

Robust Control of the Active and Reactive Power Exchanged With the Rotor of the DFIG and the Grid

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Abstract: - The doubly fed induction generator (DFIG) is a most used machine in modern wind turbines thanks to its robustness, reliability and the reduced cost of converters associated. Unfortunately, this wind turbine even with the most advanced controls, the power exchanged with the rotor of the DFIG and the grid is fluctuated precisely during the fault which affects the stator voltages and causes a severe overshoot of the rotor current. For this reason that we proposed a robust control dedicated to smoothing the rotor power injected to the grid and to reduce the fluctuation of the DC bus voltage of the DFIG. The simulations on Matlab/Simulink/SimPowerSystems were presented to validate the effectiveness of the theoretical analysis of the proposed control.

Key-Words: Electrical grid, power quality, Robust control, doubly fed induction generator, fluctuation of the rotor power, DC bus voltage

1 Introduction

Energy policy in the world tends to use renewable energy to limit environmental degradation. Renewable energy is the best solution against climate change impacts, current developments tend to alternatives resources to limit emissions of CO₂ from conventional power plants.

The wind turbine is the renewable energy source the most responded; the doubly fed induction generator (DFIG) has attracted many researchers thanks to of its advantages compared other machines. The change in speed has been guaranteed by two power converter sized from 30% to 35% of the rated power for a speed ranging $\pm 25\%$ [1]-[2]-[3]. The various controls proposed to control the DFIG, vector control, direct torque control and direct control of the DFIG powers have made much more robust and reliable for more details [3]. The DFIG is fed by two sides; the stator winding are coupled directly to the grid, the rotor of the DFIG is connected to the grid via two power converter and dc bus.

rotor side converter (RSC) and grid side converter (GSC), these two converters are based IGBT which provides the power flow in both directions from the grid to the rotor and the rotor to the grid, the GSC works a rectifier and the RSC a inverter in mode sub-synchrone therefore the power transits the grid to the rotor, in mode super-synchrone, the GSC works a inverter and the RSC a rectifier in this case the power fraction transits the rotor to the grid, the capacity of the voltage smoothing delivered by the rectifier is between the RSC and GSC for more details [4].

The power exchanged between the rotor and the grid is often fluctuated when the default occurs, causing an excess of rotor power injected by the rectifier to the DC bus, The output voltage of the inverter will be distorted, so that the quality of energy injected into the network will be poor, several techniques are used to protect power converters among them ; crowbar method and DC chopper method [1]-[6], using the first technique could cause serious stability problems, particularly with an increasing

number of wind turbines connected to the grid and the second technique causes a loss of energy in a protective resistor. The new control is designed to keep the constant DC bus voltage and smooth the active power injected to the grid and keep the factor power equal to unity.

The second section will focus on the factors responsible for the fluctuation of the DC bus voltage and the result of these fluctuations, in the third section we discuss our proposed control, and the fourth one represents the different simulation made on Matlab\Simulink\ SimPowerSystems which validates our approach.

2 The factor responsible of the rotor power fluctuation:

The figure 1 represents the main circuit of the DFIG, the stator is directly connect to the electrical grid, the rotor coils are connected to the mains via the two converters that are sized just for a fraction of DFIG rated power; converter side of the rotor DFIG (RSC), grid side converter (GSC), and between the GSC and RSC converters is the capacitor of the DC bus.

