International Journal of Innovative Science and Modern Engineering (IJISME)
ISSN: 2319-6386, Volume-4 Issue-5, May 2016

An Overview and Issues of Smart Grid and its Integration with Renewable Energy

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Abstract— Global Energy Sector largely relies on combustion of energy sources viz. fuel-oil and natural gas. However, these energy sources are becoming scarce day by day. On the other hand, global energy consumption is at its verge and is believed to triplicate by 2050. Hence, transformation of power networks into intelligent system is a viable option that can save energy, utilize renewable energy and ensure supply security. The energy sector encourages the use of renewable energy sources as it aims at reducing carbon footprint and promoting clean energy. Keeping these facts together with the issues of climate change and socio-economic challenges of current century, the need of hour is to use electric network as a Smart Grid. This paper highlights various Smart grid initiatives and their implications along with the issues involved with the development of Smart Grid Technology.

Index Terms—Smart grid, Wind energy, Solar energy, Power quality, Renewable energy integration.

I. INTRODUCTION

Smart Grid (an electricity network) is an amalgamation of reporting software, hardware and management built upon intelligent communication software. Smart grid concept interlinked with renewable market, has gained a lot of attention in energy sector [1].

Share of renewable energy (RE) in electricity generation has been increasing significantly as is evident by the penetration of high levels of RE in the grid. Solar and wind technologies have been reported to reach grid parity in accretion in economic terms [2]. The growth of RE source in centralized as well as decentralized grids requires effective use of smart grid and their technologies. Already existing grid systems incorporate smart functioning which is most often used to balance demand and supply. Smart grids very efficiently involves information and communication technology in electricity generation, delivery and consumption in a way to minimize environmental impact, improve reliability and service, enhance market and reduce cost [2].

Smart grid can play a pivotal role in maintaining sustainable energy future by facilitating smooth involvement of more renewable sources; supporting decentralized power production; improved system control; production of new business model by enhanced information flows; consumer involvement and promoting flexibility on the demand side [2]. Hence the energy produced locally through smart grid can be distributed as well as used globally [1].

Revised Version Manuscript Received on April 27, 2016.

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II. SMART GRID

Smart grid can intelligently integrate the action of all users connected to it such as generators, consumers and those that do both which in turn can very efficiently deliver sustainable, economic and secure electricity supply.

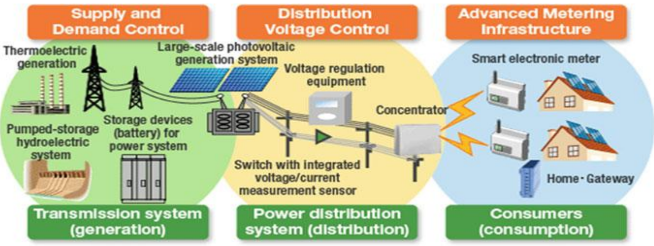

Fig. 1. Smart grid

It employs innovative products and services together with intelligent monitoring, control, communication and self-healing technologies in order to:

1) Provide consumers with more information and option of supply;
2) Facilitate connection and operation of all sized and type of generators;
3) Allow consumers to play a part in optimizing the operation of the system;
4) Reduce the environmental impact of the whole electricity supply system at a significant level;
5) Deliver enhanced levels of reliability and security of supply [3].

Smart grid promotes efficient and reliable end-to-end two-way delivery system from source to sink; and this happens through integration of renewable energy sources, smart transmission and distribution. This is why it is proposed that smart grid technology has the potential of fulfilling efficient and sustainable growing electricity demands with reliability and quality [4].

III. RENEWABLE ENERGY

RE has been continuously progressing all over the world till date. With growing recognition, unique and innovative approaches have been implemented in the field of renewable power [1].

Solar Photovoltaic (PV) and wind power often referred as first generation of renewables, have moved forward from reliability and scalability to improvement and refinement stage. Energy is being harvested from countless sources to name a few of them are: ocean waves, geothermal vent etc.

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which clearly points out that electricity in future is going to be powered by a mixture of energy sources. However, the necessary step required to exploit these resources will actually be to connect consumer demand and supply in real time [1].

