Power Quality Improvement of Power Grid Containing Wind Farm using STATCOM

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Abstract – Wind energy is one of the extra ordinary sources of renewable energy due to its clean character and free availability. We used a static synchronous compensator (STATCOM) to supply the reactive power and voltage support to a wind farm equipped with Induction Generators(IGs) and power system during grid faults. Also, the STATCOM is used in steady state to supply reactive power in power system. Simulation results show that the wind turbine bus voltage is quickly reestablished shortly after the fault has been cleared, and therefore, the wind turbine remains in service during the presence of STATCOM. The results prove the effectiveness of the proposed STATCOM controller in terms of fast damping the power system oscillations and restoring the power system stability. The choice of this study is justified by simulation in MATLAB.

Keywords: Wind farm, Reactive power, STATCOM, Asynchronous generator

1. Introduction

The global anxiety about environmental pollutions in addition to the concerns about lacking energy resources, have led to intensify the application of renewable energy resources with technology demand. Wind power has the most rapid growth in comparison with other renewable energies. The increasing demand for electric power combined with depleting natural resources has led to the substantial improvements in the usage of renewable energy systems such as wind and solar especially among the developing countries. Wind power is increasingly being viewed as mainstream electricity supply technology. Grid-connected wind electricity generation is showing the highest rate of growth of any form of electricity generation, achieving global annual growth rates in the order of 20 - 25%.

Nowadays because of increase in the rate of fuel cost, using renewable energy sources is growing, and wind turbines are very common among these kinds of sources. But wind turbines may cause some problems for electrical networks, for instance when a short-circuit fault occurs speed of induction generator is increased and demagnetization occurs because of voltage decrease. Subsequently, a large amount of reactive power flow in electrical network so the rate of active power should be decreased. As a result, the speed of wind turbine should be increased. After the fault is resolved, wind turbine needs large amount of reactive power for magnetic reuses, so these actions could make voltage sag in the electrical network ([1], [2]). Since operation and maintenance of induction motors are cost efficient, and also they are flexible and don't need to use brushes and separate DC voltage source in their structure, they are widely used [3]. Induction motors can be used in two modes, separate or connected to electrical network; however, when an induction motor is connected to electrical network it is very easy to be analyzed because its frequency and voltage is cleared by main electrical network [4],[10]. Weak voltage regulation and need for reactive power are two big problems regarding induction motors. After production of external voltage, DC link capacitor is charged and provides the required reactive power loads. Induction generators and loads usually need reactive power. Unbalanced reactive power could make voltage swing in electrical network. Thus we should consider inverted square of speed for minimum reactive power that is required in order to choose proper capacitor for induction motor. Additionally, we need to consider magnetic reactance effect for maximum reactive power that is required in network. It should also be noted that constant capacitors couldn't produce sufficient reactive power. Due to structure of induction generators and voltage instability, production of required reactive power in proper

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places is important. Weak voltage regulation and need for reactive power are two big problems regarding induction motors. After production of external voltage, DC link capacitor is charged and provides the required reactive power loads. Induction generators and loads usually need reactive power. Unbalanced reactive power could make voltage swing in electrical network. Thus we should consider inverted square of speed for minimum reactive power that is required in order to choose proper capacitor for induction motor. Additionally, we need to consider magnetic reactance effect for maximum reactive power that is required in network. It should also be noted that constant capacitors couldn't produce sufficient reactive power. Due to structure of induction generators and voltage instability, production of required reactive power in proper places is important.

Main drawbacks to wind turbines equipped with DFIGs is low voltage ride through capability or their operation during faults in the power system. Grid fault can consequent a voltage dip at the connection point of the wind turbine system. This situation leads to produce an over current in the stator windings of DFIG. Also, this current will flow in the rotor circuit because of the magnetic coupling between stator and rotor. This over current can lead to the destruction of the converter. A common solution to this problem is the use of a crowbar circuit to short-circuit the rotor windings of DFIG [16].

In [6] necessity of presence of adequate reactive power in a system, which includes high amount of wind power generation, is proved. FACTS devices may be exploited as a good solution. As an example using Static VAR Compensators (SVC) can be mentioned that is very effective because of its speed and continuous power coverage. In [6] necessity of presence of adequate reactive power in a system, which includes high amount of wind power generation, is proved. FACTS devices may be exploited as a good solution. As an example using Static VAR Compensators (SVC) can be mentioned that is very effective because of its speed and continuous power coverage.