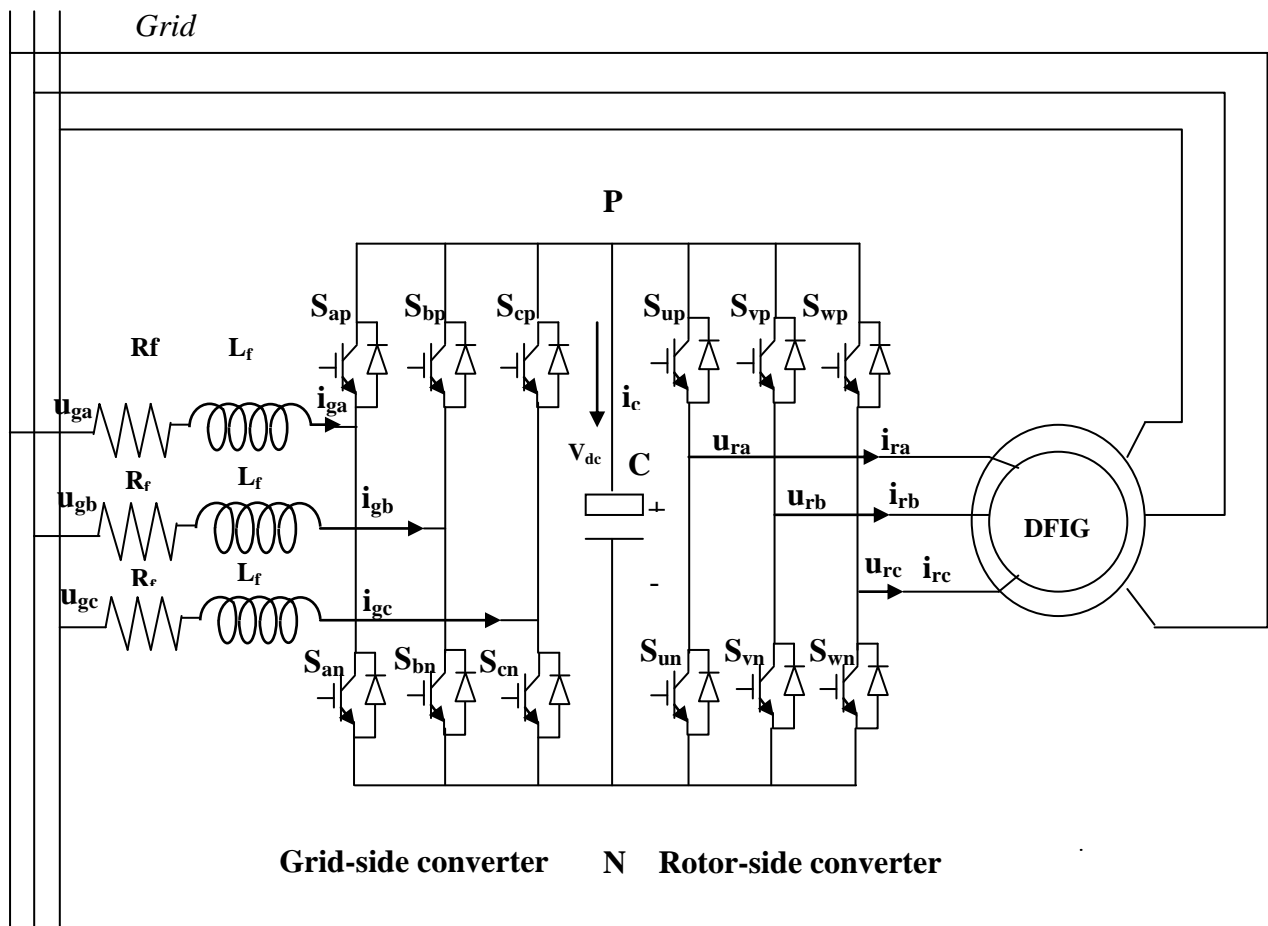


Fig.1: Main circuit of DFIG with the converter and the DC bus.

The rotor of the DFIG as shown in the figure 1 is powered by two converter GSC and RSC. The two converters have the same topology, in mode sub-synchronous RSC operates as an inverter and GSC operates as a rectifier and in

super-synchronous RSC works as a rectifier and GSC as an inverter. The main role of GSC is to maintain the DC bus voltage constant and ensure the flow of power to the grid and keep the power factor equal to unity through the

exchange of reactive power to the grid, For the RSC allows the control of the active power and reactive power, the control of the DC bus is effective for high operation performance of the DFIG [7]-[8].

