 ISBN: 2278-4187

Smart Grids and Other Measures of Renewable Energy Integration–A Status Review

Prashant Kumar Chaturvedi
Research Scholar, AISECT University, Bhopal (M.P.) India.

ABSRACT

The aim of this literature review is to give an overview of recent research works and developments in the area of Renewable Energy Integration. The research papers of last 4 years spanning from 2013 to 2016 have been reviewed. The basics of electrical engineering have not changed much over years. For example, most of the power generation is based on revolving turbines. The turbines may be steam, hydro, wind or any other. Even the solar photo-voltaic power generation is based on photo electric effect discovered by German physicist Heinrich Rudolf Hertz in 1887. Due to climate change issues, renewable sources of energy are gaining importance. Energy efficiency is another area of research work and concepts like green building are evolving. Grid is getting smarter day by day. It can gradually address issues like integration of renewable. Even Grid scale storage systems are thought of. Wireless Transmission of electricity is also researched. The papers which have been reviewed, deal with smart grid and some of them find smart grid useful for Renewable energy (RE) integration. There are other research papers dealing with grid scale energy storage system. Considering the research work in the past and the limitations of such studies, likely future scope has been discussed. For research work, capacity addition of renewable energy sources in Madhya Pradesh is examined in brief based on the projections made by the Government and also the regulatory requirements towards Renewable Power Obligation (RPO). Various features of Renewable energy like uncertainty, volatility of availability of energy, intermittent nature, reactive power requirement, problems of forecasting, 'must run' status in merit order dispatch and impact on conventional plants are involved in respect of further capacity addition of renewable in Madhya Pradesh.

I THE CURRENT STATUS

(a) India was having total installed capacity of only 1362 MW at the time of independence. Out of this, Thermal capacity was 854 MW and Hydel capacity was 508 MW. It has now increased to 298059 MW as on 31.3.2016 [1]. Out of total installed capacity in 2016, renewable sources of generation contribute 13 % (38821 MW). As against this total installed capacity in Madhya Pradesh is 17644 MW as on 31.3.2016 and contribution of renewable sources of generation is nearly 11 % (1931 MW).

(b) In a report "India Energy Outlook" [2] released by International Energy Agency in 2015, it is estimated that Installed capacity of India shall grow to 1075000 MW in 2040. Out of this share of Renewable power is estimated at 350000 MW (nearly 33%). Per capita consumption in India was 1075 in 2015, which is likely to reach 2000 kWh in 2040. This would still be below world average. Share of Industry in electrical consumption is projected to fall by 3% and agricultural sector by 6%. However, the domestic consumption is likely to increase in India sharply, due to urbanization and other factors. India's share in the global figure for people without access to electricity is likely to decline from 20% in 2013 to around 8% in 2030.

(c) Madhya Pradesh has prepared a road map for 24X7 Power for all, as a joint initiative with Government of India. This document is availble at website of Ministry of Power (www.powermin.nic.in). In order to achieve the objective of 24 x 7 power for all, it is estimated that Madhya Pradesh would need to fully meet the increase in peak demand from 9598 MW (at state periphery in Fiscal Year (FY) 2015 to 12,643 MW in FY 2019 with corresponding increase in energy requirement from 55,622 MU in FY 2015 to 80,847 MU in FY 2019. It is estimated that renewable capacity of more than 2120 MW would be added in next 3 years. Madhya Pradesh has potential of renewable cap city of nearly 30000 MW. Madhya Pradesh is already providing 24X7 powers to all consumers other than agricultural. The document provides road map to continue this measure during years to come, at the same time ensuring financial viability of the sector.

(d) The basics of electrical engineering have not changed much. For example, most of the power generation is based on revolving turbines. The turbines may be steam, hydro, wind or any other. Even the solar photo-voltaic power generation is based on photo electric effect discovered by German physicist Heinrich Rudolf Hertz in 1887. Later, Albert Einstein published a paper that explained experimental data from the photoelectric effect as the result of light energy being carried in discrete quantized packets in 1905.

