Application of STATCOM for Improved Stability and Voltage Quality in Grid Connected Wind Farms

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Abstract

With the peaking demand of electric power, wind as a renewable energy source is booming in the energy market. The need for exploitation of the full potential of the wind calls for grid integration of Wind Farms which results in increase attention to reactive power and voltage quality problems. A thorough study becomes mandatory in order to determine the causes of poor stability and its effects on the power system. In this paper, STATCOM which is able to improve the voltage regulation by absorption and injection of reactive power is investigated in a scenario of grid connected Peedempalli wind farm. Simulations are carried out using DlgSILENT Power factory for normal grid fault events and discrete loading conditions. The effectiveness of the STATCOM for fast damping of Power Oscillations and restoring the system stability is deduced from the simulation results.

Keywords: Wind Farm, STATCOM, Power Quality, Stability
1 Introduction

Today, centralized power generation systems are facing the primary constraints of shortage of fossil fuels and the need to reduce emissions. On the other hand, renewable energy resources are becoming plausible sources of energy for their potential to significantly defeat those constraints. Of them, wind is a splendid energy reserve providing tremendous environmental, social and economic benefits [1]. The astounding growth of power produced by wind has been accomplished by concentrating an appreciable number of wind turbines in the wind farms for the better exploitation of regions with abundant wind resources. Grid integration of wind farms offers several benefits [2]. However, the uniquely turbulent and unpredictable nature of power generated by wind turbines can expose the power system to issues that need attention lest the functionality of the grid be impaired [3].

One of the simplest methods of running a wind generating system is to use induction generator directly connected to the grid system as it has inherent advantages of cost effectiveness and robustness. It is well presented that induction generators require reactive power for magnetization [4]. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be alternating. A proper control scheme in wind energy generation system is required. Otherwise, it would inexorably affect the electrical and electronic equipment connected to the metering point [5].

Flexible AC transmission system devices can be a solution to various power system problems. They are based on power electronics and are capable of providing active and reactive power support and can offer greater flexibility, reliability and power transfer capability. Among the various shunt FACTS devices, STATCOM is widely used to provide smooth and rapid steady state and transient voltage control at various points in the network. The STATCOM has fast response time, typically of the order of one to two cycles and superior voltage support control [6]. However, with recent innovations in high-power semiconductor switch, converter topology and digital control technology, faster STATCOM (quarter cycle)
with low cost is emerging [7], which is promising to help integrate wind energy into the grid to achieve a more cost-effective and reliable renewable wind energy. In this paper, STATCOM is applied to 3.6MW Peedampalli wind farm. The simulations are carried out using DIgSILENT Power Factory [8] in RMS stability transients. The performance of STATCOM is studied using different scenarios such as grid faults and various loading patterns. The simulation results are evaluated against the cases considering no STATCOM and using a mechanically switched capacitor. The results show that STATCOM can significantly alleviate voltage quality problems from the network and helps in improving the stability of the overall power system. By analyzing the characteristics and quality measures of grid connected wind farms, we can optimize their performance, leading to an improved injection of clean power into the grid to meet the demands of the power deficit crisis in most parts of the world.

2 MODELLING OF WIND TURBINE

Fig.1. General Scheme of fixed speed wind turbine

Wind is an intermittent source of energy which is the outcome of air flow among areas of varying pressure. Measuring changes in pressure facilitate prediction of wind speed in a particular region. It is generally assumed that the wind speed is made by the sum of the following four components namely, the average value, the ramp component, a gust component and a turbulence component [9]. The aerodynamic power $P_{\text{wind}}$ developed for the wind turbine
with rotor radius \( R \) at a wind speed \( V_w \) and air density \( \rho \) is modeled by the relation:

\[
P_{\text{wind}} = \frac{1}{2} \rho \pi R^2 V_w^3 C_p(\lambda \beta)
\]  

(1)

The power coefficient (or aerodynamic efficiency) \( C_p \) depends on the blade angle \( \beta \) and the tip speed ratio \( \lambda \)\[10\].

The power coefficient \( C_p \) is governed by the equation:

\[
C_p = \frac{(0.44 - 0.0167\beta) \sin(\pi(\lambda - 2))}{13 - 0.3\beta} - 0.00184(\lambda - 2)\beta
\]  

(2)

The fixed speed wind turbines normally employ squirrel cage induction generator. The model available in DiGILENT is a d-q reference frame model and is used in the simulations. The stator is connected to the grid and the rotor is driven by the wind turbine. Power conversion from mechanical to electrical takes place in the generator. During times of high wind velocity, it is required to prevent the rotor speed from becoming too high. Therefore the blade pitch angle is changed so that the turbine rotates at a constant rate. This is achieved by employing servomotors on each blade that are precisely controlled by a PID controller.

