Voltage Stability using STATCOM for a Wind Generator Connected Grid

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Abstract: *Electrical power system is a very dynamicstructure, it is increasing day by day in response to the growth of society, and the demand is increasing consistently in a power square manner. Supporting the electrical power from traditional sources is no longer sustainable therefore; wind power generation has found its great integration with the traditional grid. From the literature, it can be found that there is a tremendous growth in the evolution of wind power generation system, which has been recognized as user friendly, and environmental friendly from economic point of view of electrical power generation system. With a vision to harvest more renewable power Government of India, it supporting various private player as well as government funded organization to install wind power as a substitute to meet their present electrical demand. From a study it has been found that when power is going to influence the conventional power generation system and thereby affecting their dynamic response and over I will power system performance. Therefore, it is required to study the impact of wind power system in order to identify the nature of potential problems to develop their mitigation techniques.*
Key Words: *- IEEE-14 Bus, DFIG, SCIG, Reactive Power, Real Power*

I. Introduction

The dynamic behavior of power system is usually determined by the nature of generators connected with the transmission system. Wind turbines usually affects the power system in a different way as compared to the conventional generating units. Therefore, the major power quality issues that has to be addressed are transient stability and voltage stability. From IEEE definition, it is found that voltage stability mean maintaining voltage within the operational limit at its different Buses. In contradiction, maintaining transient stability after a small and large fluction is a great concern in power system stability analysis.

Out of different wind turbine generators some popular generators which are used are squirrel cage induction generator, variable speed drive generator, doubly fed induction generator, permanent magnet synchronous generator and electrically excited synchronous generator. For operating the wind generator at a particular speed requires squirrel cage induction generator supported by a capacitor Bank for self-excited can achieve maximum efficiency. In contradiction to squirrel cage induction generator electrically excited synchronous generator required an additional converter for generating excitation system to the router. A large number of pole is required for permanent magnet synchronous generator to generate same amount of power that allows small pole pitch, it is also worthwhile to mention here that the absence of field winding results in higher efficiency.

Generator converter set consisting of of different control strategies are available in the market for meeting the required power demand for a particular wind speed. In this paper Step Up boost converter, step and search algorithm for controlling maximum power and DQ current control system has been used based on hysteresis band controller. The state and search algorithm used in this paper tracks the maximum power from the DC source and its corresponding control logic. The DQ transformation system enables the control of separate real and reactive power as an AC output variable. Hysteresis band control provides control over current major function of current variation and thereby optimizing the switching frequency and total harmonic distortion label that supply the current. The switching frequency can be made variable by changing the band size and the step size.

This paperwork tries to design a variable speed direct drive wind turbine generator with modified controller and investigates the performance of fixed speed squirrel cage induction generator along with capacitor Bank and double fed induction generator with standard control scheme. As because more number of wind generators uses fixed speed wind turbine equipped with simple induction generator therefore study of voltage stability is a key issue in in induction generator system. Induction generator usually consumes reactive power during contingency analysis and thereby deteriorating the local grid voltage stability. Controlling the grid voltage and power factor can be achieved by using doubly fed induction generator because they operate on power electronic converter and thereby generating their own reactive power demand. Because of the use of pulse width modulation the capability of double fed induction generator is limited when controlling the large

voltage. Double fed induction generator uses a small size of converter however; they disturb the power system largely because their stator winding is directly connected to the electrical grid. In contrast to double fed induction generator externally excited synchronous generator provides better performance and thereby supplies more amount of reactive power to the power system. Electrically excited synchronous generator are usually silent pole electrical machine, which are excited from the power grid. For providing operation on the low speed condition, a high pole count synchronous generator is usually recommended on the distorted condition. Overexcitation, system for controlling reactive power is possible with electrical excited synchronous generator thereby enabling The Unity power factor operation of the generator.

In order to verify the operation of wind generators IEEE-14 bus test system has been started with MATLAB Simulink software in this paper. Different power quality issues such as voltage collapse reactive power management and loading margin has been investigated in this paper. Simulation results as obtained under different condition source the superior performance of electrical excited synchronous generator and permanent magnet synchronous generator different loading conditions.

