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# FAULT RIDE-THROUGH CAPABILITY AND DAMPING IMPROVEMENT IN DFIG

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*Doubly-fed induction generator wind turbine is susceptible to faults and requires crowbar protection. When the crowbar is triggered, the rotor is short circuited over the crowbar impedance. Then, the doubly-fed induction generator operates as a squirrel-cage induction generator that tends to absorb large amount of reactive power from the grid during fault, potentially causing a voltage drop. This paper, therefore, proposes the use of doubly-fed induction generator based low-voltage-ride-through scheme including crowbar, rotor-side converter, grid-side converter and power system stabilizers. In this way, the transient stability and damping of the electro-mechanical oscillations of a grid-connected doubly-fed induction generator is obtained. The simulation results highlight that the proposed control scheme improves the operation of doubly-fed induction generator during faults. The investigation is realized by comparing the performance of doubly-fed induction generator system with and without the low-voltage-ride-through and damping control scheme.*

**Keywords**: Damping, doubly-fed induction generator, low-voltage-ride-through, power system stabilizers, squirrel-cage induction generator

## 1. Introduction

Among the most used renewable energy sources (wind, solar, geothermal), wind energy is considered as one of the most important due to its enormous potential to play a vital role in the energy market [1], [2], [3]. Due to the rapidly

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increasing wind energy integration into power system networks, many research activities have been devoted to the development of grid stability, energy-efficiency and reliable forecasting [4], [5], [6].

Moreover, specific technical requirements have been elaborated for the connection of large wind farms, usually as a part of the grid codes issued by the Transmission System Operators (TSOs) of many countries [7]. The issue of grid code compliance has been the driving force behind development of variable-speed technologies, especially DFIG (Doubly Fed Induction Generator) based wind systems employing a back-to-back converter connected via slip rings to the rotor. The DFIG offers several advantages such as speed control, reduced voltage fluctuations (flicker effect), and four-quadrant active and reactive power control capabilities when compared with the SCIG (Squirrel-Cage Induction Generator), and more economical compared with the PMSG (Permanent Magnet Synchronous Generator) [8].

DFIG is quite sensitive to grid disturbances, such as short-circuits. The DFIG requires special protection equipment like crowbar to protect it by disconnecting the RSC (Rotor Side Converter) during the fault [9]. When the crowbar is switched on, the DFIG operates like a SCIG and becomes a reactive power consumer. As a result, the electromechanical system of the generator will go into oscillation and the system can become unstable [10], [11].

Electromechanical oscillations have been observed in many power systems [12]. The oscillations may be local due to a single generator or a generator plant. These oscillations often result when a three phase fault occurs in the system [13], and to stabilize these oscillations, PSS was developed. If they are not controlled, these oscillations may lead to a total or partial power interruption and mechanical stress on the generator shaft.

In this paper, for improving the LVRT (Low Voltage Ride Through) capability of DFIG and for damping the oscillations, a coordinated control system of the crowbar protection, RSC, GSC (Grid Side Converter), and PSS (Power System Stabilizer) is implemented and proposed. A cascade proportional-integral PI based controlling technique is introduced to control the IGBT (Insulated Gate Bipolar Transistor) based frequency converter to enhance the transient stability. Compared to traditional DFIG using only crowbar protection, the simulation results show the effectiveness of the system using LVRT proposed control system.

## 2. Overview of LVRT requirements

The characteristics of LVRT capability for a WPP (Wind Power Plant) from one country to another varies. But, as shown in Fig. 1 the Implementation Guideline for Network Code “Requirements for Grid Connection Applicable to all

Generators," – European Network of Transmission System Operators for Electricity (ENTSOE) directs them in the same way.

The LVRT capability represents a voltage-against-time-profile. when the voltage level is below the solid line of LVRT, the WTs (Wind Turbines) are required to be disconnected from the grid [14]. As shown in Fig. 1, the German grid code states the most stringent requirements for LVRT capability.

