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Improvement of starting transient state in a fixed speed wind turbine using STATCOM

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Abstract

Nowadays, the effects of wind generators have become an important issue in power quality due to impressionability in the lack of uniformity in adjusting frequency and power systems' voltage. Wind turbine generators during commissioning even when they use a soft starter and connect to a power network transient and oscillatory flow have reactive power and effective voltage. With the presence FACTS devices (especially parallel devices) and reactive power injection, reactive power changes and effective voltage can be reduced. In this paper, the studied system consists of Thévenin equivalent circuit of a power network, which connects to a wind generator through transformers and transmission lines. Dynamic modeling of transient wind turbine and also, commissioning condition of power system model and simulation of computer were done in PSCAD / EMTDC software. At the end, simulation results of the desired system show that the presence of STATCOM in network improves the initial transient state of some parameters such as voltage, reactive power output of generators and etc.

Keywords: transient improvement, commissioning induction generator, STATCOM

Introduction

Traditionally, wind energy always was used as an appropriate solution for producing energy in low level and supply of energy. But today, according to the other features such as less pollution, high access possibility and on the other hand non-fossil energy use, energy production by this element is done in high levels. For this reason, one of the main concerns in the production of energy by wind is the high impact of permeability of this energy in the stability of this power system. In general, dynamical fluctuations in wind turbines (WTS) are because of active power consumption from wind turbine generators on arrival or departure of the circuit networks and power system. This will cause voltage and power instability and in some cases lead to a total collapse or being out of network. For this purpose, various methods can be used to control and commission of a wind turbine. Some of these methods are synchronous condenser, soft starter, capacitor banks and etc. But in many cases, only use high compensation may be not sufficient to meet these needs. Therefore, new technologies must be used to meet these challenges. Using FACTS devices technology is one of the new technologies in controlling problems and failures in power systems. We presented a dynamic model for wind turbines that use of a double fed induction machine (rotor winding) as productive. Through the stator and rotor voltage source converter is connected directly to the network. Using the orientation of the stator field, with separate controls, electromagnetic torque and stator reactive power of the PID controller for speed and reactive power, the simulation results show good performance of the controller to get the maximum power from wind and reactive power (Tari Moradi, 2004). A prototype (SVC), a value of RMS voltage power network, is used as a reference for adjusting reactive power of wind turbines, to reduce voltage fluctuations. Simulation and experimental studies show beneficial effects in the SVC voltage profile, even in cases of sudden changes in the effective voltage (Boynuegri, Vural, Tascikaraoglu, Uzunoglu, Yumurtacı, 2012). In this research a dynamic model of wind turbine constant speed control is not available. Because the critical design parameters are not General knowledge. The details are given in the verification of the model parameters and characteristic star-up a wind turbine, which is very important. This means that intelligent design model, such a system without knowing the turbine manufacturer, the design of the critical parameters (Peters, Muthumuni, Bartel, Salehfar, 2006). Focus on modeling and control of wind energy converters, PWM converter connected to a network by connecting DC. Here, output power transmitted from of the rectifier PWM generator and a STATCOM with bus network. The multi level inverter converts DC power into AC power. Finally, simulation results show the beneficial effect of STATCOM based on the PWM (Champa, Ajoy, Sujit, Tanushree, 2012).

In this paper, to facilitate the study of the impact of wind turbines on the dynamics of a power system is a power distribution network model of dynamical fluctuations and Transient network in connection with wind turbine generators will be investigated. As mentioned before, one of the new technologies in compensation in power systems is the use of FACTS controllers. For this reason, parallel devices FACTS (STATCOM) can improve start-up conditions by injecting reactive power.

The studied system and its characteristics

The studied power network model is an electrical distribution network, which is connected to a wind turbine and an induction generator. Here, wind power and its delivered torque are connected to a 22 / 13.8 kV transformer through a wind turbine rotor in the induction motor by a soft starter and finally, the whole set is connected to the electrical distribution network. Also, the network static compensator is added to the model in the second part of the simulation. Figure 1 shows the method of connecting these components in the power system. According to the mentioned contents, the parameters of each of the components in the system will be introduced.

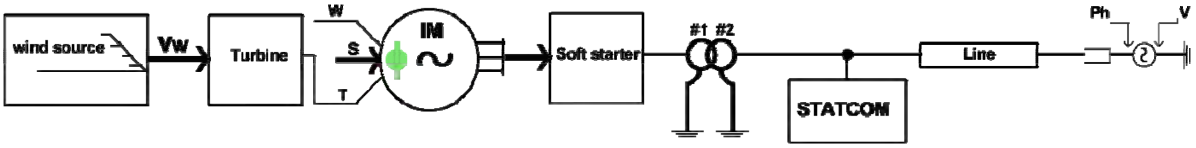


Figure 1. Simulation model components.

