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Grid integration of renewables – challenges & technology adoption

可再生能源并网发电 - 挑战与技术采纳

Himadri Endow[1*], Jayant Kumar[2]

[1]*Head, Smart Grid Business Development, Alstom T&D India Ltd*
[2]*Global Smart Grid Program Director, Alstom Grid Inc, USA*

himadri.endow@alstom.com

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Abstract - **As per conservative estimates (BAU framework), India is set to add, 19.2 GW of Solar and 22.4 GW of Wind in the 12th and 13th plan periods with sustained growth of more than 100%. This is expected to push the installed base of grid connected Wind and Solar to 38.5 GW and 20 GW respectively by the year 2022 with a combined capacity penetration of 12.5% up from the present 9.25%. However, the Wind and Solar capacity is mostly concentrated (~90% at present) in the five renewable-rich states in the south and west of the country where local penetration levels vary between 10% and 34%. To promote the use of green power among all states, the renewable purchase obligations (RPO) and Renewable Energy Certificates (REC) have been put in place. Inter-state, as well as Intra-state transmission corridors, are also being strengthened to maximize evacuation and use of the green power across state boundaries. Yet utilisation factors remain woefully low.**

The growing penetration levels and the wide diurnal and seasonal variation of wind generation, introduces complex power flows in the regional grid networks leading to issues in power balance and grid stability. It also impacts the way reserves are managed. The central and state transmission utilities are in the process of defining the requirements of dedicated renewable energy control desks throughout all the dispatching centres. This paper suggests methods fortify the systems in place at the Grid control centres to deal with the variability of renewables, yet maximize its capacity utilisation. It will enumerate the adoption and integration of new generation technology and tools with traditional Energy Management Systems to aid the operators at the grid control rooms. In the process, the basic expectations from the renewable asset owners are also defined.

Keywords – **Renewable integration; decision support; Power balance; Renewable forecasting**

I. INTRODUCTION

Around 90% of renewable generation capacity in India is today concentrated in the five renewable rich states in the west and the south. The combined penetration levels in these states are much higher (at 10% to 34%) than the national average (9.25%). The projected growths of RE capacity in these states mean that the penetration levels will steadily rise and surpass the requirements of renewable power obligations (RPO) of the states, by the end of the current 12th five year plan. Further the mechanism of renewable power certificates [1] will ensure a growing volume of renewable power being evacuated through the state as well as the inter-state transmission corridors to fulfill the RPOs of the renewable deficient states.

The network of modernized state and five regional level load dispatch facilities have been implemented by Power Grid in a phased manner between 1994 and 1996. The NLDC commenced commercial operation in April 2009. These load dispatch centres are equipped with advanced EMS centered scheduling and load dispatch solutions and together have provided the means to improve grid reliability and facilitate the effective implementation of availability based tariff.

The energy deficit situation coupled with the large inertia of the synchronous system in India is responsible for the low levels of correlation between variations in demand and that of grid integrated renewable generation. However continued integration of large amounts of highly variable resources, such as wind and solar, is going to change the grid operating paradigm to a great extent. Maintaining demand-supply balance and ensuring continued system reliability will become a real problem over time for grid operators. The fundamental differences arise from the fact that unlike other types of generation, wind and solar generation cannot be predicted with absolute certainty and cannot be dispatched up and down like a conventional generator. The unpredictable fast changing renewable output unless mitigated will create unexpected power flow situations leading to transmission security issues and also severely stress the conventional generators which will be expected to provide the power balance. A set of dedicated functions and operating plans will be required to be added to the present generation EMS systems to deal with the new reality. The present paper summarises the main technology and tools that need to be inducted and merged with the currently operating systems at the load dispatch facilities.

II. Modelling of Renewables

The renewable energy generating stations are connected to the grid normally at 33 kV, 66 kV, 110 kV, and 132 kV. The EHV transmission system beyond the first point of connection is at 132 kV, 220 kV or 400 kV. Only the large capacity generating stations are connected to the grid directly at 132 kV or 220 kV levels. Thus the renewable injections are more like distributed energy resources, not always within the direct purview of the transmission system operators (Fig. 1). So to integrate these DERs into the traditional EMS of the grid operators, the first step would be to model them so as to make them appear as clusters of equivalent generating units at different voltage levels with the net injection being dynamically computed based on all available information of RE generation. Not all of these DERs, especially the ones at the sub transmission or distribution voltage levels can be expected to be telemetered. So the modeling characteristics and rules should enable estimations of the RE clusters active power production, even if not telemetered, based on historical data and metered data from other RE sources. The estimations are typically done for a defined set of RE clusters by calculating the utilisation factors (UFs), which is the weighted average of actual use over total capacity (Refer Eq. (1)).