Operating Characteristics of Wind Turbine

Almost all the wind turbine share some common features such as startup, cut-in and cutout speed of winds. Figure 1 shows a typical output of wind turbine showing the cut-in speed and cut out speed. From the figure, it can be found out that the cutting speed is usually 3 metre per second of wind speed. From cutting speed to rated output, Speed the curve is slightly proportional to each other between Power output and wind speed. Startup wind speed is that speed which return and unloaded Rotor from its stand still position to a rotating position. Similarly, cut in speed is the minimum speed at which the blade rotate and generate usable power. For most of the wind generator, this speed is generally 12 kilometer per hour. Betz limit defines the maximum retrievable power from the wind turbine and for most of the turbine, it is 59%.

a. Fixed Speed Wind Turbine

Fixed speed wind generator are usually squirrel cage type of induction generator provided with a capacitor bank for self-excitation system. Figure number 2 shows a schematic diagram of fixed speed squirrel cage type induction generator. Out of the different generator parameters rotor of the Wind Turbine and gearbox are necessary to match the wind speed from which the power is to be extracted. Unlike other in induction generator the slip is slightly variable with the the amount of real power bank generated and therefore is not constant.
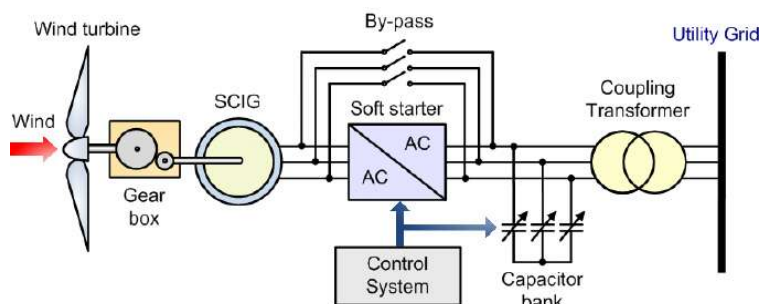

Fig.1. Fixed Speed Wind Turbine

As the variation in the wind, speed is within 1% therefore this type of wind turbine,are constant speed or fixed speed turbine. Fixed speed wind turbine usually generates power when the turbine shaft rotates faster than the frequency of the electrical grid to which it is connected and thereby creating a negative slip for the system. Due to unavailability of optimal TSR, deficiency cannot be maximized for fixed speed system. Here the output power can only be controlled by varying the pitch angle.

b. Variable speed wind turbine

Wind turbine having there is greater than one is categorized as gear drive system and comes under variable speed wind turbines. Double fed induction generator comes under this category where a gearbox is usually located in between the rotor shaft and generator shaft. Objective of the gearbox is to increase the speed of the shaft and thereby decreasing the torque, therefore small number of poles is enough to generate optimum power output of the generator. Due to use of number of gearbox, the complexity of the system is higher as compared to the direct drive system thereby making the variable speed wind turbine as less reliable. Due to the use of gearbox the maintenance and repair, cost is higher as compared to fixed speed wind turbine.
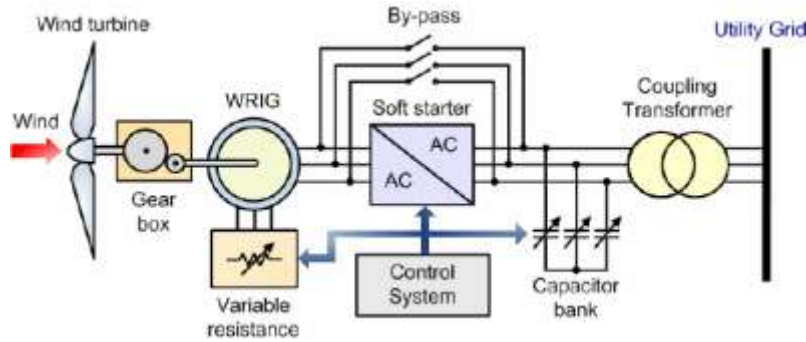
Fig.2. Variable Speed Wind Turbine

Hear the stator winding is directly connected to the grid to which it is connected and rotor winding is connected to a power electronic converter with suitable reactor. The power converter that is connected to the rotor part consists of a back-to-back voltage source converter control by an inner current control loop. In this way, the electrical and mechanical rotor frequencies are coupled to each other and the power electronic converter connecting the two system compensates the difference frequency by injecting rotor current in conjunction with variable frequency. Figure 2 shows the variable frequency wind turbine generating system consisting of a doubly fed induction generator.

