Conference Proceedings

EuroSun 2016
Palma de Mallorca (Spain), 11 – 14 October 2016

Evolution of solar forecasting in India: The introduction of REMCs

Indradip Mitra[1], Sunil Sharma[1], Mandeep Kaur[1], Aravindakshan Ramanan[1], Markus Wypior[1], Detlev Heinemann[2]

[1]GIZ GmbH, New Delhi (India)

[2] Energy Meteorology Group, University of Oldenburg, Oldenburg (Germany)

Abstract

With increasing solar PV installed capacity in India, forecasting of its generation is gaining importance. In India forecasting for renewable energy has been recently operationalized. Two kinds of forecasting needs to be done, one for the individual plants for scheduling and accounting actions and the other for entire grid control area for grid operation. Day ahead forecasting with 15 minute resolution, 16 times intra-day revision, was made mandatory as a consequence along with several sets of rules and mechanisms introduced by the Central as well as State level authorities. One innovative development is the concept of Renewable Energy Management Centers which would be co-located with existing load dispatch centers and take care about forecasting along with a few other activities. After establishment of REMC it is assumed that environment for improved grid integration of renewables would be created.

Key Words: *Forecasting of solar power; Grid integration of solar energy; Renewable Energy Management Centre.*

1. Introduction

1.1. Need for solar power forecasting in India

As of August 2016, the total installed generation capacity is India is 304.76 GW (CEA, 2016). The RES contributes to 14 % of the total installed capacity (shown in Fig 1). The Wind energy installed capacity is 27.15 GW. The contributions of different renewable energy sources are shown in Fig 2.

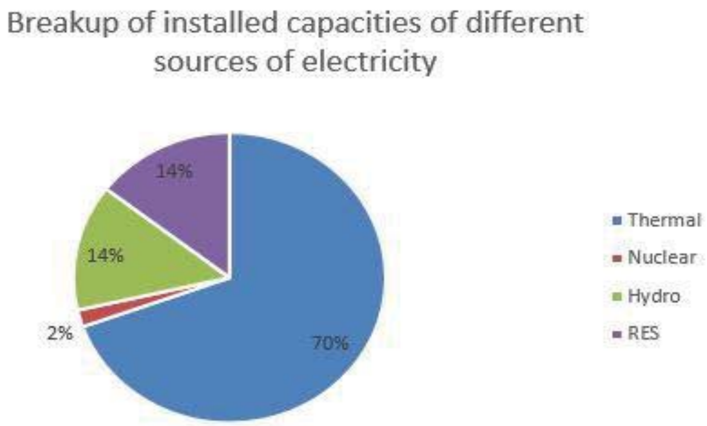

Fig. 1: The breakup of installed capacities of different electricity sources (CEA, 2016)

doi:10.18086/eurosun.2016.11.05 Available at http://proceedings.ises.org

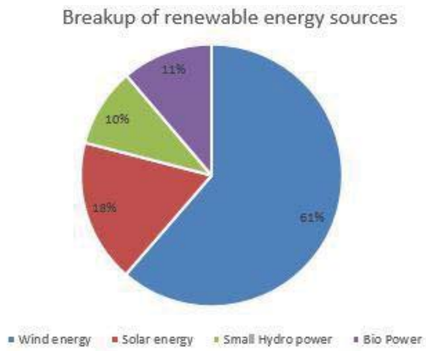

Fig.2: The breakup of installed capacities of different renewable energy sources (CEA, 2016)

In the recent years, there has been a steep increase in the solar power installations in India. Solar PV installed capacity is 8.1 GW as of August 2016. There has been an 80 % increase in the installed capacity of solar PV generations sources over the past 12 months (Economic Times, 2016). Govt. of India of also has a renewable energy installation target of 175 GW until 2022. This includes a target of installed capacity of 100 GW for solar energy, 60 GW for wind energy, 10 GW of bio energy and 5 GW for small hydro. There is a 40 GW target in roof top solar segment among the overall solar energy target (NITI Aayog, 2015). The state wise target of solar PV and wind generation installed capacities of the different states in India as per Ministry of New and Renewable Energy (MNRE) is given in Table 1 (MNRE, 2015).

