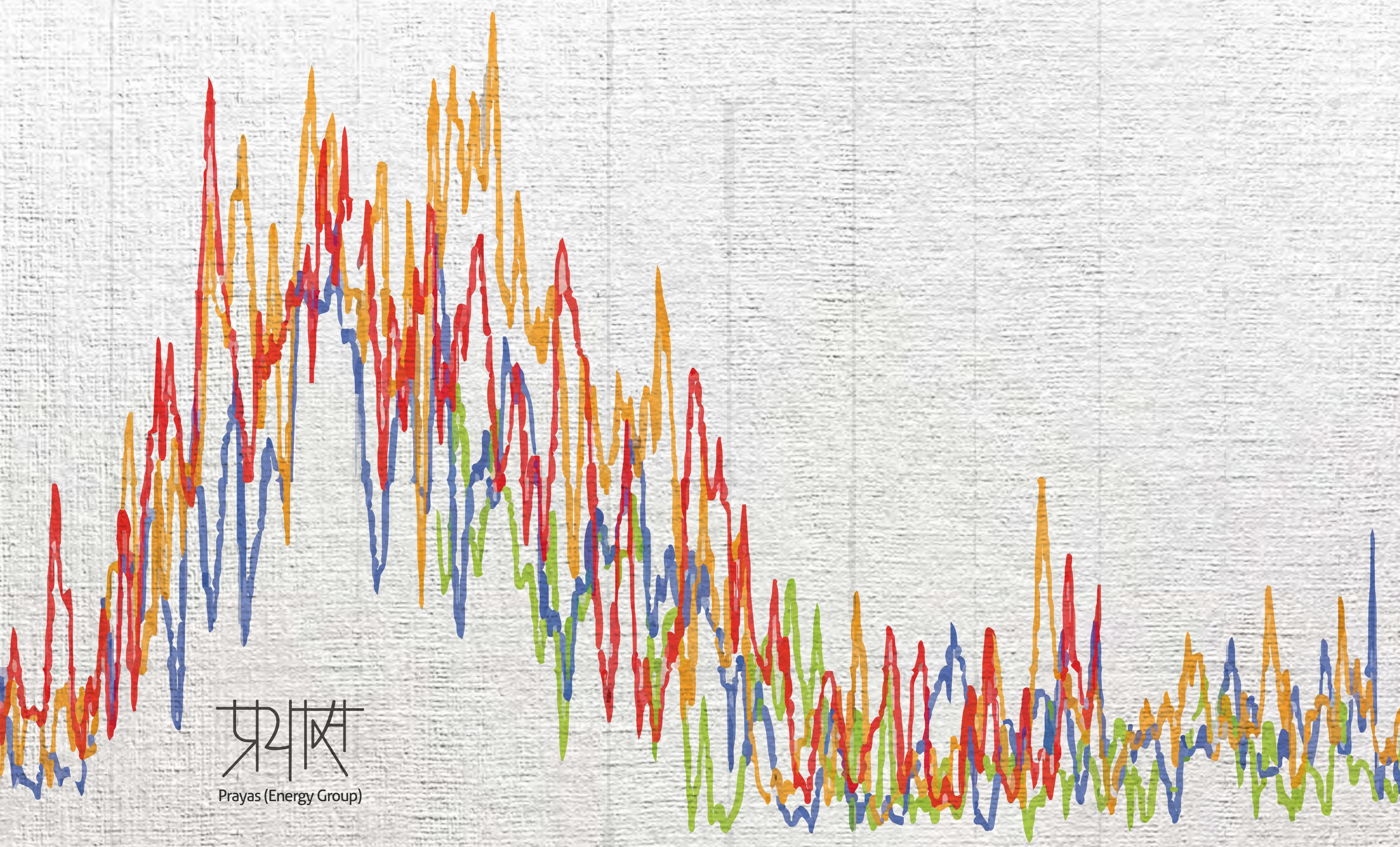
Grid Integration of Renewables in India

An Analysis of Forecasting, Scheduling and Deviation Settlement Regulations



Prayas (Energy Group)

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An Analysis of Forecasting, Scheduling and Deviation Settlement Regulations

Ashwin Gambhir | Jatin Sarode | Shantanu Dixit

September 2016

Prayas (Energy Group)

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1
Introduction

India has prioritised increasing the share of renewable energy (RE) based power generation capacity for several years. A supporting policy and regulatory framework has ensured an exponential growth in RE capacity, reaching an all time high of 42.6 GW, or 14.1% of the total generation capacity by March 2016. This share is set to increase even more rapidly in the coming six years, given the national RE target of 175 GW (100 GW solar and 60 GW wind) of RE by 2022 (Mint, 2015). It could reach as high as 32.2% by 2022, considering the 175 GW in place.[1] In terms of electricity generation, while the present share of RE is ~ 6%, the Ministry of New and Renewable Energy (MNRE) is hoping to push it to 17% by 2022, of which 8% is targeted to come from solar alone.[2] Renewable energy deployment is mainly concentrated in the Southern and Western Indian states (80% of total). Several states such as Tamil Nadu (37%), Maharashtra (17%) and Gujarat (18%) have a much higher share of RE in their generation capacity mix compared to the national share (CEA, 2016).

Renewable energy generation, especially from wind and solar power, is variable in nature, given its dependency on the weather. In addition, due to the diurnal and seasonal variations (more pronounced in the case of wind power given the Indian monsoon) in generation, its shorter time scale (minutes to hours) impacts on the grid are much higher than perceived impacts considering only the lower annual average values. For example, penetration of wind power in energy terms in Tamil Nadu in 30-35 % from June to September and 5-10% during other months (CEA, 2013). Grid operators do not have visibility with respect to wind and solar power generators[3], because until recently they were exempt from any scheduling responsibilities which were applicable to conventional generators. Maintaining constant frequency is important for the reliable and secure operation of the grid. Deviation in frequency can occur due to instantaneous differences between generation and demand, which grid operators apprehend would exacerbate due to higher penetration of renewables.

This coupled with problems of the relatively weak Indian grid such as high line losses, load shedding, low voltages at the distribution tail end, high variation in frequency, lack of adequate reserves, flexible generation and effective demand forecasting makes reliable and effective grid integration of renewables even more challenging. Hence, policy-regulatory officials and grid operators fear that such a steep and rapid increase in 'infirm' or 'non-dispatchable' renewables will affect the electricity grid and make grid operation far more complex and difficult to deal with.

Various European countries and some regions in the United States have reliably integrated high levels of variable renewables in their generation mix, and it is important to learn from their experiences.[4] However, several learnings may not be fully or immediately relevant in the Indian context because of differences in the grid infrastructure, and more importantly, in the regulations and policies governing grid planning and operation. Hence, it is important to understand the concerns of grid operators when it comes to integrating high levels of variable renewables.

This report is an attempt in that direction. We begin with an explanation of the structure of the Indian power grid, its institutional setup as well as its daily operations. With increasing renewables, we examine the potential rise in challenges to grid operation at the transmission level, and ways to mitigate such challenges through effective grid integration of renewables. This report does not look at the operational issues at the transmission planning or distribution system levels.

The focus of the report is on forecasting and scheduling of renewable power, one of the key starting points to minimise grid imbalance and aid effective integration. The report analyses the various steps at the Central and State levels towards initialising forecasting and scheduling of renewables in the country. It also examines the various supporting initiatives adopted by ERCs and policy makers towards easing grid integration. This analysis is also informed by focused discussions with a key sector stakeholder, notably grid operators. We conclude by outlining some potential suggestions and ideas for easing the challenges of grid integration. This report is being released as a working paper given the various changes which are underway in the regulations and policies related to grid operation.

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1. Conventional capacity addition data for this period is based on CEA's Perspective Transmission Plan (January 2016).
2. National Tariff Policy amendment, 2016.
3. With the exception of some states like Gujarat, Rajasthan and Tamil Nadu which have only very recently begun the process of RE scheduling.
4. (http://energytransition.de/, 2015) (Martinot, 2015) (Martinot, 2015)

2
The Indian Power System

2.1 Structure of the Indian Power Grid

The Indian Electricity Grid Code (IEGC) defines the power system as *all aspects of generation, transmission, distribution and supply of electricity*.[5] The transmission network in India consists of the inter-regional networks, the inter-state networks which connect two states, and the intra-state networks which exist within a particular state. The Power Grid Corporation of India (PGCIL) is the Central Transmission Utility (CTU) that owns, operates, maintains and plans the inter-regional and inter-state transmission networks, whereas the intra-state transmission networks are owned, operated, maintained and planned by the State Transmission Utilities (STU). As of April 2016, India had about 330,000 circuit kilometer (ckm) of AC and High-Voltage Direct Current (HVDC) lines.[6] At the end of the 12th five-year plan, transmission lines are expected to expand to about 348,000 ckm of AC and HVDC lines.

For operational and planning purposes, the transmission network is divided into five regions, namely Northern (NR), Eastern (ER), North Eastern (NER), Southern (SR) and Western (WR). While four regions were interconnected with each other over time from 1991 to 2006, the southern grid was fully connected to the rest of the grid in January 2014 (Powergrid). This integration has made the Indian grid one of the largest operating synchronous grids in the world, with about 300 GW (April 16) of installed power capacity.[7] In general, all the state owned generating stations are connected to the intra-state transmission network (InSTS), and the centrally owned inter-state generating stations (ISGS) are connected to the inter-state transmission system (ISTS). The ISGS can have shares of their capacity allocated to different states. Distribution of the electricity to end consumers is carried out by the distribution utilities connected to the intra-state network (Pandey, Vivek, 2007).

2.2 Institutional Framework for Management of Grid Operation

The PGCIL established the Power System Operation Corporation (POSOCO) of India in 2010 for the purpose of power management and an efficient operation of the grid. This apex body for power system operation consists of the National Load Dispatch Centre (NLDC) and five Regional Load Dispatch Centers (RLDCs) which coordinate electricity dispatch across the country. For operational and planning purposes, each RLDC controls each regional grid formed by the ISTS. Each state grid formed by InSTS is controlled by the State Load Dispatch Center (SLDC). While SLDCs are independent organisations, they work in close coordination with their respective RLDCs for ensuring optimal operations and take directives from the RLDCs.

The Central Electricity Regulatory Commission (CERC) is the apex body involved in framing various operational and commercial rules and regulations at the central level which apply to the ISTS. Important amongst these are the Indian Electricity Grid Code (IEGC) and the Deviation Settlement Mechanism (DSM) regulations. State Electricity Regulatory Commissions (SERC) formulate the rules for operation of the grid within the state using CERC laid norms as guidelines.

The Central Electricity Authority (CEA) is responsible for defining standards for operation of the transmission system, power plants, and safety requirements for operation and maintenance of the electrical transmission system and plants. For each region, a Regional Power Committee (RPC) is formed by the CEA. The RPC analyses the performance of the transmission system and generation stations, plans the inter-state and intra-state transmission systems, carries out stability studies, and is responsible for the commercial accounting of electricity at the regional level (Pandey, Vivek, 2007).

---

5. It includes the following: (a) generating stations; (b) transmission or main transmission lines; (c) sub-stations; (d) tie-lines; (e) load dispatch activities; (f) mains or distribution mains; (g) electric supply lines; (h) overhead lines; (i) service lines; (j) works. (CERC, 2010)
6. http://www.cea.nic.in/reports/monthly/executivesummary/2016/exe_summary-04.pdf
7. http://pib.nic.in/newsite/PrintRelease.aspx?relid=102244

Table 1 shows the various institutions involved in grid management, their functions and the regulations and policies formulated by them.

Table 1 : Institutional Set up Grid Planning, Operation and Management

<table>
<tr><th>Institution</th><th>Functions</th><th>Regulations/Procedures formulated by the Institution</th></tr>
<tr><td rowspan="5">CEA</td><td>Planning for development of the electricity system in the country</td><td>Technical Standards for Construction of Electrical Plants and Electric Lines</td></tr>
<tr><td rowspan="4">Specify standards for construction, maintenance, operation of electric plants and electric lines</td><td>Technical Standards for Connectivity to the grid, Regulations</td></tr>
<tr><td>Metering Regulations</td></tr>
<tr><td>Grid Standards</td></tr>
<tr><td>Perspective Transmission Plan, Transmission Planning Criteria Manual</td></tr>
<tr><td rowspan="9">CERC</td><td>To regulate and determine tariff for the inter-state transmission of electricity</td><td>Indian Electricity Grid Code</td></tr>
<tr><td>To issue licences to persons to function as transmission licensee with respect to their inter-state operations</td><td>Deviation Settlement Mechanism</td></tr>
<tr><td>To specify Grid Code with regard to Grid Standards</td><td>Grant of Connectivity, Long-term Access and Medium-term Open Access in inter-state Transmission and related matters (Open Access in inter-state Transmission)</td></tr>
<tr><td rowspan="6">To specify and enforce the standards with respect to quality, continuity and reliability of service by licensees</td><td>Power System Development Fund Regulations</td></tr>
<tr><td>Ancillary Services Regulations</td></tr>
<tr><td>Sharing of inter-state Transmission Charges and Losses Regulations</td></tr>
<tr><td>Fees and Charges of Regional Load Dispatch Centre and regulations about other related matters</td></tr>
<tr><td>Power Market Regulations</td></tr>
<tr><td>Measures to relieve congestion in real time operation regulations</td></tr>
<tr><td rowspan="5">SERC</td><td>Determine tariff for transmission and wheeling of electricity within the state</td><td>State Grid Code Regulations</td></tr>
<tr><td>To issue licences to persons to function as transmission licensee</td><td>Distribution and Transmission Open Access Regulations</td></tr>
<tr><td>Specify state grid code</td><td>Transmission Licensee Conditions Regulations</td></tr>
<tr><td>Facilitate intra-state transmission of electricity</td><td>Multi-Year Tariff Regulations for Transmission</td></tr>
<tr><td>Specify or enforce standards with respect to quality, continuity and reliability of service by licensees</td><td></td></tr>
<tr><td rowspan="4">NLDC/ POSOCO</td><td>Ensure Integrated Operation of Regional and National Power Systems to facilitate transfer of electric power within and across the regions</td><td rowspan="4">Various Operational Procedures</td></tr>
<tr><td>Scheduling and dispatch of electricity over inter-regional links</td></tr>
<tr><td>Coordination with RLDCs for achieving maximum economy and efficiency in the operation of National Grid</td></tr>
<tr><td>Monitoring of operations and grid security of the National Grid</td></tr>
</table>

RLDC	Optimum scheduling and dispatch of electricity within the region	Various Operational Procedures
	Monitor grid operations	
	Keep accounts of quantity of electricity transmitted through the regional grid	
	Exercise supervision and control over the inter-state transmission system	
RPC	To undertake Regional Level operation analysis for improving grid performance.	Various Operational Procedures
	To facilitate inter-state/inter-regional transfer of power; facilitate planning relating to inter-state/ intra-state transmission system with CTU / STU	
	Planning of outage of transmission system and for maintaining proper voltages	
	Undertake operational planning studies including protection studies for stable operation of the grid	
	Preparation of Regional Energy Accounts (UI, reactive energy)	
	Certify availability of Regional AC and HVDC transmission system for purpose of payment of transmission charges/capacity charges and incentive	
SLDC	Optimum scheduling and dispatch of electricity within a state	Various Operational Procedures
	Monitor grid operations	
	Keep accounts of the quantity of electricity transmitted through the state grid	
	Supervision and control of the intra-state transmission system	
	Responsible for carrying out real time operations for grid control and dispatch of electricity within the state	

(Compiled from- (Ministry of Law and Justice (Legislative Department), 2003), (CERC, 2010), (GERC) and websites of CERC, MERC, MSLDC, WRLDC, CEA, WRPC)

3
Operation of the Grid

The grid operation in India over an entire day is divided into 96 blocks of 15 minutes each, starting from 12:00 am to 11:45 pm. Grid operation is based on the operation codes mentioned in the IEGC and State Grid Codes with an aim to increase the overall operational reliability and economy of the entire grid. The operation codes contain guidelines and rules for controlling voltage levels and frequency within acceptable limits. Deviation limits for the voltage levels (765KV to 33KV) are stated in the grid codes in order to avoid unwanted disconnection of the network and voltage collapse in view of the security of the grid.

3.1 Day Ahead Scheduling

In India, the day ahead scheduling process forms the backbone of grid operation, both at the intra-state and inter-state network levels. This process is aimed at optimal scheduling and dispatch of the electricity for the next day (CERC, 2010). SLDC coordinates the day ahead scheduling process for beneficiaries and generators connected to InSTS, and RLDC coordinates this process for beneficiaries and ISGS connected to ISTS. To participate in the day ahead scheduling process, the beneficiaries and the generators use forecasting methods to predict their demand and generation for the next day respectively. These details are sent to the respective scheduling entity, SLDC or RLDC. Table 2 shows how the day ahead scheduling process is executed on day N when actual delivery of electricity is to happen on day N+1: (WRLDC, 2014) (OERC, 2015) (Vijendra Mittal, 2014).

Table 2 : Day Ahead Scheduling Process

Day	Time	Intra-State Network	Inter-State Network
N	8 am	State generators and beneficiaries including the distribution utilities send their block wise generation and demand respectively to SLDC.	ISGS send their block wise generation capabilities to RLDC.
N	9 am	SLDC receives generation capabilities of ISGS for their shares from RLDC.	RLDC distributes and sends the ISGS capabilities to respective beneficiaries including states.
N	3 pm	SLDC prepares their drawl schedule considering generation and demand data from above received data including long-term access, medium-term and short–term open access, and sends to RLDC.	RLDC matches the drawl received from the states and other beneficiaries with capabilities received from ISGS. It checks for possible technical constraints and prepares net dispatch schedule for ISGS and net drawl schedule for states.
N	6 pm	SLDC receives net drawl schedule for states from RLDC.	RLDC sends net dispatch schedule for ISGS.
N	10 pm	SLDC makes corrections if necessary based on various constraints and sends revised drawl schedule to RLDC.	ISGS make corrections if necessary based on various constraints and sends revised dispatch schedule to RLDC.
N	11 pm	SLDC receives final schedule from RLDC.	RLDC sends final schedule to beneficiaries including states and ISGS.
N+1	12 am	Actual dispatch by the generators and drawl by beneficiaries starts in the state by merit order principle, in which the least cost generation is allowed to dispatch first.	Actual dispatch by ISGS and drawl by beneficiaries starts by merit order principle in which the least cost generation is allowed to be dispatched first.
N+1	12 am onwards	SLDC starts accepting revision of schedules from state generators and beneficiaries which become effective after 4th block (1 hour).	RLDC starts accepting revision of schedules from ISGS and beneficiaries which become effective after 4th block (1 hour).

