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An ab initio issues on renewable energy system integration to grid

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ABSTRACT

With the introduction of Renewable Energy Sources (RES), Energy Storage Systems (ESS), Smart Grid technologies, Micro-Grid technologies, and Distributed Generation (DG), the power system is changing significantly. Planners, researchers, regulators, operators and policy-makers need to ensure that the power system adapts to these changes. With change comes the unknown (issues and challenges) and unless a majority of these unknowns are identified, analysed and addressed properly, the system cannot achieve its maximum potential. The proper management, operation and integration of RES in the grid is one of the promising avenues for increasing the capacity of grid and thereby decreasing environmental impacts. This paper presents a review of the challenges and issues associated with RES integration in the power system and some of the existing techniques that are in use to address these.

Keywords:

Renewable energy sources;
Distributed generation;
Energy storage systems;

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1. Introduction

In recent years, with electricity becoming more accessible and its applications more versatile, the demand for stable and adequate electricity supply is continuously on the rise [1, 2]. In some cases, these increasing electricity demands have been inadequately dealt with by expanding the capacity of the existing power stations [3]. However, with the transmission infrastructure remaining the same, it becomes increasingly difficult for a centralized grid to meet the increasing electricity demands [1, 3]. In order to meet the increasing load, one of the promising solutions is the integration of small generating units directly on the demand side. These small generating units usually connected to the distribution sector, to meet the necessary power demands mainly during peak hours, constitute the distributed generation (DG) [3, 4, 5]. Distributed generation is a general term, and is used to represent a number of individual generating units connected to the distribution site. Integrating DG to the electrical grid is an important field with regards to relieving the centralized power system from overload conditions [6, 7].

With the ever-increasing power demand, there arises a need to look for alternate sources of electricity [3, 6]. Currently, many system operators are facing the challenges of matching the available electric generation with the rate of consumption, especially during peak demand hours [3]. This gap margin between the supply and demand of power can be adjusted up to a certain extent by setting up peak load plants which will only be operated when required, i.e., during peak hours to supply the load. Employing Renewable Energy Sources (RES) instead of conventional sources to operate these peak load plants offer additional advantages including reduction in cost of operation and less pollution emissions [8, 9]. Therefore, when compared to coal or petroleum

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based power production, integration of RES-based power production is more beneficial to the grid, it also makes the grid more environmentally friendly [3, 10, 11]. When different DGs are pooled together into a single integrated unit along with components such as power electronics based converters, energy storage systems (ESS) and other necessary equipment to deliver stable supply into existing conventional grid through an interconnecting link, it initiates the concept of Micro-Grid [12].

The present paper attempts to investigate the issues that arises as a result of integrating RES-based distributed generation into the grid, and the solutions and conclusions arrived at to solve some of these issues by reviewing scholarly papers and work done on this relevant field of study.

2. Wind and Solar- based renewable energy systems

The different forms of renewable energy that are currently in use for production of electric power are wind energy, solar energy, hydropower, tidal energy, bio gas plants, geothermal energy, wave energy, ocean thermal energy, etc. Out of these, wind and solar RES [10] are considered to be among the most suitable candidates to serve as distributed generation. With current advancement in the field of wind and solar energy conversion techniques, it is now becoming easier to convert more amounts of wind and solar energy into electricity. Additionally, the release of harmful chemicals into the atmosphere from burning of fossil fuels for electricity generation is practically non-existent in electricity generation from wind and solar [11, 13], and these technologies are convenient and comparatively easy to use. It is mainly for these reasons that wind and solar-based electric generation systems are preferred over the other forms of energy for RES integration to grid, and also why the bulk of this study is based on.