The grid operators in many renewable energy rich states of India are finding it difficult to manage the grid. The absence of forecasting is hindering their operations. In year 2013, two to three billion units generated from wind were curtailed, mainly due to absence of forecasting (IWTMA, 2015). In India, primary and secondary controls are not fully operational. Therefore accurate control area wide renewable energy forecasting would go a long way for grid operators to effectively manage the grid. Accurate Forecasting by the grid operators would mitigate the actual requirement of primary, secondary and tertiary reserves.

It is also important that individual RE power plants forecasts the generation output of their power plants. This would enable them to provide accurate schedules to system operators. They can also earn better revenue by trading their electricity effectively in power exchanges.

Because of the reasons stated above, there has been a lot of developments in regulatory and institutional framework in the concept of solar power forecasting. Different important govt. institutions namely Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission, Power System Operation Corporation (POSOCO), Load Dispatch Centres (LDC), etc. have actively worked to evolve solutions in the in the recent past. This paper has details regarding the different interesting developments in this regard.

Tab. 1: Tentative breakup of targeted installed capacity of solar PV for different states in India (MNRE, 2015)

State / UTs	Solar Power (MW)	Wind Power (MW)
Delhi	2762	
Haryana	4142	
Himachal Pradesh	776	
Jammu & Kashmir	1155	
Punjab	4772	
Rajasthan	5762	8600
Utter Pradesh	10697	
Uttrakhand	900	
Chandigarh	153	
Northern Region	**31120**	**8600**
Goa	358	
Gujarat	8020	8800
Chhattisgarh	1783	

Madhya Pradesh	5675	6200
Maharashtra	11926	7600
D. & N. Haveli	449	
Daman & Diu	199	
Western Region	**28410**	**22600**
Andhra Pradesh	9834	8100
Telangana		2000
Karnataka	5697	6200
Kerala	1870	
Tamil Nadu	8884	11900
Puducherry	246	
Southern Region	**26531**	**28200**
Bihar	2493	
Jharkhand	1995	
Orissa	2377	
West Bengal	5336	
Sikkim	36	
Eastern Region	**12237**	
Assam	663	
Manipur	105	
Meghalaya	161	
Nagaland	61	
Tripura	105	
Arunachal Pradesh	39	
Mizoram	72	
North Eastern Region	**1205**	
Andaman & Nicobar Islands	27	
Lakshadweep	4	
Other (New States)		600
All India	**99533**	**60000**

2. Discussion

2.1. Structure of Load Dispatch Centers

India's power grid is synchronously connected and the operating frequency is 50 Hz. India's electrical grid is divided into five regions, in each where there is a Regional Load Dispatch Centre (RLDC) located. Each state in India constitutes a control area, where there is a State load dispatch centre (SLDC) located. SLDC is responsible for real time operations for grid control and does optimum scheduling and dispatch of electricity within the state (CERC, 2010). The RLDC exercises supervision over SLDCs in its region and is responsible for maintaining stability of grid operations, economy and efficiency of operation in the electrical region (CERC, 2010). The National load dispatch centre (NLDC) is hierarchal above RLDC. It is responsible for monitoring operations and security of national grid. NLDC is also responsible for supervision and control over inter-regional links (CERC, 2010).

2.2. Regulatory Interventions in RE Forecasting

As indicated in section 1.1, forecasting of generation is important in the perspective of grid operators and individual RE generators. Therefore CERC, SERC and FOR have taken this into cognizance and number of regulations have been drafted. Forecasting by SLDC have been suggested to be mandatory in order to maintain the grid security (APERC, 2016; FOR, 2015; JSERC, 2016; KERC, 2015; RERC, 2016; TNERC 2016). IEGC 3rd amendment mandates RLDCs to perform forecasting (CERC, 2015b). There is a huge motivation for grid operators to perform forecasting taking into consideration its importance in grid operations. Control area wide forecasting of the cumulative RE generation would be important functionality through the establishment of REMC's. Other kind of usages of forecasting for grid operators are congestion forecast, ramp forecast, reactive power forecast, etc.

