Framework for scheduling and forecasting of renewable energy

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1 Introduction

The system operators have to ensure reliability and security of the electricity grid. Hence, they must know the quantity and quality of electricity being injected into the grid by all sources of electricity, at defined intervals of time. Renewable energy, a relatively new entrant to India's power system, has increased exponentially in the past few years. This increase in variable generation has led to issues in integrating it with the power system. Scheduling and forecasting of the RE generation is presently being discussed and debated in India, to be able to manage the system effectively.

Objectives of the study

The project reviews the present policies and guidelines followed by utilities across the world to manage current penetration level of renewable energy sources. The present Indian regulations, grid codes and practices followed by wind developers have been reviewed. The data has been analyzed for Indian systems to better understand the system behavior with present renewable penetration levels. The research work further deliberates on scheduling approaches to be adopted by the wind scheduler and the system operator to handle the stochastic nature of renewable sources.

The role of various agencies (developers, independent scheduling coordinators, system operators) in operating the forecasting system and its effect on power system integration is of critical importance. International practice shows that system operators have their own forecasting system for consolidating and predicting the variable generation output in their control areas whereas individual wind farms forecast their output if they are participating in the electricity market. The pros and cons of each of the mechanisms have been discussed charting out the way forward for adoption as an integrated approach for Indian system.

Roadmap

Considering the relevance of the subject, a roadmap suggesting possible forecasting and scheduling strategies for India and implementation frameworks for the same have been evolved. The roadmap covers:

- *Scheduling process*
- *Forecasting services*
- *Error computation*
- *Data management*

2 Scheduling Process

As per present regulations in India, decentralized scheduling is adopted, which means that each wind farm with the connected capacity of 10 MW and above at interface point to the grid submits its schedule to the system operator. It is observed that most countries prefer centralized or cluster-based scheduling with the concept of virtual power plants. The practices followed are:

- ***Centralized scheduling for committed wind farms through PPA:*** An independent body or system operator schedules and forecasts on behalf of all the wind farms.

- ***Individual wind farms who participate in the market:*** The wind farms participate in the open electricity markets through bidding process and settlement takes place according to the market rules. Here, scheduling & forecasting is the responsibility of the wind farm owners.

There are advantages and disadvantages of both the approaches. For power system operation and security, the centralized mechanism is preferred. The summary of various methods is described below.

2.1 Decentralized Scheduling Mechanism

In this mechanism, each wind farm forecasts and schedules its generation. The mechanism is preferred for wind farms who wish to participate in open access or day ahead or intraday markets. As the schedule is available from individual wind farms, the transmission line congestion would be known in advance and appropriate actions can be initiated.

However, each wind farm follows its own forecast mechanism and there is no consistent approach. With many wind farms, the huge number of schedules received by the system operator may create difficulties in managing the schedules. As each wind farm has to maintain the scheduling and forecasting system, there is no optimization of costs as well as forecasting system.

2.2 Centralized Scheduling Mechanism

The centralized scheduling mechanism would result in reduction in forecast error due to aggregation taking advantage of geographic diversity and smoothing of forecasting errors. This mechanism can provide consistent wind power forecasting approach and methodology for all wind projects in the region, which will likely lead to more consistent results. With its sheer magnitude and resources, it would promote technological advances and research for better forecasting system.

The grid operator shall have access to wind generation data (and perhaps onsite weather data from all the wind plants) that can be used to improve the performance of centralized scheduling & forecasting system. Whereas in decentralized forecast method by wind farms, the system operator may not have access to wind generation data because of proprietary or confidentiality reasons. A centralized scheduling system may be able to utilize economies of scale, reducing the cost of forecasting as compared to decentralized forecasting systems.

However, the centralized forecasting system may have inconsistency as it can be based on single forecasting methodology and provider. This can be overcome by creating a structure with the competitive model and the fees paid to the forecast provider dependent on the accuracy of the forecast. The system operator receives the wind power forecast for entire state or area as one entity and hence the system operator can see one overall wind power forecast value. Under this mechanism, system operator does not perform the wind power forecast for individual wind farms. Further, it would be difficult to anticipate transmission line congestion if only the aggregate forecast is available for entire region.

It is observed that both the mechanisms have their own merits and would be useful for different purposes. Considering the Indian context where the future wind farms can trade power through any route, adopting any one particular mechanism may not serve the purpose of system operation and security. Hence it is proposed to have an integrated scheduling mechanism where the wind farms entering into PPAs with the utilities would be covered under centralized forecasting system whereas the wind farms that are into captive use or participate in the bilateral market (either through power exchange or third party sales) could follow the decentralized mechanism.

