PARTICIPATION OF FACTS IN STABILIZING DFIG WITH CROWBAR DURING GRID FAULT BASED ON GRID CODES

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ABSTRACT

This paper investigates the effect of connecting FACTS (Flexible AC Transmission System) device such as a STATCOM (Static Synchronous Compensator) to the point of common coupling (PCC) of a wind farm composed of DFIG. Simulation results show that a FACTS device can effectively enhance the performance of the DFIG, when it is disconnected by the crowbar switch during grid fault by providing additional reactive power to the system, thus improving the voltage instability performance of the DFIG and the wind farm as well.

Index Terms— Wind energy, Doubly Fed Induction Generator, Crowbar, FACTS, Grid codes.

1. INTRODUCTION

The increasing size of wind turbine and wind parks resulted in new interconnection rules called grid codes. Today, there is need to control wind power, both in active and reactive power, and to be able to stay connected with the grid when grid faults happen. The doubly fed induction generator (DFIG) has the largest world market share among the commercial available wind turbine generator systems since the year 2002 [1], because of its ability to provide variable speed operation and independent active and reactive power control in a cost-effective way.

A crowbar protection switch is normally considered to protect the frequency converter of doubly fed induction generator (DFIG) during grid fault. However, the crowbar protection has some adverse effects on the operation of DFIG as to deteriorate the independent controllability of real and reactive powers. Crowbar protection is often adopted to protect the rotor side converter (RSC) which is basically a voltage source converter (VSC) from transient overcurrent during grid fault. The severe problems are not the transient overcurrent, but the DC voltage instability in the back-to-back VSC. In the case of a weak power network and during a grid fault, the grid side converter (GSC) cannot provide sufficient reactive power and voltage support due to its small power capability, and there might 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 instability is a crucial issue in maintaining uninterrupted operation of wind turbines equipped with DFIGs. With the rapid increase in penetration of wind power to the grid, tripping of many wind turbines in a large wind farm during grid fault may influence the overall power system stability.

The problem of voltage instability can be solved by using dynamic reactive power compensation. Shunt connected flexible ac transmission system (FACTS) devices, such as static var compensator (SVC) and the static synchronous compensator (STATCOM), have been widely used to provide high-performance steady-state and transient voltage control at the point of common coupling (PCC). The application of a SVC or a STATCOM to a wind farm equipped with fixed-speed wind turbines (FSWTs) and squirrel-cage induction generators (SCIGs) for steady-state voltage regulation and for short-term transient voltage stability is already reported in [2].

This paper presents the use of a STATCOM to improve the stability of a wind farm composed of DFIG during grid fault. A crowbar protection switch is connected to the DFIG and is triggered if the DC-link voltage, $E_{dc,}$ exceeds its maximum set point value, thus making the DFIG to behave like a conventional IG during the grid fault, hence loosing controllability of both active and reactive power. The STATCOM comes into play to support the DFIG during the crowbar period that helps to handle the necessary reactive power demand to avoid voltage instability. Simulations are carried on using laboratory standard power system simulation package PSCAD/EMTDC [3].

2. MODEL SYSTEM AND CROWBAR CONTROL

The model system for this study is shown in Figure 1, where the crowbar switch is connected across the rotor of the DFIG. The rating of the DFIG is considered 50MW. The DFIG is assumed to be made up of many smaller ratings of DFIG, but the aggregated model is used for simulation purpose. The parameters of the DFIG used for this study is shown in Table 1[4].

The crowbar switch is triggered if the $E_{dc\text{-}max}$ value in as shown in the excitation parameters in Table 2 [4] is exceeded. The FACTS device which is the STATCOM is connected to the PCC.

