International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 3, March - 2014

Enhancement of Voltage Stability in Windfarm with DFIG using STATCOM

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Abstract **– Voltage stability is a key issue to achieve the uninterrupted operation of wind farms equipped with doubly fed induction generators (DFIGs) during grid faults.To harness the wind power efficiently the most reliable system in the present era is grid connected doubly fed induction generator. This paper investigatesthe application of a static synchronous compensator (STATCOM) to assist with the uninterrupted operation of a wind turbine driving a DFIG, which is connected to a power network, during grid faults. The system is implemented in SIMULINK/MATLAB simulation. Results show that the STATCOM improves the voltage stability and therefore helps the wind turbine generator system to remain in service during grid faults.**

Index Terms—Doubly fed induction generators (DFIGs), static synchronous compensator(STATCOM), wind turbine.

I. INTRODUCTION

Because of the concern about the environmental pollution and a possible energy crisis, there has been a rapid increase in renewable energy sources worldwide in the past decade. Among various renewable energy sources, wind poweris the most rapidly growing one.

Nowadays, the majority of wind turbines are equipped with doubly fed induction generators (DFIGs). In the DFIG concept, the wound-rotor induction generator is grid-connected at the stator terminals, as well as at the rotor mains via a partially rated variable frequency ac/dc/ac converter (VFC), which only needs to handle a fraction (25%–30%) of the total 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.

When connected to the grid and during a grid fault, the voltagesags at the connection point of the wind farm can causea high current in the rotor circuit and the converter. Since thepower rating of the VFC converter is only 25%–30% of theinduction generator power rating, this over-current can lead tothe destruction of the converter. One of the key issuesrelated to the wind farms equipped with DFIGs is the grid fault or low voltage ride-through capability. Therefore, voltage stability is the crucial issue in maintaining un interrupted operation of wind turbine equipped with DFIGs [1].

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. It has been reported recently[2] that integration of wind farms into the East Danish power system could cause severe voltage recovery problems following a three-phase fault on that network.

The problem of voltage instability can be solved by using dynamic reactive compensation. Shunt flexible ac transmission system (FACTS) devices, such as the static var compensator (SVC) and the static synchronous compensator (STATCOM), have been widely used to provide voltage control at the point of common coupling (PCC) [7].

TABLE I
System Parameters (on 3.6-MW 4.16-kV Bases)

Wind turbine		Induction generator	
Rated capacity	3.6 MW	*P*rated	3.6 MW
Nominal wind speed	12 m/s	*V*s,rated	4.16 KV
Cut in wind speed	5 m/s	Stator resistance r_s	0.0079
Cut out wind speed	27 m/s	Rotor resistance r_r	0.025
Rotor speed	8.5-15.3 rpm	Stator leakage reactance L_{ls}	0.07939
No. of blades	3	Rotor leakage reactanceL_{lr}	0.40
Rotor diameter	104 m	Mutual inductance L_m	4.4

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 voltage regulation and improve the short-term transient voltage stability. The DFIG and STATCOM control schemes are suitably designed and coordinated. The system is implemented in SIMULINK/MATLAB simulation.

II. POWER NETWORK MODEL

In a real power system, a large wind farm generally consists of hundreds of individual wind turbines. It has been reported in [1] that with well-tuned converters, there is no mutual interaction between wind turbines in a wind farm, independently from the conditions of the power grid. Therefore, in this paper, only one wind turbine is used to represent the wind farm.

Fig. 1 shows the single-line diagram of the power system used for this paper. In a real power system, a large powerplant is normally connected to the power network by multiple parallel power lines with certain capacity redundancy, not only because of the thermal limits of each single power line but also to increase the reliability of the power transmission in the case of the outage of one power line. As in this paper, a 3.6-MWDFIG driven by a wind turbine [4] is connected to a powergrid through a transformer and two parallel lines. A three-phase balanced electric load at the sending end bus is modeled as a constant impedance load Z_L. A STATCOM is shunt connected at the sending end bus for steady-state, as well as transient voltage support. The parameters of the system components are given in Table I.