There has been a lot of developments with respect to regulatory interventions in generation forecasting for individual wind and solar PV power plants. This has been detailed in the following section.

2.2.1 Regulatory interventions in RE forecasting for individual solar PV power plants

In India, forecasting of RE generation was conceptualised in Indian Electricity Grid Code, 2010 through the Renewable Regulatory Fund (RRF) mechanism. Forecasting was made mandatory for wind energy projects greater than 10 MW and solar energy projects greater than 5 MW (CERC, 2010). There were not any commercial implications related to accuracy of forecasting produced by solar energy projects. Owing to implementation issues, RRF mechanism was not operationalised. Central Electricity Regulator Commission (CERC) released draft regulations regarding forecasting on 31st March 2015 (CERC, 2015a) as well as corresponding draft amendments to grid code and deviation settlement mechanism. After taking public opinion into considerations, amendments to grid code and Deviation Settlement Mechanism, 2015 was finalised (CERC, 2015b, 2015c). In November 2015, Forum of Regulators (FOR) announced model regulations on RE forecasting and scheduling applicable to projects feeding power within the state boundaries (FOR, 2015). Following similar lines, states of Karnataka, Tamil Nadu, Orissa, Rajasthan, Jharkhand and Andhra Pradesh came up with their draft regulations for RE generation forecasting and scheduling applicable at intra-state level (APERC, 2016; JSERC, 2016; KERC, 2015; RERC, 2016; TNERC, 2016). After receiving public comments, Karnataka Electricity Regulatory Commission (KERC) notified the regulation on forecasting. In different regulations, 16 revisions in the schedule are allowed for RE projects on intra-day basis. The above clause encourages RE power projects to perform intra-day forecasting of generation. The regulations related to forecasting are compared in Tab 2.

Tab. 2. Detailed inter comparison of different regulations related to forecasting in India (APERC 2016; CERC, 2010, 2014, 2015b, 2015c; FOR, 2015; JSERC, 2016; KERC, 2016; RERC, 2016; TNERC, 2016)

PARAMETERS / REGULATIONS	CERC Dated 7.8.2015 DSM 2nd amendment and IEGC 3rd amendment	Forum of Regulators Dated x.x.2015	Karnataka Electricity Regulatory Commission (KERC) Dated 31.05.2016	Madhya Pradesh Electricity Regulatory Commission (MPERC) Dated 08.12.2015	Tamil Nadu Electricity Regulatory Commission (TNERC) Dated x.x.2016	Rajasthan Electricity Regulatory Commission (RERC) Dated x.02.2016	Jharkhand Electricity Regulatory Commission Dated x.x.2015	Andhra Pradesh Electricity Regulatory Commission Dated 06.09.2016
Applicability	All wind/ solar generators which are regional entities.	All wind/ solar generators connected to the state grid including those connected via pooling stations, and selling power within or outside the state.	All wind and solar generators above threshold collective capacity at the pooling station selling power within or outside the state.	All wind and solar generators connected to the state grid including those connected via pooling stations, and selling power within or outside the state	All wind and solar generators connected to the state grid, including those connected via pooling stations, and selling power within the state.	All wind and solar generators above threshold collective capacity at the pooling station selling power within or outside the state	All wind/ solar generators connected to the state grid including those connected via pooling stations, and selling power within or outside the state.	All wind/ solar generators connected to the state grid including those connected via pooling stations, and selling power within or outside the state.
Threshold Collective Capacity	50 MW and above	NA	≥ 10 MW for wind generators ≥ 5 MW for solar generators MW	NA	NA	5 MW and above	NA	NA
Data Requirement from RE Generators	Turbine availability, power output and real-time weather measurements (wind speed, temperature, pressure etc.)	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.	Technical specifications, data relating to power system output & parameters and weather related data to the concerned SLDC in real time.
Who Should do forecast	RLDC as well as wind/ solar generator.	Solar/ Wind Generator or QCA on their behalf should do forecasting for the purpose of scheduling. SLDC should also do forecasting for ensuring secure grid operations.	Solar/ Wind Generators or QCA/ Aggregator on their behalf should do forecast for the purpose of scheduling. Or services from REMC could be taken. SLDC should also do forecasting for ensuring secure grid operations.	Solar/ Wind Generator or QCA on their behalf should do forecasting for the purpose of scheduling. SLDC should also do forecasting for ensuring secure grid operations.	Solar/ Wind Generator or QCA on their behalf should do forecasting for the purpose of scheduling. SLDC should also do forecasting for ensuring secure grid operations.	Solar/ Wind Generator or QCA on their behalf should do forecasting for the purpose of scheduling. SLDC should also do forecasting for ensuring secure grid operations.	Solar/ Wind Generator or QCA on their behalf should do forecasting for the purpose of scheduling. SLDC should also do forecasting for ensuring secure grid operations.	Solar/ Wind Generator or QCA on their behalf should do forecasting for the purpose of scheduling. SLDC should also do forecasting for ensuring secure grid operations.
Frequency of schedules	Day ahead	Day ahead and week ahead schedule	A week ahead, day ahead and intraday	Day ahead and week ahead schedule	Day ahead and week ahead schedule	Day ahead and week ahead schedule	Day ahead and week ahead schedule	Week ahead, day ahead and intra-day schedule.

