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Transient Stability Analysis of Power System with Wind Generators

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Abstract

Power systems are experiencing a revolution caused by the increase of power generators fed by renewable energy sources (RESs). The complexity of power systems has been increased with the increased penetration of RESs that have more uncertain behavior and lower inertial response. This paper presents the transient stability analysis of power system with wind driven induction generator during short circuit faults. Pitch control system is proposed to prevent the windmill from excess speed increase and its effect on transient stability is analyzed. To analyze the transient stability, a test system is considered in which a synchronous generator and a wind generator delivering power to the infinite bus through transmission line. From the simulation results, it can be observed that the time constant and gain have considerable effect on the performance of pitch control system.

Keywords: Transient stability, wind generators, pitch control, synchronous generator, induction generator, power angle.

INTRODUCTION

Renewable energy systems (RESs) becomes more prominent in the world electricity market due to the increased demand for electricity generation, the deregulation of the electric power industry and the requirements to reduce CO_2 emissions, etc. Globally, about 20% penetration of renewable energy in electricity generation is considered necessary by 2020. The operation of power systems has never faced challenges of current proportions. The challenges are primarily driven by the need to substitute centralized fossil based generations by sustainable but intermittent RESs such as wind and solar. Such intermittency of RESs challenges control and optimization problems of power systems. The components of wind energy conversion system includes the turbine rotor, gearbox, generator, and transformer. The turbine rotor converts fluctuating wind energy into mechanical energy, which is converted into electrical power through generator, and then transferred into the grid through a transformer and transmission lines [1].

The Conversion of mechanical power of the wind turbine into the electrical power can be accomplished by the direct current (DC) machine, Synchronous machine and Induction machine. In the DC machine, the generated electro motive force (emf) is an alternating in nature. The DC machine must convert the ac into the dc, and does so by using mechanical commutator. The commutator performs this function by sliding carbon brushes on a series of copper segments. The sliding contacts inherently result in low reliability and high maintenance cost. The synchronous machine is not well suited for variable-speed operation in the wind plants. Moreover, the synchronous machine requires dc current to excite the rotor field, which needs sliding carbon brushes on slip rings on rotor shaft. The main advantage of the induction machine is the rugged brushless construction and no need of separate dc field power. The disadvantages of both dc machine and the synchronous machine are eliminated in the induction machine, resulting in low capital cost, low maintenance and better transient performance. Therefore, the induction generator is extensively used in small and large wind farms and small hydroelectric power plants as electromechanical conversion device [2].

References [3] presents the view of torque balance, the operating-point and variation of rotor speed are presented which are used to analyze the transient stability of wind farm consisted of Double-Fed Induction Generator. In [4], the simplified model of a modified single machine infinite bus system with a DFIG-based wind farm integrated is well studied considering the transient characteristics of the DFIG-based wind farm in the different period of a fault. Reference [5] develops models and control strategies for large wind farms comprising DFIGs, and study the impact of the wind farms on power systems. This paper investigates the impacts of wind farms on power system operation as ever-increasing penetration levels of wind power have the potential to bring about a series of dynamic stability problems for power systems [6]. The impacts of DFIG operation that limits on the controller are presented in Reference [7]. Reference [8] presents a dynamic modeling and control of DFIG based on the wind turbine systems. A simple controller based resistive solid-state fault current limiter is proposed in [9] to augment the transient stability of the DFIG based wind energy generating system. In [10], the passive Low voltage Ride Through (LVRT) capability method as well as the active LVRT capability method are proposed for the transient analysis of DFIG.

In wind power stations, induction generators are commonly used due to variable speed nature. Since, induction generators have a stability problem like synchronous machines, it is important to analyze the transient stability of a power system including wind generators.

POWER SYSTEM STABILITY

The successful operation of a power system depends on power engineer's ability to provide uninterrupted and reliable service to the customers/loads. Ideally, the loads must be fed at constant voltage and frequency at all times. In practice, it means that frequency and frequency must be held within the tolerance values, so that the consumer's equipment may operate satisfactorily. For example, a drop in voltage of (10-15)% or a reduction of the system frequency of only a few hertz may lead to stalling of the motor loads on the system. Therefore, it can be accurately stated that the system operator must maintain a very high standard of continuous electrical service. The first requirement of reliable service is to keep the generators running in parallel and with adequate capacity to meet the load. Suppose, if a generator is separated from the system, it must be re-synchronized and then loaded, assuming it has not been damaged and its prime mover has not been shut down due to the disturbance that caused the loss of synchronism.