2.1 Normal operation of DFIG

During normal operation of DFIG operation there are two different fashion that impose the direction of flow of power as cited earlier stages, sub-synchronous mode power passes from the mains to the rotor of the DFIG through the two converters power via the DC bus, the inverter is a basic IGBT, super-synchronous mode power rotor passes the rotor to the grid via the DC bus. In both modes RSC regulates the rotor current and GSC keeps the DC bus voltage constant. The two power converters control the exchange with power grids [10].

2.2 During the fault

During the abnormal condition of operation of DFIG, particularly when a fault occurs, the most critical variables are the stator voltage, the rotor currents and the DC bus voltage [10]-[11], this implies that the fluctuation of the power sent by the GSC to the grid. When a fault occurs on the stator voltages of the DFIG, a transition currents appear in the rotor coils show figure 2.

This excess is due to the natural response of the stator flux. The transition of the rotor currents of DFIG leads to sudden increase in active power sent by the RSC to the DC bus, the converter GSC is dimensioned for a fraction of the rated power of the DFIG approximately 25%. This fluctuation of the power bus voltage level may lead to the destruction of the GSC and RSC converters and the ability of the DC bus. This excess power causes a sudden increase in voltage DC show figure 3, the existence of the capacity does not allow the rapid variation of in the DC bus voltage and in addition the dynamic response of the outer loop voltage V_{dc} is slow relative the inner loop current [12]. When an overshoot of the active power occurs on the DC bus, the GSC cannot instantly transferred all power to the grid, and some of the power injected to the grid will be deform. Little research has been done to address the problem of fluctuation of the DC bus voltage, the controls have been proposed to improve the stability of the DC bus voltage, in [12] a control has been proposed to limit the fluctuation of the DC bus of DFIG based on the instantaneous power of the rotor, in [14] technology has been developed to keep the DC bus voltage constant when the voltage sensor is damaged, in [11]. With this proposal, the priority is the stability of the DC bus voltage. But at the time of default, most of the research ignores the transfer of active power to the DC bus power system since the power is fluctuated and for the protection of power converters.

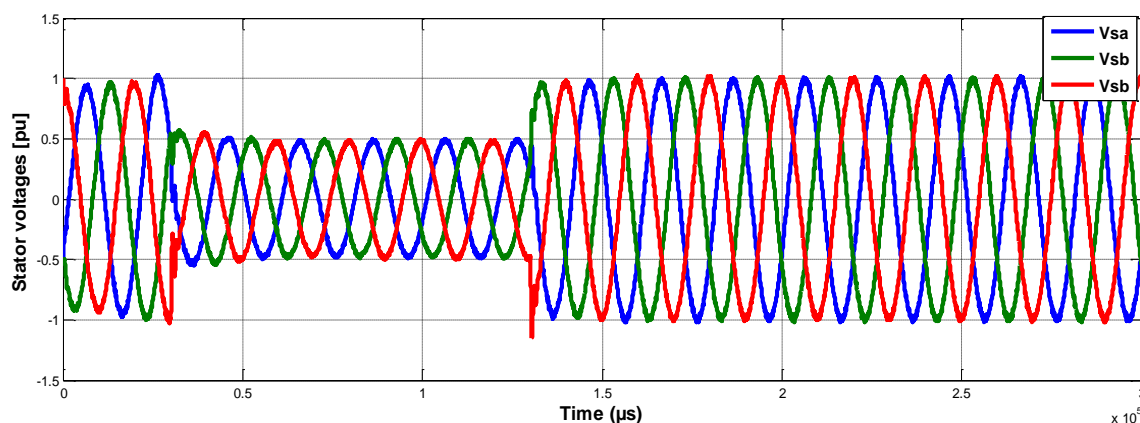


Fig. 2: The stator voltages during the fault.