$$UF = \sum_{i_{UFREF}\, in UF} \left[WEIGHT(i_{UFREF}) \cdot \frac{MW(i_{UFREF})}{MWMAX(i_{UFREF})} \right] \qquad (1)$$

where,

$MW(i_{UFREF})$= MW value of DER pointed by i_{UFREF}
$MWMAX(i_{UFREF})$= Max capacity of DER pointed by i_{UFREF}
$WEIGHT(i_{UFREF})$= Weight of i_{UFREF}

Typically each DER can be assigned multiple sources for MW value. These are field telemetry through SCADA as the primary source, one or more estimations as the secondary source and split external forecast value as a tertiary source with splitting rules defined from top level entities down to individual DERs. To take care of fluctuating telemetry, filtering rules can be applied to smoothen its effect on the calculation of UF.

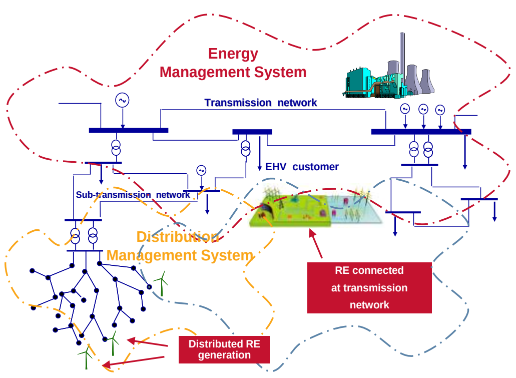

Fig.1, Renewable injections at different voltage levels

The modeling environment shall have to meet two other criteria that of time activated changes in the data model and generic grouping or aggregation of these resources. For example data model with RE sources that will be commissioned or retired in the future or taking into account that a particular resource will change ownership over time. Such criteria assumes importance because within the same RE clusters individual units may belong to different market participants with period ownerships and may ultimately impact the way power balance and settlements are handled. The generic aggregation types can be used to represent topological data such as electrical connectivity, control area or organizational data such as ownership.

III. Forecasting Renewables

There has been a lot of debate of late on how much forecasting accuracy band the wind generator shall be held responsible for in order that the transmission system operator can produce reasonable day-ahead schedules which include renewables. On the other hand, there have not been enough discussions on how to lay down a model which can improve these accuracies over a period of time and ensure that the forecasts are managed such that it can be exploited not only by the real time operating system at the grid control centres but also by other utility wide enterprise applications.

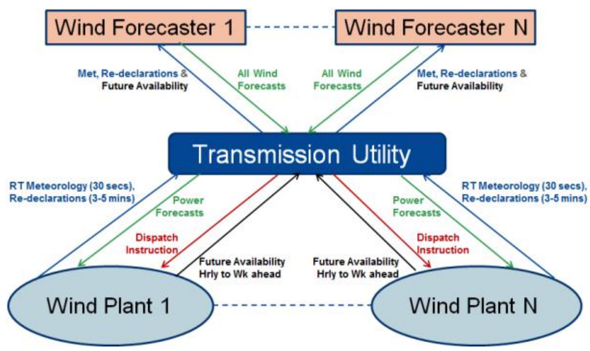

Fig.2, Data flow between RE, Transco & Forecaster

Wind power forecasting has made significant progress in the recent past. Such wind power forecasting is being offered as a service by several companies worldwide. Forecasting is usually based on Numerical Weather Prediction (NWP) models and other complex statistical techniques. Still, results have not reached the same accuracy level as in other forecast domains, often requiring use of multiple forecast sources, and blending to compose a final wind generation schedule. Studies have also shown that implementing a centralized renewable power forecast system is essential to the future of grid operations. Instead of seeking generation forecast from each renewable generator, these forecast schedules can be carried out at the level of the state transmission utility (or the regional grid operator) after ensuring that each renewable generator open up their assets to full on-line monitoring (Fig. 2). This approach will ensure the historical plant data will be always available with the transmission utility so that when the need arises switching or tuning in an additional forecast service provider as well as best case forecast compositing would be feasible. This will also facilitate sanitisation and quality checks of the raw data of the wind plants before being passed on to the forecast service provider, besides enabling analysis and audits necessary for settlement of RECs and raw forecast performance calculations. Hence the forecast management system shall have to bridge the space between the forecast provider and wind plant data stream on the one hand (top layer in Fig. 3) and the real-time grid dispatching applications on the other (bottom layer in Fig. 3).

