PERFORMANCE ANALYSIS OF DFIG BASED WIND FARM CONNECTED TO WEAK DISTRIBUTION SYSTEM

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ABSTRACT

The existing grid codes demands a wind farm to remain connected and provide necessary support to the network during fault ride through and grid-disturbances. Also with increased penetration level of wind farms the performance of the power system degrades and brings voltage stability problems. This requires a thorough study of the dynamic performance of wind turbines during and after a disturbance. This paper investigate the implementation of Static Synchronous Compensator (STATCOM) at the point of common coupling for the voltage stability issue in Doubly Fed Induction Generator (DFIG) based wind farms interconnected to weak distribution system. Modeling and simulation of system is carried out in MATLAB/Simulink platform. Analysis shows improvement in overall voltage profile, system becomes more stable and the performance is enhanced with the use of STATCOM and thus prevents the wind turbine generators from going offline during and after the disturbance.

Keywords: Wind Farm, DFIG, STATCOM, Dynamic Reactive Power Compensation, Voltage Stability

I INTRODUCTION

With the acute need for electrification and higher energy production in the country, wind energy is going to provide an increasingly significant share of the renewable based capacity [1]. In recent years there has been a continuous increase in installed wind power generation capacity throughout the world. When many wind turbines are added to the system, a grid becomes weaker as these types of generators require additional control equipment since they do not have any self-recovery capability like the conventional generators. This requires thorough study of the normal and dynamic performance of the wind turbines during and after a disturbance. The successful entry of Doubly Fed Induction Generator (DFIG) based wind turbine in to the competitive wind market stimulates to study the performance of the overall DFIG system under different operating and critical conditions. With increased penetration of wind energy and moving towards active networks, grid codes are being revised to reflect the new requirements. This has created a keen interest in many of the researchers to develop more detailed model particularly with respect to the fault analysis. The detailed 5th order model is the best suited model for studying the behaviour of the system during fault [2, 3].

II BACKGROUND

Variable speed turbine such as DFIGs are the most popular wind turbines being installed today because they perform better than fixed speed wind turbines during system disturbances and also available in high power MW range [4]. A comparison between the variable speed wind turbine and the constant speed wind turbine shows that variable speed reduce mechanical stress [5]. The DFIG system consists of a Wound Rotor Induction Generator (WRIG) with the stator windings directly connected to the constant frequency three-phase grid and with the rotor windings connected to grid through a bidirectional back-to-back IGBT based voltage source converter. This system allows a variable speed operation over a large range. The converter compensates the difference between the mechanical angular frequency and grid frequency by injecting a rotor current with a variable frequency. The power converter consists of two converters, the machine-side converter and grid-side converter, which are controlled independently of each other. The main idea behind the total system (DFIG with back-to-back converters) is that the machine-side converter controls the active and reactive power by controlling the rotor current components, while the grid-side converter controls the dc-link voltage and ensures the operation at unity power factor (i.e. zero reactive power). By means of a bidirectional converter in the rotor circuit the DFIG is able to work as a generator in both sub-synchronous and super-synchronous modes [6]. One of the major issues concerning the wind farm interconnection to a power grid concerns its dynamic stability on the power system [7]. Voltage instability problems occur in a power system that is not able to meet the reactive power demand during the faults and heavy loading conditions. Flexible AC Transmission System (FACTS) such as Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC) and the Unified Power Flow Controller (UPFC) are being used extensively in power system because of their ability to provide flexible power flow control.

III GRID CONNECTION ISSUES AND WIND FARM MODELLING REQUIREMENTS

When wind power is connected to these networks, they impose a specific set of requirements, referred to as grid codes. Before integrating large amounts of wind power with the conventional generating units, a comprehensive analysis of the power system stability and reliability issues has to be studied. A simulation study is the best known method to understand the system dynamics for operation under normal conditions and during contingencies. A grid code covers all material technical aspect relating to connection to, and the operation and use of, a country's electricity transmission system. They lay down rules which define the ways in which generating station connecting to the system must operate in order to maintain grid stability [8]. Main requirement involves:

- Active power control
- Reactive power control
- Fault ride through capability
- Grid stability
- Power quality control and improvement
- Grid synchronization

- Voltage control
- Frequency control

Several studies have been performed to evaluate the DFIG based wind farm for their active power and reactive power control capability in accordance with the grid code requirement for wind integration. This paper focuses mainly on one of the key aspects of the grid integration requirement known as Low Voltage Ride Through (LVRT) or Fault ride through capability of the wind turbines.

