Analysis of the Dynamic Behavior of a DFIG during Grid Disturbances using Active Crowbar Protection

Hammam Soliman
Elec. & Control Eng. Department, Arab Academy for Science & Technology, Cairo, Egypt
hammamaast@hotmail.com

Dr. Mostafa I. Marei
Elec. Power Engineering & Machines Department, Ain Shams University, Cairo, Egypt
mostafamarei@yahoo.ca

Prof. Rania Metwally El-Sharkawy
Electrical & Control Engineering
Arab Academy for Science and Technology, Cairo, Egypt
raniasula@hotmail.com

Dr. Khaled Mohamad El-Bahrawy
Electrical Engineering Consultant, Bahrawy Consultancy Group, Cairo, Egypt
Khaled.elbahrawy@hotmail.com

Abstract— **Nowadays, wind power has been developed very fast in the world and the installed capacity of wind turbine has been increased rapidly. Doubly Fed Induction Generator (DFIG) has been applied very popularly for its many advantages. When the grid voltage dip occurs, a crowbar beside the Rotor Side Converter (RSC) is usually activated. In this paper the effect of the active crowbar resistance are studied and analysed. The active crowbar is control to limit the rotor current and dc-link voltage. Simulation results based on MATLAB/SIMULINK are discussed.**

Keywords— **Doubly fed induction generator (DFIG), Crowbar resistance, Active crowbar.**

I. INTRODUCTION

As the electrical demand keeps growing, more generations are required to be installed into the grid. Most of those new generating units are recommended to use renewable recourses for its environmental friendliness effects. One of the most important renewable resources is the wind energy, for which it has been gaining greater attention from both the academic and industrial communities.

There are several types of the wind turbine generators (WTGs) used, one of which is the doubly fed induction generator (DFIG). During the past couple of decades, the DFIG has been applied widely in the variable speed – constant frequency wind power technology. This is due to its simple control strategy, low losses, and it being capable of regulating the active and reactive power separately. However, the DFIG suffers from its sensitivity to grid faults, as a result of its connection to the grid.

The Stator of the DFIG is connected to the grid directly, where as the rotor is connected to the grid through the back to back converter. During grid fault, the grid voltage decrease, causing a sudden increase in the stator current of the generator, along with an increase in the rotor current due to the mutual coupling between the stator and rotor [3]. The high rotor current flows through the rotor side converter (RSC) causing damage to the converter and DC-link. The DC-link voltage rises as its capacitors are charged above their nominal voltage. Some means of protection is required to prevent the converter from high inrush current faults.

A DFIG grid connected model using Matlab/Simulink is considered [1], [2]. A crowbar circuit is added to the model to limit the faulty current from reaching the RSC, in order to protect the back to back converter. The performance of the proposed system is studied during steady state, and during three phase grid fault with and without the crowbar circuit.

II. SYSTEM CONFIGURATION

A DFIG wind farm composed of six aggregated units of 1.5MW is considered. The wind turbines are pitch controlled. The DFIGs are connected to the collector system bus 25kV, via a 575V/25kV, 12MVA transformer. The DFIG wind farm is then connected to the 120kV network through a 25kV/120kV transformer. The system parameters are reported in [1], [2].

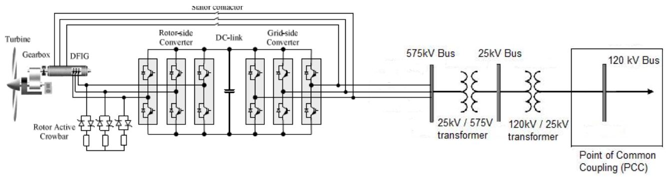


Fig. 1. System configuration

A crowbar circuit is connected between the rotor circuit and rotor-side converter to provide a bypass for the high transient rotor current which is induced by voltage dips in the grid, where the RSC is disabled. As illustrated in Fig. 2, the crowbar is made up of a switched bridge connected to a resistance.