2.1. Wind turbines

Wind energy is a clean and freely available RES exploitable through wind turbines [14]. For generating electricity from wind, generally devices like Doubly Fed Induction Generator (DFIG), Direct Drive Synchronous Machine (DDSM), and Squirrel Cage Induction Generator (SCIG) are used. The wind turbine output is dependent on the speed and velocity of the available wind. A performance comparison between SCIG, DFIG and DDSM was done in [15], and it was found that for wind energy integration to a grid, DFIG and DDSM are a better option. DFIG and DDSM are variable speed wind turbines while SCIG is a fixed speed or constant speed wind turbine. The authors in [16] have done an interesting and in-depth discussion on constant/fixed speed wind turbines and adjustable/variable speed wind turbines, and argues the advantages of DFIG in achieving improved efficiency, reduced inverter cost, reduced cost of the inverter filters and electro-magnetic interference filters, implementation of power factor control at lower cost, as well as decoupled control of the generator's active and reactive power flows. These characteristics of DFIG were also expressed in [17–19].

Considering the uncertainty and variability aspect of wind resource, incorporating ESSs with wind power technologies is always a welcome development. It has added benefits such as during unplanned or unexpected availability of wind energy, the generated electricity can be stored in batteries or other ESS units to be used as an alternate source of supply [20, 21] when required.

2.2. Photovoltaic (PV) Systems

PV systems convert the sunlight directly into electricity, which may be fed to the grid through inverter or stored in electricity storage [22, 23]. Since the direct current generated by PV systems can be stored in batteries [24] therefore, storage batteries and inverters can also be employed when PV systems are integrated into the grid [25]. With advancements and improvements in the PV technology, there is a noticeable growth in the integration of PV systems as DGs [26]. Presently, electricity generated by PV systems is allowed to fully inject into the grid [23]. Photo-voltaic Systems generate electricity depending on the availability of sunlight in the area [27, 28], and since the availability of bright sunlight is weather dependent, it leads to the variability and intermittency of supply by solar-based generating devices [29, 30]. In large PV system installations, this unpredictability prompts the issue of fluctuations in the output power and the corresponding negative impacts it will have on the systems connected to it [30, 31]. A most informative and comprehensive review on solar forecasting methods have been done in [32]. Based on the discussion in [32], the types of solar forecasting techniques generally include; Numerical Weather Prediction (NWP) based forecast, Stochastic forecast, Artificial Intelligence forecasting model and Hybrid forecasting models. In modern power systems -based on various time scales- a combination of one or more of these techniques are used to give the best forecast. The types of solar power forecast based on various time scales include: (i) Nowcasting [33] (also known as very short term forecast) which involves forecasts for the immediate or hours-ahead forecasts; some of the popular techniques employed for Nowcasting are Statistical techniques and Satellite based methods, (ii) Short-term solar power forecast deals with forecasting the availability of solar resource ranging from a day to a week; NWP based forecasts such as Global Forecast System, and Regional NWP models, are efficient forecasting techniques for short-term forecasts and, (iii) Long-term solar power forecasting, which forecasts the monthly or annual availability of resource. In [10], the authors have discussed some of the challenges related to Solar PV integration to the grid. Additionally, incorporating ESSs to address some of the issues regarding solar generators providing a stable supply of power to the consumers connected to the grid were discussed in [23].

3. Challenges in integrating renewable resources into grid

Integrating RES into the utility grid comes with many challenges; the major challenges include the issue of location and the variability and uncertainty of renewable resources [34].

3.1. The location of renewable resources

The availability of renewable resources in a particular location plays an important role in the decision to set up an RES [4, 27]. Generation of electricity from wind turbines have certain requirements that have to be satisfied such as availability of wind moving with constant or uniform velocity for a specified duration and in a specific direction, minimum obstruction to the path of the wind before hitting the blades of the turbine, and if possible, a place where the availability of wind can be accurately predicted up to a certain extent. Due to these and many other reasons including (noise) pollution concerns, a wind farm generally has to be set up far away from populated or residential areas. PV systems on the other hand basically can be set up anywhere where there is ample amount of sunshine available in the form of roof-top solar panels for residential areas and solar farms for solar power generating plants. Also, PV systems are portable and as such can be installed anywhere, and be relocated if necessary. The major drawback of deriving electricity from solar is the nature of intermittent supply since the majority of the existing solar panels are fully dependent on direct sunlight and as such, any obstruction between the sun and the solar panel drastically reduces the power output of that panel by about 70 percent or more[35, 36, 37].