The LVRT capability implies that WTs disconnect from the grid in the event of a fault only in the condition mentioned above, support the voltage level (reactive power compensation), and return to normal operation after fault clearance [15].

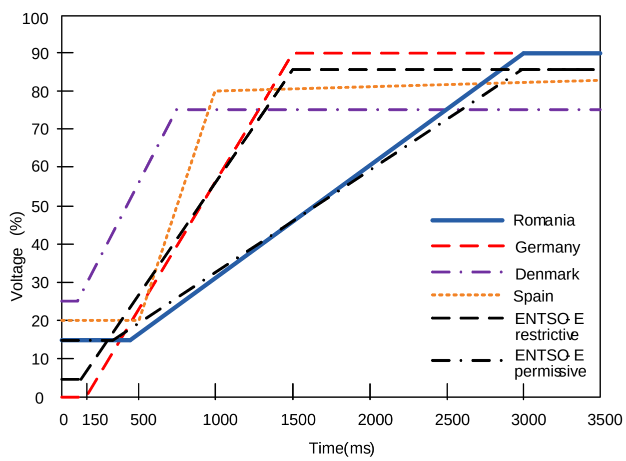


Fig. 1. LVRT capability stipulated by European international network codes

According to the ANRE - Regulatory Authority for Energy from Romania (Technical regulations - Technical conditions for connection to electric networks of public interest for wind power), after the voltage is restored within normal operating values, the WTs must automatically generate their entire available active power, with a gradient of 20 % per second [16].

### 3. DFIG model

The stator side of DFIG is connected to the grid through a transformer, while the rotor side is connected to the grid through back-to-back converters. The configuration of a DFIG wind turbine equipped with crowbar protection connected to a power grid is illustrated in Fig. 2.

Fig. 3 is a general expression of a DFIG model in an arbitrary reference frame rotating at angular speed of ω. According to Fig. 3, the stator and rotor flux as well as voltages are given by

$$\psi_s = L_s I_s + L_m I_r \tag{1}$$

$$\psi_r = L_r I_r + L_m I_s \tag{2}$$

$$U_s = R_s I_s + \frac{d\Psi_s}{dt} + j\omega\Psi_s \tag{3}$$

$$U_r = R_r I_r + \frac{d\Psi_r}{dt} + j(\omega - \omega_r)\Psi_r \tag{4}$$

where: U– voltage, *I* – electrical current, *R* – electrical resistance, *L* – inductance, $L_m$ – coupled inductance, ψ – stator flux linkages, ω – angular speed. The subscript *s* and *r* indicate stator, respectively rotor quantities.

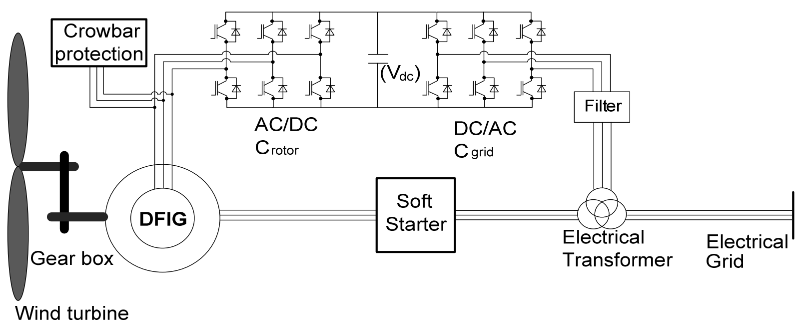


Fig. 2. The configuration of a DFIG wind turbine equipped with crowbar protection connected to a power grid

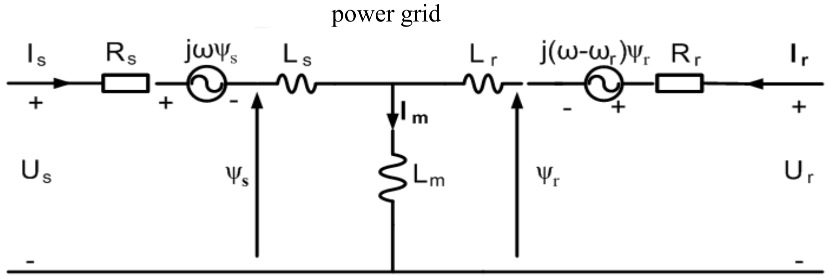


Fig. 3. Equivalent circuit of a Doubly-fed induction generator in the synchronous reference frame

