Enhancement of Voltage Stability for DFIG based Wind Farms using STATCOM

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***Abstract*— Wind farms when integrated to the weak power system pose stability and control issues. This paper investigates the use of a Static Synchronous Compensator (STATCOM) with wind farms for the purpose of stabilizing the grid voltage after a grid-side disturbance viz., a three phase short circuit fault. The strategy focuses on a fundamental grid operational requirement to maintain proper voltages at the point of common coupling in a DFIG based wind farm. The model DFIG based wind farms connected to a weak grid is simulated in DigSILENT software. Simulation results show that the STATCOM improves the transient voltage stability and therefore helps the wind turbine generator system to remain in service during grid faults.**

Keywords*— Wind turbine, Doubly-fed Induction Generator, STATCOM, three phase faults, reactive power support, DigSILENT

I. INTRODUCTION

The worldwide concern about environmental pollution and a possible energy shortage has led to increasing interest in technologies for the generation of renewable electrical energy. Among various renewable energy sources, wind power is the most rapidly growing one in all over the world mainly in India. 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 big concern. With increasing share from the wind power sources, it has become important for continuous connection of the wind farm to the system to enable uninterrupted power supply to the load even in the case of some minor disturbances. The capacity of wind farms are being increased by installing more and bigger wind turbines connected online which implies that more impedance is being added to the system, thus making the connected system as a weak grid. Voltage stability and an efficient fault ride through capability are the basic requirements of higher penetration.[1],[2],[3] The wind turbines have to be able to continue uninterrupted operation under transient voltage conditions to be in accordance with the grid codes. Grid codes are certain standards set by regulating agencies and the wind power systems should meet these requirements for their interconnection to the grid. There are different grid code standards established by different regulating bodies and the Indian Grid Codes are used here for the simulation [6].

With the recent progress in modern power electronics, the concept of a variable-speed wind turbine (VSWT) equipped with a doubly fed induction generator (DFIG) is receiving increasing attention because of its advantages over other wind turbine generator concepts. In the DFIG concept, the induction generator is grid-connected at the stator terminals. The rotor is connected to the utility grid via a partially rated variable frequency ac/dc/ac converter (VFC), which only needs to handle a fraction (25%–30%) of the total DFIG power to achieve full control of the generator. The VFC consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back-to-back by a dc-link capacitor [4], [7].

When connected to the grid and during a grid fault, the RSC of the DFIG may be blocked to protect it from over-current in the rotor circuit. The wind turbine typically trips shortly after the converter has blocked and automatically reconnects to the power network after the fault has cleared and the normal operation has been restored. In case of an uninterrupted operation feature of a DFIG wind turbine during grid faults. In this feature, the RSC is blocked, and the rotor circuit is short-circuited through a crowbar circuit (an external resistor). The DFIG becomes a conventional induction generator and starts to absorb reactive power. The wind turbine continues its operation to produce some active power, and the GSC can be set to control the reactive power and voltage at the grid connection. The pitch angle controller might be activated to prevent the wind turbine from fatal over speeding. When the fault has cleared and when the voltage and the frequency in the utility grid have been re-established, the RSC will restart, and the wind turbine will return to normal operation[8],[11] However, in the case of a weak power network and during a grid fault, the GSC cannot provide sufficient reactive power and voltage support due to its small power capacity, and there can be a risk of voltage instability. As a result, utilities, typically, immediately disconnect the wind turbines from the grid to prevent such a contingency and reconnect them when normal operation has been restored. Therefore, voltage stability is the crucial issue in maintaining uninterrupted operation of wind turbines equipped with DFIG. With the rapid increase in penetration of wind power in power systems, tripping of many wind turbines in a large wind farm during grid faults may begin to influence the overall power system stability[8],[11].

The problem of voltage instability can be solved by using dynamic reactive compensation. Flexible AC Transmission Systems (FACTS) based power electronic converters like 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. The main motivation for choosing STATCOM in wind farms is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power into the system [6].

This paper investigates the application of a STATCOM to help with the uninterrupted operation of a VSWT equipped with a DFIG during grid faults. The STATCOM is shunt connected at the bus where the wind turbine is connected to the power network to provide steady-state voltage regulation and improve the short-term transient voltage stability. The DFIG and STATCOM control schemes are suitably designed and coordinated in DigSILENT simulation software.

