14th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2010, Mediterranean Cruise, 11-18 September 2010

DYNAMIC ANALYSIS OF WIND FARM USING INDUCTION GENERATOR WIND TURBINES

Nedzmija Demirovic
Faculty of Electrical Engineering Tuzla,
Franjevacka 2, Tuzla
Bosnia and Herzegovina

Sejid Tesnjak
Faculty of Electrical Engineering and Computing
Unska 3, 10000 Zagreb
Croatia

ABSTRACT
The vast majority of wind turbines that are currently being installed use one of the three main types of electromechanical conversion system. The first type is known as the Danish concept. The second type uses a doubly fed induction generator instead of a squirrel cage induction generator. The third type is called the 'direct-drive wind turbine' because it does not need a gearbox.
In this paper (asynchronous) squirrel cage induction generator is used to convert the mechanical energy into electricity. Owing to the different operating speeds of the wind turbine rotor and the generator, a gearbox is necessary to match these speeds. Pitch-controlled variable-speed wind turbine types have been built too. The rotor speed is controlled by changing the generator power in such a way that it equals the value derived from the goal function. In this type of conversion system, the control of aerodynamic power is usually performed by pitch control.
This paper deals with the dynamic response of wind induction generator connected to the transmission network. Dynamic response of wind geneartor and the network in the case of the two-phase and three-phase faults will be discused in this paper. Effects of failure will be considered in the case of connected and disconnected device for additional reactive power compensation, STATCOM. Namely reactive power absorbed by the induction generator is partly compensated by capacitor banks connected at each wind turbine low voltage bus. The rest of reactive power required to maintain voltage close to 1 pu is provided by STATCOM.
This paper will show how the dynamic response of the system in case of different types of failure to generator an to the network and what is the role of static reactive power compensator, then how the wind turbine protection system reacts in these cases.
Keywords: Induction generators, wind turbine, pitch control, dynamic analysis, and voltage control.

1. INTRODUCTION

The main function of an electrical power system is to transport electrical power from the generators to the loads. In order to function properly, it is essential that the voltage is kept close to the nominal value, in the entire power system. Distribution grids, incorporate dedicated equipment for voltage control and the generators connected to the distribution grid are hardly, if at all, involved in controlling the node voltages [1]. The most frequently used voltage control devices in distribution grids are tap changers – transformers that can change their turns ratio – but switched capacitors or reactors are also applied. Voltage control is necessary because of the capacitance, resistance and inductance of transformers, lines and cables, which will hereafter be referred to as branches [1]. When discussing the impact of wind power on voltage control, we have to distinguish between the impact of wind power on voltage control in transmission networks and on voltage control in distribution grids. It is becoming increasingly important, for wind turbines connected to the transmission system and for those connected to the distribution system, to be able to contribute to voltage control. The vast majority of wind turbines that are currently being installed use one of the three main types of electromechanical conversion system. The first type is known as the Danish concept [1]. The second type uses a doubly fed induction generator instead of a squirrel cage induction generator. The third type is called the ‘direct-drive wind turbine’ because it does not need a gearbox. In this paper (asynchronous) squirrel cage induction generator is used to convert the mechanical energy into electricity. Owing to the different operating speeds of the wind turbine rotor and the generator, a gearbox is necessary to match these speeds. Pitch-controlled variable-speed wind turbine types have been built too. The rotor speed is controlled by changing the generator power in such a way that it equals the value derived from the goal function. In this type of conversion system, the control of aerodynamic power is usually performed by pitch control. This paper deals with the dynamic response of wind induction generator connected to the transmission network. Dynamic response of wind geneartor and the network in the case of the two-phase and three- phase faults will be discused in this paper. Effects of failure will be considered in the case of connected and disconnected device for additional reactive power compensation, STATCOM. Namely reactive power absorbed by the induction generator is partly compensated by capacitor banks connected at each wind turbine low voltage bus. The rest of reactive power required to maintain voltage close to 1 p.u. is provided by STATCOM.