N+1	12 am	Generators and beneficiaries use power trading via power exchanges to sell or buy the excess or deficit energy required for them for intra-day and day ahead activities.	ISGS and beneficiaries use power trading via power exchanges to sell or buy the excess or deficit energy required for them for intra-day and day ahead activities.
N+2	12 pm	Final schedules are recorded and sent to RPC for commercial settlement.	Final schedules are recorded and sent to RPC for commercial settlement.

3.2 Frequency Management

The voltage and frequency of the grid are the two basic and important indicators of the health of the grid. Maintaining constant voltage and frequency (within a certain tolerance level) over time are important for the reliable and secure operation of the grid. The deviation of the frequency can occur due to short-run differences between generation and demand.

Before the year 2000, generators were paid based on a single part tariff, i.e. only based on energy generation. Such a framework did not provide any incentive for increasing generation during peak demand or reducing it during off-peak hours, thereby encouraging grid indiscipline. This was reflected in the poor frequency profile during these years. To overcome this limitation, an Availability Based Tariff (ABT) mechanism was introduced in 2000. This trifurcated the existing single part payment for energy into: a) Capacity or fixed charge to be paid based on availability, b) Energy or variable charge to be paid on the basis of scheduled energy and c) Unscheduled Interchange (UI) as a penalty mechanism for deviation from generation/drawal schedule. Instituting ABT significantly improved the grid frequency profile and grid discipline in the following years.

Since 2009, the CERC began issuing separate UI regulations, which until then were specified as part of the Tariff Regulations. They introduced volume limits for the first time, though restricted only for buyers. Specifically, *"The over-drawal of electricity from the schedule by any beneficiary or a buyer during a time-block shall not exceed 12% of its scheduled drawal or 150 MW (whichever is lower) when frequency is below 49.5 Hz, and 3% on a daily aggregate basis."* (CERC, 2009) These regulations (with later amendments) remained in place until 2014. In the later years, the UI mechanism was being incorrectly used by various states like a trading platform (very high over and under drawals) resulting in grid instability. Hence, it was replaced by the Deviation Settlement Mechanism Regulations in order to further improve grid discipline and stability, and avoid large scale blackouts like the ones experienced in July 2012. Importantly, it brought in stricter volume limits, both for over/under drawal by states as well as over/under injection by the ISGS (seller). Additionally, no deviation charges were payable for over-injection by sellers and under-drawal by buyers beyond the stated volume limits unlike the UI mechanism. The UI penalty is linked to frequency and is structured such that the further the frequency is from the desired 50 Hz, the higher is the penalty. This led to smaller volumes of overdrawal by states and improved grid frequency. (energysector.in, 2014)

3.3 Deviation Settlement

The total demand of the state is the sum of the demand from distribution utilities and open access consumers. This total demand is served from generation within the state and import from other states or ISGS connected to the interstate network. The schedule can be represented by the following equation given in Figure 1. However, in real time, the events like increased or lower demand, weather changes, generator outages, and network constraints lead to entities deviating from their scheduled drawl and generation within the state and at the regional level. Equation for the deviations is as follows, where Dev_X = Scheduled_X- Actual_X. (Figure 2)

Such deviations are penalised as per the DSM mechanism, which do not allow over/under drawal above 12% of the schedule or 150 MW, whichever is lower within a frequency band of 49.7 – 50.1 Hz. More importantly, this hard limit of 150 MWs *"shall apply to the sum total of over-drawal by all the intra-state entities in the state including the distribution companies and other intra-state buyers, and shall be applicable at the inter-state boundary of the respective state". (DSM principal regs, 2014).*

Figure 1 : Relation of Components in Day Ahead Schedule of the State

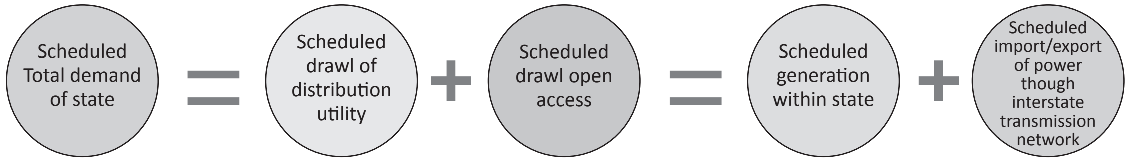
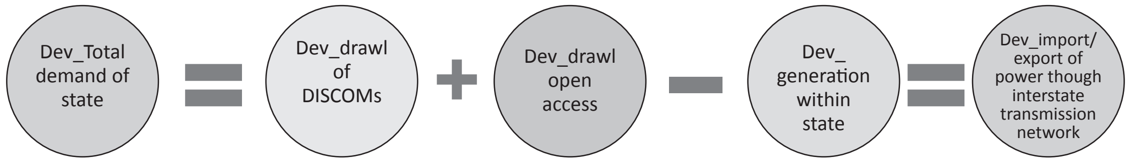


Figure 2 : Relation of Deviations of Components in Day Ahead Schedule of the State



Under the DSM mechanism, each state and ISGS is charged for deviating from its scheduled drawl or generation in each of 15 minute 96 blocks in a day. The deviation penalty is calculated by the RPC on a weekly basis, based on deviation charges notified in the CERC-DSM regulations since February 2014. The DSM mechanism is a part of the inter-state ABT mechanism for regional entities. The account which is used for transactions related to deviation charges, reactive charges or the congestion charge of the regional entity is known as the regional pool account. The state is paid for under drawl, charged for over drawl, while the generator is paid for over injection, and charged for under injection. Outside the deviation limits (minimum of 12% of schedule or 150 MW), the state and the generator incur additional deviation charges.

States try to minimise the state deviation at its boundary. The deviation can be minimised by minimising the deviation of each entity like distribution utilities drawal and generators injection, and by using intra-state ABT (if present) within the state. The intra-state ABT mechanism uses deviation settlement mechanism for the state entities like state generators, distribution utilities, and open access consumers. The deviation settlement mechanism within the state operates exactly like that at the regional level (explained in detail in Section 6.2.2). The account which is used for transactions related to deviation charges, reactive charges or the congestion charge of state entities like state generators and distribution utilities is known as state pool account. For settling of the deviation within the state, the intra-state ABT mechanism is recommended for all states since 2002-03. However, only six states, namely Delhi, Gujarat, Madhya Pradesh, Maharashtra, West Bengal and Chattisgarh have implemented the intra-state ABT mechanism (Ministry of Power, 2016) (FoR, 2016). The intra-state ABT mechanism increases the cooperation between state entities like distribution utilities and state generators to minimise the state deviation at state periphery level (MERC, 2014).

3.4 Violation of Deviation Limits and Ways to Reduce Them

The operating frequency band has improved from roughly 48.75 Hz to 50.5 Hz in 2004, to the present operating frequency band of 49.7 Hz to 50.3 Hz in 2015, chiefly due to the implementation of the inter-state ABT mechanism at the regional level and subsequent amendments in the deviation settlement mechanism from UI to DSM. (Ministry of Power, 2016)

However, while the frequency profile has improved tremendously, most states continue to consistently violate the volume limit of 150 MW (CERC, 2015). In 2014-15, the maximum range of the state deviation for over drawl and under drawl for some states (Rajasthan, Maharashtra, Gujarat, Haryana, Tamil Nadu, Uttar Pradesh) were 550MW-2100MW and 1000-2400MW respectively, exceeding the deviation volume limits many times over. (CERC, 2015) The reason for such high deviations are mainly, "*absence of or poor load forecasting, lack of planning, procedures for calling in reserves and non-adherence to schedule by grid-connected entities such as conventional generators and DISCOMs in the state".* (CERC, 2015) To determine the significant contributor to such high deviations, POSOCO carried out an analysis for 2013-14 for Gujarat and Tamil Nadu. "*The results for correlation of schedule deviations with change in demand vs. change in conventional generation vs. change in wind generation were studied. It was observed that* *there was little correlation of observed deviations on state boundary with change in wind generation, instead, much higher correlation was observed with demand change"*. (CERC, 2015) In both states, it was observed that demand changes affect deviations by an order of magnitude higher than that due to wind generation. Deviations continue to occur in windy and non-windy seasons as well as in states with high or low RE capacity. However, several RE-rich states like Gujarat disagree with the above POSOCO analysis, maintaining that wind and solar power contribute to state deviations resulting in a financial burden on the state pool. Other states like Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu also have expressed difficulty in managing solar and wind power and sought special dispensations for them. (CERC, 2016)

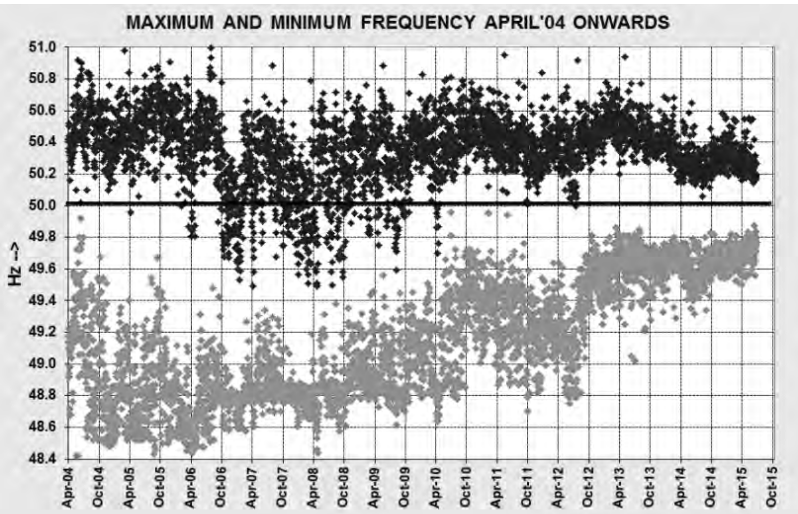
3.4.1 Demand Forecasting

As noted above, the primary cause for deviations is a lack of scientific and rigorous demand forecasting by load serving entities in many states. The CERC has strongly noted that "*long, medium and short term load forecasting and generation planning, peak vs. off-peak planning, streamlined energy accounting for all entities, RE forecasting and scheduling - these are critical and fundamental steps for sound grid management. There cannot be any excuse for not undertaking each one of these actions at the state level, and thereafter not taking responsibility for grid indiscipline that results due to absence of the above."* The MoP has directed all the distribution utilities to implement load forecasting for their utility by 1.6.2016. (Ministry of Power, 2016)

3.4.2 Reserves

In IEGC, the envisioned frequency band is 49.9 Hz - 50.05 Hz. For correcting the frequency closer to the standard value of 50Hz, different types of frequency control mechanisms are used at the generator level. In India, only primary control of frequency is present with the generator. Primary control responds to frequency deviation within one minute. (Ministry of Power, 2016) At present, though the primary control brings the frequency closer to the standard value of 50Hz, it does not restore the frequency value to exactly 50Hz. Figure 3 shows the maximum and minimum frequency of the Indian grid since April 2004. To restore the frequency accurately to 50 Hz, secondary frequency control reserves are needed. These reserves require Automatic Generation Control (AGC) implemented at the generator level and operated by the LDC. The CERC has set a target of implementing the AGC at all regional generators by 1.4.2017. (CERC, 2015) Implementing the AGC will result in support from the generation if the demand is greater than the generation. In addition to improving the frequency profile of the system, it will also help in maintaining the inter-regional line flows close to the schedule. This is an important step to move towards realising a narrower band of frequency around the standard frequency of 50Hz of the Indian grid. This would need some infrastructure updates by both the generator as well as the LDC to enable the LDC to send control signals to the generator in its control area though appropriate communication infrastructure.

Figure 3 : Maximum and Minimum Frequency of the Indian Grid since April 2004



(Source - Report of the Technical Committee on Large Scale Integration of Renewable Energy, Need for Balancing, Deviation Settlement Mechanism and associated issues)

3.4.3 Ancillary Services for Frequency Regulation

One way to supplement achieving load generation balance is by deploying the generation reserves. As noted earlier, out of the primary, secondary and tertiary reserves, only primary reserves are being used in the country. In addition, there were cases in which load shedding was carried out by the utilities despite the surplus generation being available. (CERC, 2013) In 2014-15, 3000-4000 MW of the un-requisitioned surplus (tertiary reserve) was available with the ISGS for 85% of time. (CERC, 2015)

To use the tertiary reserves present at inter-state level, the CERC notified the Central Electricity Regulatory Commission (Ancillary Services Operations) Regulations, 2015 on 13.8.2015. Ancillary services are expected to help bring the frequency back to the standard value (50Hz) and relieve transmission congestion. Under this regulation, the unrequisitioned surplus from all generating stations that are regional entities and whose tariff for the full capacity is determined by CERC is used to provide the ancillary services. The ancillary services are called Reserve Regulation Ancillary Services (RRAS), while the service providers will be called RRAS providers. NLDC, the Nodal Agency, is implementing the ancillary services with the help of RLDCs at the inter-state level. The all-India and region wise load forecast from the NLDC formed by aggregation of individual load forecasts from RLDCs and SLDCs at the regional and state levels is being used for determining the amount of reserves needed on the day-ahead basis. (POSOCO, 2016) In addition, the current forecasting regulations for renewable generators will improve the accuracy of the estimation for the amount of reserves needed by the power system on day-ahead basis. (CERC, 2015)

The ancillary services are deployed in the scenarios when there is a change in demand pattern, tripping of network element, forced outage of network element, frequency deviation trend, diversion of grid voltage at important points from the recommended values, or congestion due to real time line flows. The deployment of the ancillary services is linked to the frequency of the grid in the following manner. If the frequency of the grid remains below 49.9 Hz for more than 5 minutes, then the Nodal Agency may issue up regulation instructions and can withdraw down regulation instructions. For up regulation, the Nodal Agency can dispatch from already running units or units under the reserve shut down. If the units under the reserve shutdown are being used for up regulation, then the minimum duration of dispatch for coal based power plants under RRAS is for 96 blocks and for the gas/RLNG/liquid based power plants is 3 hours (12 blocks). If the frequency of the grid stays above 50.05 Hz for more than 5 minutes, the Nodal Agency may issue down regulation instructions and may withdraw up regulation instructions.

The Nodal Agency dispatches the generation from the RRAS providers according to the merit order stack arranged in an increasing order of variable cost for up regulation and in the decreasing order of variable cost for down regulation. For the purpose of energy accounting, the original generation from RRAS providers is rescheduled by the RLDC to accommodate the generation under the RRAS scheme, following which deviation settlement is used for these generators. The ancillary services are expected to decrease the load shedding used by the utilities for limiting the over drawl, and also the dependency on the UI mechanism for the imbalance settlement of the system. This helps in improving the frequency profile of the grid. At present, the ancillary services do not use the market mechanism for deploying the ancillary services. (CERC, 2013) It is expected that the market mechanism for ancillary services will be implemented after 1.4.2017. The new framework will allow the RRAS providers to bid at power exchanges for providing the RRAS services. Power market regulations 2010 already have a provision for trading ancillary service contracts. This market-based mechanism will help in achieving the greater economy and efficiency of the system.

3.4.4 Extended Intra-day Markets

Further, to manage the intra-day generation-demand balance, utilities can trade short-term power through the power exchanges. Earlier such intra-day trading in the power exchange was limited to only a few hours in the day. However, intra-day trading can be done for 24 hours with requested electricity delivered in 3 hours. (CERC, 2015)

In summary, while the frequency profile has undergone a sea change for the better from 2004 to 2016, much remains to be done as indicated by the large amount of deviations of the states of the order of 1000 MW as compared to the deviation limit of 150 MW, non-consistency of frequency at 50Hz, absence of reserves to handle the grid contingencies, etc. An addition of high amounts of variable renewable generation is expected to increase the complexity of handling these grid related issues.

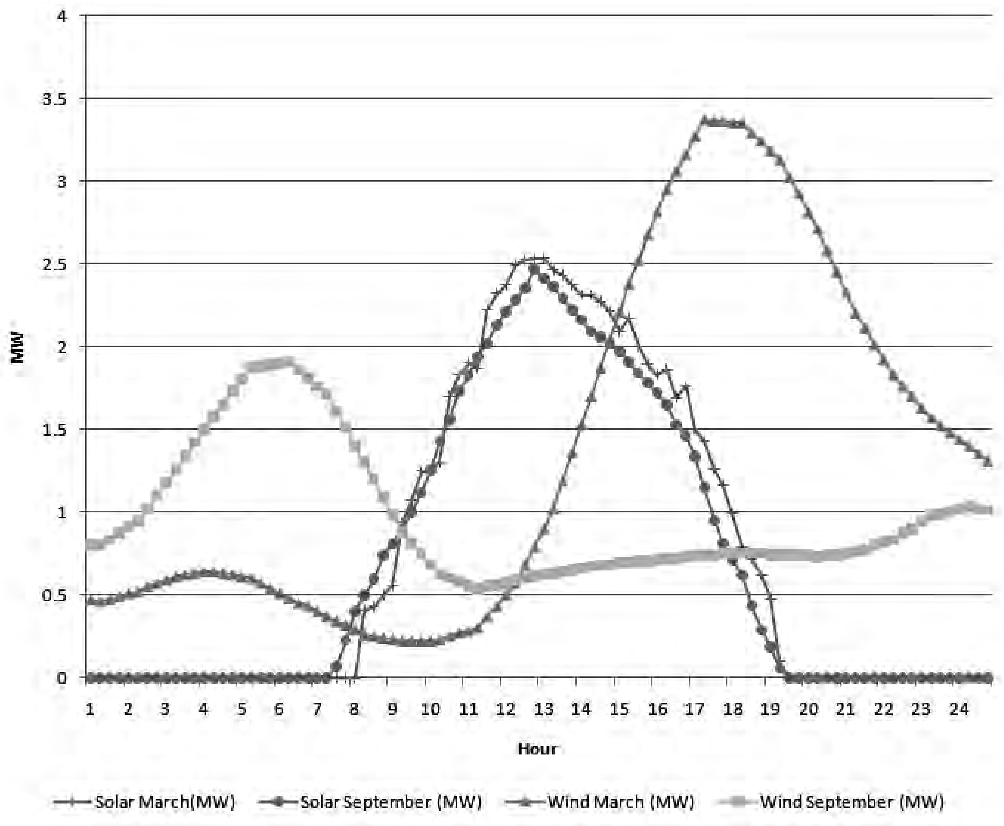
4

Grid Operation with High Penetration of Renewables

4.1 Characteristics of Renewable Generation

A basic characteristic of the renewable sources (especially wind and solar) is that they are dependent on weather conditions, making their generation output variable in nature. For example, solar power output is dependent on the irradiation and temperature of the location which vary on an hourly, daily, seasonal and annual basis. Generally, the peak solar power is generated at noon, while the peak wind power periods may vary by season. Figure 4 shows patterns of wind and solar generation in Gujarat state for the months of September and March. Secondly, depending on the extent of forecasting accuracy, there is a degree of uncertainty in this variable generation. (Arriaga, 2011) Such variability and a lack of or low accuracy of forecasting can potentially contribute to deviations from the schedule.