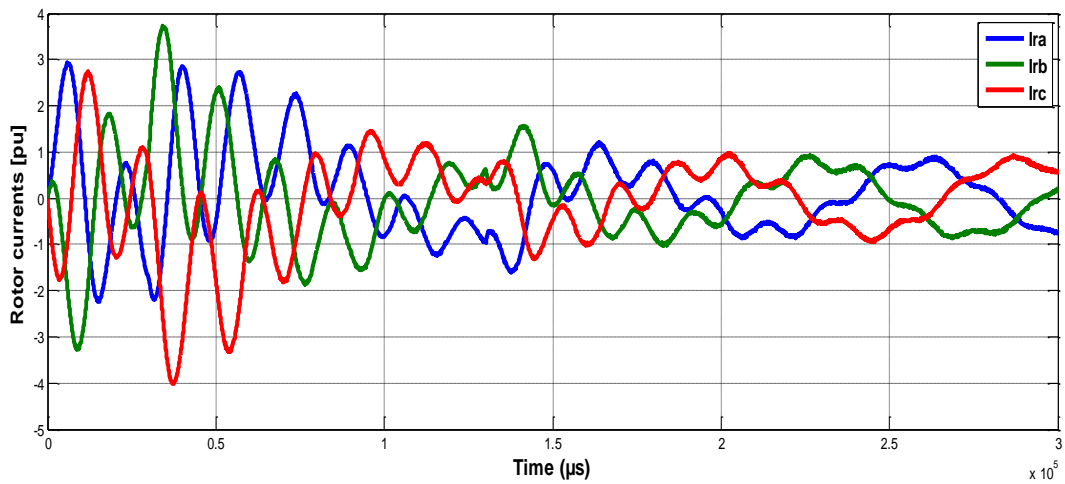


Fig. 3: The fluctuations of the rotor currents during the fault

3 Control robust of the power exchanged between the rotor of the DFIG and the grid.

The objective of our control first to smooth the power delivered by the rotor of DFIG, which is why we look to the advantage of

smoothing DC bus voltage with two nested loop outer loop voltage V_{dc} and the inner loop for current with this method the dynamic response of the dc voltage regulation will be his fast. Figure 5 show nested loop used.

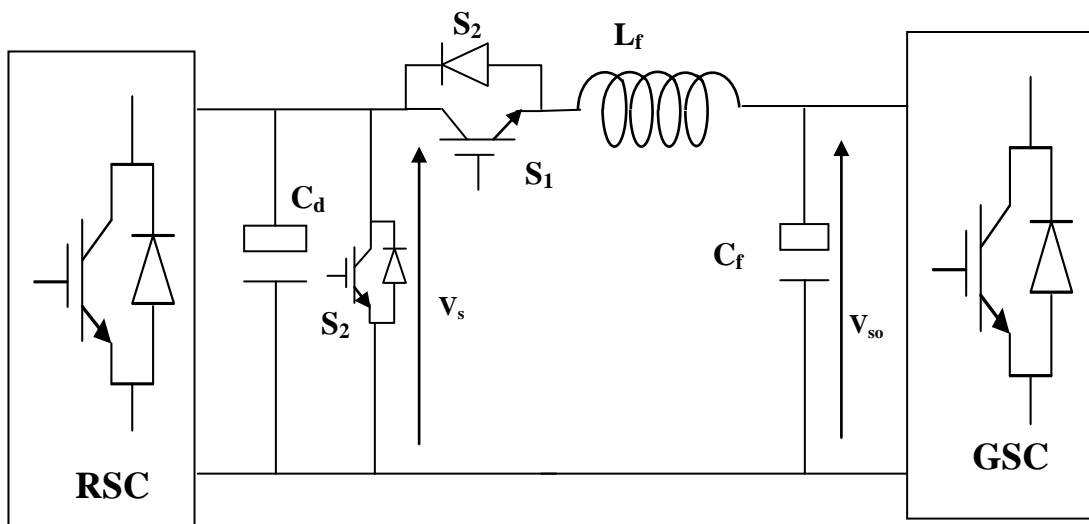


Fig. 4: Main circuit of the rotor with control cells.