2.3 Integrated Scheduling Mechanism

In this approach, it is proposed that centralized forecasting is done for each identified cluster and individual wind farm/solar farm forecast for the investors who wish to participate in the energy market. This provides high accuracy as compared with decentralized forecast due to diversity of renewable energy generators over the area/cluster. These clusters can be described as virtual power plant for all practical purposes. Under this mechanism, system operator can see the RE power forecast values for each cluster. These schedules can be integrated with the EMS (Energy management System) and would enable the system operator to handle transmission line congestion.

With economics of scale, it would be possible to reduce the cost of forecasting and at the same time promote forecast by ensemble methods (i.e., systems that make use of a variety of methodologies or forecast providers) that use five or more forecasting services to improve the forecast accuracy.

In this mechanism, all the wind farms in the clusters would be considered (irrespective of date of commissioning) for forecasting. In view of range of wind turbines commissioned in the last decade, wind farms would be categorized into three levels. First, there are plants that had no turbine and nodal-level generation or meteorological data; these can be labeled as Level 1 wind plants. These include plants that were not included in the data gathering effort and are not metered. Second are the ones in which only total power output is known at the interconnection point (Level 2). These tend to be plants that were not included in the data gathering effort but are metered. These are plants that are technically incapable of providing real-time data and/or are small in installed power. For example, turbines built prior to 2005 tend to be technically incapable of providing real time data via the architected data collection system and plants less than 10 MW were not pursued unless bundled together with other larger plants. Lastly, there are plants which are SCADA connected, that can provide turbine-level and nodal-level details (Level 3).

Most of the wind farms commissioned post 2006 have the capability to provide the real time SCADA data (with minor modification in the wind farms wherever it is needed) and would constitute around 70% of the wind generation in country. The level 3 wind farms would form the base for the forecasting and for the remaining wind farms, upscaling methods would be used to arrive at their generation. Thus in the proposed approach, the system operator would have complete information of the wind generation in the cluster and can plan their activity by considering them as virtual power plant for their operation.

Individual wind farm who are contracted by captive use and third party sales, would forecast their generation and submit their schedule to the System Operator (SO). The gaming by these wind farms would also be prevented in this approach as the intended generation in the cluster would be known through the centralized forecasting system, and if the schedule deviates beyond certain percentage, then the system operator can initiate appropriate action to correct their schedule.

The number of clusters is unique for a particular state. This can be decided upon by performing certain data analysis in depth. However, based on the research, the clusters are formed as shown in Table 1 for integrated scheduling and forecasting for high wind penetration states:

Table 1: Clusters for integrated Scheduling & Forecasting

State	**Area/zone wise Wind generation passes**
Tamil Nadu	Muppandal, Udumalpete, Theni, Thirunelveli
Karnataka	Chitradurga, Chikkodi, Gadag
Rajasthan	Udaipur, Jaisalmer, Jodhpur
Gujarat	Kutch, Saurashtra
Maharashtra	Sangli, Ahmednagar, Satara

2.4 Framework for scheduling process

To sustain the integrated scheduling mechanism, it is necessary to have a Scheduling Coordinator (SC) for each state. The scheduling coordinator will manage all the wind farm clusters in that state. In the proposed approach, the system operator has been designated as the scheduling coordinator for managing the functions and based on the experience gained; a separate agency under the system operator can be assigned this task.

The funds for forecasting services and deviations can be provided from fund collected as “Scheduling, Forecasting and Deviation (SFD) Fund” from all wind and solar developer/investor on per MW basis and this shall be managed by the scheduling coordinator of the state.

At present in decentralized forecast mechanism, the cost of forecasting services varies from Rs.1,250 to 1,750 per MW per month for the wind farms. With the economics of scale with wind clusters coupled with competition, these charges may come down to less than Rs.1,000 per MW per month. On top of this, wind farms would need to pay deviation charges if schedules go beyond the limit specified in the regulations.

In the proposed approach, it is recommended to invite bids from qualified forecast providers for each cluster (they would be called as service providers (SPs)). It could be ensured that at least two service providers be appointed in every state to be able to compare their services. In the transition period, the service providers can be paid the fee for their services which shall be scaled based on the forecast accuracy. The transition period may be 2 to 3 years. The fees for these services can be funded through SFD. In the transition period, SLDC/designated agency may have to be compensated from both SFD fund and centrally operated fund (green energy fund) for balance of actual deviation cost. After transition period, the deviation from the forecast would be accounted by SLDC/designated agency through SFD fund only.