## 4. Crowbar protection

A simple protection method is to short-circuit the rotor through a device called crowbar, which disables the rotor converter control. The crowbar protection is composed of a set of IGBTs, resistors, and a switch device that is preferable to be an active one for better performance. The crowbar protection ensures large rotor currents dispersion via the supplementary path provided [9].

The crowbar protection is turned on/off based on rotor current $i_r$ value. Based on the hysteresis comparator illustrated in Fig. 4, the crowbar protection is activated when the rotor current has a value that exceeds the settled threshold value $i_{th1}$ (safety value). When the rotor current decreases below $i_{th2}$, the crowbar protection is turned off.

The RSC is disconnected from the rotor when the crowbar protection is activated. Thus, the DFIG absorbs reactive power from the grid for its magnetization and operates like a SCIG.

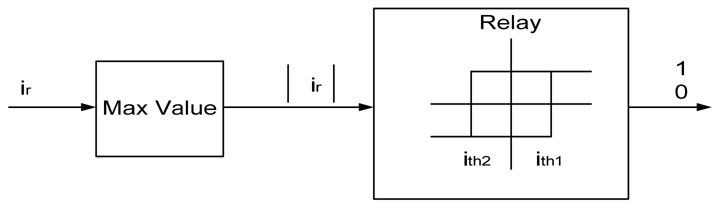


Fig. 4. The crowbar protection hysteresis control

As the crowbar protection is not triggered when the rotor current increases, but is below the threshold value $i_{th1}$, the hysteresis comparator offers a safety solution. Hence, the reactive power absorption of DFIG from the grid is avoided. Also, the $i_{th2}$ threshold value allows a more rapid disconnection of crowbar protection.

## 5. Power system stabilizer controller

From reference [17], the use of a PSS on a conventional DFIG controller in the proposed scheme can be viewed as an additional block of a RSC excitation control, added to enhance the overall power system dynamic performance, especially for the damping contribution of the DFIG electromechanical oscillations to the power network. Thus, the PSS uses auxiliary stabilizing signals such as stator electrical power, rotor speed and frequency to change the input signal to the RSC. The PSS output signal is applied at the external summing junction of Fig. 5 that is more basic applicable to DFIG control in general [18].

In this paper, the error signals of stator electrical power were used, and the PSS control loop is illustrated in Fig. 6. The input signal is initially processed through a washout filter in order to endure that PSS does not contribute under steady conditions. The signal is then passed through a compensator that provides the necessary gain and phase shift in order to ensure suitable control performance and a positive contribution to system damping. The parameters of the controller are provided from reference [17].

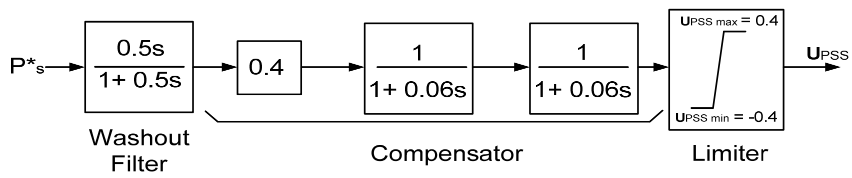


Fig. 5. Power system stabilizer controller

## 6. Coordinated control strategy for DFIG LVRT and damping

The control of both the GSC and RSC is performed through cascaded PI. There are three stages for the GSC or RSC to control the desired variables. The proposed controller combines the characteristics of both PI techniques in third stage that connected in series with PI technique in traditional stages (first and second stage) of DFIG wind generator. Figure 5 shows the block diagram representation of the cascaded control for GSC and RSC.