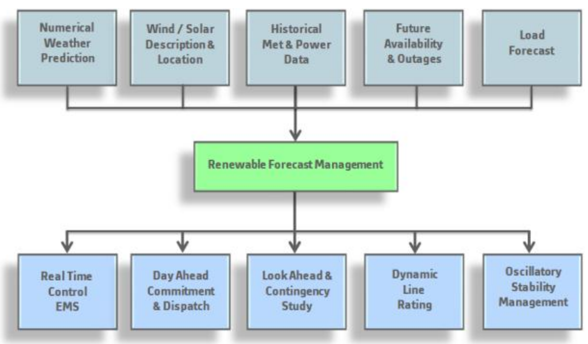

Fig.3, Centralized forecast management

The typical data the wind plant is required to share are real-time meteorology, and on-line schedule re-declarations like turbine active count, max achievable MW, Economic Max MW, Plant generation and Plant lead/lag data (Ref Fig. 4).

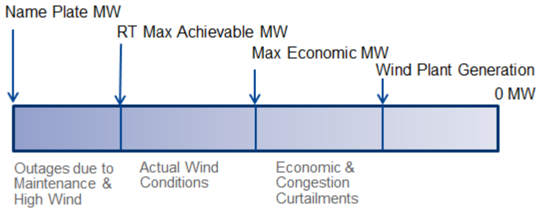

Fig.4, Renewable plant generation build

Following is a high level summary of the basic requirements of the forecast management platform,

- Get wind plant data as mentioned above through interface with SCADA
- Capable of receiving updates from multiple sources, multiple types of time series forecasts
- Monitoring timely reception of incoming forecast schedules and raising alarms for missing data
- Create contiguous composite forecasts using weighting factors (or profiles relative to current time up to a certain end time) that goes from short-term, via mid-term to long-term with the best accuracy of all three forecasts combined
- Create combination of composite schedules like schedule of net-load required to be supported by conventional generation
- Provide for granular schedule over-rides with traceability
- Schedule aggregation along with confidence intervals as per established RE models
- Alarm processing of actual and schedule data like, absolute high/low, rate of change or ramp, maximum change in forecast update and maximum deviation between forecast and actual
- Geospatial schedule visualization and temporal navigation
- Sharing relevant forecast schedules with plant operators in accordance with entity area of responsibility (EAOR), using web services to enable them to re-declare plant data
- Exporting forecast schedules and alarms thereof with the real-time EMS of grid control centre

IV. Situational Awareness

Integrating high levels of renewable generation adds a significant amount of uncertainty combined with higher probability of experiencing large scale system events. Weather related events such as storms or absence of wind/solar are likely to have a direct impact on available generation at a very large scale. Therefore, Situation Awareness becomes a key requirement to operate a system with significant renewable penetration. The goal here is to provide clear and concise information presented in a manner such that operators can quickly understand the current and near future state of the system in order to take appropriate operational decisions.

The user interface (UI) can be built as an extension of existing systems but more appropriately as a separate renewable operator desk. The UI can run within a web browser with several types of views built around a map viewer (WMS, WFS compliant) that provides advanced zooming and panning. Capability to add weather related overlays would be invaluable to depict how system events evolve. The example as in Fig. 5, show transmission lines, individual wind farms (triangles) colored by current utilization factor and total wind generation by balancing areas (green & yellow shaded areas). Details of entities on the map viewer window can be seen in the entity detail pane on the right top of the screen. The charts section below, provide a temporal view of data for the selected entity. This typically includes actual generation, short-term and medium-term forecast for a wind farm or an aggregated area and the corresponding confidence intervals. The Alarm tab is reserved for alarm information of the selected entity and the children tab, for entities that are immediate children of the selected entity in the system hierarchy, e.g., wind farms belonging to an area. By right-clicking on the Chart tab, the user can select the dual view which will simultaneously show the chart and data grid. The slide bar is used to switch from history to current mode back and forth. When in history mode,

Fig.5, User Interface built to SA principles

the map viewer is surrounded by a thick yellow border to warn the user that displayed information is not current.

