

## Research Article

# Fault Ride through Capability Improvement of Wind Turbine Based DFIG Considering an Optimized Crowbar Along with STATCOM under Grid Fault Condition

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**Abstract:** Grid disturbances, especially grid faults, have very unfavorable effect on the performance of wind turbine based Doubly Fed Induction Generator (DFIG). In this study active and reactive powers control of DFIG with STATCOM has been carried out to improve Fault Ride Through (FRT) capability of a wind turbine. In order to excel improvement of the DFIG behavior under grid fault disturbances, an optimized crowbar protection method is also considered together with STATCOM. The optimized protection crowbar resistance is achieved through Analytical Hierarchy Process (AHP) algorithm. Simulations results illustrate that an optimized crowbar protection method along with STATCOM has improved the stability of wind farm and provide grid code requirement compared with that of methods without using the optimized crowbar resistance.

**Keywords:** Analytical Hierarchy Process (AHP) algorithm, crowbar resistor protection, doubly fed induction generator, fault ride through, STATCOM

## INTRODUCTION

Variable speed wind turbines technology as the mature part of the modern power systems, are widely used. Doubly Fed Induction Generator (DFIG) is the most popular because of its advantages such as partial rated power converter and fault ride through capability. Since the stator of the DFIG is connected directly to the grid, it is very sensitive to net study disturbances especially fault condition and voltage sags (Bollen *et al.*, 2005; Xiang *et al.*, 2006; Lopez *et al.*, 2008). Since the ratio of participating wind turbines to the utility grid in power generation is increasing perpetually, many countries are updating their grid code which request that wind turbines stay connected to the grid and deliver fault clearing current in the event of voltage dips. This made it necessary to modify the conventional DFIG configuration for Ride-Through capability (FRT).

During voltage sag a high current is induced in the rotor circuit which can damage the Rotor Side Converter (RSC) and cause serious fatigue on the gearbox if no protection is applied (Morren and De Haan, 2005). These are prominent issue in asymmetrical voltage dips due to low negative sequence impedance of the DFIG (Liao *et al.*, 2011). Accordingly, a proper protection is needed for DFIG to prevent it from those over currents and provide excellence Voltage Ride Through (VRT) capability. One of the low cost and proper procedures which

provide wind turbine stability and suitable dynamic responses is employing crowbar resistance protection in the rotor circuit during the voltage sags (Morren and De Haan, 2005; Liao *et al.*, 2011; Peng and Yikang, 2007), shown in Fig. 1. The crowbar value must be chosen in such a way that not only provides FRT but also guarantees fast wind turbine restoration.

There were few investigation about the effect of STATCOM on DFIG behavior under different conditions but to the latest awareness of the author there was not any discussion about the crowbar value that was chosen in their researches and why they chose it (Ozturk and Dosoglu, 2010; Pokharel and Gao, 2010). This study concentrates on utilizing an optimized crowbar resistance based on AHP (Dong *et al.*, 2008) together with STATCOM during net study disturbance for voltage regulation and improving grid stability. Simulation results prove that the proposed protection control system can provide a desirable high performance and ride through capability of the DFIG during Voltage dips, especially Low Voltage Ride Through (LVRT) capability.

## DFIG BASIC MODEL

Evaluation of DFIG model becomes imperative in order to optimized crowbar resistances to improve LVRT capability. Hence, a fifth order algebraic differential equation in synchronous

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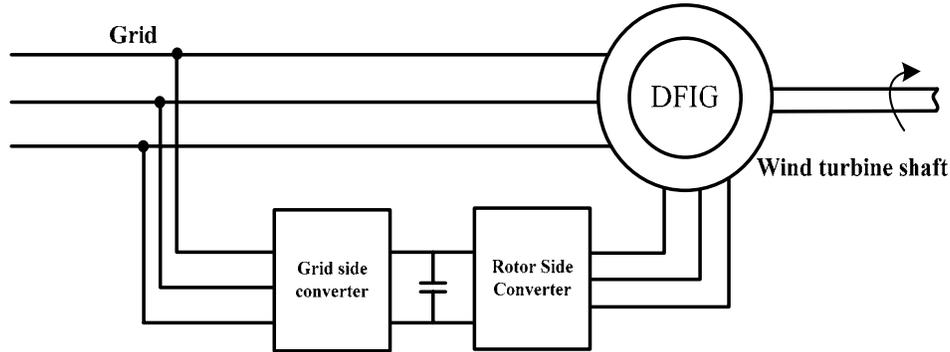