After transition period, it is recommended that for each cluster, competitive bids can be invited for services of forecasting, scheduling and deviation. The bids would be similar to uplift charges based on per MW basis for each cluster which would be a virtual power plant. The successful bidder may be paid from the SFD fund for all the services offered. The Deviation Settlement Mechanism (DSM) would be applicable for each of the clusters and could be same as applicable to utilities.

Considering the present deviation settlement mechanism, the overall charges per year for the wind farm would range from Rs.2 Lakhs/MW to around Rs.5 Lakhs/MW.

In the proposed mechanism, the wind farms can be categorized into 2 categories as presented below.

Category 1: Wind farms with valid PPAs:

- With DISCOMs within the state
- With DISCOMs of other states (for inter-state trading of wind power)

Category 2: Wind farms not having PPAs:

- Market based wind power sales through open access
- Captives

2.4.1 Category 1

The wind farm owners are free to enter into PPA with same state DISCOMs or other state DISCOMs. In this category, wind farm owners or developers would pay fee per MW towards SFD fund. The UI charges, deviation settlement will be accounted by SLDC through SFD fund. For wind PPAs with other states DISCOMs, the additional transmission charges need to be accounted.

The clusters will be formed in a particular state and the SC will be responsible for scheduling, forecasting and settlements of deviations for these clusters. As explained earlier, these services are procured from the service providers based on the fees derived from the bids. The monopoly over forecasting services shall not be entertained as this will lead to inconsistency and inaccuracy. Hence, it is advisable to always procure forecast services from more than one service providers. This will also lead to enhanced forecasting results as different forecast providers use different techniques/methodologies.

For wind farms with PPAs with inter-state DISCOM, the schedule can be given by the SC as a percentage of installed capacity in that cluster for the inter-state sales. For e*xample,* if the total installed capacity of cluster is say 1000 MW and scheduled generation given by SC for this cluster is 600 MW. If one wind farm having installed capacity of 100 MW in this cluster has PPA with inter-state DISCOM, then the schedule of this 100 MW wind farm for the inter-state DISCOM during this period is 60 MW.

2.4.2 Category 2

The wind farms under this category could forecast their generation schedule by themselves as per the regulations. Any deviations from the committed power shall be settled according to the deviation settlement mechanism as followed by the utilities.

If actual generation is higher than the schedule given by wind farm owner, then for the extra generation, the wind farm would be paid at average pooled purchase cost (APPC) of the respective DISCOM/state, and the wind farm could be allowed to sell corresponding RECs in the market. If actual generation is lower than the schedule given by wind farm owner, the wind farm could pay the DISCOM an average pooled supply cost (APSC) for the shortfall in generation and buy Renewable Energy Certificates (RECs) from the market. In both the cases, the wind farm shall make good the RECs.

For these wind generators the fee payable would be a certain percentage of the fee (SFD Fund) as they are accounted separately for a deviation settlement.

System coordinator provides the schedules for clusters for both category -1 and category-2 wind farms for system operation purpose. These cluster schedules are used for the system operation but deviation settlements would be accounted separately. However, there could be a provision for penalty if the schedule of the category-2 wind generators deviate more than a certain percentage of the cluster forecast given by SC.

In order to better understand the perspective of deviation settlement in case of category 2 wind farms, a sample calculation is made. The deviation in a time block is taken as the difference of actual total injection and total scheduled generation. Thus, a positive deviation implies over-injection. The deviation charges for additional injection of the power would be paid at APPC while for deviation for shortfall in injection shall be paid for at APSC. A typical APPC and APSC for the State are presented in Table 2.

Table 2: Typical APPC and APSC values

Standard Rates Considered	Cost per unit in Rupees
APPC	3.27
APSC	5.04

Sample calculations are presented to better understand the proposed methodology. In this sample calculation an actual injection of 30 MW for a 60 MW wind farm is considered for various possible schedules for one hour duration.

The selling price is considered as Rs 4/- per unit to third party sale or captive consumption. The results obtained for the test cases are shown in Table 3. From Table 3, it is observed that giving higher or lower schedules as compared with actual power will give good profits for wind farms and this will encourage for high accuracy forecasts.

