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Overcoming Challenges of Renewable Energy on Future Smart Grid

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Abstrak

Peningkatan kompleksitas dari grid konvensional terkait pertumbuhan penduduk, kemajuan teknologi, dan infrastruktur adalah faktor-faktor yang berkontribusi sangat besar terhadap ketidakstabilan, ketidakamanan, dan ketidakefisienan penggunaan energi listrik. Untuk mengatasi masalah ini, keberlanjutan energi lingkungan memerlukan penggunaan energi terbarukan untuk keberlanjutan pasokan listrik. Intermitansi dan fluktuasi dari energi terbarukan merupakan tantangan besar pada grid cerdas. Makalah ini mengungkapkan tantangan potensi energi terbarukan pada grid cerdas dan menawarkan solusi dengan penerapan DC tegangan tinggi (HVDC) dan piranti sistem transmisi fleksibel AC (FACTS). Fungsi dan keuntungan dari piranti FACTS disajikan dalam makalah ini. Kendali tegangan dan stabilitas dengan aplikasi FACTS juga dibahas karena FACTS memiliki pengendalian cepat dan kemampuan untuk bertukar daya aktif dan reaktif secara independen.

Kata kunci: *intermiten, kekuasaan stabilitas, energi terbarukan, stabilitas tegangan*

Abstract

The increasing complexity of the conventional grid due to population growth, advancement in technology, and infrastructures are the factors that contribute immensely to instability, insecurity, and inefficiency of the use of electrical energy. To overcome the problems, the environmental energy sustainability calls for the use of renewable energy for sustainability of power supply. Intermittency and fluctuation of the renewable energy is a great challenge on the smart grid. This paper reveal the potential challenges of renewable energy on the smart grid and proffer solution with the application of high voltage DC (HVDC) and Flexible AC transmission system (FACTS) devices. The functions and advantages of FACTS devices are presented in this paper. Voltage control and stability control with FACTS application are also discussed because FACTS has fast controllability and capability to exchange active and reactive power independently.

Keywords: *intermittent, power stability, renewable energy, voltage stability*

1. Introduction

With the new development in power system, the smart grid allows seamless integration of renewable energy sources into the conventional grid. The total amount of economically extractable from wind is considerably more than the present human power use from all resources [1]. However, with increasing level of renewable energy sources especially wind power [2] the intermittent and fluctuating features of wind generator increase the uncertainties and challenges for future smart grids [2-3]. There is uncontrollable power flow in the power system governed by Ohm's law and Kirchhoff's law which may cause bottlenecks in the power system such as angle and voltage instability. The angle and voltage instability may result in generator outages, line tripping and blackouts [4].

In most power generating system, the main source of energy (the fuel) can be manipulated, but that is not the case of wind and solar energies [5]. Both wind and solar may not always be available where and when needed [6]. They are not dispatchable like the conventional sources of electrical energy. They both have uncontrollable power output which results in intermittent generation. Control challenges are part of the key enabling technologies for the integration of renewable energy resources. Most especially, wind and solar plants exhibit dynamics changes and nonlinearities challenges that require effective use of advance control techniques. This will not only increase their performance, but would increase the number of operational hours of wind and solar plants and minimize the cost per kilowatt-hour produced.

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The challenges can be overcome with the utilization of innovative technologies like HVDC and FACTS devices which has the ability to cope with the new challenges. HVDC and FACTS has the characteristics to mitigate technical problems in the smart grid, they increase the transmission capacity and system stability very efficiently and assist in militating cascading disturbances [7]. HVDC and FACTS can make available both steady state and dynamic control for power system. With the application of HVDC and FACTS devices either of them or combination of both will result in much more secured and reliable power grid. The devices are equally useful in distributed generation interconnections, voltage and power flow controls of wind energies and improve the power quality of the system.