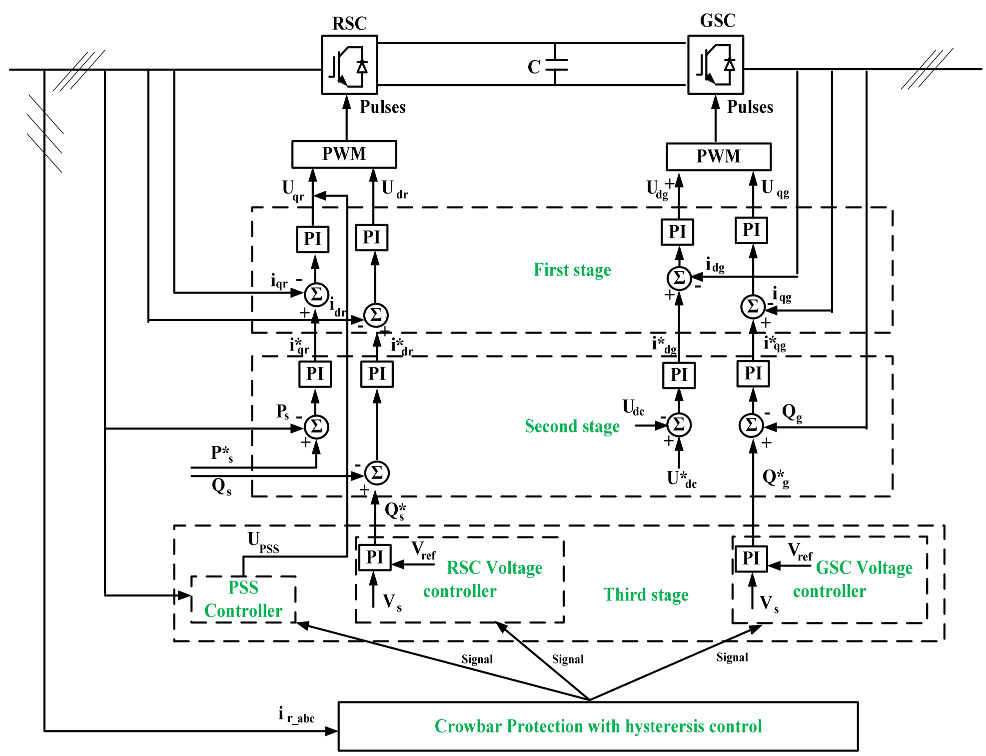


Fig. 6. LVRT and damping control scheme of doubly-fed induction generator

According to the basic control of DFIG [9], when the crowbar protection is activated, the RSC is disconnected from the rotor, and the controllability of the generator is lost.

The proposed control system enables GSC to operate in voltage control mode. Both RSC and GSC return to normal operation when the voltage level returns to the pre-set value at the PCC.

The inputs of the GSC and RSC proportional-integral blocks are the voltage threshold value $V_{ref}$ and the value of measured voltage $V_s$.

The reactive power signal of the second stage PI controller is considered to be the output of the first stage PI controller.

The second stage PI controller fulfills the control of electrical current $I_d$.

## 7. Simulation results

For DFIG output behavior, power converter control is essential both in normal operation and during fault conditions. In [1], [8], the DFIG control and its very good performance under normal grid conditions has already been discussed. However, a new solution for fault-ride through capabilities of this machine is beyond the scope of these references that is the main attention on this research.

The two control systems combined in this paper will be denominated as follows:

- Crowbar protection without hysteresis control method will be named simply *only crowbar protection*.

- The coordination of PSS, RSC and GSC converters based on crowbar protection with hysteresis control method during transient state will be named *LVRT control system*.

The performance of the proposed control system was evaluated with Simulink for a 3 MW WPP. The simulated system is shown in Fig. 7, where DFIG is directly connected to 33 kV, and through two parallel power lines of 10 km length to the point of common connection (PCC). The DFIG and the network parameters are given in Table. 1. The fault event is a three-phase to ground fault at point $F$ (about 1 km from PCC). The fault occurs at time instant 1.5 s, and lasts for 150 ms. The DC grid rated voltage is 1150 V, and has a filtering capacitor of 10 mF.