Figure 4 : Wind and Solar Generation Pattern in Gujarat in March and September



(Source- Gujarat State Load Dispatch Centre)

Another important characteristic of the renewable generation is the near zero variable/marginal cost of generation. Conventional generators using fuels (coal, gas, nuclear) have much higher variable cost of generation in comparison. System operators use merit order principle for deciding the priority of generators in dispatch. The priority is decided by the marginal cost of generation of the generator. Lower marginal cost of generation results in higher priority in dispatch. Near-zero marginal cost of generation prioritises the dispatch of renewable generators over the conventional generators in the dispatch process. (Arriaga, 2011) Hence, RE generators are accorded must-run status to the extent of transmission availability and safe system operation. This implies that grid operators will now have to effectively plan to meet 'net-load' (difference between load and RE generation) through conventional generators.

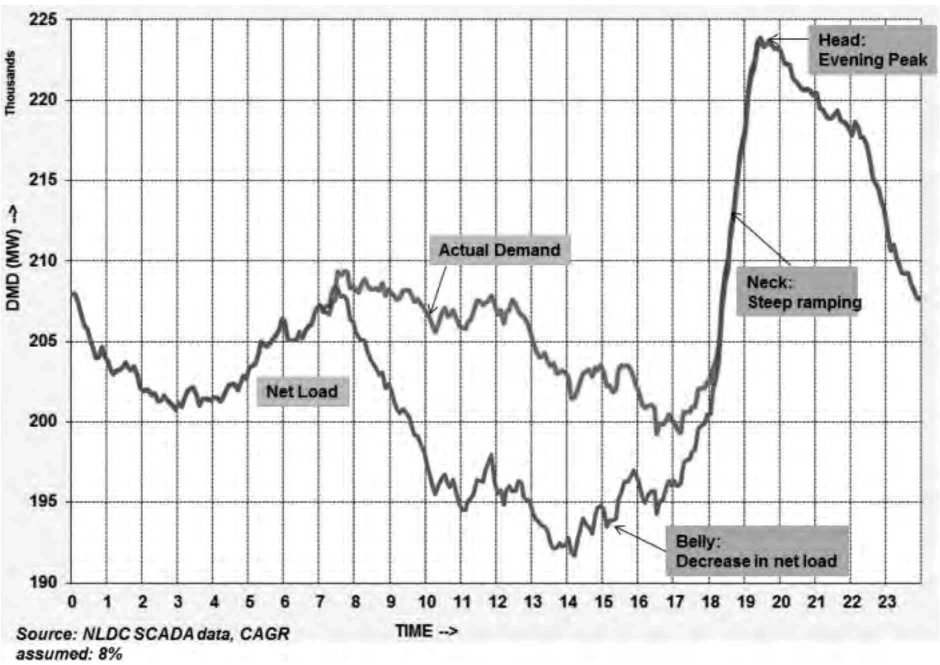
4.2 Grid Operation with High Penetration of RE

Variable renewable generation can have different impacts on different power systems depending on the characteristics of the power system, the percentage of penetration of renewables in the power systems, different voltage levels in the power systems, the generation mix of the country, the time scale used for the analysis, etc. For example, at the transmission level, issues are related to frequency regulation, load balancing, transmission planning, power system stability and security, while at the distribution level, the problems are reverse power flow handling, power quality, distribution planning, etc. In this report, we focus on the potential impact of renewable generation on the power system operation at the transmission level.

4.2.1 From Meeting Load to Meeting Net-Load

Figure 5 shows a sample actual daily demand curve of India. The lower curve shows the net load of the system, obtained as Total Demand - Renewable Generation (20 GW solar and no wind generation in this sample calculation). It can be seen that the actual demand has a steep ramp from 6 to 7.30 pm. The inclusion of solar generation marginally increases the flexibility requirements of the remaining generation fleet, as shown by the curve. However, the flexibility requirements may change in the future with a higher penetration of renewables. While RE generation reduces the net load, depending on the load profile, it could also contribute to reducing peak load and thereby could potentially reduce the need for expensive short-term power purchases.

Figure 5 : Load Curve of India without (Red) and with 20 GW of solar capacity (Blue)



(Source- Report of the Technical Committee on Large Scale Integration of Renewable Energy, Need for Balancing, Deviation Settlement Mechanism and associated issues)

4.2.2 More Flexible Conventional Generation Fleet

The uncertainty of the renewable generation to the extent of forecast error makes it difficult to perfectly predict the day ahead renewable generation. This may cause complexities in scheduling and dispatch of conventional generators. For example, if the conventional generators happen to be over scheduled as compared to the demand, it leads to backing down of generators in real time, while if the generators happen to be under scheduled, short term power purchase though intra-day trading may be required, which is generally costly and would result in an increase in the wholesale price of electricity. Forecasting errors in RE generation could also potentially increase deviations, resulting in a financial burden on the state.

To ensure generation and demand balance with the varying net load of the system, the conventional generation fleet needs to be as flexible as possible to accommodate the variability of the net load. Flexibility of the generator is determined largely by three parameters: i) technical minimum ii) ramp rate and iii) minimum-up and minimum-down time. If the net load decreases below the base load, conventional generators like coal may need to decrease their generation, going at most to their technical minimum. The lesser the value of the technical minimum, the greater is the ability of coal power plants to absorb the variation in net load. Most power generators in India have stated that their technical minimum is only 70% of their rated capacity. (MNRE, 2015) However, the CEA has clearly noted that the technical minimum could be 50% as prescribed under the CEA Technical Standards for Construction of Electric Plants and Electric Lines Regulations – 2010. (POSOCO, 2016) The CERC has recently fixed the technical minimum of central generating stations and inter-state generating stations at 55% of Maximum Continuous Rating (MCR) loading or installed capacity of the unit. Another possible way to decrease technical minimum, especially for older plants, is to opt for retro-fitting. A recent report suggests that retro-fitting costs would be Rs 1-2 Lakhs/MW for decreasing the technical minimum by 10%. Retro-fitting is also cheaper and quicker than adding new flexible generation. (MNRE, 2015)

Increasing solar penetration would need conventional plants to increase their generation in a short time frame in the evening when the output from solar power decreases. In general, coal plants with large inertia do not have very high ramp rates and are generally in the range of 1% of Maximum Continuous Rating (MCR) per minute. (CERC, 2016) A high level of cycling of coal plants also increases their costs and reduces the life of the power plant equipment. At present, the CERC has not laid down any firm regulations on ramp rates, though it has noted that, *'"ramp up' and 'ramp down' rates are other important parameters for flexibility which would gradually be introduced through regulations"*. (CERC, 2015)

4.2.3 Temporarily Increasing the Deviation Limits for RE-rich States

While the analysis by POSOCO (Section 3.4) clearly brought out the lack of co-relation between wind generation and state wise deviations, many states had approached the CERC requesting it to relax the volume limits (150 MWs) under the DSM regulations. As a temporary measure, until states build up the eco-system of demand forecasting, reserves, ancillary services and RE generation forecasting and scheduling, the CERC has agreed to higher limits for RE-rich states. For RE-rich states, the deviation limits will now be 200 MW if the installed capacity of wind and solar power in that state is between 1000 to 3000 MW, and 250 MW if the RE installed capacity is greater than 3000 MW. (CERC, 2016) These have been relaxed only until April 2017, when they are expected to be tightened again. The higher limits will reduce the financial burden on the states arising from the UI charges due to deviations.

4.2.4 Backing Down of Wind Power in Wind-rich States

In spite of the must run status for renewables, given their near-zero variable/marginal costs and higher ranking in the merit order, there have been some instances of backing down of renewable power, especially wind power. Ideally, such generation cannot be backed down except in the case of grid contingency. The Indian Wind Power Association has noted that the Tamilnadu State Load Dispatch Center (TNSLDC) has been backing down 50% of the wind generation in the state as *"variation in wind power endangers the grid"*. (CERC, 2016) This is causing financial losses for wind generators. In 2015-16, there was an apparent backing down of 5000 MU of wind power. At a tariff of Rs 3.5/kWh, this adds up to a potential loss of Rs 1650 crores. At present, there is no provision for compensation for 'deemed generation' when wind power generators were available but were backed down by grid operators. A court case in this matter has also ruled in favour of wind developers, stating that the Tamil Nadu Generation and Distribution Corporation (TANGEDCO) could not impose backing at will. (The Economic Times, 2016) Such backing down has also begun in Rajasthan, where wind developers are claiming such backing down orders from LDC two to three times a day. (The Economic Times, 2016) Very recently there have been some instances of backing down of solar power as well. Since wind and solar power have single part tariffs, backing down leads to significant revenue loss and non-recovery of even fixed costs, unlike thermal power plants. The National Solar Energy Federation of India (NSEF) has petitioned TNERC to ensure must run status for solar plants, following which TNERC has asked TANGEDCO to technically justify the backing down of solar power plants. (The Hindu Business Line, 2016) (Sanjay Vijayakumar, 2016)

The MNRE has requested the FoR for consensus building amongst ERCs to evolve clear regulations for implementing the must run status for renewables as well as revenue compensation for backing down. (MNRE, 2016) Instituting intra-state ABT, coupled with forecasting and scheduling requirements for renewables, is the only way to reduce unnecessary backing down in the long run. Another potential option which is being explored by Tamil Nadu is to sell surplus RE power to other states in need for the same. (M Ramesh, 2016) More importantly, the MNRE in conjunction with the Power Trading Corporation of India (PTC) is developing a trading platform exclusively for renewables, wherein states can buy, sell and trade RE power. (Shreya Jai, 2016) This initiative can greatly reduce the need for backing down of wind power.

4.2.5 Other Supporting Measures for Effective Grid Integration of Renewable Generation

The various measures for reducing violations of deviation limits mentioned in the previous section, namely, demand forecasting, reserves, ancillary services and extended intra-day power trading, will also help in integrating renewables into the grid. Apart from these, some other measures are noted below.

Demand Side Management: Generation and demand balance can also be achieved by regulating the system demand. Currently, load shedding is at times used as a pseudo demand side management tool by distribution utilities to achieve a balance between generation and demand. Agricultural load management through separation of feeders supplying agriculture and residential loads in rural areas is another means of demand side intervention. Here, agriculture feeders are given limited hours of supply (say 8 hours/day) to manage load.

Lack of smart meters at the distribution system level presently limits the scope of demand side management at the retail level. However, the National Tariff Policy amendment of 2016 mandates smart meters for consumers having consumption of 500 units by 2017, and for consumers having consumption of 200 units by 2019. This will help in increasing the scope of DSM programmes. (REConnect Energy, 2016) Recently, Tata power in Delhi and Mumbai has started DSM programmes for industrial consumers as pilot projects. In Delhi, the capacity of load under this programme is 12MW (Tata Power Mumbai, 2012). This is significantly less considering the 1700 MW peak demand served by Tata Power in Delhi. (CERC, 2016) Similarly, in Mumbai, the capacity of load under this programme is 10MW at present with respect to the peak demand of 1033 MW. (Tata Power Mumbai, 2012)

Storage: This can also be used as a source of flexible demand and generation. At present, given cost consideration, pumped hydro storage can aid in the integration of RE. India has a significant pumped hydro potential available, which can be developed in this regard. (MNRE, 2015) Out of the 96 GW of pumped storage potential in the country, only 4.6 GW capacity is under operation, of which 2.6 GW is being operated in the pumping mode and 6 - 10 GW is under development. (CEA, 2013) (ET Bureau, 2016) The cost of advanced grid level storage technologies like electric batteries has come down significantly in the last few years, and is expected to continue to decrease, so that these technologies will become a serious option for consideration in the coming years.

Day ahead Forecasting and Scheduling for Renewables: Until recently, the LDCs had no visibility with regard to day ahead renewable energy generation, thereby severely undermining the process of realistic generation side planning. Indian regulators and system operators have initiated the process of modifying the grid operation regulations to accommodate the renewable generation, beginning with framing forecasting and scheduling regulations, which is explained in detail in Chapter 5.

5

Regulatory Interventions for Grid Integration of Renewable Generation

While the penetration of wind and solar power remained small until 2010, grid integration was not seen as a serious issue, and hence RE was exempt from forecasting, scheduling and supporting grid management in terms of ancillary services. However, since 2010, several regulatory attempts to address grid integration beginning with forecasting and scheduling have been made. A timeline of these past events from 2010 to 2014 is captured in Annexure 1.

5.1 Renewable Regulatory Fund Mechanism

The Renewable Regulatory Fund (RRF) Mechanism was notified by CERC on 28.4.2010 as part of the Indian Electricity Grid Code, and was the first regulation through which efforts were made to introduce mandatory forecasting, scheduling and commercial settlement for deviations of the wind and solar generators. This regulation was applicable to wind generators having a capacity greater than 10 MW and solar generators having a capacity greater than 5 MW being connected to the intra-state or inter-state transmission network at a voltage>= 33 kV.

5.1.1 Forecasting, Scheduling and Commercial Settlement

Wind and solar generators were expected to give day ahead schedules to SLDC/RLDCs. Both wind and solar generation were to be paid based on actual generation. The absolute error (deviation from schedule) was defined as a percentage of the scheduled generation, i.e. (Scheduled Generation-Actual Generation)/ Scheduled Generation, and penal deviation charges were based on the CERC Unscheduled Interchange (UI) regulations. In case of wind generators, for absolute errors less than 30%, the UI charge was to be socialised among all the states with no penalty for the generator, but for errors > 30%, UI charges were to be applicable. Solar generation was completely exempt from UI charges. The UI charge was to be managed by a separate account called Renewable Regulatory Fund (RRF), due to which this mechanism was commonly known as the RRF mechanism. (CERC, 2010)

5.1.2 Implementation of RRF

The implementation of the RRF mechanism faced several difficulties including a lack of Special Energy Meter (SEM) installations, a lack of facilities for managing the forecasting data at SLDC, an unclear commercial settlement process for open access and captive consumers, demarcation between old and new wind generators for RRF applicability, unclear responsibilities of forecasting, scheduling and commercial settlement between the wind developer and generators, unclear definition of the Power Purchase Agreement (PPA) in case of multiple generators having different PPA rates connected to the same interconnection point, partial eligibility of wind farms due to a mix of old and new wind generators, disclosure of PPAs to RLDCs, etc. (CERC, 2011) (CERC, 2014) (CERC, 2013) (CERC, 2012) A task force appointed by the MNRE and chaired by POSOCO identified these issues and gave suggestions to rectify them as shown in Table 3. Based on this approach, POSOCO came up with a new procedure for implementation which was accepted by the CERC. However some issues remained, for example:

i) Unavailable metering infrastructure at the state level

ii) Fear of financial burden of the RRF mechanism on the generators

iii) Lack of attention towards setting a concrete procedure for Renewable Purchase Obligation (RPO) accounting and purchase of RECs toward RPO settlement. (CERC, 2013) (POSOCO, 2012)

Table 3 : Key Implementation Issues in RRF Mechanism and Suggested Measures

Key Issues	Applicability of RRF	Alternate mechanism for settling imbalances and RRF accounting	Institutional arrangement	Minimising volatility in revenues for wind generators	Green energy accounting (RPO accounting)
Suggestions	Should be made applicable for all wind/ solar projects connected to the pooling stations commissioned on or after 3.5.2010	Schedule based payment to RE generators instead of actual based payment Provide immunity from UI mechanism for deviation of +/- 30% of schedules in case of wind and for deviation of +/- 100% of schedules in case of solar	Provision for coordinating entity to facilitate scheduling, accounting and de-pooling arrangements Define the roles of various entities like coordinating agency, SLDC / RLDC/ NLDC, wind/ solar generators in implementing RRF	Use of uniform national or state level reference rate based on UI charge instead of contract rate It was recommended to reduce the grid frequency fluctuations to provide clear UI signal to renewable generators.	Task force did not consider the RPO accounting issue as critical for stopping RRF implementation. The task force said that the annual difference of calculated RPO due to scheduled and actual generation based accounting methods will be less than 2%.

