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Performance of an Induction Generator with or without STATCOM in Wind Farm

Sukriti Solanki[1], Vikas Khinchi[2]
Department of Electrical Engineering
Rajasthan Technical University, Kota

Abstract— in recent year's generation of electricity using wind power plant has received considerable attention worldwide. Induction machines (IM) are largely used as generators in wind power plant primarily based generations. Since IM have a stability drawback as they draw terribly massive reactive currents throughout fault condition, reactive power compensation may be provided to enhance stability drawback. In This paper deals with the Impact of Static Synchronous Compensator (STATCOM) on the alternative energy wind power plant performance and wind power plant consisting of six 1.5 MW wind turbines. Self Excited squirrel cage Induction Generator (SEIG), that uses an excitation condenser, is employed widely to convert mechanical wind energy to electricity energy, because of their low cost, small size, no need of separate dc supply and brushes. The whole electromechanical system is modeled and simulated in MATLAB using Simulink.

Keywords—Transient Stability, Active Power, Reactive Power, Bus, FACTS, STATCOM, Wind Power plant

I. INTRODUCTION

With the rise in power demand and reduce of fossil fuels, world has been forced to adopt various alternative sources for the electrical power generation. wind power plant in spite of being random in nature has proved itself as a viable solution to the present drawback. because the wind turbine technology is developing at a good pace, more and more wind power plants are being integrated with the normal type of generation[1].

One of the straightforward strategies of running a wind generating system is to use the induction generator connected directly to the grid system The induction generator has inherent benefits of cost effectiveness and robustness. However; induction generators need reactive power for magnetization. when the generated active power of an induction generator is varied as a result of wind, absorbed reactive power and terminal voltage of an induction generator can be affected significantly [1,2]. The analysis of connected induction generator is less complicated as a result of its voltage and frequency are determined by the power system grid. However, islanding of a connected IG disturbs its voltage and frequency, owing to lack or surplus of reactive and active power. the foremost effective way to control a turbine captured power is to regulate the blade pitch angle. Blade pitch is analogous to the throttling valve in typical steam turbines, except that its response is much quicker than that of steam turbines [7]. A squirrel cage IG draws reactive power for magnetization from its terminals which are undesirable. to resolve this problem a fixed shunt condenser bank is connected to the IG terminals to supply the magnetization current and even supply reactive power to the local load.

Flexible AC Transmission Systems are described by a group of power electronic devices. This technology was developed to perform a similar functions as traditional power system controllers like electrical device tap changers, phase shifting transformers, passive reactive compensators, synchronous condensers, etc. A STATCOM control scheme in wind energy generation system is planned under traditional operating condition to allow the proper control over the active power production, reaching speed, torque steady state values. within the event of grid disturbances, STATCOM is employed the machine speed not to reach below certain safe limit by injecting current primarily based control technology has been proposed for improving the power quality [6].

II. WIND TURBINE INDUCTION GENERATOR (WTIG)

The electricity-producing wind turbine is treated as a complex electromechanical system consisting of the

IG, the drive train system and therefore the rotating wind turbine. The diagram of wind turbine induction generator (WTIG) is shown in Fig 1.

