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Dynamic Performance of STATCOM on the Induction Generator based Wind Farm

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Abstract: In recent years generation of electricity using wind power has received considerable attention worldwide. Induction machines are mostly used as generators in wind power based generations. Since induction machines have a stability problem as they draw very large reactive currents during fault condition, reactive power compensation can be provided to improve stability. This paper deals with the Impact of STATCOM on the Wind Farm performance. A Case Study is represented by considering a wind farm consisting of six 1.5-MW wind turbines. Self Excited squirrel cage Induction Generator (SEIG), which uses an excitation capacitor, is used widely to convert mechanical wind energy to electricity, due to their low cost, small size, no need of separate dc source and brushes. The complete electromechanical system is modeled and simulated in MATLAB using Simulink and PSB (Power System Blockset) toolboxes.

Key words: STATCOM, PSB, Wind Farm, Reactive Power, Bus.

Nomenclature

Wind Turbine

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)

Induction Machine

R_s, L_{ls} Stator resistance and leakage inductance
R'_r, $L'l_r$ 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
V_{qs}, i_{qs} q-axis stator voltage and current
V'_{qr}, i'_{qr} q-axis rotor voltage and current
V_{ds}, i_{ds} d-axis stator voltage and current
V'_{dr}, i'_{dr} d-axis rotor voltage and current
¤$_{qs}$, ¤$_{ds}$ Stator q and d-axis fluxes
¤$'_{qr}$, ¤$'_{dr}$ Rotor q and d-axis fluxes
θ_m Rotor angular position
P Number of pole pairs

Introduction

The presence of wind power generation is likely to influence the operation of the existing power system networks, especially the power system stability. Majority of the wind power based DG technologies employ induction generators. Induction generator can operate either connected to a power network or as standalone generator. The analysis of connected induction generator is simpler because its voltage and frequency are determined by the power system grid. However, islanding (disconnecting) of a connected IG disturbs its voltage and frequency, due to lack or surplus of reactive and active power [1]. The most effective way to control a wind turbine captured power is to adjust the blade pitch angle. Blade pitch is analogous to the throttling valve in conventional steam turbines, except that its response is much faster than that of steam turbines [2]. A squirrel cage IG draws reactive power for magnetization from it's terminals which is undesirable. To solve this problem a fixed shunt capacitor bank is connected to the IG terminals to provide the magnetization current and even supplying reactive power to the local load. But now a days, a power electronics based FACTS controller (i.e. STATCOM, SVC,…) is also paralleled to IG, to improve the response of the system to sudden changes such as islanding, fault… .

There exists a large amount of bibliography on this subject. Some authors analyzed and modeled an induction generator with an excitation capacitor [3,4]. Application of new control techniques such as sliding mode , output feedback , state feedback, … are presented in [1,2,5]. Reference [6] uses D-Statcom to maintain the voltage profile of IG. Moern et al worked on frequency control of an induction generator considering IG and turbine inertia [7].

This paper presents a simple and efficient model for a Wind Farm consisting of: Wind Turbine, Induction generator, STATCOM and bus. The model clearly describes the dynamic behavior of bus voltage of a Wind Farm. Smulink based simulation results verify the validity of the proposed model.

Distribution System Models

Distribution systems are inherently unbalanced due to the asymmetrical line spacing and imbalance of customer load.
In view of this, single phase models cannot be used for accurate studies on the operation of distributed systems. Therefore in this work all network components are represented by the three-phase models.

Wind Turbine Induction Generator (WTIG)

The block diagram of wind turbine induction generator (WTIG) is shown in Figure1. The stator winding is connected directly to the 60 HZ grid and the rotor is driven by a variable-pitch 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. In order 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, according to the wind speed variations. 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. The pitch angle control system is illustrated in the Figure 2.

Figure1. Wind Turbine Induction Generator

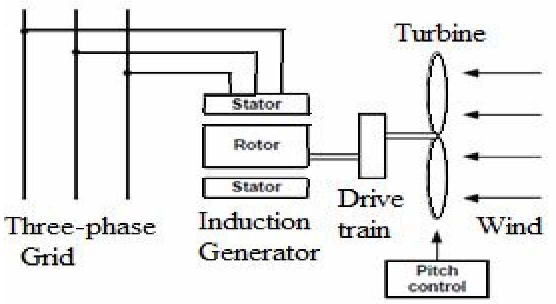
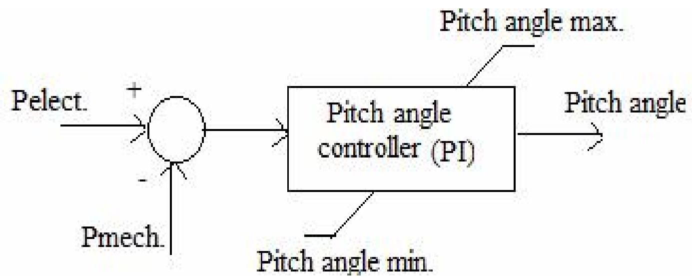