Transmission over long distances over wires continues to exist. The quest for witricity (wireless electricity) is yet to be fulfilled. Due to climate change issues, renewable sources of energy are gaining importance. Grid is getting smarter day by day. It can gradually address the issue of integration of renewable. Even Grid scale storage systems are being thought of. This study plans to review papers published in last 5 years in the area of advancements in electrical engineering, so as to come out with a way forward for further research work.

II INTEGRATION OF RENEWABLE GENERATORS INCLUDING DISTRIBUTED ENERGY RESOURCES (DERS) INTO THE GRID

(a) Technological and manufacturing progress along with climate change concerns are transforming electric power systems with the integration of an increasing share of clean renewable generation whose volatility, lack of active dispatch control, and absence of rotating inertia pose great challenges to the feasibility of efficient, resource-adequate, operationally reliable, and secure power systems. Conventional approaches to meeting these challenges with exclusive reliance on building a stronger transmission and distribution (T&D) infrastructure assisted with more flexible centralized generation e.g., combined cycle gas turbine (CCGTs) could fall short of economic and environmental sustainability goals. Recent research published in Proceedings of the IEEE (Vol. 104, No. 4, April 2016) deals with this subject and offers a distributed, massively parallel architecture that enables tractable transmission and distribution vocational marginal price (T&DLMP) discovery along with optimal scheduling of centralized generation, decentralized conventional and flexible loads, and distributed energy resources (DERs) [3].

(b) In United States, a synergistic development has transformed the consumption side of power systems, particularly in the distribution or retail parts. Broadly construed distributed energy resources (DERs) connected to primary (9–20 kV) and secondary (120–470 V) voltage feeders are rendering the "pay our light bill". DERs include roof top PV, variable speed drives that power HVAC (Heating, Ventilation, Air Conditioning) systems with storage like capabilities, plug-in hybrid electric vehicle (PHEV) and EV battery charging with flexible time-shift-able demand, all with volt/var control capable devices, and data centers and computing services with millisecond time-scale power management response capabilities. DERs can provide the requisite demand response and reserves for economically sustainable massive renewable energy integration yet to materialize.

(c) The authors of the research Paper [3] have proposed distributed CPS architecture to-

(i) Co-optimize the allocation of conventional and DER capacity among real power, reactive power, and reserves while enforcing transmission line flow and distribution voltage constraints.

(ii) Derive transmission and distribution vocational (i.e., bus specific) dynamic marginal prices (T&DLMPs) that are consistent with individual DER capacity allocation optimality.

(iii) Drill down to the seconds and real time scale to extend capacity allocation scheduling decisions to optimal-feedback closed-loop policies that allow DERs to deploy in real time the reserves promised or scheduled at the hour-ahead or longer time scale.

(iv) Implement functional interfaces between cyber and physical system layers for all systems or sub-systems involved, whether big (the overall transmission or a distribution feeder system) or small [specific DERs and T&D devices such as lines, transformers, smart solid state transformers (SSTs), volt/var control devices such as PV converters–inverters and EV chargers etc.]

(d) Research methodology adopted is that of applied research, which inquires into the current problem of massive integration of renewable generation into the grid. One hundred and fifty three (153) references have been cited in the research paper. The main thrust of study is motivated by the realization that the desired provision of efficient and plentiful reserves from DERs is limited by the inability of existing centrally cleared power markets to address without loss of tractability the often nonlinear and inter temporally coupled DER preferences. As a result, existing and emerging centralized power market clearing approaches cannot derive T&DLMPs in a computationally tractable, scalable, and robust manner. Proposed DLMP discovery approach focuses on one type of reserves. Additional reserves can be treated similarly and modeled easily, with straight forward simple modifications in the DER reserve constraints. The reserve type selected to model is secondary or regulation reserves, offered in the up and down direction, as is the current practice by PJM and NY ISO market operators.