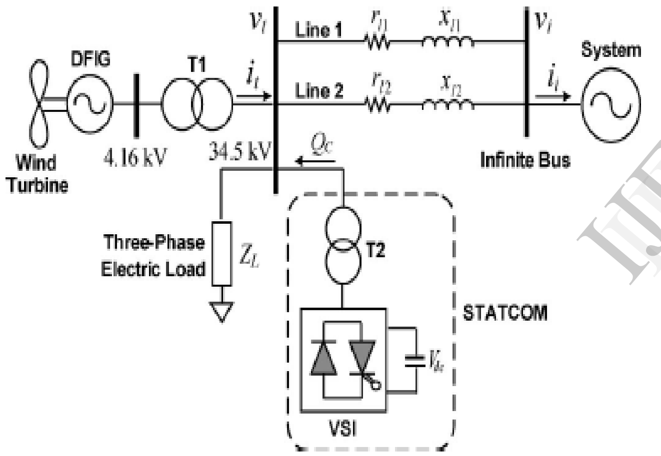

Fig. 1.Single-line diagram of the power network.

III. MODELING AND CONTROL OF DFIG

The basic configuration of a DFIG driven by a wind turbine is shown in Fig. 2. The wind turbine is connected to the DFIG through a mechanical shaft system, which consists of a low and a high-speed shaft with a gearbox in between. The wound rotor induction machine in this configuration is fed from both stator and rotor sides. The stator is directly connected to the grid while the rotor is connected to the grid through a VFC .In order to produce electrical power at constant voltage and frequency to the utility grid for a wide operating range from sub synchronous to super synchronous speeds, the power flow between the rotor circuit and the grid must be controlled both in magnitude and in direction. Therefore, the VFC consists of two four-quadrant insulated-gate bipolar transistor (IGBT) pulse width modulation (PWM) converters connected back-to back by a dc-link capacitor [5]. The crowbar is used to short circuit the RSC in order to protect it from over current in the rotor circuit during transient grid disturbances.

Control of the DFIG is achieved by control of the VFC, which includes control of the RSC [3], [5]–[6] and control of the GSC [5]. The objective of the RSC is to independently regulate the stator active and reactive powers, which are represented by *Ps* and *Qs*, respectively. Fig. 3 shows the overall vector control scheme of the RSC. For the rotor-side controller the actual electrical output power measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current Iqrref that must be injected in the rotor by RSC. This is the current component that produces the electromagnetic torque Tem. The actual Iqr component is compared to Iqrref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by RSC. The current regulator is assisted by feed forward terms which predict Vqr. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the RSC. The reactive power is exchanged between RSC and the grid, through the generator. In the exchange process the generator absorbs reactive power. The excess of reactive power is sent to the grid or to RSC.

When the wind turbine is operated in var regulation mode the reactive power at grid terminals is kept constant by a var regulator. The output of the voltage regulator or the var regulator is the reference d-axis current Idr_ref that must be injected in the rotor by RSC. The same current regulator as for the power control is used to regulate the actual Idr component of positive-sequence current to its reference value. The output of this regulator is the d-axis voltage Vdr generated by RSC. The current regulator is assisted by feed forward terms which predict Vdr. Vdr and Vqr are respectively the d-axis and q-axis of the voltage Vr.

The objective of the GSC is primarily to keep the dc-link voltage constant regardless of the magnitude and direction of the rotor power. In this paper, the GSC control scheme is also designed to regulate the reactive power exchanged between the GSC and grid.