Table 3: Sample calculations based on APPC & APSC method

Sl. No	Schedule in MW	Actual in MW	Deviation in MW	Deviation Payment in Rs.	Revenue through third party sale (Rs.)	Net Amount (Rs.)
1.	60	30	-30	-1,51,200	2,40,000	88,800
2.	57	30	-27	-1,36,080	2,28,000	91,920
3.	35	30	-5	-25,200	1,40,000	1,14,800
4.	25	30	5	16,350	1,00,000	1,16,350
5.	6	30	24	78,480	24,000	1,02,480
6.	3	30	27	88,290	12,000	1,00,290

{Calculation for Sl.No.1:

Deviation power	*= actual power – scheduled power*
	= 30 – 60 = -30 MW
Deviation payment during 1st hour	*= energy*APSC*
	*= -30,000*5.04 = Rs. -1,51,200*
Revenue through sales during 1st hour	*= scheduled energy*committed tariff*
	*= 60000*4 = Rs. 2,40,000*
Net Amount	*= -1,51,200 + 2,40,000 = Rs. 88,800*

Calculation for Sl. No.5:

Deviation power	*= actual power – scheduled power*
	= 30 – 6 = 24 MW
Deviation payment during 1st hour	*= energy*APPC*
	*= 24,000*3.27 = Rs. 78,480*
Revenue through sales during 1st hour	*= scheduled energy*committed tariff*
	*= 6,000*4 = Rs. 24,000*
Net Amount	*= 78,480+ 24,000 = Rs. 1,02,480 }*

The deviation settlement calculation is made for a wind farm in Karnataka with total installed capacity of about 58 MW. The scheduled power, actual power and grid frequency are collected for a period of 30 days and the deviation calculation by both approaches are presented in the Table 4.

Table 4: Deviation settlement calculations

Approach	Total payment due to deviations (Rs)	Total revenue through third party sale (Rs)	Net total (Rs)
Case 1: Calculation for 30 Days actual schedule			
Based on APPC and APSC as per Category 2	-2,72,27,847	9,55,54,653	6,83,26,805
Based on deviation calculation with UI rates	-62,70,171	9,55,54,653	8,92,84,481
Case 2: Calculation for 30 Days at schedule of 100% capacity			
Based on APPC and APSC as per Category 2	-8,72,51,761	16,19,88,750	7,47,36,988
Based on deviation calculation with UI rates	-4,59,53,033	16,19,88,750	11,60,35,716
Case 3: Calculation for 30 Days at schedule of 75% capacity			
Based on APPC and APSC as per Category 2	-3,77,25,641	12,14,91,562	8,37,65,920
Based on deviation calculation with UI rates	-2,17,45,305	12,14,91,562	9,97,46,257
Case 4: Calculation for 30 Days at schedule of 25% capacity			
Based on APPC and APSC as per Category 2	4,24,43,936	4,04,97,187	8,29,41,124
Based on deviation calculation with UI rates	-1,01,56,491	4,04,97,187	3,03,40,695
Case 5: Calculation for 30 Days at schedule of 10% capacity			
Based on APPC and APSC as per Category 2	6,25,69,917	1,61,98,875	7,87,68,792
Based on deviation calculation with UI rates	-1,65,74,805	1,61,98,875	-3,75,930

The net total earned by the developer/investor is lower in the proposed APPC & APSC approach as compared to the present approach of deviation settlement mechanism as stated in section 2.4.1. This implies that the earnings from the deviations are considerably reduced thereby encouraging the developers/investors to make a more accurate forecast.

3 Forecasting services

Presently, forecasting in India is carried out by companies such as 3-Tier, Garrad Hassan, AWS Truepower. Most of their services are based on the models created based on European/USA context and is applied in India. There is a need to create a comprehensive and competitive mechanism for forecasting services in India.

Forecasts highly rely on high quality of meteorological and other data (both historical and real time data) made available in a timely manner to the forecast providers for use within their models. The data includes the following real time data, metrological data and static data as shown in Table 5.

Table 5: Data required for wind power forecast

Turbine data		Meteorological Tower Data at sensor heights
Real time data	**Static data**	
Turbine generation	Latitude & Longitude	Wind speed
Nacelle wind speed	Hub Height (m)	Wind direction
Wind direction	Turbine Model	Temperature
Turbine availability status (or equivalent on wind farm level)	Manufacturer's Power curve	Pressure
		Air density

It is proposed that, the regulation shall make it mandatory for providing the real time data by all the wind farm owners depending on the levels (level 1 to 3 as defined in section 2.3) described earlier.