(e) Mathematical models have been developed by the authors. They have presented a distributed Cyber Physical System (CPS) architecture framework that overcomes existing power market computational tractability and information communication limitations to derive dynamic T&DLMPs, at distribution network buses. Extensive Lagrangian relaxation work specialized to robust and tractable versions of proximal message passing (PMP) algorithms including alternating direction method of multipliers (ADMM) algorithms, predictor corrector proximal multiplier (PCPM) and others are applied to proposed distributed CPS architecture framework. These algorithms can handle convex relaxation ac load flow modeling. Aspects like compatibility with cyber security remedies, operational efficiency and smart islanding and market performance including distribution market malfunction are discussed by the authors. Individual DER sub-problems and their cyber physical interfaces have been dealt with in the study. Illustrative numerical results of a distribution market with active distributed participants who participate in the clearing of DLMPs in a 24-h day-ahead market setting are annexed with the study as Appendix.

(f) The study has proposed an extension of marginal-cost-based wholesale power markets covering today hundreds of participants to include millions of distribution-network connected loads, generators, and distributed energy resources. Most importantly, tractable distributed computation and communication architecture is proposed that renders clearing of this new power market practically implementable. In this manner, cost of securing reserves may be brought down by enabling massive integration of renewable generation into the grid. Overall, this research paper provides solution not only to the issues faced by US but also by the rest of the world.

(g) It is assumed by the authors that the regulation reserves offered to date primarily by centralized generators can be potentially provided by DERs at a possibly lower cost. The overall cost involved in communication and operational aspects need to be further studied, as associated distribution feeder line buses number may be in millions.

III TRANSMISSION PLANNING CONSIDERING WIND POWER UNCERTAINITIES

(a) Renewable including wind powers are adopted worldwide to mitigate climate change issues. However, there are uncertainties involved with the wind power. Sometimes load or wind curtailment is required due to inadequate transmission network. Recent research [4] published in CSEE Journal of Power and Energy Systems (Vol. 2, No. 1, March 2016) investigates a robust transmission planning method using scenarios of wind power uncertainties. Research methodology is experimental and a heuristic moment matching (HMM) method is applied to approximate the stochastic features of wind power. The simulation is carried out capturing various features using a number of scenarios. Twenty one (21) references have been cited by the authors.

(b) In the opinion of authors, the problem of transmission network expansion planning (TNEP) has become increasingly complex. As per authors, one major challenge is that wind power has stochastic variations, and its stochastic features cannot be accurately formulated using a tractable mathematical equation. Robust TNEP can cope against all possible realizations of the renewable power defined in the uncertainty set. However, the uncertainty set needs to be carefully designed. A small uncertain set may not cover the entire spectrum and can result in solutions that may not correspond to all uncertain situations. On the other hand, the large uncertain set may lead to conservative solutions and thereby reduce the operating profits. Alternatively, a robust TNEP based on scenarios is proposed in the study, which avoids the chosen of uncertainty set.

(c) Authors have applied an HMM method to generate scenarios to approximate the stochastic features of wind power, including expectation, standard deviation, skewness, kurtosis, and correlation matrix of wind farms. A robust TNEP problem is formulated based on the representative scenarios of wind power and random load. The proposed problem is optimally coordinated between the construction cost and penalty cost of both wind and load curtailment. The factors influencing the TNEP are studied, including the number of scenarios, wind farm capacity, and penalty factors. The results of the analysis provide the references for flexible choosing parameters.

(d) An analysis of the influence of the parameters on the planning scheme is shown by the authors in terms of number of wind power scenarios, capacity of wind farm and penalty factors for load or wind curtailments. The study is useful and can provide solution to Transmission planning based on the wind farm capacities and the penalties lay down by the Regulator. As renewable generation capacities are increasing day by day, transmission planning is required to take into account of uncertainties of such generation.

(e) Study is, however, tested only on three cases: Garver 6-bus system, IEEE24-bus system, and IEEE RTS-96 system. The wind data is taken only from 3 wind farms. There is further scope for considering uncertainties of solar generation. The paper also does not consider the use of hybrid systems to avoid uncertainties of renewable generation. Further study may be conducted in minimising the uncertainties, firstly through hybrid generation and then the approach suggested in the study may be adopted to further optimize the transmission planning process.

