Integration of renewable energy sources into the electricity smart grid: study

Smart grid technology is the key for an efficient use of distributed energy resources. The smart grid is the future conversion for the techniques and strategies of production and the interaction of all the components of power grid. Noting the climate change becomes an important topic of concern, the whole world is currently facing the ever increasing price of petroleum products, coal etc and also the reduction in cost of renewable energy power systems, giving opportunities for renewable energy systems to address electricity generation. However, to achieve this task, an efficient energy management system needs to be addressed. In this context, the concept of smart grid plays a crucial role and can be successfully applied to the power systems. This paper presents the study of integrating renewable energy in smart grid system. The introductory part provides the role of renewable energy and distributed generation in smart grid system. The concept of smart grid renewable energy system and its applications along with the PV smart grid system are also been discussed and studied. It concludes that smart grids offer solutions to various challenges associated with variable RE, including providing additional flexibility, unlocking demand side participation, and deferring more costly grid upgrades.

This paper also discusses about the following:

- *What are the challenges of integrating variable RE into power grids?*
- *What types of smart grid solutions are emerging to integrate variable RE?*
- *What are the good examples from around the world of smart grids aiding in the integration of variable RE?*
- *What types of policy and regulatory approaches are emerging to support smart grid solutions in relation to RE?*

Introduction

The quest for cleaner, green and more reliable energy sources has considerable implications to the existing power transmission and distribution system.

Now in the immediate future, renewable energy sources cannot support the entire grid by themselves. So they have to be connected to the main grid acting as auxiliary power sources thus reducing the overall burden on the primary power generation units. They could also be employed to serve load units totally isolated from the main grid.

A power system having wind powered turbines, micro generators, fuel cell based system and PV systems augmenting the main power lines will constitute a distributed power generation (DG) system which are playing an important role in meeting the ever increasing power demands by using an alternative source of energy such as photovoltaic, wind, fuel cells, etc.

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. It could reach as high as 32.2% by 2022, considering the 175 GW in place. 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.

It is important 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 and analyses the various steps at the Central and State levels towards initialising forecasting and scheduling of renewables in the country.

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. For operational and planning purposes, the transmission network is divided into five regions, namely Northern (NR), Eastern (ER), North

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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.

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.

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.

The UI penalty is linked to frequency and is structured such that the further is the frequency from the desired 50 Hz, the higher the penalty is. This led to smaller volumes of overdrawal by states and improved grid frequency. (energysector.in, 2014)

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:

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. Depending on the extent of forecasting accuracy, there is a degree of uncertainty in this variable generation. Such variability and a lack of or low accuracy of forecasting can potentially contribute to deviations from the schedule.

Grid operation with high penetration of renewables

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. 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. 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.

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."

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. Lack of smart meters at the distribution system level presently limits the scope of demand side management at the retail level.

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.

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.

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 not considered 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.

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.

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. 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.

Monitoring of renewable generation

Renewable Energy Management Centers (REMC) is 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 ongoing grid infrastructure initiatives relevant to RE 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.

Changes in wind and solar generation infrastructure

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. 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.

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. 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.

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.

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 24×7 intra-day markets, accepting revisions to schedule through the day, data collection, storage and dissemination for the appropriate agencies would have to be developed.

Need of integrating the renewable energy

The need of integrating the renewable energy into power system is to minimize the environmental impact on conventional plant. Smart grid plays a major role here. The basic objective of smart grid is to promote active customer participation and decision making as well as to create the operation environment in which both utilities and consumers can interact with each other. In smart grids, users can influence utilities by providing DG sources such as photovoltaic modules or energy storage devices at the point of use, and reacting pricing signals. Additionally, utilities can improve reliability through the demand response programmes, adding DG or energy storage at substations, and providing control automation to the grid.

Before exploring how strong, flexible, and smart grids are supporting variable RE integration around the world, we first examine the nature of variable RE grid integration challenges that have arisen recently.

Two distinct categories of challenges can be identified and are the focus of this report:

1. Technical challenges: Ensuring power system reliability as uncertainty and variability increase.
2. Economic, policy, and regulatory challenges: Effectively managing the cost of RE integration and the grid investments that support it, designing policies to harness maximum value from RE, and ensuring that appropriate incentives are in place to encourage appropriate grid investments.

Technical challenges

Two dominant technical challenges can be identified with a higher penetration of RE generation:

1. Managing variability and uncertainty during the continuous balancing of the system, and
2. Balancing supply and demand during generation scarcity and surplus situations.