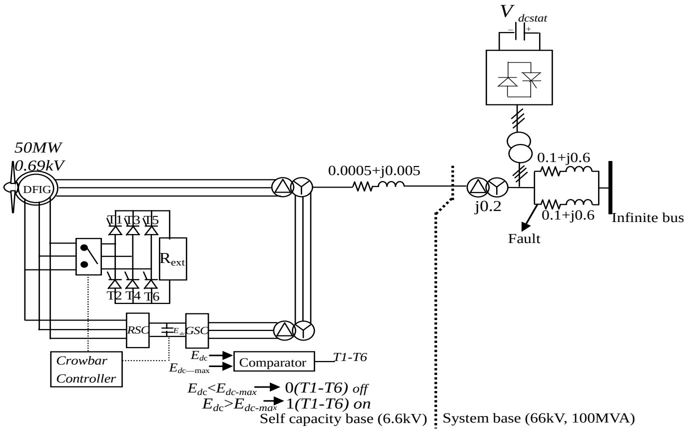

Figure 1. Model system

Table 1. DFIG parameters

Generator Type	DFIG
Rated voltage	690V
Stator resistance	0.01pu
Stator leakage reactance	0.15pu
Magnetizing reactance	3.5pu
Rotor resistance	0.01pu
Rotor leakage reactance	0.15pu
Inertia constant	1.5sec

Table 2. Parameters of excitation circuit

DC link voltage	1.5kV
DC link capacitor	50,000 μF
Device for power converter	IGBT
PWM carrier frequency	2kHz
Upper limit of DC voltage (E_{dc-max})	1.65kV (110%)
Lower limit of DC voltage (E_{dc-min})	0.75kV (50%)
Short circuit parameter of protective device for over voltage	0.2 ohm

3. WIND TURBINE MODEL

The aerodynamic torque and the mechanical power of a wind turbine are given as follows [4].

$$T_M = \frac{\pi \rho R^3}{2} V_w{}^2 C_t(\lambda) \ [\mathrm{NM}] \tag{1}$$

$$P_M = \frac{\pi \rho R^2}{2} V_w{}^3 C_p(\lambda) \ [\mathrm{W}] \tag{2}$$

Where ρ is the air density, R is the radius of the turbine, V_w is the wind speed, $C_p(\lambda, \beta)$ is the power coefficient given by equation (3).

$$C_p(\lambda, \beta) = 0.5(\Gamma - 0.02\beta^2 - 5.6)e^{-0.17\Gamma} \tag{3}$$

The relationship between C_t and C_p is

$$C_t(\lambda) = \frac{C_p(\lambda)}{\lambda} \tag{4}$$

$$\lambda = \frac{\omega_r R}{V_w} \tag{5}$$

In (3), $\Gamma = \frac{R}{\lambda} \frac{(3600)}{(1609)}$ and in (5), λ is the tip speed ratio.

The wind turbine characteristics for the DFIG are shown in Figure 2. In Figure 2, the wind turbine characteristics in terms of turbine power and the rotor speed are shown. The dotted lines show the locus of the maximum power point trajectory of the turbine which is used to determine the output power reference output P_{ref} of DFIG.

Equations (6) and (7) are used to obtain the regulation of the active power according to P_{ref} as shown in Figure 3. The optimum rotor speed ω_{ropt} is given in equation (8) and the maximum rotor speed chosen is 1.3pu.

$$P_{ref1} = 0.1571 V_w - 1.035 \ [\mathrm{pu}] \tag{6}$$

$$P_{ref2} = 0.2147 V_w - 1.668 \ [\mathrm{pu}] \tag{7}$$

$$\omega_{ropt} = 0.0775 V_w \ [\mathrm{pu}] \tag{8}$$

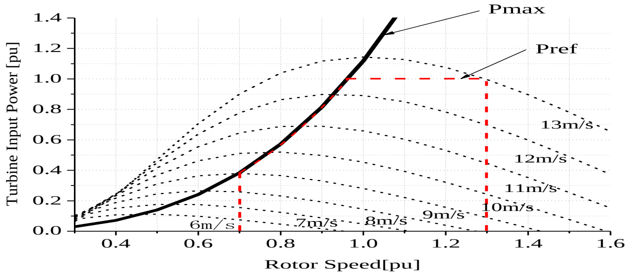

Figure 2. Turbine characteristic with maximum power point tracking (MPPT)