2. MODEL DESCRIPTION

A wind farm consisting of six 1.5-MW wind turbines is connected to a 25 kV distribution system exports power to a 120-kV grid through a 25-km 25-kV feeder. Wind turbines use squirrel – cage induction generators (IG). The stator winding is connected directly to the grid and the rotor is driven by a variable-pitch controled wind turbine Figure 1 [2]. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9 m/s). Each wind turbine has a protection system monitoring voltage, current and machine speed. Reactive power absorbed by the induction generator is partly compensated by capacitor banks connected at each wind turbine low voltage bus. The rest of reactive power required to maintain the voltage at bus B25 close to 1 p.u. is provided by a 3-MVAr STATCOM with a 3% droop setting.

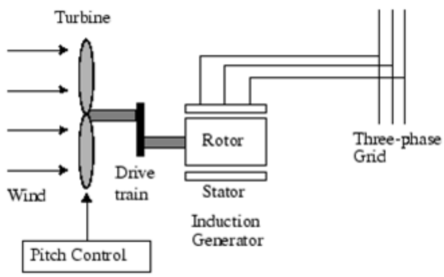

Figure1. Wind turbine conection

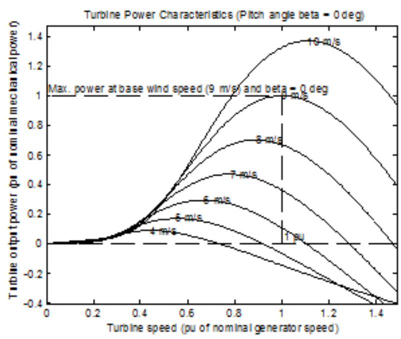

Figure 2. The wind turbine characteristics

2.1. Turbine model

The model is based on the steady-state power characteristics of the turbine, Figure 2. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation:

$$P_m = c_p(\lambda, \beta)\frac{\rho A}{2}v_{wind}^3 \quad (1)$$

Where are:

P_m- Mechanical output power of the turbine (W)

C_p-Performance coefficient of the turbine

ρ- Air density (kg/m3)

A- Turbine swept area (m2)

v_{wind}- Wind speed (m/s)
λ-Tip speed ratio of the rotor blade tip speed to wind speed
β- Blade pitch angle (deg)

The three inputs are the generator speed (ω_r) in p.u. of the nominal speed of the generator, the pitch angle in degrees and the wind speed in m/s. The tip speed ratio λ in pu of λ_{nom} is obtained by the division of the rational speed in pu of the base rotational speed (defined below) and the wind speed in p.u. of the base wind speed. The output is the torque applied to the generator shaft. The stator winding is connected directly to the network and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds.

2.2. Pitch angle control system

A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value [1], [2], [3].

3. DYNAMIC ANALYSIS

This section analyses the dynamic behaviour of the wind turbine concept. Dynamic characteristics of the system involves the way the system response to certain disturbances such as disconnection of the generator, the appearance of lightning, the occurrence of short circuits and etc [4]. One of the most important dynamic characteristics of the classification system is definitely a time-response system.

3.1. Turbine response to a change in wind speed

In order to obtain the results simple wind turbine induction generator matlab-based model, connected to the grid is used. For each pair of turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3 MW in approximately 8s. Over that time frame the turbine speed will have increased from 1.0028 p.u to 1.0047 p.u. Initially, the pitch angle of the turbine blades is zero degree. When the output power exceed 3 MW, the pitch angle is increased from 0 deg to 8 deg in order to bring output power back to its nominal value. Observe that the absorbed reactive power increases as the generated active power increases. At nominal power, each pair of wind turbine absorbs 1.47 MVAr. For a 11m/s wind speed, the total exported power measured at the B25 bus is 9 MW and the STACOM maintains voltage at 0.984 p.u. by generating 1.62 MVAr, Figure 3 and Figure 4.

