection pattern, change on existing power network, a HVDC system which is backbone of huge power evacuation form power pooling stations has been simulated. It's known that Effective Short Circuit Ratio (ESCR) is governed by power injection pattern/load pattern at AC/DC interface bus. ESCR is ratio between the short circuit level reduced by the reactive power of the shunt capacitor banks and AC filters connected to the AC bus at 1.0 per-unit voltage and the rated DC power. This can be given as -

$$ESCR = (S - Q_c) / P_d,$$

S = short circuit level of the AC bus

P_d = converter DC power and

Q_c = reactive compensation of the DC converter

High short circuit ratio is preferred for acceptable operation. With low or very low short circuit ratio systems, difficulties may arise following load changes. Lower ESCR or SCR means more pronounced interaction between the HVDC substation and the AC network. With upcoming RE penetration which is intermittent leading to power injection pattern change, thus affecting the Grid voltage at AC switchyard and EV charging points which may be viewed as fast load variation, also there can be an excess or deficiency of reactive power at the AC commutating bus which may result in over and under voltages respectively. In case of high ESCR systems, changes in the active/reactive power from the HVDC substation lead to small or moderate AC voltage changes. Therefore, additional transient voltage control at busbar is not normally required. The reactive power balance between AC network and the HVDC substation can be achieved by switched reactive power elements/FACTS Controllers. In case of low and very low ESCR systems, the changes in the AC network or in the HVDC transmission power could lead to voltage oscillations and a need for special control strategies. This can be achieved with UPFC control if adequately embedded at AC/DC Interface.

System Studies

It is pertinent to mention that in upcoming RE and EV charging station era of power system, the strong AC system may become weak in case of sudden loss of RE due intermittency and also an unacceptable load may be viewed if at given point of time the sub transmission experiences relatively larger loading pattern due to upcoming EV charging infrastructure, which is again variable and undefined thus adding more complexity at interface AC/DC bus both existing and upcoming as high trunk power corridor. If re-allocatable FACTS controllers in hierarchical layered structure are not planed, designed and installed, the entire system may experience severe oscillations. The operational scenario may keep on changing with changing RE/EV charging station dynamics and penetration volume as well. This has been simulated in PSCAD as change in ESCR in a given HVDC sample system shown in Fig.4. Fig. 5 shows the impact of low ESCR on entire converter operation and AC switchyard power instability. It can be noticed from Fig. 6 that an effective control of power is ensured with Unified Power Flow Controller (UPFC) where all oscillations are damped.

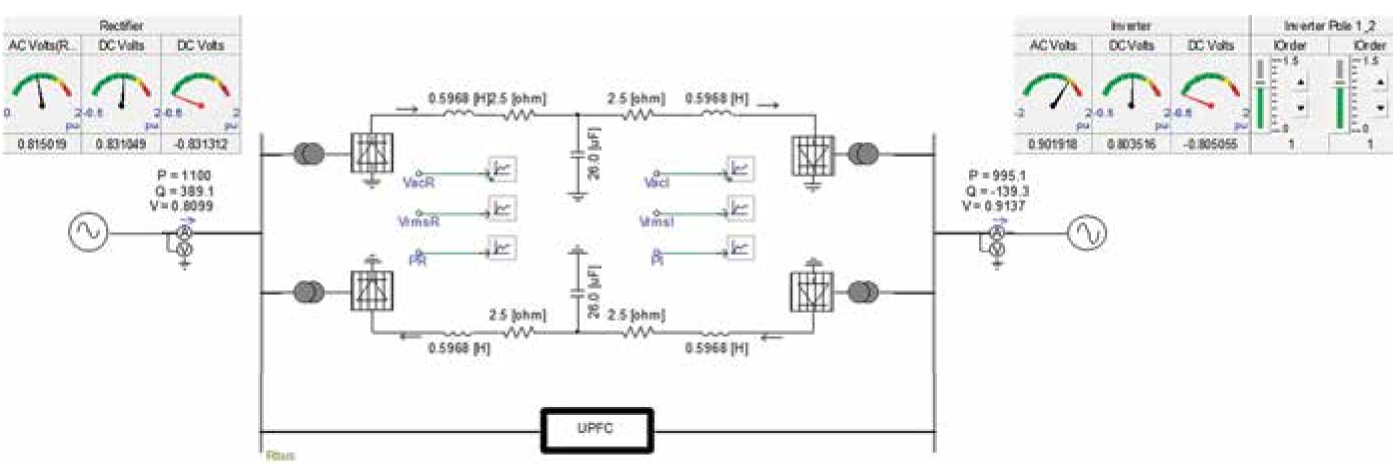
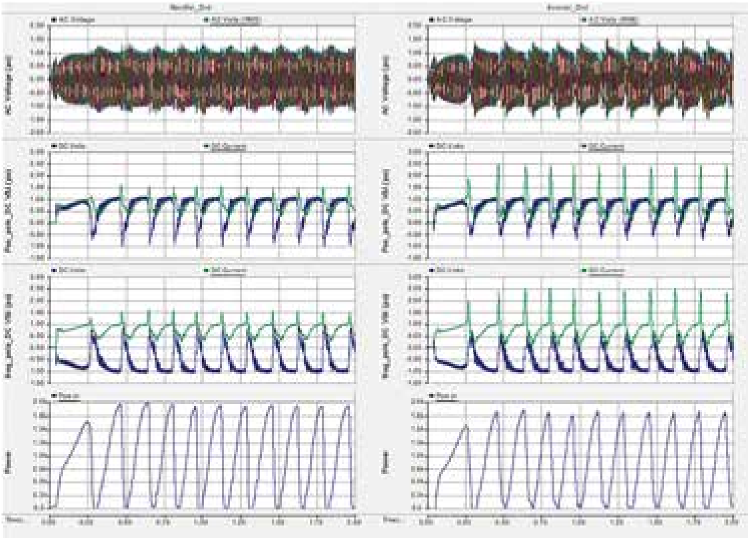
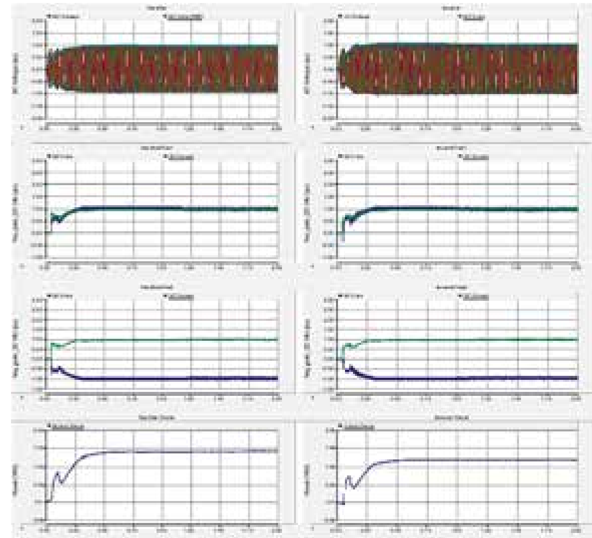


Figure 4: Two Terminal HVDC Sample System



Rectifier terminal ESCR = 1.7 and inverter terminal ESCR = 1.2 without UPFC

Figure 5: Response of HVDC Converters and Power at Rectifier Terminal



Rectifier terminal ESCR = 1.7 and inverter terminal ESCR = 1.2 with UPFC

Figure 6: Response of HVDC Converters and Power at Inverter Terminal

To understand the power oscillations impact, an actual system performance has been shown for national Grid early in 2014 (Figures 7 and 8) which necessitates the need of Smart controllers in power network without further delay.

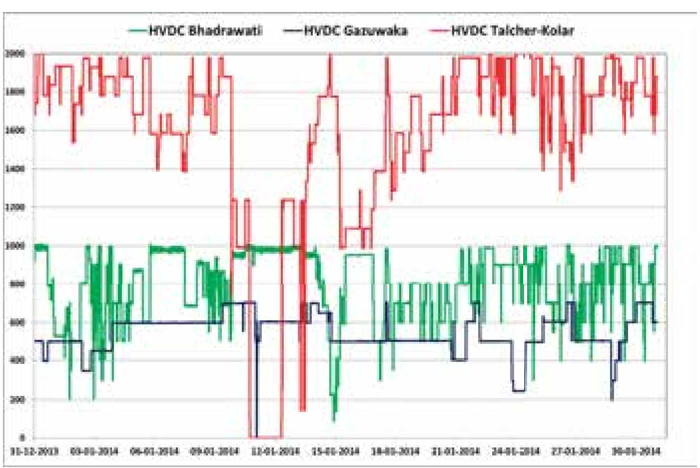


Figure 7: HVDC Performance (Courtesy POWERGRID)

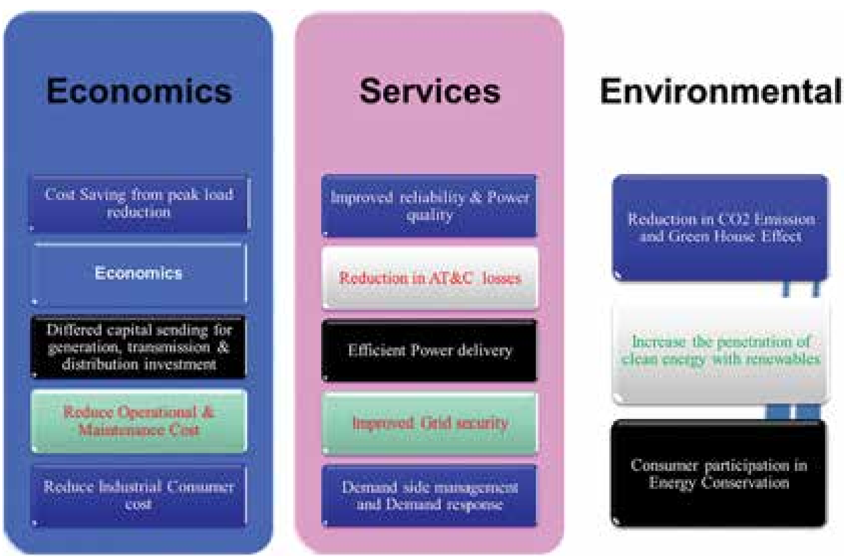
Figure 8: Power Oscillations due to Line Tripping and Associated Recovery with SPS (Courtesy POWERGRID)

Renewable Energy Management Centre: Functionalities

It is required to evolve an Expert/Intelligent system to supplement conventional SCADA which can visualize Grid at Sub-Second level. The Tools to comprehend situational awareness and to derive corrective actions while contingencies are propagating need to be developed. Automations including special protection schemes (SPS) may help the fast recovery in extreme violations. Phasor Measurement Units (PMUs) may be a sensory device to have real time signal processing and associated analysis can be done with data analytics parallelly to assess the variational aspects of Grid. PMU can send field data at sub-second having global Time synchronization.

This may help the planning and coordination of upcoming smart FACTS controllers based on the typical operational violations. The visualization of Phasor Measurement (PM) and Angular Difference Measurement (ADM) information is now possible at control centres with PMUs which may facilitate the controller activation depending upon the frequent variations of Grid parameters. India has also adopted the technology at Regional and national level as pilot and demo projects. It is essential in hybrid energy mix era that the compliance of Standards and Grid Code very effectively to have secure Grid operation. Therefore, strict enforcement of compliance to standards and relevant Regulations (Grid Code) has to be observed. The balancing, handling intermittency and variability of RE can be managed with energy storage options utilising both battery storage and pumped hydro at site specific requirements as determined by study groups. Also, flexible conventional generation has to be ensured with better plant maintenance and operation to cope up the further intermittency. Flexibility required in terms of generation flexing as per requirement, such as ramping up & down. It's also required to have two shifting of thermal machines, quick start & stop of machines. In general, hydro generation should also come in flexible mode with advance controls. It is mandatory to have adequate load forecasting by states/distribution utilities to maintain load generation balance at all times else may lead to operational chaos. In new hybrid energy era, the flexible distribution system is needed for demand response and suitable price signals to have better energy market. Optimal utilization of storage-based technologies, generation reserves, gas turbines and pumped storage hydro plants has to be ensured. In REMC, Smart Grid (SG) will facilitate to have efficient and reliable end-to-end intelligent two-way delivery system from source to sink as well as integration of renewable energy sources suitably. It encompasses integration of power, communication, intelligent devices, intelligent computing system for improved electrical infrastructure that serves consumers with reliability, quality at affordable price. Therefore, SG is an ideal framework for RES integration. Smart grid will be able to coordinate the needs and capabilities of distribution utilities, end users and electricity market stakeholders in such a way that local system will remain functional without any operational violation. It can also optimise asset utilization, resource optimization, control and operation along with reduction in losses and also improves performance. It also helps both utility and consumers to participate in the management of electricity sector including efficient utilization of assets – bringing efficiency and sustainability.

Smart Grid-Attributes



- Renewable Energy Management Centers (REMC)
  - At State, Regional and National level
    - Co-located with respective Load Despatch Centres
    - Coordination between the State / Regional / National Load Despatch Centre.
  - Integrated with real time measurement and information flow.
    - Visibility of the grid status in neighbouring balancing areas
    - Communication & IT infrastructure with adequate resilience and redundancy.
  - Interfacing with Indian Metrological Department (IMD) at local and global level.
  - REMC may have following functions:
    - Real time tracking of generation from RE sources
    - Geo-spatial visualization of RE generation
    - Advanced decision-making and control systems

Conclusion

It can be seen that in large interconnected Grid with massive penetration of RE and upcoming EV charging points, a special care has to be taken at the system planning itself. The existing infrastructure need to be properly assessed for integration of upcoming RE and EV charging points looking into operational constraints, and therefore Renewal Energy Management Centres (REMCs) may become an integral part of load dispatch centres of all states and RLDCs as well. The REMC design must be having advanced monitoring mechanism and smart IoT control activation logic to alleviate any intermittency observed due to either RE or EV charging points operational impact on Grid. It is proposed to have smart control in hierarchical framework with decentralized approach in entire power system to ensure reliable system operation and maximum efficiency as well.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Deeper Analysis of Low Voltage Ride through (LVRT) Regulation: Part - I

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I. Introduction

Renewable energy (RE) integration is being rapidly integrated into power systems, with wind and solar PV power being the front runners. The global cumulative installed capacity of wind power has risen to 539.5 GW by the end of the year 2017, with around 52 GW installed in 2017 only, as shown in Fig. 1. Many countries, including India have set ambitious targets of RE integration at regional/national level to reduce carbon emission from various fossil fuel based unclean energy sources. During the past decade, India has experienced a rapid increase in wind power installed capacity, with current (as of October 2018) installed capacity of around 35 GW, as shown in Fig. 2. With current RE installed capacity of little over 71.5 GW, India has set a promising goal of RE integration through recently revised target of 227 GW by the year 2022.