4 Error computation

As per present regulations, the error computation is with respect to schedule power. As wind generation varies from zero to maximum, the error distribution is very wide with respect to schedule. Worldwide practice is to compute error with respect to installed capacity. Error with respect to installed capacity provides the operator/stakeholders to understand the deviations better provided the wind farm owners share the turbine availability information for the scheduling intervals. Hence it is recommended to use the error deviations with reference to installed capacity for comparing the forecasting services. This shall be used for payment for forecasting services to provide level playing field.

5 Data management and Data repository

System operator or scheduling coordinator needs to maintain databases for renewable energy sources in addition to existing conventional data in Data Exchange Centre (DEC).

The data management is critical for better forecasting and future operation. Hence it is recommended that the data sharing by the wind farms be made mandatory as part of the regulation. The regulation shall provide the manner in which the data to be shared along with data interval mechanism on par with other conventional power plants.

6 Role of various agencies

Based on the above proposed frame work for scheduling and forecasting of renewables, the following roles are proposed for different entities.

Wind investor/ developer

- Wind Forecasts rely on high quality data made available in a timely manner for the forecasting functions.

- The regulation could make mandatory that
  - ✓ Developer/investor needs to make a provision for SCADA connectivity with the system control center (SLDC / wind energy management center).
  - ✓ Wind developers need to provide real time data as per the requirements.

- While making a provision for SCADA connectivity the wind farm developers/investors can use the existing real time SCADA of the respective SLDCs/RLDCs to optimize on the communication facility.

Scheduling Coordinators (SC)

- The system operator could forecast the RE power in their state either by themselves or can contract this task to the service providers.

- The service provider's task would be to forecast wind power in their area/cluster for different time frames (for e.g. up to 72 hours, day ahead, hour ahead etc).

- Consolidation of the forecasted values and preparation of the scheduled generation and submission of the scheduled generation to system operator shall be part of scheduling coordinator.

- SLDC needs to appoint different scheduling coordinators for identified areas/clusters and who could use different forecast methods. This is to ensure better accuracy and comparison.

- Payment mechanism for these services could be based on accuracy of the forecast in the transition phase.

- After transition, the bidding can be carried out based on uplift payment for each cluster.

System Operator

- The system operator needs to set up an operational planning wing that will receive the identified cluster/area forecast from the service provider/SC.

- Operational planning wing need to optimize the generation schedule of conventional generation considering the schedules from renewables over various time frames to ensure integration of high wind generation.

7 Way Forward

As a way forward, the following steps are recommended:

- Changes in state/central Grid Code to incorporate the scheduling and forecasting processes by the system operator/designated agency or through service providers.
- The scheduling, forecasting and deviation settlement for third party sales and captive generation by the respective wind farm owners.
- CERC could introduce changes in IEGC (Indian Electricity Grid Code) to mandate data sharing by wind farms.
- Regulations concerning the deviation mechanism, if it is separate from the conventional schemes.
- Creation of SFD fund and institutional mechanism. Considering the present deviation settlement mechanism, the overall charges per year for the wind farm would range from Rs.2 Lakhs/MW to around Rs.5 Lakhs/MW.
- Formulation of guidelines for selecting the forecast service providers by state regulators.

The recommendations are summarized in Table 6:

Table 6: Recommendation for Scheduling & Forecasting of Renewables

Recommendation	Proposed Actors
Changes in the Central Grid code for interstate sale of power from Renewable Energy sources	Central Regulator (CERC)
✓ Changes in State Grid code for intra state scheduling and forecasting of Renewable energy sources ✓ Guidelines/Model changes	State Regulators Forum of Regulators/CERC
Wind farm data sharing (required data) for centralized wind power forecast	Grid code by Central Regulators
Deviation mechanisms for centralized forecast system	State regulator for Intra-State sales and Central Regulator for Inter-State sales
Creation of Scheduling & Forecasting Fund with contributions from Wind farm owners. Maintained by State utility or third party	Respective SLDCs based on the guidelines of State Regulators
Selection of forecasting service agencies	SLDCs as per the guidelines of State Regulator

About the Study

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About Shakti Sustainable Energy Foundation

Shakti Sustainable Energy Foundation works to strengthen the energy security of the country by aiding the design and implementation of policies that encourage energy efficiency as well as renewable energy.

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