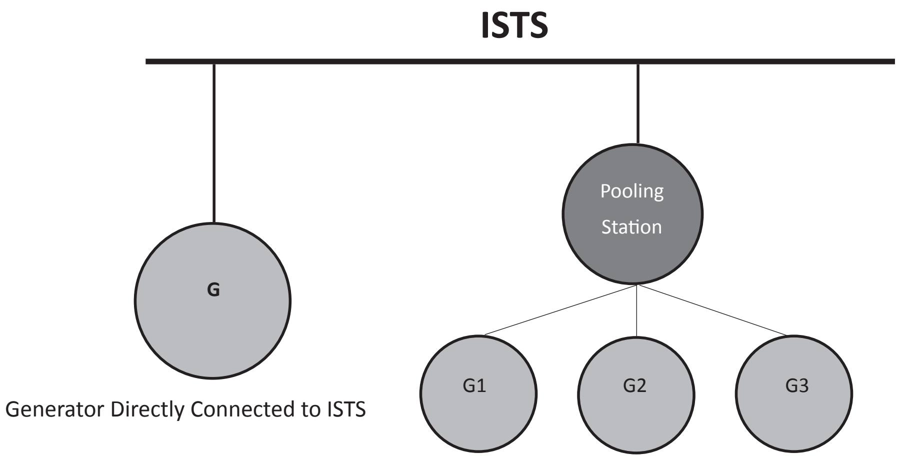
An expectation of high forecast errors by the wind generators led to apprehensions about frequent violations of the 30% band and subsequent financial penalties burdening wind projects. Also, there was a question raised over the CERC's jurisdiction over intra-state generators. Representatives of wind developers like Wind Independent Power Producers Association (WIPPA), Indian Wind Power Association (IWPA) and GMDC filed cases against the implementation of the RRF mechanism in Madras, Delhi and Ahmadabad High Courts respectively, resulting in a stay on the commercial settlement part of the regulation, but continued forecasting and scheduling of the wind generation. The CERC invited comments from all the stakeholders and also followed the steps of the Madras high court which stayed the commercial settlement part of the regulation but continued forecasting and scheduling of wind generation on 31.1.2014. (RAMESH, 2013) (Jai, 2013)

5.2 CERC Framework on Forecasting, Scheduling and Imbalance Handling For Variable Renewable Energy Sources (Wind and Solar)

The failure in implementing the RRF mechanism prompted the CERC to come out with a fresh discussion paper on this issue along with draft regulations in April 2015. After due public process, in August 2015, the CERC came up with the Framework on Forecasting, Scheduling and Imbalance Handling for Wind and Solar Generators Connected to ISTS as a substitute to previous RRF Mechanism. (CERC, 2016) (CERC, 2015) The IEGC and DSM regulations were suitably amended to incorporate this framework.

Figure 6 shows the schematics of the connection of generators and pooling stations to ISTS. Most existing wind and solar projects are connected to the intra-state network and hence these regulations would not apply to them. However, it is expected that significant new capacity additions of renewable energy, especially solar parks, will be at the regional level and connected to ISTS. Similarly, the MNRE is proposing new ISTS connected wind capacity to meet RPO requirements of non-windy Eastern and Northern states. This is also supported by a recent amendment to the National Tariff Policy that has waived off inter-state transmission charges for renewable generators. (REConnect Energy, 2016)

Figure 6 : Schematic Diagram of Network Connection of Regional Wind and Solar Generators Connected to ISTS



5.2.1 Applicability

This framework is applicable to all wind and solar generators which are regional entities. Further, the draft procedure to implement these regulations as proposed by POSOCO includes renewable generators connected to ISTS and having aggregate capacity of 50 MW and above, and a UMPP based on wind and/or solar having capacity of 500 MW. It will also apply to any renewable generation station of capacity between 5 MW to 50 MW developed by a generating company in its existing generation station in accordance with the CERC Transmission Open Access Regulations (Third Amendment) and connected to the existing connection point with the ISTS. (CERC, 2015)

5.2.2 Forecasting and Day Ahead Scheduling

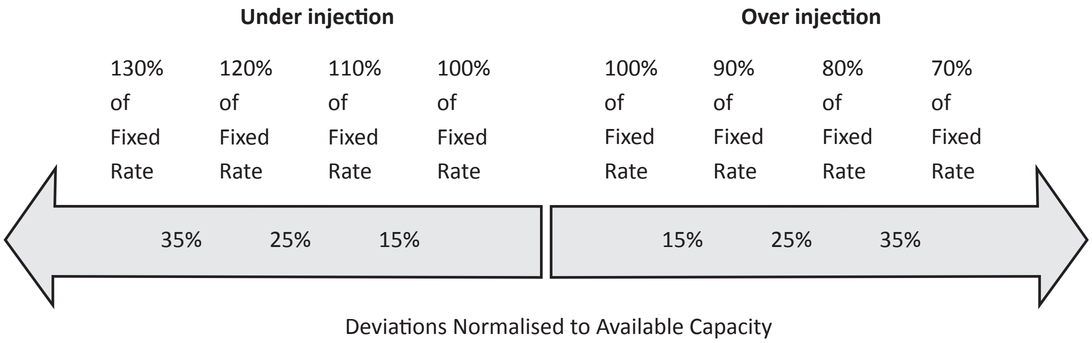
In this framework, the hybrid approach is adopted for forecasting at the interconnection point with CTU, in which RLDC forecasts separately with the aim of secure grid operation, while the forecast from generators or pooling station is used for commercial settlement. For the purpose of scheduling, the regional wind and solar generators can use their own forecast or that prepared by the RLDC, though the commercial impact due to deviation from the schedule will be fully borne by the generators themselves. To decrease the risk associated with uncertainly of the forecast, as forecast error decreases with time closer to actual generation, the wind and solar generators are provided with an option of 16 revisions to the submitted schedule, each revision for a duration of 1.5 hours during day of actual dispatch. These revisions will be effective from the 4^{th} block after the notice of revision is received by the RLDC. (CERC, 2015)

A draft procedure for implementation of this framework was released by the CERC on 12.2.2016. This procedure gives detailed information about the definitions, roles and responsibilities of entities involved and the procedures to be followed by them for implementing the above framework. In this procedure, there is a provision for the Qualified Coordinating Agency (QCA). With regard to multiple generators connected to the ISTS through a pooling sub-station, the lead generator or the principal generator may serve as the QCA. The QCA is responsible for all the operational and commercial responsibilities like providing data related to day ahead schedules, available capacity, forecast, and actual generation to the RLDC, undertaking the commercial settlement, allocation of the deviations charge among the generators connected to the pooling station, and technical coordination between the generators within the pooling station etc. on behalf of the generators connected to the pooling station. (CERC, 2016)

5.2.3 Commercial Settlement

The renewable generators at the regional level will be paid according to the scheduled generation. The absolute error (deviation from schedule) is defined as a percentage of the Available Capacity, i.e. (Schedule Generation-Actual Generation)/Available Capacity. The framework for commercial settlement for the deviation due to under/over injection is outlined in the second amendment to the CERC DSM regulations. The generator will be paid for over injection from the regional DSM pool and will pay the regional DSM pool for under injection according to the deviation charges. The deviation charges are equal for both wind and solar generators. Deviation bands and charges are shown in Figure 7.

Figure 7 : Deviation Bands and Charges for Regional Wind and Solar Generators



Fixed rate is the weighted average of PPAs of all the generators connected to the pooling stations. If the generator is directly connected to the ISTS, the PPA of the generator serves as the fixed rate. For non utility transactions (like captive and Open Access (OA) consumers), the deviation settlement mechanism will use the national Average Power Purchase Price (APPC) determined by the CERC as the Fixed Rate. The energy accounting and deviation settlement of the regional renewable generators will be done by the RPC on a monthly and weekly basis respectively.

5.2.4 RPO Accounting

RPO will be allotted to the buyers on the basis of scheduled drawl. To settle the difference in the scheduled generation and actual generation for RPO accounting, the deviations from all the generators will be netted off for the entire pool by the RPC on a monthly basis. The RECs will be brought by the NLDCs from power exchanges and allotted to the DSM pool, if actual generation from the generators is less than scheduled generation, and will be carried forward if the opposite is true. (CERC, 2015)

5.2.5 Metering

According to the draft implementation procedure, the Interface Energy Meters will be installed by the CTU and STU for regional and intra-state entities respectively to facilitate boundary metering, accounting and settlement for RE generators, while data from such meters will be communicated to the RLDC by the Automated Meter Reading (AMR) system. Turbine/Inverter level data, at a frequency <=10 seconds will be provided to the RLDC by the QCA/Generator through data telemetry. (CERC, 2016)

5.2.6 Analysis of CERC Framework

Payment to the Generator

According to this framework, the regional wind and solar generators will be paid for energy charges according to their scheduled generation. The regional wind and solar generators will get the deviation charge from the regional DSM pool for over injection and will pay the deviation charge to regional DSM pool in case of under injection. This will lead to easy adoption of existing regional energy accounting and commercial settlement framework for the regional wind and solar generators.

Deviation Bands

The new definition of absolute error based on available capacity was introduced because of the high sensitivity of the RRF error definition which was defined as a percentage of the scheduled generation. Wind developers argued that in a low generation scenario, the scheduled generation term is numerically smaller, leading to a high value of absolute error. Also, the scheduled generation is a weather dependent term. To remove the dependency of the denominator on weather, the scheduled generation term was replaced with the Available Capacity (AvC). Except in case of plants under maintenance, AvC is equal to the installed capacity. This also incentivises the generator to keep the total available capacity at the maximum to reduce the absolute error. (CERC, 2015) Data on forecasting errors compiled by the CERC showed that the absolute forecasting error is less than 15% (for 95% of the wind energy generation) and less than 10% (for 80% of solar energy generation). (FoR, 2015) Hence, the deviation charges are designed such that for deviation less than 15%, the net payment to the regional wind and solar generators post deviation settlement is same as the payment made to them for their actual generation. Hence, this new error deviation coupled with the error bands should come as a great relief to generators who are not expected to lose much revenue with effective forecasting.

Deviation Charges

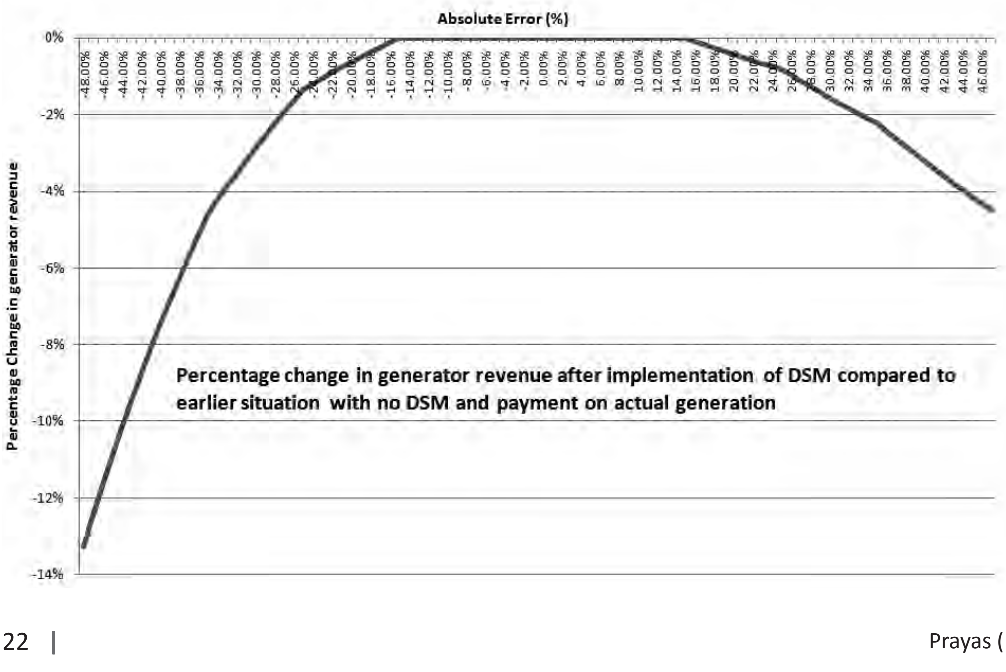
The deviation charges are independent of the grid frequency unlike in the earlier RRF mechanism or under the UI mechanism for conventional generators. Hence, wind and solar generators are not expected to respond to grid frequency in the way conventional generators are expected to. Also, the deviation charges for regional wind and solar generators are dependent on the fixed rate (linked to PPA) as defined in Section 5.3.3. In case of multiple generators connected to the pooling station, the weighted average of tariffs as per PPA will be used as the fixed rate. In case of high variation in PPA prices, the deviation charges may not be equitably distributed.

Impact on Generator Revenue Post Implementation of the DSM regulations

Case 1: Comparing revenue post DSM with situation prior to implementation of DSM, i.e. payment based on actual generation with no deviation penalty.

Figure 8 plots the percentage change in revenue for the generator post implementation of the DSM regulations as compared to payment on actual generation prior to implementation of the DSM regulations (with no deviation penalties) for a wide range of absolute errors (-48% to +48%). By design, there is no change in revenue for an absolute error of -15% (under-injection) to +15% (over-injection). However even for an absolute error of -27% or +33%, the loss to the generator is only 2%. This should practically remove any financial concerns of the renewable energy generators over the deviation penalty structure under this forecasting and scheduling framework unlike the RRF mechanism.

Figure 8 : Impact of Deviation Charges on Revenue of the Generator



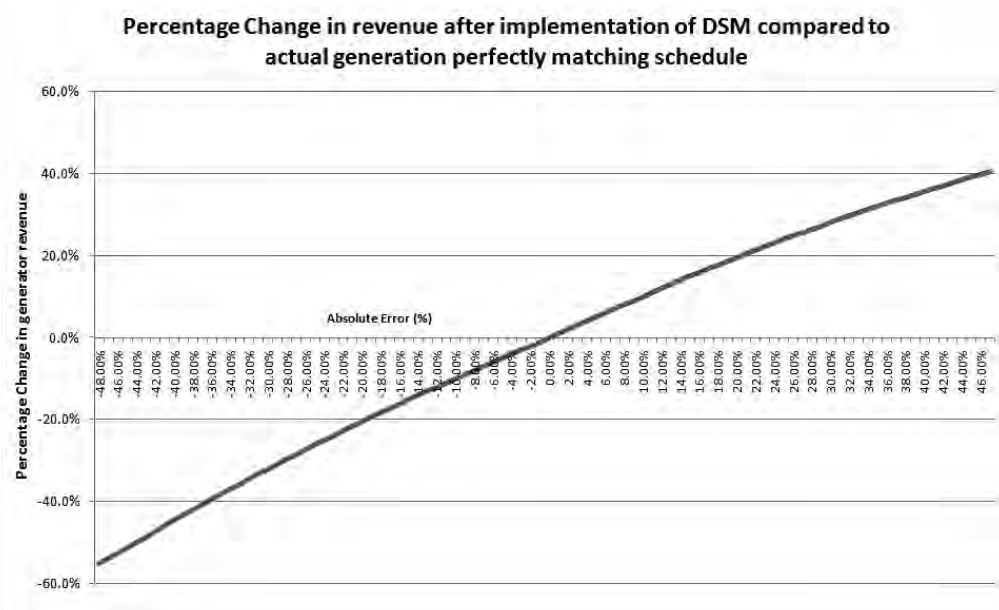
Case 2: Comparing revenue post DSM with revenue wherein there is perfect match of schedule and actual generation (no deviation from schedule)

Figure 9 plots the percentage change in revenue for the generator post implementation of the DSM regulations as compared to a situation where there is a perfect match of schedule and actual generation (no deviation) for a wide range of absolute errors (-48% to + 48%). It depicts the impact on generator revenue for a deviation from the schedule. The generator loses revenue for any under-injection, while gains some for over-injection. Similarly, in the previous graph, it is clear that the revenue loss is much higher for under-injection than over-injection. **Both these factors thereby structurally incentivise the generator to slightly under-schedule (within 15%) and over-inject.** The distribution of the revenue loss is same even if the fixed rate (linked to PPA) differs. Therefore, generator behavior to the deviation charges is independent of the PPA tariff. As is already stated by the CERC, the deviation bands may be revised downwards in time. (CERC, 2015) The CERC should critically examine this issue of possible under-scheduling when the deviation band review process is undertaken.

Depooling of Deviation Charges

Depooling is the segregation of total deviation settlement charges for the entire pooling station amongst its member generators by the QCA. Due to relatively larger project sizes and direct connection to the ISTS, there has been no need for a QCA yet, but this may change in the near future. At present, no methodology for depooling the deviation settlement charges for the entire pooling station has been suggested by the CERC.

Figure 9 : Impact on generator revenue for deviation from schedule

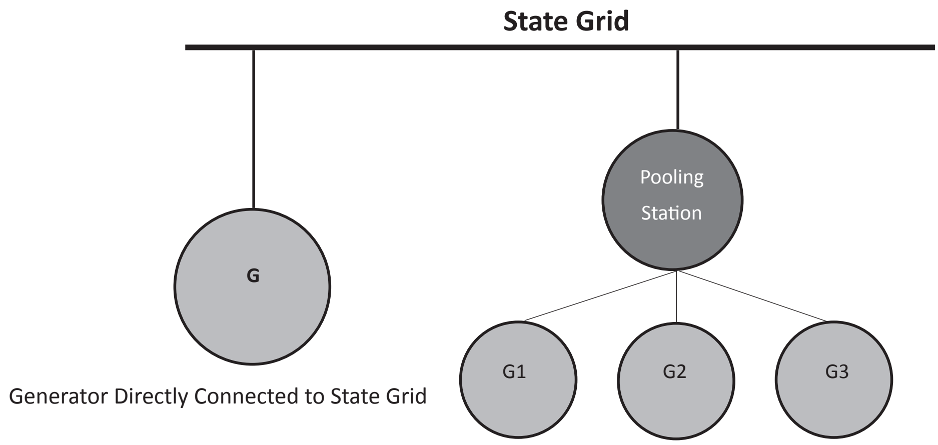


5.3 Model Regulations on Forecasting, Scheduling and Deviation Settlement of Wind and Solar Generators at the State Level

While the CERC framework is applicable to generators connected to the ISTS, there was a dire need for a similar forecasting, scheduling and settlement mechanism at the state level, where most of the existing wind and solar projects lie. The first step to operationalise this process was taken by the Forum of Regulators (FoR) by framing a model framework for forecasting and scheduling of wind and solar generators connected to the state grid. States are expected to finalise their regulations using this model framework as a guideline.

According to the FoR framework, with regard to multiple generators connected to the InSTS through a pooling station, the Qualified Coordinating Agency (QCA) will be responsible for forecasting and providing schedules, metering, data collection, communication with the SLDC as well as commercial settlement of deviations. Figure 10 shows the connection of generators and pooling stations to the state grid.

Figure 10 : Schematic Diagram of Network Connection of State Wind and Solar Generators to State Grid



5.3.1 Applicability

The framework applies to all the wind and solar generators connected to the state network whether the generator is selling power inside (intra-state transaction) or outside of the state (inter-state transaction). (FoR, 2015) The generators whose Commercial Operation Date is prior to the date of effect of the regulations of the individual state are defined as 'Old generators', while the generators whose Commercial Operation Date is after the data of effect of the regulations of the individual state are defined as 'New generators'.

