The Impact of Wind Farms on the Stability of Electric Networks

Issa Etier[1], Mohammad Abderrazzaq[2]

[1]The Hashemite University, Electrical Engineering Department, 13115 Zarqa, Jordan.
[2]Yarmouk University, Hijjawi Faculty for Engineering Technology, Irbid, Jordan
Corresponding author: etier@hu.edu.jo

ABSTRACT

Wind energy integration into distribution networks is currently an international trend. The achieved high penetration level of wind energy has changed the conventional view of wind energy role. The exclusion of wind energy from the studies, concerning steady state and abnormal conditions, is no longer acceptable approach to the decision makers in energy industry. In this paper, the main issues, related to the role of wind energy in keeping the power systems running efficiently and securely in normal and abnormal conditions, will be highlighted. The impact of wind energy isolation during the fault is determined. The role of advanced wind turbines in enhancing the weak distribution networks is assessed. The significance of wind in deregulated systems and privatization schemes is discussed. Finally, the recent development in communication system and its role in improving the integration of wind energy into local distribution networks will be summarized.

Keywords: Wind Energy, Wind Turbine, Wind Farm, Grid connected.

1.INTRODUCTION

With increasing demand for clean energy, wind power seems to stand out as a global success story. On the other hand, the continuous fluctuation in oil prices in response to wars and political instabilities has made the Wind Turbines (WTs) the fastest growing energy source in the world. Wind power's dominance has been so significant that advocates are now gathering around an idea that would have seemed fantastic just a couple of years ago: that the wind would supply 12% of the world's electrical demand by 2020 [1]. The fear of high dependence on wind energy is no longer exists because the new systems are based on advanced power electronics and energy storage devices which assist in managing power flows from WTs. This arrangement enables the wind systems to contribute mightily to electricity grids without putting those grids at risk. The current technology improves the wind energy in two directions: firstly by making the wind power more portable to grid operators and by making it possible for engineers to exploit the wind resources in remote locations.

2. GENERAL REQUIREMENTS FOR GRID-CONNECTED WIND ENERGY SYSTEM

With the increase in number and size of WTs, wind farms have grown to include dozens of turbines and hundreds of megawatts- reaching the size of conventional power plants. To encourage the acceptance of installations like those, power system operators had to fight with the tendency of WTs to introduce voltage instability into electrical grids. That tendency follows from the intermittent nature of wind-generated electricity, which directly affects the daily prediction and forecasting the consumer demand.

To understand the issues of the system's instability and the related solutions, one needs a few basics on the nature of power flows on utility grids. On the other hand, declining voltage on a network is a function of the consumption of both active and reactive power. This means that if a large load consumes significant amount of reactive power, it will cause the voltage to dip immediately unless the reactive load is adequately compensated for. The compensation can be achieved by supplying reactive power directly from the generators themselves or by installing banks of capacitors close to inductive loads. It is easy to understand the relationship of these issues to wind energy if we remember that most of the current WT generators are of induction type, which consumes a considerable amount of reactive power.

Generally, utilities require that wind farms should be able to provide dynamic reactive compensation, exactly as a conventional generator would be able to do. This means that these wind systems should be able to assist in restoring stability during a disturbance or some other crisis on the grid. In the past, when a generator failure or a momentary short-circuit occur, wind farms would automatically disconnect themselves. But now, most grid operators prefer keeping these WTs running during the disturbance events. As a response to this operational progress, wind farms and turbine developers must modify their designs and operating procedures to cope with these requirements, particularly for voltage faults.

Concerning the power quality problems, it is worth mentioning that the new models of MW class WTs have less effect on power quality issues such as harmonics, voltage flicker and voltage dip. The advanced technology, adopted for modern wind energy generation, has enabled the manufacturer to limit the power quality problems and to be in harmony with international standards and grid codes. The regular inspection and testing schemes of the wind-generated power give a chance to correct any deviation in the power supply.

