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WIND FARM TRANSIENT BEHAVIOR OPTIMIZING BY CAPACITOR BANKS SWITCHING

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Abstract- The main problem of self exciting induction generators are used in wind farms is its requirement a reactive power to generate output voltage. In order to provide the mentioned reactive power, using of fixed capacitors, that they are connected to generator terminals, is one of the usual methods. Since the requirement of induction generators to reactive power is varied by load changes and wind speed therefore using of variable and switch able capacitor banks can be one of the methods to generate reactive power for induction generators and to keep voltage stability. In this paper accrued transient condition by capacitor banks switching in wind farm are simulated by MATLAB and methods are suggested to optimize mentioned conditions.

Keywords: Induction Generators, Wind Farm, Reactive Power, Capacitor Bank.

I. INTRODUCTION

Recently renewable energy sources such as wind have a great importance to generate distributed energy and power. Induction generators are used in wind farm for many reasons. Their low cost, rotor structure, no need to separated source to excitation, low weight, good reliability and long life are some of the reasons to choose self exciting induction generators as a good chance to use in distributed generation.

One kind of these generators that it uses in wind farm is squirrel cage induction generators which are connected to grid directly. Main weaknesses of these machines are voltage uncontrollability and requirement to absorb reactive power from grid.

The easiest way to solve the induction generators problem, reactive power absorption requirement, is using number of fixed capacitors or changeable that they connect to its terminal [1,2]. These capacitors switching creates some transient voltages in grid which causes problems for equipment. In this paper transient condition, created by switching or out capacitor banks which provide reactive power in wind farm is studied and some its optimization methods are mentioned.

II. TRANSIENT CONDITION CAUSED BY CAPACITOR SWITCHING

Capacitor banks in distribution and industrial grids have a great use to compensate reactive power in recent years. By switching or out capacitor banks to grid relatively transient over voltage and over currents are generated and will create insulating problems and interruption in sensitive load function.

Under following conditions transient voltages states will be worse:

A) At the moment of capacitor bank switching a short circuit occurs at the terminal.
B) Two back to back capacitors switching on a similar bus.
C) Capacitor discharging under short circuit condition.
D) Capacitor switching in higher voltage level at the existence of capacitor in lower voltage level.

In the conditions that two capacitors switching occur in same voltage, transient voltage mainly is because of energy transmission between two capacitors. The maximum switching transient current and its frequency are calculated by equations 1 and 2 [3,4].

$$i_{\max\, peak} = \frac{\sqrt{2}E_{ll}}{\sqrt{3}}\sqrt{\frac{C_1 C_2}{(C_1+C_2)L_m}} \tag{1}$$

$$f = 1/2\pi\sqrt{L_m\frac{C_1 C_2}{C_1+C_2}} \tag{2}$$

where C_1 and C_2 are capacitance in F. L_m is the circuit inductance between two capacitors in H. It’s necessary to study transient over current changes ratio while using capacitors switching in back to back mode in order not to let it be more than maximum connecting and disconnecting switches symmetrical cut power changes ratio. For conditions that capacitor switching occurs in two voltage level in distribution grid and installed capacitor switches in high voltage side greater transient over voltage occurs in the position of capacitor installed in lower voltage level. This is for the fact that the switching resonance frequency is close to the system frequency. Over voltage value is calculated as follow:

$$\frac{f_c}{f_m}=\sqrt{\frac{L_m C_m}{L_s C_s}} \tag{3}$$

where f_c is coupling frequency, f_m is switching main frequency and L_s and C_s are secondary circuit inductance and capacitance respectively. As small as this relation is transient conditions depending in secondary to capacitor switching in primary increases [4].

III. WIND TURBINE MODEL

The mathematical relation for the mechanical power extraction from the wind can be expressed as follows:

$$P_m=\frac{1}{2}\rho\pi R^2 C_p V_\omega^3 \tag{4}$$

where, P_m is the extracted power from the wind, ρ is the air density, R is the blade radius (m), V_ω is the wind speed (m/s) and C_p is the power coefficient which is a function of tip speed ratio, λ, and blade pitch angle, β (deg). C_p can be shown from the following equation [5].

$$C_p=\frac{1}{2}\left(\lambda-0.022\beta^2-5.6\right)e^{-0.17\lambda} \tag{5}$$

$$\lambda=\frac{V_\omega}{\omega_B} \tag{6}$$

Simulation of wind farm control model and wind turbine model is shown in Figures 1 and 2.