5.3.2 Forecasting and Day Ahead Scheduling

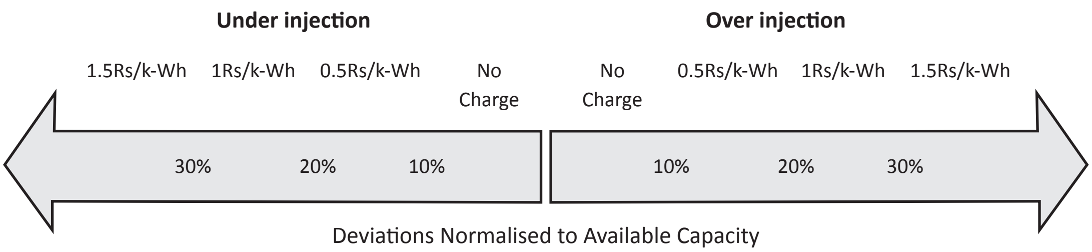
In this framework, a hybrid approach is adopted for forecasting in which the SLDC forecasts separately with the aim of secure grid operation while the forecast from generators/QCA is used for commercial settlement. If a single plant is connected directly to the state grid then the forecasting will be done either by the generator or the SLDC. The generator is allowed to use their forecast or the SLDC forecast for scheduling their generation with all the commercial impact to be borne by the generator. For generators connected to the state grid via a pooling station, the forecasting is to be done by the QCA which can be the principle or the lead generator. Similar to the CERC framework for regional generators, the QCA can have its own forecast or can adopt the forecast from the SLDC. Individual generators connected to the QCA can also decide to forecast themselves, and the QCA can prepare the schedule for pooling stations by aggregating the individual schedules of the generators.

As the forecast error decreases with time closer to actual generation, to decrease the risk associated with the uncertainty of the forecast, the RE generators are provided with an option of 16 revisions to the submitted schedule, each revision for a duration of 1.5 hours during the day of actual dispatch. These revisions become effective from the 4th block after the notice of revision is received by the SLDC. (FoR, 2015)

5.3.3 Commercial Settlement

Generators connected to the state grid and which sell power within the state (intra-state transactions) will be paid according to the **actual generation,** and those selling power outside the state (inter-state transactions) will be paid according to the **scheduled generation**. This difference is primarily due to the lack of an ABT compliant energy accounting framework in most states. However, as the intra-state ABT is implemented across most states, the payment to the renewable energy generators for intra-state transactions should be based on scheduled generation. For deviation settlement, absolute error is calculated as a percentage of available capacity, i.e. (Schedule Generation-Actual Generation)/Available capacity (AvC). The commercial settlement for intra-state transactions for the deviation due to under-injection or over-injection is to be done based on deviation charges specified in the framework, outlined in Figure 11 below. These deviation charges are specified as absolute values in Rs/kWh unlike the fixed rate, which is dependent on the PPAs of the renewable generators. The deviation band differs for generators selling power within and outside the state. For intra-state transactions, deviation charges are **always payable to the state DSM pool by generators** irrespective of under or over-injection.

Figure 11 : Deviation Band and Charges for Intra State Transactions



For generators selling power outside the state, the deviation charges are the same as that of the CERC Framework outlined in section 5.3, but with settlement done in the state DSM pool. Depooling beyond the pooling station will be achieved by the QCA by allocating deviation charges in proportion to actual generation or AvC of the generator. If the net effect of the deviation settlement on the state DSM pool is negative due to RE generators, the state pool will be compensated from the National Clean Energy Fund (NCEF) or the Power System Development Fund (PSDF) until 31.3.2019. In the long term, once states become ABT compliant, the FoR regulation expects intra-state transactions to follow the CERC DSM mechanism. (FoR, 2015)

5.3.4 RPO Accounting

RPO will be allotted to the buyers based on scheduled drawl. Deviations from all the generators will be netted off for the entire state pool on a monthly basis. The RECs will be brought from power exchanges by the SLDCs and allotted to the state DSM pool, if actual generation from the generators is less than scheduled generation, and will be carried forward in the opposite case.

5.3.5 Metering

Special energy meters and communication infrastructure must be installed by all generators while metering and communication of real time data at the turbine/inverter level are proposed. This will help the QCA improve forecasting accuracy. The energy accounting and commercial settlement of the RE generators will be carried out by the QCA.

5.3.6 Analysis of Draft State Regulations

Table 4 Comparison of State Draft Regulations for Intra-State Transactions

State	Applicability to Generators	Generators payment based on	Error Definition	Permissible deviation without penalty	Deviation charges
FoR Model Regulations	All	Actual Generation	AvC Based	10% for new generators, 15% for old generators	Absolute value(Rs/kWh)
Tamil Nadu	All	Actual Generation	AvC Based	10% for Wind and 5% for Solar generators	Absolute value(Rs/kWh)
Karnataka (Final Notified)	Wind Generators >10MW, Solar Generators >5MW	Actual Generation	AvC Based	15%	Absolute value(Rs/kWh)

Odisha	All solar and wind generators including OA>5MW and CPP >5MVA	Scheduled Generation	AvC Based	15%	Fixed rate
Madhya Pradesh, Andhra Pradesh and Jharkhand	All	Actual Generation	AvC Based	10% for new generators, 15% for old generators	Absolute value(Rs/kWh)
Chhattisgarh	All	Scheduled Generation	AvC Based	15%	Fixed rate
Rajasthan	All wind and solar generators greater than 5 MW	Actual Generation	AvC Based	15%	Absolute value(Rs/kWh)

Based on the model regulations by FoR, eight states have proposed draft regulations. Some of them differ from the model regulations in aspects like definition of error, basis of payment for generation, and deviation settlement mechanisms. The analysis below gives probable impacts of these changes on generators, DSM pools, difficulties of implementation. etc. Table 4 gives a comprehensive comparative picture of draft state regulations. (KERC, 2015) (MPERC, 2015) (OERC, 2015) (JSERC, 2016) (TNERC, 2016) (RERC, 2016) (APERC, 2016) (CSERC, 2016) (*Shaded cell indicates diversion from FoR model regulations)* In this section, we analyse the draft regulations (Karnataka recently notified final regulations) (KERC, 2016) for both inter-state and intra-state transactions.

5.3.7 Intra-State Transactions Analysis

Applicability

FoR model regulations proposes the forecasting, scheduling and deviation regulations to be applicable for all the solar and wind generators connected to the state grid. However, some states like Karnataka, Odisha and Rajasthan have put capacity constraints on applicability of the regulations to solar and wind. It will be necessary to check the percentage of the capacity left outside the ambit of the regulations and when, if at all, such regulations will be applicable for such capacity in the future.

Error Definition

On the line of FoR model regulations, all states have adopted a new definition of the absolute error based on the AvC.

Method of Payment

In all states except Odisha and Chhattisgarh, the energy charges to the wind and solar generators will be paid according to the actual generation of the generator. In Odisha and Chhattisgarh, the energy charges for the wind and solar generators will be paid according to the scheduled generation (OERC, 2015) (CSERC, 2016).

Deviation Bands

For intra-state transactions, the deviation band proposed by the FoR for new generators where no penalty is applicable is 0-10% (0-15% for old generators), while penalty increases gradually as the absolute error increases beyond 10% as shown in Figure 11. Data on forecasting errors compiled by the CERC showed that the absolute forecasting error is less than 10% (for 87% of the wind energy and 80% of the solar energy generation). (FoR, 2015) Hence, the deviation charges are designed such that for deviation less than 10%, the net payment to the wind and solar generators post deviation settlement is the same as the payment to them for their actual generation. Hence, generators are not expected to lose much revenue with effective forecasting.

Some states like Karnataka, Odisha and Rajasthan have adopted same deviation bands for old and new generators. Interestingly, Tamil Nadu has adopted a tighter deviation band (no penalty only up to 5%) for solar generators selling power within the state, while the CERC data on forecasting accuracy suggests slightly lower accuracy with respect to solar in comparison to wind. This may put solar generators within Tamil Nadu state under more financial burden than wind generators.

Deviation Charges

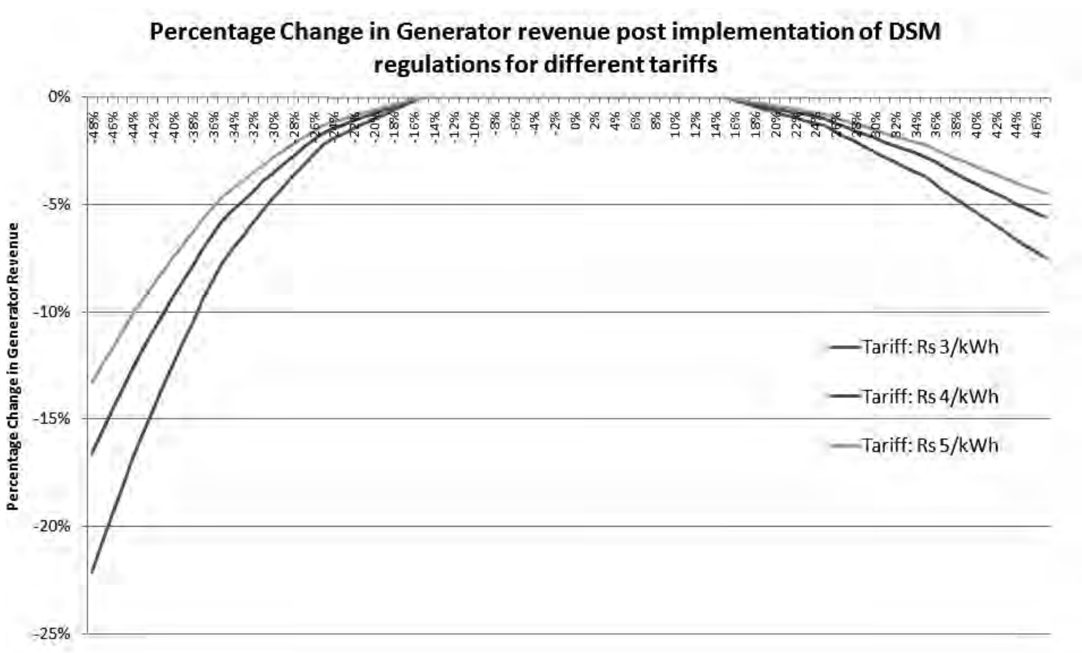
The deviation charges are independent of the grid frequency unlike in the earlier RRF mechanism or under the UI mechanism for conventional generators. Hence, wind and solar generators are not expected to respond to grid frequency in the way the conventional generators are expected to. For intra-state transactions, the FoR has proposed deviation charges as fixed absolute values in Rs/kWh ranging from 0.5 Rs/kWh to 1 Rs/kWh to 1.5 Rs/kWh for each subsequent deviation band beyond 10% as shown in Figure 11. All states have adopted this design of deviation charges except Odisha where the deviation charges depend on the fixed rate (i.e. linked to the PPA).

The above fixed absolute values are equivalent to using a fixed rate of Rs 5/kWh in the CERC framework for regional entities. The CERC had assumed prices for wind and solar as Rs 5/kWh and Rs 7/kWh respectively. However, prices are dependent on many factors like technology, location of plant, method of project finance, etc. and are rapidly changing. Prices for wind power generally range between 3.5-5.5 Rs/kWh, while prices for solar PV are now between 4.5-5 Rs/kWh but are expected to fall further. (Times of India, 2016) **Hence, penalties based on absolute values need careful attention and regular revision in line with the wind and solar prices. Ideally, states should quickly move to ABT based accounting and align the state framework for RE forecasting and scheduling in line with the CERC framework for regional entities.**

Impact on Revenue of the Wind and Solar Generators

For intra-state transactions, the deviation charges are always payable by the state wind and solar generators to the state pool irrespective of over-injection or under-injection. Hence, the generator always loses revenue due to deviation from schedule if the deviation is greater than 10%. Figure 12 plots the percentage loss in revenue due to deviation charges in intra-state transactions. For the same absolute error, loss in revenue is always less for over-injection than under-injection. This structurally may bias the generators to under-schedule slightly and over-inject. Similarly, since penalties are stated as absolute values, they have a higher impact on projects with lower tariffs (PPAs) than on those with higher tariffs as is depicted in Figure 12.

Figure 12 : Impact of Deviation Charges on Revenue of the Generator



Impact on State Pool

All states have adopted the new definition of absolute error normalised to available capacity. The deviation charges are designed such that the wind and solar generator will face no financial burden if the deviation remains below 10% for intra-state transactions. Wind and solar generators are expected to fall within this limit for most of the time (87% and 80% of wind and solar generation respectively (FoR, 2015)). As a result, the state will pay for deviation charges to the regional UI pool for deviation caused by the RE generators (within the 10% band). This is expected to cause a financial burden on the state pool account of the host state. Hence, state DISCOMs may not agree with this new definition of absolute error normalised to available capacity. While the FoR has recommended that this burden on the state pool should be compensated for from the NCEF or PSDF, it remains to be seen if that will be allowed.

The method of payment, deviation band and deviation charges adopted by Odisha for intra-state transactions are the same as that for FoR inter-state transactions and the CERC DSM regulations for regional wind and solar generators. Hence, analysis of Odisha intra-state transactions is the same as that in section 5.3.6.

Also, the FoR has decided to engage a consultant to conduct a study for the technical committee for smooth and effective implementation of the forecasting framework on renewables at the state level. The consultant is expected i) to overview the status of intra-state ABT within the states and suggest ways to overcome the difficulties, and draft and implement the intra-state ABT for states, ii) to give inputs on implementing the forecasting, scheduling and deviation settlement for renewables iii) to give inputs on implementing the state level framework on Ancillary Services/Reserves. (FoR, 2016)

5.3.8 Inter-state Transactions

The model proposed by the FoR for inter-state transactions for projects connected to the state grid is exactly the same as the one in place for regional entities under the CERC framework. Hence, the analysis for these transactions is the same as that in section 5.3. Table 5 below provides a state wise comparison of draft regulations with regard to inter-state transactions, shaded cells indicating a change from FoR model regulations. While most states have followed the FoR guidelines, Tamil Nadu has not specified anything with respect to inter-state transactions. All states except Karnataka have adopted a design of deviation charges based on the fixed rate, while Karnataka has adopted deviation charges based on the Absolute Value. (KERC, 2016)

Table 5: Comparison of State Draft Regulations for Inter State Transactions

State	Applicability to generators	Generators payment based on	Error definition	Permissible deviation without penalty	Deviation charges
FoR Model Regulations	All	Scheduled Generation	AvC Based	15%	Fixed rate
Tamil Nadu	TNERC does not specify details of inter-state transactions				
Karnataka (final notified)	All	Scheduled Generation	AvC Based	15%	Absolute value(Rs/kWh)
Odisha	All solar and wind generators including OA>5MW and CPP >5MVA	Scheduled Generation	AvC Based	15%	Fixed rate
Madhya Pradesh, Jharkhand, Chhattisgarh and Andhra Pradesh	All	Scheduled Generation	AvC Based	15%	Fixed rate
Rajasthan	All wind and solar generators>5 MW	Scheduled Generation	AvC Based	15%	Fixed rate

5.3.9 Depooling of deviation amongst generators connected to a pooling substation

If there are multiple generators connected to the state grid via a pooling station, the following two options are available to the QCA to prepare schedule of the pooling station as shown in Table 6.

Table 6 : Options Available to QCA for Preparing the Schedule of Pooling Station

Option 1	Option 2
QCA prepares the schedule for the entire capacity behind the pooling station based on a single forecast. QCA can also use SLDC prepared schedule for the pooling station.	Each generator (or QCA on their behalf) forecasts its own generation and prepares its individual schedule. QCA aggregates the individual schedules of the generators connected to the pooling station to arrive at schedule for the pooling station.

The schedules arrived at by using options 1 and 2 can differ according to the accuracy of the forecasting algorithm used by the forecasting entity. Hence, the deviation and deviation charges for the pooling station can also differ depending on the chosen option.

The FoR model regulations propose that "*The State shall maintain separate records and account of time-block wise schedules, actual generation and deviations for all generators, including wind and solar generators"* (Clause 3.6). All state draft regulations have adopted this clause. This has two important implications.

1. If QCA uses option 1 for preparing the pooling station schedule, a method will be needed to arrive at the individual schedules of the generators by segregation of pooling station level schedule.
2. According to the FoR regulations, the SEM meters are to be installed only at the interface points with the state grid, while the sampling rate of turbine/inverter level data to be collected by the QCA is not mentioned in the regulations. Hence, it is unclear how the block wise actual generation of all the renewable generators will be measured.

The idea behind the QCA was to limit the number of entities that the LDCs will have to deal with, however clause 3.6 could undermine this benefit. Keeping track of each individual generator is not practical for LDCs. Hence we recommend that a proviso be added to clause 3.6 in the FoR model regulations to address this issue.

"*The State shall maintain separate records and account of time-block wise schedules, actual generation and deviations for all generators, including wind and solar generators"*

> *Provided that if renewable energy generators are connected to the state grid via a pooling station, then the separate records and accounts would only be maintained at the level of the pooling station.*

In case of schedule prepared according to option 2, if the errors in the individual forecasts of generators accumulate, then the accuracy of the total schedule may suffer. However, by constant monitoring and correction of the biases of the errors in individual forecasts of the generators over time, the accumulation of errors can be avoided in the aggregated schedule for the pooling station.

Possible methodologies for depooling

Practically speaking, the ERC/LDC need not look into/regulate how the QCA depools or divides the total deviation charges applicable to a pooling station amongst its member generators, as long as such charges are paid regularly and on time. Notwithstanding this, the FoR model regulations suggest two possible depooling methodologies to be adopted by the QCA. All state draft regulations have adopted this clause. Clause 3.5 notes that "*The QCA shall also de-pool* ***the energy deviations as well as deviation charges*** *to each generator using one of the following options: (a) In proportion to actual generated units for each time-block for each generator (b) In proportion to available capacity of each generator".* All state draft regulations except of Andhra Pradesh have adopted this clause. Andhra Pradesh draft regulations suggest the QCA to depool only on the basis of actual generated units for each time-block for each generator.

The purpose of depooling the 'energy deviations' is unclear, since depooling of deviation charges would ideally suffice. However, depooling of the energy deviations may be useful when **entities having intra-state transactions and inter-state transactions are connected to the same pooling station.** This is because the design of the deviation charges for these two types of transactions is different, either based on absolute value or fixed rates. One potential way around this is to depool energy deviations amongst generators behind a pooling station and then calculate corresponding deviation charges for each generator. Andhra Pradesh draft regulations address this by allowing interstate transactions only through a separate feeder. It also mandates separate energy accounting and deviation settlement of interstate and intrastate transactions at the pooling station.