Stability in a Synchronous Machine:

Synchronous machines does not fall out of step easily under the normal operating conditions. If a machine tends to speed up or slow down, synchronizing forces tend to keep it in step. Conditions do arise, however, in which the operation is such that the synchronizing forces for one or more machines may not be adequate, and small impacts in the system may cause these machines to lose synchronism. A major shock to the system may also lead to a loss of synchronism for one or more machines. However, stability problem is concerned with the behavior of synchronous machines after they have been perturbed. If the perturbation does not involve any net change in power, the machines should return to their original state. If an unbalance between the supply and demand is created by a change in load, in generation, or in network conditions, a new operating state is necessary. In any case all interconnected synchronous machines should remain in synchronism if the system is stable. The transient following a system perturbation is oscillatory in nature, but if the system is stable, these oscillations will be damped toward a new quiescent operating condition [11].

Any unbalance between the generation and load initiates a transient that causes the rotors of synchronous machines to swing, this is because the net accelerating/decelerating torques are exerted on these rotors. If these net torques are sufficiently large to cause some of the rotors to swing far enough so that one or more machines *slip a pole*, synchronism is lost. To assure the stability, a new equilibrium state must be reached before any of the machines experience this condition [12]. Loss of synchronism can also happen in stages. For example: if the initial transient causes an electrical link in the transmission network to be interrupted during the swing. This creates another transient, which when superimposed on the first may cause synchronism to be lost.

During a transient the system seen by a synchronous machine causes the machine terminal voltage, rotor angle, and frequency to change. The impedance seen looking into the network at the machine terminal also may change. The field-winding voltage will be affected by [11]:

- Induced currents in damper windings due to the sudden changes in armature currents. The time constants for these currents are usually on the order of less than 0.1s and they are referred to as the sub-transient effects.
- Induced currents in the field winding due to sudden changes in the armature currents. The time constants for this transient are on the order of seconds and are referred as the transient effects.
- Change in rotor voltage due to change in exciter voltage if activated by changes at the machine terminal. Both, the sub-transient and transient effects are observed. Since, the sub-transient effects decay very rapidly, they are usually neglected and only the transient effects are considered important.

Stability in Induction Machine:

When the grid connected induction generator is subjected to a nearby fault, its rotor may accelerate to very high speed far from the system frequency, but it is not covered in conventional stability concepts, such as rotor angle stability, voltage stability and frequency stability [13]. After fault clearance, the system voltage may be recovered to a new allowable value, but the speed of induction generator may rise to an unaccepted value. Therefore, this cannot be classified under the voltage stability phenomenon. The frequency of the system after clearance may be acceptable. Hence, it cannot also be classified under the frequency stability phenomenon. Thus, this kind of stability phenomenon is termed as the rotor speed stability [14]. This rotor speed stability refers to the ability of an induction (asynchronous) machine to remain connected to the electric power system and running at mechanical close to the speed corresponding to the actual system frequency after being subjected to a disturbance.

The rotor speed stability of a constant speed wind turbine generator depends on the machine operating point, rotor inertia, short circuit power and distance from the fault location. Among these factors, active power output can be controlled by pitching wind turbine blades. By reducing the

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output power of the wind turbine, the speed can be maintained within the acceptable limits [15]. The pitch angle regulation is required in conditions above the rated wind speed when the rotational speed is to be kept constant. Small changes in pitch angle can have a considerable effect on the power output of the wind turbine. One concept that is fundamental to the control dynamics is that the rotor speed change is relatively slow because of the high inertia involved. Pitch control is relatively fast and can be used to limit the rotor speed by regulating input aerodynamic power flow, especially when near the high speed limit [16].

SIMULATION RESULTS AND DISCUSSION

To perform the transient stability analysis of power system with wind generator, a test system is considered and this system has a synchronous generator having the rating of 100 MVA, 11kV and a wind energy generator having the rating of 30MVA, 0.69kV, and they are the delivering power to a infinite bus through the transmission line. Figure 1 depicts the test system considered for this study.