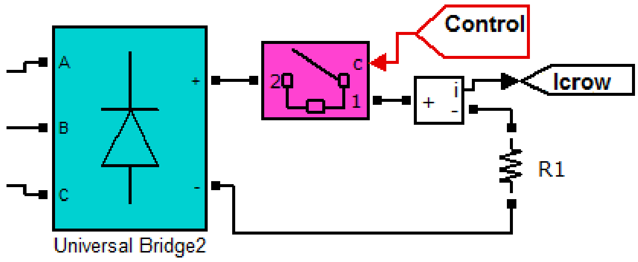


Fig. 2. Crowbar circuit

The value of the crowbar resistance is chosen according to [4]. The choice of the crowbar resistance is very important. The crowbar resistor should be sufficiently low to avoid large voltages across the converter terminals. On the other hand, it should be high enough to limit the rotor current [4] [5]. In this study, the resistance value is chosen to be equal to thirty times the rotor resistance. Regarding the grid codes [6], the passive crowbar is no longer accepted. Therefore, an active crowbar is designed to protect the DFIG against overvoltage and to limit the rotor current during grid faults [7]. The proposed active crowbar control is illustrated in Fig. 3. The proposed control actives the crowbar and deactivate the RSC if the rotor current, ir, exceeds the threshold value, ith, or if the dc-link voltage, Vdc, exceeds the threshold value, Vdc-th.

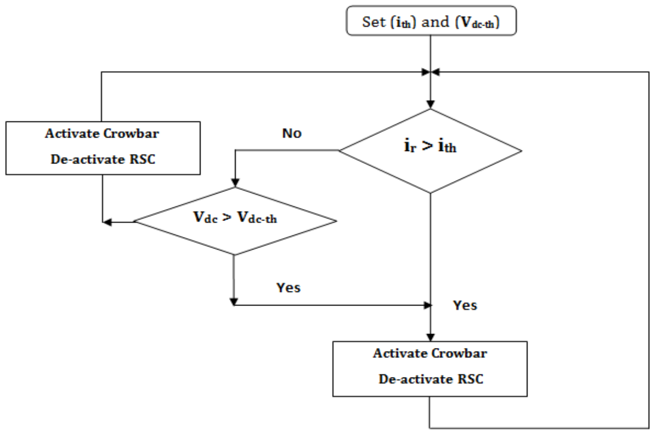


Fig. 3. Active crowbar control flowchart

III. SIMULATION RESULTS

The proposed method is simulated on MATLAB/Simulink. The three-phase to ground fault is located at the 25kV bus, which is known by the point of common coupling (PCC). The applied fault is initiated at t = 1s and cleared at t = 1.1s. The dc-link voltage is set to 1150V. The threshold values for the rotor current and the dc-link voltage are set at 1.3pu and 1200V, respectively. Three case studies are carried out to investigate the dynamic performance of the active crowbar. The first two cases are dedicated to study the system performance with and without crowbar being activated. Finally, the third case investigates the effect of varying the crowbar resistance on the dynamic performance of the DFIG.

A. *System without crowbar*

A three-phase fault is applied at t = 1s for 100 msec at the PCC without activating the crowbar. To meet the grid code requirements, the back-to-back converter of the DFIG is controlled to feed reactive power to grid during the fault until successful recovery. As a consequence of the sudden grid fault, the stator voltage drops, as shown in Fig. 4, to a value that is corresponding to the reactive power fed from the DFIG. During the fault, the dc-link voltage is discharging as presented in Fig. 4. The active and reactive powers generated from the wind farm are portrayed in Fig. 5. During the whole simulation time, the wind speed is constant and equals to 15 m/s. The wind farm under study feeds its rated active power of 9 MW under rated wind speed. During the fault, no active power is transmitted to the gird and the DFIG are controlled to feed reactive power. The peak rotor current exceeds more than double the nominal value as portrayed in Fig. 6.