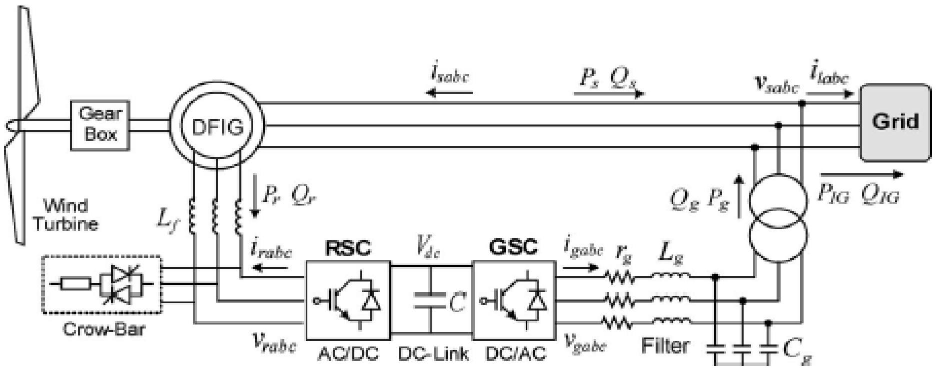

Fig. 2.Configuration of a DFIG wind turbine.

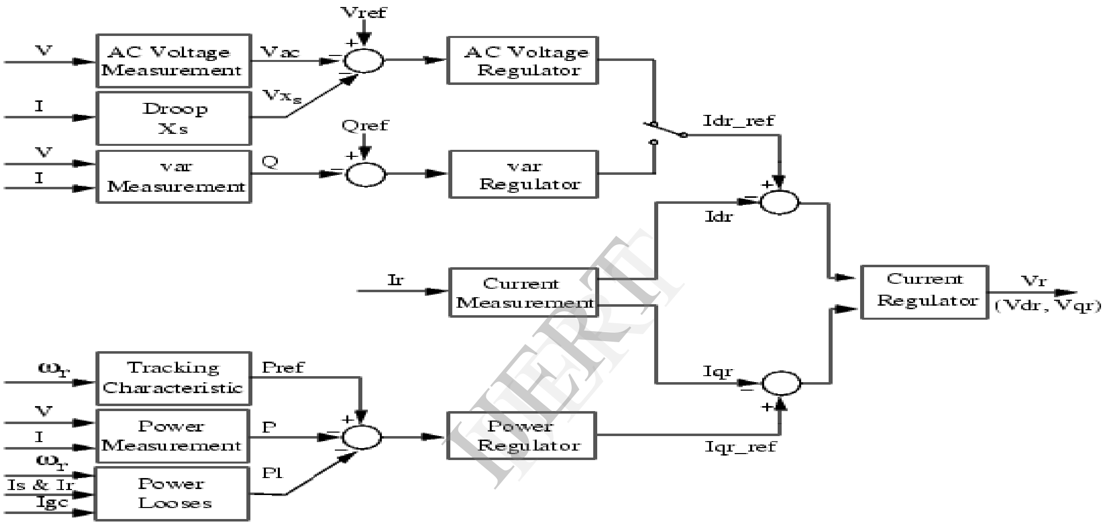

Fig. 3. Overall control scheme of the RSC.

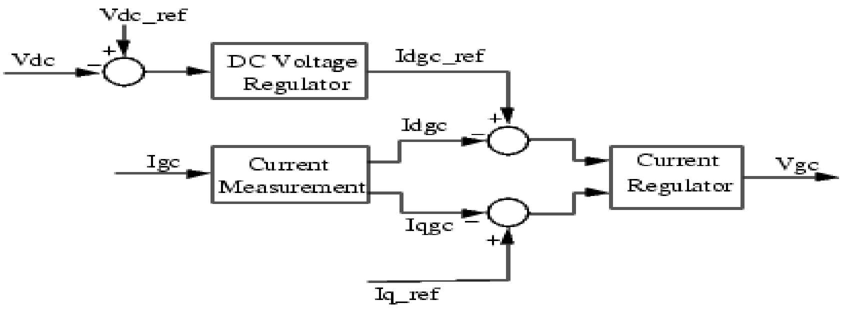

Fig. 4. Overall control scheme of the GSC.

Fig. 4 shows the overall control scheme of the GSC. For the grid-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. The current regulator controls the magnitude and phase of the voltage generated by converter Cgrid (Vgc) from the Idgc_ref produced by the DC voltage regulator and specified Iq_ref reference. The current regulator is assisted by feed forward terms which predict the RSC output voltage.