Wind system

Equations and models of wind turbines

The power that a wind turbine can extract is determined by the equation 1 and 2:

$$Pm = Cp\, P\omega \quad (1)$$

$$P\omega = \frac{1}{2}\pi\rho R^2 Vw^2 \quad (2)$$

In which, Pm is mechanical power that is given from the wind by a wind turbine, $P\omega$ is available wind power, ρ is the air density based on kg/m^3, R is radius of the turbine blades, Vw is wind speed based on m/s and finally, Cp is the turbine efficiency coefficient. Efficiency coefficient (Cp) specifies the percentage or portion of wind energy that is extracted by the turbine. Figure 2 shows efficiency coefficient (Cp) in β values and various wind speeds and Figure 3 shows the mechanical power of the turbine for various speeds of wind. In the studied system simulation, the β value is 10 degrees (Petersson, 2003).

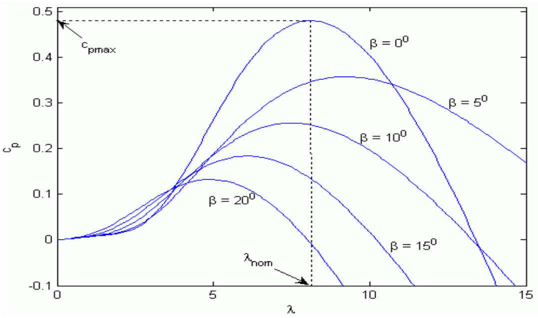


Figure 2. Efficiency coefficient (Cp) in β values and various wind speed

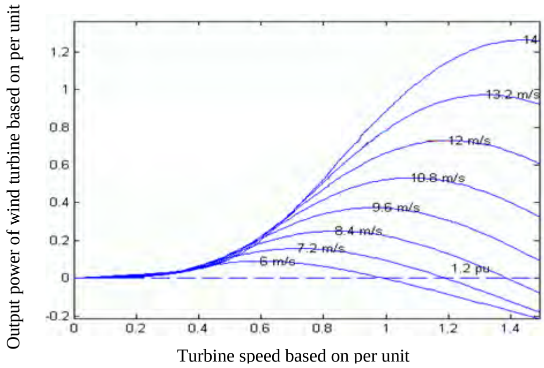


Figure 3. mechanical power of the turbine for various speeds of wind

Generated torque by the wind turbine at different speeds obtained from equation (3):

Ta = $Pm/\omega t = 1.2\,\pi\rho R^2 V w^2/\omega t$ (3)

In which, Ta is torque in the turbine axis and always its value is determined according to a dynamic model of the wind turbine (Figure 4) and applied to the machine (Chee-Mun Ong, 1998).

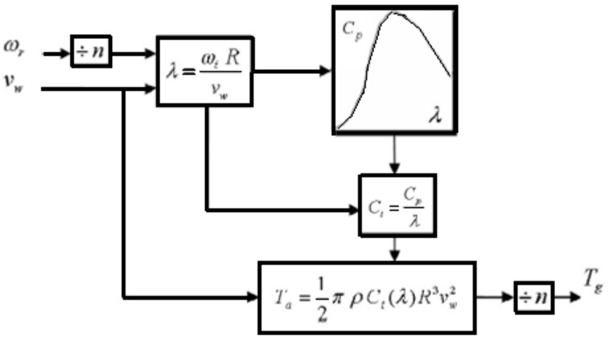


Figure 4. dynamic model of the wind turbine

Wind turbine governor parameters

The governor model was MOD2 (in Pscad software) and its power and demand are set on 2.5 MW and the reference frequency is 60 Hz. Differences in work mode setting on the governor with other modes is that unlike other modes that have an open-loop system, the applied control system is a closed loop and the beta angle is regulated by a feedback mode. Figure 5 shows a block diagram of wind turbine governor. Thus, wind turbine governor system performance here is in such a way that first, wind power enters governor as a parameter and then, the governor controller changes the turbine blade rotation angle from 10 ° to 12 °. Figure 6 shows the general structure of the network system in the studied network.