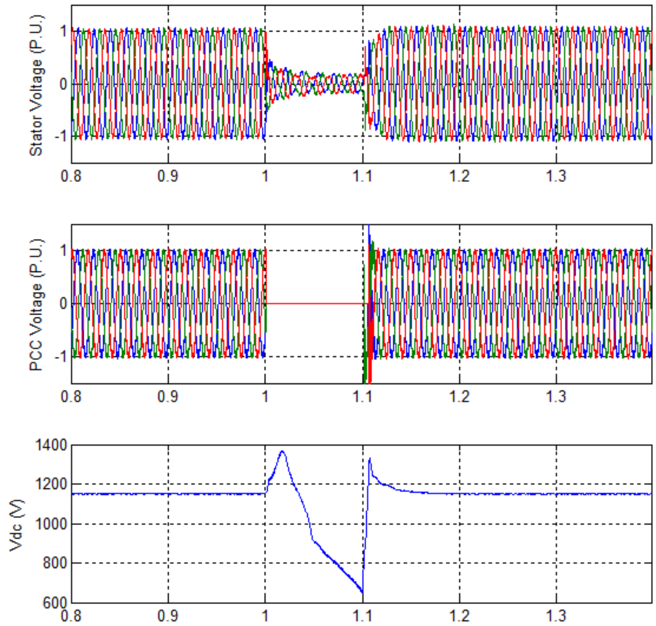


Fig. 4. Stator voltage, PCC voltage, and dc-link voltage.

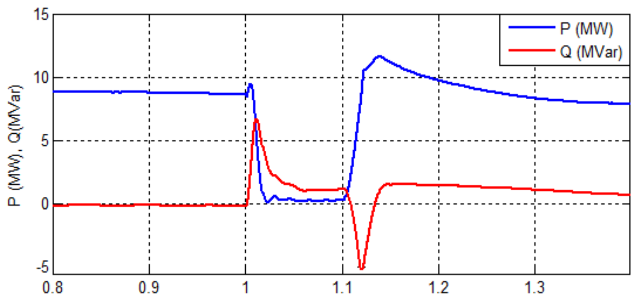


Fig. 5. Active power and reactive power fed to PCC from the wind farm.

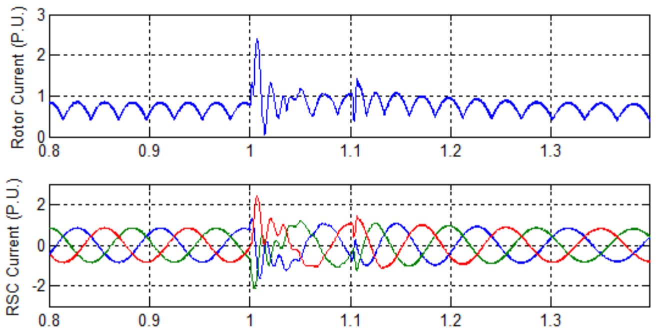


Fig. 6. The peak rotor current and the three-phase RSC current.

B. *System with crowbar activated*

The same fault was applied to the system, but with activating the crowbar. When the rotor current exceeds its threshold setting, the rotor is short circuited through the crowbar resistance and the DFIG behaves as a squirrel cage. Moreover, to keep the dc-link voltage within the rated limits, the crowbar is activated during the instants of fault incidence and clearance. Activation of the crowbar lasts for a few milliseconds depending on the threshold values of rotor current and dc-link voltage. When the crowbar is deactivated, the RSC reconnects. Thus, the back-to-back converter is under control during the fault period.

Comparing Fig. 8 with Fig. 5, illustrate that the active crowbar increase the recovery period of the wind farm. This is due to the increased reactive power drawn from the grid when the crowbar is activated to limit the dc-link voltage. As shown in Fig. 9, the activation of the crowbar limits the rotor current. Since the RSC is disconnected, the high rotor current is prevented from harming the converter. The activation of the crowbar controls the shape of the dc-link voltage as shown in Fig. 7.