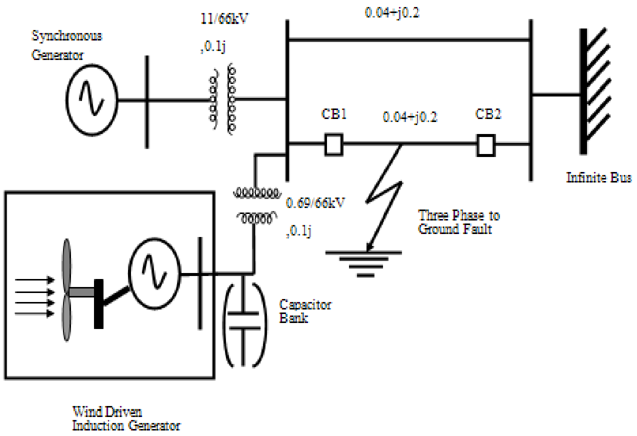

Figure 1: Test system considered for the transient stability study.

The wind farm is connected to the main circuit through a local transmission line. Wind farm is composed of many generators connected in parallel with the utility to fulfill partial demand. The synchronous generator is considered as a PV specified generator and the induction generator is treated as asynchronous one.

One important care to be taken while simulating the synchronous generator is that the power output and voltage generated by the synchronous generator should be maintained constant. This can be done by keeping automatic voltage regulator (AVR) and governor. AVR and governor will take care of voltage generation and power generation. A capacitor (C) is connected to the terminal of the wind generator to compensate the reactive power demand for the induction generator. The capacitor value can be decided based on the reactive power consumed by the induction generator under normal working conditions. The transmission line parameters are calculated on 100MVA, 11kV base. The base impedance is 1.7102 Ω. So, the transmission line resistance and reactance are 0.0484 Ω and 0.2420 Ω respectively.

The total simulation time is selected as 15 seconds. A three phase to ground fault is simulated on the transmission line-2 at 4sec and it is cleared at 4.4sec. The presented case studies are developed on a Personnel computer with 4GB RAM, 2.5GHz Intel Core i5 processor and simulated in MATLAB SIMULINK. The synchronous generator model is depicted in Figure 2.

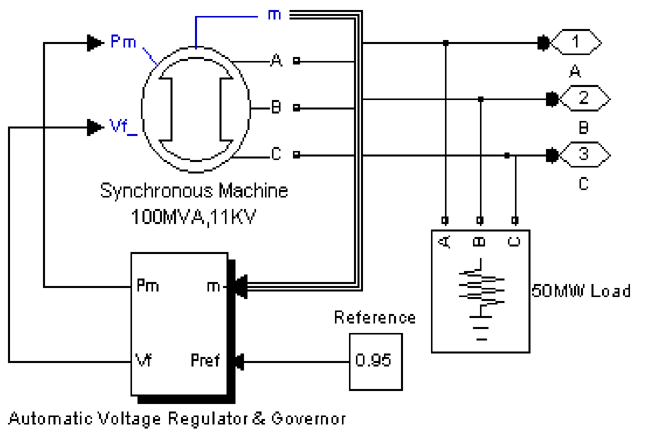

Figure 2: Model of synchronous machine.

In this two case studies are performed, and they are:

- Case Study 1: Simulations under normal operating conditions.
- Case Study 2: Simulations under faulty operating conditions with pitch control.

The above case studies are performed to study about speed of the induction generator, active power of the induction generator, terminal voltage of the induction generator and the power angle of the synchronous generator.

Case Study 1: Simulations under normal operating conditions:

In this case study, no fault is created. Here, the normal system operating conditions are considered. Figures 3, 4 and 5 depicts the speed, active and reactive power magnitudes, and voltage and current waveforms of induction generator, respectively. Figure 6 depicts the power angle of the synchronous generator.