Fig. 1: Schematic of wind turbine based DFIG

rotating reference frame can be used (Xiang *et al.*, 2006). Accordingly, d and q component of the stator and rotor voltage vector are expressed as Dong *et al.* (2008):

$$v_{ds} = R_s i_{ds} + y_{qs} + \frac{1}{w_s} \frac{dy_{ds}}{dt} \quad (1)$$

$$v_{qs} = R_s i_{qs} - y_{ds} + \frac{1}{w_s} \frac{dy_{qs}}{dt} \quad (2)$$

$$v_{dr} = R_r i_{dr} - s y_{qr} + \frac{1}{w_s} \frac{dy_{dr}}{dt} \quad (3)$$

$$v_{qr} = R_r i_{qr} + s y_{dr} + \frac{1}{w_s} \frac{dy_{qr}}{dt} \quad (4)$$

where,  $y_{ds}$ ,  $y_{qs}$ ,  $y_{dr}$  and  $y_{qr}$ , are the stator and rotor d-q axis flux components. Also,  $R_s$ ,  $R_r$ ,  $X_{ls}$  and  $X_{lr}$  are the stator and rotor resistances and reactances, respectively. Beside,  $s = (w_s - w_r)/w_s$  and  $w_r$  is the generator rotor speed. The Stator and rotor current component in reference frame are as follows:

$$i_{ds} = (y_{ds} c_{lr} - y_{dr} c_{ms}) / D \quad (5)$$

$$i_{qs} = (y_{qs} c_{lr} - y_{qr} c_{ms}) / D \quad (6)$$

$$i_{dr} = (y_{dr} c_{ls} - y_{ds} c_{ms}) / D \quad (7)$$

$$i_{qr} = (y_{qr} c_{ls} - y_{qs} c_{ms}) / D \quad (8)$$

In the above equations  $X_m$  is magnetizing reactance, where:

$$D = c_{lr} c_{ls} - c_m^2 \quad (9)$$

The electromagnetic torque of the DFIG can be calculated based on the stator and rotor interaction as:

$$T_e = y_{ds} i_{qs} - y_{qs} i_{ds} \quad (10)$$

**Crowbar optimization:** Protection of DFIG during the faults is done by set of crowbar is connected to the rotor known as crowbar. The large value of the crowbar can impressively decrease the current peaks amplitude however it may cause the capacitor anti-charge and also may damage the insulation of the rotor winding hence selecting an optimized crowbar become imperative. Crowbar optimization method was partially discussed in Abbaszadeh *et al.* (2009) where the maximum value of the crowbar is given by:

$$R_{cb} < \frac{\sqrt{2} V_{rmax}}{i_{rmax}} = \frac{\sqrt{2} V_{rmax} \cdot D}{\sqrt{\frac{c_m^2}{c_s^2} (2 - s)^2 V_s^2 - 2 V_{rmax}^2}} \quad (11)$$

where,  $V_{rmax}$  is the maximum voltage of the rotor side convertor.

The effect of crowbar resistance on important constraints such as rotor peak current, voltage of RSC terminals, electromagnetic torque peak during fault and reactive consumption are investigated. Note that the normalization method is used in the procedure of finding an optimal crowbar:

$$y_{normal} = \frac{d - c}{b - a} (x - a) + c \quad (12)$$

In Eq. (13) a and b refer to minimum and maximum peak values of obtained parameters from simulation, respectively and x is the value within this interval. Besides, c and d are equaled to one and nine,