3.1 LVRT (Low Voltage Ride Through)

A turbine's Low voltage ride through (LVRT) capability is its ability to survive a transient voltage dip without tripping. Wind turbines' LVRT capability is vital for wind farm interconnection because the tripping of a wind farm due to a fault on a nearby power line results in the loss of two major system components (the line and the wind farm).

3.2 Uninterrupted behaviour of DFIG based wind turbine during grid fault

During grid fault, undesirable high current induced in the rotor windings and the protection system may block the RSC to protect it from over current in the rotor circuit. With RSC blocking, the rotor circuit is short circuited by a crow bar. The wind turbine continues its operation with the DFIG rotor short-circuited. During such an operating condition, the controllability of the RSC is almost lost, and there is no longer any independent control of active and reactive powers in the DFIG. The DFIG now becomes a conventional induction generator, which starts absorbing reactive power and continues producing an active power.

When RSC blocked, the GSC is the only available option to control the reactive power exchange between the DFIG and grid. The controllability of the GSC is however limited due to small power rating of the converter. If weak grid is to be considered then as a result, there can be the risk of the voltage instability and the subsequent tripping of the wind turbine generator.

Hence to minimize effects of the grid side disturbances like 3-phase fault, abrupt load change, voltage swelling and sagging in DFIG-wind farm during and after fault, reactive power compensation is required because DFIG-based wind farm can't provide sufficient reactive power and voltage support due to its limited power capacity [9], for example 9 MW (2 wind turbines, each with 4.5 MW capacity) in this studied case.

IV STATCOM AND ITS CAPABILITIES

The main motivation for choosing STATCOM in wind farm is its ability to provide bus bar system voltage support either by supplying and/or absorbing reactive power into the system [10]. The STATCOM can supply both the capacitive and inductive compensation and is able to independently control its output current over the rated maximum capacitive or inductive range irrespective of the amount of ac system voltage. That is, the STATCOM can

provide full capacitive-reactive power at any system voltage-even as low as 0.15 p.u. The STATCOM can also contribute to the low voltage ride through requirement because it can operate at full capacity even at lower voltages. In this paper, a voltage source converter (VSC) PWM technique based STATCOM is proposed to stabilize grid connected DFIG based wind turbines.

V TEST SYSTEM

The test system used for this study is shown in the single line diagram, Fig.1. The distribution grid consists of a 30 kV, 60 Hz, grid supply point. The system is connected to an external grid whose short circuit capacity is 150 MVA, i.e., it is a weak grid and cannot respond to system disturbances There is one load in the system of 30 MW and 5MVAr at 15 km from the transformer at the load bus. The 30 kV, 15 km long line is represented as nominal-Π line. The DFIG-based wind farm consists of two wind turbines each with 4.5 MW (total 9 MW) which have a protection system monitoring voltage, current, machine speed and DC link voltage. The wind speed increases slowly from 8 m/sec and reaches the final constant value of 14 m/sec at 35 sec. All the tests here are studied after system reaches steady state i.e. after 35 sec. The GSC in DFIG maintains the DC link voltage almost constant at 1200 V during normal operating condition. The main intent of this study is to force the DFIG and STATCOM to respond to disturbances in the area of interest. Dynamic compensation of reactive power is provided by connecting STATCOM in combination with MSCs at the point of wind farm connection.