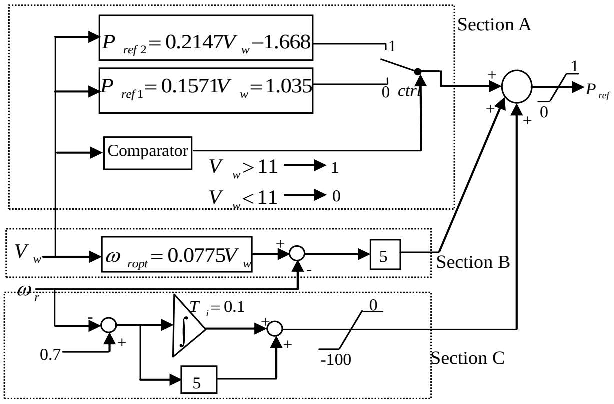

Figure 3. MPPT control block

The control block for the pitch controller used in DFIG is shown in Figure 4.

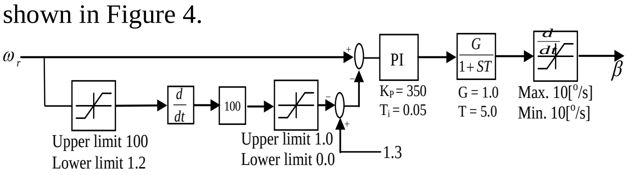

Figure 4. Pitch angle controller of DFIG

The pitch controller starts to work when the maximum rotor speed of 1.3pu is exceeded.

4. GRID CODES

The most worrying problem that wind farm must face is a voltage dip in the grid during grid fault. The magnitude of the voltage is controlled by the reactive power exchange, since in most networks as $Q \propto \Delta V$. Figure 5 displays the typical requirement for fault-ride through grid code. The wind farm must remain connected even if the voltage drops suddenly for the short duration, defined by the retained voltage r.m.s value shown by the solid line, and the duration of the fault are also shown in the curve [5]. Figure 6 shows the required reactive current support from the generating plants during voltage dip.

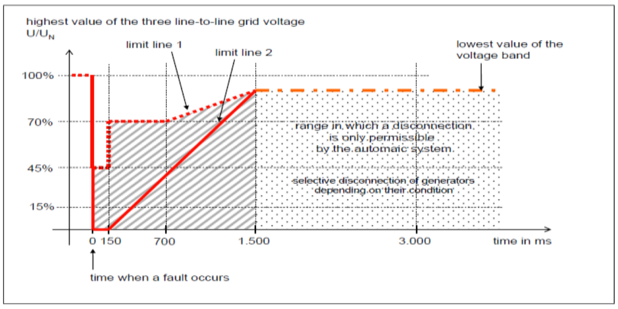

Figure 5. Fault ride through requirement for wind farm as set by E.ON Netz

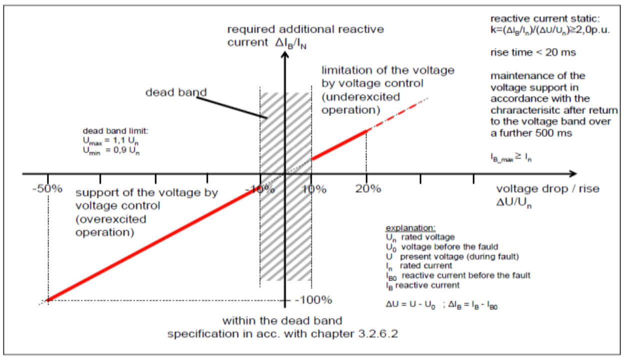

Figure 6. The rule of voltage support during grid fault as set by E.ON Netz

5. DFIG AND FACTS CONTROL SYSTEMS

The control system and the configuration of the DFIG are shown in Figure 7. The control system of the DFIG is made up of the rotor side converter (RSC) and the grid side converter (GSC). The rotor side converter controls the terminal (grid) voltage to 1.0 pu. The d-axis current controls the active power, while the q-axis current controls the reactive power. After dq0-to-abc transformation, V_{dr}^* and V_{qr}^* are sent to the PWM signal generator and V_{abc}^* are the three-phase voltages desired at the rotor side converter output.