PARAMETERS / REGULATIONS	CERC Dated 7.8.2015 DSM 2nd amendment and IEGC 3rd amendment	Forum of Regulators Dated x.x.2015	Karnataka Electricity Regulatory Commission (KERC) Dated 31.05.2016	Madhya Pradesh Electricity Regulatory Commission (MPERC) Dated 08.12.2015	Tamil Nadu Electricity Regulatory Commission (TNERC) Dated x.x.2016	Rajasthan Electricity Regulatory Commission (RERC) Dated x.02.2016	Jharkhand Electricity Regulatory Commission Dated x.x.2015	Andhra Pradesh Electricity Regulatory Commission Dated 06.09.2016
Revisions Allowed	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day.	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day.	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day.	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day.	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day.	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day.	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day..	Max 16 revisions are effective from 4th time block starting from 00:00 hours of a particular day..
Normalised Error Definition	$Error(\%) = \frac{(AG-SG)}{AvC^{1}} x100$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$	$Error(\%) = \frac{(AG-SG)*100}{AvC}$
Tolerance band	± 15% applicable for both wind/ solar generators	Generators selling power within state can deviate upto ±15 % (prior) and ±10 % (after) this regulation Generators selling power outside state can deviate up to ±10 %	± 15 %	Generators selling power within state can deviate upto ±15 % (prior) and ±10 % (after) this regulation Generators selling power outside state can deviate up to ±10 %	10% for wind and 5% for solar generators	± 15 %	Generators selling power within state can deviate upto ±15 % (prior) and ±10 % (after) this regulation Generators selling power outside state can deviate up to ±10 %	Generators selling power within state can deviate upto ±15 % (connected prior to regulations) and ±10 % (connected after this regulation) Generators selling power outside state can deviate up to ±10 %.

2.3. Infrastructure to support the activity of solar power forecasting

2.3.1. Solar Radiation Resource Assessment (SRRA) stations

As an intermediate step in the prediction of solar PV power output, Global Horizontal Irradiance (GHI) is predicted through the run of Numerical Weather Prediction (NWP) models. Ground measured value of GHI is really important to fine tune the predicted output. This step is called post-processing. It would help in eliminating the statistical bias.