In [7] SVC is utilized in external part of an induction motor of a wind turbine to regulate voltage especially when turbulence occurs in electrical system. In the same way, STATCOM is a device that connects to network in parallel but as they are expensive, they are merely used in some of the wind farms for producing power when a fault occurs. In reference [8] a strategic control method has been suggested for reducing voltage swing which is based on STATCOM. In [9] STATCOM has been exploited to minimize the steady-state and dynamic behavior associated with wind farms.

In this paper, a complete wind farm is modeled with STATCOM to stabilize grid connected Asynchronous wind generator system. A theoretical and simulation study by MATLAB software of wind turbine generation is analyzed by this paper. New ideas in this article are evaluation capability of a wind farm for compliance of load demand when a fault occurs and separation of wind farm system from the main network. In other words we can show range and capacity of STATCOM in different situations [11],[13].

2. STATCOM Modeling and Structure

The first STATCOM has been designed in 1990. This is a voltage converter based on GTO or IGBT powered by batteries of capacitors. The assembly is connected in parallel to the network through a coupling transformer[14]:

$$Q_{sh} = \frac{|V_k|^2}{X_{sh}} - \frac{|V_k|\,|V_{sh}|}{X_{sh}}\cos(\theta_k - \theta_{sh}) = \frac{|V_k|^2 - |V_k||V_{sh}|}{X_{sh}} \tag{1}$$

If Vk>Vsh then Qsh become positive and the STATCOM absorbs reactive power.

If Vk<Vsh then Qsh become negative and the STSTCOM supplies reactive power.

STATCOM is a static synchronous generator whose capacitive or inductive output current can be controlled independent of the AC system voltage [15]. It is a solid state switching converter capable to generate or absorb real and reactive power at its output terminals, when it is fed from an energy source or an energy storage device of appropriate rating.

There is a (VSI) that produces a set of three phase ac output voltages, each of which is in phase with, and coupled to the corresponding ac system voltage via a relatively small reactance. The VSI is driven by a dc storage capacitor. By regulating the magnitude of the output voltage produced, the reactive power exchange between STATCOM and the ac system can be controlled.

The STATCOM is a power electronic device based on Synchronous Voltage Generator (SVG) that generates a three-phase voltage from a dc capacitor in synchronism with the transmission line voltage and is connected to it by a coupling transformer as shown in Fig. 1.

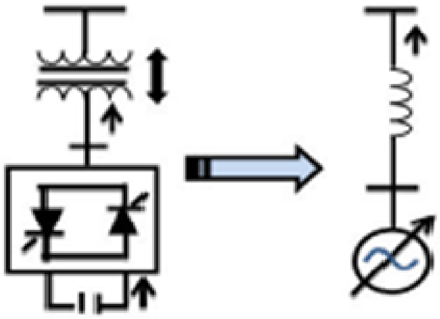

Figure 1: Structure of Static synchronous compensator (STATCOM)

By controlling the magnitude of the STATCOM voltage, Vs, the reactive power exchange between the STATCOM and the transmission line and hence the amount of shunt compensation can be controlled. From Fig.2 STATCOM exhibits constant current characteristics when the voltage is low/high under/over the limit.

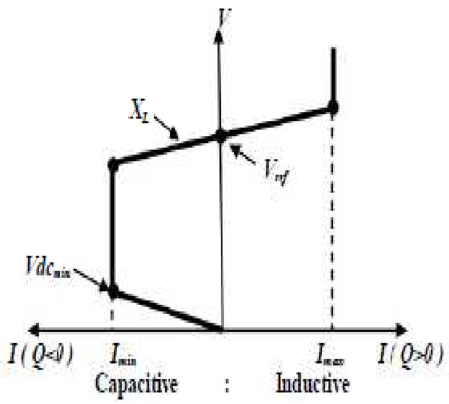

Figure 2: Terminal characteristic of STATCOM

The following mode of operation of STATCOM given as:

- Over excited mode of operation (Vbus ≤ V0):

That is, if the amplitude of the output voltage is increased above that of the Alternative Current System (ACS) voltage, then the current flows through the reactance from the STATCOM to the ACS and the STATCOM generates reactive (capacitive) power for the ACS.

- Under excited mode of operation (V0 ≤Vbus):

On the other hand, if the amplitude of the output voltage is decreased below that of the ACS, then the reactive current flows from the ACS to STATCOM, and the STATCOM absorbs the reactive (inductive) power.