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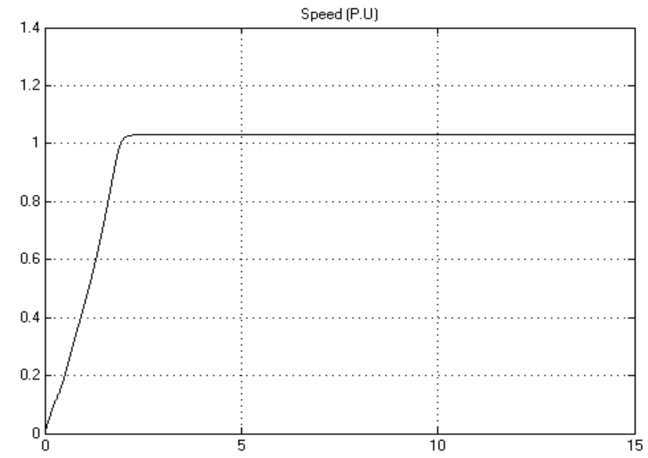

Figure 3: Speed of the induction generator for Case Study 1.

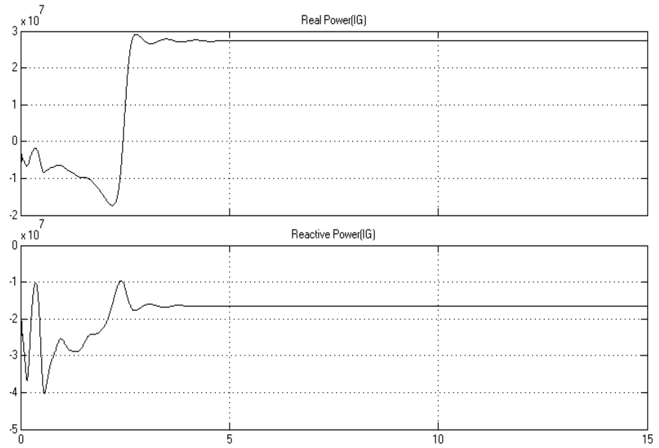

Figure 4: Active and reactive power magnitudes of induction generator.

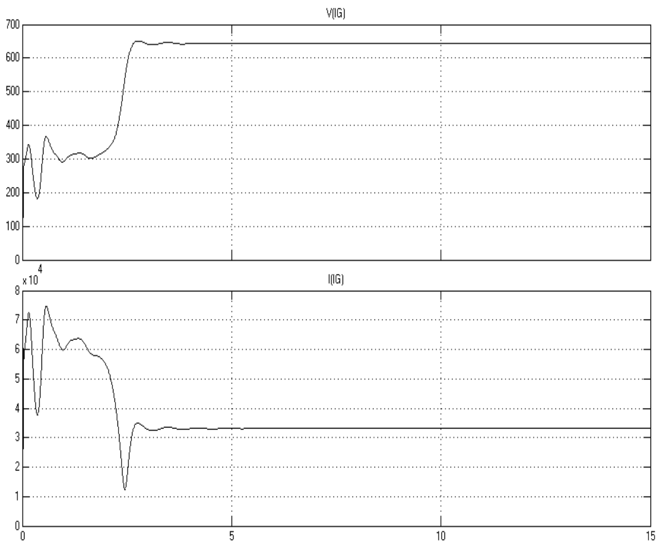

Figure 5: Voltage and current waveforms of induction generator.

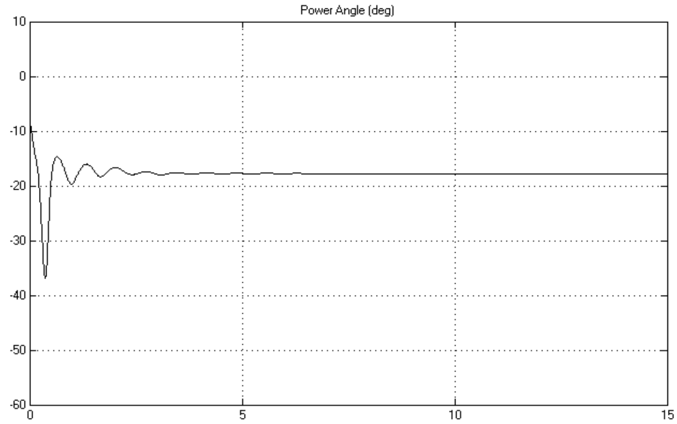

Figure 6: Power angle of synchronous generator.