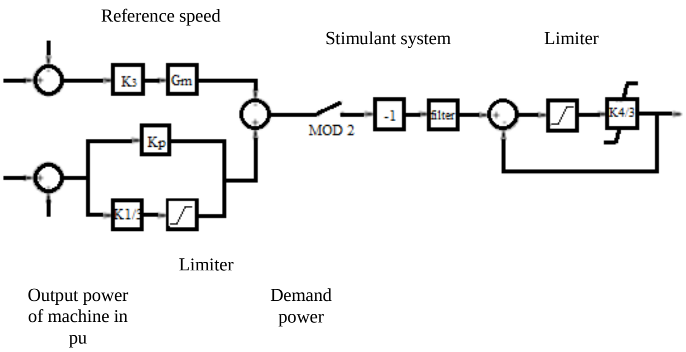


Figure 5. Wind turbine governor diagram block

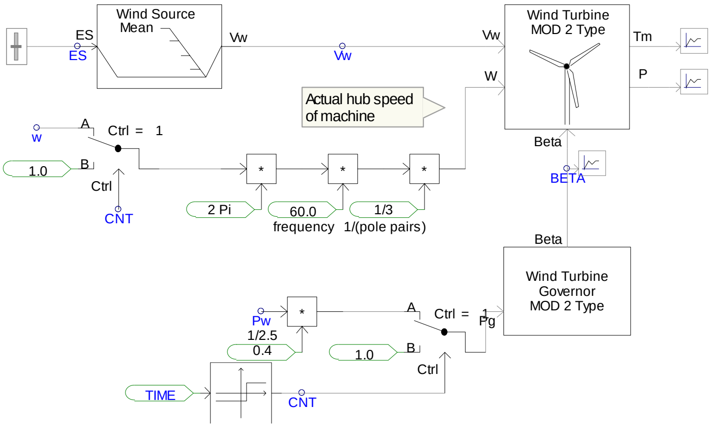


Figure 6. General structure of wind system in the studied network

The output torque of the wind turbine

Output kinetic energy from a wind turbine rotor is due to aerodynamic characteristics of wind and its conversion into rotational Stimulant system .ine. Screw (shaft) of the rotor is connected to a gearbox (transmission) that is used for change and adjust the rotation speed. Here, the differential angle results from changing the speed of shaft rotation and it is defined as $d\theta$ and the amount of differential work ($d\omega$) is expressed as Equation 4. Finally, T is the output torque resulting from kinetic energy of the wind that is expressed as Equation 5 with (P) power.

$$d\omega = \mathrm{T}\ d\theta \tag{4}$$

$$P = d\omega/dt = T\ \ d\theta/dt \tag{5}$$

Induction generator

Our induction generator is a two-shelf type that has a capacity of 2.5 MVA. Also, the effective output voltage of this generator is 13.8 kV and the effective flow is equal to 0.1046 amps. Sets of equations 6 show the relationship between voltage and current generator on the d-q axis Peters, Muthumun, Bartel, Salehfar, Mann, 2010)

$$\begin{bmatrix} \mathrm{Vqs} \\ \mathrm{Vds} \\ \mathrm{Vdr} \\ \mathrm{Vdr} \end{bmatrix} = \begin{bmatrix} Rs + pls & \omega rLs & pM & \omega rM \\ -\omega rLs & Rs + pls & -\omega rM & pM \\ pM' & 0 & Rr + pLr & 0 \\ 0 & pM' & 0 & Rr + pLr \end{bmatrix} \cdot \begin{bmatrix} iqs \\ ids \\ iqr \\ idr \end{bmatrix} \tag{6}$$

In the above relations, p is the number of machine poles and M mutual inductance between the stator and the rotor and electromagnetic torque of the machine can be calculated from equation 7:

$$Tem = 1.5 * p/2 + (M\ iqs * idr - ids * iqr) \tag{7}$$

Also, the frequency of the machine is 60 Hz.

Soft starter

A soft starter is used to reduce transient startup and also, to reduce the fluctuations in wind turbine generator connected to the power distribution network. As is shown in Figure 7, this soft starter is made of power electronics devices and here, it is associated with a circuit breaker in the system. The components of this soft starter are a thyristor bridge, capacitor banks, and etc. Here, circuit breakers are for isolating generator and other parts of the wind turbine in the network. Generally, it will be closed after commissioning the breaker and thyristors are creating a connection path between induction generators and electrical distribution network. Figure 8 represents the control system firing angle of one of the soft starters that has each of three controller phase. Basically, the soft start function is such a way that synchronism fire of thyristors creates a locked ring of phase (PLL) by the network voltage that will be done in the same way for each angle of voltage phase of the network. Finally, the angle is applied on the fire control block to compare with a defined angle (α). When angles are equal to each other, a pulse of fire is delivered to a thyristors. This function occurs for both the half cycle voltage, the positive section (0-180) and the negative voltage (180-360). In Figure 7, PFA1 is the send fire pulse signal to an anti-parallel thyristors for the positive half cycle voltage and PFA2 is the send fire pulse signal to a negative half-cycle pulse voltage. In fact, progress of fire angle in the system will continue until the rotational speed of the generator does not reach the synchronous speed. Therefore, a speed reference should be defined for machine, in which 0.95 pu is defined for the machine(Peters, Muthumuni, Bartel, Salehfar, 2006).