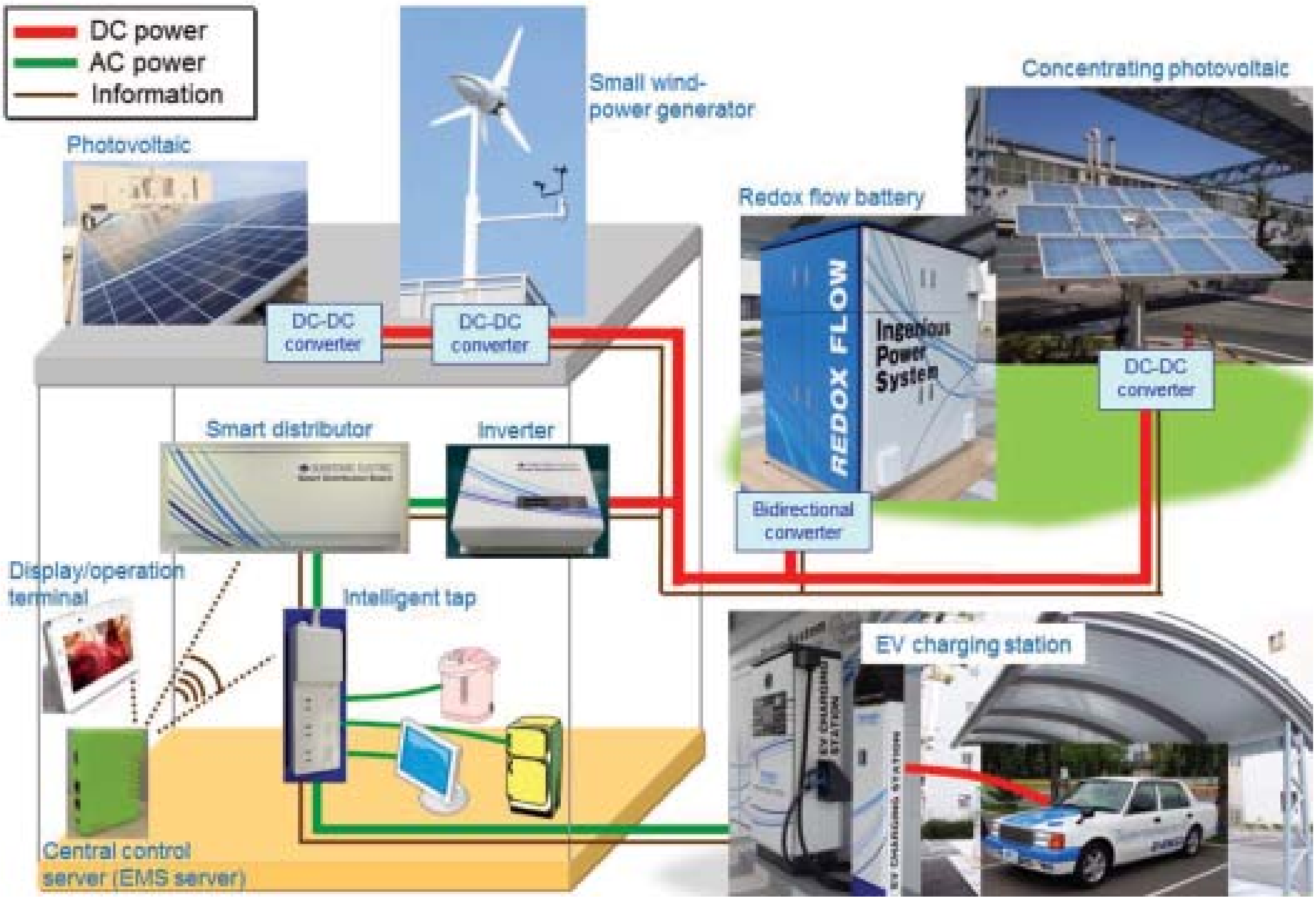
Smart grid solutions emerging to manage continuous balancing of the system include:

- Better forecasting: Widespread instrumentation and advanced computer models allow system operators to better predict and manage RE variability and uncertainty.
- Smart inverters: Inverters and other power electronics can provide control to system operators, as well as to automatically provide some level of grid support.
- Demand response: Smart meters, coupled with intelligent appliances and even industrials cale loads, can allow demand-side contributions to balancing.
- Integrated storage: Storage can help to smooth short-term variations in RE output, as well as to manage mismatches in supply and demand.
- Real-time system awareness and management: Instrumentation and control equipment across transmission and distributions networks allows system operators to have real-time awareness of system conditions, and increasingly, the ability to actively manage grid behaviour.