For testing the correct operation of the proposed controller, the wind speed is varied and the DFIG performance is analyzed during the transient period. The wind speed profile used as input in the proposed control is reported in [6].

In Fig. 8, the simulation result of hysteresis output signal to turn on/off crowbar protection is shown. It can be seen from the figures that before the rotor current exceeds $I_{th1}$, the relay signal remains zero, the DFIG is running at normal status without crowbar protection. At time $t$ = 1.515s, the crowbar protection is activated due to rotor current increase. When relay signal remains one the DFIG is running at LVRT control system with crowbar protection. At time *t* = 1.56s, we can see a crowbar early removal before clearing fault since rotor current decreases. Obviously, the crowbar protection is removed 4 cycles before the voltage recovery.

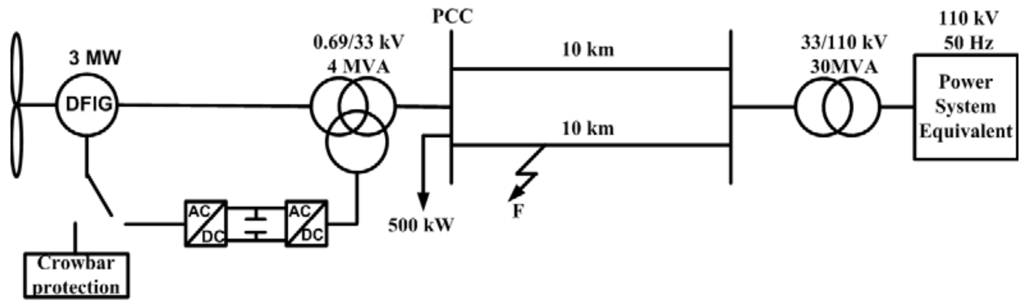


Fig. 7. DFIG based WPP connected to the PCC

Fig. 9 shows transient-state responses of the DFIG rotor current using the crowbar protection with the conventional DFIG and with proposed control scheme. As soon as the fault happens, due to the limited capability of the power converter the rotor current exceeds the threshold value. By using the crowbar protection, the rotor current decreases rapidly to the secure region. An improved hysteresis control strategy is adopted in LVRT control scheme in order to reduce the operation time of the crowbar. In contrast to DFIG with only crowbar protection, which shows the rotor current decreases continuously, the rotor current increases significantly inside the secure region due to LVRT scheme operation suddenly from 1.6 s.

*Table 1*

**DFIG wind turbine parameters (on base of machine rating)**

| Parameters | Value | Unit |
|---|---|---|
| Base power | 3 | MW |
| Rated speed | 12 | m/s |
| Cut in wind speed | 5 | m/s |
| Cut out wind speed | 19 | m/s |
| Base voltage | 690 | V |
| Frequency | 50 | Hz |
| Rs | 0.016 | pu |
| Rr | 0.00549 | pu |
| Lls | 0.18 | pu |
| Llr | 0.16 | pu |
| Lm | 2.9 | pu |