Besides all the advantages of RE, due to its variable nature coupled with progressive displacement of conventional power plants, integration of RE introduces various challenges in grid operation, ranging from short-term dynamic voltage and frequency stability issues, and protection issues to long-term generation-load balancing, and steady state voltage control. The extent of such issues for a particular system will also depend

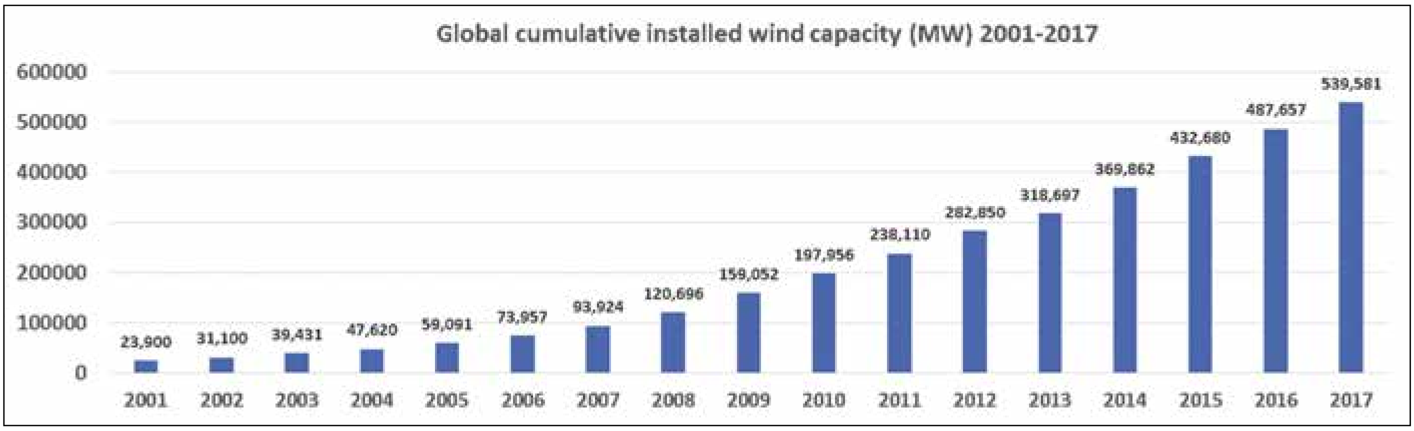

Figure 1: Global Cumulative Installed Capacity of Wind Power [Source: GWEC]

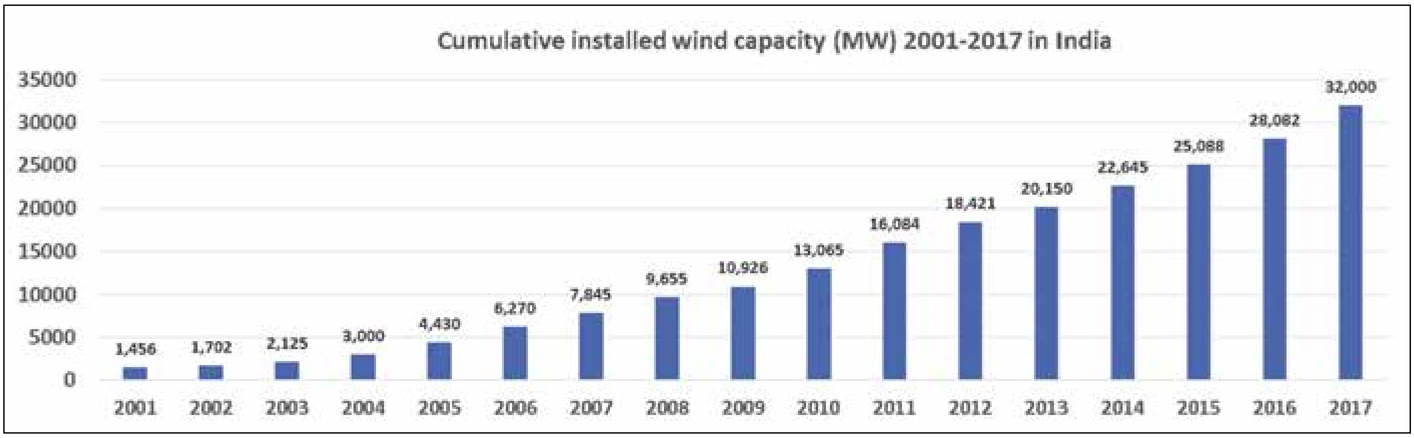

Figure 2: Cumulative Installed Capacity of Wind Power in India [Source: GWEC & IRENA]

on various other factors, such as RE penetration level, system size, characteristics of grid (weak or strong), unit commitment and economic dispatch framework, network configuration, electricity market etc. Therefore, to maintain secure and stable grid operation, system operator/regulators are endeavouring to tackle such issues through grid code regulations and/or by considering alternative sources of grid support services, by installing new infrastructure or procuring through electricity market. In fact, system operators expect RE generating unit to behave similar to conventional synchronous generator based units, as that will allow the use of well-known/established grid operating procedures to maintain secure system operation. Low voltage ride through (LVRT) capability is one of the critical requirement for RE generating units among various other requirements concerning grid code regulation.

The main focus of this article, which is first among a series of forthcoming articles, is on understanding LVRT capability of wind turbine generators (WTGs), emergence of LVRT from no LVRT to current stringent LVRT requirement for grid connection of WTGs, and to understand different LVRT requirement in different countries. The main purpose of this article series is to provide deeper technical analysis of grid code regulations for RE generators, concerns from system operators and RE industry/manufacturers/developers, in international and domestic context. It is worth to mention that vast majority of the discussion on grid code regulation for WTGs will be applicable to grid connected solar PV generators as well.

II. Emergence of Low Voltage Ride Through Capability Requirement

The history of extracting energy through wind mills is many centuries old, however, Johannes Jull together with the Danish electricity company SEAS built one of the very first modern wind turbine of 10 kW capacity in 1950s. The renewed interest in wind power, however, started only after 1970s oil crisis, which forced many countries to explore wind/RE as an alternative to oil. It is also interesting to notice that the first multi-megawatt wind turbine of 2 MW capacity was built by a local community of teachers and students from Tvind school in Denmark, which even made noise in the USA in an article published in The New York Times on July 29, 1978 [1]. In fact, this particular 2 MW WTG provided a way forward to major wind industries of the time, and hence a new industry (wind industry) was born. The first modern wind turbine technology which was built using Fixed Speed Induction Generator (FSIG), were among the first Danish wind turbines which dominated the wind turbine market till late 1990s. With favorable policy and financial incentives, many WTGs were being connected to the main grid, however, aggregate installed capacity of such WTGs was still low compared to total conventional generation. Considering the generation technology used and low wind power penetration level, WTGs were initially allowed to have a simple ON/OFF operation, thus allowing them to disconnect from the main grid during any reasonable voltage disturbance observed at point of common coupling (PCC). Under low penetration level, simple ON/OFF operation of FSIGs was not only beneficial to the WTG, but was also helpful for secure and stable grid operation, which can be attributed to the following two factors.

- Induction generators do not have an excitation system of their own, and such direct connected FSIGs draw reactive power from grid or local capacitor banks to establish their magnetic circuit. During low voltage dip, FSIGs draw very high reactive power from grid, which is quite detrimental for system stability during a voltage disturbance.
- Power systems were still dominated by conventional synchronous generators which have inbuilt capability of riding through a fault and to provide voltage support during transient voltages. Therefore, outage of FSIGs during low voltage was indirectly reducing otherwise significant reactive power load.

However, with the increase in wind penetration level, the system operators, particularly, in Denmark and Germany (where wind penetration was rapidly increasing), were concerned about simple ON/OFF operation of WTGs. At higher wind penetration level, a severe voltage dip due to a fault at high voltage level may lead to outage of significant wind power generation if WTGs are simply allowed to trip during a voltage disturbance, which in turn may result in large frequency upset and in the worst case may lead to cascading effect eventually resulting in system black out. Various local voltage events leading to tripping of multiple WTGs were experienced in many countries, with more recent example of China [2]. This concern encouraged impact studies of high wind penetration on system stability during dynamic voltage events. Therefore, to safeguard the system against such issues, system operators/regulators started issuing grid connection guidelines which later came into existence as grid code regulations for WTGs. Denmark and Germany were among the very first countries to formulate grid code regulations for WTG connection in 1990s, and since then almost all the countries with RE penetration have issued their grid code regulations, which have been regularly updated to incorporate more stringent requirements for grid connection of WTGs. LVRT has been one of the critical requirement concerning grid code regulations, and to a significant extent, Denmark and Germany have influenced LVRT requirement across the world. Stricter LVRT requirement, besides other factors such as variable speed operation with maximum power extraction from wind, has been one of the important driving factors in WTG technology development. LVRT capability is shown in Fig. 3, generally represents the worst possible voltage recovery profile in the network, following a severe fault. LVRT regulation requires WTGs or wind power plants (WPPs) to successfully ride through a voltage dip by not only staying connected to the grid during the voltage transient, but also support the grid by supplying reactive and active power in a desired manner. LVRT curves required in various countries are shown in Fig. 4, with some countries even demanding zero voltage ride through. It can be observed from Fig. 4, the shape of LVRT curve is different in different countries, as the shape of the LVRT curve and corresponding current injection requirement from WTG/WPP is dictated by various factors as stated below.

- Grid strength (weak/strong)
- RE penetration level
- Size of the power system
- Dynamics of the system load (extent of induction load)
- Available dynamic reactive power capability in the system
- Extent of HVDC links and HVDC technology in the grid
- Generation mix

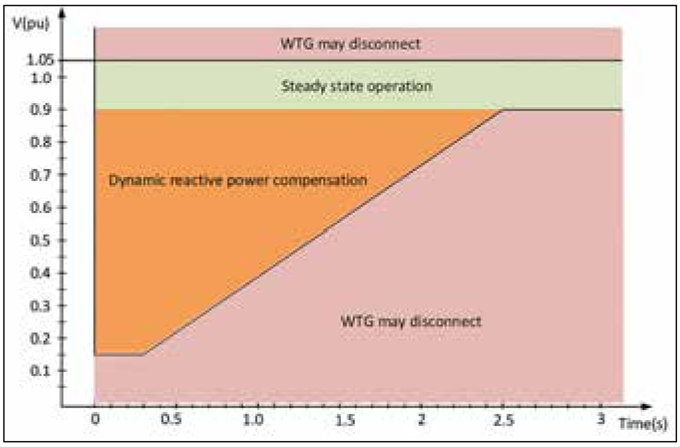

Figure 3: A Representative LVRT Curve

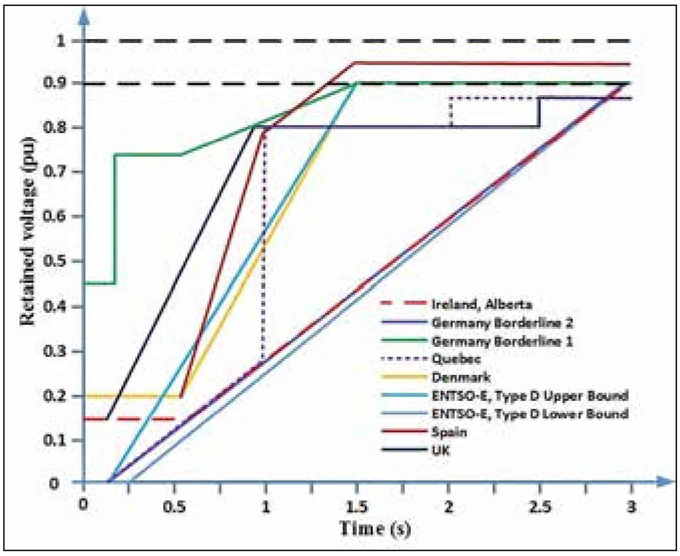

Figure 4: LVRT Curves in Different Countries

With increased level of wind power penetration, like many other countries, LVRT requirement in the Danish grid code has become more stringent, not only in terms of withstanding severity of the voltage, but also in terms of duration for which the WTG/WPP should stay connected to the grid, as can be observed from Fig. 5 [3,4]. It is noteworthy that the Danish power systems has significant penetration of induction generator based type-1 and type-2 WTGs. Despite having maximum wind penetration level (%) in the world, with instantaneous penetration level of even higher than 100% at times, LVRT requirement in the Danish grid code is still less strict compared to various other countries including Germany. Over past more than a decade, the Danish national transmission system operator (TSO), Energinet.dk, has also aggressively focused on enhancing network infrastructure to accommodate ultra-high wind power penetration level, with noticeable measure of installing several synchronous condensers, both new and old refurbished from conventional power plants. Synchronous condensers not only improve dynamic reactive power/short circuit power reserve in the system, but also provide synchronous inertia which improves frequency stability under high penetration of RE. Synchronous condensers, as a thumb rule, provide 1/3rd of inertia of a synchronous generator of the same capacity. Energinet.dk has recently been able to run the Danish power system without any conventional central

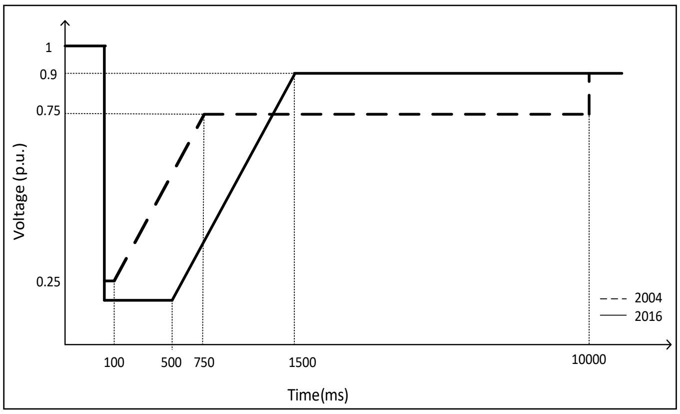

Figure 5: LVRT Curves in Danish Grid Code Regulation

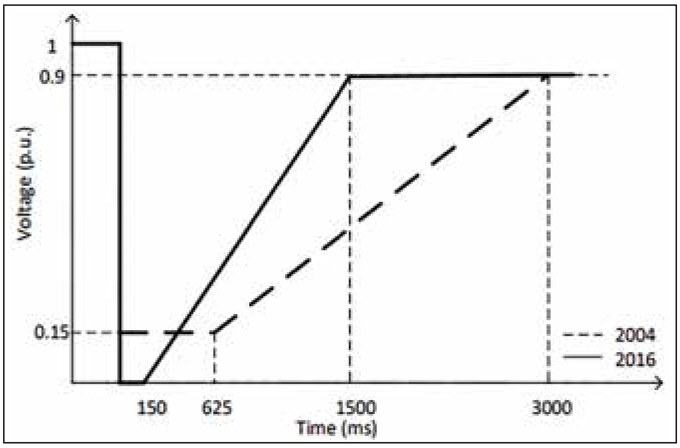

Figure 6: LVRT Curves in German Grid Code Regulation

power plant in operation, thanks to synchronous condensers and other countermeasures that Energinet.dk has undertaken during past few years.

