Power Quality and Transient Stability Improvement of Grid Connected Wind Energy System Using STATCOM

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ASTRACT-One of the major issues concerning a wind farm interconnection to a power grid concerns its dynamic stability on the power system. Voltage instability problems occur in a power system that is not able to meet the reactive power demand during faults and heavy loading conditions. Flexible AC Transmission Systems (FACTS) devices such as the Static Synchronous Compensator (STATCOM) and the Unified Power Flow Controller (UPFC) are being used extensively in power systems because of their ability to provide flexible power flow control. FACTS devices can be used in wind power systems to improve the transient and dynamic stability of the overall power system. The STATCOM is from the family of FACTS devices that can be used effectively in wind farms to provide transient voltage support to prevent system collapse. In the present research paper power quality improvement using STATCOM under faults is proposed. Improvement of power quality with and without STATCOM and reactive power injecting by a STATCOM is studied. Simulation results are given, commented and discussed. The test results prove the effectiveness of the proposed STATCOM controller in terms of fast damping the power system oscillations and improving the power quality and transient stability.

Keywords-- *Transient Stability, Power Quality, Induction Generator, Active Power, Reactive Power, FACTS, STATCOM, Wind Farm*

INTRODUCTION

The wind power penetration has increased dramatically in the past few years, hence it has become necessary to address problems associated with maintaining a stable electric power system that contains different sources of energy including hydro, thermal, coal, nuclear, wind, and solar. In the past, the total installed wind power capacity was a small fraction of the power system and continuous connection of the wind farm to the grid was not a major concern. With an increasing share derived from wind power sources, continuous connection of wind farms to the system has played an increasing role in enabling uninterrupted power supply to the load, even in the case of minor disturbances. The wind farm capacity is being continuously increased through the installation of more and larger wind turbines. Voltage stability and an efficient fault ride through capability are the basic requirements for higher penetration. Wind turbines have to be able to continue uninterrupted operation under transient voltage conditions to be in accordance with the grid codes [2]. Grid codes are certain standards set by regulating agencies. Wind power systems should meet these requirements for interconnection to the grid. Different grid code standards are established by different regulating bodies [3].

One of the major issues concerning a wind farm interconnection to a power grid concerns its dynamic stability on the power system [4]. Voltage instability problems occur in a power system that is not able to meet the reactive power demand during faults and heavy loading conditions. Stand alone systems are easier to model, analyze, and control than large power systems in simulation studies. A wind farm is usually spread over a wide area and has many wind generators, which produce different amounts of power as they are exposed to different wind patterns. The applicability of a STATCOM in wind farms has been investigated and the results from early studies indicate that it is able to supply reactive power requirements of the wind farm under various operating conditions, thereby improving the steady-state stability limit of the network [6]. Transient and short-term generator stability conditions can also be improved when a STATCOM has been introduced into the system as an active voltage/VAR supporter [5, 7]. Reactive power is required to compensate for the additional reactive power demand of the generator and the matching transformers so that the wind power installation does not burden the system [9].The transient behaviour of wind farms can be improved by injecting large amounts of reactive power during fault recovery [8, 10].

WIND TURBINE MODEL AND INDUCTION GENERATOR

Figure 1 shows the Wind Turbine Model. The mathematical relationship for the extracting of mechanical power from wind may be given by:

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

Where Pt is the power developed by the wind turbine, ρ is the air density [kg/m3], R is the blade radius[m], V is the wind speed [m/s] and Cp is the power coefficient which depends on both the tip speed ratio and the blade angle of inclination

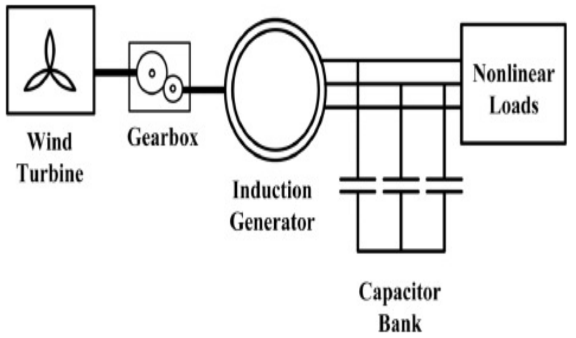

Figure 1 Wind Turbine Model

The normal operation point is achieved when cutting the mechanical torque of the electric torque curve. Assuming condition of the generator, the generator will speed up during fault in the power system in accordance with the next equation of movement

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

A typical torque-speed characteristic of an induction machine is presented in Figure 2.