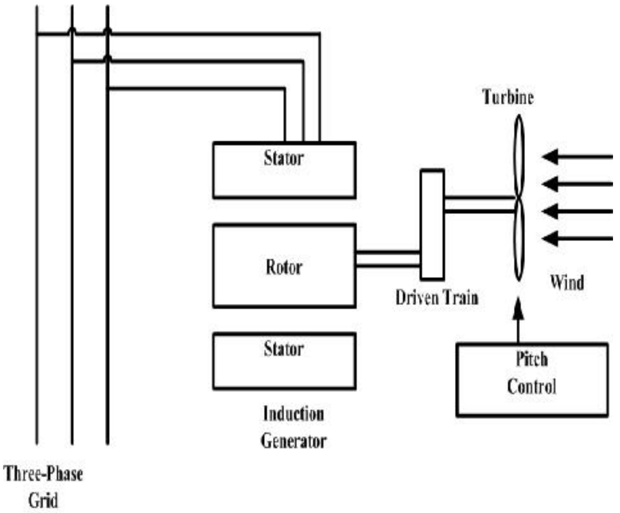


Fig. 1: Wind Turbine Induction Generator

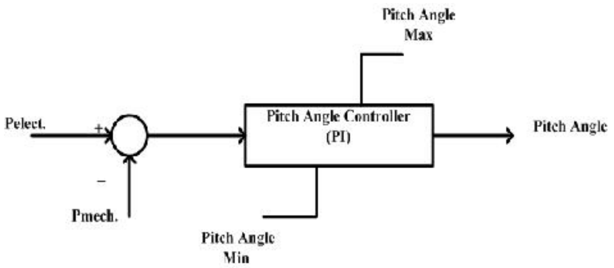


Fig. 2: Control System for Pitch Angle Control

The stator winding is connected to the three-phase grid at 50 Hz frequency and rotor is driven by a variable-pitch wind turbine. The captured wind turbine power is regenerated into electric power by the IG 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 prime wind speeds. So as to generate power the induction generator speed must be slightly above the synchronous speed. The pitch angle controller regulates the wind turbine blade pitch angle β, consistent with the wind speed variations.

A Proportional-Integral (PI) controller is used to control the blade pitch angle. The pitch angle is kept constant at zero degree when measured electrical output power is lower its value. Once it increases higher than its nominal value the PI controller raises the pitch angle to get back the measured power to its face value. The pitch angle system is illustrated in the Fig 2.

A. WIND TURBINE SYSTEM

The wind turbine model used for simulation purpose is a per unit model based on the steady state power equation of a wind turbine. The gear box used for coupling the induction generator with the grid.

The wind turbine model is utilized within the present study is based on the steady-state power characteristics of the turbine. The wind turbine mechanical power output is a function of rotor speed similarly as the wind speed and is expressed as:

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

$$C_p(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)\exp\left(-\frac{c_5}{\lambda_i}\right) + c_6\lambda \quad (2)$$

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (3)$$

Where

P = Mechanical output power of the turbine (W)

C_P = Performance coefficient of the turbine,

C_1 =0.5176, C_2 =116, C_3 =0.4, C_4 =5, C_5 =21, C_6 =0.0068

ρ= Air density (kg/m3)

A =Turbine swept area (m2)

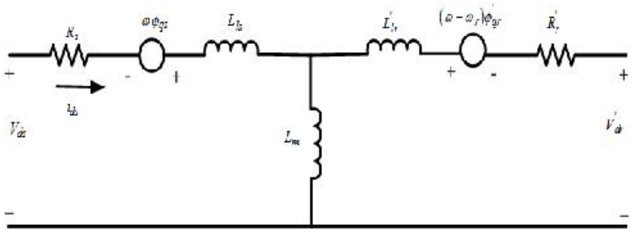
V_{wind}= Wind speed (m/s)

λ =Tip speed ratio of the rotor blade tip speed to wind speed

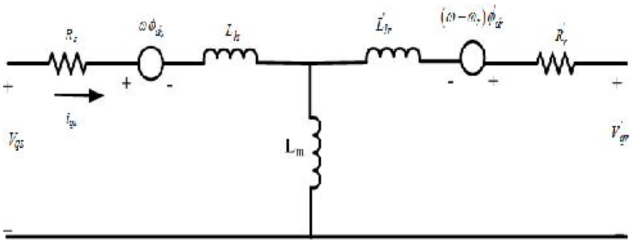
β = Blade pitch angle (deg)

B. INDUCTION MACHINE

In the induction machine, the electrical part of the machine is described by a fourth-order state-space model and the mechanical part of machine is described by a second-order state-space model. The d-axis and q-axis equivalent circuit of induction machine is shown in Figure 3 (a) and 3 (b).