IV. WIND ENERGY SYSTEM

Wind energy is one of the most efficient renewable powers used to for its conversion into another form of energy. Wind energy conversion system transforms kinetic energy of the incoming air stream into electrical energy.

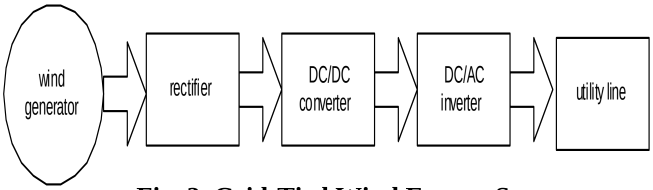

Fig. 2. Grid-Tied Wind Energy System.

A. Principle:

Wind turbine generators (WTGs) extract energy from wind and convert it into electricity with the help of an aerodynamic rotor, which is connected by a transmission system to an electric generator [5].

Wind turbine and turbines supplying motive power to the majority of the traditional power plants (gas, steam, or hydro turbines) differ from each other. In traditional turbines, the rotational speed remains nearly constant and locked to system frequency whereas the speed of a wind turbine however is not synchronized with grid and is controlled in order to maximize active power production. According to Miller et al. [6], wind power production is not inherently coupled to the system frequency as it does not provide inertial and governor response unless it is specifically controlled to do so.

Thermal units can be replaced as their output is displaced by lower-marginal-cost wind generation. The governor having most desirable frequency response can be most economic to displace. Such changes in the system operations are the primary concern that wind generation may aggravate frequency performance challenges [6].

V. SOLAR ENERGY SYSTEM

Solar energy depends on the nuclear fusion reaction occurring in the core of Sun. This energy can be collected and converted in a few different ways ranging from solar water heating with solar collectors or attic cooling with solar attic fans used for domestic purpose to the complex technologies of converting sunlight to electrical energy using mirrors and boilers or photovoltaic cells. However, the produced energy is still insufficient to completely supply power to our society [7].

A. Principle:

Photovoltaic cells made up of semiconductors such as silicon are most commonly used in modern society. When light strikes the cell, certain portion of it is absorbed within the semiconductor material, further the energy knocks electrons loose, allowing them to flow freely [8].

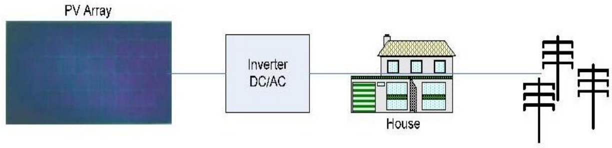

Fig. 3. Grid-Tied Solar Energy System

A PV system is able to directly convert solar energy into electric energy through photovoltaic effect. PV modules are the main building blocks which can be arranged into arrays to increase the production of electric energy. In order to transform energy into a useful form or store energy for future use, some additional equipment is necessary.

In comparison to wind power, solar energy is better in terms of frequency response. All solar power system networks consist of solar PV cells connected to an inverter which converts D.C. into A.C., which is more useful form of energy. Hence, the frequency response of the solar power thus relies on the performance/functioning of inverter. It has been observed that integration of solar power with grid is not as alarming issue as with wind power integration. However, the drawback related to variations in magnitude of power is prevalent in both forms of energy.

VI. ISSUES WITH RENEWABLE ENERGY INTEGRATION

Wind and solar generation both experience combination of non-controllable variability, partial unpredictability and depend on the resources that are location-dependent [9]. Three distinct aspects that create distinct challenges for generation owners and grid operators in integrating wind and solar generation are:

A. Non-controllable variability

Wind speed and available sunlight may vary from moment to moment, affecting power output Wind and solar output. This fluctuation in power output results in the requirement of additional energy to balance supply and demand on the grid, as well as ancillary services such as frequency regulation and voltage support.

B. Partial unpredictability

Wind and sunlight availability is partially unpredictable. A wind turbine may produce electricity only when the wind is blowing, and solar PV systems require the presence of sunlight in order to operate. Unpredictability can be managed through more accurate weather forecasting technologies, proper maintenance of reserves/stores that stand ready to provide additional power whenever less energy is produced than predicted by RE generation, and the availability of dispatch able load to remove excess power when RE generation produces more energy than predicted.