II. DFIG BASED WIND TURBINE

The DFIG is a wound rotor induction machine with slip rings attached to the rotor. The AC/DC/AC converter is divided into two parts, rotor side and grid side. The rotor is fed by the rotor side power converter and the grid side power converter is used to generate or absorb power in order to keep the DC link voltage constant. Generation of power at variable speeds ranging from below synchronous speed to above synchronous speed can be achieved using DFIG. Control of the DFIG is achieved by control of the RSC and control of the GSC[10]. The model is shown in Fig 1.

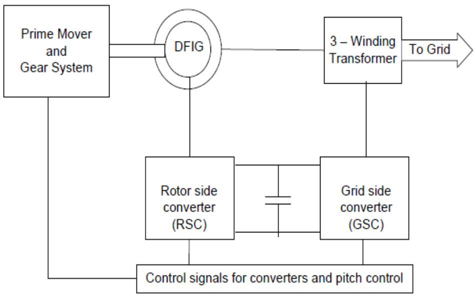

Fig 1. Block diagram of DFIG

III. STATCOM

The STATCOM is a static var generator, whose output can be varied so as to maintain or control certain specific parameters of the electric power system. The reactive output power of the compensator is varied to control the voltage at given terminals of the transmission network so as to maintain the desired power flow under possible system disturbances and contingencies. STATCOMs have the ability to address transient events at a faster rate and with better performance at reduced voltages than a Static Voltage Compensator (SVC). The maximum compensation current in a STATCOM is independent of the system voltage. In all, a STATCOM provides dynamic voltage control, power oscillation damping, and improves the transient stability of the system. By controlling the angle Φ, the flow of current either from the converter to the ac system or vice versa, can be controlled currents in the dq coordinates and they are needed to calculate the power injections by the STATCOM as in below equations.

$$P_{inj} = v_i \left(i_d \cos\theta_i + i_q \sin\theta_i \right)$$

$$Q_{inj} = v_i \left(i_d \cos\theta_i - i_q \sin\theta_i \right)$$

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 bock diagram of STATCOM is in fig 2.

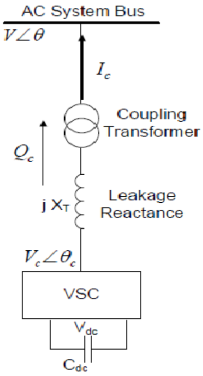

Fig 2. Block diagram of STATCOM

The exact ratings of STATCOM are derived based on many parameters. The rating of the STATCOM required to serve its purpose is mostly governed by the amount of reactive power demanded by the system to recover and ride through typical faults on the power system and to reduce the interaction of other system equipment from going out of synchronism with the grid. Though the final decision of the desired rating of the STATCOM is decided based on economics of the system the capacity thus chosen will be at least enough for the system to stabilize after temporary disturbances in the system. In the case of this test system, the STATCOM rating chosen is ±150 MVA which is found to be the maximum capacity required to maintain the voltage of the load bus to 0.9p.u. The location of STATCOM is mostly chosen as close as possible to the grid or the load. Also, a STATCOM connected in a transmission system is mostly used to support the grid voltage at severe disturbances and to control the reactive power. The control scheme of STATCOM is in fig 3.

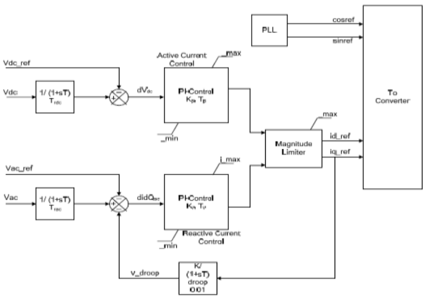

Fig 3. Control scheme of STATCOM

IV. TEST SYSTEM

The simulation study has been conducted on the system shown in Fig. 4, which represents a typical power system load being supplied by the local synchronous generators and also by the installed wind turbine (DFIG). Fig. 4 is a sketch of the power system that has been studied to evaluate the system performance under different transient conditions like a three phase fault and a sudden load change.