IV RENEWABLE ENERGY DIFFUSION IN THE DEREGULATED TEXAS ELECTRICITY MARKET

(a) All over world measures are being taken to mitigate climate change. In the United States, emission regulations are enacted at a state level; individual states are allowed to define what methods they will use to mitigate their carbon emissions. As a consequence of this, in the state of Texas new legislation has created a "deregulated" electricity market in which end-users are capable of choosing their electricity provider and subsequently the type of electricity they wish to consume (generated by fossil fuels or renewable sources). A research paper [5] published in 2015 in Journal of Power and Energy Engineering (2015, Vol.3) examines Renewable Energy Diffusion in the Deregulated Texas Electricity Market. The study analyzes the effects of carbon tax on the development of renewable generation capacity at the utility level while taking into account expected adoption of rooftop PV systems by individual consumers using agent based modeling techniques. Monte Carlo simulations have been performed to show carbon abatement trends and proffer updated renewable portfolio standards at various levels of likelihood. Research methodology is experimental in nature. Thirteen (13) references have been cited by the authors.

(b) In Texas, electricity industry was restructured similar to India in terms of having Generation and Transmission & Distribution sector. However, retail electric providers (REPs) were also mandated in Texas, who purchase the power from the Power Generating Companies (PGCs) and sell it to the end-use customer. Power generated is sent through power lines that belong to the Transmission & Distribution Service Provider (TDSP). The major incentive for the deregulated market is to allow the customers choose their REP as well as sell electricity back to the grid if they opt to do so. Environmental protocols mandates setting up a renewable portfolio standard (RPS) and mandating that half of all new capacity must be natural gas-fired (as opposed to the more traditional coal). The RPS also mandated that all utilities in the state must produce at least 2,000 MW of renewable energy (solar, wind, biomass, tidal, hydroelectric, geothermal, or landfill gas) by 2009. In 2005, the installed renewable capacity was past the 2009 goal and the State Senate Bill 20 updated goal to 5,880 MW (of which at least 500 must be from non-wind resources) for 2015 and a further goal of 10,000 MW was set for 2025. Meanwhile, the RPS allowed for the creation of a Renewable Energy Credit (REC) trading program to help meet the renewable energy capacity goals of the RPS. This program allowed utilities to buy and trade RECs to meet their company's RE capacity goals if, for whatever reason they did not want to install their own RE capacity directly.

(c) To analyze the Texas electricity market a nimble model, is developed by the authors, that combines both an agent-based framework, which characterizes adoptions of renewable power among individual consumers with a decision tree that characterizes the capacity building and electricity purchasing decisions made by energy consumers. The two sub-models were coded on the same program to perform an integrated analysis on the diffusion of power generation profiles and the evolution of electricity Because of the high level of detail in the model, different functions are broken up into both functional groups to simplify calculations and into separate locations for a visually manageable and well-defined format. Different consumer segments have been examined and considering various carbon tax levels updated RPS have been proposed for a period upto 2030.

 ISBN: 2278-4187

(d) The study has developed a model to analyze the renewable energy potential in the deregulated Texas electricity market, when a carbon tax is introduced. Utilizing data on consumer behavior, this research suggests that the combination of agent-based modeling and decision tree analysis can be a very useful tool for analyzing the future of the deregulated energy market. However, the study is limited to Texas in US and the income distribution data is taken only for the period from2005 to 2009. In US itself different policy is applicable for each State. As such, there is further scope to study the State in US, which has attained maximum RE potential till date.

V INTEGRATING RENEWABLE ENERGY AND SMART GRID TECHNOLOGY INTO THE NIGERIAN ELECTRICITY GRID SYSTEM

(a) Renewable Energy and smart grid technology is being considered even for the countries having poor infrastructure in the area of power infrastructure. A research paper [6] published in 2014 recommends use of Renewable Energy and smart grid technology in the Nigerian Electricity Grid System. Research Methodology adopted is exploratory in nature. Twenty four (24) references are cited in the study.