3.2. The variability and uncertainty of renewable energy

The variability of renewable energy is another major issue facing RES integration to grid. Power from RES is highly weather dependent. The variability of renewable energy arises as a result of the variable nature of availability of renewable resources. The uncertainty and unpredictability aspect of availability of renewable energy on the other hand is mainly due to inevitable errors inherent in the forecast data used as inputs in RES forecasting models [38]. Figure 1 shows the variable and intermittent nature of solar and wind supply data in India

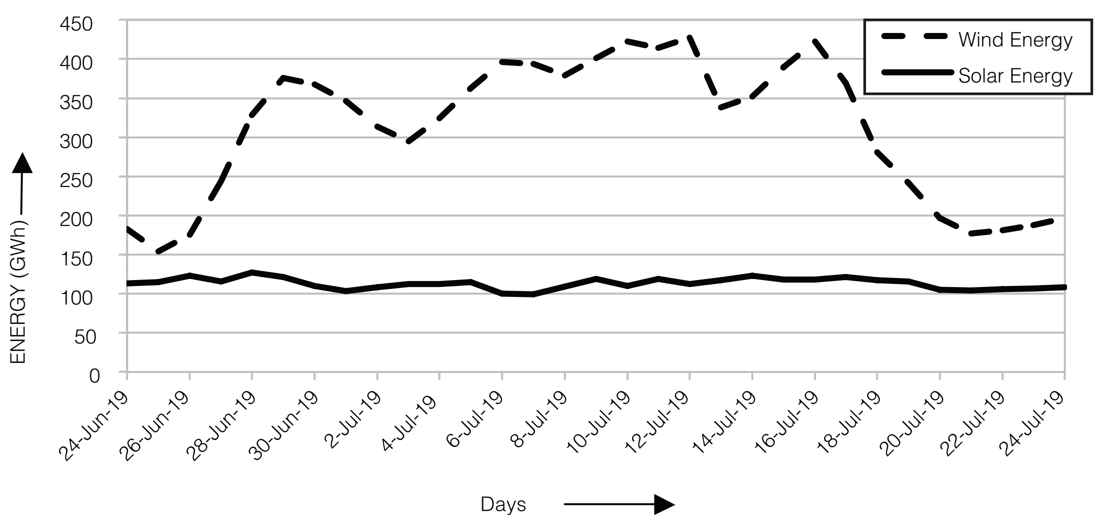

Figure 1: Wind and solar PV generation in India from 24 June – 24 July 2019[39]

during the time period of 24th June to 24th July 2019 [39]. Figure 2 shows the fuel-wise generation pattern in India from monthly reports, and Figure 3 shows the electricity demand and renewable generation for Belgium for a week in the month of May 2014.

3.2.1. Measures to address the variability of renewable energy supply when demand and supply move together

Certain measures to address the uncertainty aspect of renewable generation when supply from RES rise and fall with demand patterns are discussed below:

(i) Proper management and operation of fast-acting conventional reserves on the basis of continuously updated weather forecasts

Integration of RES into an electric grid also initiates the need for implementation of suitable contingency plans such as the need for a stable and reliable spinning reserve, which can deliver the load demand in case of failure or unavailability of renewable energy sources [27] for short durations. RES produce power on the basis of availability of renewable resources such as wind and solar, which can be predicted upto some extend via weather forecasts. In the case that during high demand, if the renewable plants are unable to meet the demand adequately due to resource constraints such as drop in wind-speed for wind turbines or overcast sky for solar plants, an alternate source has to supply the deficit in the demand. This alternate source should have the same or higher generating capacity as that of the renewable power plants and should have provisions for fast operation and connection to the grid to supply the load with minimum time delay. Conventional resource-based power plants such as gasoline-powered generators are more suited to play the role of fast-acting reserves due to their ability for a quick start and less time consumption to reach their optimal performance mode. With more amount of renewable energy integration to the grid, it becomes that much more necessary to provide proper fast-acting reserves for the smooth operation of supply.