Germany, unlike Denmark, has four TSOs operating different network jurisdictions that are governed by different grid code regulations. Development of LVRT over past decade from TenneT (a major German TSO) can be seen in Fig. 6. The LVRT requirement has become more stringent as ZVRT is required for WTGs under new LVRT requirement, which again can be attributed to rising RE penetration level. However, it can be observed that while ZVRT has been introduced, duration of ZVR has been reduced to 150 ms, and the overall LVRT period has been reduced from 3 to 1.5 seconds. While the reduction in ZVR time may be due to other system/equipment protection time limits, delayed voltage recovery in 2004 LVRT requirement may be attributed to significant share of old direct drive induction generators which have relatively reduced in the present scenario.

III. Types of LVRT Requirement

While LVRT curve dictates under what voltage conditions (observed at PCC), the WTG should stay connected or otherwise, the corresponding requirement for current injection from the WTG during LVRT period can be classified in two categories, i) Reactive current (active power) priority, where the WTG is required to prioritise reactive current over active current injection during the LVRT period, and ii) Active current (active power) priority, where the WTG should prefer active current over reactive current injection. Considering the fact that WTGs, particularly, the interfacing power electronic converters can only control the current injection, as power injection is dictated by the retained terminal voltage, current injection requirement is generally specified in grid code regulations. Therefore, accordingly, LVRT requirement can be broadly classified in two categories, reactive and active power priority LVRT requirement.

1. Reactive Power Priority LVRT Regulation

Under this LVRT category, WTG/WPP is required to prioritise reactive power injection during an LVRT event, while the magnitude of the reactive current depends on retained voltage. During a fault induced voltage dip, enhanced reactive current injection is required for fast voltage recovery, to maintain stable operation. Grid code regulations in most of the countries, such as, Germany, Denmark, Spain, and New Zealand demand reactive power priority LVRT from WTGs to successfully recover voltage to a steady state value. For example, as shown in Fig. 7, the Danish grid code regulation requires WTGs to inject reactive current (i_q) proportional to the retained voltage (U_{WTT}) from 0.9 per unit to 0.5 per unit retained voltage, beyond which reactive current should be 100% of the nominal value (i_n). Therefore, active current during LVRT period will be limited to the remaining margin, thus resulting in reduced active power injection during voltage dip.

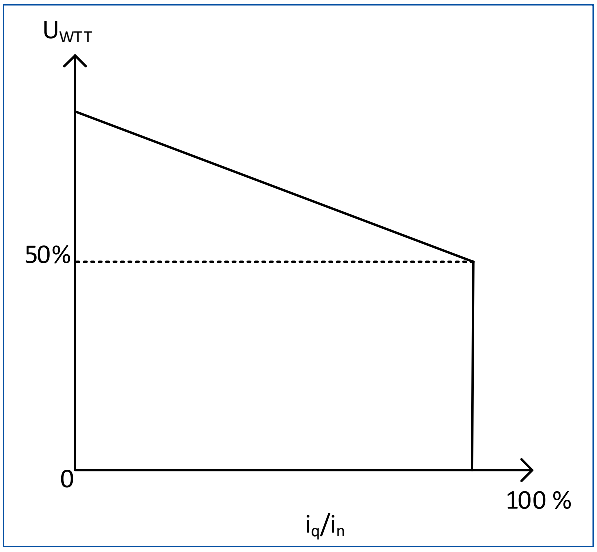

Figure 7: Reactive Current Delivery Requirement as per Energinet.Dk TSO, Denmark

2. Active Power Priority LVRT Regulation

Under active power priority LVRT, WTG/WPP is required to ride through a voltage dip while prioritising active current over the reactive current injection during LVRT period. Reduction in active power injection due to high reactive current injection and low voltage under reactive power priority LVRT, results in reduced active power output from the affected WTGs. Subsequently, following the fault clearance, the WTG has to recover from the reduced active power, which is however, limited by active power ramp up limit, which can be primarily attributed to stress on the mechanical system while ramping up the power output. It is important to mention that during LVRT period, to balance turbine power and electrical power output of WTG, wind turbine power output is reduced either by rise in speed or pitch angle control (wherever available) or combination of the two. Therefore, following a fault clearance, WTG output recovery is delayed due to ramp up constraint, which can potentially result in temporary shortfall in wind power generation. Hence, a severe short circuit fault, resulting in a widespread voltage dip in a region hosting substantial wind capacity, may result in a temporary shortfall in wind power generation, which in some cases may even exceed the size of the largest infeed. Such a temporary shortfall in wind power generation may result in frequency excursion, leading to under frequency load shedding, potential outage of WTGs, and in the worst case may lead to cascading events [4]. Generally, delayed active power recovery is of concern for small islanded systems, as even lower shortfall in generation may result in a potential frequency event. Therefore, in view of delayed active power recovery from WTGs following a voltage dip, some countries require that active current is prioritised during LVRT period, in order to minimise shortfall of wind power generation and potential frequency event. Ireland

and Alberta are among the few regions that follow active power priority LVRT requirement. EirGrid requires that active power output of WTG should be at least proportional to the terminal voltage, while reactive power injection should be maximised within the remaining margin of the capability limit, to control the local voltage. It is important to note that LVRT regulation in India is similar to that of Ireland, however, with varying nominal voltage dependent fault duration limits.

While majority of the countries follow reactive power priority LVRT regulation, some countries follow active power priority LVRT regulation. It is worth to explore how a system regulator should decide which LVRT priority should be adopted for a particular grid, and on what basis should such decisions be taken. More important question that needs to be answered is whether following reactive or active power priority based LVRT regulation is optimal for secure and stable grid operation, or do we have a better option to handle LVRT regulation. We have carried out a research study to find answers to these questions, which has suggested the answer probably lies somewhere in between, and I will try to provide a detailed discussion on this issue through a separate article in forthcoming articles under this series.

In the next article, LVRT testing and certification, in the global and domestic context will be discussed.

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Managing Grid with Variable Renewable Energy

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National Targets of Renewable Energy

India is highly pro-active in capacity addition of renewable energy with high targets of 175GW by 2022 with wind and solar. As the penetration level of renewables increase in the grid the techniques to avoid grid instabilities by appropriate regulations and best practices of grid management becomes increasingly important. Tamil Nadu in the Southern Regional Grid (Figure. 1) has one of the highest penetration of renewables (wind and solar) in its Utility Grid system in our country. Grid augmentation needs for the state of Tamil Nadu is discussed in this article with a focus on grid management possibilities in future.

Evolution of National Grid - One Nation, One Grid, One Frequency

Power evacuation with an assured "must-run" status for renewables and grid management is becoming more difficult with increasing share of variable renewable energy in the grid. India's massive power grid system needs re-balancing to deal with the fluctuating/ erratic nature of power generated from renewable energy flowing into the system and keep supply in synchronisation with demand, which is also highly fluctuating.

The fluctuating nature of renewable energy, be it solar or wind, is a problem for any grid in the world. For the Indian grid, which is generally unstable,

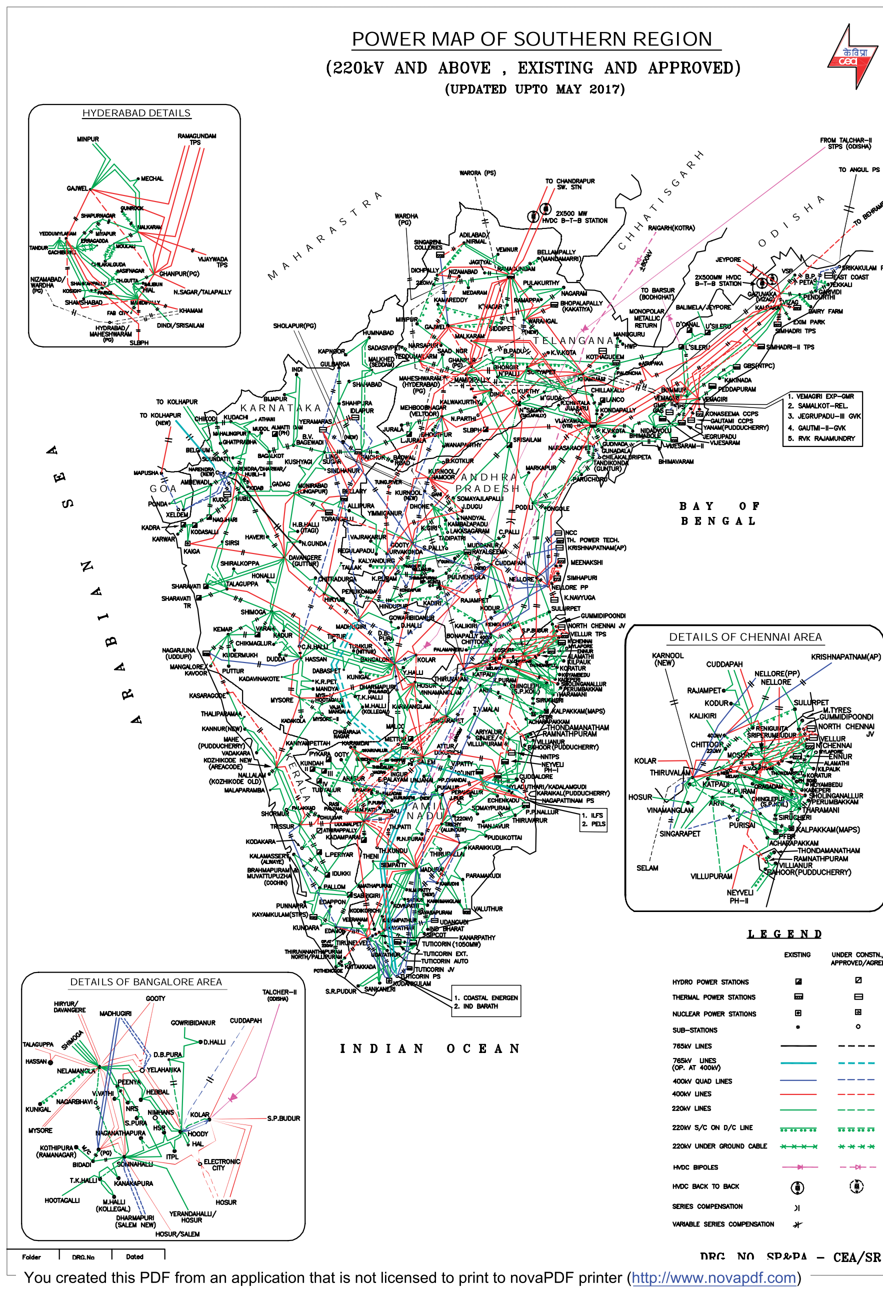

Figure 1: High Penetration of RE in Tamil Nadu of Southern Regional Grid

Source: http://www.cea.nic.in/reports/powermaps/sr.pdf managed manually and experiences shortfalls instead of having reserves and alternatives — like the grids in developed countries, the growing renewable capacity may become an issue over the next 3-5 years. The Indian power system for planning and operational purposes is divided into five regional grids. The integration of regional grids, and thereby establishment of National Grid, was conceptualised in early nineties. The integration of regional grids which began with asynchronous HVDC back-to-back inter-regional links facilitating limited exchange of regulated power was subsequently graduated to high capacity synchronous links between the regions.

Grid management on regional basis started in sixties. Initially, State grids were inter-connected to form regional grid and India was demarcated into 5 regions namely Northern, Eastern, Western, North Eastern and Southern region. In October 1991 North Eastern and Eastern grids were connected. In March 2003 Western Region and Eastern Region-North Eastern Region were interconnected. August 2006 North and East grids were interconnected thereby 4 regional grids Northern, Eastern, Western and North Eastern grids are synchronously connected forming central grid operating at one frequency. On 31st December 2013, Southern Region was connected to Central Grid in Synchronous mode with the commissioning of 765kV Raichur - Solapur Transmission line thereby achieving 'One Nation' - 'One Grid' - 'One Frequency'. By the end of 12th Plan the country has total inter-regional transmission capacity of about 75,050 MW which is expected to be enhanced to about 1,18,050 MW at the end of XIII plan.

Synchronisation of all regional grids will help in optimal utilization of scarce natural resources by transfer of Power from Resource centric regions to Load centric regions. Further, this shall pave way for establishment of vibrant Electricity market facilitating trading of power across regions.

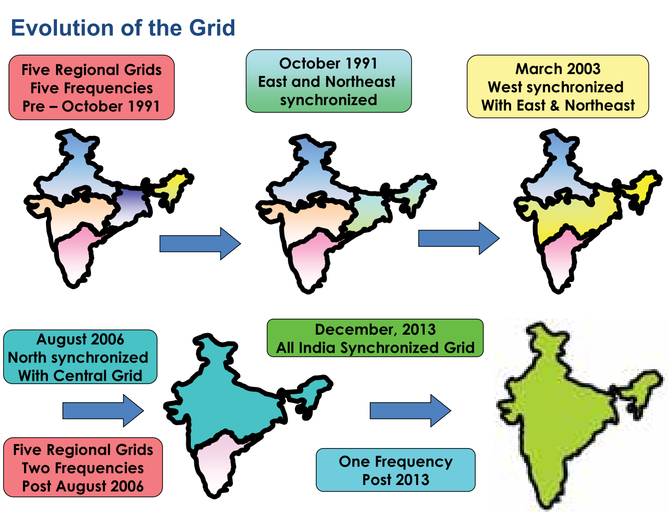

Figure 2: Evolution of the Grid

Peculiarities of Regional Grids in India

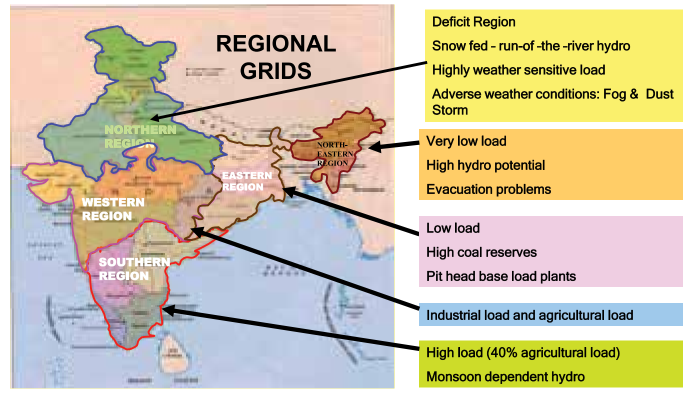

Figure 3: Peculiarities of Regional Grids in India

Specific IEGC Provisions for Compliance of Renewables Integration

Clause 3.4(b)-(vi):

- CTU shall carry out the planning process including Renewable capacity addition plan issued by MNRE

Clause 5.2 (u):

- Must-run stations in normal conditions –
- curtail its reactive power injection /drawl
- Data Acquisition System facility shall be provided for transfer of information to concerned SLDC and RLDC.