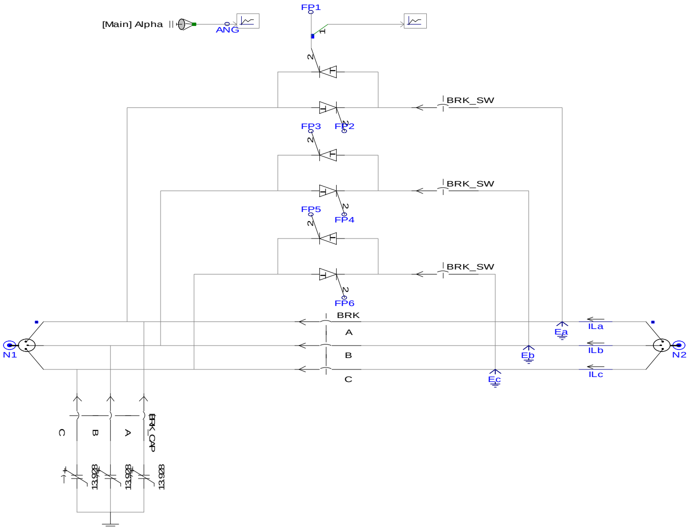


Figure 7. The structure of used starter in the studied system

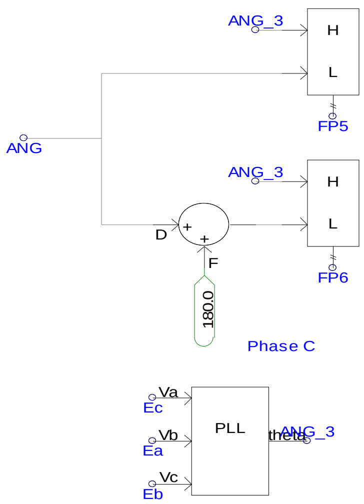


Figure 8. Fire angle control system of one of the soft starter's phases (C)

Connected distribution network

As is evident in Figure 1, the connected distribution network in this simulation is modeled with a wind turbine generator and transformer with a power source that is connected to the mentioned sections by a power distribution line. The network capacity is 3 MVA and its voltage is 22 kV (Petersson, 2003).

Static synchronous compensator

The applied compensator in the studied system is a six-pulse STATCOM. This compensator consists of Pulse Width Modulation (PWM) system. Also, the static compensator parameters are selected based on trial and error testing. Figure 9 shows the STATCOM transient (dynamic) model. Here, R+JX are resistance and reactance of the transformer and parameter C is the coefficient of the Pulse Width Modulation convertor index. Also, Figure 10 shows the static compensator used in the simulation of the system (Singh, Kadagala, 2012; Da´valos, Ricardo, Ramı´rez, Juan, Tapia, Rube´n, 2005).