Considering the various possibilities that the QCA has in terms of a) scheduling (options 1 and 2), b) choosing the quantity to be depooled (energy deviations or deviation charges) and c) method to depool (in proportion to AvC or actual generation), there is a wide range of implications for the generators. We have prepared a simple mathematical model which represents the range of these possibilities, details of which are given in Annexure 2. Based on this analysis, the following important considerations should be taken into account while finalising the depooling methodology.

1. The two depooling methods (in proportion to AvC or actual generation) may result in different values of the depooled quantity in some cases. The results will be identical if the ratio of actual generation to the AvC is the same for all time blocks for all the generators connected to the pooling station. However, this ratio can differ among the generators connected to the same pooling station experiencing the same weather conditions, in case the technology amongst generators is different. For example, for same capacity of solar plant actual generation from crystalline PV, thin film and tracking based solar plant would be quite different. Hence, this ratio is important to consider while finalising the depooling methodology.

2. Secondly, the entire deviation at the pooling sub-station (over-injection or under-injection) gets proportionately distributed amongst the generators. However, it is possible that while there is net over-injection at the pooling station (for example), some generators may be under-injecting or maintaining perfect schedule during that time block. As noted earlier in this report, impact of over-injection and under-injection on the revenue of the generator is not the same. The range of such possible mismatches is given in the Annexure 2.

3. In case individual generators prepare their own forecasts and schedules, the QCA is aggregating such schedules into one schedule for the pooling station. The accuracy of each individual forecast/schedule affects the final net deviation of the pooling station, which in turn impacts all generators. If some generators have low forecasting accuracy, it may inequitably burden some other generators. This leads to unequal sharing of responsibility of the deviation at the pooling station.

Hence, given these three important considerations, it is suggested that if the block wise actual generation data for each generator were available (considering the needed metering infrastructure in place), then *a better methodology of depooling the net deviation at the pooling station would be in proportion to the actual deviations of the generators behind the pooling station*.

Hence, we suggest that the FoR model regulations can add sub-point (c) to its clause 3.5.
Clause 3.5 (c): in proportion to actual deviation for each time-block for each generator.

These three possible options are only for the QCA and the generators connected to a pooling station to consider as the best possible way for depooling the deviation charges. As such, anyone could be adopted by the QCA depending on the type of generators and the metering infrastructure available, and the ERC need not mandate any specific depooling methodology.

For a snapshot comparison of the three frameworks described above (RRF, CERC framework for regional entities and FoR model regulations for state entities), please see Annexure III.

6
Ongoing Grid Infrastructure Initiatives relevant to RE

Importance of Grid Infrastructure

Most of the wind energy resource and much of the good quality solar resource lies in the Southern and Western Indian states. Hence adequate transmission capacity, both at the inter-state and intra-state level, is necessary to evacuate renewable power from these states to the rest of the country. This is especially important given the high RE targets for the country and the gestation mismatch between the time needed for RE generation projects (1-1.5 years) and the much longer lead time for transmission projects. Apart from transmission, lack of real time visibility of the RE projects for LDCs in terms of Remote Terminal Unit (RTU) data telemetry etc. remains a serious challenge. Finally, while most of the states notified intra-state ABT regulations during 2004-05, only five states have implemented them (Ministry of Power, 2016). One of the major reasons for this failure was a lack of installation of ABT meters and the associated communication infrastructure at the LDC.

6.1 Transmission network for evacuation of Renewable Power

Given the long lead time in deploying transmission capacity and its associated costs (~ one crore/MW (NITI Aayog, 2015), long term planning based on detailed studies of the power system that encompasses the changes in conventional and renewable generation mix over time, spatial availability of generation resources in the country, load pattern of states including peak demand projection, etc. are necessary. In India, three recent studies related to transmission planning were carried out since 2012. (Powergrid, 2012) (CEA, 2016) (Powergrid, 2013) These studies are summarised in the Table 7.

Table 7 : Transmission Planning Studies in India

Transmission Expansion Study	Envisaged Renewable Capacity	Part of the Transmission System Under Consideration	Likely Expenditure
Green Corridors (2012-17, 12th Plan) published in July, 2012	55/66 GW by 2017	Inter-state and Intra-state transmission capacity addition plan of renewable rich states like Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Maharashtra, Rajasthan, Himachal Pradesh and Jammu & Kashmir	Rs 20,000 crore for strengthening of intra-state transmission system. Rs 19,000 crore for strengthening of inter-state transmission system of renewable rich states
CEA's Transmission Perspective Plan 2016-2036 published in Feb, 2016	175GW by 2022, 250 GW by 2027, 350 GW by 2032, 410 GW by 2037	Entire transmission system in India	Not given
Desert Power India – 2050 published in Dec, 2013	485 GW at the end of 2050 of which 300 GW could be from desert areas of Rann of Kutch, Thar, Ladakh, Lahul and Spiti.	Transmission capacity from Rann of Kutch, Thar, Ladakh, Lahul and Spiti to states in southern and northern regions	Rs 300,000 crore for inter-sate transmission corridors. Rs. 150,000 crores for strengthening of InSTS

Monitoring of Renewable Generation

6.2.1 Renewable Energy Management Centers (REMC)

For better grid integration of renewables, system operators need an equivalent of a RE dedicated SCADA/ EMS system. Under the Green Corridor project, Renewable Energy Management Centers (REMCs) are proposed to be established at each SLDC, RLDC and at the NLDC. The various system operation objectives of the REMCs as outlined in a recent report are: i) at state level - optimal scheduling and balancing of power, ii) at regional level - optimal coordination of regional grid, iii) at national level - maintaining safety and security of the grid. The REMCs will preserve the above objectives of the hierarchical LDCs for grid management.

The REMCs at the state and regional levels are proposed to be responsible for the forecasting and scheduling of renewable generation in its respective area. The detailed proposed functionalities of the REMCs are i) real time monitoring of all the renewable generation at the pooling station level ii) intra-day, day ahead forecasting of renewable generation, iii) coordination with corresponding LDC for scheduling and dispatch of renewable generation it its area of responsibility, iv) coordination between corresponding LDC and renewable developers. The REMCs at the state level will have the additional responsibility of monitoring the operating reserves in the state. The REMC at the national level is responsible for monitoring of renewable generation, analysis of collected data and coordination with LDCs for maintaining the security and stability of the system.

For carrying out the above functions, the REMCs will have five major tools with functions stated in Table 8. (MNRE, 2015) (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2015)

Table 8 : REMC Tools and Functions

REMC Component	Function
REMC Scada Monitoring Tool	Real time monitoring of renewable generation by collection of data from Remote Terminal Units (RTUs). Refresh rate of 2-4 seconds. SEM data can be used in case RTU is not available.
Forecasting Tool	Collection of i) forecast data from Forecast Service Providers and exchange of weather data with them, ii) site level actual RE generation data from REMC SCADA tool, and iii) weather forecasts, analysis and validation of accuracy of the forecast provided by individual RE developers, iv) provide forecast to RE developers not owning forecasting tool, v) provide point of injection level intra-day and day ahead data to REMC scheduling tool.
RE Scheduling Tool	Preparation of schedule from forecast received from RE forecasting tool. Coordinate with RE developers to integrate their individually submitted schedule.
REMC Wide Area Measurement System	Data collection of critical substation via existing WAMS system in control center.
RE Control Reserve Monitoring Tool	Real time analysis of reserves in own control area and in neighboring area, Scenario analysis of renewable generation for balancing the RE generation.

While REMCs can play an important role in easing the integration of renewables into the grid, a greater synergy and acknowledgement of their role in the regulatory process is necessary. Presently, their development appears to be happening independent of the evolution of the regulatory process for forecasting, scheduling and deviation settlement.

New guidelines for development of onshore wind power projects published in May 2016 by MNRE mandate installation of ABT meters by the project developer at pooling station and communication of vital grid parameters to the respective LDC on a real time basis. This guideline will supplement the REMCs for ensuring collection of real time data from all wind projects (MNRE, 2016).

6.2.2 Intra-State ABT Mechanism

The regional ABT mechanism was successful in improving the grid discipline at the inter-state transmission network and its various advantages are well documented. Similar mechanism has for long been recommended for intra-state entities by the national electricity and tariff policies. (FoIR) At the state level, the Forum of Indian Regulators (FoIR) has recommended the same frequency band and deviation charges as that at the inter-state level, as determined under CERC DSM regulations to facilitate back to back operation of state and regional DSM pools (FoIR). The same deviation charges at the regional and state level ensure passing of deviation penalty on the state entity directly responsible for the deviation.

While states started framing intra-state ABT regulations since 2003-04, only some have implemented them. According to a recent report by the FoR titled SAMAST (scheduling, accounting, metering and settlement of transactions in electricity), all states have been doing energy accounting, but only six states, namely Delhi, Maharashtra, Gujarat, Madhya Pradesh, West Bengal and Chattisgarh have implemented the intra-state ABT system completely (FoR, 2016). All other states have partially implemented the intra-state ABT mechanism except for Tamil Nadu which has recently brought out draft regulations. The deviation settlement in Maharashtra, Andhra Pradesh and Telangana are System Marginal Price based unlike others which follow a frequency based deviation settlement mechanism. Presently, only 8 SLDCs have been carrying out the weekly deviation settlement for the intra-state entities. For more details, on the SAMAST report, please see Annexure V . Table 9 indicates status of implementation of intra-state ABT in few states. (APERC, 2014) (KERC, 2005) (TNERC, 2016) (MERC, 2014) (MPERC, 2009) (State Load Dispatch Center, Gujarat, 2014).

Table 9 : Status of Intra State ABT Mechanism in States

State	Maharashtra	Tamil Nadu	Karnataka	Gujarat	Madhya Pradesh	West Bengal
Description	Regulations notified on ABT mechanism Commercial settlement is based on System Marginal Price (SMP) and is different from CERC DSM regulations	Draft Regulations for intra-state ABT mechanism notified on 13 Jan 2016. Deviation charge is based on CERC DSM regulations.	Final regulations for intra-state ABT mechanism notified on 20 June 2006. Deviation charge based on CERC DSM regulations. Mock procedures are being done since 2006.	Final regulations for intra-state ABT mechanism notified on 11 August 2006. Deviation charge based on CERC DSM regulations	Final regulations for intra-state ABT mechanism notified on 12 October 2009. Deviation charge based on CERC DSM regulations	ABT regulations introduced in 2007. Balancing and settlement code was introduced in 2008
Status of ABT	Implemented	Not Implemented	Not Implemented	Implemented	Implemented	Implemented

Intra-state ABT mechanism implementation helps bring uniformity of forecasting, scheduling, accounting and commercial settlement procedures at state and regional level. This can help remove the different deviation settlement mechanisms for renewables at the inter-state and intra-state levels as currently proposed by the FoR.

6.3 Changes in wind and solar generation infrastructure

6.3.1 Low Voltage Ride Through (LVRT)

In case of grid disturbances like line-faults, the grid voltage may undergo a temporary dip. Since wind generators require the grid voltage to be of an appropriate magnitude for their normal operation, they are presently required to trip if the voltage dips below 85% of nominal voltage at interconnection point for a certain time. (CERC, 2016) Unfortunately, if significant wind generation capacity goes offline due to this reason, it leads to further low voltage and may lead to a cascade tripping of other generators. If the amount of wind capacity that goes offline is large, it may lead to significant overdrawl from the ISTS and the DISCOM bearing the associated deviation charges. For example, on 26.6.2015, a grid fault led to tripping of around 1000MW of wind generation in Tamil Nadu, causing the UI of the state to increase from -150 MW to 840 MW. (CERC, 2016) To avoid cascade tripping of generators and avoid loss of generation for momentary voltage dips, wind generators should have a technical capability of Low Voltage Ride Through (LVRT). This essentially allows wind generators to continue being online for momentary voltage dips up to a certain time.

On 15.10.2013, the CEA notified an amendment to CEA (Technical Standards for Connectivity to the Grid), 2007. (CEA, 2013) In the amendment, separate connectivity standards were specified for wind generators and generators connected to the grid via inverters. For new generators (i.e. generators connected on or after completion of the 6 months from the date of publication of the amendment (15.4.2014)), a new operating frequency band, power factor range and LVRT capability was specified. The new generators are required to be capable of supplying dynamically varying reactive power to the grid, while maintaining their power factor from 0.95 leading to 0.95 lagging. Also, they are required to be capable for operating in a wider frequency range of 47.5 Hz to 52 Hz and maintaining their rated output for a frequency range of 49.5 Hz to 50.5 Hz. Wind generators connected to the grid at voltage greater than 66kV will have the facility to control the injected active power according to the direction from the LDC. Also, it will be ensured that the reduction in the injected active power will be shared by all the wind generators in proportion to their capacity, and shutting down of single operational unit will be avoided as far as possible.

Finally, generators connected to the grid at voltage level greater than 66kV, are required to remain connected to the grid for a certain time, if the voltage dips down. The time for which the generator should remain connected to the grid corresponding to different levels of voltage dips is determined by a characteristic defined in the amendment. The generator is expected to trip instantaneously only if the voltage is less than 15% of nominal voltage at the interconnection point. The 15% of nominal voltage limit is considerably less than the present setting of 85% of nominal voltage for tripping. Wind generators also need to maximize the reactive current injection during the voltage dip until the time the voltage starts recovering or for 300 ms, whichever is lower. (CEA, 2013) For older generators, the standards are to be mutually decided between the generator and the licensee of the electric system. The amendment had specified that these regulations will come into effect by April 2014, however it appears that no progress was made in this direction.

In February 2015, the SRLDC petitioned the CERC (Petition No. 420/MP/2014) against the SLDCs of Tamil Nadu, Kerala, Andhra Pradesh, Karnataka and the IWPA seeking directions to the SLDCs to ensure installation of LVRT on wind turbines. Various stakeholders like the Indian Wind Turbine Manufacturers Association (IWTMA) and the IWPA sighted difficulties in implementation, like applicability of LVRT for older wind generators, applicability to solar generators, financing for LVRT retrofitting, etc. Except for old stall type turbines (expected to be phased out in 3-4 years) which form 11% of the 25,807 wind turbines existing as on April 2014, and some models which cannot be retrofitted due to technical constraints, all other turbines can implement LVRT. Cost of LVRT retrofitting ranges from 25-50 Lakhs/turbine. (CERC, 2016) It is estimated that 97% of the annually added wind turbines from 2015 are suitable for LVRT implementation. Similarly, the National Institute for Wind Energy has confirmed that 49 of the 58 wind turbine models having valid type approval/certificate comply with the LVRT requirement. Of the models having capacity > 1 MW, only one model does not comply with the LVRT requirement. (NIWE, 2016) As per the CERC order (January 2016) in this case, wind turbines of capacity more than 500 kW except of stall type are directed to comply with LVRT by 2018. For financing the cost of retrofitting for LVRT, CERC has requested the SERCs to include the cost of retrofitting for LVRT in tariff calculation under the change in law provision, while the OA wind generators are requested to factor the cost of LVRT while quoting the price of electricity to sell.

Recognising the expected large capacity addition of solar power, the CEA is in the process of amending the Central Electricity Authority (Technical Standards for Connectivity to the Grid), 2007 regulations for mandating LVRT for solar generators (except rooftop solar). Hence, the solar generators whose bidding process has not started yet should plan for incorporating LVRT at their generating stations. (CERC, 2016)

7
Conclusions

1. **Grid Strengthening Initiatives Underway :** The Indian electricity grid has seen significant improvements in the last 10 years, as indicated by the improvements in frequency profiles, the entire grid operating synchronously as one national grid, higher regional transmission capacity, etc. However, at the same time, it continues to remain weak in several areas in terms of high distribution losses, continued load shedding, low voltages at the distribution tail end, variation in frequency (though this has considerably decreased recently), lack of adequate reserves, flexible generation and effective demand forecasting, etc. Several initiatives to address the above issues are currently underway. Some of these initiatives include, a) operationalising regional reserves across the country, b) start of frequency regulation under the ambit of ancillary services, c) pilots on AGC, d) more states moving towards the intra-state ABT mechanism, e) 24X7 intra-day power markets, f) operationalising technical minimum (55%) operation of ISGS/Inter-state coal plants, g) scaled up implementation of Phasor Measurement Units (PMU), etc. Effective demand forecasting by DISCOMs (which has been identified as the primary reason for large deviations, see Annexure IV) and regulation of ramp rates for power plants are expected to be operationalised in the near future. These will go a long way in reducing many of the existing problems in the Indian grid. *More importantly, all these measures are needed for effective, reliable and secure operation of the grid, irrespective of whether the grid has a high penetration of variable renewables like wind and solar or not. However, these will also help ease the integration of renewables into the grid.* For effective RE integration, apart from RE specific initiatives, it is equally important how the rest of the system evolves.