Figure2. Control System for pitch angle control



Wind Turbine

The wind turbine model is employed in 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 as well as the wind speed and is expressed as:

$$P_m = C_p(a,\ )\frac{°A}{2}V_{wind}{}^3$$

$$C_p(a,\ ) = c_1(\frac{c_2}{a_i} - c_3\ \ - c_4)\exp(-\frac{c_5}{a_i}) + c_6 a$$

with

$$\frac{1}{a_i} = \frac{1}{a + 0.08} - \frac{0.035}{{}^3 + 1}$$

Induction Machine

In the present study, the electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. All stator and rotor quantities are in the arbitrary two-axis reference frame (d-q frame). The d-axis and q-axis block diagram of the electrical system is shown in Figures. 3 (a) and 3 (b).

The electrical equations are given by:

$$v_{qs} = R_s i_{qs} + \frac{d}{dt}¤_{qs} + µ¤_{ds}$$

$$v_{ds} = R_s i_{ds} + \frac{d}{dt}\text{¤}_{ds} - \mu\text{¤}_{qs}$$

$$v'_{qr} = R'_r i_{qr} + \frac{d}{dt}\text{¤}'_{qr} + (\mu - \mu_r)\text{¤}'_{dr}$$

$$v'_{dr} = R'_r i_{dr} + \frac{d}{dt}\text{¤}'_{dr} - (\mu - \mu_r)\text{¤}'_{qr}$$

$$T_e = 1.5p(\text{¤}_{ds} i_{qs} - \text{¤}_{qs} i_{ds})$$

Where

$$\text{¤}_{qs} = L_s i_{qs} + L_m i'_{qr}$$

$$\text{¤}_{ds} = L_s i_{ds} + L_m i'_{dr}$$

$$\text{¤}'_{qr} = L'_r i'_{qr} + L_m i_{qs}$$

$$\text{¤}'_{dr} = L'_r i'_{dr} + L_m i_{ds}$$

With

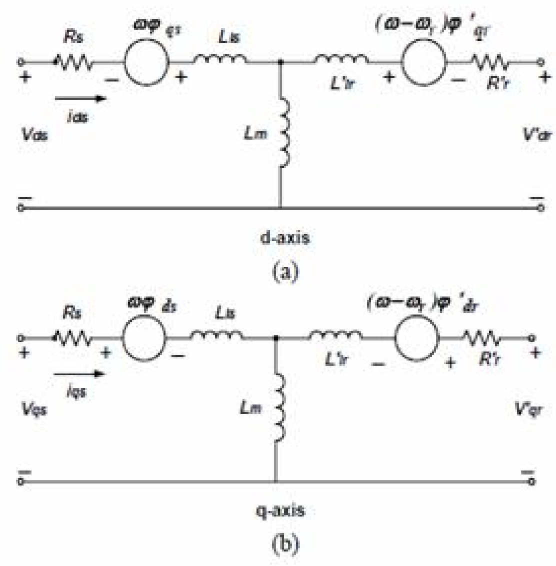
$L_s = L_{ls} + L_m$ and $L'_r = L'_{lr} + L_m$

The mechanical Equations are given by

$$\frac{d}{dt}\mu_m = \frac{1}{2H}(T_e - F\mu_m - T_m)$$

$$\frac{d}{dt}\_{m} = \mu_m$$

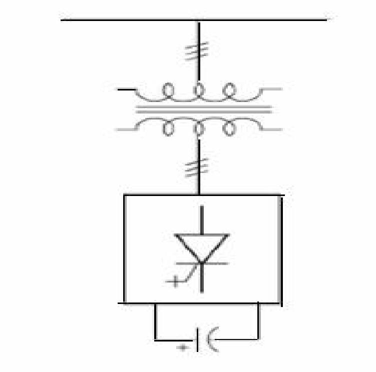
Figure3. Induction Machine equivalent circuits (a) d-axis equivalent circuit (b) q-axis equivalent circuit



STATCOM

Static Synchronous Compensator (STATCOM) is a shunt controller mainly used to regulate voltage by generating/absorbing reactive power. The schematic diagram of STATCOM is shown in Figure 4.