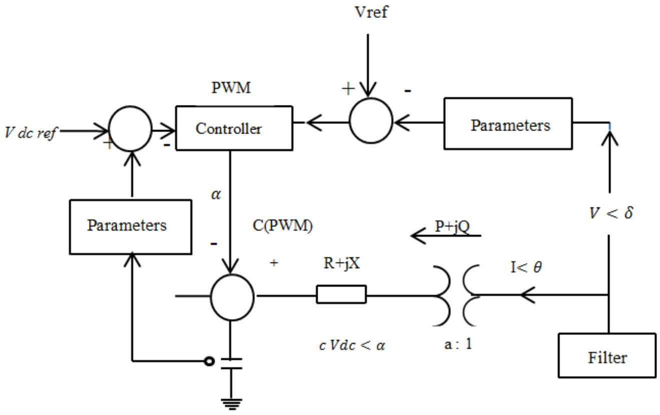


Figure 9. STATCOM transient (dynamic) model

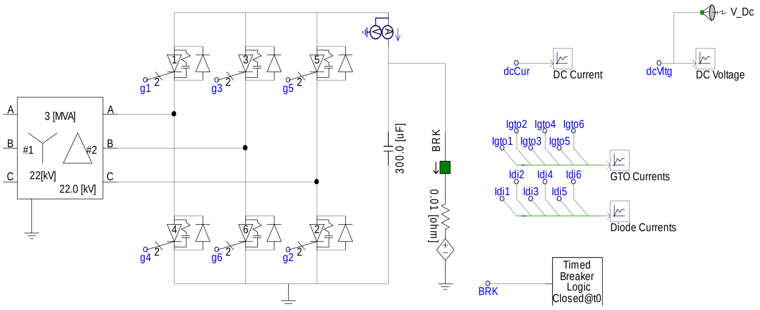


Figure 10. Static compensator structure

The basis of the compensator in here is that a reactive power source (Qm) logs in to the voltage control loop system with a single voltage. In this loop, reactive power reference value with a fixed amount of three percent loss with a unit voltage enters to the down pass filters in a function and these two quantities will be compared with a reference voltage. The amount of reference voltage in this simulation is set by one per unit (1 Pu). Figure 11 shows an overview of STATCOM control system based on voltage source converter. In this control loop, a PI controller is used that the output of this controller is the angle direction. This indicates the required change between the system voltage and generation voltage by STATCOM element. This change is for determining the amount and actual power distribution (Jeong, Seok, Jyung, Young., Baek Young, 2011; Mienski, Pawelek and Wasiak, 2004; Sethy, Moharana, 2012).

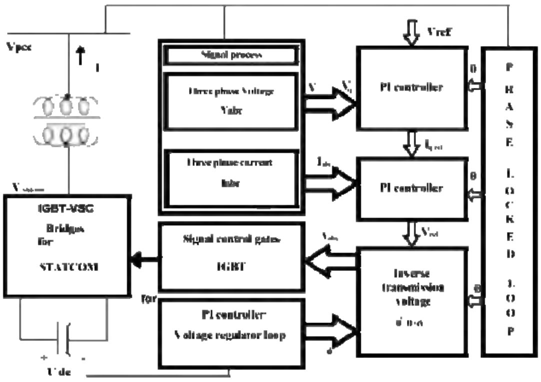


Figure 11. Overview of the control system STATCOM, based on voltage source converter (VSC)

Simulation Results

After introducing all components and elements in the studied system in the above section, we will evaluate the simulation results of the system initially without compensation case and finally, we will add compensator system to the circuit and analyze the results.

Machine's terminal voltage and speed output curve

Figure 12 and 13 show the voltage and speed curve of the induction machine. As shown in figure 11, in the initial state of commissioning, the system has fluctuation that finally, the machine terminal voltage is fixed in 12.6 kV and speed curve in Figure 12 is damped in the amount of 2.12(pu) and has a steady state.

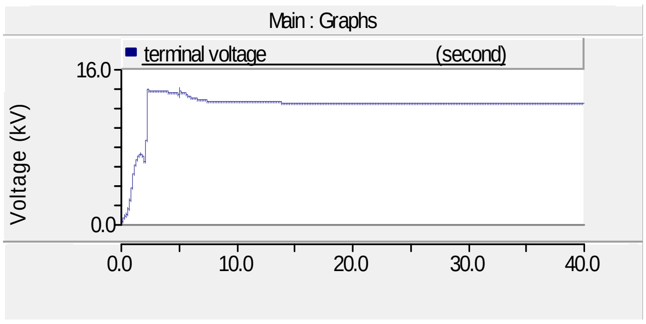


Figure 12. output terminal voltage Curve

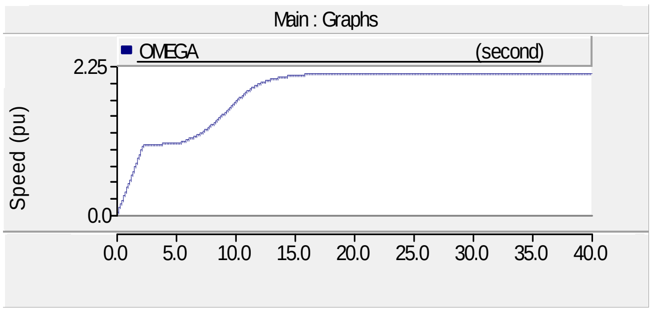


Figure13. Output speed induction machine curve

Active and reactive power of the generator output

Figures 14 and 15 show the active and reactive power of the generator. As is evident in Figure 14, active power output of the generator at the beginning (before closing the breaker of soft starter) has a high fluctuation and transient (machine works in engine mode), but as we see, in second 5 the power in high transient mode has an intense fluctuation that this state does not last more than a few hundredths of a second. This is because that in the fifth second induction machine connected to the network by a soft starter, but fluctuation is inhibited very rapidly because in this moment, the capacitor bank of the soft starter enters the circuit. In Figure 15, the reactive power at the beginning of the period, has a high fluctuation between second 1 to second 2.2 (for commissioning). Finally, it is damped in 2.78 MW and reaches its steady state.