c. Direct drive Synchronous Generator

Hear the gear ratio; is usually one thereby enabling the wind generator to be connected directly to the Grid? A low speed multipole wind generator with compatible rotational speed converts the mechanical energy into its corresponding electrical energy. Permanent magnet generator are usually used for direct drive synchronous generator. Unlike variable speed wind, turbine generator the stator is connected to the grid voltage source converter. Diode rectifier with a single voltage source converter is usually used to solve this purpose. Figurethreeshows direct drive synchronous generator electrically excited synchronous generator system.
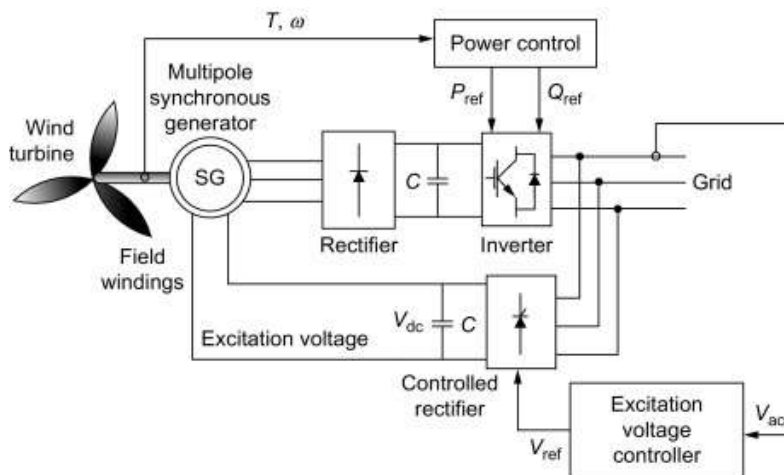

Fig. 3. Direct Drive Synchronous Generator[16]

d. Wind Power Modelling

Power captured through Aerodynamic process is given by equation.1

$$P_w = \frac{1}{2}\rho\pi R^2 V^3 \qquad (1)$$

Where P_w is the power captured, ρ represents the air density, R is the radius of blade in m. and V represents the wind velocity in m/s. The Mechanical Power extracted by wind blades is shown in equation no. 2

$$P_{mech} = C_p P_{wt} = \frac{1}{2}C_p\rho\pi R^2 V^3 \qquad (2)$$

Here C_p represents the coefficient of power.

e. Drive Train Modelling

The shaft dynamic equations are

$$T_{IN} = J_T\frac{d\omega_T}{dt} + k\Delta v + B\Delta\omega \qquad (2)$$

$$k\Delta v + B\Delta\omega = J_G \frac{d\omega_G}{dt} + T_e \qquad (3)$$

$$\Delta\omega = \omega_T + \omega_G \qquad (4)$$

$$\Delta v = v_T + v_G \qquad (5)$$

Where J_T and J_G represents the Moment Inertia of Turbine and Generator respectively in (kg.m^2), T_{IN} and T_e represents the input and generator electromagnetic torque in N-m , B represents the absorption of the shaft. w represents the angular speed of generator and the subscript G and T represents the angular speed of generator and turbine respectively. $v_T$andv_G represents the angle of turbine and generator in rad.

f. Generator Modelling

The stator voltage in d and q axis is given by

$$v_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{dt} + \omega_s \varphi_{qs} \qquad (6)$$

$$v_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_s \varphi_{ds} \qquad (7)$$

Similarly rotor voltage is given by

$$v_{dr} = R_r i_{dr} + \frac{d\varphi_{dr}}{dt} + s\omega_s \varphi_{qr} \qquad (8)$$

$$v_{qr} = R_r i_{qr} + \frac{d\varphi_{qr}}{dt} + s\omega_s \varphi_{dr} \qquad (9)$$

Flux linkage is given by

$$\varphi_{ds} = L_m i_{dr} - L_{sl} i_{ds} \qquad (10)$$

$$\varphi_{qs} = L_m i_{qr} - L_{sl} i_{qs} \qquad (11)$$

$$\varphi_{dr} = -L_m i_{ds} - L_{rl} i_{dr} \qquad (12)$$

$$\varphi_{dr} = -L_m i_{qs} - L_{rl} i_{qr}$$

Electromagnetic Torque

$$T_{el} = \varphi_{qr} i_{dr} - \varphi_{dr} i_{qr} \qquad (13)$$

Synchronous Generator

$$v_{ds} = -R_s i_{ds} - L_s \frac{di_{ds}}{dt} + L_s \omega_r i_{qs} \qquad (14)$$

$$v_{qs} = -R_s i_{qs} - L_s \frac{di_{qs}}{dt} + L_s \omega_r i_{ds} + \omega_r \varphi \qquad (15)$$

