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GRID CONNECTED WIND TURBINES – A SIMULATION STUDY

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ABSTRACT

This paper investigates the grid-connection problems for wind turbines and offers appropriate solutions. This paper provides a simulation for the power system during the faults by using PSCAD and MATLAB. A comparison between using PSCAD and MATLAB in electrical circuits is investigated in this paper. The power system simulation used in this paper consists of an AC generator of a power rating 1 MVA and a wind turbine generator 2MVA. The grid frequency before and after the fault is also investigated in this paper. It investigates many case studies and the corresponding analysis for the waveforms and the data involved. The results of the simulation study show that the location of the fault is a very important factor in the power system analysis. Faults in the transmission lines have a dangerous effect in the wind turbines, which are connected to the electrical grid. The results of the simulation also show that the wind turbine, in this case study, supported the electrical grid to maintain the frequency in the same value.

Keywords: renewable energy, wind turbine, simulation.

INTRODUCTION

Wind energy is one of the fastest growing sources of energy production and one of the fastest growing energy markets in the world today. Wind turbines today produce large amounts of electricity. The wind turbines vary in size from small 1 kW structures to large machines rated at 7.5 MW. A common sized machine in the U.S. is a state-of-the-art 2.5 MW turbine that stands as tall as a 20-25 story building. Wind power has to face some technical and economic barriers if they produce a substantial part of the electricity (Rosas, 2003).

Grid connection of all these sources plays a very important role in order to share the high demand of the electricity. More conventional power plants are replaced and wind power penetration in power systems increases; however, the main concerns of the power system operators are the stability and reliability of their power systems (Jauch, 2006). A strong grid will increase the overall power system reliability and decrease the possibility of the black out. A weak grid increases the probability of the blackout and decreases both the reliability and the stability of the grid.

The engineers have to consider many variables in the system before connecting the wind turbine to the electrical grid. The output variable should match with the grid in order to have a reliable and stable connection. For instance, there is not any possibility to connect 50 Hz wind turbine with 60 Hz grid with AC transmission lines. The main variable for the output is the wind speed. If the wind speed changes, the frequency will change.

The grid mainly uses thyristor inverters such as the 6 or 12 pulses. This type of inverter produces integer harmonics like the 5th, 7th, 11th, 13th order etc. for different frequency. In general harmonic filters are used reduce. (Wind Turbine Grid Connection and Interaction, 2001).

Frequency variation is one of the main problems in the electrical grid connection process. Wind speed is the most important factor in wind energy production, but it is not a fixed factor. To keep the condition of the grid stable, engineers should keep the frequency constant. However, the frequency variations which are produced when the differences in power balance between generation and demand exist and the connection and disconnection of wind turbines cause differences in the electrical generation, which affect the whole power system (Ibrahim *et al.* 2011).

A power distribution system operation was investigated in four steps:

1. Source of electricity.
2. Transformers.
3. Transmission lines.
4. Loads (Abdel-Salam, 2011).

Due to different component types with different rates, any technical problem in any element could affect the others.

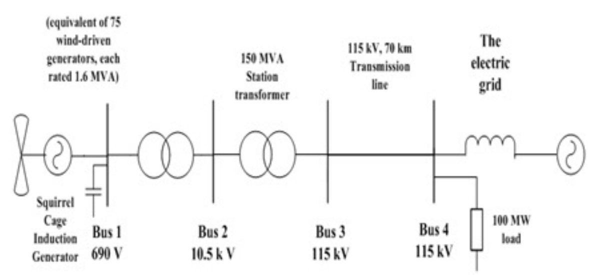

Figure-1. Power distribution system.

The event of an emergency stop wind turbine output could be changed from nominal power to zero in (Szafron, 2011).

The imbalance between generation and consumption has an impact on the frequency level. Avoiding the problem of the grid becoming unstable, begs the necessity of ongoing frequency control (Elia, 2011).