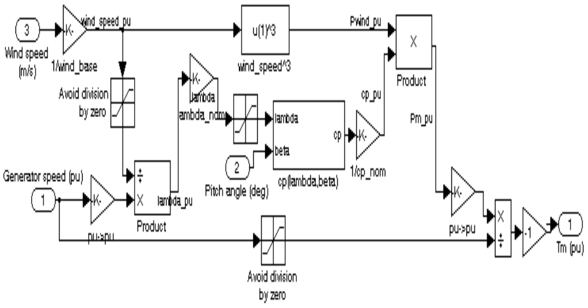

Figure 1. Wind turbine control model

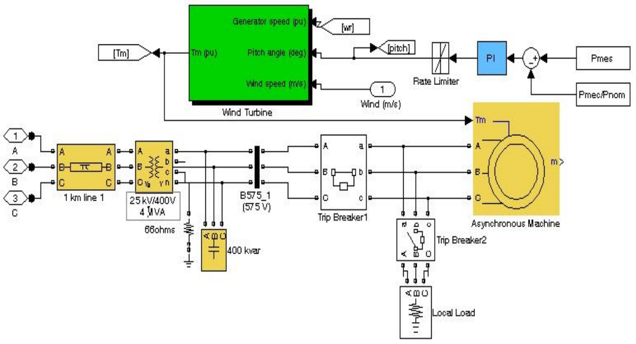

Figure 2. Wind turbine model

IV. INDUCTION GENERATOR MODEL

Induction generator is modeled using d-q equations as below.

$$\begin{aligned}
V_{sd}&=R_s i_{sd}+\frac{d}{dt}\lambda_{sd}-\omega_d\lambda_{sq}\\
V_{sq}&=R_s i_{sq}+\frac{d}{dt}\lambda_{sq}-\omega_d\lambda_{sd}\\
V_{rd}&=R_r i_{rd}+\frac{d}{dt}\lambda_{rd}-\omega_{dA}\lambda
\end{aligned} \tag{7}$$

$$\omega_{dA}=\omega_d-\omega_m \tag{8}$$

$$T_{em}=\frac{P}{2}=(\lambda_{rq}i_{rd}-\lambda_{rd}i_{rq}) \tag{9}$$

$$T_{em}-T_L=J_{eq}\frac{d}{dt}\omega_{mech} \tag{10}$$

Here, V_{rd}, V_{rq}, i_{rd}, i_{rq}, λ_{rd}, λ_{rq} are rotor quantities and V_{sd}, V_{sq}, i_{sd}, i_{sq}, λ_{sd}, λ_{sq} are stator quantities. Ω_d is synchronous reference frame speed and ω_m is rotor speed in electrical radians per second. Here it is to be noted that T_L is load torque, but for modeling the induction machine as generator it is considered as negative torque [6].

V. TEST SYSTEM MODEL

The system studied in this paper has a 3 MW wind turbine which is connected to 400 volts grid. Mentioned unit is connected to grid by a 0.4/ 20 kV transformer and a 20 kV distribution line with 25 km length and a 20/132 kV transformer. Generator used in this model is a squirrel cage induction generator and connected to grid directly. In the connection point in order to compensate required reactive power, capacitor bank is used. Test system model is shown in Figure 3. Induction generators equivalent circuit with grid equivalent impedance is shown in Figure 4.

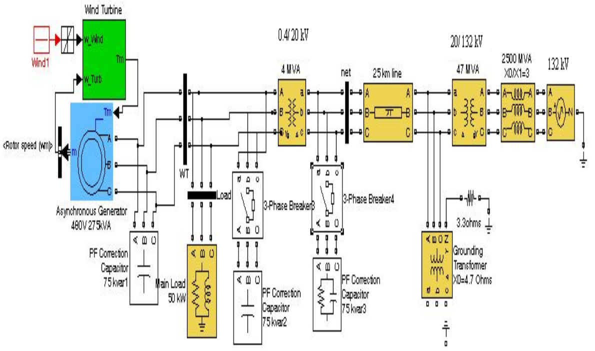

Figure 3. Test system model

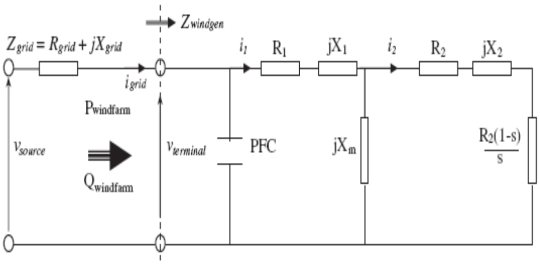

Figure 4. Induction generator and grid impedance equivalent circuit

With respect to the circuit above induction generator output active and reactive power is calculated by (11), (12) and (13).

$$Z_{WINDGEN} = \left\{ \begin{matrix} \left[\left(\frac{R_2}{S} + jX_2 \right) \| (jX_m) \right] \\ + R_1 + jX_1 \end{matrix} \right\} \| jX_{PFC} \quad (11)$$

$$i_{grid} = \frac{U_{source}}{Z_{grid} + Z_{windgen}} \quad (12)$$

$$V_{terminal} = V_{source} - i_{grid} \times Z_{grid} \quad (13)$$

In Figure 4 fixed capacitor connected to induction generator terminal is for initial excitation. This capacitors volume is calculated by numerical methods. Required reactive power for generator varies by load changing and wind speed. These changes are shown in Figure 5 for condition where wind speed changes from 7m/s to 11 m/s in 0.1 second.