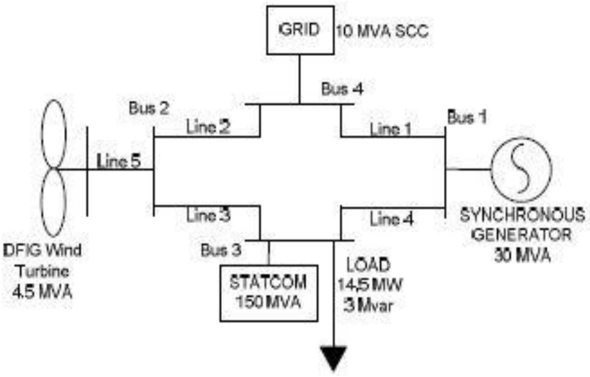

Fig 4. Single line diagram of the test system

The wind turbine has more constraints and is complex to control and make it react to the emerging power system problems. Hence, additional system equipment is required to help maintain the power grid to be stable during and after the occurrence of a fault. The proposed test system has two generators; one source is the wind turbine which is Doubly Fed Induction Generator (DFIG) and the other is a synchronous generator. The total system has a typical load connected to the system at bus 3. The active voltage supporter, STATCOM is connected to the load bus. Grid represents an external system which is connected to the system of interest through a weak link. The main reason is that the intent to force the generator and STATCOM to respond to faults in the area of interest. The short circuit power of the connected electric power grid is 13 MVA. This is a very weak grid and hence requires a compensating device of a higher rating. One of the objectives of this paper is to evaluate the specific needs of the system to restore to its initial state after the fault has been cleared. The STATCOM capacity required to restore after a three phase short circuit fault for this test system is about ±150 MVA. This is very high and is the maximum required capacity to restore and prevent the wind turbine from tripping during or after the fault has been initiated. The source of reactive power is always connected as close to point where it is required and this is basically the main motivation for connecting the STATCOM and the load to the same bus. This is specifically done to facilitate the effective operation of the STATCOM and to avoid excessive interaction of the connected power system.

V. SIMULATION RESULTS

When the DFIG generates rated power (super synchronous operation) the reactive power generation/absorption capability of Rotor Side Converter and Grid Side Converter are very low. If the active current I_d of RSC is high in order to stick to the rated KVA loading, the reactive current has to be within limits. On the other hand, the primary task of GSC is to transfer the rotor active power, which leaves very small space for reactive current, in turn, Q capability of GSC.

If the terminal voltage reduces, more active current is needed to keep the torque at its reference. This will further reduce the margin for reactive current. During any remote faults, sudden drop in terminal voltage can be compensated by RSC without overloading the converter. Moreover the GSC stays reactive neutral is most of the practical cases. So STATCOM is controlled to keep the voltage at PCC at 1 p.u.

In the analysis, a three phase short circuit fault at the load bus is created at 0.5 seconds, the fault is cleared after 200 milliseconds. This causes the fall in PCC voltage, the reactive power compensation provided by the STATCOM is negligible, but the post-fault voltage recovery depends on it. Figure shows the profile of PCC voltage, with and without STATCOM in the network. The magnitude of voltage decreases to 0.03 p.u, but in case of STATCOM supports, it remains at 0.05 p.u. Also it is obvious that settling time of the PCC voltage is 0.01 milliseconds after clearing the fault with STATCOM. This proves that the STATCOM improves the PCC voltage profile. The following figure shows the waveform of PCC voltage with and without STATCOM.

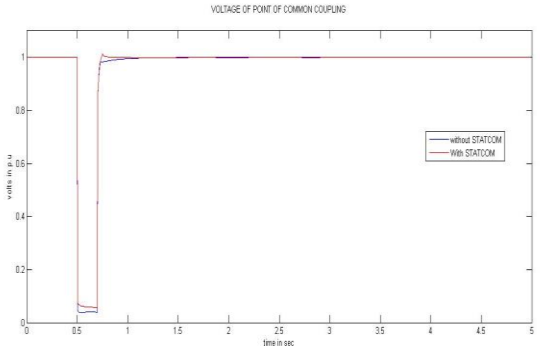

Fig 5. PCC voltage without and with STATCOM

Figure 6 shows the reactive power supplied by the external grid. When STATCOM is not in the system, then grid supplies its full capacity of reactive power ie 13 MVA during fault period to improve the voltage profile of PCC. When STATCOM is in the system, then reactive power supplied by the grid gets reduced.