The GSC of the DFIG system is used to regulate the dc-link voltage (E_{dc}) to 1.0pu. The d-axis current controls the DC-Link voltage, while the q-axis current controls the reactive power of the grid side converter. After a dq0- to-abc transformation, V_q^* and V_d^* are sent to the PWM signal generator. Finally V_{abc}^* are three voltages at the GSC output for the IGBT's switching.

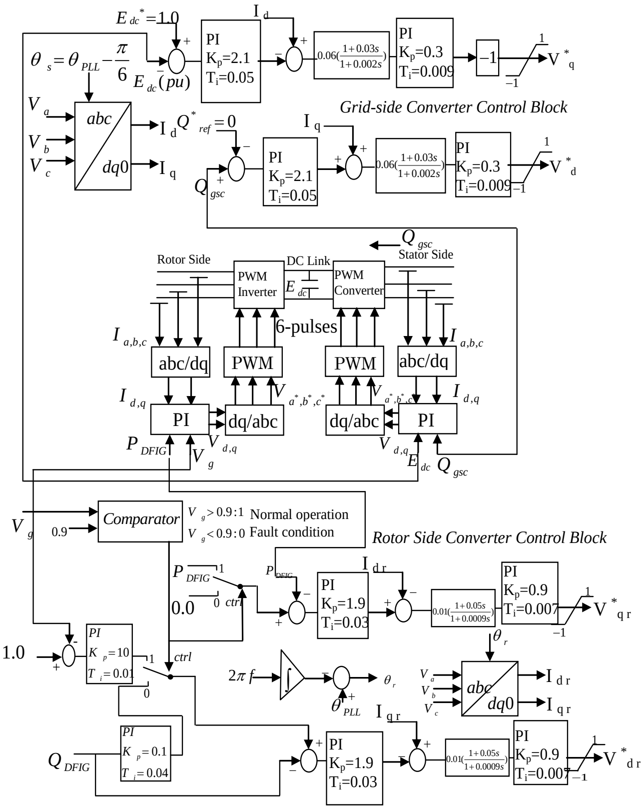

Figure 7. Control blocks and configuration system of DFIG

STATCOM can enhance the transient stability and significantly minimize the blade-shaft torsional oscillation of wind turbine generators [2, 6 and 7]. The reactive power of a STATCOM is provided by voltage source converter (VSC). The VSC converts the dc voltage into a three-phase output ac voltage with desired amplitude, frequency and phase. The control scheme and switching strategy for the STATCOM is shown in Figure 8, while Table 3 shows the parameters of the STATCOM as given in [2].

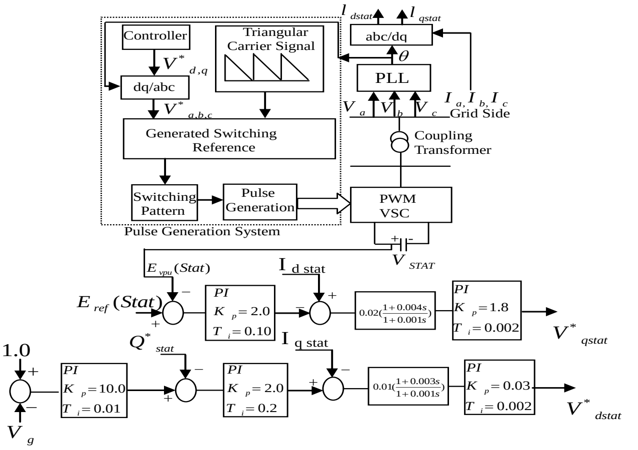

Figure 8. Control block and switching strategy of STATCOM

Table 3. Parameters of STATCOM

DC link voltage	6.6kV
Dc link capacitor	50,000 μ F
Device for power converter	IGBT
PWM carrier frequency	1050Hz
Rated Power	20MVA
Rated Voltage	3.50kV