Clause 6.1(d): RRF Mechanism

- Wind farms with collective capacity of 10 MW and above,
- Solar generating plants with capacity of 5 MW and above connected at >=33 KV level
- Wind generators to forecast up to an accuracy of 70%

Clause 6.5 (23): Forecasting & Scheduling

- Revisions up to a max 8 times in day (1 for each 3 hr time slot)
- Revisions after a 6 time block notice

Integration issues

- Planning criterion for RE
- Variability and Intermittency
- Scheduling
- SCADA / telemetry
- Network related Problems and Congestion
- Protection
- Commercial mechanism implementation

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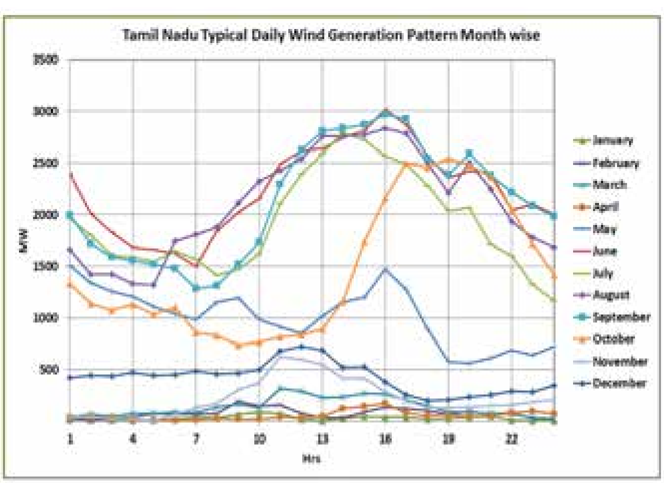
Planning Transmission System for Renewable Energy

- ➢ System Studies
- ➢ Trade off between network optimal utilization and redundancy
- ➢ Network development and O&M
- ➢ Dynamic Line Rating- to be duly factored while designing evacuation systems.
- ➢ Diversity Factor - to be duly factored while designing evacuation systems.
- ➢ Wind/Solar farms are known to be providing lesser grid support during system disturbances/exigencies than the conventional.

Sudden Large Variation in Load/Generation

- ➢ High Ramp rate of load- evening peak hours
- ➢ Sharp change in load, particularly at the hour boundaries mainly due to agricultural
- ➢ Load changes with consequent frequent spikes, frequency fluctuations:
  - due to generation or load loss
  - poor Frequency Response Characteristics (FRC) of individual sub-systems
- ➢ Impact of Wind Generation variability on Host state –UI implication



Tamil Nadu typical daily Wind Generation Pattern Month wise (Source-TAN SLDC)

Figure 4: Tamil Nadu Daily Wind Generation Pattern Month-wise

Dealing with Wind Variability

Flexible Generation and Generation Reserves

Primary reserve/ Frequency response reserve

Secondary reserve - Spinning & non spinning reserves

Tertiary reserve

Hydropower Plant with Reservoir

Pumped Storage Power Plant

Flexibility for market participants

Scheduling of Thermal & Wind power as per forecast and revisions thereof “smart” demand-response management to shift flexible loads to a time when more renewable energy is available

Inter-state and Inter-regional transfer of power to harvest diversity

Mass megawatt battery storage systems to back renewable generation

Pumped Storage Plants

Pumped Storage Plants	Purulia (4x225 MW)	Srisailam (6x150 MW)	–Kadamparai (4x100 MW)
Pumping Mode:	Fixed timing, Typically between 00 to 06 hours, Irrespective of frequency	Seasonal	Frequency dependent Generally during 00 to 06 hours
Generator mode during day/peak hours			During Morning Peak (06 to 09 hrs) During Evening Peak (16 to 21 hrs)

Balancing Renewable Generation

Challenges

- ➢ Variability, intermittency and ramping up or down (LVRT/ HVRT)
- ➢ Sudden onset or offset of wind generation

Remedies

- ➢ Generation balancing by the conventional energy sources.
- ➢ Greater the penetration, greater the balancing requirement.
- ➢ Forecasting of renewable generation (Solar and wind)
- ➢ Ramp forecast is also essential.

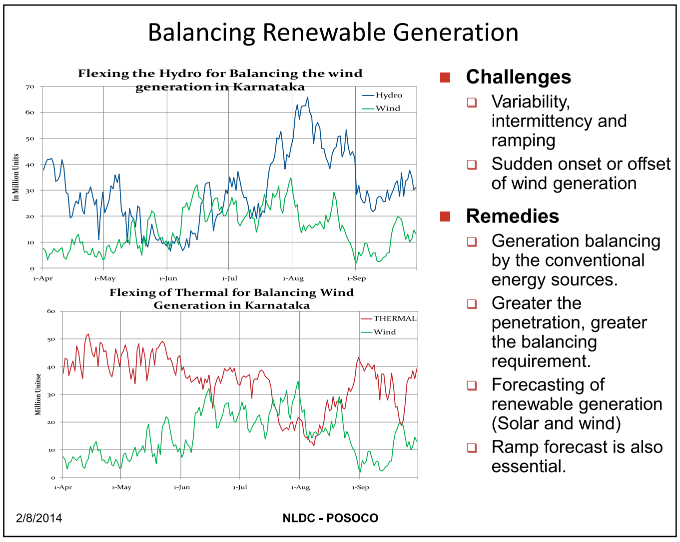


Figure 5: Flexing the Hydro and Thermal Power for Balancing Wind Generation in Karnataka

Need for Scheduling

- To maintain Load Generation balance
- Increasing penetration of Renewable power
- To handle the absence of spinning reserve
- To handle the effect of variability and intermittency
- Grid code provisions
- Revising to minimize UI
- Real Time monitoring (SCADA requirements)
- Implementation of RRF Mechanism

SCADA and Telemetry

Telemetering the data is a challenge - due to wide geographical diversity

- Real time data from wind turbines to be metered and shall be transmitted to the local control centre of each wind farm
- The net injection of the wind farm to be measured at pooling station
- Deployment of synchrophasor technology i.e., PMUs/ WAMS on pooling stations and interconnection with centralized control centre for real time information, monitoring and control.
- Real time monitoring system using Synchrophasor Technology
- As of now only partial data is being transmitted to RLDCs/ SLDCs
- State-of-the-art in Centralized Forecasting centre and integration with SCADA through telemetry

Telemetry is a must for scheduling and monitoring.

Commercial Mechanism

- Market mechanisms would further help large scale integration of renewable sources of energy:
  - Suitable market design to handle reserves for power balancing
  - Flexible Generators
  - Ancillary Market
  - Evening markets-through PXs
- Renewable Energy Certificate (REC) Mechanism
- Renewable purchase Obligation (RPO) – promotes the market mechanisms

Options for RE Generators

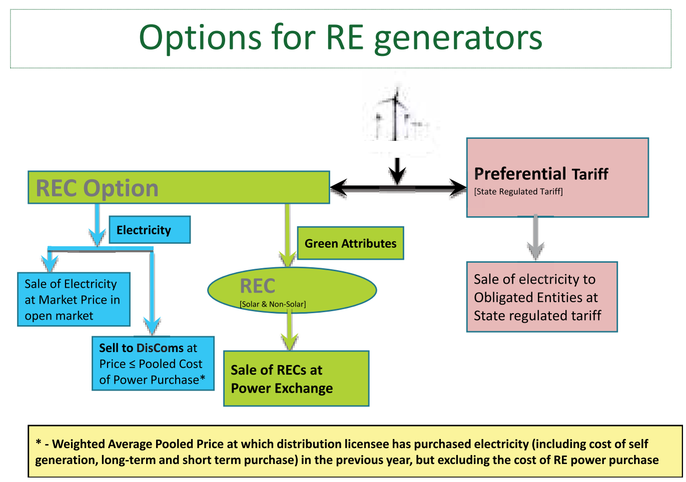


Figure 6: Options for Renewable Energy Generators

Weighted Average Pooled Price at which distribution licensee has purchased electricity (including cost of self generation, long-term and short-term purchase) in the previous year, but excluding the cost of RE power purchase.

REMCs (Renewable Energy Management Centres under SLDCs), Facilitation of "Green Corridor" for efficient management of RE in Grid, higher band width of exchange of excess renewable power through State Transmission Unit (STU) over to the interstate Central Transmission Units (CTU), Training of engineers and implementing of running Coal power plants at lower load levels, step-by-step digitisation of past history of substation-wise renewable energy mix in the grid, training the Engineers for interpreting day-ahead wind power forecasting and scheduling, has resulted in significant success in the management and operation of one of the world's high RE mix in the utility grid of the state of (Tamil Nadu)TN and is certainly convincing and setting the way forward to the country as a whole for follow through.

Some of the results depicted in the policy document 2018-19 are:

The penetration of Renewable Energy in the Tamil Nadu energy mix is as follows.

Tamil Nadu Installed Capacity as on 31.03.2018

Sl. No.	Category	Capacity in MW
I	**Conventional Energy sources**	
1	Hydro	2307.90
2	Thermal	4320.00
3	Gas	516.00
4	Central Generating Stations	6152.00
5	Power Purchases	
	Independent power Projects	746.50
	Long-term Open Access (LTOA)	3330.00
	Medium-term Open Access (MTOA)	300.00
	Total Power Purchases	4376.50
6	Captive Power Projects	1074.80*
	Total Conventional	**18,747.28**
II	**Renewable Energy Sources**	
1	Wind	8152.39
2	Solar	2034.25
3	Biomass-Combustion	237.67
4	Co-Generation	688.40
	Total Non-Conventional	**11,112.71**
	Grand Total	**29,859.99**

* These CPPs though not supplying to TANGEDCO, they supply through Open Access to private consumers.

On the Green Energy initiative, Tamil Nadu, is a leader in Renewable Energy sector among all States and has a total installed capacity of 11,113 MW as on 31.03.18 against 10,480MW on 31.05.2017. The State has harnessed around 13,000 million units (MU), of wind energy and 2,905 million units of solar energy during 2017-18. By way of harnessing the Green Energy, the State has reduced use of hard coal and thus reduced about 5,406 Million tonnes of Carbon emission.

Source: Tamil Nadu Electricity Policy Document 2018-19

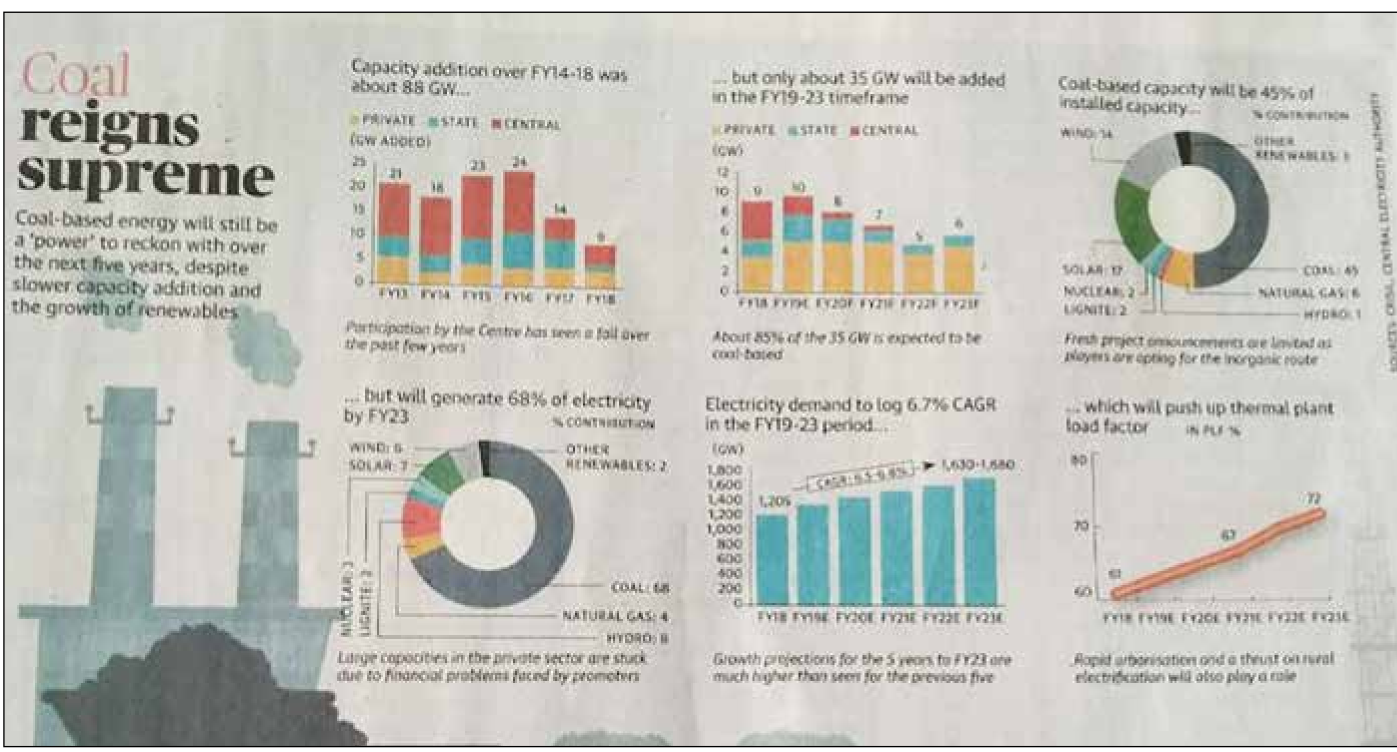


Figure 7: Coal will remain the Base Power for some more time

Source: The Hindu, 4th November 2018

While one of the key focuses of Government of India being electrification of every village, providing 24x7 continuous power supply, energy access to every house and transformation towards green energy with climate change obligations in the fore front, for some more time the coal is likely to be the base power provider as per the latest study reported in the news:

However with a significant penetration of renewable energy of 31% or more depending on development path by private players by 2023, in the energy mix, the grid management has to be further modernised and sophisticated to handle infirm renewable energy which is going to cost less than that of conventional power.