2. **RE Forecasting, Scheduling and Deviation Settlement Regulations :** One of the most important RE specific change includes the new frameworks for mandatory forecasting, scheduling and commercial settlement of deviation for RE (wind and solar) generators. While the framework for regional entities connected to the ISTS is already notified by the CERC and is operational, the FoR has provided model regulations for states to build upon for their state specific regulations. Based on this, eight states have come out with their draft regulations, and one of them (Karnataka) has finalised the regulations. Two important conclusions come to the fore based on the analysis of these regulations.

    a. Since the commercial settlement for deviations with regard to state grid connected RE generators is delinked from UI, the difference between UI charges due to RE deviations and the penalties for RE (due to over or under-injection) would have to be borne by the host state DISCOM. Additionally, since the new definition of absolute error is defined as a percentage of Available Capacity (AvC in MW), which is generally much higher than the scheduled capacity, errors are expected to be much lower in comparison to the earlier RRF mechanism which defined error as a percentage of the scheduled capacity. Both these factors (delinking from UI and error definition which lowers errors) will reduce revenue uncertainty for generators, but are likely to make host states/DISCOMs oppose greater increase in the deployment of variable RE. *In the medium term (after implementation of the first round of forecasting and scheduling regulations), it is important for the RE generation deviation (over the whole state) penalties to be linked to UI so as to easily integrate with the overall sector and lessen opposition to its growth.*

    b. Since penalties (beyond permissible deviation limits) for under-injection are higher than that for over-injection, both for state and regional generators, *it may bias the generators to under-schedule*. This possibility should be considered when deviation bands are revised in the future.

    c. Deviation penalties for inter-state transactions and for regional entities are based on fixed rates (linked to tariff under their PPAs), while those for intra-state transactions are based on absolute value (absolute value in Rs/kWh). Such absolute values need careful attention and regular revision in line with the wind and solar market prices. *Ideally, states should quickly move to intra-state ABT* *based accounting and align the state framework for RE forecasting and scheduling in line with the CERC framework for regional entities*. Or else there might arise a situation in which deviation charges under these two frameworks may vary, even when projects are situated next to each other. There may be practical/legal difficulties in getting "existing generators" with payments based on actuals to move to an intra-state ABT system with payments based on schedules. Regulatory mechanisms to overcome such hurdles will need to be worked out. One possibility is to have some form of vintage based multiplier for older projects.

d. Practically speaking, the ERC need not regulate how the QCA depools the total deviation charges applicable to a pooling station amongst its member generators, though the FoR model regulations have given some suggestions. However, the *"SLDCs have suggested the need for regulation of the activities of the designated QCAs and further clarification of the functions and responsibilities of the QCA".* (FoR, 2016) Taking into account some potential issues of depooling deviations amongst generators connected to a pooling station, namely a) different values of depooled quantity based on methodology used (in proportion to available capacity or actual generation), b) net deviation (either over or under injection) at the pooling station getting proportionally distributed amongst generator even when some generators maybe under or over-injecting or maintaining perfect schedule, c) accuracy of individual forecasts (when schedule of the pooling station is made up by aggregating individual forecasts) affecting other generators, QCAs could consider the following option. *If the block wise actual generation data for each generator were available with existing metering infrastructure, then a better methodology of depooling the net deviation at the pooling station could be in proportion to the actual deviations of the generators behind the pooling station.*

e. If there remains a wide variation in defining absolute error, deviation bands and deviation errors among states, there is a fear that newer investments may not come up as expected in states with higher risk of penalties. *Hence, the FoR should try to evolve consensus amongst states to have the same deviation framework.*

3. **Renewable Energy Management Centres :** REMCs are being set up in all SLDCs, RLDCs and the NLDC and are expected to carry out various functions like forecasting and monitoring of RE generation, coordination with LDC for schedule and dispatch, coordination between LDC and generators, etc. *While REMCs can play an important role in easing the integration of renewables into the grid, there needs to be greater synergy and detailing of their role in the regulatory process, which is evolving in parallel. Similarly, they will have to be closely integrated with LDC operations and protocols to avoid any duplication of efforts.*

4. **New Technical Requirements in RE Generators:** The CEA has mandated new technical requirement for certain wind and solar generators. These include Low Voltage Ride Through, reactive power support, regulation of active power and a newer frequency band for operation. *These will certainly aid in RE supporting grid operation in terms of ancillary services.*

5. **Wider sharing of generation resources to reduce balancing requirements :** The CERC DSM regulations require deviation settlement to take place at the geographical boundary of states. The state as a whole is the control area to which the deviation limits in terms of the minimum of 12% of schedule or 150 MW apply (200-250 MW for RE-rich states). Hence states try to do load-generation balancing (optimise dispatch within the state) as one entity to avoid violating these DSM volume limits.

   a. Two easy ways to manage load-generation balance are to either shed load (mostly in states with high amount of cross-subsidised agriculture/rural consumers) or violate the DSM limits and use the grid as a de-facto trading platform (under/over drawal) to manage load, while paying UI charges.

   b. On the generation side, states plan to not only dispatch state generators, but also require ISGS and short-term power from power exchanges or bilateral contracts. Finalisation of state schedule is also done in consultation with the RLDC to optimally utilise ISGS. Similarly, ISGS and state generators regulated under intra-state ABT respond to dynamic variations in frequency and help balance load through UI incentives. Frequency regulation as an ancillary service to be provided by ISGS is another new option available for load generation balance. Hence, to this extent there is already sharing of generation resources across states and along wider areas.

c. However, this sharing of generation resources can be taken further to reduce balancing requirements of states, which are potentially slated to increase with increase in variable RE. For example, a host state with old depreciated hydro plants may be currently using such a resource partly to meet its peak load, or partly as a base load / energy resource. It does this to ensure that the full benefit of this low cost resource is directly passed on only to its state consumers in terms of lower consumer tariffs. For such states to share these resources with other states (to help in their incremental balancing requirements[8], due to increase in RE or to meet peak load of other states), they would need to be incentivised to such a level that their consumers continue to benefit financially as before. At a minimum, the difference in cost between the alternative source of generation and the low cost hydro would have to be made up for the host state. However, this value of the resource should not be so high that it is greater than the cost of other potential resources (intra-day markets, generators in other states, demand response, storage, etc.) which could have been used for the balancing requirement for that state. Essentially the value of this hypothetical old depreciated hydro resource for meeting the balancing needs of other states is bounded by these two limits. Arriving at this value is a non-trivial exercise.

d. Such sharing of resources across states and making use of intra-day trading possibilities at the power exchange would *entail a change in role for the DISCOM officials handling power purchase*. From decision making which mainly looked at the medium to long term (seasonal and beyond), they *will have to also look at short term (intra-day/day ahead planning) and take on a more pro-active and dynamic/nimble role to maximise the benefits for the DISCOM*. It will also require *new and more nuanced regulatory approaches which will enable dynamic decision making at the DISCOM level, but at the same time provide risk mitigation for DISCOM consumers* on account of losses due to highly inappropriate trading / use of market mechanism by the DISCOM.

e. Sharing of generation resources across states is not limited only to incremental balancing needs on account of renewables. It could also be used from states with surplus, where plants are being backed down, and for states where there is simultaneous load-shedding, need for generation resources and a willingness to pay for them. Wider sharing of resources could also be facilitated by coordinated scheduling/centralized dispatch, but, in the current federal structure, this could be challenging, as states may not be willing to give up their scheduling and dispatch control. Further studies to investigate sharing of balancing resources using innovative regulatory and market based instruments need to be done. *So essentially wider sharing of generation resources is certainly possible (much more than currently practised) and should be strongly encouraged. However, this will need strong political support across states to ensure that the easier but more harmful options of load shedding and/or violating DSM limits are strictly not exercised.*

6. **LDC Autonomy:** The Electricity Act 2003 envisaged the load dispatch centres to be independent and autonomous organisations that would optimally schedule and dispatch power. (Ministry of Law and Justice, 2003) Recognising the fact that some time would be required to set up such organisations, the Act allowed the state or central transmission utilities to operate these bodies in the interim. Unfortunately, more than ten years since the act came into force such interim arrangements continue to be the norm. Recently, there has been an effort to separate the central LDC from the CTU, but at the state level there has not been any such move. In the erstwhile integrated utility model, LDC autonomy was not much of an issue. However, with more players entering the scene, autonomy and independence of the system operator becomes a crucial factor and has serious implications for competition, optimum dispatch and grid stability. Already, there are a significant number of cases before the various SERCs and the Appellate Tribunal filed by generators and/or open access consumers alleging the LDC's failure to act as an independent system operator. (MERC, 2014) (APTEL, 2013) Similarly, some state LDCs have also appealed against ambiguities and/or inconsistencies in

8. The peak wind generation season in India (monsoon) coincides with high hydro generation as well as low demand and hence the practical possibility of this suggestion needs to be technically investigated.

the regulations concerning open access, unscheduled interchange, and merit order dispatch. (APTEL, 2014) This highlights the need to address the issue of autonomy and independence at the earliest, even from the perspective of RE grid integration.

7. **Institutional Strengthening:** With over 300 GW of existing generation capacity which is likely to quickly grow to roughly 700 GW by 2027 and 1200 GW by 2037, India will have one of the largest synchronous electrical grids in the world. Simultaneously, the share of variable renewables is also set to sharply rise over this period. To deal with all the issues arising out of operating such a large grid, *electricity planning and operational institutions (LDCs, RPCs, CEA, SNAs, DISCOMs, MNRE, etc.) need significant strengthening in terms of personnel, training and financial resource outlays. Forum of Load Disptachers (FOLD) can act as an LDC data repository and institutional memory.* New operational protocols to use the 24X7 intra-day markets, accepting revisions to schedule through the day, data collection, storage and dissemination for the appropriate agencies would have to be developed.

8
Glossary

Ancillary Services: *In relation to power system (or grid) operation, the services necessary to support the power system (or grid) operation in maintaining power quality, reliability and security of the grid, e.g. active power support for load following, reactive power support, black start, etc.* (CERC, 2010)

Automatic Generation Control (AGC): *A regulatory mechanism and set of equipment that provides for automatically adjusting generation within a balancing area from a centralized location to maintain a specified frequency and/or scheduled interchange* (Greening the Grid).

Available Capacity (AvC): *Available Capacity for wind or solar generators is the cumulative capacity rating of the wind turbines or solar inverters that are capable of generating power in a given time-block.* (CERC, 2015)

Balancing Area: *A metered segment of the electric power system in which electrical balance is maintained. In a balancing authority area, the total of all generation must equal the total of all loads (as supplemented by electrical imports into and exports out of the area)* (US Department of Energy, 2011).

Congestion Charge-: *Charges incurred by generator or beneficiary causing transmission system congestion.* (CERC, 2010)

Demand Side Management: *Demand-side management and demand response enable consumers to participate in load control based on price signals*. (Greening the Grid)

Flexibility: *The ability of a power system to respond to changes in electricity demand and supply.* (Greening the Grid)

Flexible Generation: *The ability of the generation fleet to change its output (ramp) rapidly, start and stop with short notice, and achieve a low minimum turn-down level.* (Greening the Grid)

Frequency Response: *The ability of generation (and responsive demand) to increase output (or reduce consumption) in response to a decline in system frequency and decrease output (or increase consumption) in response to an increase in system frequency. Primary frequency response takes place within the first few seconds following a change in frequency. Secondary frequency response (also known as regulating reserve) takes place on a timescale of minutes (or faster) following a disturbance.* (Greening the Grid)

Grid Contingency: *The unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch or other electrical element.* (Greening the Grid)

Economic dispatch: *The allocation of demand to individual generating units on line to effect the most economical production of electricity.* (Greening the Grid)

Net Load: *Demand that must be met by other generation sources if all wind and solar power is consumed.* (Greening the Grid)

Operating Reserves: *Electricity generating capacity that is available to a system operator to provide for regulation (i.e., response to random movements during normal conditions), load forecasting error, forced and scheduled equipment outages, and local area protection. Other types of reserves include contingency (deployed in response to generator failures), regulating (secondary frequency response via AGC), or flexibility (reserves to address variability and uncertainty on timescales longer than regulating reserves).* (Greening the Grid)

Pooling station: *The sub-station where pooling of generation of individual wind generators or solar generators is done for interfacing with the next higher voltage level: Provided that where there is no* *separate pooling station for a wind / solar generator and the generating station is connected through common feeder and terminated at a sub-station of distribution company/STU/CTU, the sub-station of distribution company/STU/CTU shall be considered as the pooling station for such wind/solar generator, as the case may be.* (CERC, 2010)

Ramp rate: *The change in output of a generating unit per unit time, often measured in megawatts per minute.* (Greening the Grid)

Regulation Down Service*:* *An Ancillary Service that provides capacity that can respond to signals or instructions of the Nodal Agency for decrease in generation, within the technical limit and time limit, to respond to changes in system frequency or congestion in the system.* (CERC, 2015)

Regulation Up Service: *An Ancillary Service that provides capacity that can respond to signals or instructions of the Nodal Agency for increase in generation, within the technical limit and time limit to respond to changes in system frequency or congestion in the system.* (CERC, 2015)

Reactive Charge: *Charges incurred by generator or beneficiary for reactive energy exchanges.* (CERC, 2010)

Reactive Power: *The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers. It also must supply the reactive losses on transmission facilities.* (Greening the Grid)

Uncertainty: *The inability to perfectly predict the electricity demand and/or generator output, which can be caused either by unexpected outages or due to the unpredictability of the resource.* (Greening the Grid)

Unscheduled Interchange (UI): *Unscheduled Interchange in a time block for a generating station or a seller is its total actual generation minus its total scheduled generation, and for a beneficiary or buyer is its total actual drawal minus its total scheduled drawal*. (CERC, 2010)

Variability: *The changes in power demand and/or the output of a generator due to underlying fluctuations in resource or load.* (Greening the Grid)

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Annexure I : Timeline of RRF (2010-14)

Timeline for Introduction of Forecasting, Scheduling and Commercial Settling Mechanism for Renewable Generators at Regional and State Level

28.04.2010
- CERC notified IEGC, 2010, requiring wind and solar projects to undertake forecasting and scheduling.
- Included a UI based commerical settlement mechanism for wind and solar deviations. The collected UI charge was named as Renewable Regulatoy Fund (RRF).

30.11.2010
- POSOCO submitted procedure for implementation of RRF mechanism to CERC.
- IWTMA requested the CERC to postpone the date of implementation of RRF due to lack of preparedness of the wind generators for forecasting and scheduling, resulting in RRF to be implemented from 01.01.2012 instead of 01.01.2011.
- CERC approved procedure submitted by POSOCO on 18.02.2011.

01.07.2011
- Date of commencement of mock exercise of RRF mechanism.
- On 15.12.2011, POSOCO submitted that the stakeholders including SLDC, wind generators had not yet shared requisite data which seriously affected the mock excercise.

23.03.2012
- MNRE acknowledged problems faced by all the stakeholders and constructed a task force under the chairmanship of POSOCO CEO.
- The task force submitted the report on 02.07.2012.

09.07.2012
- CERC approved new procedure for implementation of RRF based on the task force report submitted by POSOCO on 12.06.2013.
- The new RRF procedure was to be implemented from 15.07.2013.

22.07.2013
- WIPPA filed petition in Delhi high court against CERC for implementing RRF, stating difficulties to limit the forecasting error within the limits specified in RRF which would result in a 12%-15% revenue loss to the wind generators.

01.08.2013
- Madras high court stayed the commerical settlement in RRF mechanims, though allowing forecasting and scheduling of the wind generators.

31.01.2014
- CERC through suo motu Petition Order 356/SM/2013 received feedback from stakeholders regarding difficulties in implementation of RRF and suspended commercial settlement of wind geenerators under RRF till further notice.

(Compiled From- (CERC, 2011) (CERC, 2014) (CERC, 2013) (CERC, 2012) (CERC, 2012) (CERC, 2011) (CERC, 2013) (CERC, 2015) (CERC, 2015)

Annexure II : Analysis of Depooling

In section 5.3.9, we have analysed depooling both possible quantities (i.e. energy deviations and deviation charges) by the two possible methods (in proportion to available capacity or actual generation). This yields four options for depooling as shown in Figure 13. The impact of each option may differ according to the scheduling option adopted, type of deviation charges, design etc.

Figure 13 : Options to QCA for Depooling

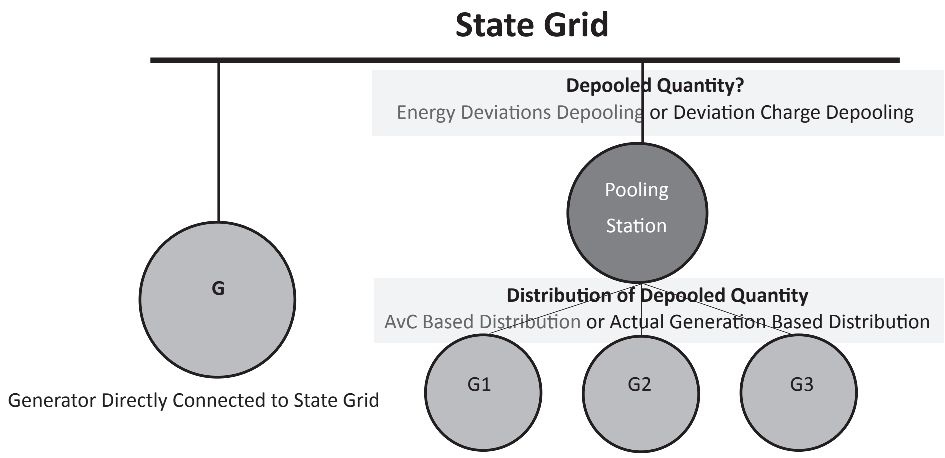

Table 10 : Symbols and Corresponding Meanings Used in the Analysis

Symbol	Meaning
S	Schedule of the pooling station
A	Actual generation measured at pooling station
D	Energy Deviation measured at pooling station
DVC	Energy Deviation charge calculated at pooling station
s_i	Schedule of the i^{th} generator
a_i	Actual generation of the i^{th} generator measured by SEM meters
d_{i_actual}	Actual energy deviation of the generator a_i - s_i
dvc_{i_actual}	Deviation charge incurred to the generator for deviation d_{i_actual}
d_{i_cal}	Energy deviation for i^{th} generator calculated by depooling
dvc_{i_cal}	Deviation charge for i^{th} generator corresponding to energy deviation a_i - s_i
AvC_i	Available capacity of the ith generator
w_{ci}	$= AvC_i/(\sum AvC_i)$(Weight based on the AvC of the generator)
w_{ai}	$= a_i/(\sum a_i)$ (Weight based on the actual generation of the generator)
S1	Schedule of the pooling station after using the forecasting option 1
S2	Schedule of the pooling station after using the forecasting option 2
D1	$=(\sum a_i - S_i)$ (Deviation at pooling station after using the forecasting option 1)
D2	$=(\sum a_i - \sum s_i)$ (Deviation at pooling station after using the forecasting option 2)
DVC_1	Deviation charge for the pooling station corresponding to D1
DVC_2	Deviation charge for the pooling station corresponding to D2

Table 11 shows formulae for depooled quantities calculated for each option for i^{th} generator connected to the pooling station. Following symbols are adopted for analysis as shown in Table 10.