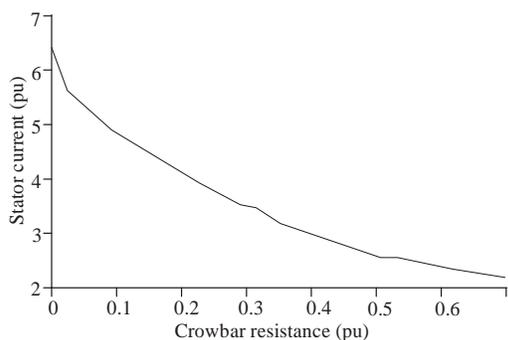


Fig. 2: Peak of stator current magnitude variation

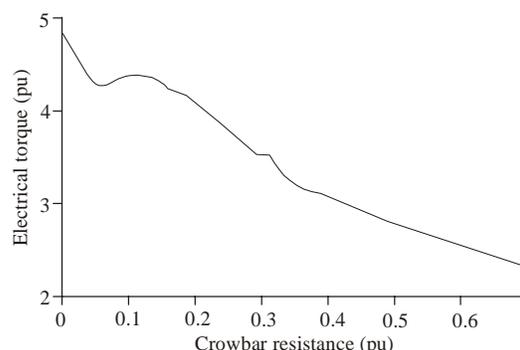


Fig. 4: Electromagnetic torque magnitude variation

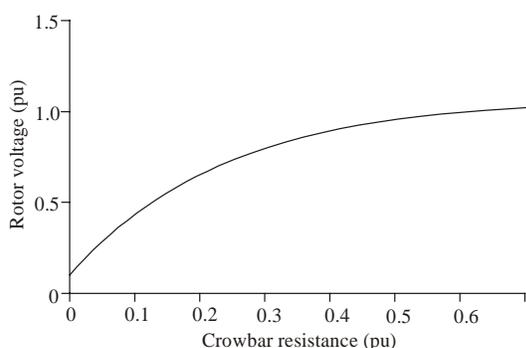


Fig. 3: Peak of rotor voltage magnitude variation

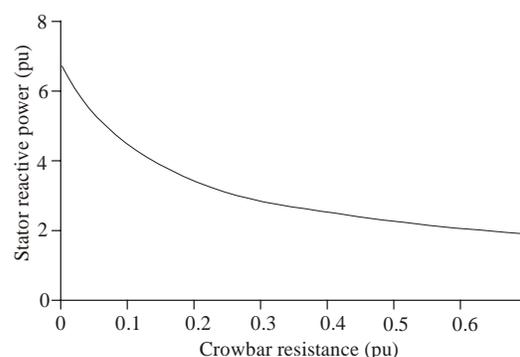


Fig. 5: Peak of stator reactive power versus crowbar

respectively. The effect of crowbar on the amplitude of the mentioned constraint for single phase is given in (Pokharel and Gao, 2010). This section merely studies the effect of crowbar on the amplitude of the mentioned constraint for phase to phase net study disturbances.

**Peak of stator current:** The effect of the crowbar variation on the peak amplitude of the rotor current during the phase to phase fault is given in Fig. 2. It is obvious that increasing the crowbar resistance cause the rotor peak current magnitude to decrease. Hence, larger resistors are more desirable; in contrary, the larger crowbar values make switching time to increase. This causes the converter operation to start with a delay consequently consumption of reactive power increases.

**Rotor voltage:** Rotor peak voltage at the occurrence time of fault versus different crowbars is shown in Fig. 3. Note that increasing the crowbar value ended up in increasing the rotor voltage terminal magnitude. If the rotor terminal voltage exceed fro 1.2 p.u the RSC converter can be exposed into a high risk of insulation damage that is consider an significant drawback and limit of crowbar resistances.

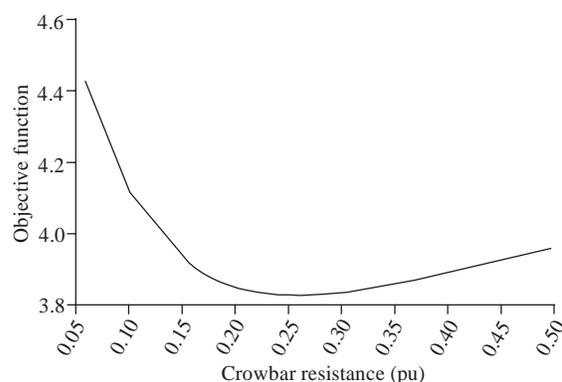


Fig. 6: The optimized crowbar plot over the objective functions

**Electromagnetic torque:** Changes in electromagnetic torque create mechanical stresses during voltage dips that can damage gearbox and mechanical couplings. Therefore, the crowbar must limit these kinds of disturbances. Electromagnetic torque peak magnitude variation is plotted in Fig. 4.