(ii) By installing high capacity ESS at proper locations in the grid

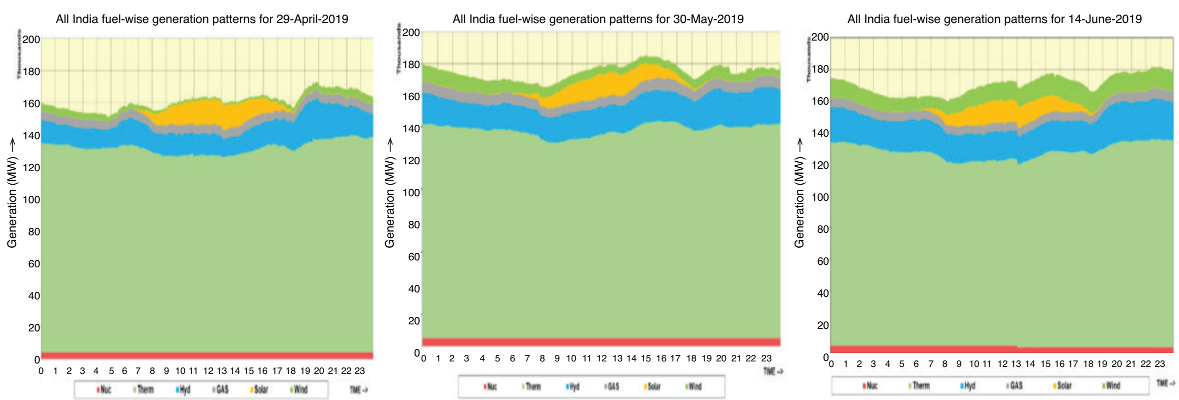

Figure 2: All India fuel-wise generation pattern from monthly operation reports 2019-20[39]

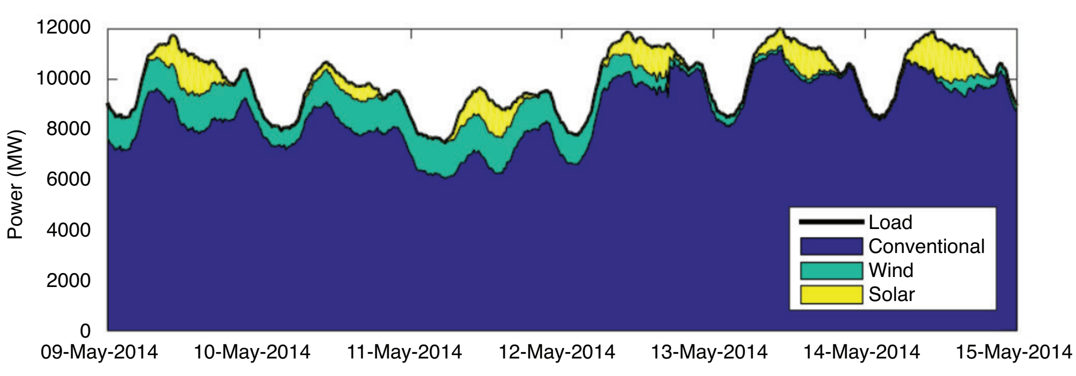

Figure 3: Electricity demand and renewable energy production in Belgium (May 2014)[38]

In [27, 40] the possibility of implementing large electric power storage devices at certain locations in the grid which will store energy when excess energy is present and supply the stored energy when demand rises, were discussed. The excess electrical energy may be stored in many forms [41, 42] such as rechargeable batteries [25], fly-wheel technology, heat energy, potential energy, mechanical energy and many other forms of energy which can be converted back to electrical energy when required. By installing devices with a capability of large storage on the grid, surplus electrical energy can be stored in huge amounts and this stored energy can be utilized when the demand rises or during an emergency [25, 40, 43]. In [44], applications of different ESSs for operation in timescales ranging from few microseconds (for maintaining power quality, and proper frequency response) to months (for cases involving seasonal storage) were identified and discussed.