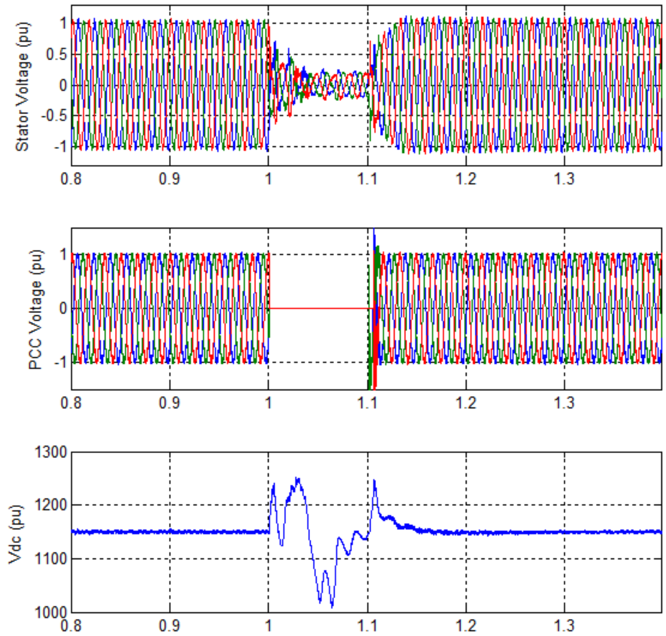


Fig. 7. The stator voltage, the PCC voltage, and the dc-link voltage.

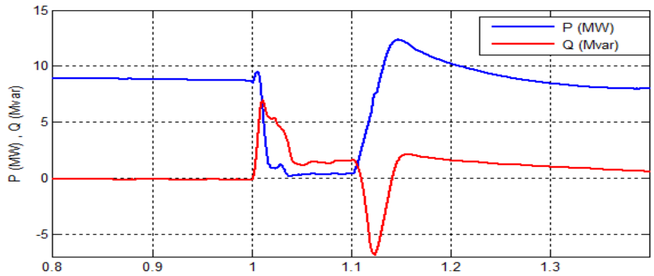


Fig. 8. Active power and reactive power fed to PCC from the wind farm.

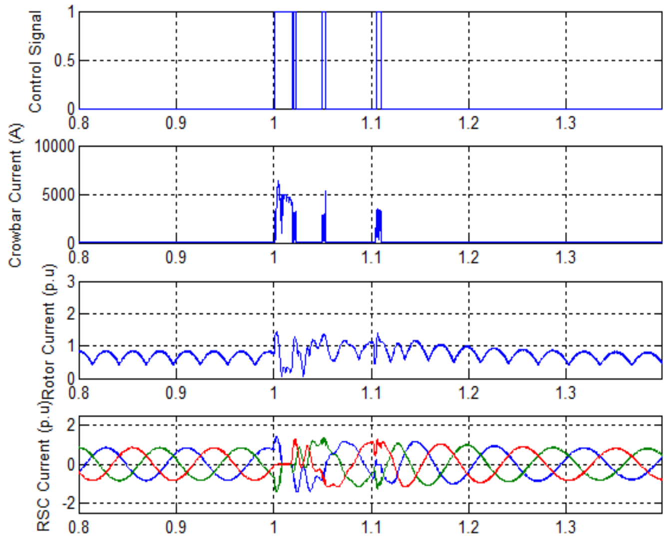
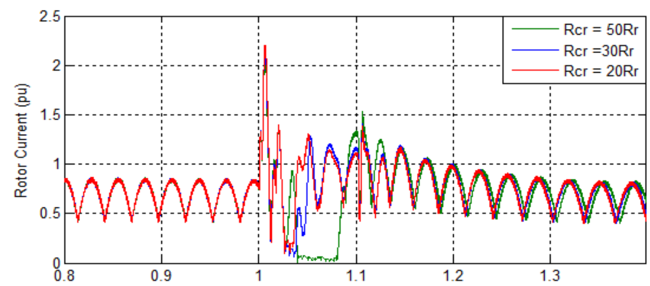


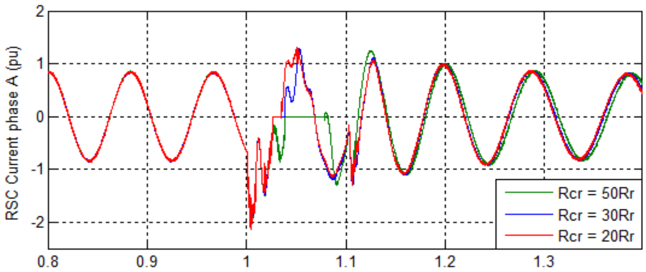
Fig. 9. Control signal, crowbar current, the peak rotor current, and the three-phase RSC Current.