Solar Radiation Resource Assessment (SRRA) project of MNRE is an important initiative that has a huge relevance in solar PV power forecasting as explained above. MNRE initiated the SRRA project and implemented it through National Institute of Wind Energy in 2010. GIZ provided technical assistance to the project. SRRA stations were setup in 121 locations across India. It is world's largest network of solar radiation resource assessment stations setup all over the country. It measures GHI, DHI, DNI along with other environmental parameters like ambient temperature, relative humidity, atmospheric pressure, wind speed and wind direction. The different parameters are measured every second and averaged over one minute interval. Secondary standard pyrheliometers are employed for measuring DNI. First class pyranometers are employed for measuring GHI and DHI. In every station, there are two pyranometers and one pyrheliometer. The measured data is stored in the Central Receiving System (CRS) established at NIWE. Four of the measurement stations are certified by Baseline Surface Radiation Network (BSRN).

2.4 Proposed infrastructure for aggregated Solar PV power forecasting

On advice of MNRE, Forum of Regulators (FOR) and CERC, Power Grid Corporation of India Limited (PGCIL) initiated a study to identify the transmission and control infrastructure up-gradation required for integrating renewables in the 12th five year plan of government of India. The Capital expenditure requirements and strategy framework for funding the same was analysed as well. Concept of Renewable Energy Management Centres (REMC) to effectively manage the intermittency and variability of resources was proposed (PGCIL, 2012). Total cost of six billion Euros was identified as the requirement to enhance the transmission and control infrastructure. The transmission lines that is being constructed under this project would evacuate power from renewable rich states to load centres. In India, this is the first project, in which transmission lines are being built on the basis of available renewable energy resource potential. Government

[1] AvC = Available Capacity for wind or solar generators means the cumulative capacity rating of the wind turbines or solar inverters that are capable of generating power in a given time-block;
AG = Actual Generation
SG = Scheduled Generation
Time–block; means a time block of 15 minutes, for which specified electrical parameters and quantities are recorded by special energy meter, with first time block starting at 00.00 hrs

of Germany through Kreditanstalt für Wiederaufbau (KfW Bank) had sanctioned concessional loans upto 1 billion Euros. The technical assistance is provided through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. GIZ did studies in the areas of forecasting of renewable energy, balancing, improved market mechanisms, ancillary services, grid code, automatic generation control, etc that would help Indian govt achieve the huge targets for renewable energy. GIZ worked with the consortium of Ernst & Young, University of Oldenburg, Fraunhofer IWES, Ficthner to perform the different studies. Detailed Project Reports (DPR) were submitted for REMCs to be established in India. By September 2016, applications for tender for the REMCs to be established at Tamil Nadu, Andhra Pradesh, Karnataka and Southern Regional Load Dispatch Centre (SRLDC) were released by PGCIL (PGCIL, 2016). Tender applications for REMCs to be established at other SLDCs and RLDCs are expected to follow soon.

Indian Meteorological Department (IMD) and National Centre for Medium Range Weather Forecasting (NCMRWF) are the govt. owned weather services of the country. They have capabilities in running numerical weather prediction models and have shown interest in supporting the initiative of renewable energy forecasting in India.

2.4.1 Renewable Energy Management Centres

The REMCs are envisaged to be co-located with the already existing load dispatch centres at seven renewable rich states. They would also be co-located with RLDCs at southern, western, northern region and NLDC. Ministry of Power will bear the cost of 11 REMC control centre development (SCADA System including maintenance, Forecasting & Scheduling Tool / Software, Wind and Solar generation forecasting services for first 4 years, Servers, other control centre equipment). The location of 11 upcoming REMCs are shown in the Fig 5.

Fig 5: The locations of envisaged REMCs.

From the tender specifications released for REMC for southern region, certain features are explained in this paper. The schematic of REMC architecture is shown in Fig 6.