Wind generator connected to distribution network with low short circuit capacity and in some conditions can end to voltage instability and at last end to wind units failure. In this condition reactive power providing is one of the necessary affairs in order to keep the wind units stability.

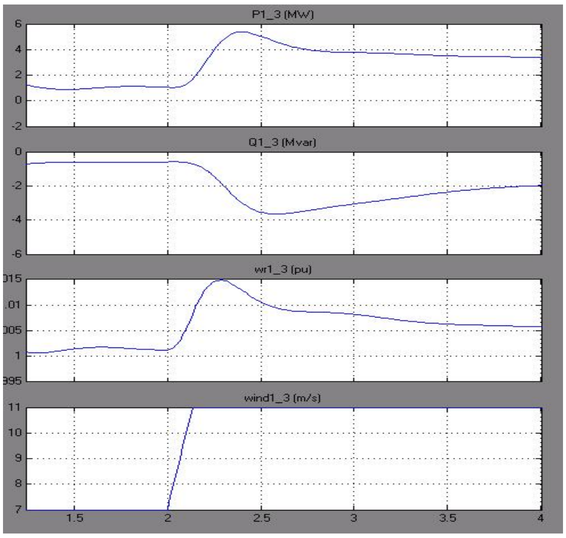

Figure 5. Induction generator active and reactive power changes with wind speed changes

So reserve capacitor banks will be switched. Induction generator electrical torque is proportional with terminal voltage second order. So capacitor banks switching will cause bus voltage oscillation which at last above oscillation pulses will be transmitted to machine shaft. In order to study the above conditions, system is modeled in two parts:

Part one:

a) More reactive power is provided in 0.4 kV bus by assuming constant wind speed or in other words constant mechanical torque.

b) By keeping above condition switching is modeled in 20 kV bus.

Part two:

a) Under condition where wind speed is assumed to be constant at 7 m/s, additional capacitor is out of circuit in 0.4 kV bus.

b) Under condition where wind speed is assumed to be constant at 7 m/s, additional capacitor is out of circuit in 20 kV bus.

VI. SIMULATION RESULTS

Figures 6 and 7 show active and reactive power of generator terminal voltage while capacitor bank switching in 0.4 and 20 kV bus. This fact is under condition where by switching the equivalent capacitor by the previous condition in 20 kV bus, the over voltage will be 2.1 pu which is because of capacitors switching in a higher voltage level.

So in distribution grids where wind farm connected to grid, we should be sure of capacitor banks installation and exploitation condition.

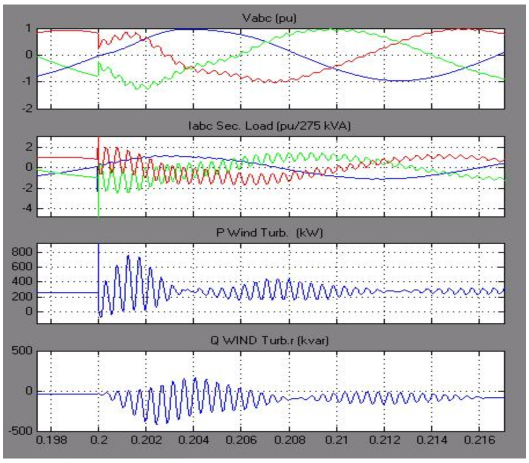

Figure 6. Capacitors switching in 0.4 kV bus

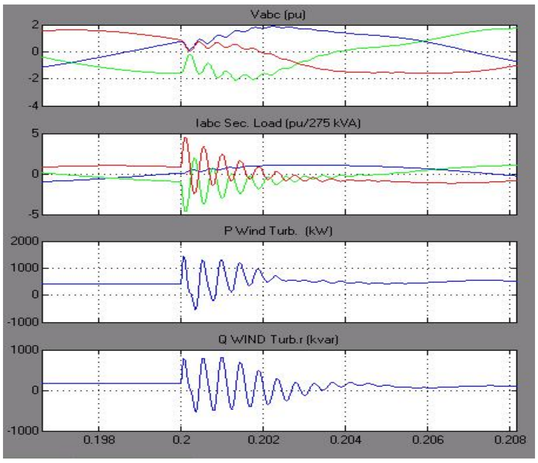

Figure 7. Capacitors switching in 20 kV bus

Why capacitors switching is source of over voltage in power plant bus and causes oscillation in induction generator output power as you see in Figures 6 and 7.