C. *Effect of varying crowbar resistance.*

Simulations are carried out to study the effect of the crowbar resistance on the dynamic performance of DFIG wind turbines. Three values of crowbar resistances are used, 20, 30, and 50 times of rotor resistance. Fig. 10 illustrates the effect of the crowbar resistance on the performance of the DFIG. Fig. 10(a) and Fig. 10(b) indicate that the rotor and RSC currents are decreased against the increase of the crowbar resistance. Moreover, Fig. 10(c) illustrates that at the moment of clearing the fault, the active power injected by the DFIG is more increased for low values of the crowbar resistance. This result reveals that increasing the crowbar resistance decreases the clearance time and enhance the stability of the DFIG.



(a)



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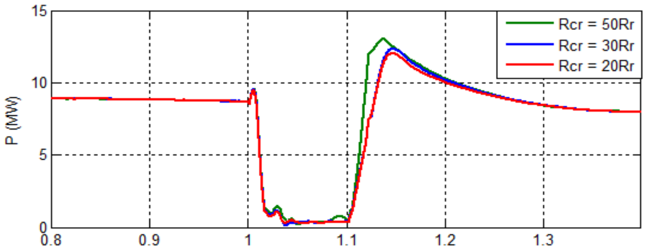

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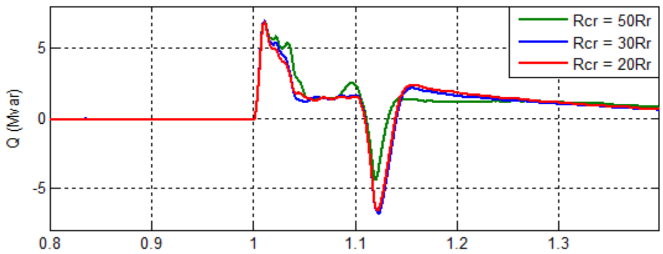

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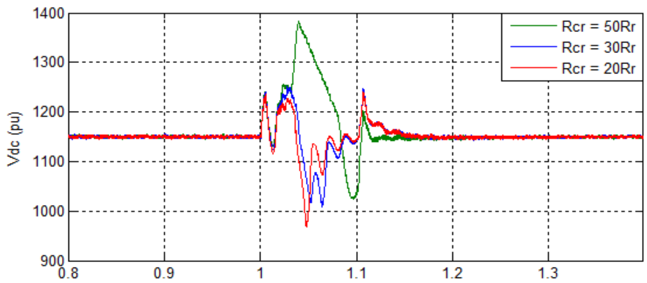

(e)

Fig. 10. Effect of varying crowbar resistance on the dynamic performance of the DFIG.

IV. Conclusion

The presented work is mainly about the control strategies and the protection schemes for the DFIG based wind turbine system. A DFIG model was developed using MATLAB-SimPowerSystems, and the control strategy was verified. The over current in the rotor windings and over voltage in the DC bus can be well limited through an active crowbar circuit. In order to reduce the activated time of the crowbar as much as possible, an improved hysteresis control strategy has been proposed. The effect of the crowbar resistance has been studied. In this paper, a three-phase fault is applied at the PCC to investigate the system behavior with and without the active crowbar protection. The effect of the crowbar resistance on the dynamic performance of the DFIG is presented with different crowbar resistances. The expression of rotor current in fault condition and the optimized crowbar resistance which makes the least DC link voltage ripple is deduced.

V. References

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