C. Location dependence

Wind and solar resources are based at specific locations and, unlike other non-renewable energy sources such as coal, gas, oil or uranium cannot be transported to a generation site that is grid-optimal.

Generation site must be co-located with the resource site, and often these locations are far from the places where the power will ultimately be used. New transmission capacity is also more often required to connect wind and solar resources to the rest of the grid. For offshore wind resources, transmission costs is also an important factor, and such lines often necessitate the use of special technologies not found in land-based transmission lines [10].

VII. ISSUES WITH POWER QUALITY

With increasing level of RE penetration, the characteristic of grid dominates by inverters than traditional generators and the network and impedance of the grid seen by a particular inverter becomes more effective by neighboring invertors than by the actual grid. RE integration into power grid introduces new power quality problems such as intermittency of renewable production leads to more frequent voltage fluctuation and power electronic interfaces injects high frequency harmonics into the system which may finally cause harmonic resonance. Such voltage fluctuations cannot be mitigated by reactive power compensation alone even with fast control because the problem is caused by active power variation, and to avoid this situation electronic devices are needed to comply with certain electro-magnetic interferences limits (EMIs). Invertors that are connected with Grid for RE application have to comply with harmonics and other power quality limits but so far no EMI limits have been reported to be set for such invertors.

Issues related to Power Quality issues can be summarized as:

A. Harmonics

Harmonics in the power system results from the operation of power electronic converters. It increases in magnitude due to increase in use of power electronics. Distributed generation with power electronic converters such as PV systems or wind power systems can have negative impact on the harmonic magnitude within a distribution grid. Remedial techniques like: Passive harmonic filters and active filtering techniques are usually preferred. Standards that limit the allowed harmonic disturbances of equipment connected to the grid can be used to avoid their occurrence. In order to correctly evaluate the harmonics, standards have to consider certain voltage harmonics and nonlinear behavior [11]-[13].

B. Transient

Transients are usually caused by lightning. Connecting or disconnecting a considerable amount of power generation to the network however, can result in transients if large current flows are permitted. Transients can either result in overvoltage protected equipment to trip or to be destroyed.

C. Frequency

Most of the electrical equipment depends on a stable network frequency and to acquire a stable frequency, generation has to match the load. At present rotating generators in power plants direct frequency to the grid, while distributed generation synchronizes to this frequency. As the frequency drops below 47.5 Hz the regularly distributed generation disconnects and if they are not able to provide more power their speed of rotation and the network frequency will drop further. In case of failures, fault ride can be utilized to stabilize the frequency. As the frequency exceeds 50.2 Hz, distributed generation modulates their power in order to reduce the frequency rise.

D. Unbalance

In optimal operation the voltage sine curves of the three phases differ by 120° exactly and have the same amplitude and each deviation from this condition is referred as unbalance. Single phase connection of loads and generators to the low voltage grid causes unbalanced. Depending on severity, the unbalanced state can have serious negative impacts on transformers, controls, distributed three phase generators and power electronic devices. The small loads and generators have little impact on the systems balance and are regularly compensated by loads or generators connected to another phase within the distribution network. Connection of a number of smaller generators to the same phase in the network, can have significant influence. Unbalance can be corrected by a balanced connection of loads and generators. One phase connection of loads and generators should be compensated by the coordinated connection of similar equipment to other nearby phases.

E. Flicker

Voltage variations below a certain frequency can result in visual effects and this effect is known as flicker. Such voltage variations cause lighting equipment to flicker. According to EN 50160, if this flicker is visible to humans then it is classified as relevant flicker. The exact limits for flicker are defined in the standard EN 61000-2-2. Wind power plants and PV systems are tested on the basis of their flicker influence on the network. Normally used energy saving light bulbs is less sensitive to flicker as they are connected by power electronic converters.