3. SPECIFIC REQUIREMENTS FOR WIND ENERGY CONNECTION TO GRID

3.1 Behavior during the fault

In systems with significant wind energy resources, the nature and role of such energy has been changed in the last two decades. The power systems did not depend on the energy generated by WTs, which were small in size and limited in contribution at that time. Under these circumstances, the behavior of WT at faults was not critical and the simple control systems, equipped with these turbines, were efficiently able to disconnect these machines from the network immediately when the fault occurs.

Currently, the WTs are large in size and the capacity of new wind farms can attain hundreds of megawatts. They are distributed on large areas as shown in Figure 1.

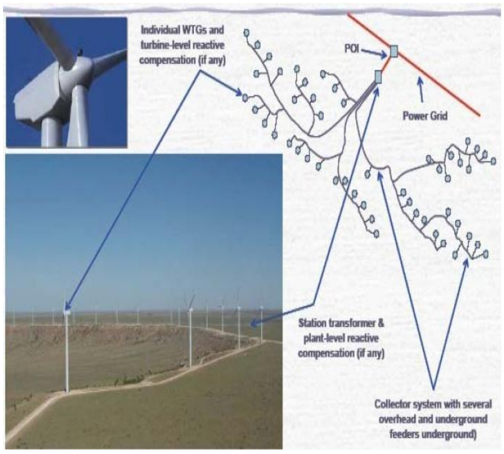

Figure 1: Typical wind farm layout

The disconnection of WTs due to a fault in nearby feeders is no longer preferred. It is desirable to keep the WTs running during the faraway faults. This arrangement reduces the chance to cause consequential loss of generation, which might lead to a voltage collapse. This requirement implies that the new generation of WTs should be able to keep running with voltage dips caused by faults in remote feeders. A series of load flow and short circuit calculations were made to study the impact of wind energy on the local distribution networks. Figures 2-4 show the dependence of voltage dip on the distance of fault location in a typical radial distribution system. Figure 2 illustrates the disturbance effect when a fault on the same feeder connected to induction generators occurs, whereas Fig.3 shows a very slight voltage variation in a remote busbar due to a short circuit applied at different locations on the induction generator feeder.

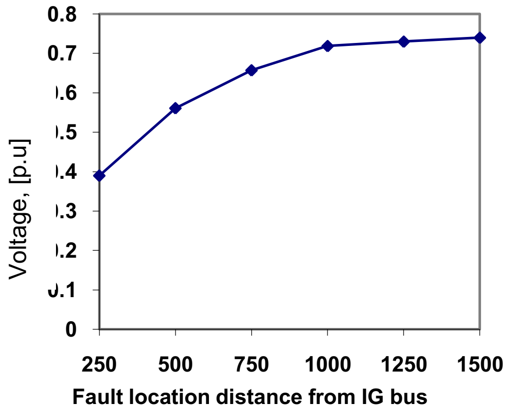

Figure 2: the impact of fault location on the voltage of the same feeder where the wind turbines are connected

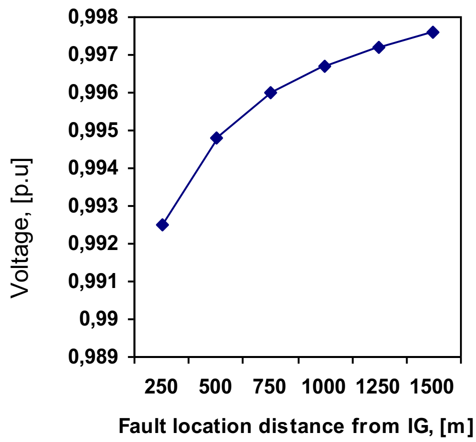

Figure 3: The impact of fault location on the voltage of a remote busbar (short circuit applied at different locations on the induction generator feeder).

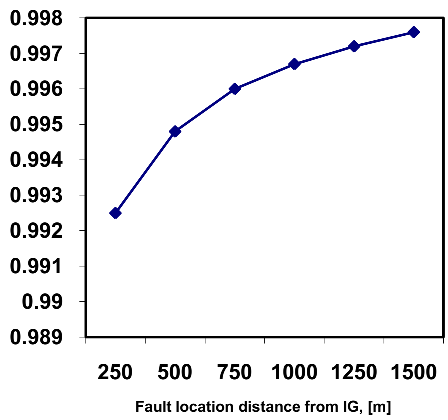

Figure 4: Recovery after the fault

Regarding the behavior during the short circuit, it is worth mentioning here that the induction generator characteristics are closely dependent on the deviation between the rotor speed and the synchronous speed.