Privatization and deregulation are posing lots of challenges on the electrical power system. This makes the grid to be loaded up to its stability limits and wide-area power trading with quick varying load patterns will add to increasing transmission congestion [8]. There are lots of challenges before the electricity distribution system in responding to the increasing demand of customer for electricity in the modern world [9]. The more the demand on electricity, the more the likelihood of outages, voltage and frequency violation and other power quality disturbances. However, more demand on renewable energy, distributed generators and storage devices is driving the conventional grid into what is popularly known as smart grid. Moreover, increasing numbers of distributed generation, most especially wind generation, integrated with the power grid brings further uncertainty of load and power flow distribution which gives additional strain to the system [4]. The daily wind production patterns for the month of May 2007 in Tehachapi, Califonia is shown in fig. 1 while fig. 2 shows the load and wind production for a typical spring day [10]. The variability of the wind energy has a great consequence on the voltage fluctuation at the bus where the wind generator is connected and the load voltage fluctuation which affects the power system voltage stability. This is a big challenge to the distribution system operator (DSO) to match demand with energy produced.

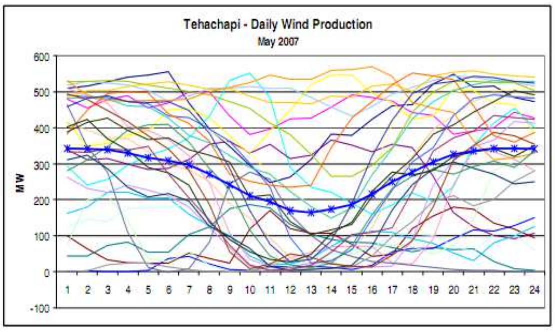

Figure 1. Daily output of wind production -May 2007 [10]

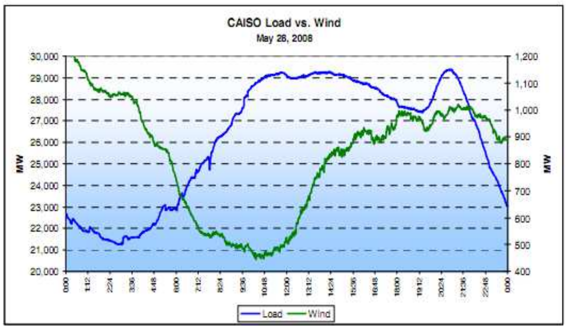

Figure 2. Comparison of wind generation to load demand [10]

2. Renewable Energy Challenges

Renewable energies such as wind and solar are more often looked at as been too costly as alternative for generating electricity, but, it is environmental friendly [11]. The renewable energy and information technology are very important to smart grid because of their significant improvement on how electricity is generated, delivered and consumed. Renewable energy most especially wind energy is part of distributed generation technology. Wind energy is widely used to generate electricity because it is the most promising clean energy globally due to its reduced cost [12]. This distributed generation including wind farms or smaller wind turbine can be seamlessly integrated directly to the distribution system [4]. With more connections of wind farms on the grid system, some impact on the conventional grid system operation needs to be investigated. Large amount of wind energy can result in unpredictable variability in order of GW, thus challenging the smart grid [13]. The conventional grid is dependent on constant power flow but the wind energy is fluctuating and intermittent resulting in spike output power due to large in-rush of wind and also it can bring a change to the dynamic operating condition of the power system [3]. Several wind turbines are grouped into wind farms with ratings ranging from MW to tens MW. The wind intermittent and fluctuations has a great consequence on the voltage fluctuation at the bus where the wind generator is connected and the load voltage fluctuation which affects the power system voltage stability. [14-17], addressed the challenges of wind energy fluctuation and intermittency to system stability and control for the future smart grid.

Environmental constraints have significant effect in the power system development. There are lots of challenges in integrating renewable energies such as large wind farms into power system, most especially when connecting AC links are weak and none availability of sufficient resources capacity in the neighbouring systems. Connection of the increasing part of the installed capacity to the distribution level (dispersed generation) posses more problems to the planning and safe operation of the power system. Then, introduction of power electronics can clearly enhance the power system and improve their performance. Output power of the wind generator varies quickly in a wide range, depending on the weather conditions. In the light of this a reasonable amount of controlling power from the network is needed to make up the positive or negative difference in actual wind power in-feed to the scheduled wind power amount [18].