Table 11 : Formulae for depooled quantities calculated for each option for ith generator connected to the pooling station

	Depooled quantity	Method of depooling	Depooled Quantity for i^{th} generator for Schedule arrived using scheduling option 1	Depooled Quantity for i^{th} generator for Schedule arrived using scheduling option 2	Actual value of the depooled quantity for i^{th} generator
1	**Energy deviations**	In proportion to AvCs	$d_{i\_cal} = D_1 * w_{ci} = (\sum a_i - S_1) * w_{ci}$	$d_{i\_cal} = D_2 * w_{ci} = (\sum a_i - \sum s_i) * w_{ci}$	$a_i - s_i = d_{i\_actual}$
2	**Energy deviations**	In proportion to actual generation	$d_{i\_cal} = D_1 * w_{ai} = (\sum a_i - S_1) * w_{ai}$	$d_{i\_cal} = D_2 * w_{ai} = (\sum a_i - \sum s_i) * w_{ai}$	$a_i - s_i = d_{i\_actual}$
3	**Deviation charges**	In proportion to AvCs	$dvc_{i\_cal} = DVC_1 * w_{ci}$	$dvc_{i\_cal} = DVC_2 * w_{ci}$	Dev charge corresponding to $a_i - s_i$ (d_{i_actual})
4	**Deviation charges**	In proportion to actual generation	$dvc_{i\_cal} = DVC_1 * w_{ai}$	$dvc_{i\_cal} = DVC_2 * w_{ai}$	Dev charge corresponding to $a_i - s_i$ (d_{i_actual})

Based on the methods of depooling and type of schedule at the pooling station, above formulae were arrived at for the depooled quantities d_{i_cal} and dvc_{i_cal}. The difference in the formulae arrived at for depooling is due to the presence of different weights w_{ci} and w_{ai} used for depooling and different options (options 1 and 2) used for the scheduling of the pooling station. The weight w_{ci} in case of AvC based depooling and w_{ai} in case of actual generation based depooling may differ. For the AvC based depooling and actual generation based depooling to be equal, w_{ci} must be equal to the w_{ai}. This holds true when the ratio of AvC to actual generation for all the generators behind the pooling station is the same in one time block. The ratio of AvC_i/a_i can differ among the generators connected to the same pooling station experiencing same weather conditions, in case the technology used for different generators is different. For example, for the same capacity of solar plant actual generation from crystalline PV, thin film and tracking based solar plant would be quite different. Hence, this ratio is important to consider while finalising the depooling methodology. Different AvC_i/a_i ratio can lead to different allocation of deviation charges or energy deviations among the generators in one time block. Hence, QCA must study these ratios and decide the method for depooling.

Secondly, the entire deviation (D_1) at the pooling sub-station (over-injection or under-injection) gets proportionately distributed amongst the generators (d_{i_cal}) However, it is possible that while there is net over injection at the pooling station (for example), some generators may actually $a_i - s_i$ (d_{i_actual}) be under-injecting or maintaining perfect schedule during that time block. As noted earlier in this report, impact of over-injection and under-injection on the revenue of the generator is not the same.

If current depooling methods based on the AvC or actual generation are used, the magnitude of calculated energy deviation d_{i_cal} or deviation charges dvc_{i_cal} may or may not be equal to the magnitude of actual energy deviation of the generator $a_i - s_i$ (d_{i_actual}) or the deviation charge dvc_{i_actual} corresponding to this actual energy deviation. Depending on the magnitude and direction of deviation (over/under) of d_{i_cal} and d_{i_actual}, there are eight possibilities of the relationship between d_{i_cal} and d_{i_actual}. These possibilities are noted in Table 12.

Table 12 : Possibilities of the relation between calculated energy deviations and actual energy deviation of the i^th^ generator

Possibility	Deviation direction (over/ under) of d_{i_cal}	Deviation Direction (over/under) of d_{i_actual}	Comparison of magnitudes of d_{i_cal} and d_{i_actual}	Example of possibility
P1	Overinjection	Overinjection	$\| d_{i\_cal} \| > \| d_{i\_actual} \|$	d_{i_cal} =30MW Overinjection and d_{i_actual} =20MW Overinjection
P2	Overinjection	Underinjection	$\| d_{i\_cal} \| > \| d_{i\_actual} \|$	d_{i_cal} =30 MW Overinjection and d_{i_actual} =20 MW Underinjection
P3	Underinjection	Overinjection	$\| d_{i\_cal} \| > \| d_{i\_actual} \|$	d_{i_cal} = 30 MW Underinjection and d_{i_actual} =20 MW Overinjection
P4	Underinjection	Underinjection	$\| d_{i\_cal} \| > \| d_{i\_actual} \|$	d_{i_cal} =30 MW Underinjection and d_{i_actual} =20 MW Underinjection
P5	Overinjection	Overinjection	$\| d_{i\_cal} \| < \| d_{i\_actual} \|$	d_{i_cal} =20 MW Overinjection and d_{i_actual} =30 MW Overinjection
P6	Overinjection	Underinjection	$\| d_{i\_cal} \| < \| d_{i\_actual} \|$	d_{i_cal} = 20 MW Overinjection and d_{i_actual} =30 MW Underinjection
P7	Underinjection	Overinjection	$\| d_{i\_cal} \| < \| d_{i\_actual} \|$	d_{i_cal} = 20 Underinjection and d_{i_actual} =30 Overinjection
P8	Underinjection	Underinjection	$\| d_{i\_cal} \| < \| d_{i\_actual} \|$	d_{i_cal} = 20 Underinjection and d_{i_actual} =30 Underinjection

These possibilities can have different impacts on the revenue of the generator. Also in P3 and P7, the generator gets charged for under-injection even if it is over-injecting. As seen in the previous section, under-injection leads to more revenue loss to the generator than over-injection.

Annexure III : Comparison of Past and Present Forecasting Frameworks for Renewable Generators

Table 13 : A comparison of different forecasting, scheduling and commercial settlement mechanisms

	RRF Mechanism	CERC framework for Regional Entities	FoR Model Guidelines for States	
			Inter-state Transaction	**Intra-State Transaction**
Applicability	Pooling stations commissioned on or after 03.05.2010, connected to state distribution or state transmission or interstate transmission at voltage level (33kV and above) and having wind or solar generators of collective capacity greater than 10MW and 5MW respectively	All the renewable generators which are regional entities, renewable generators of aggregate capacity greater than 50MW connected to ISTS, UMPP based on wind and solar having capacity greater than 500MW, any renewable generation station of capacity between 5MW to 50MW and connected to existing generation connected to ISTS	All wind and solar generators connected directly to the state grid or through pooling station and selling power within or outside the state	
Absolute Error Definition	(Actual Generation-Scheduled Generation)/ Scheduled Generation	(Actual Generation-Scheduled Generation)/Available Capacity		
Allowable Deviation without any penalty	Wind - 30% (with maximum injection capped at 150% of the scheduled generation). Solar - no fixed limit.	15% of absolute error.	15% of absolute error.	15% of absolute error for wind or solar generators commissioned prior to the date of effect of the regulations. 10% of absolute error for wind or solar generators commissioned after the date of effect of the regulations
Penal Rate	Based on UI charges depending on frequency	Fixed rate, i.e. tariff as per PPA for projects selling to DISCOMs. For OA/CPP projects, rate is national APPC as defined by CERC	Fixed rate, i.e. tariff as per PPA for projects selling to DISCOMs. For OA/CPP projects, rate is national APPC as defined by CERC	Absolute values ranging from 0.5 Rs/ kWh to 1 Rs/ kWh to 1.5 Rs/ kWh
Link to UI	Linked to UI	Not Linked to UI	Not Linked to UI	Not Linked to UI
Payment Basis	Actual Generation	Scheduled Generation	Scheduled Generation	Actual Generation

Metering	ABT compliant SEM meters were to be installed by CTU and STU for the regional and intra-state entities at the cost of respective entities. The SEM meters were to be capable of time-differentiated measurements for time block wise active energy and voltage differentiated measurement of reactive energy. It was the responsibility of coordinating agency to provide the Data Aquisition System to transfer the information to RLDC/ SLDC as applicable, also to provide weekly data of scheduled generation, actual generation and deviation of pooling station to RLDC/SLDC as applicable	For Regional Entities (Generator directly connected to the ISTS/ Pooling Station Level) -The Interface Energy Meters will be installed by the CTU and STU for regional and intra-state entities respectively to facilitate boundary metering, accounting and settlement for RE generators while data from such meters will be communicated to RLDC by Automated Meter Reading (AMR) system. Turbine/Inverter level data, at a frequency <=10 seconds will be provided to the RLDC by the QCA/Generator through data telemetry	For State Entities (Generator directly connected to the State Grid/Pooling Station Level)- The interface meters (SEM meters) and communication infrastructure will be installed at interface point with state grid. Within Pooling Station-SLDC may receive only Pooling station Level data while the QCA will have the turbine/inverter level data for improving its forecasting, pooling or depooling of deviations.	
RPO accounting	On the basis on Actual Generation	On the basis of Scheduled Generation	On the basis of Scheduled Generation	On the basis of Scheduled Generation

Annexure IV : Excerpts from 'CERC's Statement of Reasons – 3rd Amendment to the Deviation Settlement Mechanism Regulations dated, 23rd Oct 2015

1. However, many states continue to deviate heavily from the schedule on a consistent basis (Annexure I - 'Trends of Deviation' for a few states). This is primarily due to absence of or poor load forecasting, lack of planning, procedures for calling in reserves and non-adherence to schedule by grid-connected entities such as conventional generators and DISCOMs in the State. The plots also illustrate that deviations are irrespective of windy vs non-windy season, or whether the State has large renewable capacity installed or not. Additionally, volume of these deviations in the past has been shown to be statistically uncorrelated to renewable penetration for specific Renewable-rich states (Annexure II Analysis on correlation of State boundary deviations with variation in wind and solar sources). Notwithstanding the above, several states have emphasized that managing renewables, especially wind, is posing a huge challenge, which is causing the States to deviate from schedule, and resulting in huge financial burden.

2. Notwithstanding that errors in load forecasting are possible, as pointed out by Gujarat & Maharashtra, the States must ensure that load-serving entities are investing in improving load forecasting methods by analyzing accuracy of their forecasting algorithms over time. If a fairly good load forecast is made, the standard deviation of the forecast error is expected to be of the order of 2% or less and this is known upfront, i.e., before dispatch. Such anticipated variations in the load need to be taken care of through deployment of reserves in the system. There are many states where scientific methods of load forecasting are yet to be put in place. Such States must first take the requisite steps, and then proceed to show the inadequacy of these processes, if any remains. Long, medium and short term load forecasting and generation planning, peak vs off-peak planning, streamlined energy accounting for all entities, RE forecasting and scheduling- these are critical and fundamental steps for sound grid management. There cannot be any excuse for not undertaking each one of these actions at the State level, and thereafter not taking responsibility for grid indiscipline that results due to absence of the above.

3. For large-scale integration of solar and wind generators into State grids, the Forum of Regulators (FOR) has evolved a State Model Regulation, which outlines a model for operational and commercial management of variable RE sources. The proposed framework for forecasting, scheduling, and deviation settlement of solar & wind generators is similar to that notified by CERC for regional entities in August 2015. However, it is pertinent to explicate the commercial arrangement suggested for the States. In the Model Regulation, it has been recommended that if the State DSM pool goes negative due to implementation of the regulation, the States may approach national funds such as NCEF or PSDF for covering the deficit. It has been underlined that this would be only to the extent of deficit caused by RE generators. Hence, to qualify for such compensation, the States must undertake separate scheduling and energy accounting of all entities, as explained in the document. The Commission feels that this will address a major part of the problem, as currently stated by the RE-rich states.

4. The Commission is being very liberal, and is going against international best practices, but it must be reiterated that this measure is meant as a one-time measure for a specified period. These limits have been relaxed only up to April 1st, 2017, The States must plan to have sound grid management practices as well as firm up their strategy for maintaining load generation balance in the wake of increasing share of renewables by then. The limits shall be revised towards more stringent norms post April 2017. (CERC, 2016)

Annexure V : Highlights of the SAMAST report

FoR released a new report titled SAMAST on Scheduling, Accounting, Metering and Settlement of Transactions in Electricity on 15 July 2016 (FoR, 2016). The report highlights the status of the metering, energy accounting, scheduling, financial settlement of energy transactions in India and stresses upon the need for improving the metering, communication, IT infrastructure and energy accounting and settlement. This was done through a survey of 28 SLDCs and 5 RLDCs.

According to the report, the numbers of intrastate entities within control of a particular SLDC vary widely (Min-7, Max-971, and Median-182). The intra state RE generator entities in RE-rich states range from 100-200. The report recommends to identify all the intrastate entities and to make them members of the state pool. For preparation of the state energy account, the report proposes instituting State Power Committees (SPC) having representatives from state pool members. SERCs could notify the role and responsibilities of various entities in the state energy accounting and settlement.

While giving the status of placement of the Interface Energy Meters (IEM) across the country, it is stated that the number of interface points in the country are 23301, while the number of IEMs are 22406 (less than interface points) indicating inadequate placement of meters in the country. Only 30% meters employ AMR due to lack of communication infrastructure and software limitations at SLDCs. Hence it recommends identifying all the meter locations in the intra state system for placement of meters. Future meter procurement should comply with CEA “Functional Requirement of Advanced Metering Infrastructure” standards, have least count of 5 minutes and frequency resolution of 0.01Hz. The meters would be capable of recording Voltage and Reactive Energy at every 5 minutes in view of uneven loading of transmission lines due to renewable generation, and would have the feature of auto-time synchronisation through GPS. The report also recommends setting the infrastructure for AMR, data collection and meter management system for automatic data validation and estimation, archival of meter data and its use for load forecasting and big data analysis.

The SAMAST report also recommends i) scheduling based on coordinated multilateral model which separates roles of market players and grid operators in commercial decisions and grid security ii) *5 minute settlement interval in next five years* to address the ramping challenge due to renewable generation iii) scheduling based on security constrained merit order with a well defined time line iv) no post facto correction in energy rate for merit order dispatch v) transparency related to transfer capability data of SLDC, transmission losses data.

The report also advocates a simple, robust, scalable but dispute-free settlement system. In this settlement system the state pool will be delinked from super (regional) and sub-pool which would avoid the ripples related to change in accounting in one pool to another. The settlement system should include i) mutual settlement of capacity charge and energy charge by the market participant and only deviation settlement by the system operator ii) gross settlement for the ancillary services iii) implementation of dispatch with ancillary services.

For facilitating the enhanced grid security and economic dispatch, the report suggests identification of marginal cost of generation for cost plus thermal plants, different tariff for peak and off peak generation, two part tariff for reservoir based hydro stations to exploit their flexibility, *valuation of conventional generation stations for handling variability of demand and RE, exploration of two part tariff for RE generators, creation of distribution system operators, and introduction of time of day tariff.* The report also advises to move towards voltage based reactive power pricing instead of power factor based pricing.

List of Abbreviations

ABT	-	Availability Based Tariff
AvC	-	Available Capacity
CEA	-	Central Electricity Authority
CERC	-	Central Electricity Regulatory Commission
CTU	-	Central Transmission Utility
DSM	-	Deviation Settlement Mechanism
EMS	-	Energy Management System
IEGC	-	Indian Electricity Grid Code
InSTS	-	Intra State Transmission System
ISGS	-	Inter State Generating Station
ISTS	-	Inter State Transmission System
LDC	-	Load Dispatch Center
NLDC (POSOCO)	-	National Load Dispatch Center (Power System Operation and Control)
PMU	-	Phasor Measurement Unit
PPA	-	Power Purchase Agreement
QCA	-	Qualified Coordinating Agency
REMC	-	Renewable Energy Management Centers
RLDC	-	Regional Load Dispatch Center
RPC	-	Regional Power Committee
RPO	-	Renewable Purchase Obligation
RRF	-	Renewable Regulatory Fund
SCADA	-	Supervisory Control and Data Acquisition
SERC	-	State Electricity Regulatory Commission
SLDC	-	State Load Dispatch Center
STU	-	State Transmission Utility
UI	-	Unscheduled Interchange
UMPP	-	Ultra Mega Power Project

Related publications of Prayas (Energy Group)

1. The future electricity grid: Key questions and considerations for developing countries (2016)
http://prayaspune.org/peg/publications/item/321.html

2. Grid Integration of Distributed Solar Photovoltaics (PV) in India: A review of technical aspects, best practices and the way forward (2014)
http://prayaspune.org/peg/publications/item/276.html

3. Solar Rooftop PV in India (2012)
http://prayaspune.org/peg/publications/item/186.html

4. Data Gaps in India's Energy Sector (2015)
http://prayaspune.org/peg/publications/item/313-data-gaps-in-india-s-energy-sector.html

5. Comments and Suggestions for the Draft Amendment of the National Tariff Policy, May 2015 (2015)
http://prayaspune.org/peg/publications/item/299-comments-and-suggestions-for-the-draft-amendment-of-the-national-tariff-policy.html

6. How Much Energy Do We Need:Towards End-Use Based Estimation For Decent Living (2015)
http://prayaspune.org/peg/publications/item/298-how-much-energy-do-we-need-towards-end-use-based-estimation-for-decent-living.html

7. A 'Dashboard' for the Indian Energy Sector (2015)
http://prayaspune.org/peg/publications/item/296-a-%E2%80%98dashboard%E2%80%99-for-the-indian-energy-sector.html

8. A Commentary On The Electricity (Amendment) Bill, 2014 (2015)
http://prayaspune.org/peg/publications/item/293-commentary-on-the-electricity-amendment-bill,-2014.html

The 175 GW renewable generation capacity target for 2022 has fundamental implications for electricity grid planning and operations. Renewable energy generation, especially from wind and solar power, is variable in nature, given its dependency on the weather. Maintaining continuous balance in demand and supply and constant frequency is important for the reliable and secure operation of the grid. Deviation in frequency can occur due to instantaneous differences between generation and demand, which grid operators apprehend would worsen due to higher penetration of renewables. This coupled with some pre-existing problems of the relatively weak Indian grid makes reliable and effective grid integration of renewables even more challenging. Hence, policy-regulatory officials and grid operators are very concerned that such a steep and rapid increase in 'infirm' or 'non-dispatchable' renewables will affect the electricity grid and make grid operation far more complex and difficult to deal with.

This report is an attempt to understand the concerns of grid operators when it comes to integrating high levels of variable renewables. The focus is on forecasting and scheduling of renewable power, one of the key starting points to minimise grid imbalance and aid effective integration. It also examines the various supporting initiatives adopted by ERCs and policy makers towards easing grid integration. We conclude by outlining potential suggestions and ideas for easing the challenges of grid integration.

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