**Reactive power:** After fault occurrence, generator control system will separate rotor terminals from the

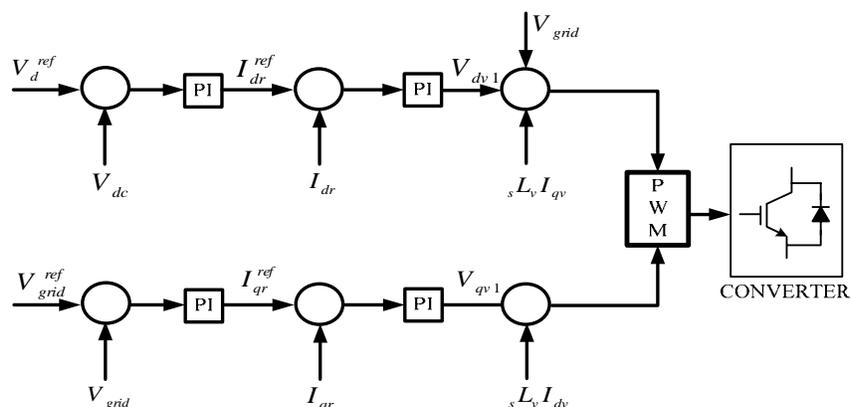


Fig. 7: Overall control sketch of STATCOM

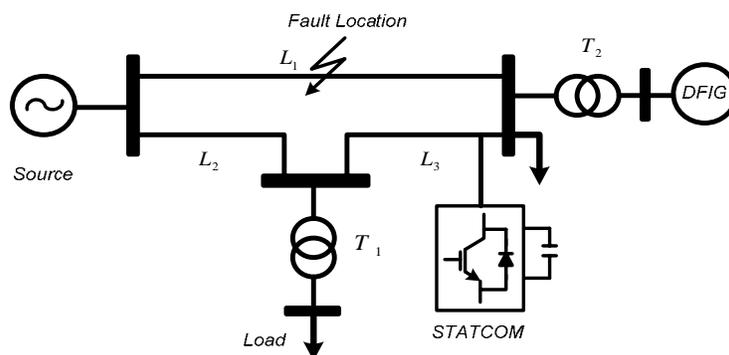


Fig. 8: Schematic of rural grid

rotor side converter and connects the crowbar to rotor circuit. As a result, the DFIG becomes wounded rotor induction generator with a fixed resistance. Figure 5 shows the impact of the crowbar value on the reactive power.

Note that negative value of the stator reactive power means that the machine under fault absorbs the reactive power which is decreased by increasing the crowbar resistance value. By employing the objective function the crowbar resistance variation is obtained According to the latter discussion as shown in Fig. 6. The optimal crowbar resistance is directly proportional to the minimum point of the curve. Therefore, 0.26 p.u. is chosen as an optimal value for crowbar resistance.

**STATCOM modeling:** STATCOM also known as an advanced static synchronous compensator is a shunt connected FACTS device. It produces a set of balanced three-phase sinusoidal voltages at the fundamental frequency, with instantaneously and continuously adjustable amplitude and phase angle. A common approach of a STATCOM is supporting voltage to

provide grid code requirement along with grid stability. In this study, the STATCOM is modeled as a GTO PWM converter with a dc-link capacitor and used with the optimized crowbar for faster dynamic performance of the system, improving the grid stability and PCC voltage regulation after fault clearance. The overall control scheme of the STATCOM is shown in Fig. 7.

### SIMULATION RESULTS

In order to provide the grid code requirement and continuous wind turbine connection to the grid, the DFIG should not remove from the power system during voltage distortion, so the STATCOM is used along with an optimized crowbar to provide the required reactive power for voltage dip compensation and faster recovery after the fault. The obtained optimized crowbar for single phase is applied in a rural grid as it can be seen in Fig. 8 and the parameters are given in appendix. The result is compared with the No Compensation (NC) status.