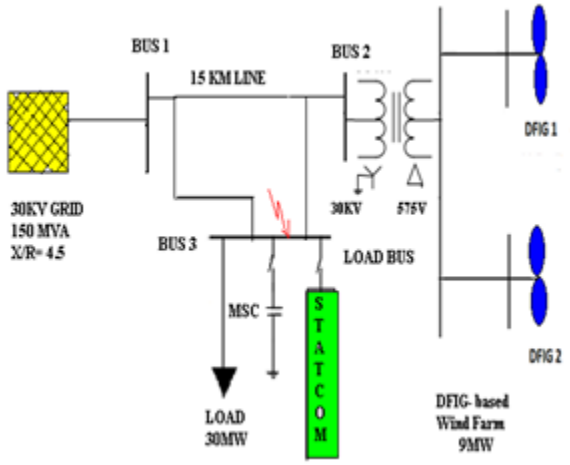


Fig.1 Single line diagram of test system

VI SIMULATION RESULTS

To evaluate the voltage support provided by a STATCOM which is connected to a weak grid, simulations have been performed in MATLAB/Simulink Version 7.7.The distribution systems are naturally unbalanced in most of the cases because of unsymmetrical spacing and unbalanced consumer loads so all the network components are modelled in three phase. The power system is studied to evaluate the system performance.

The results are shown in the subsequent sections and discussions are presented therein.

6.1 Small Duration Three Phase High Impedance Fault

In this case, a 3-phase, 2-cycle, high impedance fault (Zf = 8Ω) with value of ground impedance 5 Ω and initiated at t = 35.4 sec was studied at load bus B3. The MSCs remains always connected at bus B3 to provide voltage support. The voltage at the grid reduces from0.925 p.u.to 0.62 p.u.as shown in Fig.2.

The voltage at load bus reduces from0.92 p.u. to 0.61 p.u. as shown in Fig.3.

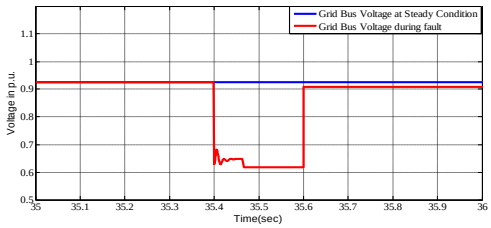


Fig.2.Grid voltage during fault

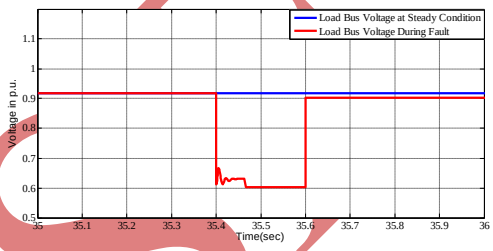


Fig.3.Load bus voltage during fault

As shown in Fig.4.the DFIG terminal voltage falls to around 0.6 p.u. during the fault.

It is observed that without STATCOM, the voltage across the load bus B3 and wind turbine does not recover even after the fault is cleared and the protection system has tripped DFIG at 35.41 sec because of abrupt rise in DC voltage across DC link capacitor from 1200 V to about 1425V as shown in fig.7 below because fault makes active power unbalance between RSC and GSC higher. This is dangerous because high DC voltage across capacitor might damage the power electronic devices in voltage source converters of DFIG. This tripping of DFIG is not in accordance with new grid code.

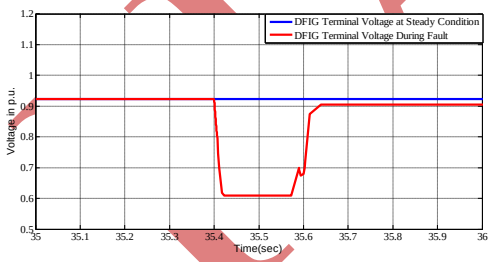


Fig.4.DFIG terminal voltage during fault

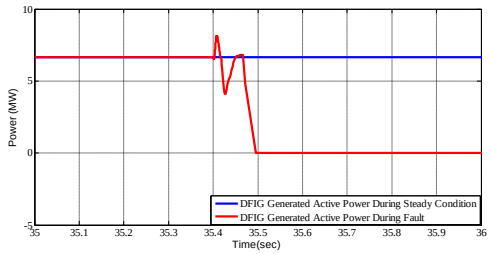
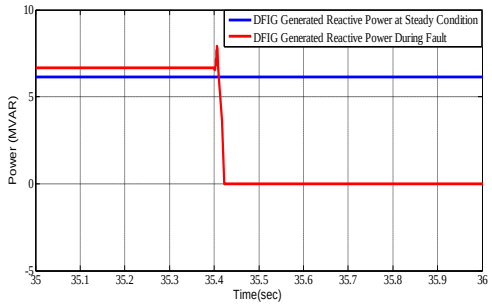


Fig.5.DFIG generated active power during fault

Fig.5 shows the variation of power generated by DFIG turbine in MW with respect to time without application of compensating devices. It is also shown that during the fault, power generated by the DFIG is reduced to zero as protection system disconnected it from the grid, and it remains disconnected even after the clearance of the grid fault.