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There are many techniques to control the output from the wind turbines. One of them is pitch angle technology which control the speed of rotation by changing the angle which the blades face the wind (Ibrahim *et al.* 2011). The Proportional-Integral-derivative (PID) controller which determines the pitch angle of the blades (Szafron, 2011).

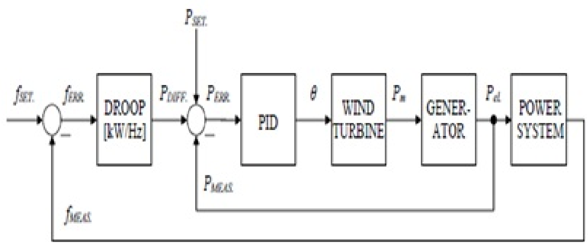

Figure-2. Control circuit of the PID power system.

PID controller is a control feedback controller widely used in industrial systems. PID consists of three main parameters:

- P depends on present error.
- I depends on accumulation of past errors.
- D is the prediction of future errors that is calculated from current rate of change.

The major impact of voltage and current harmonics, both frequency dependent, is the increase in machine heating caused by increased iron losses and copper losses (American Bureau of Shipping, 2006).

The transmission lines are very important in the electrical grid; any effect on the transmission line will affect the whole electrical system. There are many types of faults in the transmission lines and can be caused by different events. Line faults are the most common faults. For instance, lightning strikes, trees may fall across lines, fog, ice and snow loadings may cause insulator strings to fail mechanically (Bouthiba, 2004)

Limiting the high current in the rotor and in the generator by using a bypass can help to keep the wind turbines connected to the grid during the fault (Morren and Haan, 2005).

This study investigates the grid-connection problems for the wind turbines. A modeling and simulation study for the entire electrical grid will be completed for normal operation and a number of fault studies.

It discusses the problems that are associated with the connection of the wind turbine with the electrical grid such as voltage flickers, harmonics and transients.

This study provides a simulation for the power system during the faults. In the simulation, faults are applied to many different nodes in the grid. This paper investigates the transient and steady state operation with the signal waveforms for the voltage and the current before and after the fault. It also investigates the values of the grid frequency after and before the faults.

This paper is a case of study of an actual power distribution system. It studies the performance of wind turbines during and after a fault was applied in one phase. It provides solutions for a fault situation. This also implements a new approach where the power is not moving in one direction from the generating side to the customers, but the wind turbines are supporting the grid from the customer's side. The PID controller was tuned and simulated by MATLAB Simulink.

Synchronization

One of the major connection challenges is connecting AC generators to the electrical grid properly. Many important connection problems could occur during the synchronization. The synchronization issues of the wind turbine generators can be listed as

- The magnitude of the system voltage.
- Frequency.
- Phase sequence.
- Phase shift.

In the three-phase system, all phases have the same magnitude of the voltage; however, there is a 120 degree phase shift between each phase as seen in Figure 3simulatedby PSCAD.

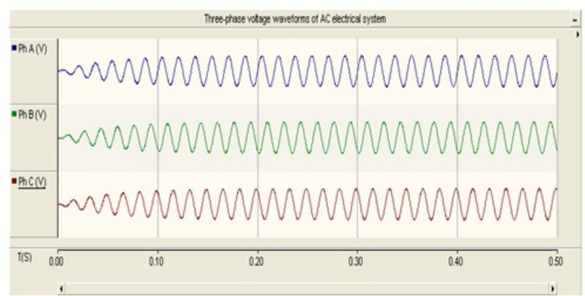

Figure-3. Three-phase voltage waveforms of AC electrical system.

Voltage Flickers

Voltage flickers are caused by the switching loads and/or electricity sources. Large voltage flicker occurrence may happen due to:

- Sudden variations of the wind speed.
- Connecting high loads equipment.

The acceptable tolerance in the voltage is about 3% of its value. There should not be any effect of this tolerance on any electrical equipment.