Here V_s, i_s and ψ_s represents stator voltage , current and flux respectively and V_r, i_r and $\psi_r$represents the rotor voltage , current and flux. The notion d and q represents the direct and quadrature axis respectively. L_{sl}andL_{rl} represents the stator, rotor leakage inductance and L_m represents the mutual inductance respectively.

Electromagnetic Torque

$$T_e = \frac{3}{2} p\varphi l_{qs} \qquad (16)$$
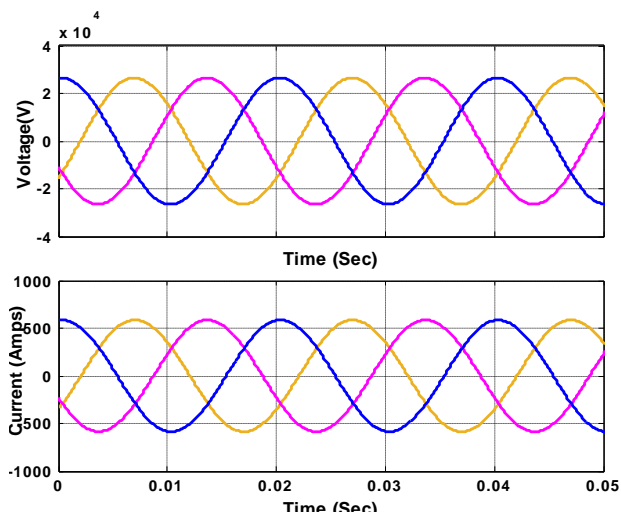
Impact of Wind Turbine Generator on Power System

Power system stability and transient behavior need to be at rest while interconnecting a large wind farm to the traditional grid. power system stability of the concerned grid is largely depends upon Type of fault, tripping of Transmission lines, laws of production and short circuits maybe single line to ground fault or double line to ground faults. Power system on balance and distribution of real and reactive power may lead to drop of voltage label at its boundary value leading to instability of the system. Sometimes this brown out leads to blackout on the power system if sufficient measures are not taken at the right time. Many power system failures are rectified headed by disconnection of transmission line or by reclosers. During the early stage of development of wind turbine only few wind turbine were connected to the grid, on this condition if any fault occurs in the transmission line reduces the voltage near wind turbine then the wind turbine is simply disconnected from the grid and again reconnected after the clearance of the fault. Since every small amount of wind, power was connected to the grid so disconnection of wind system from the grid does not affect the performance of the system and therefore not affecting the stability problem.

With the rapid increasing in the interconnection of renewable energy such as wind energy, the contribution of of wind power is significant from the grade point of view. Under the fault condition if the entire power plant is disconnected from the system then the system will lose its production capacity and for the leads to blackout. Back out at a particular portion sometimes leads to increase in voltage level at other buses, which are, are supported by traditional generator. If the remaining power stations does not have sufficient spinning reserve in order to support the start, present time then a large amount of frequency and voltage drop may occur and possibly complete loss of power system may occur. This concept leads to design of low ride through capability wind turbine, which can tolerate these small disturbancesto avoid total disconnection of power system from the grid. In order to keep the stability of the system it is necessary to ensure that the wind turbine must gain its normal operation in an appropriate way within the stipulated time. Sometimes the above statement can be
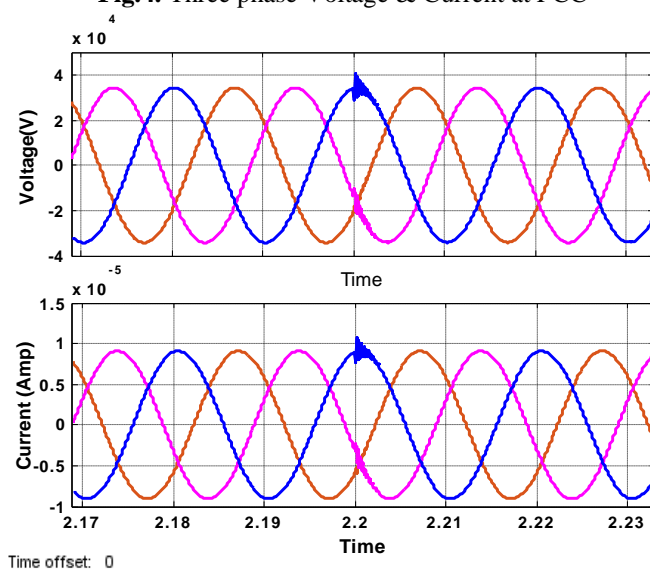
achieved by incorporating the wind turbine with some additional power system protection and Quality Management devices such as STATCOM, SVC.