Fig.6 shows the variation of reactive power generated by DFIG turbine in MVAr with respect to time without application of compensating devices.



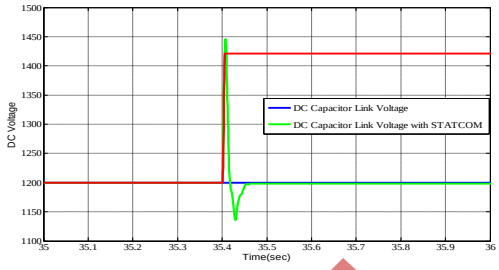
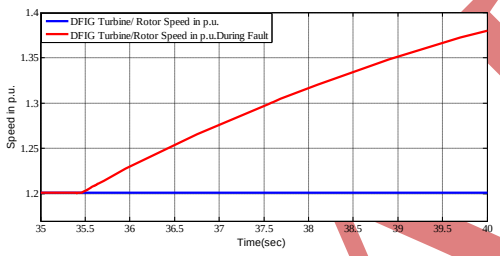


Fig.6.DFIG generated reactive power during fault **Fig.7.DC capacitor voltage during fault**

Fig.6 shows the variation of reactive power generated by DFIG turbine in MVAr with respect to time without application of compensating devices.

Fig.7 shows that due disconnection of the wind farm the DFIG cannot able to supply the power even after the clearance of the fault and hence the speed of the turbine increases from 1.2 p.u. to 1.4 p.u. during the time of fault and corresponding pitch angle is increased in order to limit the speed as shown in Fig.8.



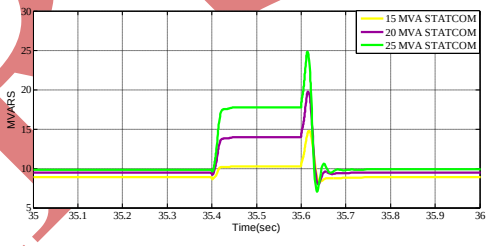


Fig.8.DFIG turbine/rotor speed in p.u. during fault **Fig.9.Reactive power supplied by STATCOM during fault**

Fig.9 shows the reactive power of the STATCOM. At t=35.4 sec, a three phase high impedance short circuit fault occurs at the load bus. The voltage at the fault bus drops depending on the fault location and the fault impedance. This initiates the operation of the STATCOM. The drop in the terminal voltage determines the amount of reactive power needed. The STATCOM can operate at full capacity even at low voltages. The STATCOM in this case supplies the necessary reactive power to support the load bus voltage.

At t=35.6 sec, when the fault is cleared, the voltage rises and the reactive power provided by the STATCOM overshoots.

At t=35.6 sec, the three phase short circuit fault is cleared and the system starts to recover from the fault. The load bus voltage is improved when compared to same without any compensating device (Fig.10).

From Fig.11 it is observed that without use of STATCOM, before the initiation of the fault the load voltage is approx 0.92 p.u. and even after clearance of the fault the terminal voltage of the DFIG does not recover its normal

value. Also without application of STATCOM during transient or fault condition the load voltage drops abruptly to 0.6 PU and DFIG protection system force to operate and disconnect the DFIG with the grid.