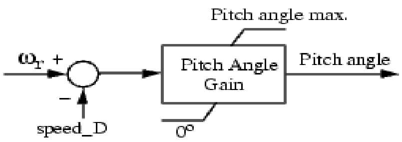

Fig. 5. Wind-turbine pitch angle controller.

Pitch angle control is used to limit the aerodynamic power above rated wind speed in order to keep the turbine shaft torque within its design limits.To maximize the efficiency of the
turbine, vary its rotational speed to follow the wind speed. The objective of the pitch angle control is to achieve high efficiency and at the same time have a smooth power output.

IV. STATCOM MODEL

A STATCOM [7], [8], also known as an advanced SVC, is a shunt-connected FACTS device. It generates a set of balanced three-phase sinusoidal voltages at the fundamental frequency, with rapidly controllable amplitude and phase angle. A typical application of a STATCOM is for voltage support. In this paper, the STATCOM is modelled as a gate turn-off thyristor (GTO) PWM converter with a dc-link capacitor. The objective of the STATCOM is to rapidly regulate the voltage at the PCC in the desired range. It can enhance the capability of the wind turbine to ride through transient disturbances in the grid.

V. SIMULATED RESULTS

A wind farm equipped with doubly fed induction generator is simulated inSIMULINK/MATLAB.

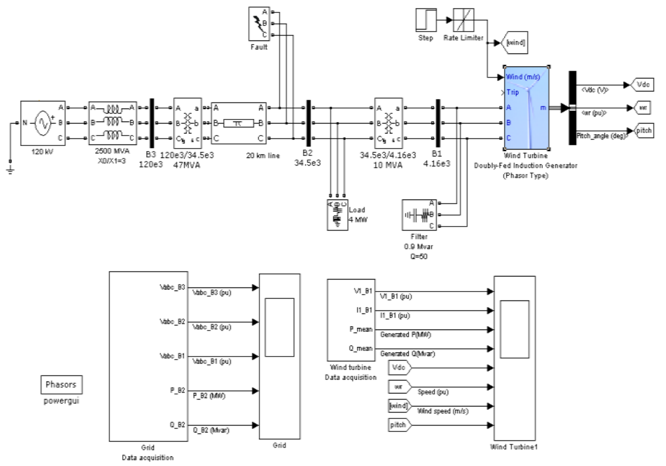

Fig. 6.Block diagram of Doubly fed induction generator (DFIG) during Three-phase fault

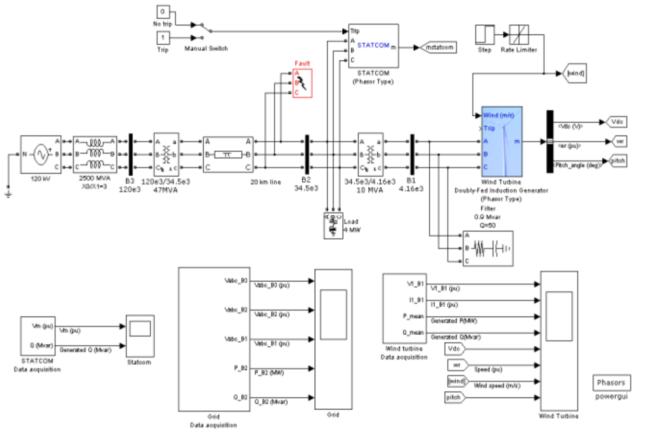

Fig. 7.Block diagram of Doubly fed induction generator (DFIG) with STATCOM during Three-phase fault