3(a) d-axis



3(b) q-axis

Fig. 3: Induction Machine equivalent circuits 3(a) d-axis 3(b) q-axis

The electrical equations are given by:

$$V_{qs} = R_s i_{qs} + \frac{d}{dt}\phi_{qs} + \omega \phi_{ds} \quad (4)$$

$$V_{ds} = R_s i_{ds} + \frac{d}{dt}\phi_{ds} - \omega \phi_{qs} \quad (5)$$

$$V'_{qr} = R'_r i_{qr} + \frac{d}{dt}\phi'_{qr} + (\omega - \omega_r)\phi'_{dr} \quad (6)$$

$$V'_{dr} = R'_r i_{dr} + \frac{d}{dt}\phi'_{dr} - (\omega - \omega_r)\phi'_{qr} \quad (7)$$

$$T_e = 1.5\, p\left(\phi_{ds} i_{qs} - \phi_{qs} i_{ds}\right) \quad (8)$$

Where

$$\phi_{qs} = L_s i_{qs} + L_m i'_{qr} \quad (9)$$

$$\phi_{ds} = L_s i_{ds} + L_m i'_{dr} \quad (10)$$

$$\phi'_{qr} = L'_r i'_{qr} + L_m i_{qs} \quad (11)$$

$$\phi'_{dr} = L'_r i'_{dr} + L_m i_{ds} \quad (12)$$

With

$$L_s = L_{ls} + L_m \quad (13)$$

And

$$L'_r = L'_{lr} + L_m \quad (14)$$

The mechanical Equations are given by-

$$\frac{d}{dt}\omega_m = \frac{1}{2H}\left(T_e - F\omega_m - T_m\right) \quad (15)$$

$$\frac{d}{dt}\theta_m = \omega_m \quad (16)$$

Where

R_s, L_{ls} - Stator resistance and leakage inductance
R'_r, L'_{lr} - Rotor resistance and leakage inductance
ω_r - Electrical angular velocity
θ - Electrical rotor angular position
T_e - Electromagnetic torque
L_m - Magnetizing inductance
L_s, L'_r - Total stator and rotor inductances
Vqs, iqs - q-axis stator voltage and current
V'qr, i'qr - q-axis rotor voltage and current
Vds, ids - d-axis stator voltage and current
V'dr, i'dr - d-axis rotor voltage and current
Øqs, Øds - Stator q and d-axis fluxes
Ø'qr, Ø'dr - Rotor q and d-axis fluxes
θ_m - Rotor angular position
P - Number of pole

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III. STATCOM

STATCOM is a shunt controller primarily used to regulate voltage by generating/absorbing reactive power. They're effective for damping electromechanical oscillations. The STATCOM is FACTS controller supported voltage source converter (VSC) Technology. STATCOM perform faster response due to its turn-on and turn-off capabilities. Different types of shunt compensators are presently being used in power system. The schematic diagram of STATCOM is shown in Fig 4.

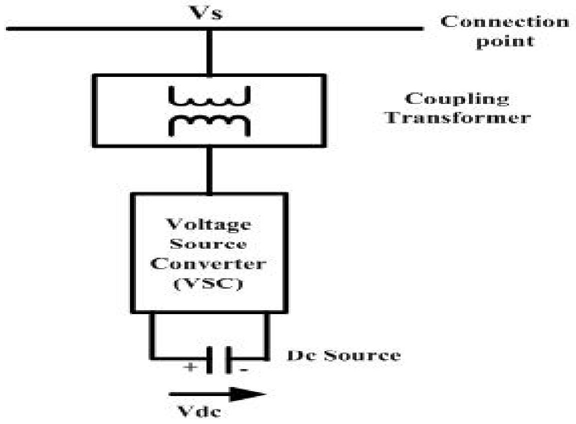

Fig. 4: STATCOM

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A. *Operating Principle of STATCOM*