Harmonics

Because of power electronics switching devices and other non-linear loads, harmonics may constitute a major problem in the electrical systems.

In the AC system the voltage and current waveforms are expected to be sinusoidal wave shape. The tolerance could reach 3% of the value of the voltage. Distortion in the current or the voltage waveform called a harmonic. If the fundamental frequency is 60 Hz, the 2^{nd} harmonics will be 120 Hz, and the third harmonics will be 180 Hz and so forth.

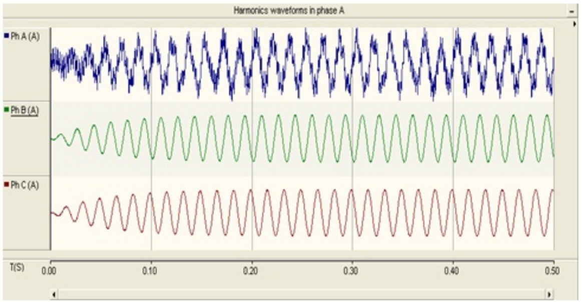

Figure-4. Harmonics waveforms in phase A.

PSCAD simulation study in Figure-4 shows that harmonics affect the sinusoidal wave shape of Phase A.

Transient Current

Rapid increase in current in a small period of time is called transient current. The transient current usually occurs during the start-up and shut down of the wind turbine. Because of its high peak, transient current may damage the components. High transient current could increase synchronization problems, because it makes the grid unstable. The transient current can be reduced by:

- Using soft starter for the generator.
- Using shunt capacitor bank.

CONFIGURATION OF PROCEDURE

The power system simulation used in this paper consists of several components. The following components were used for the PSCAD simulation study:

- AC generator of a power rating 1 MVA, and a wind turbine generator 2MVA.
- A circuit breaker is installed to check the grid connection and operation.
- A source of harmonics injection is installed to the generator's output.
- Wind source component provides a wide range of wind speed values in the simulation study.
- Synchronous generators are commonly used in the generation.
- Ac exciter supplies the DC magnetizing current to the field windings of a synchronous generator that produces AC voltage and current in the generator armature.
- A line to ground fault, which is common power system fault, is applied in many different nodes in the system.

Figure-5 shows overall power system schematic diagram for the wind power system by using PSCAD.