Future of One GRID in India

Future grid managers should be prepared to handle with adequate ICT infrastructure the Demand side management with several out of box generation and load demand creation possibilities some of which are listed below.

Use of repowering with wind and solarisation (of extra land in old wind farms), can use the grid effectively since most wind turbines will operate in the slope of the power curve, not to the full capacity of the turbine, average wind speeds being 5-7m/s.

Solar is spread uniformly through the year but wind is seasonal. Hence fill up the PPA capacity of wind power deficit in the off-season using solar generation making best use of grid infrastructure. Such increased generation (hybrid) 49% to 84% can be well used with storage and existing evacuation capacities itself, by effective management of the grid with wind as well as solar forecasting and scheduling. Tamil Nadu is 4th high-density wind cluster as a state in the world.

Sub megawatt machines should be grid tied with a micro-grid for localised regional distribution network. This will enable demand side management (DSM) of grid using distributed generation built-in with a smart-grid coupled with storage system.

Alternatively local micro-grids can relieve the utility grid of some possible overloading and any excess renewable energy generation can be used to establish electric vehicles battery charging stations, hydrogen generation stations for fuel cell cars, powering desalination of water and many such local sustainable energy/electricity demands.

One third of (Tamil Nadu) Chennai's peak load can be handled with just 4kW solar or small wind systems in each of 2.5 Lakh residential tax payers of Greater Chennai Corporation. The released excess power (1000MW) from the grid can be supplied to industrial loads at a competitive tariff enabling the electricity boards make higher returns through a smart grid management.

Slowly and steadily time of the day costing of power sales can be implemented through a highly transparent smart metering system which would provide a peak shaving possibility in the grid management with better usage control and "load and generation" forecasting.

Lastly if EV2030 is making a fast track head way there are twin applications of vehicle batteries which may get plug-in points enabled through renewables (fuel price zero), and also vehicle to GRID (V2G) in the case of large corporate parking slots, to manage the grid in short-term.

If one looks at the EROI (Energy Returned of Investment (used to put the system in operation for energy capture)) index, it is about 6 for solar PV, and 38 for wind, hence solar cell manufacturing (highly energy intensive) in India may not be insisted, rather module fabrication, module mounting systems and Balance of Plant can well be promoted, with top priority for roof tops (land is assured and the onus of cleaning and O&M is with the house owner) unlike the mega SPV plants. This way of smart generation would enable GRID management easier to meet DSM.

With larger grid interconnection the variability can be better handled along with forecasting, operational planning can be better executed. With scheduling the accountability is induced.

With REC mechanism and trading across seams, renewable energy will be an attractive business. Concerns of System Operators will be taken care of and a separate Control Centre for Renewable Power (REMCs) at each LDC has already been started. There are countries heading for 100% green power very soon, if there is a "socio political awareness and will to do" then GRID management which is ICT driven today will have no technical issues of management for higher RE penetration in the energy mix.

Acknowledgement: The author thankfully acknowledge the assistance rendered by Dr Rishi Muni Dwivedi, to compile vital information in short notice, to be included in this compilation from public domain literature. The discussions and suggestions are personal opinion of the author not of Government of India or any state department in India.

References/Sources: MNRE, MOP, CEA, PGCIL, POSOCO web-sites and various journals

Energy Storage for Integrating Renewable Energy in Indian Grid

Dr. Rahul Walawalkar, Executive Director
India Energy Storage Alliance (IESA)

The Government of India has come up with an ambitious plan to deliver 175 GW of renewables by 2022 and 24x7 power for all by 2019 by creating an efficient, resilient and financially sustainable power sector. Furthermore, India in the recent COP 21 has committed to generate 40% power from clean energy sources by 2032. This objective, along with clean energy access, has become the centre of all plans around economic development and environment.

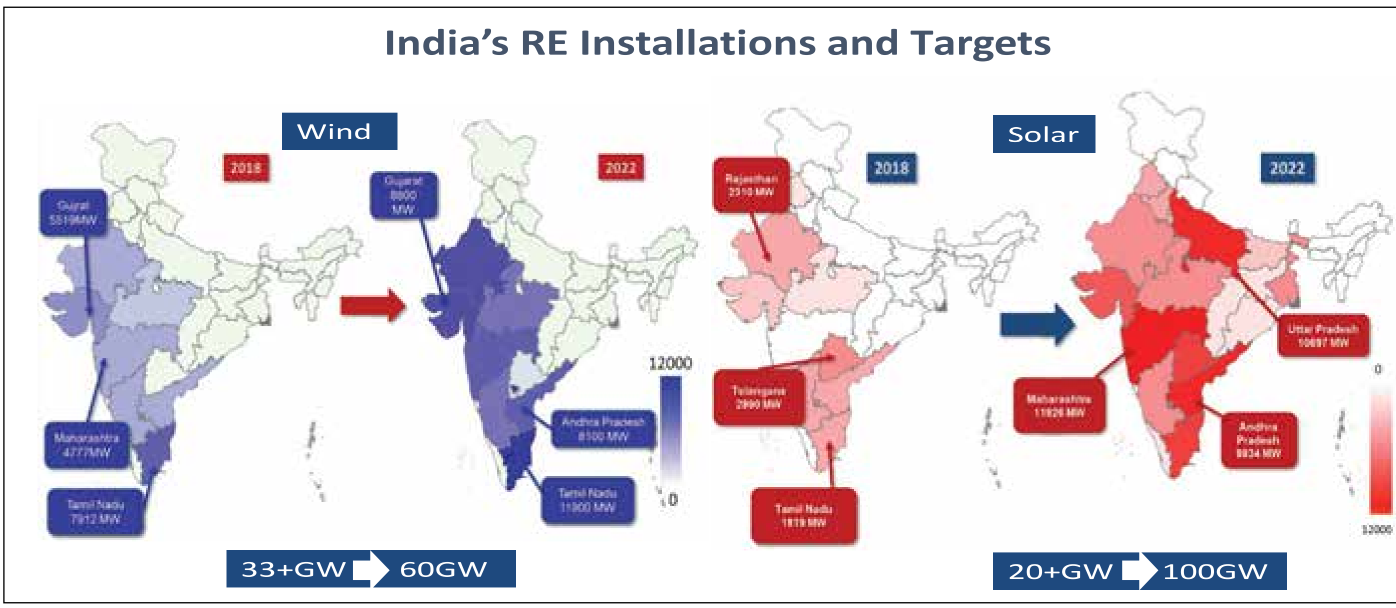


Figure 1: Renewable Energy Installations and Targets

High deployment of renewable energy and its use requires technical as well as commercial solutions and a variety of policy decisions around minimizing the impact of intermittency and enabling grid integration of renewable energy. The falling costs and rising efficiencies of the supporting technologies, such as energy storage, are already making the generation of renewable power compete with conventional thermal power. Such technological advancement and cost reduction in both the renewable energy and energy storage options will facilitate the exploitation of the abundant renewable resources.

Expected India Net Load Curve 2022 (with 100 GW of Solar Generation)

Energy storage technologies can provide an array of services to modern grid such as peak load management, grid balancing and renewable energy integration. Historically, storage systems such as pumped hydro were deployed for energy arbitrage; however, emerging distributed energy storage technologies are currently used in many other areas such as grid balancing and renewable energy integration in addition to energy arbitrage.

Globally, renewable energy + energy storage is being increasingly seen as an alternative to building peaking power plants. Energy storage integrated with renewable energy generates a smooth and firm output that is controllable, which subsequently optimizes transmission investments. A key application for energy storage in transmission is to defer the investments on upgrade for new capacity projects required to reduce renewable energy curtailments.

Expected India Net Load Curve 2022 (with 100 GW of Solar Generation)

Figure 2: POSOCO's Projections for India Net Load Curve with 20 GW Solar PV

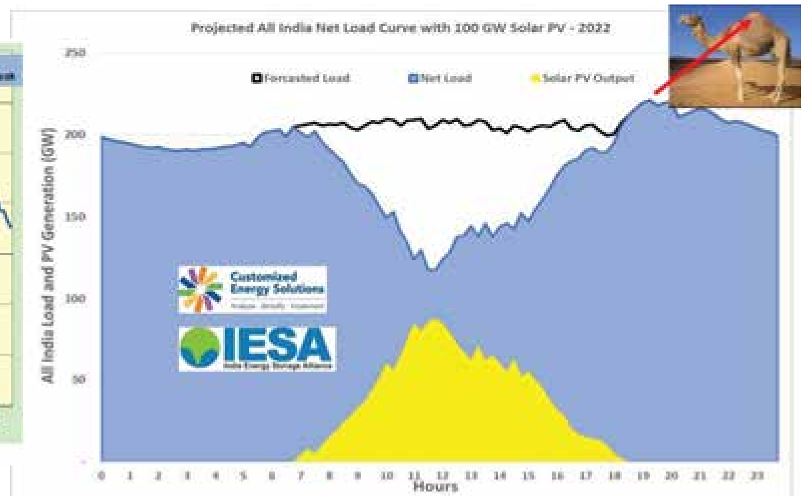


Figure 3: IESA Projections for India Net Load Curve with 100 GW Solar PV

Ancillary Services
Technology choice: Environmental Impact

Conventional Grid | **Smarter Solution: Storage**

Figure 4: Technology Choice: Environmental Impact in Conventional Grid and Grid with Storage

Manage renewable variation by fossil generators varying output

- ➢ Decreases efficiency
- ➢ Increases fuel consumption
- ➢ Requires more maintenance
- ➢ Increases emissions

Store energy when supply exceeds load; Inject energy when load exceeds supply

- ➢ High round trip efficiency
- ➢ Low operating cost
- ➢ Near instantaneous response
- ➢ Zero direct emissions
- ➢ Frees up generation capacity

20% of the CO2 emission reduction and up 100% of the NOX emission reduction expected from wind and solar power may be lost because of ramping fossil Plants.[1]

1. Katzenstein, W., and Jay Apt. Air Emissions due to Wind and Solar Power. Environmental Science & Technology. 2009, 253-258.

As highlighted by the CERC's staff paper on energy storage, transmission companies can deploy energy storage systems at grid-level substations and use the assets to participate in energy markets for grid support like the ancillary services. Transmission companies can be the owners of energy storage systems without being involved in the trading of the stored energy. The National Electricity Plan (NEP) highlights the role of energy storage in maintaining grid security with increasing penetration of renewable energy in addition to addressing the intermittency of renewable energy to a large extent. At the consumer's end, energy storage can be used as a back-up power while reducing the use of diesel consumption and integrating with solar rooftop PV systems, as well as a standalone back-up for reducing demand charges.

Before the push for 175 GW of renewable power, India's coal generation rapidly expanded at more than double the rate of electricity demand in the country between FY 2011-17. The Indian power sector suddenly found itself in the unfamiliar territory of being "power surplus", especially at some times of the day or year, and based on the procurement chosen by Discoms. This capacity overhang is the main reason we have seen the plant load factors (PLF) of coal power plants falling from 73% just a few years ago to below 60% recently. Demand growth has also slowed down, some of which is structural (rise of services beyond manufacturing) and some due to energy efficiency.

India has a nationally unified synchronous grid which means power can go from any point to any point. In practice, there are transmission limits to shipping power point to point, say, to use the surplus wind of Tamil Nadu in Delhi. Operations are split across five regions which are more tightly integrated, with lower amounts of inter-regional transfer capability. This is not unusual when we examine large synchronous grids such as in the US and China. The grid frequency, a measure of supply-demand mismatch, still varies much more than targeted, and there are limited grid reserves. Thus most of the policy makers are now convinced that energy storage needs to be part of the solution for India to achieve our renewable energy integration goals for 2022 and beyond.

Secretary, Ministry of New and Renewable Energy created an Expert Committee in February 2018 to draft National Energy Storage Mission (NESM). Key focus areas for NESM include energy storage for large scale renewable energy at transmission level, on-site energy storage integration at distribution level, rural micro-grids and storage component in electric vehicle plans. Honorable Prime Minister announced the impending launch of NESM during the inauguration of Renewable Energy Invest Conference on 2nd October 2018. Currently, the NESM draft is going through final approval from Cabinet and is expected to get launched by end of the year. NESM has set objective to strive towards leadership in the energy storage sector by creating an enabling policy and regulatory framework that encourages deployment, innovation and further cost reduction through multiple strategies. NESM will provide clear signal that the Government of India's strong and long-term commitment to the importance and need for energy storage in India. NESM will work to facilitate market led technology deployment at scale across multiple applications and multiple geographies, while gaining valuable technology, policy and regulatory experience. Lastly but most importantly, NESM also expected to set a goal of making India a global R&D and manufacturing hub for advanced energy storage technologies.

With the technology becoming affordable, what we need is the RE developers to explore new business models and start deploying hybrid projects that can help India capture the true potential of renewable energy in India. India Energy Storage Alliance has been working on capacity building in this area, and currently includes over 20 leading renewable energy developers who are part of the alliance.

Role of Energy Storage in Smarter Grid

By supplying power when and where needed, energy storage will improves the reliability of electricity supply and reduces variability, uncertainty and increases stability. Better integration of renewables into the system increases the efficiency (economic & utilization) of existing generation & transmission facilities. It reduces the need for additional transmission assets. Be the preferred supplier of ancillary services.