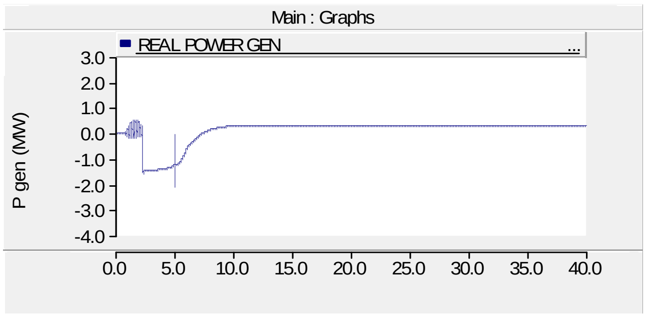


Figure 14. Induction generator active power output curve

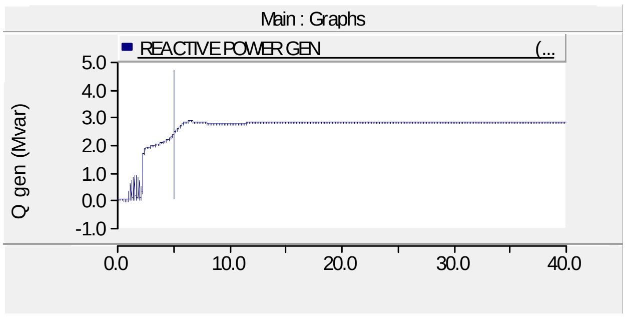
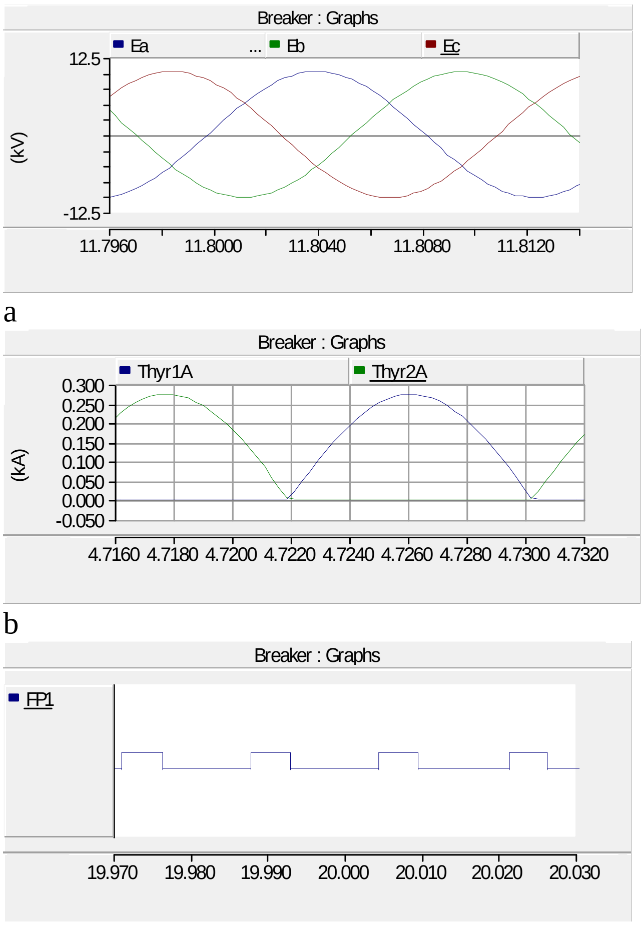


Figure 15. Induction generator reactive power output curve

Three-phase voltages, thyristory bridge flow, and thyristors, fire angle in soft starters

Figure 16 shows the three components of voltage, thyristory bridge flow, and thyristors' fire angle in soft starters. As can be seen in section (a and b), the duration of a complete cycle in three-phase voltages and thyristory bridge flow is one hundredth of a second; also, the fire angle of one of the thyristors is shown in part (c) that the on and off time of this thyristor is set at 0.005 second.



a

b

c

Figure 16. a) three-phase voltage soft starter, b) of the thyristor soft starter, c) thyristor firing angle

Machine terminal voltage output curve with the STATCOM

Figure 17 shows the voltage of the power system with the STATCOM. By adding the static compensator it can be seen that the amount of fluctuation in the terminal voltage unlike the previous case of compensation, is disappeared and damped.