(iii) By spreading out RES installations over a wide area

The availability of renewable resources varies over a wide area [4], and these characteristics can be noticed even when we consider a place such as a town or a city. Sometimes, it may be noticed that while one part of the town is sunny, there is rainfall in the other part of the town. And, even during clear weather days presence of an occasional passing clouds affects the exposed area portion by portion, and also that the speed of the wind does not remain constant over the whole town instead it varies throughout. Taking these small details into consideration, it may be observed that installing small interconnected RES spread out over different locations of the town would provide a more stable and steady supply as compared to setting up one huge plant at a designated location which generates maximum power when renewable resources are available and negligible power during unavailability of resources [27]. Thus, instead of setting up a huge renewable energy power plant in one location, setting up small interconnected RES over a wide area will go a long way in providing a stable and constant transmission of electric power to the consumers [4, 27].

At present, the variability of renewable energy is mostly addressed by installation and proper control of the fast-acting reserves but as the integration of renewable energy into the grid grows more and more, installation of ESSs and controlled transmission becomes more appealing.

3.2.2. Issues with matching with reserves during renewable energy and demand mismatch

Now, the variability of renewable energy is relatively easily accommodated by means of the above mentioned approaches when the demand and renewable supply are moving together i.e., high availability of renewable resources when demand is high and vice-versa, but when demand and supply move in opposite directions, operation of conventional reserves to accommodate, address or relieve the situation becomes more challenging both in terms of cost and management of resources. The two major cases of renewable energy mismatch with demand include:

(i) Availability of high renewable energy during periods of low demand

This condition is mostly observed in wind RES. In wind farms, sometimes due to abnormal weather conditions, there may be an availability of high amount of renewable resource (wind moving at high speeds) during periods of low demand hours such as at night-time. This leads to a condition of surplus availability of electric power in the grid but nowhere to use it since the demand is low. Integrating huge electrical ESS is being discussed as one of the potential measures to address this issue. By installing high capacity ESS at proper locations in the grid any surplus or excess energy can be diverted to charge the ESS, and this stored energy can be fed back to the system whenever required or when the demand rises [40]. The constraints involved include finding the optimal locations for installing the ESSs as well as the cost involved in the installation and maintenance of the ESSs units.

(ii) The absence of renewable energy when demand is high or during peak demand

On the other extreme end is the condition of absence of renewable energy during peak demand hours. This condition affects both wind and solar-based RES. As can be observed from figures 2 and 3, as well as in the literature [5, 45, 46] that the power generated from solar and wind power technologies are in most cases used to supply the peak demand. With power generation from solar and wind technologies being fully dependent on weather patterns, any abnormal weather conditions for a prolonged period of time lasting from several days to weeks will have a significant impact on the grid, and in worst cases no power may be generated by the RES during the affected time period. For such eventuality, alternate arrangements have to be planned in advance to ensure that the power demand is delivered. Installation and proper management of spinning reserves are being considered for addressing these issues, but the cost involved in setting up the reserves serves as a barrier. Spreading out interconnected RES over a very wide area in order to collect resources from more locations [4] is also another option that is being considered but it has some constraints such as power loss involved during transmission between the different areas as well as concerns over the security and cost of maintenance of the interconnected individual renewable energy plants.

Dealing with the above two cases is still a major challenge facing renewable energy integration to the grid, and research is still being done to find the best possible solution to properly address these issues.

The intermittency in supply due to the nature of variability and unpredictability of renewable energy sources are currently being addressed via flexibility in generation [34, 38], supported with reliable and accurate weather forecast data [38] for precise and accurate prediction of availability of supply as well as employing ESS units [42] at strategic and optimal locations, and adoption of efficient and energy saving practices and actions in the usage of available electric supply.