This leads to the fact the stator current increases very rapidly when the motor slip frequency increases.

3.2 Post fault behavior

Two important factors can affect the speed of recovery of wind machine after the fault; the demagnetization and the negative slip due the increase in rotor speed. The impact of the first factor depends on the strength of the electric network to which the WTs are connected. On the other hand, if the short circuit duration is relatively long and the magnetization process of the induction machine is slow, the generator speed increase becomes significant. Therefore, to improve the induction generator response to the system disturbances including short circuits and to successfully recover from the fault, it is necessary to build a fast process of magnetization so that it can produce torque and reduce the generator over speed.

3.3 Frequency and voltage control

Voltage and frequency control, during load variations, mainly depends on the behavior and the parameter adjustment of the voltage and speed regulators of the generation units. With the increase in the number of WTs, it becomes difficult to control the node voltages adequately by only using the synchronous generators in large-scale conventional power stations. Therefore, it is essential that all WTs also contribute to voltage control. The fact that the voltage is not the same throughout the system makes it a local quantity, as opposed to frequency, which is a global quantity, because it is identical in the whole system. Voltage problems must always be solved at or in the vicinity of the node at which the problem occurs, as opposed to frequency problems that can be solved everywhere, provided that no branch over loadings occur. The WTs distributed over a wide area and in different locations can be of great importance in this field [2]. On the other hand, the increasing of wind energy penetration can cause an overvoltage to some bus bars, if these turbines operate simultaneously. However, the probability of a simultaneous operation of WTs is very low even during the gust on a certain wind farm. When it is not possible to keep all node voltages in the system within the allowed deviation from their nominal values from the synchronous generators, other technologies must be used, such as capacitor banks, SVC's or STATCOMs.

Since the current power systems are still depending on massive generation units to produce the required electricity, the outage of these plants is usually associated with serious problems ranging from the usage of the expensive emergency reserve units to applying the load shedding scheme. The categories of the load-shedding scheme are based on the importance of the load to be shed. Usually, the rural residential loads are classified in many countries as less important loads, which are switched off first in order to improve the frequency level. However, the presence of large-scale WTs can assist the frequency control in two ways. Firstly, wind energy can reduce the shortage in conventional generation and consequently lower the rate at which the frequency starts to decay. Secondly, WTs in windy sites can quickly restore the supply to the remote locations after load shedding. If the wind speed is increased by 2 folds the power generated from the wind turbine will increase by 8 folds according to the following equation

$$P=\frac{1}{2}\rho C_p A V^3 \tag{1}$$

Where, P is the output power in kW, ρ is the air density kg/m^3, C_p is the power coefficient, A is the swept area in m^2 and V is the wind speed in m/s.

4. WIND TURBINES AND SYSTEM STABILITY

4.1 Dynamic behavior of wind turbines

Different models have been proposed to study the dynamic behavior of the WTs [3]. With the classical approach, the wind farm terminal voltages have recovered quickly, whereas with the physical model various oscillations were noticed in the terminal voltages. It is worth noting that the overspeed of WTs as a consequence of the fault was not high enough for the turbine to be disconnected and stopped by the protection system. The rotor speed was slightly decreased when subjected to the fault and thereafter increases in speed. If the overspeed is significantly low, the protection system of WTs does not react immediately. The presence of large-scale wind farms with high capacities in one location can have a bad effect on the system stability during the fault. Naturally, the windy sites are distributed in different locations in each country, which can be employed to enhance the system stability and prevent the voltage collapse.

4.2 Wind energy influence on voltage stability

Various studies have been performed to analyze the impact of wind energy on voltage stability [4,5]. The active and reactive powers are the main parameters used in the assessment of voltage stability limits. In all cases it has been concluded that voltage stability depends mainly on the network characteristics. Therefore, the distribution lines, known by their losses can be operated in more stable way with WTs. The later are characterized by their active power injected to the system and consequently an increase of system voltage at the terminals of these turbines. This voltage increase can compensate the reduction due to reactive power demanded. In the current work a typical radial distribution system was examined to assess the network transient behavior when a three-phase fault is applied to an 11kV line. Figure 3 shows the voltage variation and the fast recovery after the transient.