Case Study 2: Simulations under faulty operating conditions with pitch control:

In this case, the simulation studies are performed by under the faulty operating conditions using the pitch control. Figures 7, 8 and 9 depicts the speed, active power and voltage at the terminals of the induction generator, respectively. Figure 10 depicts the power angle characteristics of the synchronous generator. In this case study, the speed of induction generator is not rising enormously. But there are some oscillations present in the waveform. This is because of the pitch control system effect. Whenever the control system finds increase in speed, it will automatically generate the pitch angle signal and the wind turbine act accordingly.

The real power of induction generator is becoming zero during the fault period. But, after clearance of fault the machine is feeding real power to the network. Again it regains its original condition. The terminal voltage of induction generator is becoming zero during the fault period. But, after clearance of fault the voltage has regained its original position. From Figure 10, it can be observed that the power angle of the dynamics of wind generators is not at all affecting the stability of synchronous generators.

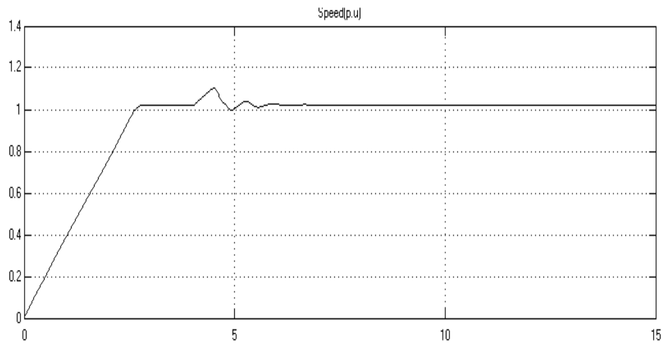

Figure 7: Speed of induction generator for Case 2.

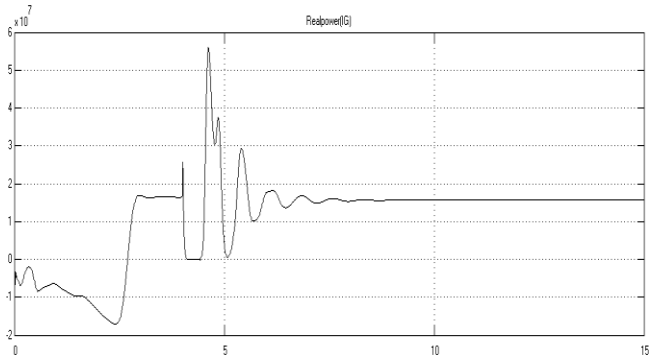

Figure 8: Active power of induction generator for Case Study 2.

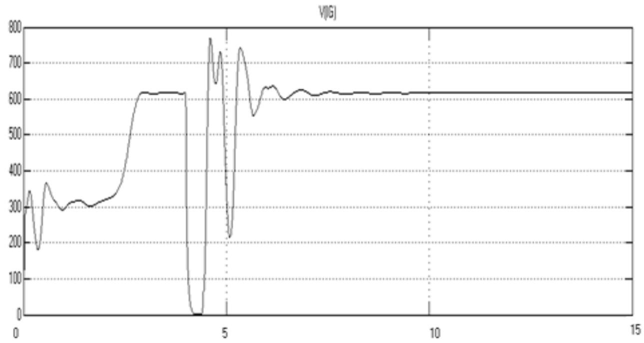

Figure 9: Voltage at the terminals of induction generator for Case Study 2.

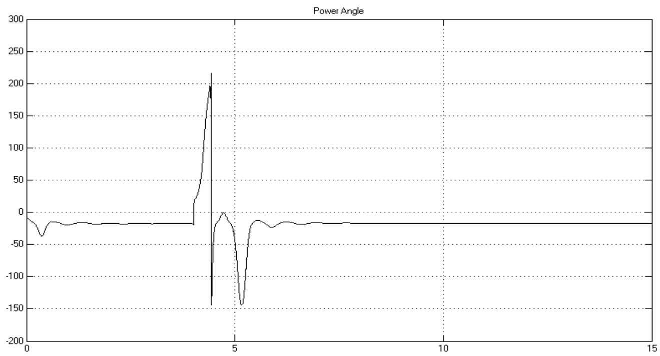

Figure 10: Power angle variation of synchronous generator for Case Study 2.