4. RES enabled Distributed Generation (RES-DG) and its impacts

Small generating units connected to the distribution side to deliver the demand when required and which acts as an alternate source of supply are normally termed as distributed generation (DG). The concept of introducing distributed generation as an additional power source has been discussed by many intellectuals and scholars alike for many years. Over the years, DGs have been tested out in various places and found useful in many cases. The potential benefits involved have led many countries to integrate a number of DG units into the electricity grid [4, 47, 48]. Introduction of DG units have also led to the minimization of setting up of new localized power plants such as coal or petroleum powered thermal power plants. It is expected to play a major role in the deregulation of the electricity network especially in the generation sector [6]. The distributed generation with a special focus on RES has become more popular due to its eco-friendly and cost-effective approach towards power production [49]. RES are also employed in Community Renewable Energy Networks [50], an application of RES integration for electricity generation owned, operated and traded by either individuals or community to fulfil their own electricity needs. Slowly, the generation of electricity is shifting towards RES-based electric power generators from the more conventional fossil fuel based generators. These changes in the power system network as a direct or an indirect result of the introduction of RES-DG also leads to several impacts within the network itself.

In a power system network, the production and demand keep on changing continuously with time. Due to the dynamic nature of the power system network, it is difficult to observe or estimate all the impacts on the network as a result of the addition of new DGs into the network. Major concerns with DG integration include the issue of power dispatch from RES-based smaller generator units, and the issue of proper operator distribution planning to include the unpredictable nature of DG supply. It may also be noticed that though the distribution networks were designed to transport and deliver power from the substations to the consumers and not the other way around, the integration of distributed generation is normally being done on the distribution side of the power system network. This contradictory connection of DGs to supply via the distribution side causes a number of problems especially in situations of uncontrolled and unsupervised connection of DGs in huge numbers.

4.1. The severity of the impacts with RES-DG includes:

Increase in uncertainty due to fluctuating and unpredictable power sources are one of the main concerns for the transmission system operator [51]. The behaviour of small or novel generators during large disturbance is unknown and as such may make it difficult for the network operator to operate the network in a secure way. Very large disturbance within the network itself may have a huge impact on the DGs connected to it, and in severe cases, it may even lead to some individual DG units being destroyed as a result of the backlash from the main network. In some cases due to abnormal conditions in the network, huge disturbance may be introduced into the network through the accumulation of small disturbances by the high amount of DGs connected to it. Such an abnormal condition may lead to the collapse of the whole network if proper contingency plans are not implemented in advance. Incorrect operation of the protection is another issue that occurs with a bulk integration of distributed generation. If proper regulations are not chalked out in advance, it may lead to unwanted operation of the protection devices when not required and in some cases, failure of the protective devices to operate when required [27, 52]. Unwanted operation of the protective devices will lead to the links between supply and demand being disconnected prematurely thereby failing to meet the load demand even though generation assets to supply the load exists. On the other hand, failure of operation of the protective devices when required is a more serious issue as this may lead to malfunction of electrical components and devices both on the producers side and the consumers side, and in severe cases the distribution sector as well as the DGs connected to it may burn-out or get damaged beyond repair.

5. Measures to address issues of RES integration to Grid

Provisions and measures to address some of the issues of RES integration by different researchers and authors are discussed below. Also, some measures discussed in section 4.4.1 are discussed in more detail in this section.

5.1. Smart Grid Renewable Energy Systems with demand response

Smart Grid may be defined as the electricity networks fully equipped and integrated with real-time monitoring sensors and advanced communication standards that intelligently integrates the generators with the consumers, is self-healing, resilient, sustainable, efficient adaptive, safe and which efficiently delivers electricity [3, 47, 53]. Compared to integrating RES into conventional electric grid, Smart Grid RES provides certain advantages and benefits which include, but is not limited to, facilities to implement cost-effective higher penetration of RES into the grid with noticeable improvements in the power quality, reliability, and resiliency [3, 6, 47, 53, 54]. Also, in smart grid, the consumers are also considered as active participants in the electricity system and any activities of the consumers are reflected in the operation of the grid. Consumers are given incentives inorder to motivate and encourage them to work towards a lifestyle that brings about more savings in energy consumption. In smart grid, implementation of demand-response programs based on the consumer consumption patterns leads to a lot of advantages and savings for the electric utility grid. Demand response focuses on controlling the demand to match the supply instead of focusing on the supply [51]. For demand response to work efficiently, consumer participation is the most important factor, and in smart grid-DG integrated networks, its importance is felt even more. Active consumer participation in the daily activities of a power system network is a measure that has been investigated for a long time by different intellectuals and scholars as a measure for the smooth and efficient functioning of the grid. Demand-side flexibility can address some of the problems due to variable renewable energy integration [34, 55]. With the active participation of the consumers, not only is the cost of operation of the grid greatly reduced but the power from RES can also be more efficiently utilized.