The figure 4 shows the circuit that controls the power flowing between the rotor of the DFIG and the network, which consists of an input capacitance C_d , and a filter composed of a coil L_f and a capacitance C_f , and two switching cells S_1 and S_2 , the elements of the filter used to reduce the ripple voltage, the inductor L_f and capacitor C_f , respectively, are calculated as follows [14][15]. :

$$L_f = \frac{V_{dc}(1-\alpha)}{f_s|\Delta I_d|} \quad (1)$$

$$C_f = \frac{1}{8 L_f f_s^2 |\Delta V_{dc}|_{out}} (1-\alpha) \quad (2)$$

α is the duty ratio of DC-DC converter, ΔI_d is the peak to peak ripple of I_d , the ripple of the inverter input voltage V_{dc} is ΔV_{dc} , and f_s is the switching frequency of the cells switching. The power input capacitor value; C_d is calculated as follows [14]:

$$C_d = \frac{(I_d)_{avg}}{f_s |\Delta V_{dc}|_{in}} \quad (3)$$

From the circuit of the Figure 1, the voltage between the terminals of the coil and the current in the output capacitor C_f can be represented respectively by the following system:

$$\left\{ \begin{aligned} L_f \frac{di_l}{dt} &= \alpha \cdot V_s - V_{so} \end{aligned} \right. \quad (4)$$

$$\left\{ \begin{aligned} C_f \frac{dV_{so}}{dt} &= i_l - \frac{V_{so}}{R} \end{aligned} \right. \quad (5)$$

$$V_{so} = \alpha \cdot V_s - l \frac{di_l}{dt} \quad (6)$$

(6) In (5) gives:

$$C_f \cdot V_s \frac{d\alpha}{dt} - L_f C_f \frac{d^2 i_l}{dt^2} = i_l - \alpha \cdot \frac{V_s}{R} + \frac{l}{R} \frac{di_l}{dt} \quad (7)$$

The Laplace transform of (7) gives us the following equation:

$$C_f \cdot V_s \cdot p \cdot \alpha - L_f C_f \cdot p^2 \cdot i_l = i_l - \alpha \cdot \frac{V_s}{R} + \frac{l}{R} p i_l \quad (8)$$

$$(C_f \cdot V_s \cdot p + \frac{V_s}{R}) \alpha = (1 + \frac{l}{R} p + L_f C_f \cdot p^2) i_l \quad (9)$$

Equality (9) gives the following transfer function:

$$\frac{i_l}{\alpha} = \frac{\frac{V_s}{R} (C_f R p + 1)}{1 + \frac{l}{R} p + L_f C_f \cdot p^2} \quad (10)$$

The transfer function (10) is used to regulate the current in the inductor. Once the current i_l reached the desired value I_{ref} , the V_{so} is expressed by:

$$\frac{V_{so}}{I_{Lref}} = \frac{R}{(R C_f \cdot p + 1)} \quad (11)$$

This equation is valid since the dynamic response of the voltage is slower than that of the current in this case the current calculated by (11) can be regarded as the reference value for controlling the current in (10), the two equations allow construct the control law switches show figure 6.

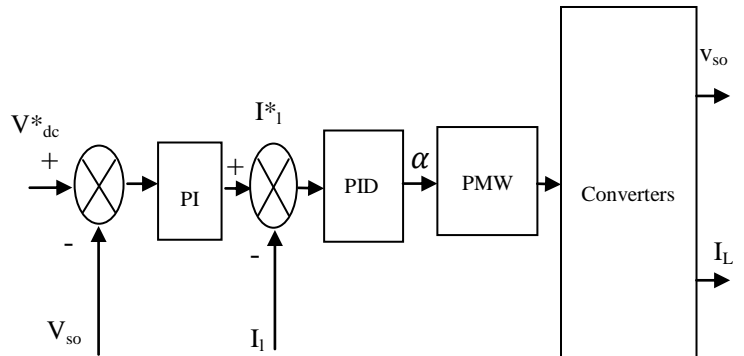


Fig. 5: overall control Diagram of the DC bus circuit.