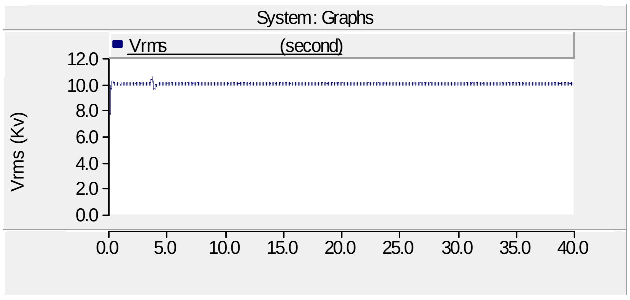


Figure 17. The terminal voltage of the system under study, with the STATCOM

Induction machine speed curve with the STATCOM

Figure 18 shows the induction machine speed curve with the STATCOM compensator. This curve shows that the induction machine reaches its nominal speed in second 14. While, in the previous section (without compensation), the machine car reaches its nominal speed in second 20. This is for this reason that in the case without compensator, the time to reach the nominal speed for machine takes 5 seconds (the required time for closing the soft starter circuit breakers), but by adding a static compensator, this time reduces to 0.15 second.

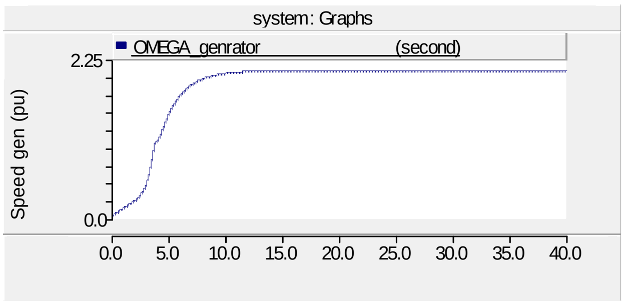
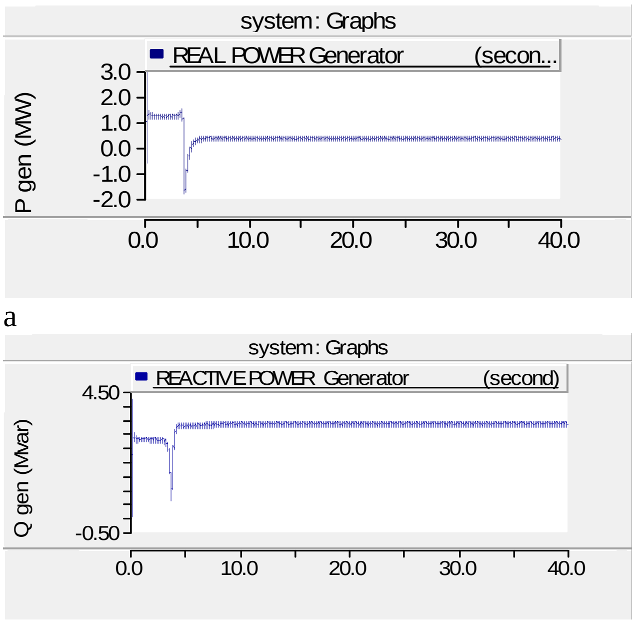


Figure 18. speed induction machine Curve with the STATCOM

Active and reactive power of the generator with the STATCOM

Figure 19 shows the generator’s active and reactive power using compensator. As is evident in section a of this figure, active power of generator only has a major fluctuation in second 3.5 and no fluctuation was observed in switching (connecting the machine to the network) by the soft starter breaker. In section b of this figure, reactive power curve unlike the case without compensation system that has high fluctuations, has a relatively stable state and only has one major fluctuation that occurs in second 3. Thus, by closing static compensator circuit breaker at second 0.1, a major change in reactive power and other network parameters can be observed.

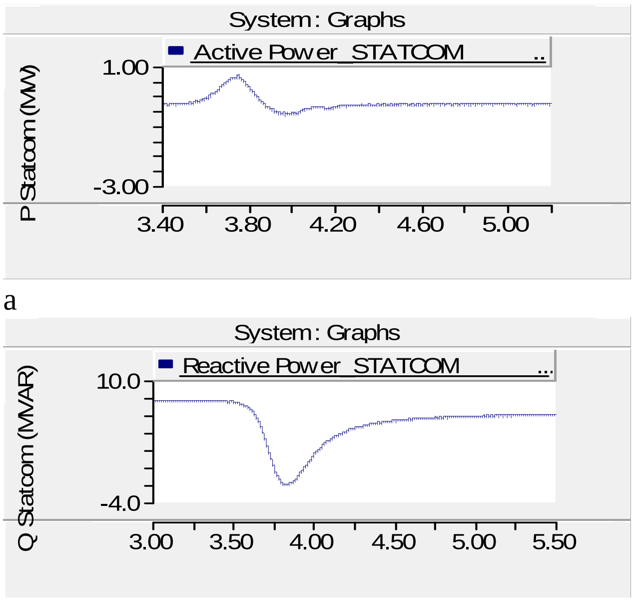


b

Figure 19. a) active power induction machine curve, b) reactive power induction machine curve