5.2. Micro-Grid

Renewable energy sources or alternative electrical energy sources connected together in a harmonious arrangement with ESS [6, 7, 52], dedicated loads, protection and control devices and power electronic based converters [56, 57], and which can act as a standalone self-sustaining generation side grid and is equipped with provisions to connect and disconnect with the utility grid via a power electronic based connecting link or a transformer makes up a micro-grid [12, 47, 58]. Micro-Grid can act as a distributed generation unit or an islanded standalone electricity generation plant or system [52, 56]. Micro-Grid acts as a common pool of electrical energy, where all the connected energy sources are provided with provisions to integrate smoothly with the existing electric grid [12, 57, 59]. Power electronics plays a very important role and is a critical component of any microgrid system. The attraction of Microgrid lies in its possibility of accommodating a wide range of growing needs in a seamless manner and with flawless control techniques [52, 56, 60], which is achieved through the use of power electronics. In a microgrid, micro sources should be able to seamlessly integrate as well as disconnect with the existing microgrid without the need for any extensive modification of the existing micro sources. Generator ‘plug and play’ can be enabled through implementation of proper inverter control techniques [6, 61], thereby providing the much needed generator flexibility. A microgrid requires highly flexible power supply from every possible micro sources connected to it in order to ensure smooth and controlled operation as a single microgrid unit; which can only be achieved with power electronic based micro sources [59]. Flexibility is desired for addition as well as islanding of micro sources. Microgrid control using inverters can also provide greater flexibility via implementation of the plug and play functionality [56].

5.3. ESS- Energy Storage Systems

Energy Storage Systems are devices that have capabilities to store huge amount of electricity, and the stored energy of which can be utilized whenever required [27, 40, 41, 43, 62]. With the increase in the integration of renewable resources into the grid, proper implementation and utilization of more number of EESs also become important [7, 42, 62]. Also, improvements in the technology associated with EES can address some of the problems such as issues with peak load management, improvement in electrical stability and improvement in the power quality [7, 40, 63]. Electrical energy can also be stored in the form of potential energy through mechanisms such as pumping up water to high locations in huge amounts during availability of high surplus power, and this stored potential energy can be converted back to electrical energy through electrical turbines which converts the mechanical energy of moving water into electrical energy which can then be supplied to the grid when the demand for power rises. Electric cars as potential ESS units were discussed in papers [27, 51, 64]. Proper implementation and installation of ESSs in RES integrated power systems can go a long way in ensuring that for sudden momentary dips in system voltage, the system is compensated for those short periods without the need for new generating plants to be started [62, 65]. Some of the problems faced by current ESSs include role and design of ESS [43], limited storage capacity, limited shelf life of batteries, etc.

5.4. Advanced Forecasting

The electricity generation of an RES-based generation unit is directly dependent on the amount of availability of the sources such as wind and solar, and their availability is dependent on the weather conditions. With advancement in technology, it is now possible to forecast weather conditions around the world hours and days ahead with high accuracy [51] using weather satellites and other means. Using this and other already available means to accurately make weather forecasts of a particular region hours and days ahead especially with regards to availability of wind and solar resources also provides some help in solving the nature of variability of these sources [55]. With advanced forecasting, scheduling of the renewable generation assets with other conventional generation assets also becomes easier and generator commission and decommission also becomes more efficient[4]. By accurately predicting the weather pattern in advance, faster operation of reserves to deliver any deficiency in supply, due to a failure of operation of renewable sources, can also be achieved [55].