(b) The authors have given an overview of the power sector and current electricity situation in Nigeria. Inadequate generation capacities and poor maintenance thereof, insufficient coverage of transmission network, poor distribution infrastructure, high technical and commercial losses and power deficit conditions are discussed in the paper. Research paper states that Nigeria has huge renewable energy potential, which may be tapped to increase availability. Authors recommend use of Smart grid technology to integrate renewable energy resources. The contradictions between smart grid and the existing Nigerian Grid are also tabulated in the study. Considering the benefits of smart grid technology policy recommendations are made in the study. It is concluded that integration of smart grid technology and renewable into the Nigerian electricity grid system is the only solution to the electricity crisis in that country. As per study, the benefits of the smart grid technology will not only improve electricity production and efficiency in Nigeria, but will also enable electricity consumers to become producers of electricity and enhance Nigeria's international competiveness.

(c) Analysis like cost benefit analysis, Feed-in-Tariffs (FITs), Renewable Portfolio Standards (RPS), Renewable Energy Certificate (REC) are not discussed in order to determine the best policy mechanism for renewable energy and smart grid integration in Nigeria. There is scope of subsequent research in these areas.

VI GRID SCALE ENERGY STORAGE SYSTEM

(a) Energy storage is recognized as an essential component of significantly increasing the penetration of renewable energy generation. As such, significant government and private efforts are being made in this direction. A research paper [7] included in the proceedings of IEEE (2014) deals with use of advanced lead acid batteries for grid scale energy systems. Research methodology adopted is exploratory in nature. Thirty (30) references are cited in the paper.

(b) The research paper discusses the 150 years history of lead acid batteries and evolution of valve regulated lead–acid (VRLA) cells at a system level. It is mentioned in the study that Advanced Lead Acid Battery Consortium (ALABC) was formed in 1992 and has been a major sponsor of the advancement of a new generation of lead–acid battery design over the past 20 years. After high carbon content was found to provide benefits, the focus moved onto carbon-enhanced designs. Integrating carbon into the negative electrode of the cell has allowed VRLA cells to enter a new application space, cycling for extended periods at a partial state of charge (pSoC). Various developments in lead acid battery are given chronologically, including thermal management of an Ultra Battery bank (an inverter/charger and smart grid management), which can monitor the state of charge (SoC) and the state of health (SoH) of the battery during system operation.

(c) Study underlines that as the amount of renewable penetration is increasing, utilities are placing constraints on the output of renewable generation plant. The most common form of constraint is ramp-rate limiting, where a utility would typically specify that a generation facility should not ramp at more than 10% of the maximum output per minute. This tends to exclude residential plant and is more commonly a requirement when plants are of a commercial size. Grid operators need to balance generation and load. On the generation side, the slower generators typically change hourly while generation associated with frequency regulation requires much faster response times. With renewable generation increasing in US, it is estimated by the authors that the demand for frequency regulation is expected to rise from around 1% of capacity to around 2%–7% of capacity, depending on network constraints, as wind penetration reaches 20% of capacity. The fast response time of battery energy storage compared to gas turbine generators has found promising use in grid frequency regulation (often abbreviated to "regulation").

(d) It is concluded by the authors that the significant advances in VRLA technology over the past decades have allowed lead–acid batteries to provide power handling performance and longevity competitive with other battery chemistries. This is also based on a technology that is well known in the industry, supported by proven transport, fire codes, building codes, and other safety standards as well as a mature, nearly 100%, recycling process. VRLA cells can now operate for extended periods at a partial charge, facilitating operation in utility applications, where the energy store can be called on to absorb or release energy. Based on the experience gained over the past decade with initial megawatt scale systems, a new generation of VRLA cell designs, system designs, and packaging are now emerging that are both lowering the cost of MW scale systems and improving performance.