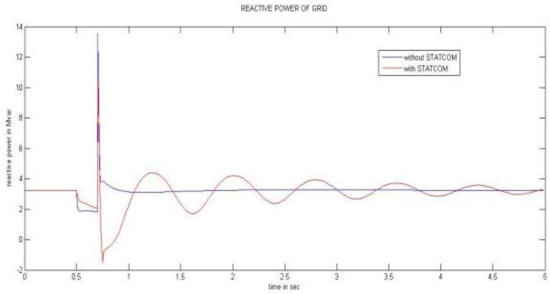

Fig 6. Reactive power of external grid without and with STATCOM

Then considering the location of the STATCOM, the above steady state analysis is done in two different locations of the STATCOM. The two different locations of STATCOM are in the load bus and PCC. When considering different locations of STATCOM for steady state analysis, a three phase short circuit fault is created in the load bus at 0.5 seconds and cleared it at 0.7 seconds. The waveform of PCC voltage without STATCOM and different \locations of STATCOM are given in figure 7.

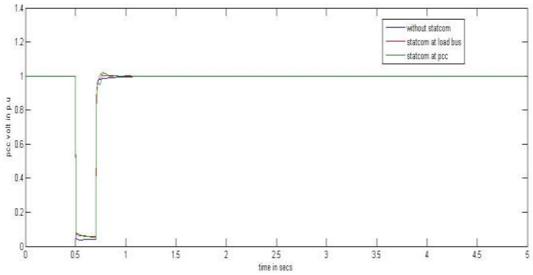

Fig 7. PCC voltage

Due to fault, PCC volt drops to 0.3 p.u when STATCOM is not in the system. But connecting STATCOM in the system the PCC volt drop improves to 0.5 p.u. When STATCOM is connected in PCC, the settling time of PCC volt after fault clearing is 0.86 seconds. When STATCOM is in load bus, the settling time of PCC volt after fault clearing is improved to 0.78 seconds. So STATCOM at load bus is improves PCC volt than in STATCOM at PCC.

Then considering the SCR and X/R ratios of external grid, the above steady state analysis is done in two different values of SCR and X/R ratios of external grid. Different SCR and X/R ratios of external grid are 500,100 and 10,5 respectively. These values of SCR and X/R ratios are chosen because weak grid has normally low values of SCR and X/R ratios. While considering SCR and X/R ratios of grid, the steady state analysis is done by creating a three phase short circuit fault is created at load bus in 0.5 seconds and cleared it in 0.7 seconds. From the simulation we can get the PCC volt drop during fault and setting time of PCC volt after fault clearance. The below bar diagrams shows the PCC volt drop during fault and settling time of PCC volt after clearing fault for different values of SCR and X/R ratio of grid.

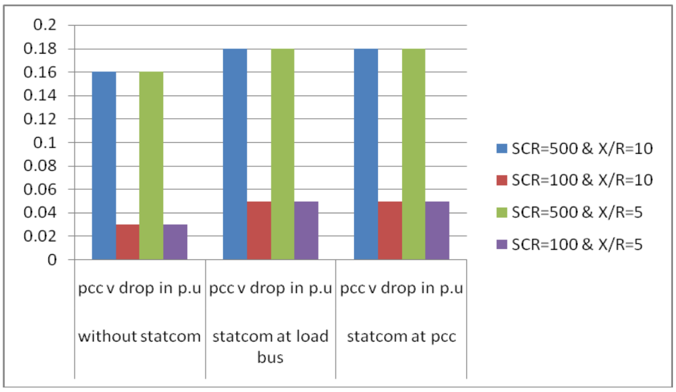

Fig 8. Volt drop values of PCC during fault for different values of SCR and X/R ratios of grid