5.5. Faster dispatch instead of long duration fixed schedule of generators

Generally, generators are made to operate on a fixed schedule to supply the demand for a certain period. During this period of scheduled operation, the selected generators are fully committed to their fixed schedules and will not be available to do other tasks such as providing help to relieve the electricity network during times of fault situations or scheduled deviations. So, during fixed scheduled operation of generators, if the demand of the grid suddenly increases then the committed generators will not be able to balance the load even though they may have the capacity to do so. Now, instead of committing the generators over long periods of fixed schedules, if the generators are operated with faster dispatch intervals, then it becomes increasingly easier to match the load and generation levels and any overproduction of power or deficiency in supply can also be quickly addressed [51]. Fast dispatch of generators is more desirable in the operation of renewable generators as well, since with faster dispatch of generator assets, activating the corresponding conventional reserves during times of sudden fluctuations in weather conditions can be significantly improved to meet the load demand [51, 66]. On the other hand, if there is an availability of renewable resource at any time of the day, then some of the conventional fuel based generators can be decommissioned in favour of commissioning the renewable generators to supply the demand. Fast dispatch of all generation assets is somewhat limited by current existing technology.

5.6. Flexibility in generation

Some papers such as [66] also discuss the use of flexible generation sources for smooth integration of renewable resources. In simple terms, the flexibility of a generator is nothing but the ability of a generator to start quickly, reach optimum operating conditions in the least amount of time, and stop when desired. The flexibility of a generator unit or a generation unit (fleet of flexible generators) is very much required if we want to integrate RES smoothly, efficiently and quickly. The variability of renewable resources leads to the power generated from RES to be of an unpredictable and variable nature. Thus, it becomes increasingly difficult to integrate RES into an existing rigid and scheduled based generation units. If, on the other hand, the generation units are flexible with an ability to easily increase as well as decrease their operation without experiencing any major backlash or any negative impacts on its individual generators, then in such a flexible network, the integration of variable RES becomes easier. In such a flexible network, during availability of RES supply, the grid generators can be easily deactivated in order to accommodate the power received from RES [27] and during run time of the scheduled operation of the RES if there are any sudden events such as unavailability of renewable resources, the flexible grid generators can be quickly started to their optimal running conditions and be connected to the grid to deliver the load. Generators with high flexibility include natural gas combustion turbines [58], hydro power plants and internal combustion engines as their operation can be adjusted as required when not subjected to other constraints, whereas coal and nuclear power are among the least flexible of generators.

6. Conclusion

Renewable energy is a clean and free source of energy. Wind and solar RES-based electric power generation units have many benefits and advantages over the conventional thermal power plants. Though the initial investment for setting up RES may be high, once it is properly set up, it makes a full return on the investment and with even more benefits. The benefits of properly installed RES includes but is not limited to; green energy, low running costs, free fuel, a return of investment, cost savings, low or negligible marginal cost of power production, and many other additional benefits. In order to avail all or some of these benefits on a large scale such as a utility grid, a seamless integration of the renewable energy generation units is required. Unfortunately, the operators and planners of the power system utility still face many challenges when it comes to seamlessly integrating renewable energy generation units to the utility grid. Through our study of some of the past and current literature related to the topic of renewable integration, we were able to identify and isolate some of the major concerns plaguing renewable resource and grid interconnection.

With the passage of time, many issues related with RES integration have been sorted out and addressed, but even with all these solutions, planners and operators of the power system network still continue to face many challenges as a result of advances in the field of renewable energy generation or due to upgradation of equipment, and so the process of finding new solutions as new challenges arise is an ongoing activity. We also observed through the literature review the need for and the importance of the smart grid in providing assistance towards achieving a seamless integration of renewable and other alternative power sources to the grid.

The importance of the micro grid is also on the rise. Micro-grids, with its micro-sources, ESSs and power electronic based controlling units are becoming more widely used to address many of the challenges faced in integrating RES to grid. For achieving better interconnection relation between grid and renewable energy integration, issues related with the design and sizing of the system, and suitable and efficient models incorporating the technical and financial aspects of grid integration, etc are some of the issues that also need to be addressed.

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