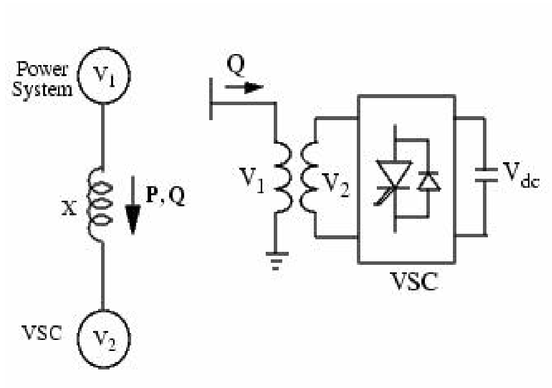
Figure 4. STATCOM Structure



Operating Principle of the STATCOM

When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive).The variation of reactive power is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_2 from a DC voltage source. The principle of operation of the STATCOM is explained on the Figure 5 showing the active and reactive power transfer between a source V_1 and a source V_2. In this figure, V_1 represents the system voltage to be controlled and V_2 is the voltage generated by the VSC

Figure 5. STATCOM Operating principle



$$P = \frac{V_1 V_2 \sin\delta}{X}$$

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

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 V_2 generated by the VSC is in phase with V_1 (=0), so that only reactive power is flowing (P=0). If V_2 is lower than V_1, Q is flowing from V_1 to V_2 (STATCOM is absorbing reactive power). On the reverse, if V_2 is higher than V_1, Q is flowing from V_2 to V_1 (STATCOM is generating reactive power). The amount of reactive power is given by

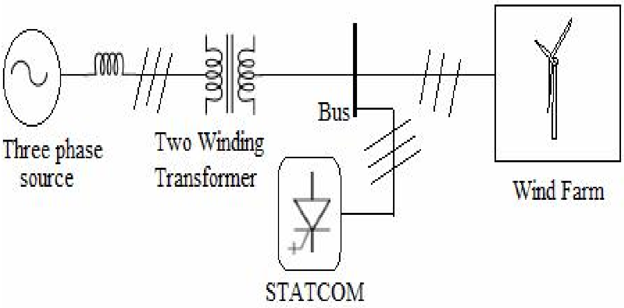
$$Q = \frac{V_1(V_1 - V_2)}{X}$$

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

System Model of Wind Farm with STATCOM (A Case Study)

A distribution system supplying a Wind Farm is taken up for study. The system diagram is shown in Figure 6. A STATCOM of suitable 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 25-km 25-kV feeder. The 9-MW wind farm is simulated by three pairs of 1.5 MW wind-turbines. Each wind turbine has a protection system monitoring voltage, current and machine speed.

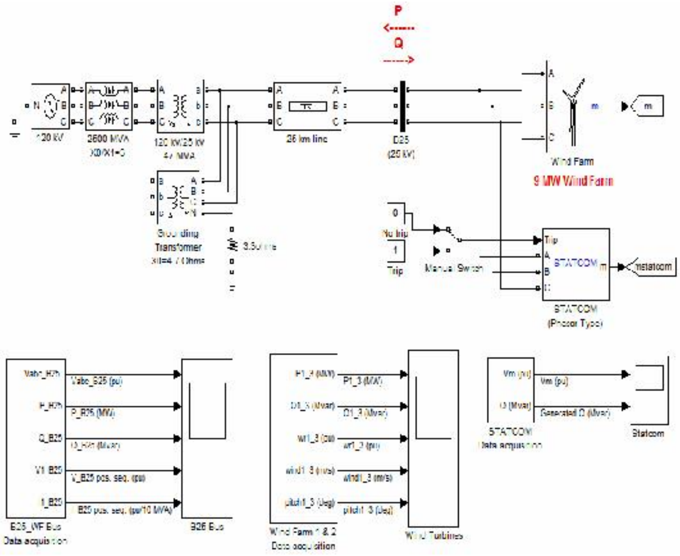
Figure 6. System Diagram



Simulink Model of Wind Farm

Figure 7. shows the basic simulation model of Wind Farm system that correlates to the system configuration shown in Figure 6. in terms of source, Wind Farm, STATCOM, and Bus. Reactive power absorbed by the IGs is partly compensated by capacitor banks connected at each wind turbine low voltage bus (400 kvar for each pair of 1.5 MW turbines). The rest of reactive power required to maintain the 25-kV voltage at bus B25 close to 1 pu is provided by a 3-Mvar STATCOM with a 3% droop setting.