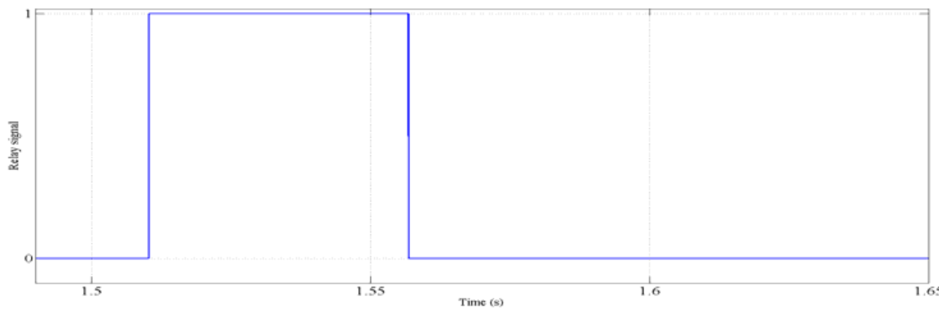


Fig. 8. Hysteresis control signal

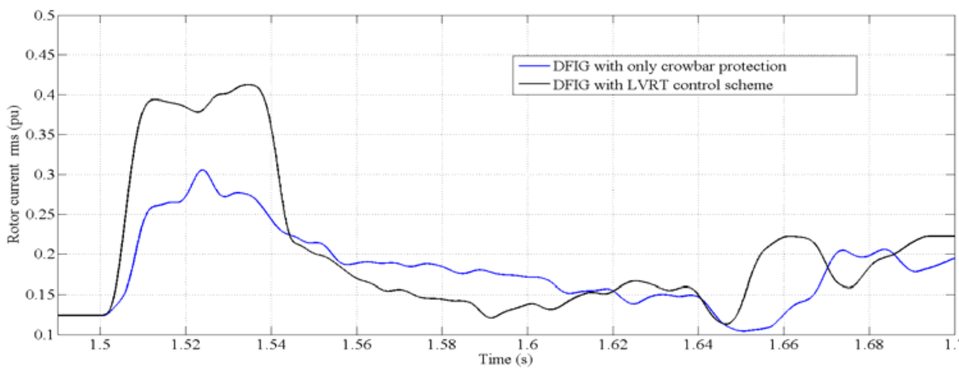


Fig. 9. Rotor current

In order to evaluate the effect of the damping controller in case of fault, the rotational speed of generator can be seen in Fig. 10. It is clear that the oscillations excited by grid fault are quickly damped over few seconds with the damping controller used in LVRT scheme, compared to the case without damping controller.

In Fig. 11, the voltage variation at PCC during and after the grid fault is illustrated. The impact of voltage grid support for both control system cases studied can be easily observed. The proposed control with LVRT control scheme helps the voltage to return to 1 p.u. after the fault clearance.

Analyzing the DFIG with LVRT control system in Fig. 12, it can be observed that when the crowbar protection is activated, the GSC controls the voltage in order to provide reactive power support for the electrical grid. For the same case analysis, in Fig. 13, it can be seen that the RSC controls the grid voltage using reactive power support after crowbar protection is turned off.

Because of the excess of reactive power in the electrical grid for the case without voltage control enabled for DFIG, as illustrated in Fig. 11, initially, the variation of voltage at PCC after grid fault occurrence has an important decrease.

After a short period it starts to increase. However, the voltage level does not return above the limit imposed by the LVRT requirement.

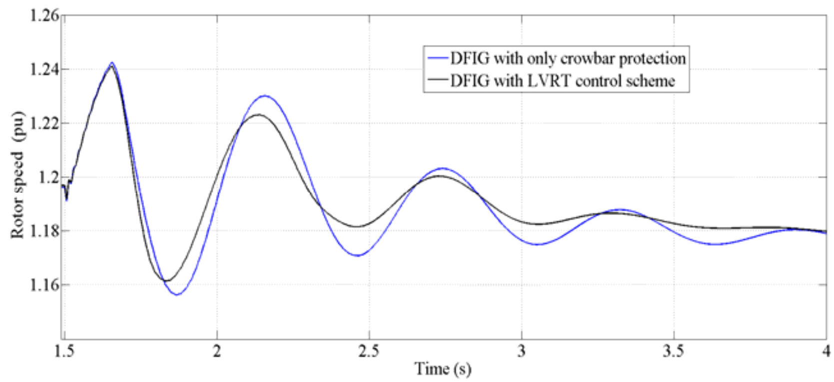


Fig. 10. Rotor speed.