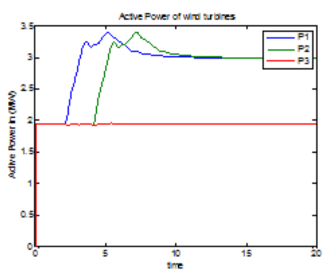

Figure 3. Active power of wind turbines in the case of change of wind speed

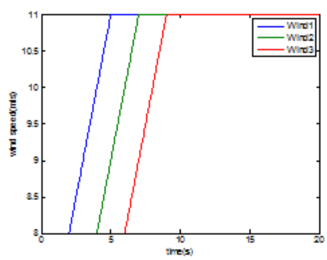

Figure 4. Speed of wind for turbines 1,2,3 respectively

3.2. Fault simulation (statcom is not included)

At t=15 s, a phase to phase fault is applied at wind turbine 2 terminals, causing the turbine to trip at t=15.11 s. Only wind turbine 3 continues to work, and wind farm 1 is tripped because of over current protection and wind farm 2 is tripped because of under voltage protection. It is also useful to observe a voltage change at output terminals of wind turbines, Figure 5 and Figure 6.

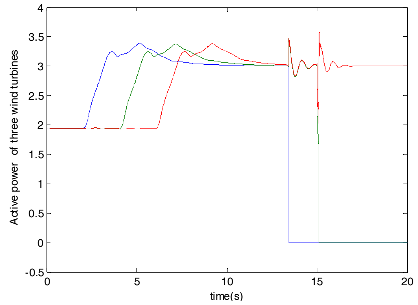

Figure 5. Active power of three wind turbines

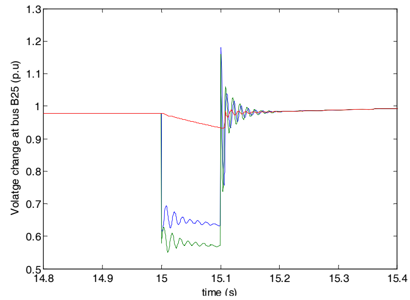

Figure 6. Voltage change at bus B25 during the fault (STACOM is not included)

3.2. Fault simulation (STATCOM is included)

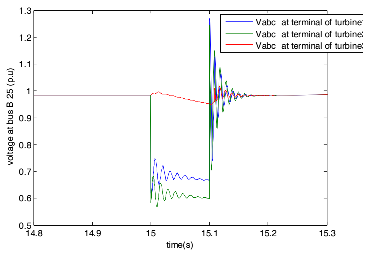

Figure 7. Voltage change at terminals of wind turbines during the phase to phase fault (STACOM is included)

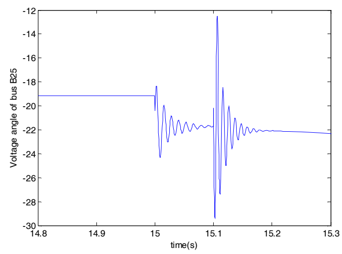

Figure 8. Change of voltage angle at output terminals of wind turbine VB25 (STACOM is included)

Observing the Figure 7 and 8 it can be seen that angle oscillations starts at the moment of fault (that is 15 s), then at the moment of tripping of wind turbine 2 starts to oscillate again and reaches steady state value approximately at t=15.2 sec. This means that from the time of the failure, and tripping wind farm 2 has passed around 0.2 sec, and change of volatge angle shows that system will remain stable.

4. CONCLUSION

In this paper phasor simulation of wind farm using induction generator wind turbines is presented. In order to introduce this model some characteristic responses are presented. It was shown that phase to phase fault in the network without connected STATCOM causes tripping of two turbines. Lowered voltage of the second turbine will cause overloading the first one. Due to, under voltage and over current protection has worked off. It is shown that STACOM plays a significant role in additional compensation of reactive power absorbed by the induction generators.

5. REFERENCES

[1] Thomas Ackerman, Wind Power in power Systems, Wiley, 2005, p. 463.

[2] P. S. Mayurappriyan, Jovitha Jerome, M. Ramkumar and K. Rajambal: Dynamic Modeling and Analysis of Wind Turbine Driven Doubly Fed Induction Generator, International Journal of Recent Trends in Engineering, Vol 2, No. 5, November 2009.

[3] Matlab-SimPowerSystems, Users Guide.

[4] David T. Johnsen, Willi Christiansen: Optimisation of the Fault Ride Through strategy of a Wind Farm, Master Thesis, September, 2006.