F. Voltage

For operation of every electrical appliance, voltage is the most important parameter. Within traditional low voltage networks, the transformer supplies nominal or slightly higher voltage to ensure the voltage to be within the authorized range at any position within the grid. The connection of distributed generation increases the voltage locally which may lead to violation of the upper voltage limit. Voltage regulation is the main challenge faced by the distributed generator integration into the low voltage grid, especially at the end of feeders and in rural areas. On-Load Tap Changers (OLTC) is used to keep voltage within the desired range and Line Drop Compensation (LDC) can be used to control OLTC to keep the voltage at a point in the feeder constant. The FACTS equipment such as STATCOMs can be used to control voltage by reactive power control [14]-[22].

VIII. ROLE OF SMART GRID FOR EFFICIENT INTEGRATION OF RE

Need to integrate RE, improve energy efficiency and allow consumers more control over their energy consumption leads to major transformation in power grids. The involvement of large quantities of renewable energy sources such as wind and solar power will require changes in operation of transmission system. The issues to be considered are Variability of renewable energy sources, Integration costs, Transmission, Frequency response, Emissions, Energy storage, System balancing, Solar and wind forecasting, Energy management systems (EMS), and High-penetration variable generation.

Coming out with possible solutions to these challenges will surely enable maximum penetrations of renewable generation sources on the electric power system and will direct towards future growth of RE.

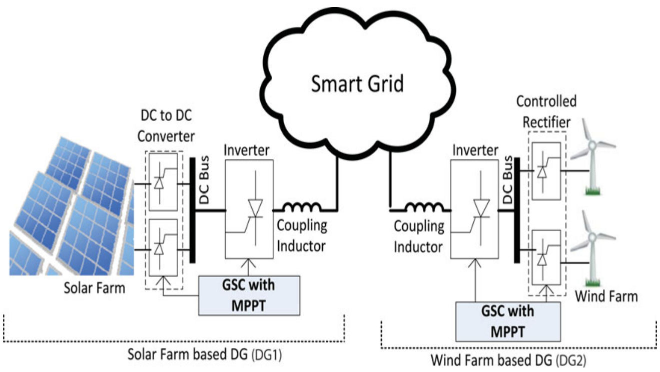

Fig. 4. Smart Grid and Solar/Wind Energy System

Energy management systems are usually utilized by the power system operators to monitor power grid working conditions and control grids in a reliable, secure, and economic way. It interacts with the grid through a supervisory control and data acquisition (SCADA) system [23].

Current energy management system scheme faces great challenges imposed by increased penetration of renewable generation on the power grid, because renewable resources differs from conventional generation due to their uncertainty and variability. Therefore, a fully integrated and intelligent distributed energy management system is a way to meet these challenges [23].

Smart grid implementation will ensure the incorporation of such high levels of integration in a reliable manner. Smart Grid possess several features such as: Power Electronics (HVDC/FACTS), Network Planning, Smart automation and protection, Bulk Energy Storage, Integrated Substation Condition Monitoring (ISCM), Advanced Energy Management Systems, Communication Solutions, Distributed Energy Resources, Distribution Management Systems, Smart Metering Solutions and Decentralized Energy Management System (DEMS).

Power plants focus on ensuring reliable supply using generation resources efficiently on one hand while reducing transmission losses on the other. An advanced EMS within a smart grid is provided with an interface which permits it to function like an EMS in a conventional plant but with inclusion of RE generation. Therefore, maximum power is being extracted from RE sources when they are available while during periods of fluctuations the back-up gen sets are used in the most efficient and economic way to achieve better feasibility.

In order to maintain the reliability of grid, smart grid can also include the facility of interfacing the information received from advanced weather forecast into the system operating procedures. Wind and solar resource forecasting predictions for future energy output are based on numerical weather prediction models and statistical approaches. Resource forecasting is relatively new as compared to system load forecasting, and its accuracy is little questionable. As the smart grid is deployed, options for fast automatic response to routine generation ramps can be improvised and implemented.

Within wind and solar energy, storage is another feature which can help smooth fluctuation in generation inherent. Smart grid permits the deployment of efficient and reliable bulk storage devices which includes a range of technologies with the ability to store electricity on the grid and permit/allow it to be dispatched as required. Such storage can increase the flexibility of grid through short term storage for peak-shaving and power quality uses, and long-term storage for load-leveling and load-shifting applications.