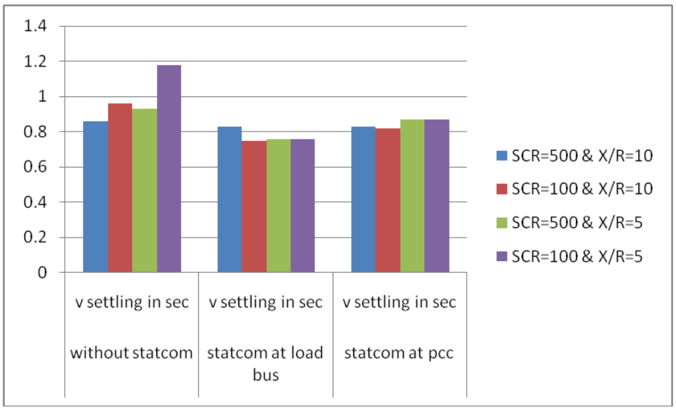

Fig 8. Settling time of PCC volt after clearing fault for different values of SCR and X/R ratios of grid

From the first bar diagrams, it is seen that the volt of PCC drops to 0.16 p.u for SCR 0f 500 and X/R of 10 when the STATCOM is not connected. Volt drop gets improved to 0.18 p.u for SCR of 500 and X/R of 10 with STATCOM. Whenever the SCR and X/R ratio are in 100 and 5 respectively, the volt drop is about 0.03 p.u in case of without STATCOM and 0.05 p.u in case of with STATCOM. Here location of STATCOM did not produce any effect in PCC volt drop. From the second bar diagrams, it is seen that the settling time of PCC volt after clearing fault is about 0.9 seconds for SCR 0f 500 and X/R of 10 when the STATCOM is not connected. Settling time gets improved to 0.85 seconds for SCR of 500 and X/R of 10 with STATCOM which is connected in PCC. Settling time gets improved to 0.82 seconds for SCR of 500 and X/R of 10 with STATCOM which is connected in load bus. Whenever the SCR and X/R ratio are in 100 and 5 respectively, the settling time is about 1.05 seconds in case of without STATCOM and 0.82 seconds in case of STATCOM connected in PCC and settling time is improved to .76 seconds in case of STATCOM connected in load bus. Here location of STATCOM produce effect in settling time of PCC volt after clearing the fault. Settling time is improved when STATCOM is connected in load bus than connected in PCC.

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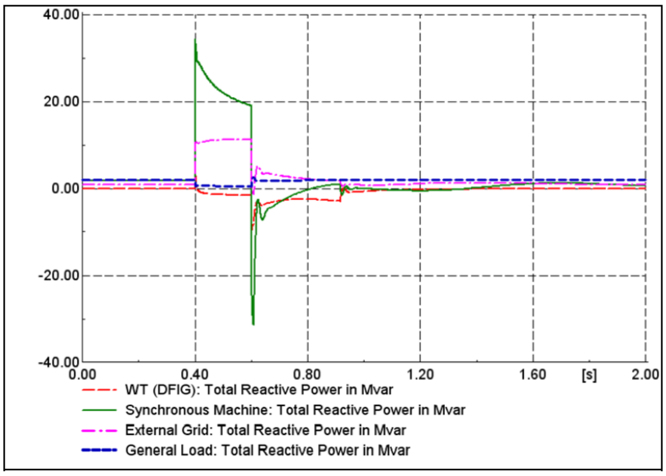

Fig 9. Reactive powers in the system with a 150 MVA STATCOM

Fig 9. shows the reactive powers in the system with a 150 MVA STATCOM. Whenever the rotor current exceeds its rated value (at t=0.504 sec), the converter protection shorts the RSC with an impedance, at which time the DFIG becomes a conventional induction generator. The DFIG then absorbs reactive power from the power network, which is necessary for the generator excitation. The control of the RSC is now inactive and dynamic reactive compensation must be incorporated near the wind farm connection point to meet the reactive power demands. The additional dynamic reactive power compensation helps reduce the voltage drop at grid faults and performs dynamic reactive power control.

V.CONCLUSION

This paper explores the possibility of connecting a STATCOM to the wind power system in order to provide efficient control. In this thesis, the wind turbine modeled is a DFIG that is an induction machine which requires reactive power compensation during grid side disturbances. An appropriately sized STATCOM can provide the necessary reactive power compensation when connected to a weak grid. Also, a higher rating STATCOM can be used for efficient voltage control and improved reliability in grid connected wind farm but economics limit its rating. 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.

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