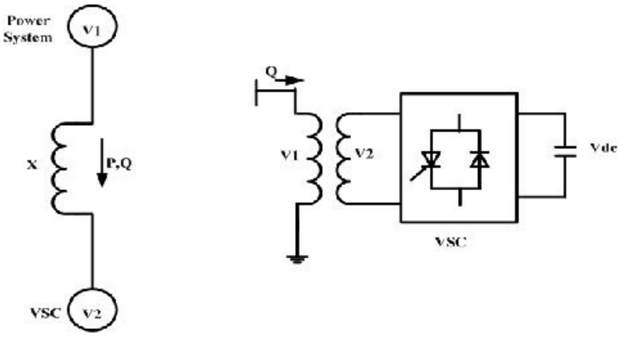

Fig. 5: Operating Principle of STATCOM

When system voltage is low, the STATCOM generates capacitive reactive power of STATCOM. When system voltage is high, it absorbs inductive reactive power of STATCOM. The variation in reactive power is performed by means of a voltage source converter(VSC) connected on the secondary side of transformer. The principle of operation of the STATCOM is explained on the Fig 5 showing the active and reactive power transfer between a source V1 and a source V2. during in this figure, V1 represents the system voltage to be controlled and V2 is the voltage generated by the VSC.

$$P = \frac{V_1 V_2 \sin\delta}{X} \quad (17)$$

$$Q = \frac{V_1(V_1 - V_2\cos\delta)}{X} \quad (18)$$

Where

V_1=line to line voltage of source V_1

V_2=line to line voltage of V_2

X=Reactance of interconnection Transformer and filters

δ= angle of V_1 with respect to V_2

In steady state operation, the voltage V2 generated by the VSC is in phase with V1 =0, so that only reactive power is flowing (P=0). If V2 is lower than V1, Q is flowing from V1 to V2 (conductive reactive power). On the reverse, if V2 is higher than V1, Q is flowing from V2 to V1 (inductive reactive power). The amount of reactive power is given by-

$$Q = \frac{V_1(V_1 - V_2)}{X} \quad (19)$$

A condenser connected on the DC side of the VSC acts as a DC source. In steady state the voltage V2 has to be part shifted slightly behind V1 so as to compensate for transformer and VSC losses and to keep the condenser charged.

B. *V-I Characteristics of STATCOM*

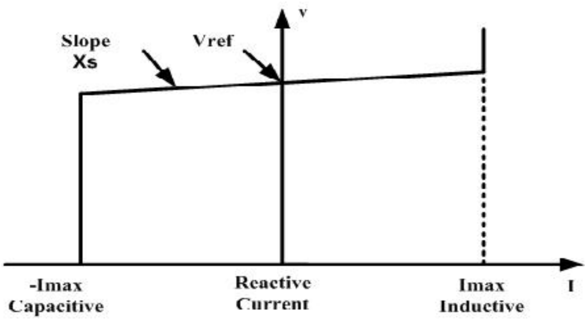

Fig. 6: V-I Characteristics of STATCOM

As long because the reactive current stays within the minimum and minimum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. However, a voltage droop is generally used (usually between 125th and 4wd at most reactive power output), and therefore the V-I characteristic has the slope indicated within the fig 6. In the voltage regulation mode, the V-I characteristic is represented by the following equation:

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$$V = V_{ref} + X_S I \quad (20)$$

Where

V=Positive Sequence Voltage (Pu)

I=Reactive Current (I>0 indicates an Inductive Current)

Xs=Slope or Droop Reactance

IV. SYSTEM MODEL OF WIND FARM WITH STATCOM

A distribution system supplying a wind farm is concerned for study. The system diagram is shown in Figure 7.

STATCOM of appropriate rating is connected in parallel with the wind farm. 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 20-km 25-kV feeder. The 9-MW wind farm is simulated by 3 pairs of 1.5 MW wind-turbines. SEIG, in this model every turbine includes a protection system to monitoring voltage, current and machine speed of the system.