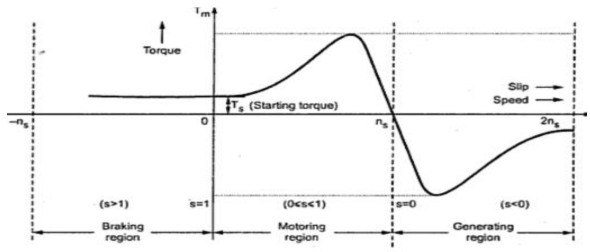

Figure 2 Torque-Speed Characteristics of an Induction Machine

During the grid faults in the power system, *Tm* is the mechanical torque almost unchanged. In contrast, the electrical torque will drop because the electrical torque is proportional to the square of the voltage. This means that the speed allowed in depends on the inertia constant H of the generator, the fault duration and severity of the fault. To improve the transient voltage stability and therefore help the wind during grid faults, an alternative is to utilize dynamic reactive power compensation such as a STATCOM as considered in this study.

STATCOM MODELLING

Figure 3 shows the basic model of a STATCOM which is connected to the ac system bus through a coupling transformer. In a STATCOM, the maximum compensating current is independent of system voltage, so it operates at full capacity even at low voltages as shown in the characteristics of STATCOM in Figure 4. A STATCOM's advantages include flexible voltage control for power quality improvement, fast response, and applicability for use with high fluctuating loads. The output of the controller Q_C is controllable which is proportional to the voltage magnitude difference (V_C – V) and is given by

$$Q = \frac{V\ (V_C - V)}{X} \qquad (3)$$

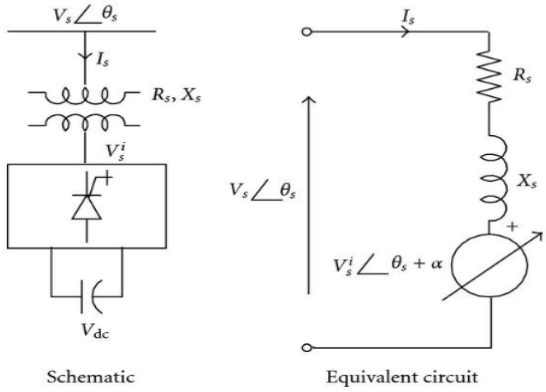

Figure 3 Basic Model of a STATCOM

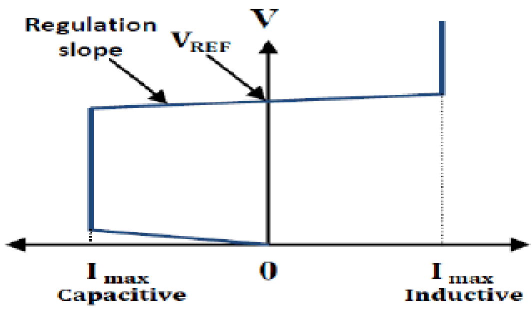

Figure 4 Characteristics of STATCOM

As long as 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 normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. In the voltage regulation mode, the V-I characteristic is described by the following equation.

$$V = V_{ref} + IX_s \quad (4)$$

Where

V = positive sequence voltage

I = Reactive current

X_s = slope or droop reactance

The STATCOM ratings are based on many parameters which are mostly governed by the amount of reactive power the system needs to recover and ride through typical faults on the power system and to reduce the interaction of other system equipment that can become out of synchronism with the grid.

LOCATION OF STATCOM

Simulation results show that STATCOM provides effective voltage support at the bus to which it is connected to. The STATCOM is placed as close as possible to the load bus for various reasons. The first reason is that the location of the reactive power support should be as close as possible to the point at which the support is needed. Secondly, in the studied test system the location of the STATCOM at the load bus is more appropriate because the effect of voltage change is the highest at this point.

TEST SYSTEM

To evaluate the voltage support provided by a STATCOM which is connected to a weak grid, simulations have been performed in MATLAB/SIMULINK. Figure 5 shows the test system that includes a load supplied by the local grid as well as from the installed wind turbines. The power system is studied to evaluate the system performance under different transient conditions such as a single line to ground fault, line to line fault and three phase fault.

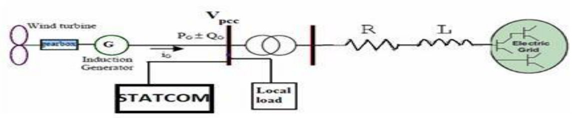

Figure 5 Test System

PERFORMANCE EVALUATION

A. Single Line to Ground Fault

The effect of a single line to ground short circuit fault at the load bus is studied. The ground fault is initiated at t=4 sec and cleared after three cycles. The system is studied under two different conditions at the load bus: (i) without a compensating device, (ii) a STATCOM. Figure 6 and Figure 7 shows the voltage at the load bus or the fault bus for the two different operating conditions discussed earlier. Figure 8 shows the reactive power supplied the STATCOM.