- Normal (floating) excited mode of operation (Vo = Vbus):

If the output voltage is equal to the ACS voltage, the reactive power exchange is zero. In STATCOM, the resonance phenomenon has been removed. So STATCOM is having more superior performance as compare to SVC [15].

The STATCOM provides the same control that SVC but with more strength. It is capable to supply reactive power even if the voltage at the busbar is very low. According to its characteristics, we find that the maximum current of the STATCOM is independent of the node voltage. For an ideal STATCOM, the active losses are negligible and the equation (1) of the reactive power, describes the flow of the latter with the electrical network [16].

3. System Description

With Matlab software, an electrical network with Asynchronous generator, voltage source, various loads and a 9MW wind farm which has a 3 MVA STATCOM has been modeled. Figure3 has shown the overall scheme.

The characteristic parameters of STATCOM, wind turbine and Loads are as follows:

Table 1. Characteristics parameters of STATCOM

Parameter	Value
Rating power	3MVA
Line Voltage	25 kv
Capacitor	1125µF

Table2. Characteristics parameters of IG and wind turbine

Parameter	Value
Rating power	3.3MVA
Stator voltage	575 V
Stator resistance	0.004843
Stator Inductance	0.1248
Rotor resistance	0.004377
Rotor Inductance	0.1791
Magnetizing inductance	6.77
Number of pole pairs	3
Pitch angle controller [Kp Ki]	[5 25]
Base wind speed (m/s)	9
Maximum pitch angle (deg):	45

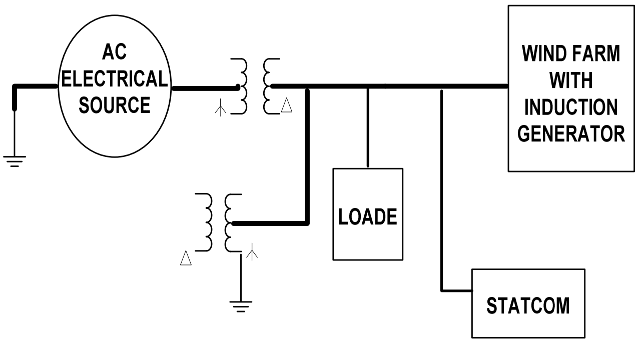

Figure 3. Overall scheme of electrical network

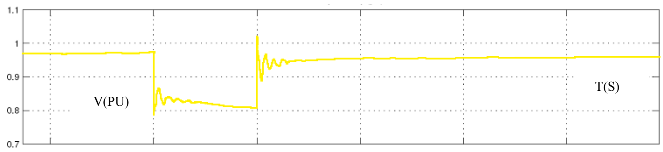

Figure 5. Voltage domain characteristic of wind farm bus for connected network

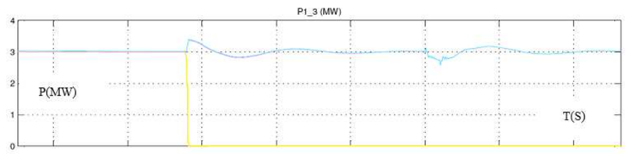

Figure 6. Output of active power –wind turbine

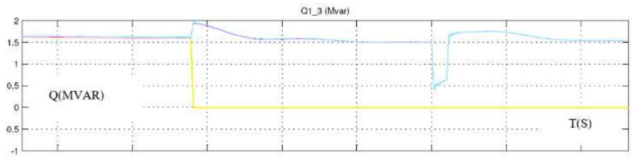

Figure 7. Output of reactive power –wind turbine

4. System Analyzing

In this study there are three wind turbines 3.3MVA in the wind farm that we analyze two scenarios; without and with using of STATCOM in power network.

A single phase fault has been considered that starts at t=15 sec and finishes at t=15.1 sec.

A. Without STATCOM

Output active power of network with considering of wind farm without using STATCOM is shown in figure (4). Based on output characteristic, when the fault starts, active power is 4.1 MW and after that the rate of active power increases to 4.5 MW more than fault point. During this action, wind farm cannot produce active power for local loads.

In figure (5), bus voltage magnitude of network is depicted. In this figure we can see that magnitude of bus voltage is almost 0.8 PU during the fault occurrence and after repairing the fault it increases to 0.98 PU.