(e) The research paper focuses only on lead acid batteries for energy storage. There could be other approaches such as pumped hydro, thermal energy in storage (such as molten salt), kinetic energy in flywheels, compressed air energy storage (CAES) and electrical energy in capacitors. In batteries, even Lithium batteries may be considered. There is scope of further study in these areas and a comparison of various approaches may also be made by way of cost benefit analysis.

VII A FRAMEWORK FOR QUALIFYING AND EVALUATING SMART GRIDS APPROACHES

(a) Smart Grids (SGs) can efficiently control power flows by means of Information Technology (IT). Technically, a SG consists of a power system and a bi-directional communication system. Multi-Agent Systems (MAS) constitute a possible technology that can be applied to control and monitor the operation of power grids. Moreover, MAS exhibit distribution, adaptive and intelligent features. A research paper [8] published in Journal of Smart Grid and Renewable Energy (2013) proposes a framework of qualification and evaluation for comparison of SG approaches. The research methodology adopted is descriptive in nature. Fifty Nine (59) references have been cited by the authors.

(b) A smart grid is defined as having the following seven principal characteristics, as specified by the US Department of Energy's National Energy Technology Laboratory in its modern grid strategy [8]. A smart grid:
   (i) enables active consumer participation
   (ii) accommodates all generation and storage options
   (iii) enables new products, services, and markets
   (iv) provides power quality for the digital economy
   (v) optimizes asset utilization and operates efficiently
   (vi) anticipates and responds to system disturbances
   (vii) operates resiliently against attack and natural disaster

(c) An overview of an evaluation framework for smart grids is given in the study. It is proposed to evaluate the societal impacts based on the criteria of Green House Gas (GHG) reduction, Energy security, Economic competitiveness & affordability and human integration. Different aspects of the framework are composed by the first (qualification) and second (evaluation) steps. The first step is detailed through two view-points or dimensions (structural and family problems) and the second step is detailed through the societal dimension. In order to evaluate the impact of the incoming smart grids, concepts must be defined, The concept of sustainability usually considered as a composition of Environment, Economy, and Society is integrated and human dimension representing system's control and supervision capabilities is also added in the study. Authors collected them within an assessment frame-work combining 4 different perspectives grouped under the umbrella term societal dimension, namely environmental, economic, quality of services and human integration approach.

(d) Finally, a comparative study of the main multi-agent approaches for smart grids was conducted using the qualification and evaluation framework previously defined. Evaluations based on Grid Agent, Home bots, Intelligent Distributed Autonomous Power System (IDAPS), Ideas and Power Matcher are tabulated in the study for common criteria. The study [8] aims at defining cartography of the existing contributions to smart grid and analyzes their strengths and weaknesses. As per authors, objective of the study was not to determine which approach is the best among the chosen ones. Such a choice would be dependent on many conditions specific to the deployment context. However, the survey presented in this paper attempts to help a stakeholder with the comparison of the defined features.

(e) The results presented in the study are only for all chosen approaches based on the available documentation (articles, technical reports and presentations). All the elements could not have been captured. The study is theoretical and no real experimentation was made to test the different approaches. Future works may improve these features and go further. Future directions for this work may consist in deploying a website in order to store the presented results, enable and perform new experiments with addition of new features.

VIII CONCLUSION

Although basics of electrical engineering have not changed much, there are several recent advances mostly in the areas of Renewable energy and Smart grid. Madhya Pradesh has share of renewable grating capacity of 11 % as against all India average of 13 %. States like Tamil Nadu and Gujarat are having higher share of renewable power. Various features of Renewable energy like uncertainty, volatility of availability of energy, intermittent nature, reactive power requirement, problems of forecasting, 'must run' status in merit order dispatch and impact on conventional plants are involved in respect of Renewable capacity addition in Madhya Pradesh. In view of the upcoming regulatory mechanism similar to those applicable in US and other developing countries, suitable model is required for load balancing. Review of the research papers carried out gives a way forward to integration of renewable energy sources into the grid.

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