Reactive and active output powers are facing problem till oscillation damping conditions creation after capacitors switching and for capacitor switching in higher voltage conditions are worse and units failure possibility is more. Also, under conditions where wind speed decreases and reactive power providing necessarily for induction machine disappears, capacitor existence is affective in machine dynamic conditions.

For the above condition wind speed is assumed 7 m/s and additional capacitors out is simulated. And its results in 20 kV and 0.4 kV voltage levels are presented in Figures 8 and 9. Respectively as its seen capacitors out, in addition to oscillating induction machines active and reactive power, it provides conditions to have a voltage damping. 20 kV side capacitors switching provide worse conditions for the wind unit. In this condition instability and unit out possibility is more often.

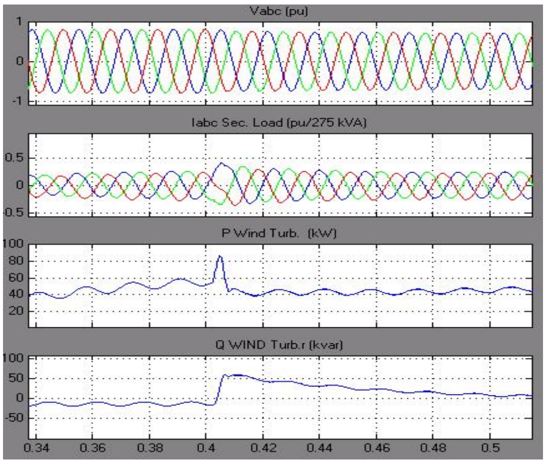

Figure 8. Capacitor out in 0.4 kV bus

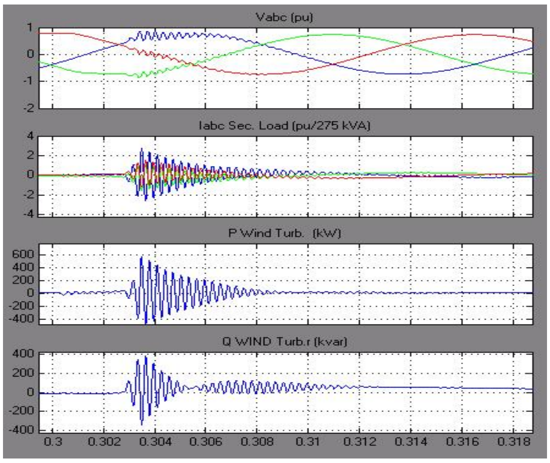

Figure 9. Capacitor out in 20 kV bus

Results show that in order to have a balance in transient condition to provide induction units reactive power, using switchable capacitor banks in the same level voltage is more appropriate. Since this issue is not practical, it is necessary to create a transient analysis to determine the extra voltages domain before exploitation. From below factors, the conditions can be controlled also.

a) Series current limiting reactor.
b) Capacitor banks divided to smaller steps.
c) Surge arrester.

VII. CONCLUSIONS

This paper studies capacitor bank switching conditions at the existence of wind farm in a distribution grid. Studies results show the fact that before using any controllable capacitor banks to compensate the induction units required reactive power, it's necessary to study the grid at the point of transient condition caused by capacitors switching.

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BIOGRAPHIES

Ghasem Ahrabian received the Dipl.-Ing. degree on Starkstrom Technik from the RWTH, Aachen, Germany in 1969. From 1970 to 1971 he worked for AEG, Frankfurt, Germany on electric distribution system planning. From 1972 to 1977 he was a lecturer of Electrical Engineering at University of Tabriz, Tabriz, Iran. From 1977 to 1979 he was as postgraduate student in UMIST, England, where he received M.Sc. degree on Power System. From 1980 to 2007 he was a professor of Electrical Engineering of University of Tabriz. In February 2007 he was retired. During his working in University of Tabriz he was from 1988 to 1989 in RWTH Aachen, Germany and 1996 to 1997 in Electrical Engineering Department of University of Saskatchewan, Canada in Sabbatical leave. His research interest is in electrical machines, modeling, parameter estimation and vector control.

Amin Lafzi was born in Urmia, Iran in 1981. He received the B.Sc. degree and M.Sc. degree in power electrical engineering from University of Tabriz, Iran in 2008. His research interests include renewable energy applications in power systems and power quality.