6. SIMULATION RESULTS

Simulation analyses for a three-line-to-ground (3LG) fault as shown in Figure 1 were performed to show the effect of the crowbar switch in protecting the DFIG during grid fault, and for cases, where STATCOM is connected to the PCC and with no STATCOM is connected. In the fault analysis, it is seen that the DFIG is generating its rated power under a constant wind velocity of 15m/sec. The simulation is carried out using PSCAD/EMTDC, and the fault was considered to occur at 0.1sec. The circuit breakers on the faulted line were opened and reclosed at 0.2 sec and 1.0 sec respectively. The simulation time step for the study is 0.00001 sec and some of the simulation results for 3 sec duration are shown in Figures 9 to 12. The simulation result in Figure 9 shows the effect of the crowbar switch from which it is clear that high DC link voltage due to high rotor currents experienced during the grid fault can be avoided when crowbar protection is considered.

Also, in Figure 10, the terminal voltage instability of the DFIG caused by the disconnection of the RSC system from the generator rotor by the crowbar switch during grid fault could be improved with STATCOM connected at the PCC. This is because the STATCOM handles the reactive power demand of the system and maintains the voltage at the desired level. Figures 11 and 12 respectively show the response of the DC-link voltage and the reactive power of the STATCOM during the grid fault. It could be seen from Figure 12, that about 25% of the reactive power from the STATCOM is needed to stabilize the system.

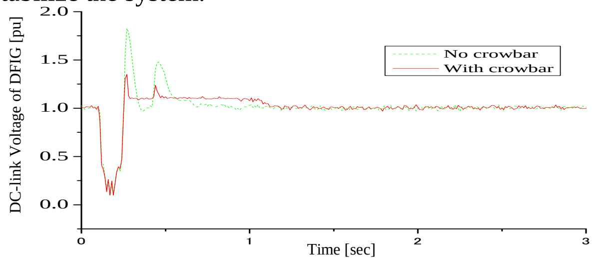

Figure 9. DC-link voltage of DFIG

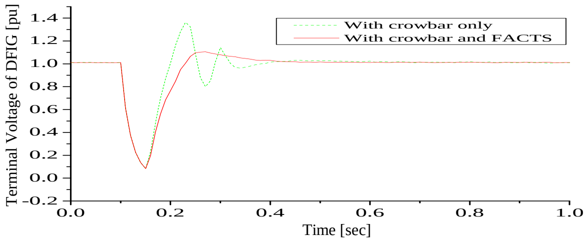

Figure 10. Terminal voltage of DFIG (zoomed)

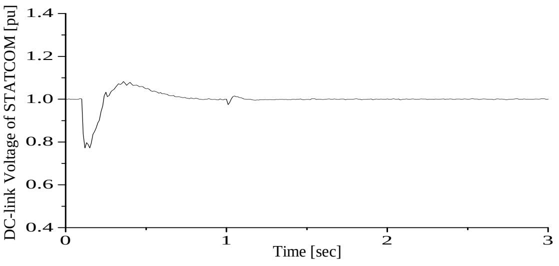

Figure 11. DC-link voltage of STATCOM

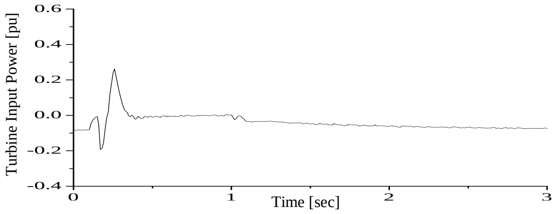

Figure 12. Reactive power of STATCOM

7. CONCLUSION

The effect of connecting FACTS to the point of common coupling (PCC) of a wind farm composed of DFIG has been investigated. The FACTS can greatly enhance the performance of the DFIG, when its frequency converter is disconnected from the rotor with a crowbar switch during grid fault in order to protect the DC-link voltage from damage. The FACTS provides additional reactive power to the system, thus improving the performance of the terminal voltage of the DFIG by reducing the voltage instability caused by the grid fault.

8. ACKNOWLEDGMENT

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9. REFERENCES

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