Figure 7. Simulink Diagram of Wind Farm

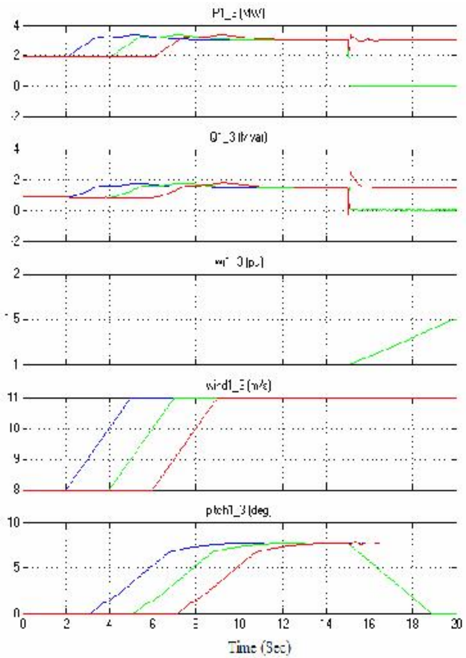


Simulation Results

The simulation of Wind Farm is carried out in MATLAB environment through SIMULINK. From the simulation results, the following observations are made:

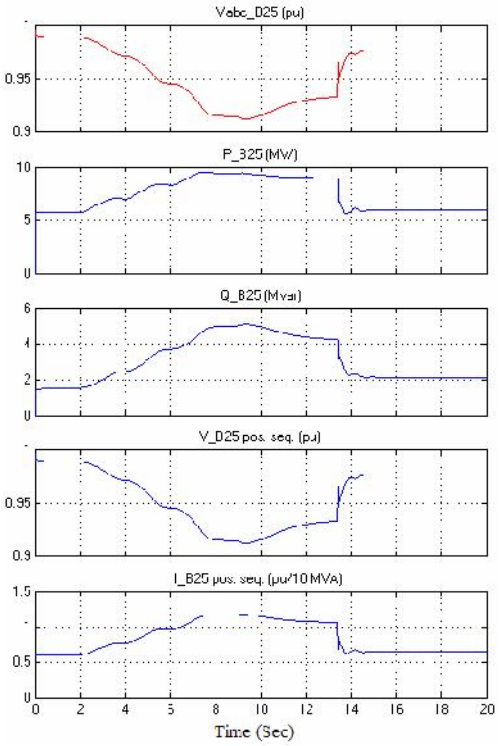
(1) Wind Turbines scope monitoring active and reactive power, generator speed, wind speed and pitch angle for each turbine is shown in Figure 8. For each pair of turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3 MW in approximately 8s. 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.

Figure 8. Waveform of active and reactive power, generator speed, wind speed and pitch angle



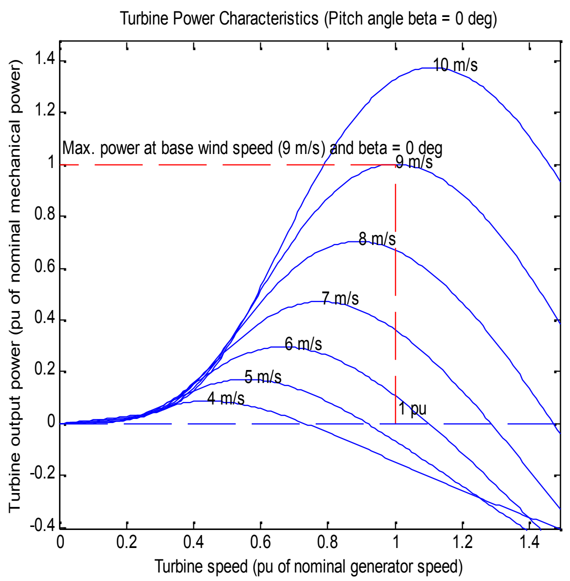
(2)We will now observe the impact of the "STATCOM". By opening the "Fault" block menu and disable the phase to phase fault. Then putting the "STATCOM" out of service. Observe on “B25 Bus" scope as shown in Figure 9. that the voltage at bus "B25" now drops to 0.91pu.

Figure 9.Various Waveform of voltages, current, active and reactive power on the Bus



In Figure 10. The turbine mechanical power as function of turbine speed is displayed for wind speeds ranging from 4 m/s to 10 m/s. The nominal wind speed yielding the nominal mechanical power (1pu=3 MW) is 9 m/s.

Figure10.WindTurbinePowerCharacteris-tic



Conclusion

This paper represents a wind farm model which shows the relation between electrical and mechanical parts of a system which give very deep insight to the system behaviors. When the STATCOM is disconnected with the Wind Farm because of the lack of reactive power support, the voltage at bus "B25" now dropped. This low voltage condition results in an overload of the IG of "Wind Turbine 1". To avoid this STATCOM can be a better choice for required reactive power support.

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