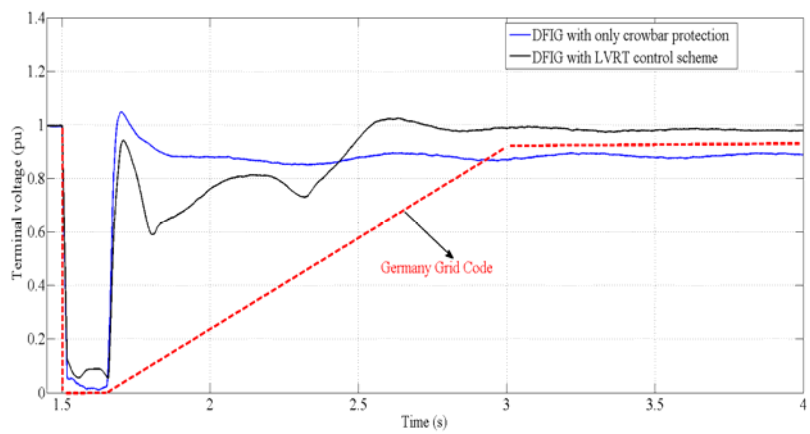


Fig. 11. PCC voltage variation.

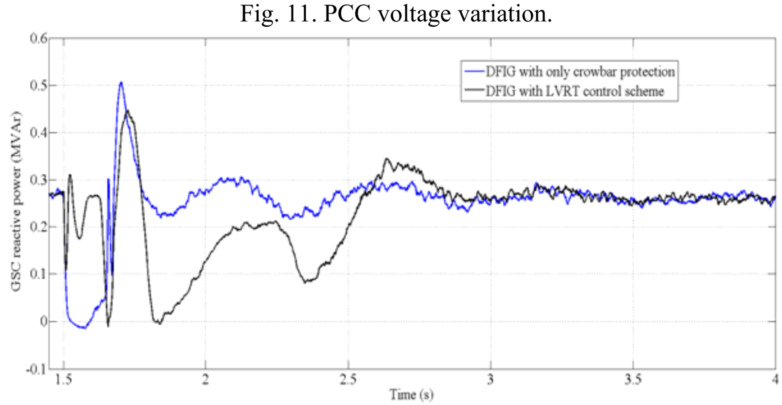


Fig. 12. GSC reactive power support.

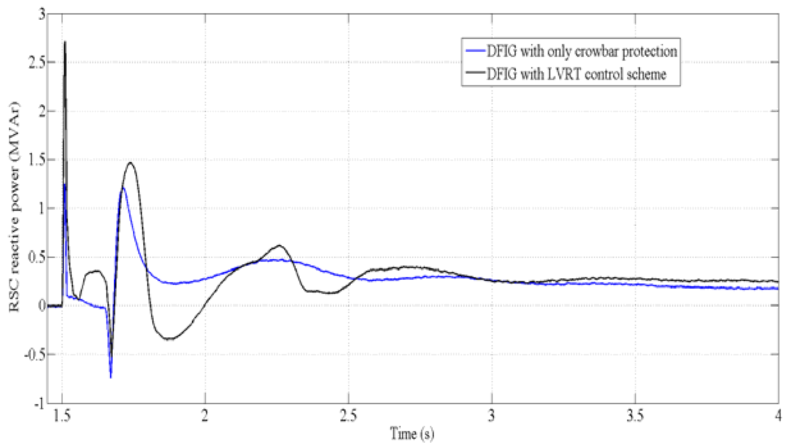


Fig. 13. RSC reactive power support

## 8. Conclusion

This paper proposes a voltage grid support control strategy for a DFIG-based wind turbine in order to improve LVRT performance of this generator by utilizing the good control capability of the DFIG wind system. The idea of this control scheme is that both RSC and GSC take part in the voltage control in a coordination mode.

The damping controller is investigated based on the fact that grid faults cause torsional oscillations and high mechanical stress on drive train of wind turbine machine. This controller has to be implemented and tuned to damp actively these oscillations.

The simulation results have shown that when the LVRT and damping control strategy is used, the extra reactive power from the RSC and GSC enables the DFIG wind system to improve LVRT requirements.

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