FACTS devices such as static synchronous compensation (STATCOM) can be incorporated for voltage stability improvement [19-21]. The following technical solutions are available to the challenges facing the smart grid. Demand management such as demand response, smart meter and variable pricing to reduce electricity consumption; use of energy storage techniques and development of smart buildings with smart meters. Others include the use of information technology in monitoring and control of electrical grid in real time; reliable bi-directional communication technology and utilization of green information technology (IT) equipment and technology [15].

3. Expectations from Smart Grid

According to [22] “smart grid is an electricity network that can intelligently integrate the action of all users connected to it-generators, consumers and they that do both-in order to ensure economically efficient, sustainable power system with low losses and high level of quality and security of supply and safety”. One of the smart grid objectives is to update the power system automation which includes transmission, distribution, sub-station, individual feeder and customers using latest technology. With the introduction of smart grid, consumers can manage their energy consumption by monitoring their voltage and power [23]. It is to achieve reliability, efficiency and optimization in operation, planning, demand response, as well as utilization of diverse resources [24].

Smart grid creates the platform for deploying smart technologies which improves demand response and load management that makes the nation’s power transmission system more efficient, encourage renewable energy resources, and give consumer better control over their usages and costs. It provides high interconnected network between electricity suppliers and electricity consumers embracing generation, transmission and distribution. It involves real-time two- way digital communications between utilities and their consumers, this includes power delivery components, control and monitoring throughout the smart grid and more informed customer option and bring an improvement to resilient, and reliable electric grid that provides for environments stewardship, is secure, cost effective, and is a predominant driver to economic stability and development.

Smart grid uses sensors, monitoring, communications, automation and computers to improve the flexibility, security, reliability, efficiency, and safety of the electric system, and it is an infrastructure that puts the emphasis on active rather than passive control. With the above concept of smart grid, there is a great assurance for power quality and reliability of power system [24]. It is an infrastructure that puts the emphasis on active rather than passive control. Therefore, there is need for active participation of all stake holders from production level down to consumer level. The smart grid should be able to provide reliability, security, safety and efficiency as well as economic, environmental friendly operation with in-built self-healing in delivering quality electricity to consumers [25].

4. Smart Grid Solution with HVDC and FACTS Technologies

HVDC came up at the middle of the past century with new dimension for long distance transmission (LDT). This new idea came up with the transmission of power rating of a few hundred MW. By this development HVDC became matured and reliable technology.

Transmission line rated 3 GW over a long distance with one bi-polar DC line are state-of–the-art in many grids today. HVDC can be integrated at several points with the AC networks because of its multi-terminals system. Today transmission can go up and even above 6 GW over long distance with just one bi-polar DC transmission system [26].

FACTS based on power electronics came up in the 60's as a development to improve the performance of AC system and for AC LDT. It contributes to solve technical problems in the interconnected grid. FACTS can be utilized in parallel {static VAR compensator (SVC), static synchronous compensator (STATCOM)} or series {fixed series compensation (FSC), thyristor controlled/protected series compensation (TCSC/TPSC), solid-state series compensation (SSSC)} or in conjunction of both {unified power flow controller (UPFC), convertible static compensator (CSC)} for load flow control and dynamic conditions improvement [8]. GPFC is a special DC back-to-back (B2B) link, which is made for fast voltage and power control at both terminals. Therefore, GPFC is a FACTS B2B, which is less complex and cost effective than the UPFC. SVCs can have a maximum rating of 800MVAr, and series FACTS devices can be utilized on 550kV and 735kV level to improve the transmission line capacity up to many GW. Through DC and AC Ultra High Power transmission technologies, the smart grid will be smarter for a secure and sustainably made available to large renewable energy resources [8].