V. Integration With RT Control System

The conventional real time control systems at the various load dispatch centres have two broad suites of applications,

- Network security analysis and optimization
- Generation / Reserves scheduling, monitoring and control

These are equipped to provide steady state solutions for specific constrained objective functions of the power system. Typically in this case generation and load schedules along with regulating reserves are planned a day in advance. Fig. 6 is a schematic of this real time system showing standard EMS functions (in light blue colour) with specific application modules (in orange colour) added to manage renewables in the mix.

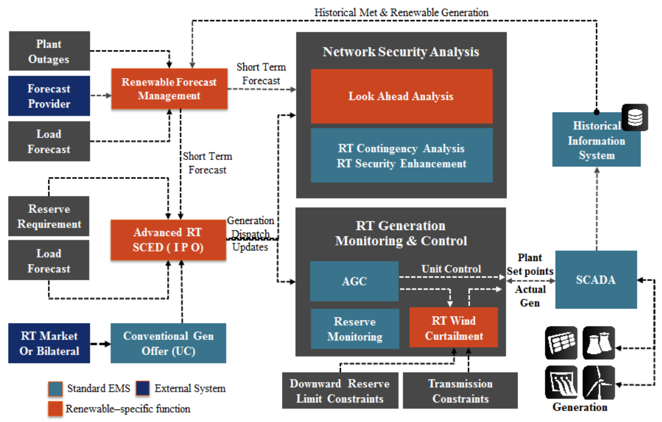

Fig.6, Renewable management within real time EMS system

Generation Dispatching

With RE added to the portfolio, the task is to set up a base load plan considering a reasonable variability (confidence level) of RE generation forecast. This is done by performing a modified and advanced Economic Dispatch (named Intraday Plant Optimization or IPO) to calculate unit base points for current time and for times in the future. To accommodate evolving RE conditions this is repeated so as to further update and implement the short term base load plan every 5 minutes or so. IPO receives the current operating plans for the conventional units, submitted unit offers of currently committed units and the latest load and renewable forecast results. It then produces least cost, minute based unit generation schedules for the next several hours, respecting their minimum and maximum generation limits and also taking into account ramp up/down rate limit and unit forbidden zones. As constraints are modelled in a generic way in the optimization problem, hence additional constraints can be defined, such as network security constraints where IPO is coupled with the contingency application that verifies network security.

Optimal unit generation trajectories computed by IPO are transferred to AGC for real time implementation. Typically it is executed periodically (configurable) and at the occurrence of events like changes in RE production forecast, generation cost curve etc. If the renewable assets and storage devices are clubbed into virtual power plant (VPP), the IPO can be implemented to determine optimal schedules of both the conventional units as well as the VPP to provide instantaneous power demand for each time point and distribute the VPP schedules over the individual assets. For the units, these correspond to not only the required generation MW level, but also to the reserve and regulation requirements. If the total RE generation is too high, the system may not have the required down regulating reserve to balance. In such cases RE curtail limit commands in the form of “output not to exceed” shall be issued to the VPP or RE. As the value of down regulating reserve recovers, curtail limits are withdrawn that is limit values are raised. A similar dispatching may take place to alleviate network congestion if that is identified as the mitigating source.

Look Ahead Network Analysis

Network analysis relies on well-established processes, such as Power Flow, Contingency Analysis, Security Enhancement, Short-Circuit Analysis, Volt-VAR dispatch and dynamic stability. These applications are made to embrace the RE generation through proper modelling (Section II) so that these RE appear as generator clusters feeding into different injection points with defined composite schedules and confidence levels (Section III). Renewable area forecasts are applied to the model for each time point in the future and the suite of network analysis functions is run. The output results lists all security issues reported for each time point in the future as well as the net transfer capacities of a pre-defined list of corridors.