Result Analysis

An IEEE-14 bus system has been used to analyse the effect of wind turbine on the grid system. Figure number four shows the three-phase voltage and current at the PCC. Where both wind and station are connected together. Before the occurrence of powersystem fault, voltage magnitude was maintained at 220 kV and that of the current is maintained to be 610 ampere. Simulation period of 0.05 second has been fixed for this particular program.

Fig.4. Three phase Voltage & Current at PCC

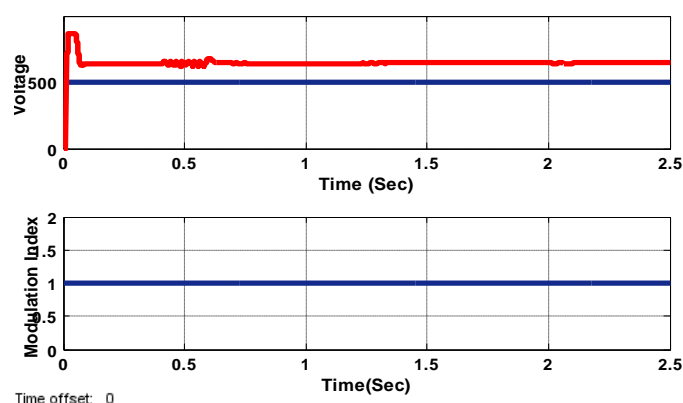**Fig. 5.** Three phase Voltage & Current at PCC during grid disturbance condition

Fig.6. DC link voltage and Modulation Index Maintained by STATCOM during Compensation mode
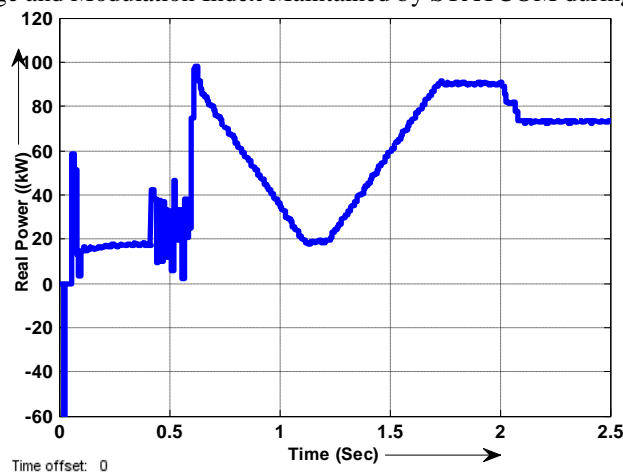

Fig. 7. Real Power Maintained by STATCOM during VAR Compensation mode

From the same figure, it can also be noticed that both three phase voltage and current are in phase with each other. Figure 5 shows 3 phase voltage and current at PCC during the grid disturbance. Attime, about 2.2 second an induction motor has been turned on which leads to a voltage notch and a current notch in the system. This forces the statcom to compensate against by controlling the voltage at the PCC. Figure 6 shows the reference disallowable and the modulation index that is maintained by the voltage source converter for controlling the voltage. Similarly figure seven shows real power controlling action during the grid failure condition. Figure number 8 shows the amount of reactive power that is exchanged with the grid .As shown in figure number 8, the reactive power is maintained at zero level throughout the simulation however during the fault condition which begins at 0.22 second statcom supports the reactive power and it can be found that the reactive power has increased up to 4 times as required by the system.

II. Conclusion

Detailed load flow analysis has been carried out for IEEE14 bus system. During the occurrence of fault,the generator bus bar voltage decreases to a nominal value and by the use of statcom, it can be again maintained after 2.2 second.

Acknowledgements

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