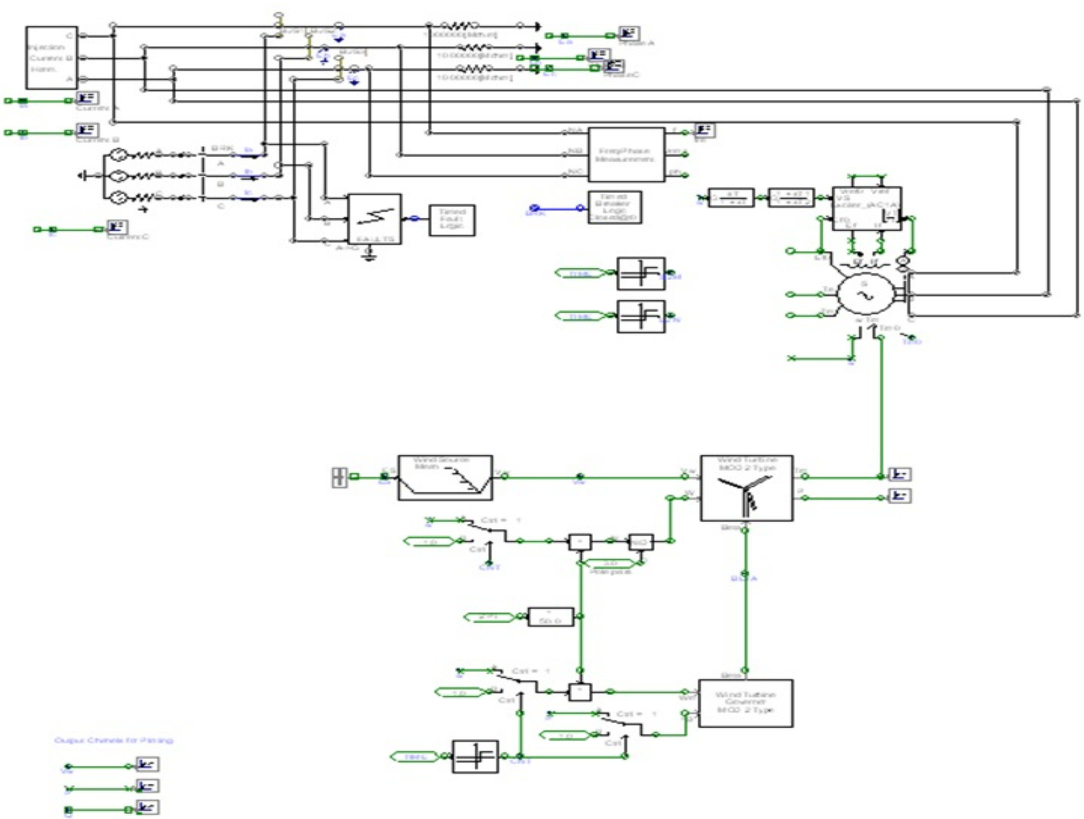

Figure-5. Power system schematic diagram for the wind power system.

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The first case of this study is the normal operation for the electrical grid. Wind turbine is connected with the generator in normal operation. Figure-6 shows three-phase voltage waveforms of AC system. Figure-7 presents the system's frequency 60 Hz under normal working condition.

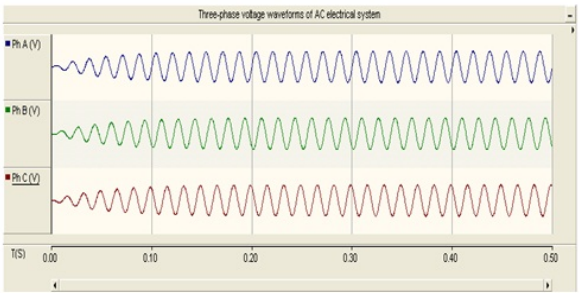

Figure-6. Voltage waveforms in the electrical grid in normal operation.

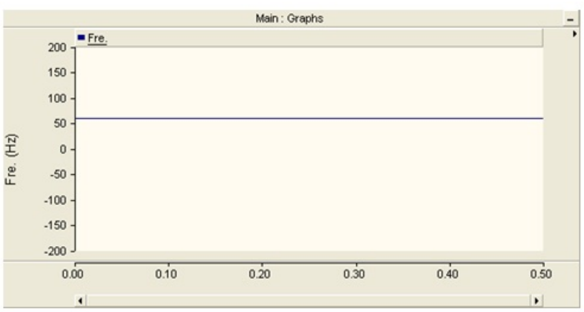

Figure-7. Frequency in the electrical grid in normal operation.

The second case of study was made by applying fault in Phase A in the generator in order to see the system reaction. Voltage waveform and frequency was monitored for the generator during the fault.

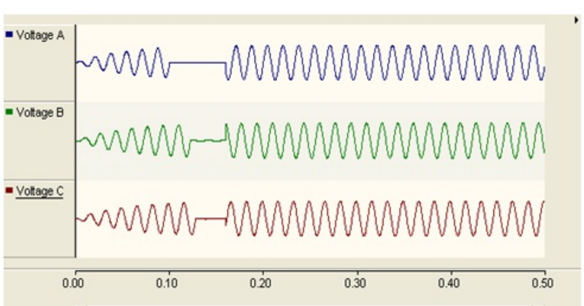

Figure-8. Voltage waveform of the generator during the fault on the generator.