CONCLUSIONS

This paper has analyzed the impact of wind energy generators on the transient stability of power system. Generally, the induction machines are used as generators in wind power stations. As the induction machines have stability problem similar to the synchronous machines, it is important to analyze the transient stability of power system including wind power stations. In this paper, the simulations and analysis of transient stability of power system including induction generator during short circuit fault conditions are carried out. The effect of the pitch angle control on the stability of power system is analyzed.

REFERENCES

[1] Available. [Online]: (Accessed Sept. 10, 2017). http://www.world-nuclear.org/information-library/energy-and-the-environment/renewable-energy-and-electricity.aspx

[2] P.W. Carlin, A.S. Laxson, E.B. Muljadi, The History and State of the Art of Variable-Speed Wind Turbine Technology, NREL/TP-500-28607, *NREL Technical Report*, Feb. 2001.

[3] L. Lin, H. Zhao, T. Lan, Q. Wang, J. Zeng, Transient stability mechanism of DFIG wind farm and grid-connected power system, *IEEE Grenoble Conference*, Grenoble, 2013, pp. 1-9.

[4] Q. Wang, A. Xue, T. Bi, Y. Zheng, Impact of DFIG-based wind farm on transient stability of single machine infinite bus system, *IEEE PES Asia-Pacific Power and Energy Engineering Conference*, Kowloon, 2013, pp. 1-5.

[5] K. Elkington, The Dynamic Impact of Large Wind Farms on Power System Stability, *Doctoral Thesis*, 2012. Available. [Online]: https://www.diva-portal.org/smash/get/diva2:516618/FULLTEXT01.pdf

[6] P. He, F. Wen, G. Ledwich, Y. Xue, Investigation of the Effects of Various Types of Wind Turbine Generators on Power-System Stability, *Journal of Energy Engineering*, vol. 141, no. 3, Sept. 2015.

[7] J. Shu, B.H. Zhang, C.G. Wang, Z.Q. Bo, "Investigation of control for grid integrated doubly fed induction wind generator," *IEEE Power & Energy Society General Meeting*, Calgary, AB, 2009, pp. 1-7.

[8] G.S. Kaloi, J. Wang, M.H. Baloch, Active and reactive power control of the doubly fed induction generator based on wind energy conversion system, *Energy Reports*, vol. 2, pp. 194-200, Nov. 2016.

[9] Md.E. Hossain, Improvement of transient stability of DFIG based wind generator by using of resistive solid state fault current limiter, *Ain Shams Engineering Journal*, Aug. 2017.

[10] M.K. Döşoğlu, Hybrid low voltage ride through enhancement for transient stability capability in wind farms, *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 655-662, Jun. 2016.

[11] Paul M. Anderson, A. A. Fouad, *Power System Control and Stability*, 2nd Edition, Wiley-IEEE Press, Oct. 2002.

[12] S. Pal, A Novel Software Approach Scheme Analysis And Utility Of Transient Stability Analysis In Power System, *International Journal of Engineering Research & Technology*, vol. 1, no. 10, pp. 1-6, Dec. 2012.

[13] P. Bhakre, A.G. Thosar, Transient Stability of Grid Connected SCIG Wind Turbine, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 5, no. 5, pp. 3884-3891, May 2016.

[14] M.Q. Duong, F. Grimaccia, S. Leva, M. Mussetta, K.H. Le, Improving Transient Stability in a Grid-Connected Squirrel-Cage Induction GeneratorWind Turbine System Using a Fuzzy Logic Controller, *Energies*, pp. 6328-6349, vol. 8, 2015.

[15] M.G. Kanabar, C.V. Dobariya, S.A. Khaparde, Rotor Speed Stability Analysis of Constant Speed Wind Turbine Generators, *International Conference on Power Electronic, Drives and Energy Systems*, New Delhi, 2006, pp. 1-5.

[16] E. Muljadi, C.P. Butterfield, Pitch-controlled variable-speed wind turbine generation, *IEEE Transactions on Industry Applications*, vol. 37, no. 1, pp. 240-246, Jan/Feb 2001.