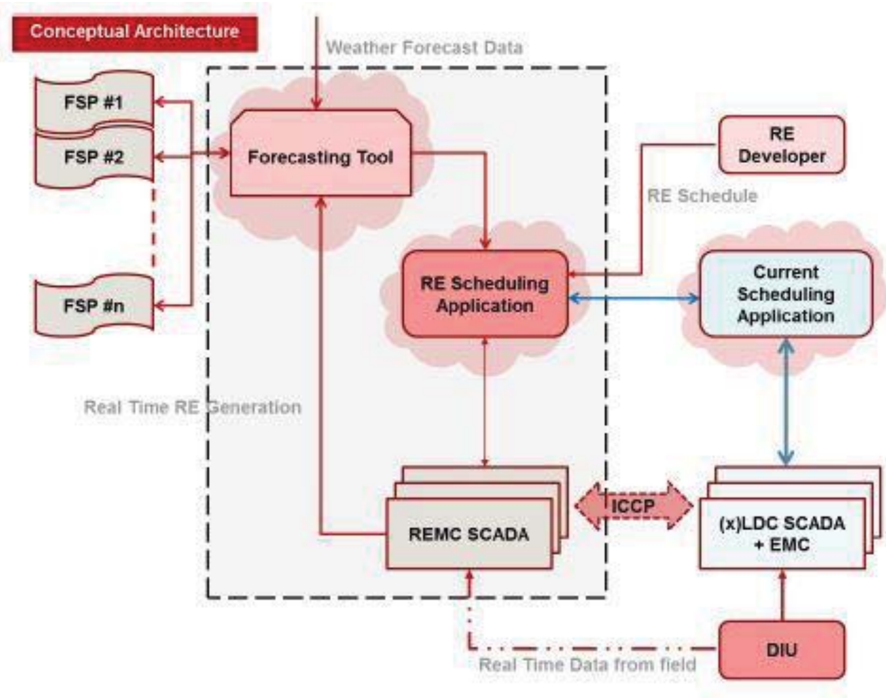

Fig.6: Schematic architecture of REMC (PGCIL, 2016)

The major functionalities of REMCs are the following:

- Real time RE generation Data Acquisition and Monitoring.
- Provide RE data to its partner xLDC, forecasting and scheduling applications.
- Forecasting of RE generation.
- Data Archiving and Retrieval.
- Providing RE information to its concerned xLDC for dispatching and balancing RE power.
- Central Repository for RE generation data that will be used by the concerned xLDC for Management Information System (MIS) and commercial settlement purposes.
- Coordination agency on behalf of xLDC for interacting with RE Developers.
- Developing future readiness for advanced functions such as Virtual Power Plants, Storage etc.

2.4.1.1. Forecasting tool

The schematic of the forecasting tool is depicted in Fig 7. The external Forecast Service Providers (FSPs) provide week ahead, day ahead and intra-day forecasts for wind and solar PV generation at pooling sub-station level as well as aggregated forecasts at state level. The forecasts are provided for intra-day, day ahead and upto week ahead time resolution. It would provide forecasts in 15 mins resolution for day ahead and intra-day forecasts and hourly resolution for week ahead forecasts. The forecast provided by the tool would assist SLDC personnel in scheduling the conventional generation, estimation of control reserves and load flow calculation. Historical SCADA data from STU pooling stations, available real time RE generation data from STU pooling station and static information about wind and solar power projects would be shared with the FSPs by the REMCs (PGCIL, 2016). It is crucial information for performing RE generation forecast.

The forecast combination and aggregation tool combines the external and internal forecasts in an optimal fashion using auto adaptive algorithms. The different FSPs and internal forecasting tool is expected to have strengths and weaknesses according to different weather situations. Therefore historical performance of the forecasts for the different weather conditions would be taken into account while arriving at combined forecasts. Through suitable upscaling technique, aggregated forecasts for the pooling stations and whole state are derived.

Internal forecasting tool produces forecasts for the different time resolutions in parallel to external FSPs. It is fully automatic and runs on an auto adaptive algorithm. It does not require operator’s interaction. Static data, historic SCADA data, real time generation data are to be provided to the internal forecasting tool. The algorithms would be tuned based on the forecasts and real time generation data. A service provider who provides weather forecast data is contracted for a period of four years to provide input to this tool.