Figure-8shows three-phase voltage waveforms before and after fault is applied for the power system. Figure-9 clearly shows the grid voltage was stable until the fault happened. When the fault is applied the circuit breakers detect the fault. Then the circuit breakers open the circuit and disconnect the generator from the electrical grid in a very short period of time. Timing is really important to prevent any damage which could happen from the fault transient.

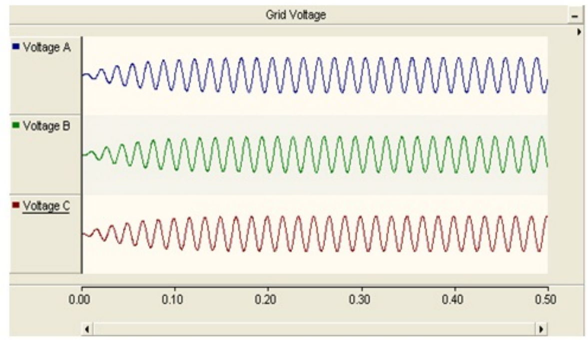

Figure-9. Voltage waveform in the grid during the fault.

Figure-9 shows the voltage waveforms in the electrical grid. As seen in Figure-9 three-phase voltage waveforms still pure sinusoidal and stable. The reason for this is the wind turbine can share the loads alone for a certain period of time until the fault is cleared. Figure-10 represents the grid frequency which changes during the fault operation and after cleaning the fault, frequency turns back to normal.

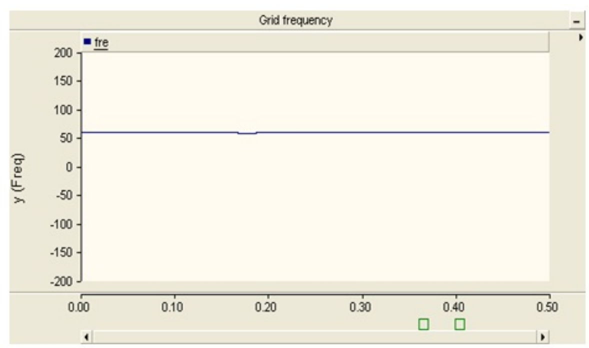

Figure-10. Changing in frequency before and after the fault in the power system.

MATLAB Simulink™

MATLAB Simulink™ is used in this paper to monitor the exact values for the voltage, the current, and the power during the faults. Figure 11 shows power system schematic diagram for the wind power system. The following components are used in MATLAB Simulink™ for the studied power system.

AC generator used as supply a three-phase voltage source

Step-up and step-down transformers are used in the simulation system to reduce the voltage.

Two AC transmission lines are used in the simulation study. The first one is from the 120kV/25kV step down transformer to the power plant considered. The second one

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is from the power plant to the 25kV/575kV step up transformer.

Generator with ratings of 1.68 MW with a power factor 0.93 lagging operation is used.

Five MW power system loads are used.

6 wind turbines with a nominal power rating of 1.5 MW are selected for wind farms of in To see system reaction there is a three-phase fault is applied to the power system.

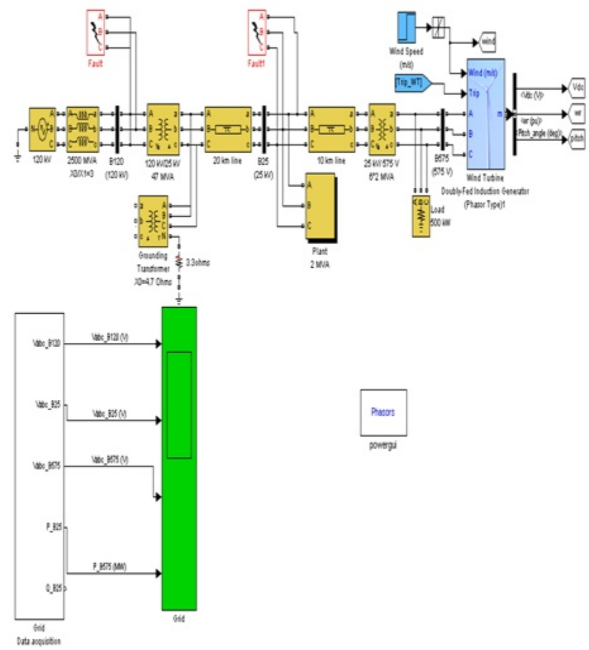

Figure-11. MATLAB schematics of the wind power system.