### 3 STATCOM MODEL

STATCOM is a shunt FACTS device which is capable of absorbing or injecting reactive power into the system. Figure 2 shows the basic model of STATCOM connected to an ac bus system by means of a shunt coupling transformer. In a STATCOM, the compensating current is independent of the system voltage, so it operates at full capacity even at low voltages. This makes it superior to other devices like SVCs \[10\].
The output of the controller $Q_c$ is controllable which is proportional to the voltage magnitude difference ($V_c - V$) and is given by (3)

$$Q_c = \frac{V(V_c - V)}{X} \tag{3}$$

The STATCOM consists of three main components namely, the shunt inverter, transformer and connection filter. The magnitude of the bus voltage is maintained constant by controlling the magnitude and phase shift of the VSIs output. The value of $i_q$ is controlled for the proper exchange of reactive power. The dc capacitor voltage is maintained constant and the error in the voltage normally determines the exchange of active power with the system. A STATCOM provides dynamic voltage control and power oscillation damping, and improves the system's transient stability. Figure 3 shows the block diagram of STATCOM control system available in DIgSILENT Power Factory.
STATCOM is chosen as a source for reactive power support because it has the ability to continuously vary its susceptance while reacting fast and providing voltage support at a local node. The outputs of the controller are $i_{d\text{ref}}$ and $i_{q\text{ref}}$ which are the reference currents in the dq coordinates which are needed to calculate the power injections by the STATCOM as in (4) and (5).

$$P_{inj} = V_i (i_d \cos \theta + i_q \sin \theta) = v_d i_d + v_q i_q$$ \hspace{1cm} (4)$$

$$Q_{inj} = V_i (i_d \sin \theta - i_q \cos \theta) = v_d i_q + v_q i_q$$ \hspace{1cm} (5)$$

where $i_d$ and $i_q$ are the reference d and q axis currents of the ac system. The control variables are the current injected by the STATCOM and the reactive power injected into the system. The STATCOM should be placed close to the load bus for effective control. Therefore, STATCOM is normally employed at the point of grid integration.

4 WIND FARM UNDER STUDY

The single line diagram of the wind farm and its location from the substation is shown in figure 4. The wind farm consists of six units of fixed speed wind turbines which are stall controlled, each connected to a squirrel cage induction generator which generates 600kW at 690V. The total capacity of the wind farm is 3.6MW. The voltage generated by the squirrel cage generator is directly connected to the LV side of a transformer rated at 80kVA, 690/11kV.
Reactive power compensation is provided on the LV side of this transformer by using a thyristor based switched capacitor. The outgoing feeder of the substation is rated at 110kV. Peedempalli Substation is connected to an 11kV substation through a step up transformer rated at 16MVA, 11kV/110kV.

Fig. 4 Single line diagram of Peedempalli Wind Farm

5 SIMULATED NETWORK MODEL

Six wind turbines of rating 600KW each are modeled and connected accordingly in order to simulate the network model to carry out the dynamic stability studies. Each of the squirrel cage induction generators requires approximately 450KVA of reactive power support from the grid. The generator transformers are rated at 690V/11KV. Transformer rated at 11KV/33KV connects the wind turbine to a 33KV double bus bar for distribution. The objective of this paper is to be able to restore the system to its initial operating point immediately after fault clearing. The STATCOM is normally connected as close as possible to the load bus for the compensation to be effective. The STATCOM rated at 3MVA, 33KV is connected to the double bus bar as shown in the figure 5. This also ensures there is not much unnecessary interaction with the power system. To facilitate inclusion of loads in the system the 33KV is stepped down to 11KV by means of a 33KV/11KV step down transformer. This model is developed in accordance to the Indian Standards. Each wind generator comprises of a soft-starter connected to the grid to reduce the transient currents on start-up. Apart from these, a mechanically switched capacitor of the same rating as the STAT-
COM is included so as to validate the performance of STATCOM superior to the MSCs.

Fig.5.Simulated Network Model

6 SIMULATION RESULTS

The system is studied for different simulation scenarios. They are:
i) Three phase impedance fault on the system ii) Load changes which involve sudden addition and removal of loads. The subsequent sections deal with the following two cases.
i) Three phase impedance fault: In this study, three phase high impedance faults in the system are studied. The fault is studied for three different cases a) without any compensating device b) with mechanically switched capacitors c) with Static Synchronous Compensator (STATCOM). The fault is initiated at time t=0.4 seconds and is cleared at t=0.6 seconds. The simulation results are discussed below. The study evaluates the voltage recovery time, voltage levels, peak overshoot and settling time.