5. Roll of Smart Grid on Renewable Energy

FACTS power electronics base controller is used to improve the controllability and increase power transfer ability [27]. The better way of preventing voltage fluctuation and intermittency of wind energy is the application of FACTS controllers with self-commutated static converter to control voltage source. This could be achieved because of its fast controllability and capability to exchange active and reactive power independently. The group of FACTS controller is shunt and series controllers. The compensation device is connected in-between two transformers integrating the wind turbine to the grid. The series controller which is dynamic voltage restorer (DVR) is connected in series with the line to directly influence the line voltage at the wind turbine. While the shunt controller, STATCOM control the line voltage indirectly by injecting a current that causes an additional voltage drop at the line impedance which causes a decrease in the wind turbine voltage. Both DVR and STATCOM base on voltage source converter. The DVR takes care of series compensation to inject dynamically the controlled inverse fault voltage to keep the wind turbine voltage constant [28], but the STATCOM, a shunt compensation produce shunt current compensation [20], [29], [30-31]. It can be utilized for reactive power compensation, flicker and prevention of harmonic [29].

6. Voltage and Stability Control on the Smart Grid

The wind intermittent and fluctuations has a great consequence on the voltage fluctuation at the bus where the wind generator is connected and the load voltage fluctuation which affects the power system voltage stability. Voltage and stability control can be done at different scale. While voltage control is at a relatively slow time scale, the stability control is at a fast time scale [4].

Voltage Control: The following conditions must be met in order to have efficient, secure and reliable operation of the power system; bus voltage magnitude should be within acceptable limit, power voltage control and reactive power management should be able to improve system transient stability and voltage stability and the reactive power flow should be reduced so that the active and reactive power losses can be minimized. Also the bi-product of the minimum reactive power flows can reduce the voltage drop at transmission line and transformers. Suitable control algorithms, software tools and voltage control devices such as shunt reactor, shunt capacitors, synchronous generators, SVS, and converter-based FACTS are required to determine controls settings of and coordinate the control actions of all the voltage control devices sited at different location of the system. The converter-based FACTS have excellent dynamic reactive power and voltage control capability. Although, optimal power flow (OPF) is security and economic control-based, it reduces active power transmission losses and at the same time control reactive power from generator and compensating devices and control of tap-changing transformers are scheduled and coordinated. The voltage control and VAR management by OPF minimizes circulating VAR flow, which results in flatter voltage profile.

Stability Control: Proper design of damping controller offers the FACTS devices of providing add-on damping for small signal disturbances. Installation of FACTS in the transmission lines make the damping controller design more challenging in the sense that there are difficulties in selection of feedback signals and in finding damping torque paths. The use of linear matrix inequality (LMI) is good in the design of FACTS based damping controller and robust damping controller of FACTS. A new two-step LMI method needs to be used for design of output feedback damping controller for a multi-model system considering multiple operating point. This method can be utilized to design STATCOM damping controller with consideration of STATCOM internal controller [32].

7. Conclusion

Renewable energies such as wind and solar are more often looked at as been too costly as alternative of generating electricity but, it is environmental friendly. The renewable resources, most especially wind energy can be interconnected seamlessly to support the existing power source. The challenges on the new smart grid are how to mitigate the possible potential impact of wind energy intermittence and fluctuation. This paper discusses the challenges of wind energy on the smart grid as regards power system operation, voltage stability and control. Application of HVDC and FACTS devices make the wind energy comply with smart grid requirement without changing the wind turbine. It is revealed in the paper the impact of FACTs devices in protecting the smart grid against the intermittency and fluctuation of wind energy. Different FACTS devices are discussed with their area of application. The functions and advantages of FACTS devices are spelt out so as to make the smart grid a super grid. Voltage control and stability control of intermittency and fluctuation of renewable energy achieved with FACTS application are presented. The application of HVDC and FACTS provide both steady state and dynamic control for power system. It was discovered that these HVDC and FACTS can effectively incrase transmission capacity and system stability; they significantly enhance the voltage profile and thus the loadability margin of the power system. The impact of HVDC back-to-back (B2B) on long distance transmission system performance based on the principle of load flow control needs further study.

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