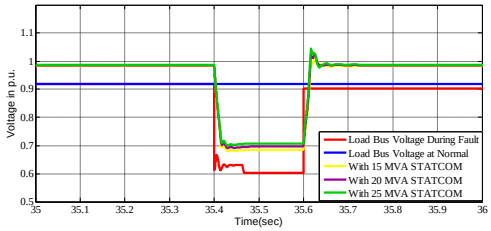


Fig.10

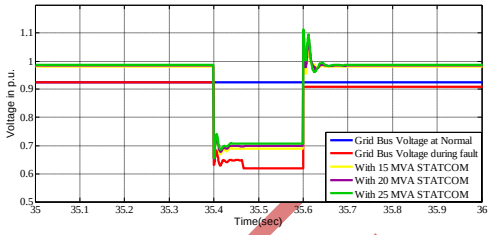


Fig.11

Fig.10.Grid voltage with and without compensating device

Fig.11.Load bus voltage with and without compensating device

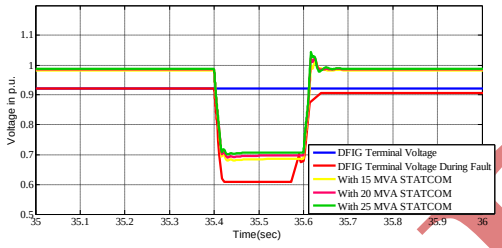


Fig.12

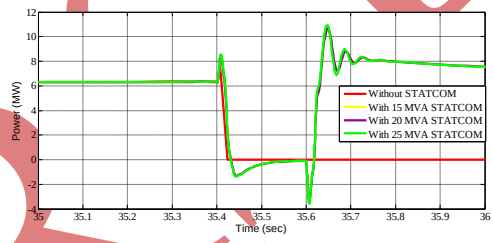


Fig.13

Fig.12.DFIG terminal voltage with and without compensating device .

Fig.13.DFIG generated active power with and without compensating device

It is observed from the Fig.12 that without STATCOM voltage at the terminal of the DFIG drops abruptly to 0.62 p.u. and it forces to operate the protection system of the DFIG and disconnect the DFIG from the system. It is also shown that even after clearance of the fault the terminal voltage of the DFIG does not recover its normal value. With STATCOM the voltage remains in the limit of the turbine protection system (0.72 p.u.) which forces the wind farm to remain connected with the system. It is also observed that voltage is recovered after the clearance of the fault.
It is clearly shown in the Fig.11 and fig.12 that with the use of STATCOM the transient voltage during the fault is improved to 0.74 p.u. and made the DFIG to remain connected with the system during the fault

As shown in Fig.13 and Fig.14 without STATCOM, wind turbine generates around 6 MW active power and 6 MVAR reactive power to maintain normal voltage in system and trips when fault occurs but after connecting STATCOM, wind farm generates around 8 MW active power and only 1.5 MVAR reactive power. Hence with the presence of STATCOM in the system, power factor of the wind farm generated power can be controlled.

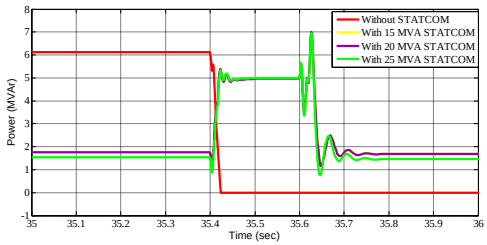


Fig.14.DFIG generated reactive power with and without compensating device

VII CONCLUSION

DFIG have various advantages over other types of wind turbines.It requires disturbances mitigating system to enhance the voltage stability such as dynamic reactive power compensation devices.Dynamic reactive power compensation using STATCOM at the point of common coupling (PCC) is a feasible option. The STATCOM helps to provide better voltage profile during three phase fault.

VIII FUTURE SCOPE

In this paper, simulation studies show that the dynamic performance of wind farms is improved with the use of a STATCOM. Future work can involve response of the system to other types of faults. The study can also be extended to various types of wind turbines and also to a larger system to evaluate the support provided by STATCOM. The study can also extended to optimise the parameters of the RSC and GSC controllers in order to obtain better response of DFIG.

IX APPENDIX

Input data of Doubly Fed Induction Generator as mentioned in [9]

Transmission Line Parameters:

Parameters	Positive sequence	Zero sequence
Resistance	0.1273Ω/Km	0.3864Ω/Km
Inductance	0.3337mH/Km	4.1264mH/Km
Capacitance	12.74nF/Km	7.751nF/Km

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