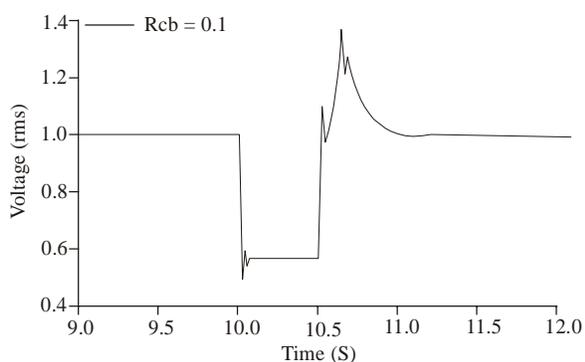


Fig. 9: DFIG voltage variation during single phase fault with a typical crowbar

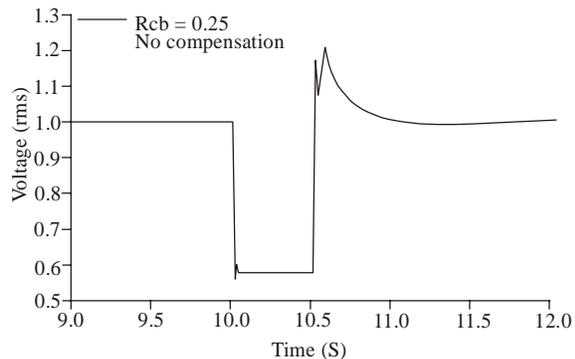


Fig. 10: DFIG voltage variation under single phase fault using optimize crowbar

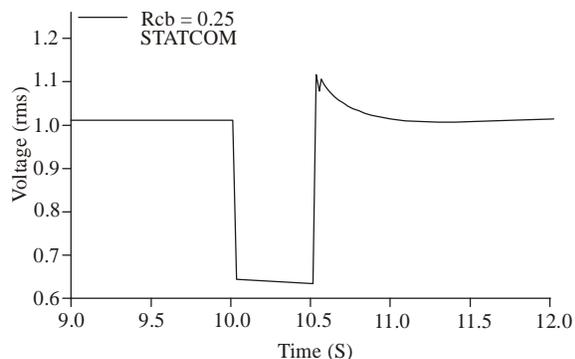


Fig. 11: DFIG rotor voltage variation during single phase fault using optimized crowbar and STATCOM

Notice that these asymmetrical voltage dips induces into the net study by far apart net study fault. It should be mentioned that the optimized crowbar resistance for any investigation is achieved according to the last section concept.

It can be concluded from Fig. 9 that, if only non optimized crowbar apply to the rotor circuit, voltage

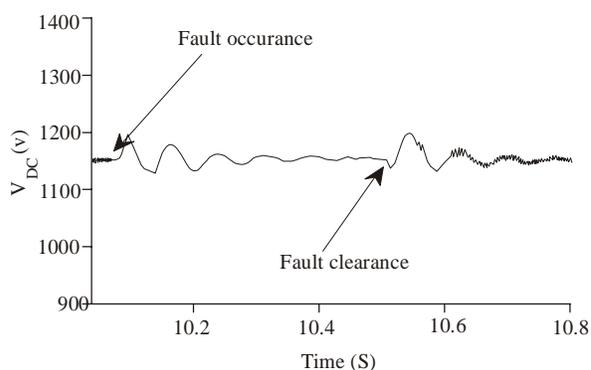


Fig. 12: DC link voltage of the STATCOM

amplitude of the wind turbine bus decline during the fault and it take much more time to reach steady state situation after fault clearance.

In Fig. 10 when the optimized crowbar is employed but no reactive power is injected by the STATCOM to improve the DFIG behavior under the fault it can be observed that in comparison with Fig. 9 it has better performance during and after the fault clearance. Figure 11 shows that by applying the obtained optimized crowbar together with reactive power injection of the STATCOM voltage sag during the fault is the least and DFIG become steadier also has faster recovery procedure.

The STATCOM DC link voltage has provided appropriate performance as it can be observed from Fig. 12. As it is shown in this figure, the DC link voltage both at the fault time occurrence and fault clearance has a suitable overshoot in a way that the DC link voltage is almost constant.

The DFIG behavior under low terminal voltage has shown its perfect reliability. Consequently, the FRT capability of the generator is satisfied. Indeed, the proposed optimization algorithm along with STATCOM reactive power injection not only provides an excellence protection during asymmetrical fault but also guarantees a desirable performance of the wind turbine. So, this method shows its bright features and provides a new opportunity for wind turbine protection for any kind of voltage distortion.

## CONCLUSION

In this study active and reactive powers control of DFIG with STATCOM has been carried out to improve Fault Ride Through (FRT) capability of wind turbine. In order to excel the improvement of the DFIG behavior under grid fault disturbances, an optimized crowbar protection method is also considered together with STATCOM. The optimized protection crowbar resistance is obtained through Analytical Hierarchy Process (AHP) algorithm.

The developed system is simulated in MATLAB/SIMULIK and the results show that an optimized crowbar protection method along with STATCOM has improves the stability of the DFIG and provides grid code requirement compared with any methods without using the optimized crowbar resistance. Also, better FRT responsibility of DFIG has been achieved under various grid conditions without violation from any grid code requirement.

#### APPENDIX

The DFIG parameters

p	2 MW
$v_s$	690 v
$r_s$	0.048 pu
$r_r$	0.018 pu
$X_{ls}$	0.075 pu
$X_{lr}$	0.12 pu
$X_m$	3.8 pu
f	50 Hz

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