Figure-12 shows the impact of a fault is applied in phase A in Bus 25. Bus bar 120 showed a little effect of the fault. On the other hand, Bus 25 was not able to work properly. As seen in the figure the impact of the fault is not the same as Bus 120. Phase A of Bus 25 is not operating any more due to the fault.

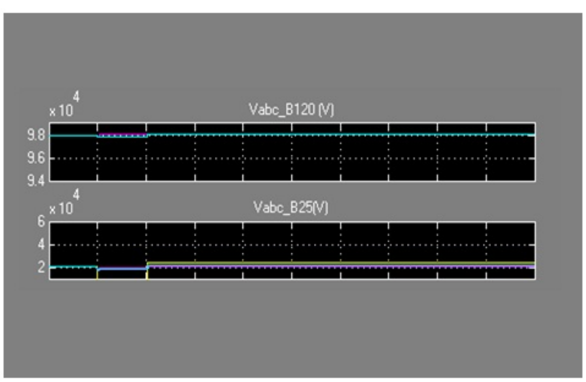

Figure-12. Applied fault in phase A in Bus 25.

The fault also affects the voltage in Bus 575 as seen in the Figure-13. However, the wind farm can handle the fault and still assist the grid for the stable operation. Figure 13 also shows a disturbance in the power in Bus 575. Again the wind farm handles disturbance smoothly and supports Bus 575, so the electrical system continues to work in normal operation during the fault.

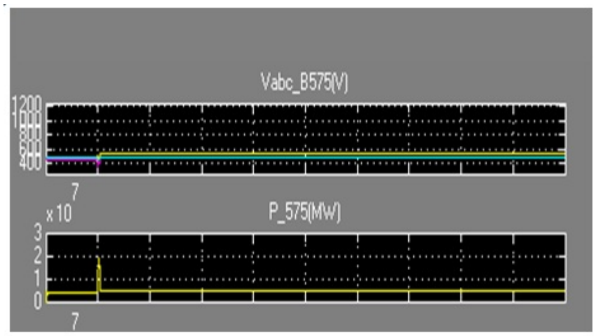

Figure-13. Voltage and power waveform of Bus 575.

CONCLUSIONS

The transmission line faults have a dangerous effect on the wind in real time power system applications. During the fault, the electrical current in the transmission line rapidly reaches very high values which can easily cause damage. To reduce the probabilities of damage, it is crucially important to use different sources of electricity. In the simulation studies, it is clearly seen that in an event of faulty operation, faulty part of the system would be disconnected automatically and the loads will be supplied by another source of energy. PSCAD, is a very helpful program in monitoring the current and the voltage waveforms, is a specialist program in power system analysis. PSCAD uses a lot of wires and model when a bigger power system is designed. On the other hand, MATLAB would provide better judgment in such cases in order to determine the exact value of the voltage.

There are many ways to support the grid during the fault. The location of the fault plays an important role in finding a solution. The easiest way to accomplish this is to isolate the load where there is a fault. The ring network will allow the load to be supplied from a different electrical source. In this case of study, the wind turbine will be able to share the whole load for a certain period of time without encountering any problems. If there is another pack up generator, it will run and start sharing loads with the wind turbines. Good communication between the generating side and load side will affect the performance. The pack up generator will not be able to share the loads immediately. It should run for ten to fifteen minutes and then be connected to the grid. Having a different source of electricity, such as a solar cell will help the grid to be more stable. Connecting a solar cell on the customer side will be studied in a different paper.

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