Economics, policy, and regulatory challenges

In addition to technical challenges, institutional challenges also arise with increasing shares of variable RE. Broadly these relate to the unique economics of variable RE, which give rise to various policy and regulatory issues.

Two specific challenges are identified here: capital intensive grid upgrades, and uncertain project costs and cash flows. Capital-intensive grid upgrades grid upgrades



Managing variability and uncertainty during the continuous balancing of the system variable.

may be required to accommodate wind and solar power. For example, to the extent high quality wind and solar resources are located far from demand centers, new transmission lines or upgrades to existing lines may be required. At the distribution level, rooftop PV may accelerate the fatigue of distribution components, such as low-voltage transformers, Smart grid is a concept and vision that captures a range of advanced information, sensing, communications, control, and energy technologies. Taken together, these result in an electric power system that can intelligently integrate the actions of all connected users – from power generators to electricity consumers to those that both produce and consume electricity ("prosumers") – to efficiently deliver sustainable, economic, and secure electricity supplies

General features of smart grid

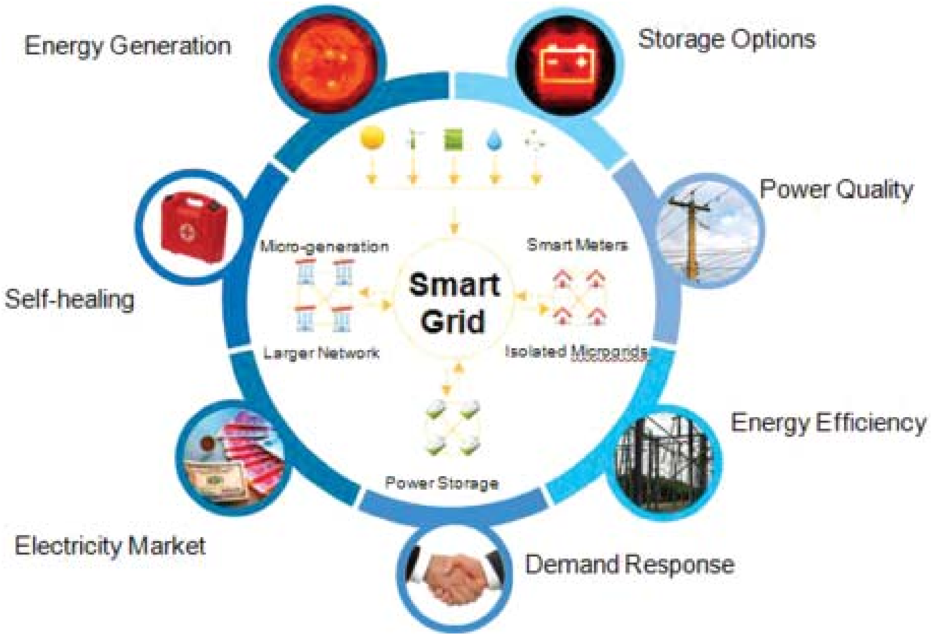
Smart grid has different aspects and can be characterized as follows:

1. Interactive with users and markets
2. Adaptive and scalable to varying situations
3. optimized to make the best use of resources and equipment
4. Pro-active instead of reactive to prevent emergencies
5. Self-healing grids with advanced automation
6. Integrated, merging monitoring, control, protection
7. Maintenance, EMS, DMS, AMI, etc.
8. Having plug-and-play – features for network equipment
9. ICT solutions
10. Secure and reliable
11. Cost efficient
12. Provides real time data and monitoring

Traditional grid includes centralized power generation, and at the distribution level unidirectional power flow and weak market integration. Smart grids include centralized and distributed power generation produced considerably by renewable energy sources. They integrate distributed and active resources (i.e. generation, loads, storages and electricity vehicles) into energy markets and power systems. Smart grid is nothing but the electricity network that smartly integrates producers and consumers to efficiently deliver electricity which is sufficiently capable and coverage area accessible, safe, economic, reliable, efficient, and sustainable. Smart grid development tends to be driven by one of the two principal visions for enhancing electric power interactions for both utilities and end use customers

Conclusions

While building new infrastructures, smart grid technologies can also help utilities to alleviate grid congestion and to maximize the potential of our current architecture. As smart grid technologies become more popular, the electrical grid will be made more efficient, resulting in reduction of issues of congestion. Lots of sensors and controls will help intelligently, reroute power to other lines when required, accommodating energy from renewable sources, so that power can be transported to a greater distance, where it is needed. Smart grid delivers electricity from suppliers to consumers using digital technology through control automation, continuous monitoring and optimization of distribution system, in order to save energy, reduce consumer cost and improve reliability.



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