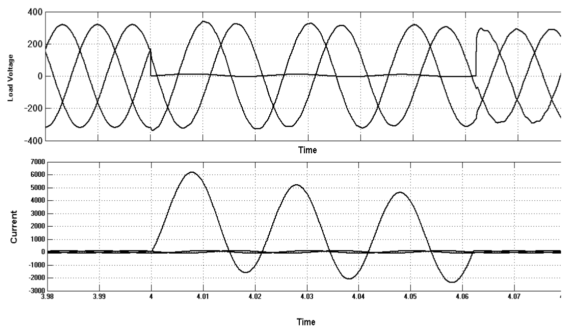

Figure 6 Voltage and Current at the Load bus without STATCOM for L-G fault

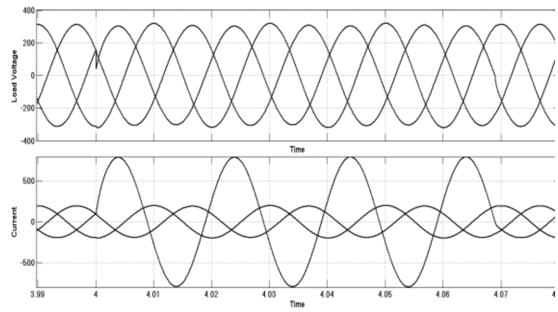

Figure 7 Voltage and current at the Load bus with STATCOM for L-G fault

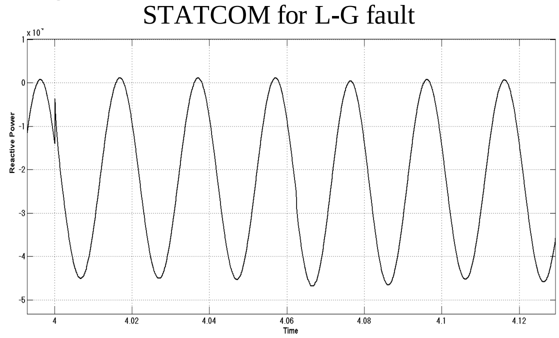

Figure 8 Reactive Power supplied by STATCOM for L-G fault

B. Line to Line Fault

The effect of a line to line short circuit fault at the load bus is studied. The ground fault is initiated at t=4 sec and cleared after three cycles. The system is studied under two different conditions at the load bus: (i) without a compensating device, (ii) a STATCOM. Figure 8 and Figure 9 shows the voltage at the load bus or the fault bus for the two different operating conditions discussed earlier. Figure 10 shows the reactive power supplied the STATCOM.