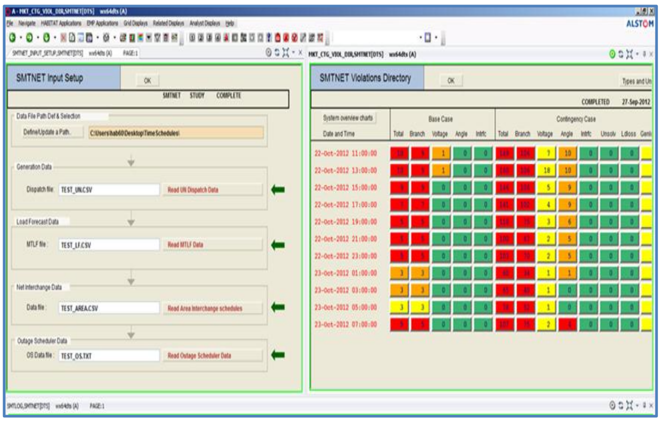

Fig.7, Look Ahead study results within real time EMS

In Fig. 7, the navigation pane on the left is the area where the inputs like load forecast, RE forecast, generation schedules, network analysis function etc. are configured. When the Look Ahead function runs it provides the various base case and contingent case node and branch violations as shown on the right side pane of Fig. 7. The results show the network security over the next twenty two hours in eleven runs. The violations are depicted in various coloured cells where green means normal conditions and yellow, orange, red colours indicate increasing levels of severity of the violations.

Dynamic Transfer Limits

As part of the renewable integration targets, India has plans to strengthen the intra-state as well as inter-state transmission system to facilitate transfer of RE power from RE rich states to other states. This build up is taking place between 132 kV through to 765 kV levels. However the capacity build-up is always faster than building transmission infrastructure leaving gaps in the extent to which the demand will be actually served.

In this context calculating the Total Transfer Capacity (TTC) and the Available Transfer Capability (ATC) for defined transfer paths becomes important. In a conventional EMS system these are calculated following a rigorous process taking into account a variety of factors that can limit the MW transfer. These include branch flow limits, voltage limits, voltage collapse and MW/MVAR interface limits. As a part of the Look Ahead Network Analysis, the RE forecast estimations (Section III) can be factored in to tune the standard TTC/ATC calculations to conform to RE generation forecast. However this still would remain a static calculation as it does not account for the dynamic impacts on the transfer corridor from factors like ageing, current loading of feeder, ambient temperature, solar heating, wind speed and direction, humidity etc. which has a bearing on the conductor's dynamic thermal capacity and consequently capacity to carry load. Field trials have already proven that transfer capacities (or ampacity) can be improved upon by 20% to more than 50% (at times even 70% for shorter periods) for defined intervals of time if impacts of weather and current loading conditions are taken into account. This is a substantial amount which cannot be ignored if injection of bulk renewable power in the grid network is to be maximized. Evolutions in the EMS today provide an alternative to conventional TTC/ATC calculations by providing dynamic line rating calculation module with forecasts (based on historical observations) made available that can be effectively used alongside the renewable forecasts. To calculate ampacity figures on-line, the feeder's sag has to be measured and kept updated. For this three broad methods are employed. These are measurement of weather data, measurement of tension on the conductor or measurement of vibration of the conductor.

VI. Conclusion

Seamless integration of renewable plant visibility and output forecasting, into utility control room operations is fundamental to accommodating large penetrations of wind energy in a huge power system network as exists in India. The forecast need to be updated on an hourly or sub-hourly basis to factor in the dynamically changing conditions of the renewable generation. This is then used to reschedule reserves and re-dispatch conventional generation as often as necessary, as a last resort curtailing RE if enough down regulating reserves are not available. To be able to do all this, all distributed renewable plants have to be modeled in the power system network irrespective of injection voltage levels and 100% visibility of these generations obtained through either real-time telemetry or estimations. Forecast algorithms will mature over time. For use in real-time operations, best-in-class accuracies can be obtained by blending outputs of multiple forecast sources as well as combining forecasts of different time horizons (short term, medium term and long term) together with their varying accuracy levels. Ideally forecasts should be managed centrally at the utility level and shared with renewable generators for the purpose of re-declaration of the renewable generation.

Present generation EMS applications shall have to embrace the embedded renewable generation and carry out intra-day generation schedule optimization to meet active, reserve and regulation requirements. With time series renewable forecasts, the real-time network analysis functions would be able to depict base case and contingent network and branch node violations from the present time to time points in the future. This look-ahead capability would enable the renewable desk operator to modify his dispatching actions as frequently as required. Total transfer capacity of major network corridors could be substantially improved by taking advantage of the dynamic line rating calculation module. The operator user interface should make the operator aware at all times, the evolving weather and system events with a geographical perspective showing balancing area alarms and temporal trends for actual generation, forecasts and forecast errors.

REFERENCES

[1] Central Electricity Regulatory Commission "Regulation on Renewable Energy Certificates", India, 14th Jan, 2010.

[2] Power Grid Corporation of India Ltd. "Transmission Plan for Envisaged Renewable Capacity," 1st July 2012.