IX. ROLE OF SMART GRID FOR POWER QUALITY IMPROVEMENT

Smart grid methodology for power quality improvement is based on current control voltage source inverter which supplies the current into grid in a way that the source current are harmonic free and their phase-angle in relation to source voltage has a desired value. The injected current cancels the reactive part and harmonic part of the load and induction generator current, thereby improving the power factor and power quality. To fulfill these aims the grid voltages are sensed and synchronized in generating the current command for inverter. Smart grid connected system is executed for power quality improvement at point of common coupling (PCC) (Fig. 5).

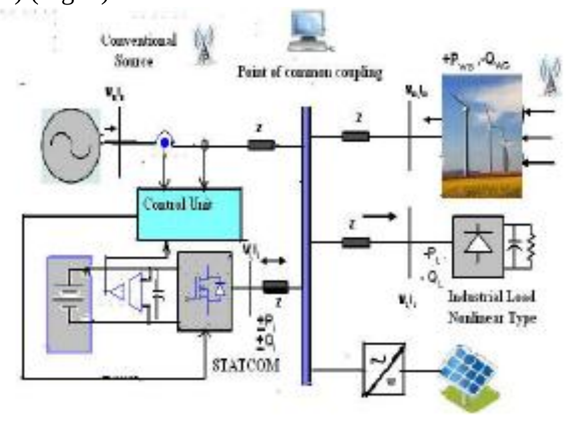

Fig. 5 Grid topology for Power Quality Improvement

The grid connected system (Fig.5) comprises of wind energy generation system, solar system and battery energy storage system with power converter as a current control voltage source inverter.

The system comprises of:

A. Primary control:

Primary control consists of power electronics converter which can absorb or supply the active and reactive into the grid. It allows the sharing of power between power converter and grid. Utilization of these power converters has marked benefit in grid operation. The grid voltage control, harmonic reductions and in-phase operation are the power quality benefits that can be acquired without excessive compromise.

B. Secondary control:

Secondary control manages the electrical parameter within the grid by using a central controller with communications to each individual control and sends the output of its regulation through a communication system. It also takes care of synchronization with network [21]-[22].

X. TECHNO-ECONOMIAL ISSUES

Electricity production of a particular wind turbine is highly variable however; the aggregate variability of multiple turbines at a particular single site is significantly less variable. Collection of multiple wind generation sites over a large geographic area results in even less variability. It has been observed that variability decreases with decrease in timescale [24]. A few aspects of solar variability are predictable (sunrise and sunset) while the other such as intermittent cloud cover are quite less predictable. Similar reduction in variability is observed for the aggregation of solar PV plants over a broad geographic area [24].

The above discussed facts persuade us to promote the penetration of wind and solar energy into the grid by utilizing these resources to the maximum level. It is essential to consider the factors of not only exploiting energy from them but also making sure that the energy profile is maintained constant by including advanced energy management systems, EMI for power-electronic equipment co-ordination advanced forecasting systems, storage devices, etc.

The collective effect of considering these factors leads to the concept of integration of wind and solar energy into the highly expensive smart grid. These factors can be tackled by increasing the tariffs levied on per unit of kWh energy generated however; this would discourage the masses from utilizing this electricity.

XI. CONCLUSION

Humans have been blessed up with nature which itself provides ample opportunities to make best use out of its resources on one hand, while still maintaining its beauty on the other. From present study it can be concluded that the power plant location poses strong affect on its performance. This paper focuses and points out the issues of integration of renewable generation.

Smart grid being a new idea for electricity networks across the world aims at increasing the efficiency together with maintaining safety and reliability of electricity networks by transforming the current electricity grid into an interactive service network; and to swipe away the technical impediments to the large scale installation and fully integration of RE sources.

The integration of RE resources into the electricity grid is a convincing and challenging venture. It offers set of research problems, which may critically require systems and control methods in the solution. An attempt has been made to collect a partial list of specific problems driven by the variability and uncertainty of renewable resources. It is noteworthy to mention that taking incompletely matured smart grid technologies into use and resulting in power quality problems or major blackouts would mean a step backwards for smart grid deployment.

Smart grid is advancement towards an enhanced and viable energy system which is more intelligent, efficient, feasible and reliable and most importantly has positive influence on the climate change.

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