Active and reactive power curve of STATCOM

Figure 20 shows the active and reactive injected power by the static compensator (STATCOM). As can be seen in section a of this figure, STATCOM does not have a significant impact on the compensation of active power, but in section b of this figure, it can be seen that the compensator applies about six megawatts of reactive power for compensation.



b

Figure 20. a) active power STATCOM curve, b) STATCOM reactive power

Conclusion

Wind energy production methods due to environmental issues and other features are preferred compared to other energy sources. A major transient state (fluctuation) is created in the system due to the use of induction generators in wind turbines while commissioning these generators to the system and power network. This is because of the consumption of reactive power by induction generator. In this research, our studied system was a wind turbine which was connected to the power distribution network through a soft starter. In the initial modeling and simulation of the system which is done without compensation, the results show that very strong fluctuations were created in the generator's output powers while commissioning. These fluctuations were effective on other parameters. By adding a six-pulse static compensator (STATCOM) (equipped with Pulse Width Modulation) to the power system in the second section of simulation, major changes in the generator power, terminal voltage and network power curve can be seen. Thus, the induction generator's power output has milder fluctuations than in the previous case; and in fact, the initial loss and fluctuation of system are improved. Evaluating the transient state of power systems has always been a challenge for engineers and designers in the industry. In this study, it has been tried to analyze a part of this challenge.

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References

Boynuegri, A.R., Vural, B., Tascikaraoglu, A. , Uzunoglu, M., Yumurtacı, R. (2012) Voltage regulation capability of a prototype Static VAr Compensator for wind applications, Elsevier Ltd, Applied Energy, 2 (1) Green Energy; (2)Special Section from papers presented at the 2nd International Enery 2030 Conf , 93, 422–431;

Champa, N., Ajoy, Kr. C., Sujit, D., Tanushree, Deb. (2012) Modeling and Simulation of Wind Farm with STATCOM in PSCAD/EMTDC Environment, International Journal of Applied Information Systems, Foundation of Computer Science FCS, New York, USA, 1(7), 16-20;

Chee-Mun.Ong, (1998). Dynamic Simulation of Electric Machinary using Matlab/Simulink, PRINTICE HALL

Da´valos, M, Ricardo, Ramı´rez, Juan, M., Tapia, O, Rube,´N. (2005), Three-phase multi-pulse converter StatCom analysis , Elsevier Ltd, Electrical Power and Energy Systems, 27(1), 39-51;

Hill(petersa), R. R., Muthumuni, D., Bartel, T., Salehfar, H. (2005) A Dynamic Simulation of a Fixed Speed Stall Control Wind Turbine at Start Up, IEEE Power Symposium, North American, pp 421-425;

Jeong, K.Seok., Jyung, T. Young., S. Baek Young. (2011). Modeling and Dynamic Analysis of STATCOM for Short-Term Voltage Stability Improvement using EMTP/RV, Journal of International Council on Electrical Engineering, 1(2), 129-134;

Mienski, R., Pawelek R. and I. Wasiak, (2004). Shunt compensation for power quality improvement using a STATCOM controller: modelling and simulation, MODERN ELECTRIC POWER SYSTEMS, IEE Proc.-Gener. Transm. Distrib., 151(2), 274-280;

Peters, R. R., Muthumuni, D., Bartel, T., Salehfar, H. (2006) Dynamic Model Development of a FixedSpeed Stall Control Wind Turbine at Start-Up, IEEE , Power Engineering Society General Meeting, pp 1-7;

Petersson, A. (2003) Analysis, Modeling and Control of Doubly-Fed Induction Generators for Wind Turbines, Department of Electric Power Engineering CHALMERS UNIVERSITY OF TECHNOLOGY GÖteborg, Sweden, Thesis;

Peters, R. R., Muthumun, D., Bartel, T., Salehfar, H., Mann, M. (2010) Static VAR compensation of a fixed speed stall control wind turbine during start-up, Elsevier Ltd, Electric Power Systems Research, 80(4), 400–405;

Singh, B., Kadagala, V. S. (2012) A new configuration of two-level 48-pulse VSCs based STATCOM for voltage regulation , Elsevier Ltd, Electric Power Systems Research,82(1), 11-17;

Sethy, S.K., Moharana, J.K. (2012). Design, Analysis and Simulation of Linear Model of a STATCOM for Reactive Power Compensation with Variation of DC-link Voltage, International Journal of Engineering and Innovative Technology, .2(5), 183-189;

Tari Moradi. H. (2004) The dynamic modeling of wind turbines based on electric generators with double-fed, Eighteenth International Conference on Electricity, Energy Research, Tehran, 331-340.