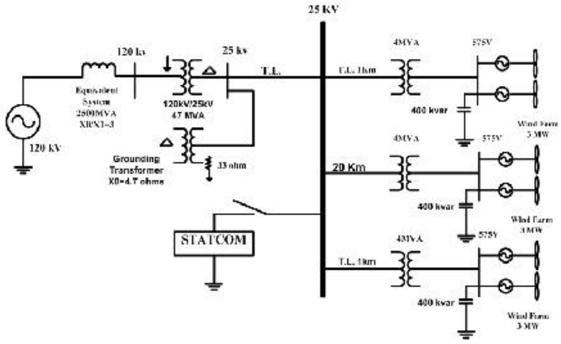

Fig. 7: System diagram of wind Farm with STATCOM

A. Simulink Model of Wind Farm

Fig 8 shows the simulation model of wind farm system that correlates to the system configuration shown in Figure 7. In terms of source, Wind Farm, STATCOM, and Bus.

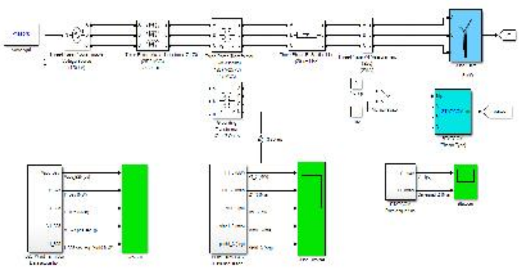

Fig. 8: Simulink Model of Wind Farm

B. Simulation Results of Wind Farm

Wind Turbines system monitoring active, reactive power, generator and wind speed and pitch angle of wind turbine with and without STATCOM as shown in Fig 9 and 10. For every pair of turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3 MW in roughly 8s, the pitch angle is increased from 0 deg to 8 deg in order to bring output power back to its nominal value. The effect of a phase--phase to ground fault with wind turbine. The ground fault is initiated at t = 10s and cleared at t = 10.1s as shown in Figure 9 and 10.

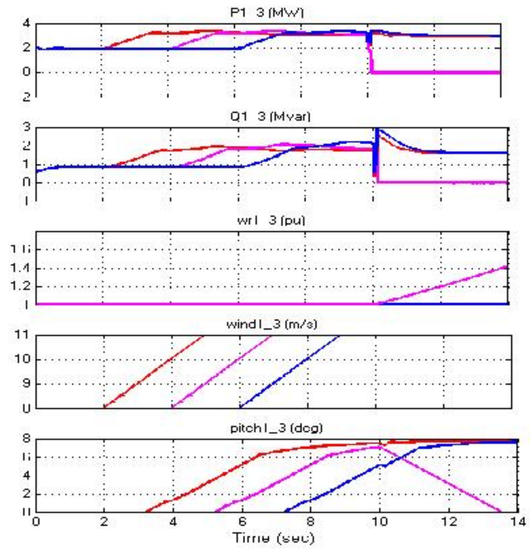

Fig. 9: Active power, reactive power, generator speed, wind speed and pitch angle with STATCOM

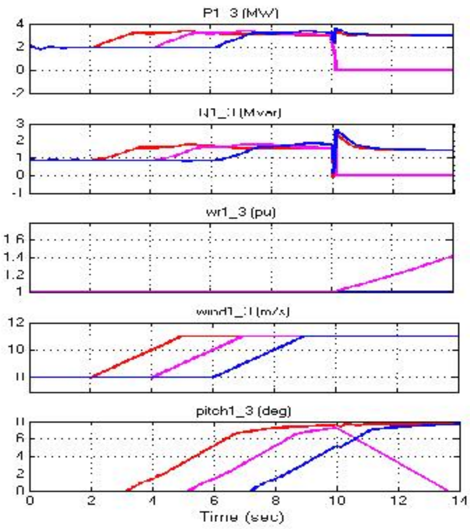

Fig. 10: Active power, reactive power, generator speed, wind speed and pitch angle without STATCOM

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Now we will observe the Waveform of Voltage, Current, Active and Reactive power at "B25" with and without STATCOM as shown in Figure 11 and Figure 12.