Three external FSPs are contracted for the first two years to provide wind and solar generation forecasts. The two best performing FSPs would be retained for the subsequent two years. The contract for FSPs could be extended for further two years (beyond the serviced four years) at the same terms and conditions as per mutual agreement. The FSPs performance is continuously monitored. Normalised Root Mean Squared Error (NRMSE) is the metric according to which FSPs performance is monitored. RMSE is normalised with available generation capacity in each time block (PGCIL, 2016). The financial reward to FSPs would depend on the accuracy of the forecasts provided by them. During first year of operation, there is no financial implication as it is considered as the stabilisation period. From the second year, payment to the FSPs would be based on the following:

- Provide 100 % of payment if error (NRMSE) of the control area wide RE generation forecast is less than 7 %.
- Provide 90 % of payment if error (NRMSE) of the control area wide RE generation forecast is between 7 % and 9 %.
- Provide 80 % of payment if error (NRMSE) of the control area wide RE generation forecast is between 9 % and 11 %.
- Provide 70 % of payment if error (NRMSE) of the control area wide RE generation forecast is greater than 11 %.

If there is a slump in performance of WSP impacting the power forecast of the internal forecasting tool, then it could potentially be replaced without any additional financial implications.

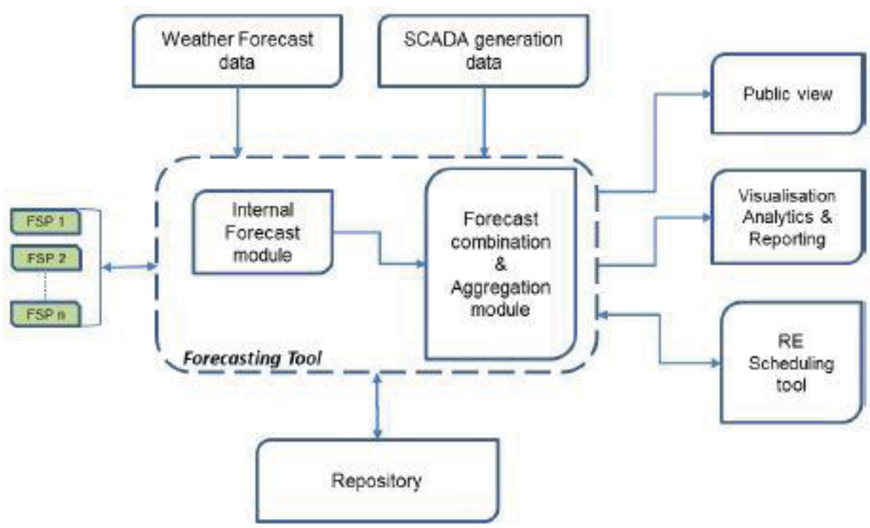

Fig.7: The schematic architecture of forecasting tool (PGCIL, 2016)

2.4.1.2. Scheduling Tool

The main functionality of the tool is collection of the proposed schedules from the RE generators. The individual RE power projects could upload the schedules into the system using web based system. The tool has the ability for bidirectional data exchange with forecasting tool and SLDC's main scheduling tool. The tool is configured for entering schedules for each time block (15 mins) on a day ahead basis. Individual RE generators must be able to provide revisions for 16 times in a day. The revised schedules are applicable from the fourth time block from which it is issued. Taking information from this tool, SLDC's main scheduling tool manages the schedule for conventional generation. Available capacity is submitted by individual generator in every 15 min time block. This tool must have the capability to calculate the error in every time block. Therefore, real time generation through SCADA data is made available to the scheduling tool. This tool must be capable of producing alarms/ alerts for non-publishing of schedules by individual RE generators.

Due to congestion and other operational issues, there is a curtailment module that could issue instructions for reduction of power output from the RE power projects. Instructions could be given in terms of percentage reduction in generation or specifying the absolute power to be curtailed (in MW).

3. Conclusion

There has been a lot of developments in regulatory and institutional framework in the sector of wind and solar power forecasting. This is indeed very urgently required to satisfy govt. of India's huge renewable energy target. The REMCs once they are fully operational and functional, would go a long way to assuage the apprehensions of RE power projects owners. This would help in ensuring uninterrupted offtake of their generated power. REMCs could trigger more potential investments into this sector.

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