6.1 Without compensating device

A short circuit fault is created at the 33KV bus bar. Without any compensating device, the voltage at the faulted point i.e., the 33KV bus immediately falls to zero. When the fault is cleared at t=0.6 second, the system does not restore back to its normal operating point, but requires some time to settle. It can be seen from the graph that at time close to 0.7 second, the system voltage becomes
The graph below shows the voltage at the 33KV busbar for the case of without compensating device.

Fig.6. Voltage magnitude at 33KV busbar without compensating device

Fig.7. Voltage magnitude at 33KV busbar with MSC

6.2 With Mechanically Switched Capacitors

A Mechanically Switched capacitor of rating 3MVA is connected to the 33KV bus bar during the three phase impedance fault. The capacitor supplies reactive power to the grid and thereby provides voltage support to the grid. The voltage magnitude remains close to 0.2 p.u. as shown in figure 7. However, it can be seen that the capacitor has larger switching time and the nominal operating point is obtained few cycles after fault clearing, approximately at time, t=0.7 seconds. An advantage of the MSC is that they do not have overshoot at recovery as compared to STATCOM. The reactive power supplied by the MSC is proportional to the square of the voltage level of the grid. Thus as the grid voltage decreases during
the fault, the capability of the capacitor to provide compensation reduces.

6.3 With Static Synchronous Compensator (STATCOM)

A STATCOM of rating 3MVA is connected to the 33KV busbar. The reactive power demand of the system is provided by the STATCOM and the system is not over stressed. At time $t=0.4$, the fault is initiated. This results in drop in voltage at the busbar of 33KV magnitude. The drop in voltage determines the reactive power that is to be supplied by the STATCOM. The STATCOM can operate at its full capacity even at low voltages. The voltage magnitude at the busbar is maintained at around 0.40 p.u and the voltage magnitude can be increased by using higher rating STATCOM. It can be seen that the STATCOM exhibits overshoot during recovery. However, the settling time is faster as compared to the mechanically switched capacitors. Figure 8 shows the performance of the STATCOM for this case.

Fig.7. Voltage magnitude at 33KV busbar with STATCOM

Fig.8. Voltage magnitude at generator1 during load changes without STATCOM
It can be concluded that the voltages take a long time to stabilize in systems without STATCOM. Therefore, by employing STATCOM voltage stability can be achieved. In addition, STATCOM provides reactive support to the grid during fault condition which helps in voltage regulation. Higher the rating of the STATCOM better is the reactive power support.

ii) Load Changes
The system is studied for different load changes such as sudden addition and removal of loads. The load being inductive in nature requires active power for operation. It is assumed that initially some load is present in the system. 50% of the load is removed at t=0.4 seconds. Since some of the load is removed, it is worthy to note that there is a rise in the generator voltage. 150% of the present load in the system is added at a time, t=0.6 seconds. With the sudden inclusion of load, the generator voltage drops. The system is brought back to the normal working load at t= 0.8 seconds. The simulation results are discussed below. A) Without STATCOM
The graph in figure 8 shows the case of load change without a compensating device. The voltage at the generator terminals swings according to the load additions and rejections as mentioned above. It can be seen that when the nominal load on the system is restored back at t=0.8, the voltage magnitude does not immediately recover to 1p.u, but gradually recovers. Figure 9 shows the change in voltage magnitude at load bus.

![Fig.9. Voltage at load bus during load changes without STATCOM](image-url)
B) With STATCOM

The STATCOM acts like a reactive power reserve. It can be used to absorb or supply reactive power instantaneously. It can therefore act as an effective reactive power compensator. This is clearly indicated in figure 10 which shows the variation of the voltage at generator1. The STATCOM can thus quickly damp out power system oscillations. Thus in effect, STATCOM improves the system stability.

Fig.10. Voltage magnitude at generator1 during load changes with STATCOM

7 Conclusion

The increase in demand for electric power along with depleting natural resources has augmented the number of wind farms. Grid integration of wind farms results in several voltage quality and stability problems. In this paper, STATCOM is used as a compensating device in order to investigate the compensation levels under different scenarios such as three phase impedance faults and varying load conditions. The simulation results reveal that STATCOM acts as a voltage regulator at the point of coupling, either by absorbing or supplying reactive power to the system. Also, STATCOM acts quickly in order to damp out the power system oscillations. Thus, the STATCOM proves to be an excellent compensating device in order to improve the system voltage quality and stability thus leading to clean injection of power into the grid.
References


[9] DIgSILENT GmbH DIgSILENT Power Factory 14.- User Manual, DIgSILENT GmbH.