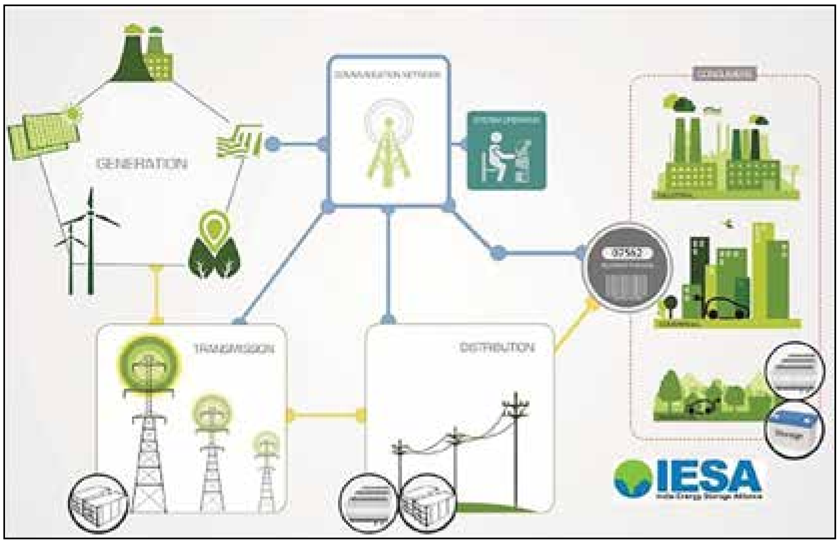


Figure 5: Role of Energy Storage in Smart Grid

Challenges in Renewables Integration

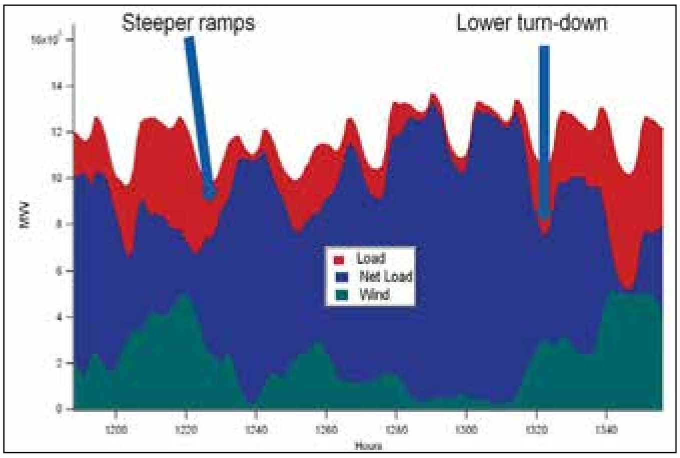


Figure 6: Sharp Variability of Wind

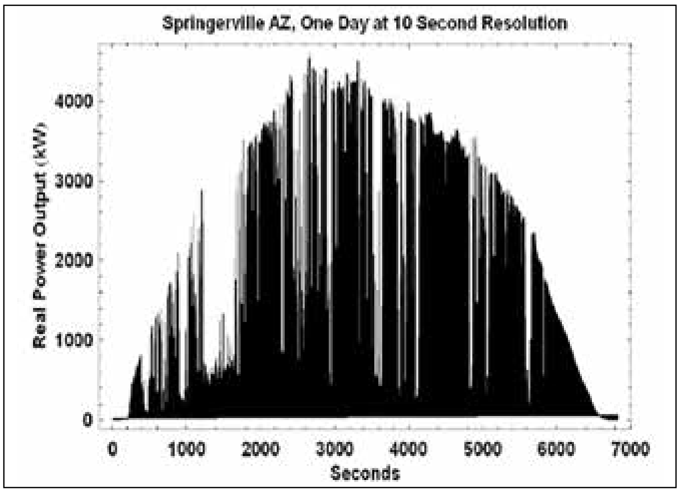


Figure 7: Variability at Springerville AZ, One Day at 10 Second Resolution

Source: Dr. Michael Milligan NREL / AWEA : Dr. Jay Apt, CMU

Variability and uncertainty due to RE integration, strains the grid and challenges system control, making it difficult to forecast and schedule for dispatches.

Impact of RE Integration into Grid

1. Risk of over generation and wastage of resources, due to high RE uncertainty.
2. The fluctuations of RE output affects transmission efficiency.
3. High variability and uncertainty significantly complicates the demand-supply balancing system and requires additional flexibility in power systems.
4. High uncertainty requires additional secondary and tertiary operating reserves, increased ramping.
5. High intermittency of renewable energy make it difficult to forecast and schedule for dispatches.
6. Higher penetration (with rapid deployment) of RE resources may ultimately result in unstable grid

These challenges present a historic opportunity to modernize the grid to smooth short-term variability and uncertainty with ESS, real time communication and control automation in grid systems.

Energy Storage for Wind Smoothing

Energy Storage is the solution for RE integration challenges, which absorbs excess RE (ramp control), enables power producers provide the grid with consistent power and respond immediately and precisely to changes in load.

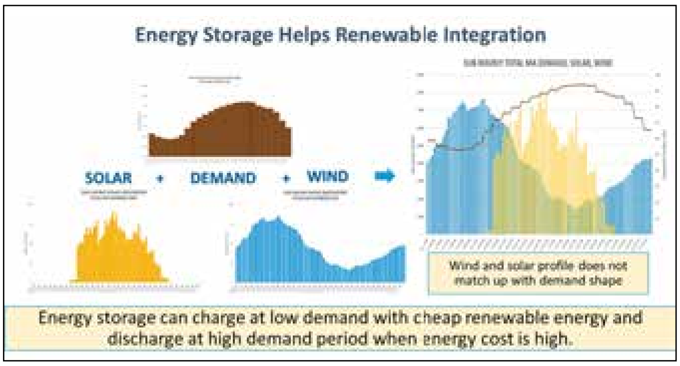


Figure 8: Energy Storage Helps Renewable Integration

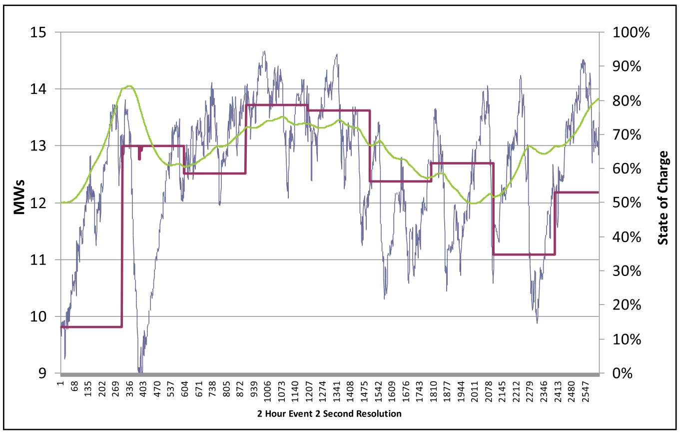


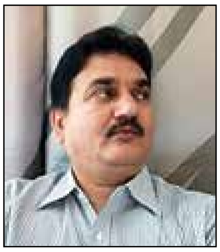
Figure 9: Energy Storage for Wind Smoothing

Snippets on Wind Power

Deutsche WindGuard Starts Indian Subsidiary

Deutsche WindGuard India Private Limited, founded in 2018, is the Indian subsidiary of Germany-based wind energy consultant Deutsche WindGuard GmbH. It is offering wind resource assessments, measurement services as well as a multitude of other services from the WindGuard Universe. The Group operates in the fields of technical inspections and management, site assessments, measurements on wind turbines, wind tunnel measurements, consulting and certification services. Dr. Kumaravel Rathinavel is the Managing Director of the Indian subsidiary.

Wind Forecasting for Stable, Reliable and Secure Grid Operation - First Approach



B.B. Mehta, Chief Engineer, State Load Dispatch Center
Gujarat Energy Transmission Co. Ltd, Vadodara, Gujarat

Looking to the overall phenomena of India, power demand of region with respect to different source of generation and potential/availability of renewable energy generation in State/region, it is utmost necessary to manage or balance the system by proper establishment of renewable energy with predefine solution mechanism. Renewable energy, mainly wind generation, is having variability, intermittent and is of uncertain nature that directly affects conventional sources, grid parameters and system operation.

To deal with challenging nature of wind generation and ever-increasing wind energy penetration and to overcome its impacts, realistic forecast is one of the vital tools which can pre-requisite for reliable grid operation and planning for resources/reserves management. Many renowned agencies worldwide are providing the services for wind generation forecasting. However, the result/output of each Forecasting Service Provider (FSP) vary due to quality, quantity and utilization of various static, variable/dynamic data and weather data as such it is a challenge to forecast wind generation accurately. Further, the methodology developed by each FSP may also differ. Moreover, real time wind generation and operational availability of windmills is also a crucial part for more accurate wind generation forecasting. Apart from above, inconsistent and interrupted nature of weather data available through various weather sources also poses greater difficulty for accurate wind generation forecasting.

As per Forecasting Service Providers (FSP), a wind forecast model or wind generation forecast system can be considered as a "black-box". This "black-box" takes various data as inputs and generates wind power production forecasts as output. FSPs are utilizing various weather data as input from Numerical Weather Prediction (NWP) model. NWP models are also having various methodologies for weather forecast. Physics-based and statistical model are developed and being utilized for wind generation forecasting. There are various stages of forecast such as downscaling, conversation to power and upscaling exploit by FSPs. As per the view of FSPs, higher accuracy can be obtained during high wind generation and accuracy would be less during low or average wind generation. However, substantial experience for each pooling station, covering every season, is essential to forecast the trend nearer to realistic.

Wind generation forecasting comprised with certain database, i.e. the number of windmills, latitude & longitude, hub height, swept area, type, date of commissioning of each windmill, historical and real time generation data and operating status of each windmill. Further, mean sea level and terrain is also play crucial role. Apart from this, historical, real time and forecasted weather data for each defined point is essential to develop forecasting model. However, weather data and mainly wind speed at specific height need to be more accurate. As far as concerning to Indian renewable power scenario, complete data set availability of certain static, variable data, running status of windmills, real time data and weather data is limited due to certain technical, commercial and regulatory reason.

As a way forward, there is a need to identify the nature and pattern of wind generation through various seasonal cycles in each state/area of India. Daily and monthly pattern needs to be developed. The availability of accurate weather data from various sources needs to be scrutinized. Subsequently, there is a need to develop a simple and feasible method for wind generation forecasting for state as a whole as per various data availability in Indian scenario. Fundamental power equation for wind generation output states that the wind generation is directly proportional to air density and cube of velocity. This power equation for each separate plant can be applied; also, it can be applied on area/region with wind farm congregation and obtain the wind generation forecast for the state as a whole. However, the equation and methodology need to be modified in accordance to the data base analysis.

We are addressing the requirement of accurate and full-fledged wind generation forecasting mechanism for stable, reliable and secure grid operation. Further, precise mechanism of weather data should be established for the counter check for forecasted data available from various sources. Apart from big data base model and methodology, by accommodating large number of static, variable and weather data and more research in fundamental wind generation power equation and its proper utilization with various data base lead to more accurate wind generation forecasting with least resources.

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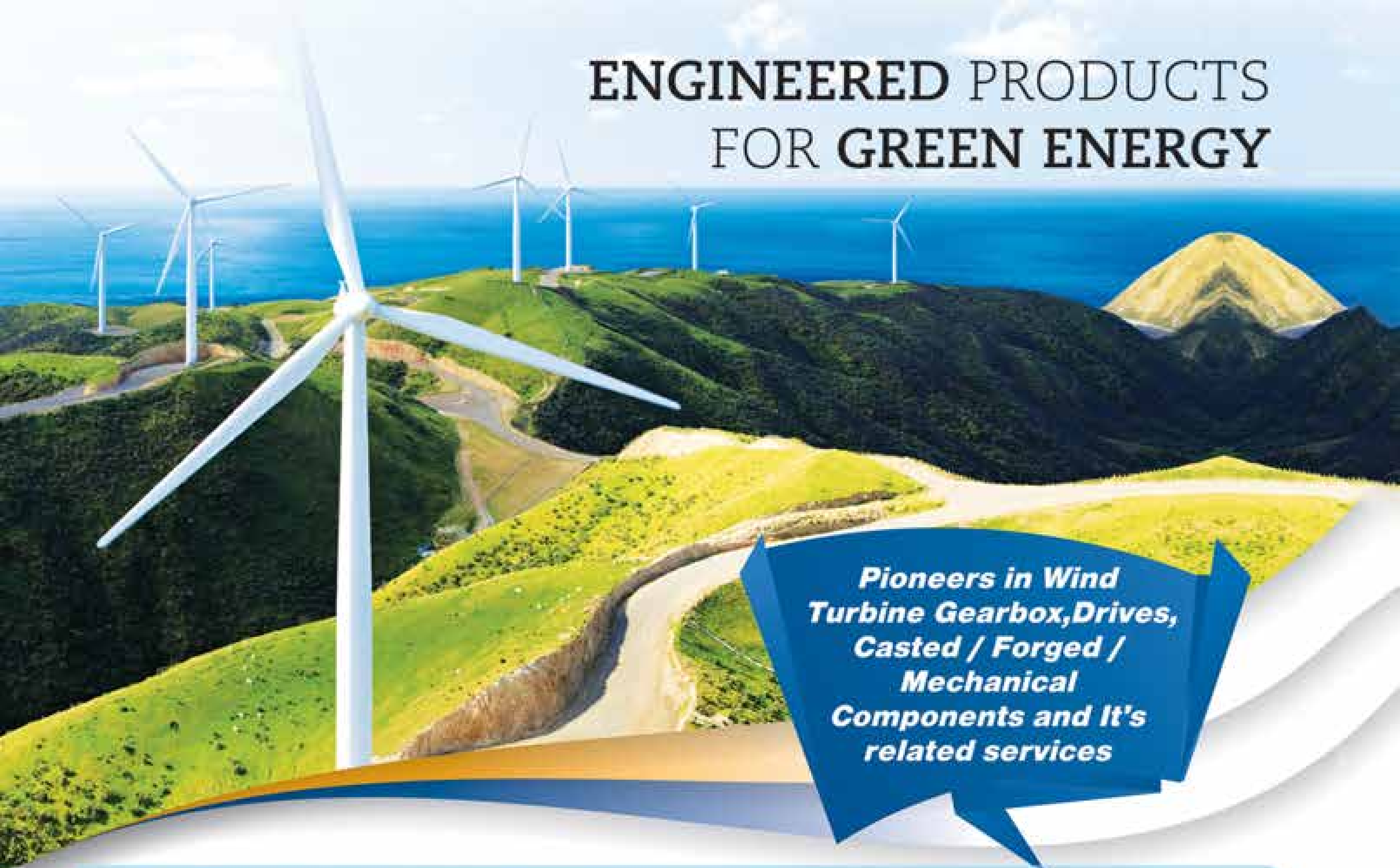

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Grid Management with Large Scale Renewable Energy in the Grid

Bhagavatheeswaran H **Krishnajith M.U.**
Consultants, Idam Infrastructure Advisory Private Limited

The Government of India has set a target of 175 GW renewable energy capacity additions, with 160 MW of capacity addition expected from solar and wind put together. In order to accomplish the target, the Government has initiated steps such as competitive bidding, resulting in large-scale capacity addition as well as significant decrease in the cost of electricity produced from renewable energy. Owing to these initiatives, India boasts 71.5 GW of grid connected renewable energy installed capacity (excluding large hydro power) as on July, 2018. Wind energy has been a flag bearer in the renewable energy sector having 34.4 GW capacity and thus comprising of around 50% of the total installed renewable energy capacity.