Output active power of wind farm without using STATCOM is shown in figure (6) and Output reactive power of wind farm without using STATCOM is shown in figure (7), Output reactive power of a wind turbine is depicted. In this figure we can see that magnitude of reactive power is almost 0.35 PU during the fault occurrence and after repairing the fault it increases to 1.72 PU(in state of without STATCOM, a wind turbine tripped from the circuit).

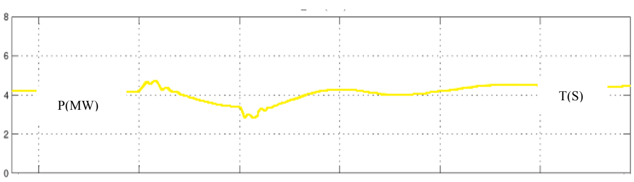

Figure 4. Output of active power in connected network

B. With STATCOM

In this state when the fault occurs, output does not totally change but its value can change only in the moment of starting fault.

Output of active power in connected network with 3MW STATCOM is shown is in figure(8) and characteristic of voltage magnitude is shown in figure (9). It is obvious that when STATCOM is used, rate of voltage variation is about 0.08 PU that is better than last state. Moreover, in repairing moment, voltage magnitude has an impulse change and will be stable on 0.985 PU.

Output characteristic of reactive power of the STATCOM can be seen in figure (10). This picture shows a noticeable change when fault starts and it will not be constant until the fault finishes. After that the rate of reactive power returns to requirements of the network.

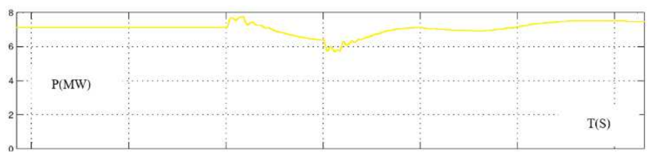

Figure 8. Output of active power in connected network with 3MW STATCOM

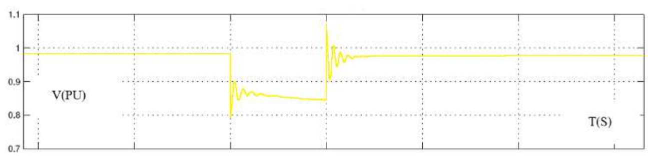

Figure 9. Voltage domain characteristic of wind farm bus with 3MW

STATCOM for connected network

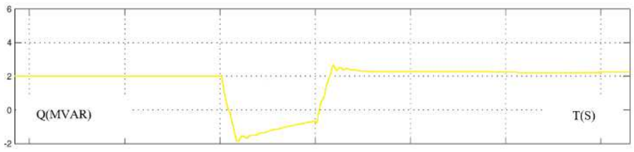

Figure 10. Output of reactive power in connected network with 3MW STATCOM

Output active power of wind farm with using STATCOM is shown in figure (11) and Output reactive power of wind farm with using STATCOM is shown in figure (12), Output reactive power of a wind turbine is depicted. In this figure we can see that magnitude of reactive power is almost 0.52 PU during the fault occurrence and after repairing the fault it increases to 1.5 PU.

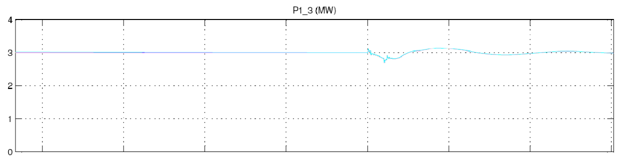

Figure 11. Output of active power –wind turbine

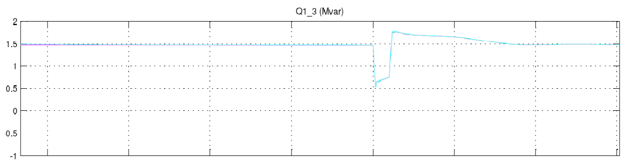

Figure 12. Output of reactive power –wind turbine

5. Conclusion

This paper, investigates applying STATCOM to obtain uninterrupted operation of a wind turbine equipped with IG during a grid fault. The SATCOM is shunt-connected with the terminal that the wind farm system is connected to and supplies required reactive power to the induction generator during a grid fault. It also provides required reactive power to the power system during normal operation and a grid fault. The simulation has been executed with MATLAB. The STATCOM with its reactive energy intake stabilizes the voltage at a relatively constant value even in the presence of the fault in the network. This, will avoid disconnections following tripping of protective equipment wind farms, and help maintain the grid connected to wind turbines.

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