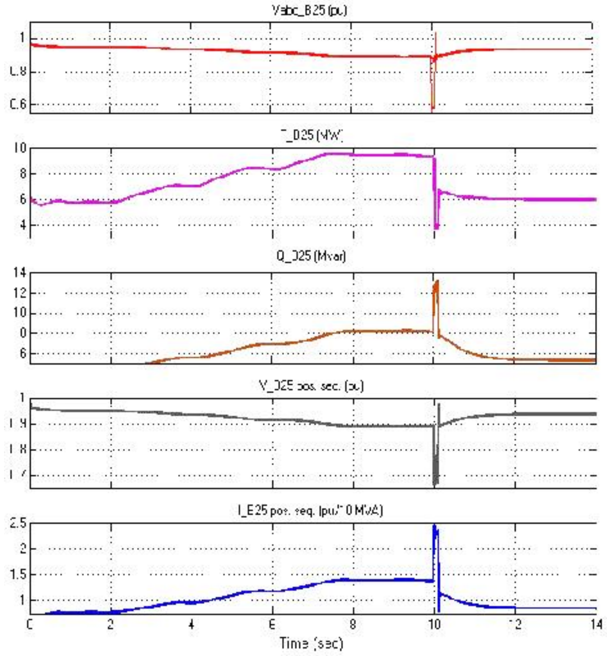

Fig. 11: Waveform of Voltage, Current, Active Power, Reactive Power on the Bus25 with STATCOM

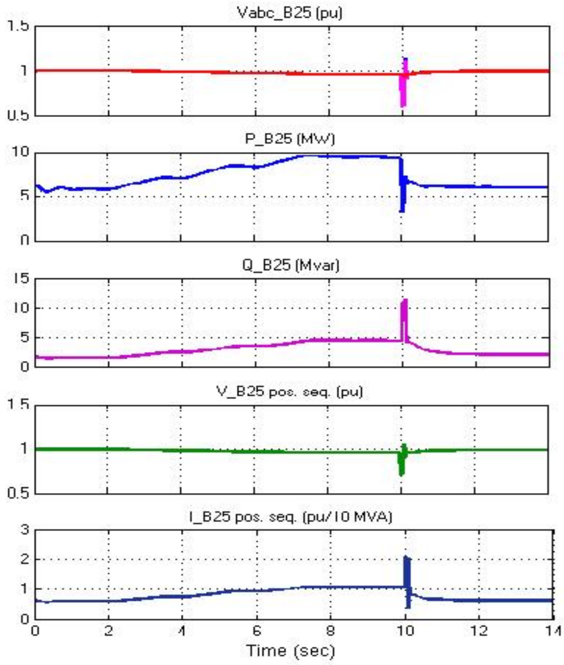

Fig. 12: Waveform of Voltage, Current, Active Power, Reactive Power on the Bus25 without STATCOM

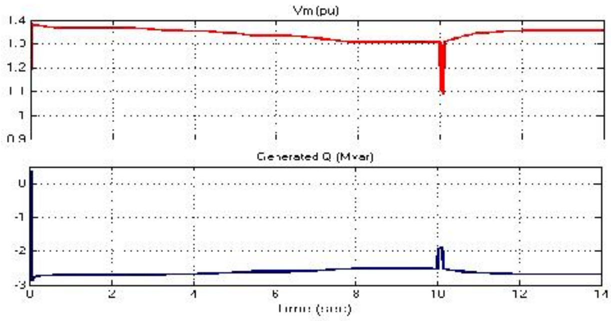

Fig. 13: Waveform of Active and Reactive Power of STATCOM

CONCLUSION

Power system with wind farms performance will be improved using FACTS devices such as STATCOM. FACTS devices are power electronics device primarily based on reactive compensators that are connected in a power system and are capable of up the facility system transient performance. during this paper system stability of SCIG wind farms has been investigated. The dynamic model of the studied power system is simulated using Simulink/Matlab package software. The Statcom will normally exhibits a quicker response as a result of with the voltage source converter (VSC), the STATCOM has no delay related to the thyristor firing. therefore STATCOM provides quick acting dynamic reactive compensation for voltage support during contingency event which would otherwise depress the voltage for a significant length of time.

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