Source	Total Installed Capacity (MW)	Target for 2022 (MW)
Wind	34,402	60,000
Solar	23,115	100,000
Biomass	9,378	10,000
Waste to Power	138	
Small Hydro Power	4,493	5,000
Total	71,526	175,000

With the renewable energy sector in the country poised to achieve the target, it is imperative that necessary grid infrastructure facilities have to be in place to enable seamless integration of renewable energy. Further, managing the grid effectively with a never before level of proliferation of renewable energy, is the key.

The development of India's interstate green power corridor is a major policy initiative that is motivating the rapid deployment of renewable energy infrastructure. Since many states are falling short of meeting Renewable Power Obligation (RPO), the renewable energy surplus generation states like Tamil Nadu and Karnataka, are likely to be much in demand in the national market. In February, 2018, the Central Government extended the waiver of interstate transmission charges and losses for first 25 years of operation from date of projects commissioned till 2022, to facilitate more inter-state transactions.

In the recent times, the transition to an auction-determined tariff regime stimulated large-scale renewable energy addition year-over-year. In the coming years, the proliferation of renewable energy would significantly increase. The increasing share of renewable generations in the grid has impacted the traditional approach of load-generation balancing in the grid. The renewable sources with un-priced fuel such as wind and solar power are intermittent in nature that is their output depends on external conditions, such as sunshine or wind. In such circumstances, safety and security of the grid would be paramount and hence, cannot be compromised.

To address the grid management with more renewable energy capacity addition, the following issues are deliberated in the article:

- Grid Stability
- Managing Resource Variability & Intermittency
- Forecasting and Scheduling
- Impact on Conventional Generators

A. Grid Stability

Grid Stability becomes a major issue especially when there is high penetration of renewable energy. Majority of the existing renewable energy installations does not have capabilities to support the gird in the event of transients. For instance, most of the wind plants installed are not Fault Ride Through (FRT) capable, leading to collapse of the grid due to sudden loss of large chunk of renewable energy generation. The basic technical challenge comes from the variability of wind and solar power affecting the load generation balance and varying demand for reactive power, and has an impact on voltage stability. However, the burgeoning problem lies in the sudden loss of wind generation, which has a much more cascading effect as opposed to the gradual variability.

The non-availability of real time data of renewable energy generation to SLDCs is another important issue compounding the problem, particularly in renewable energy rich states. The real time data integration of renewable energy to SLDC's SCADA system is far below 100%. However, the availability of real time data has improved in some states such as Karnataka and Gujarat in the recent past. In order to ensure safe, secure and optimal operation of the overall grid, there is a need to improve coordination between conventional generators, renewable energy generators and State Load Despatch Centre (SLDC).

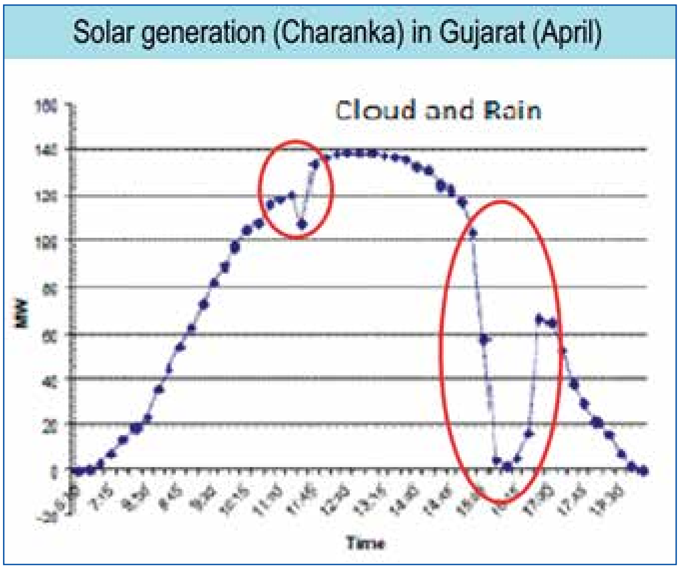


Figure 1: Solar Generation in Gujarat

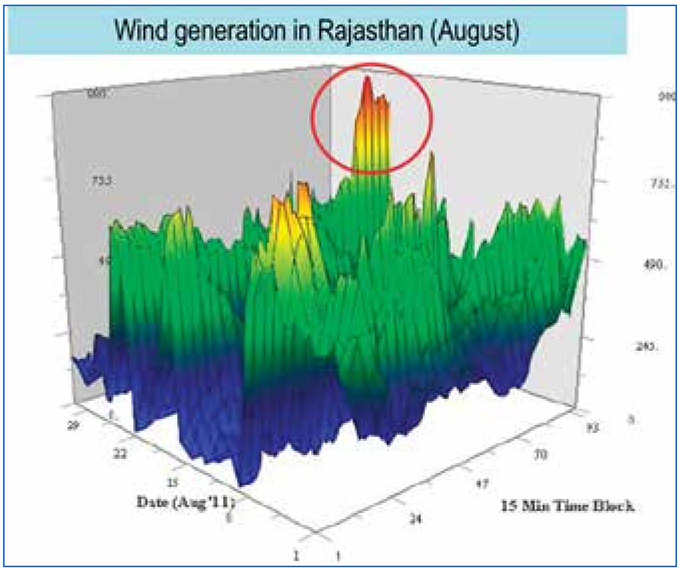


Figure 2: Wind generation in Rajasthan

B. Managing Resource Variability & Intermittency

Large scale renewable energy integration with grid has significant challenges which are both technical and economic in nature. The intermittent generation from renewable resources, due to seasonal weather fluctuations introduces uncertainty in the generation trend of days and months. System operators would find it difficult to balance the grid with sudden rise or fall of renewable energy in the grid.

The above graph scenarios show that sudden fall in solar generation due to clouds and rainfalls. There is no sufficient hydro/gas based power plants in the grid to balance the sudden downfall. Due to high penetration of wind (being seasonal), the thermal generators have limited ability to back down due to technical minimum generation. One approach to address the variability of renewable generation is capacity addition of conventional load following generating stations such as hydroelectric plants and gas based plants. As per Energy Storage Report published by CERC, the use of load following generating stations is not limited to variation of load, but its use is now extended to counter the variability of renewable generation. The higher penetration of renewable generation will require higher capacity of load following generating stations. The balancing through the conventional load following generating stations such as hydroelectric plant and gas based thermal plant would not be adequate. The renewable generation dominated states use coal based thermal generating stations to counter balance the variability of the renewable generation. However, regulating generation output of coal based thermal generation plants; to address the variability of renewable generation is not recommended based on number of considerations including uneconomical cost and challenges involved in practical implementation.

Managing the duck curve phenomenon with advent of large scale solar in the grid is perceived as another major challenge for grid stability. As per the duck curve phenomenon, ramp up rate increases significantly during the evening time of the day when contribution from Solar generation recedes, however demand pick up. The existing conventional generation sources are not sufficient to provide such high ramp rates in the grid. In this context, it is worthwhile to note that wind generation can be of rescue in such situations, whereby wind can provide sufficient support to the Grid. Wind generation peaks in the evening when solar generation recedes and thus reduces the duck curve impact (of high ramp up requirement) on the grid. This very feature establishes the need for promoting wind hand-in-hand with solar. The following graphs depict the wind generation profile that establishes the above argument.

Alternately, other options for addressing the duck curve challenge includes Wind-Solar Hybrid, Energy storage, Pumped storage, Electric vehicles, Grid strengthening which needs to be explored. Out of these options, Wind Solar Hybrid has many advantages as Wind and Solar generation complement each other. Other benefits of the Wind Solar Hybrid projects include improved land usage, shared evacuation and shared operation infrastructure. In order to provide adequate policy and regulatory support for large scale deployment of such projects, the Government announced National Wind Solar Hybrid Policy. The following figure highlights the modulation in the generation profile that wind-solar hybrid solutions can offer. The graph on the left hand side shows independent generation profile of wind-solar Hybrid and the one at the right hand side shows the net-generation considering hybrid benefit.

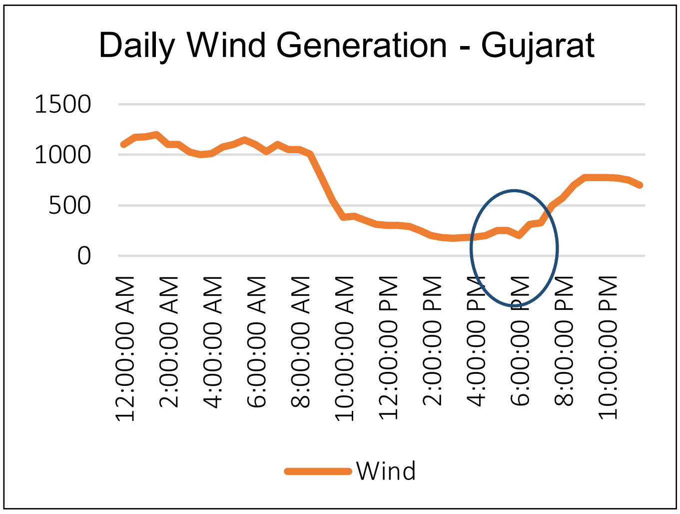


Figure 3: Daily Wind Generation – Gujarat

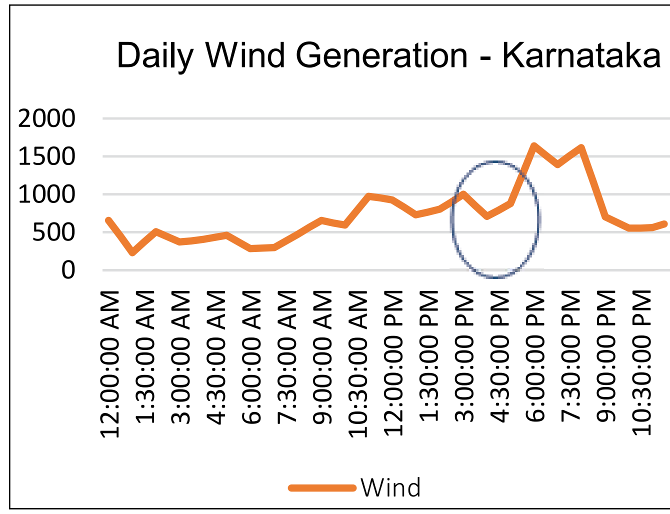


Figure 4: Daily Wind Generation – Karnataka

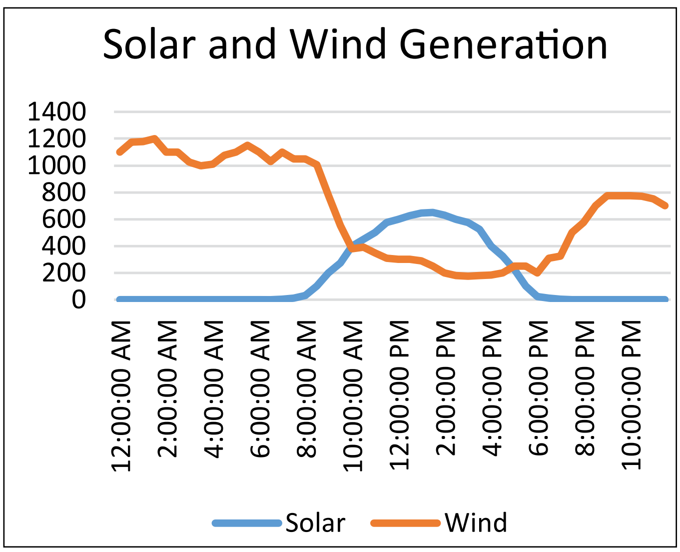


Figure 5: Solar and Wind Generation

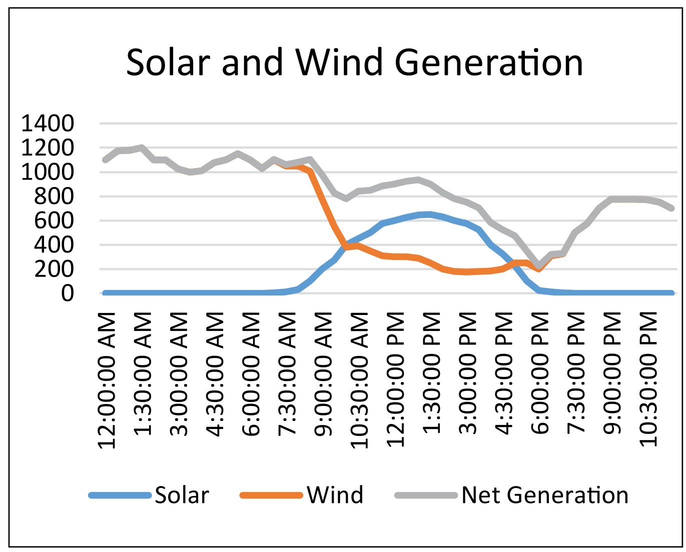


Figure 6: Hybrid Generation Profile

Fact Check

International study shows that variable renewables are not threat to grid reliability.

If the grid reliability in other countries are studied and compared to US, Denmark and Germany, which host some of the highest levels of non-hydro renewables in the world, have 10 times fewer minutes of outages each year. Germany and Denmark have two to four times the renewables of the USA. Still, the presence of very high amounts of renewable energy in European countries made possible with sophisticated grid management techniques does not itself make the grid less reliable.

(Source: Greentechmedia)

C. Forecasting and Scheduling

The practice of forecasting renewable energy generation and scheduling the same can be a potential and economical solution to tackle the issues posed by resource intermittency and will facilitate better balancing of the grid.

Most of the existing wind and solar generating stations are directly connected to the state grid and hence they fall under the operational control area of the respective SLDCs. The SLDCs/RLDCs are mandated by the Electricity Act to keep account of the

electricity in the state/regional grid. Forum of Regulators (FOR) has published model state-level framework for Forecasting and Scheduling that outline a methodology of forecasting, scheduling and commercial settlement of intra-state renewable energy generators. However, implementation of such mechanism at state level would be quite challenging as the roles and responsibilities of the SLDC increases with the higher volume of generators; and more participants for off-take. With envisaged large scale integration of renewable energy in the state as well as interstate level, the number of players, energy transactions, market volume, complexity of pool administration would increase manifold. Further, different models are adopted in different states depending on applicability, which leads to practical difficulties in implementation of policies and regulations. The solution is to develop a forecasting and scheduling model that fits for all permutations and combinations for all participants.