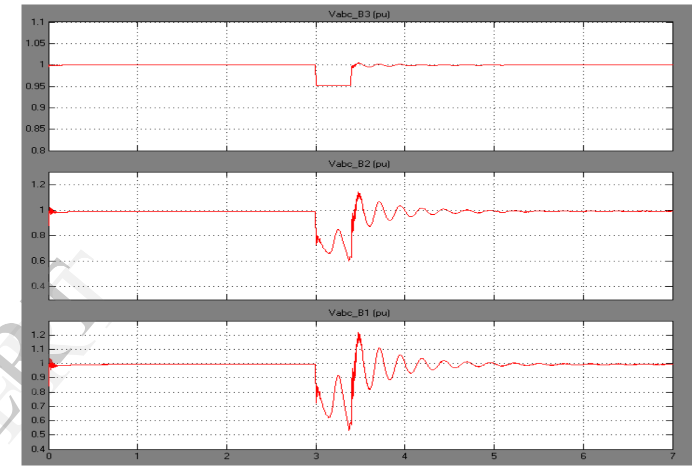

Fig. 8.Variation of Voltage at the bus B1, B2 and B3with respect to time without STATCOM

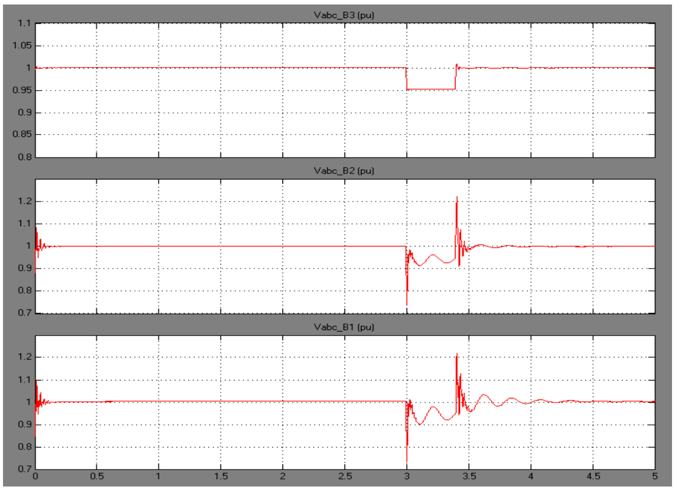

Fig. 9.Variation of Voltage at the bus BI, B2 and B3with respect to time with STATCOM

To demonstrate the effectiveness of the STATCOM to help the wind turbine ride through grid faults, a three-phase permanent short circuit is now applied at bus B2. The STATCOM is now used to help achieve the uninterrupted operation of the wind turbine.The objective of the STATCOM is to rapidly regulate the voltage at the PCC in the desired range.It can enhance the capability of the wind turbine to ride through transient disturbances in the grid.

Fig .8 shows the variation of voltage at the bus B1, B2 and B3 with respect to time without STATCOM. The fault is programmed to apply a three-phase fault at t = 3s. The fault clearance time is 3.4s. At Bus B2 where the fault is applied, the voltage has come down to 0.6 p.u. After the clearance of fault, variation of voltage is identified.

Fig. 9 shows the variation of voltage at the bus B1, B2 and B3 with respect to time with STATCOM. The fault is programmed to apply a three-phase to fault at t = 3 s. The fault clearance time is 3.4 s. At Bus B2 where the fault is applied, the voltage has boost upto 0.9 p.u with the help of STATCOM. After the clearance of fault, variation of voltage is identified.

VI. CONCLUSION

The successful integration of wind farms to power systems might need dynamic reactive compensation to assist with voltage support, particularly during grid disturbances.This paper has investigated the application of a STATCOM to achieve the uninterrupted operation of a DFIG wind turbine during grid faults. The STATCOM is placed at the bus (PCC) where the DFIG is connected to the power grid, for steady-state voltage
regulation and transient voltage support. The control schemes of the DFIGRSC, GSC, and the STATCOM have been suitably designed and coordinated.

The system has been implemented on an RTDS and subjected to short-circuit grid faults. Real-time implementation results show that with the STATCOM providing dynamic voltage support, the PCC voltage can be re established shortly after grid faults, and therefore, the wind turbine remains in service. However, without the STATCOM for voltage support, the PCC voltage Cannot be re established after grid faults so that the wind turbine has to be tripped from the power network. The STATCOM improves the transient voltage stability and therefore enhances the grid fault ride-through capability of the wind-turbine generator system.

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