5. WIND ENERGY AND DEREGULATION

The tendency toward deregulation and privatization policies is gaining ground nowadays. This process goes in harmony with the distribution generation schemes, which consists of various sources generation including wind energy and other renewables. The companies operating these new plants try to limit the expenses on the engineering part and to run these plants as simple as possible. Therefore, the conventional power plants are not preferred choice for these new systems and many of them strongly support the installation of large-scale WTs. On the other hand, wind energy plants are easy to own, operate and maintain by small companies and local communities. In addition to the environmental considerations associated with wind energy, many small utilities and local communities have created new tariff schemes to encourage the customers to purchase the energy from WTs.

6. WIND ENERGY AND TECHNOLOGICAL DEVELOPMENTS

Advanced current design standards and certification rules have been positively reflected on wind energy development. Therefore, remarkable advances in wind power design have been achieved. One aspect of WTs that will increase rapidly is the use of information technology and sophisticated communication systems for the real time monitoring and control. No other commercial plant is operated remotely in this way [6]. This development will improve the protection and control systems of these turbines and consequently enhance the networks' stability. Moreover, the parallel progress in wind energy prediction will encourage the utilities to include more WTs in their local networks and enhance the weak grids significantly.

7. MAXIMIZING THE ROLE OF WIND FARMS

Wind resources must be adequate to be commercially viable. Moreover, the commercial outcome is very sensitive to wind speed, thus siting is important. The presence of strong transmission system is important to maximize the wind energy penetration. On the other hand, WT starting and stopping transients and power fluctuations during operation must not lead to unacceptable voltage or frequency fluctuations, excessive load-following costs or excessive wear and tear on turbine components. Wind farm designers and network service providers must avoid unsatisfactory network voltage profiles and protection problems due to either excessive or insufficient fault level. The prediction of wind farm production must be sufficiently accurate to avoid unnecessary network investment or generation reserve requirements and to satisfy wind farm investment risk management criteria. The new system operators try to benefit from installed wind turbines as much as possible by concentrating on improving the efficiency, reducing the losses and developing new models of wind speed prediction. The concentration is mainly on the short term prediction of wind energy to facilitate commercial tools for such energy. This trend is becoming more and more important with the continuous reduction and shortage of conventional resources.

Finally, the current developments in communications, information technology will enhance the new role of wind energy in electrical system stability. The data exchange and remote operation of wind farms become an easy task with the development of wireless communication system and fiber optics techniques.

8. CONCLUSION

The technical impact and stability issues concerning the connection of large-scale wind turbines to a typical network were discussed. The load flow and fault studies have illustrated that the voltage dip initiated by induction generators decreases significantly as the fault location distance increases. Regarding the dynamic response of the machine during transient conditions, it was shown that a complete recovery was achieved quickly. The distribution of WTs in different locations enhances the voltage and frequency stability of the system. The load shedding schemes in networks with high wind energy penetration must benefit from the existing WTs and modify these schemes accordingly. On the other hand, the trends of systems restructuring and deregulations give a potential to large scale wind energy schemes.

REFERENCES

[1] P. Fairley, "steady as she blows", electric power, IEEE Spectrum, 2003.

[2] T. Tomson, "Wind power grid matching problems. The Estonian case study", EWEC 2001, pp.1007-1009.

[3] V.Akhmatov et al., Electrical Power and Energy Systems, 22 (2000), 421-434.

[4] Popvic, Hiskins and Hill, "Stability of induction motors networks", Electrical power and energy, Vol. 20 No.7, 1998, pp. 475-487.

[5] Andres Feijo and Jose Cidras, "Modeling of Wind Farms in the Load Flow Analysis", IEE Transactions on power systems, Vol. 15 No.1, 2000.

[6] James and James, "Renewable energy world. Technology update, wind power". Science publishers, UK, Vol 2 No.1, January 1999, p 45.