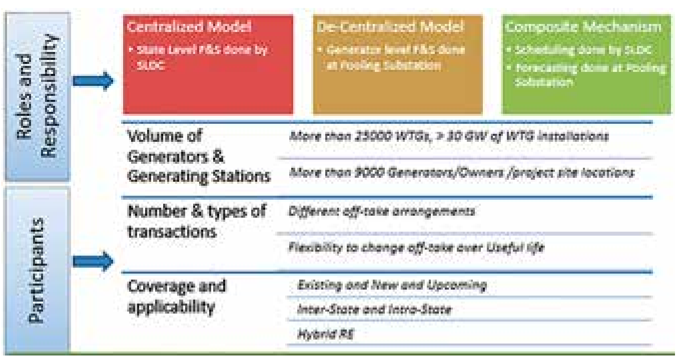


Figure 7: Premise for Establishing a Robust Forecasting and Scheduling Framework

As per present scheduling regulations, decentralized scheduling is adopted, which means that each wind farm submits its schedule to the system operator. It is observed that most countries prefer centralized or cluster-based scheduling with the concept of virtual power plants. The practices followed are:

- Centralized scheduling for committed wind farms through PPA: An independent body or system operator schedules and forecasts on behalf of all the wind farms.
- Individual wind farms who participate in the market: The wind farms participate in the open electricity markets through bidding process and settlement takes place according to the market rules. Here, scheduling & forecasting is the responsibility of the wind farm owners.

There are advantages and disadvantages of both centralized and decentralized approaches. For power system operation and security, the centralized mechanism is preferred.

The, Composite Model (Scheduling done by SLDC and Forecasting done at Pooling Substation) combines the advantage of all models and safeguards generators against individual forecast risk. Hence, a solution that fits for all permutations and combinations for all participants has to be developed.

D. Impact on Conventional Generators

The higher penetration of renewable energy also has an adverse impact on conventional generators (such as coal and gas power plants). In order to accommodate renewable energy, coal and gas power plants need to be backed down. Under the flagship PACE-D (The US-India joint partnership) programme, a Committee published a report on "Greening the Grid (GTG)" which suggests various pros and cons of addition of 100 GW solar and 60 GW wind in the National grid. The following figure depicts the impact as highlighted in the said report.

(Source: GTG Report)

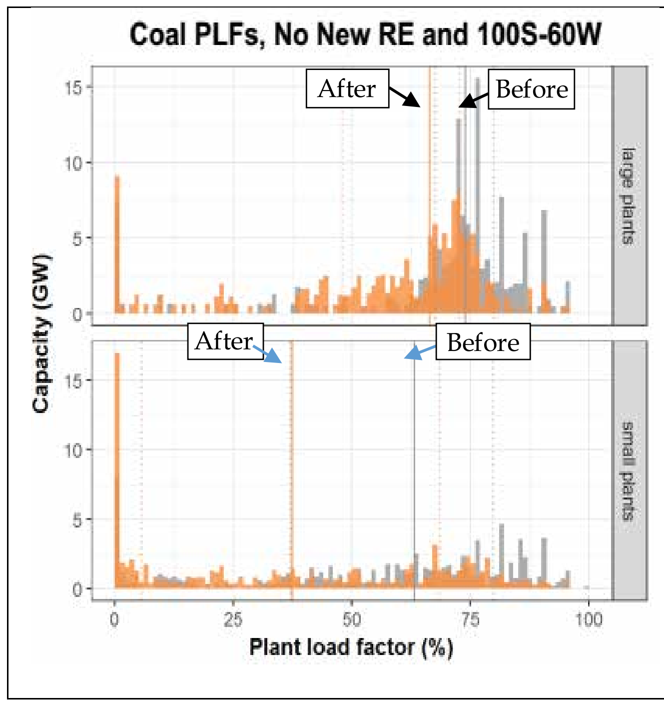
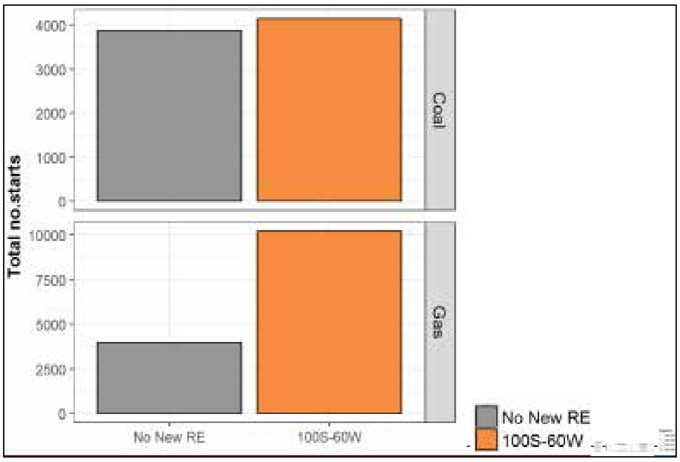


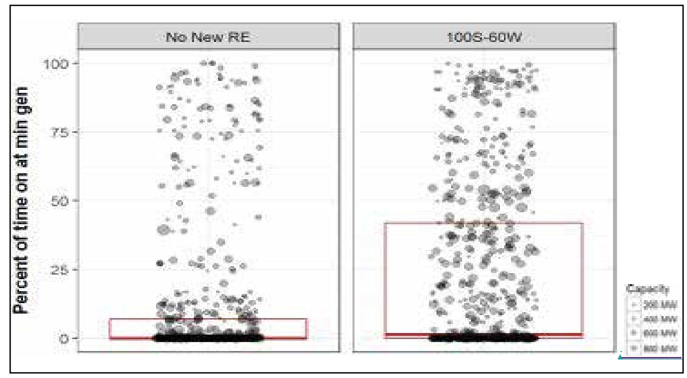
Figure 8: Impact on Coal PLFs & no. of starts under No New Renewable Energy and 100S 60W scenarios

In 100S-60W (100 GW solar and 60 GW wind scenario), the average coal Plant Load Factor (PLF) would drastically fall down as compared to no new renewable energy capacity addition scenario. The same results are applicable to gas based power plants as well. The report states that gas power plants would have to face more start-ups and spend more time at minimum generation. The graph depicts the total number of start-ups for coal (top) and gas (bottom).



(Source: GTG Report)

Figure 9: Impact on number of starts under No New Renewable Energy and 100S 60W scenarios



(Source: GTG Report)

Figure 10: Impact on Online Status at Minimum Generation of Coal Plants

The report further states that the percentage of time, the coal power plants spends online at minimum generation (minimum stable level), also increases under the 100S-60W scenario as compared to no renewable energy capacity addition scenario.

As can be seen from similar studies, large scale renewable energy integration is envisaged to have impact on conventional generators, however through appropriate compensation for such generators coupled with grid management regulations could bring in win-win situation for the stakeholders involved.

Conclusion

Addressing grid management issues upfront, is the key for increasing acceptability of more and more renewable energy in the grid. Sustainable efforts has to be put while adopting green energy and the countries resources has to be optimally utilised while evaluating the production costs on a continual basis. In the long-run, bearing in mind the interest of developers, institutions, Regulatory Commissions, utilities, funding agencies and other stakeholders in power sector, a coherent approach has to be followed to tackle the issues discussed and an energy plan could enable to handle more green power penetration.

Snippets on Wind Power

European Investment Bank, SBI Expand Cooperation in Wind Energy Financing

The European Investment Bank and State Bank of India have agreed to cooperate on financing renewable energy and providing new support for wind energy projects across India by expanding the ongoing financing initiative in the field of onshore wind projects. With this collaboration, the promoters of wind projects in India will benefit from long-term low cost financing under the dedicated EUR 600 million renewable energy financing programme that is already supporting large-scale solar investment across the country. EIB has also approved a new line of credit to Yes Bank to boost private investment in clean energy projects.

Floating Wind Farm in Portugal

A consortium led by Portugal's EDP Renewables (EDPR) will invest 125 million euros ($144 million) over three years in a 25 MW floating offshore wind farm in the Atlantic about 20 km off the coast of Viana de Castelo in northern Portugal. The project, Europe's second floating wind farm, involves anchoring three turbines on semi-submersible platforms at water depths of up to 100 meters with each turbine of 8.4 MW capacity. The European Investment Bank (EIB) is providing 60 million Euros of the funding for the new wind farm. Offshore floating wind farms are an attractive alternative energy source because they open up areas of deep ocean to harness energy, unlike fixed offshore wind turbines that need to be installed in shallower coastal waters.

Source: REUTERS, 20 October 2018

Country's Tallest Hybrid Concrete Tubular Wind Turbine Generator Commissioned by Suzlon

Suzlon has commissioned the first prototype of country's tallest hybrid concrete tubular Wind Turbine Generator. The 140 metre tall tower in Tiruneveli district is a combination of concrete base and foundation, supporting a tubular steel tower and avoids exponential increase in weight and costs of steel tubular towers. The S120 rotor incorporates fourth generation rotor aerodynamics and enhanced pitch control systems to reduce overall loads.

Source: PTI, Chennai, October 3, 2018

Photo Feature

Technical Brainstorming Session on IWTCS

A Technical Brainstorming Session was conducted on Draft Indian Wind Turbine Certification Scheme (IWTCS) of the Ministry of New and Renewable Energy on 26th November 2018 by IWTMA at Le Meridien, Chennai. The photographs for the session are given here.

Snippets on Wind Power

How Electricity Helped India Gain on Ease of Doing Business Ranking

The reduced cost and time taken to get a power connection in the metro cities of Delhi and Mumbai over the past year is among the main reasons why India gained in the World Bank's latest Ease of Doing Business ranking. Getting Electricity was made cheaper and faster in Delhi with the cost for low voltage connections reduced by more than 30 percent of the income per capita, while the time needed was reduced to 31 days, from 39 days. The report measures progress of economic reforms in only two cities including Delhi and Mumbai. For measuring electricity reforms, it considered power supply data on Tata Power Delhi Distribution (TPDDL) in Delhi and Reliance Utilities and Power in Mumbai. Overall, India has jumped 23 places to 77th rank in the rankings thanks to feedback from stakeholders that it is now significantly simpler to get construction permits and ship goods across the country's borders, among other things.

Source: ET Energy World, 31st October 2018

Wind Power: Transmission Gap Between States a Concern for Capacity Addition

Existing inter-state transmission infrastructure in the states with high wind potential may not be sufficient to provide connectivity to capacity bid out by central government agencies, research firm ICRA has said. Augmentation of transmission systems would take about 24-36 months, whereas developers are mandated to commission wind power projects within 18 months from the time letters of award are issued. Such impediments potentially pose a risk on project viability, as delays beyond six months from scheduled commissioning date would result in reduction in PPA tariffs, ICRA noted.

FY22 target warrants major ramping up of transmission capacity. Inadequate transmission infrastructure has forced the government to reduce capacities offered in the upcoming auctions by more than 50% to 1,200 MW.

Source: Financial Express Bureau, October 17, 2018

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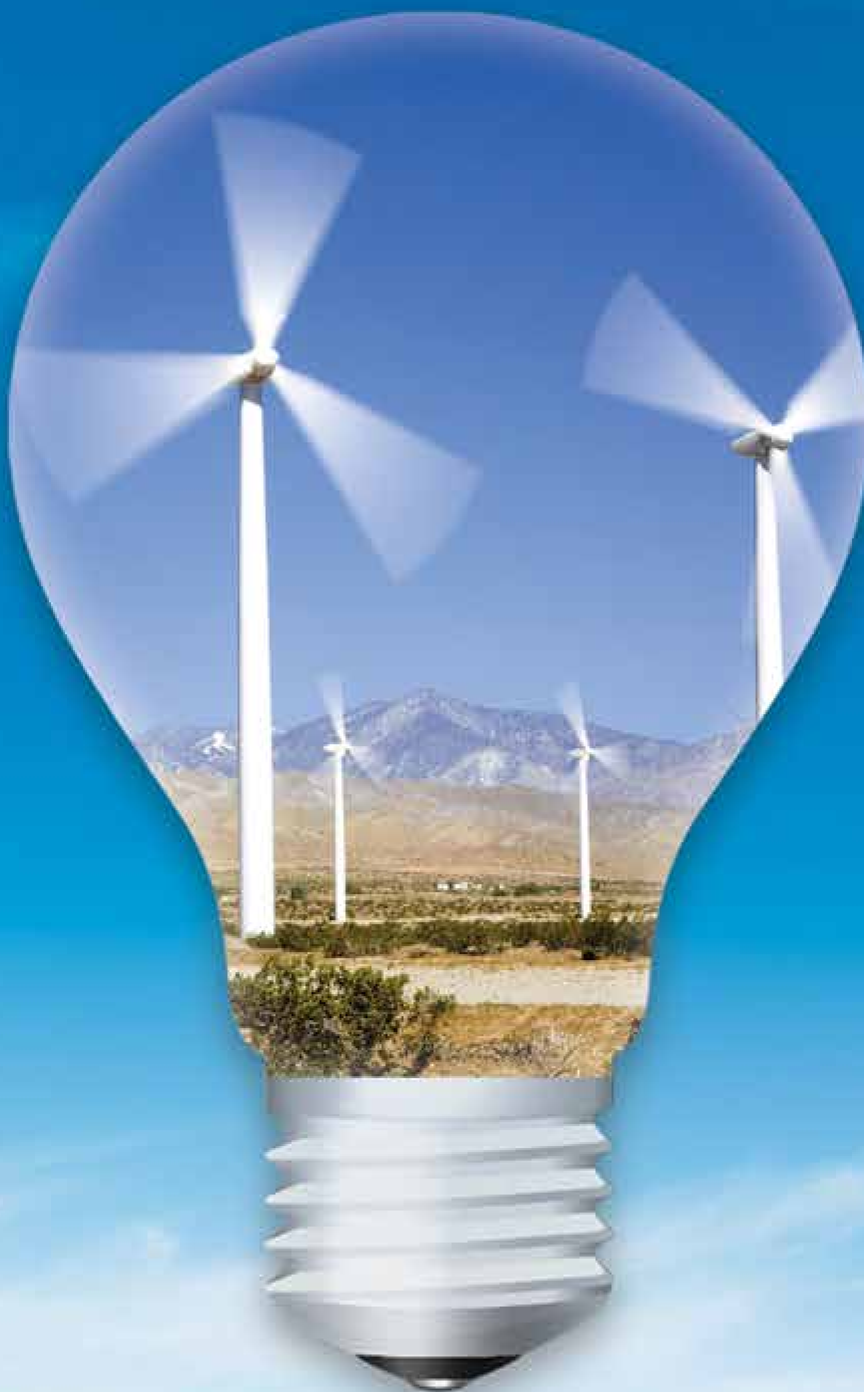

Wind - the energy of now and the future

ACE DATA, Coimbatore