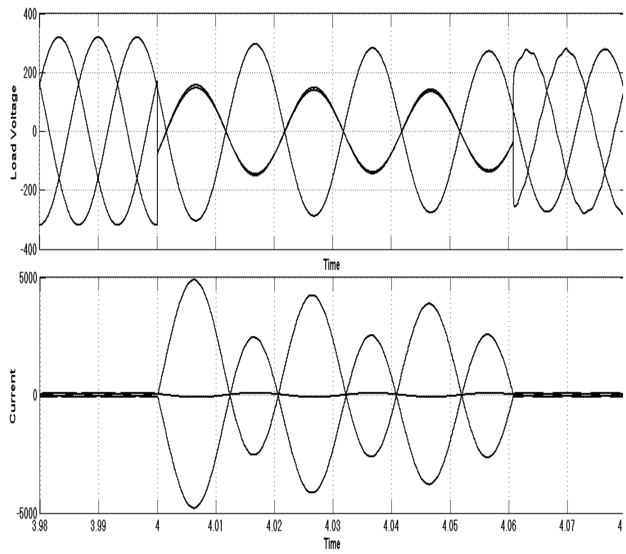

Figure 9 Voltage and Current at the Load bus without STATCOM for L-L fault

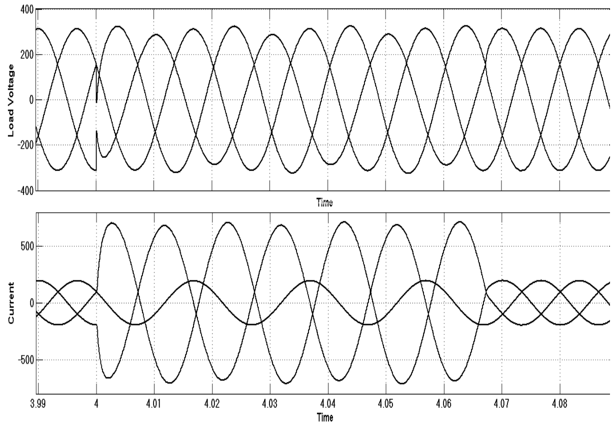

Figure 10 Voltage and Current at the Load bus with STATCOM for L-L fault

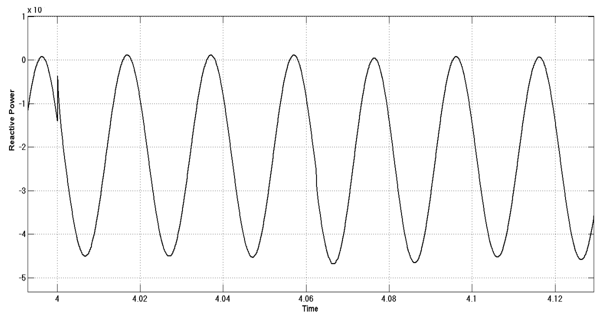

Figure 11 Reactive Power supplied by STATCOM for L-L fault

C. Three Phase Fault

The effect of a single line to ground short circuit fault at the load bus is studied. The ground fault is initiated at t=4 sec and cleared after three cycles. The system is studied under two different conditions at the load bus: (i) without a compensating device, (ii) a STATCOM. Figure 5 and Figure 6 shows the voltage at the load bus or the fault bus for the two different operating conditions discussed earlier. Figure 7 shows the reactive power supplied the STATCOM.

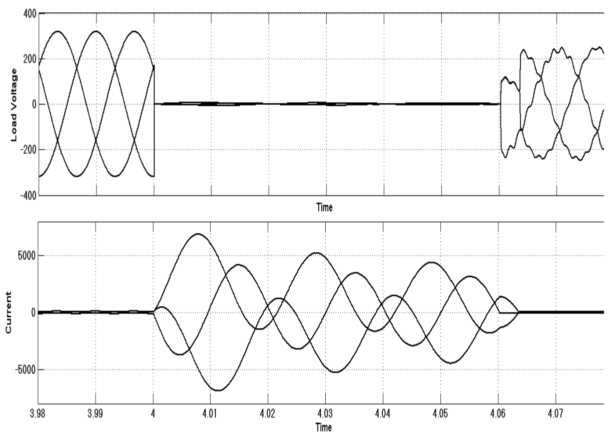

Figure 12 Voltage and Current at the Load bus without STATCOM for Three Phase fault

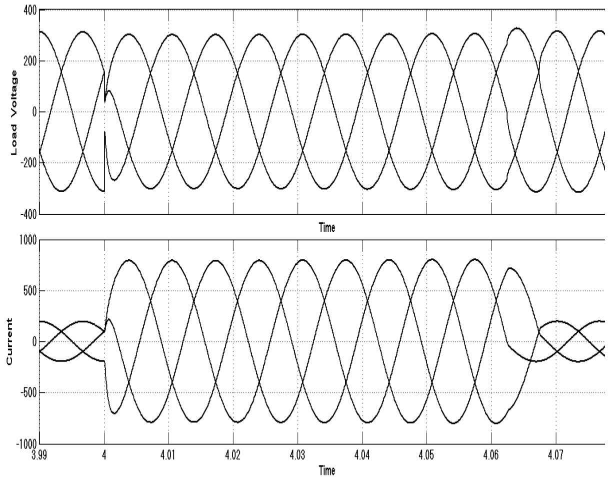

Figure 13 Voltage and Current at the Load bus with STATCOM for Three Phase fault

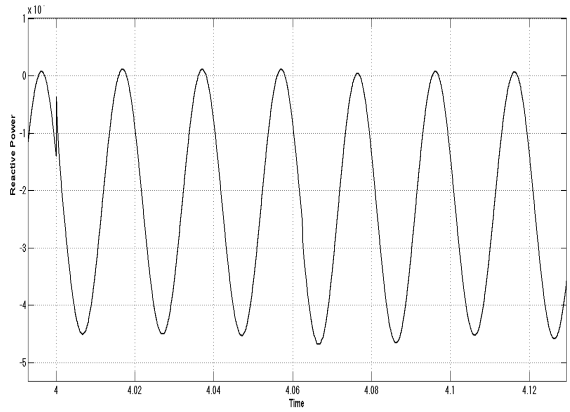

Figure 14 Reactive Power supplied by STATCOM for Three Phase fault

CONCLUSION

Simulation studies have shown that the additional voltage/VAR support provided by an external device such as a STATCOM can significantly improve the wind turbines fault recovery by more quickly restoring voltage characteristics. The extent to which a STATCOM can provide support depends on its rating. The higher the rating, the more support provided. The interconnection of wind farms to weak grids also influences the safety of wind turbine generators. Some of the challenges faced by wind turbines connected to weak grids are an increased number and frequency of faults, grid abnormalities, and voltage and frequency fluctuations that can trip relays and cause generator heating.

The dynamic performance of wind farms in a power grid is improved by the application of a STATCOM. The STATCOM helps to provide better voltage characteristics during severe faults like three phase impedance short circuit faults as well.

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