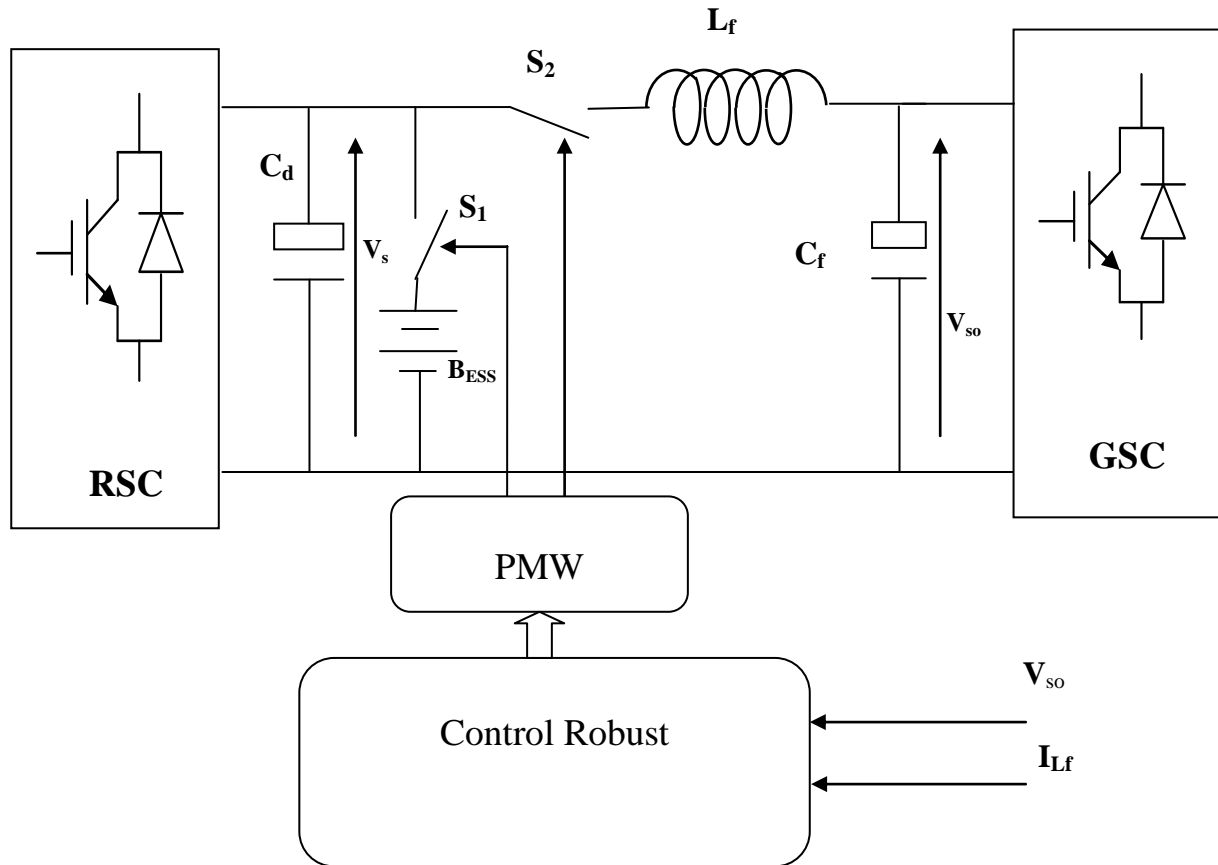


Fig. 6: The block diagram of the robust control of rotor power

The controllers used in the nested loop are a PI for the outer loop, then a PID is used in the inner loop for improving the response time.

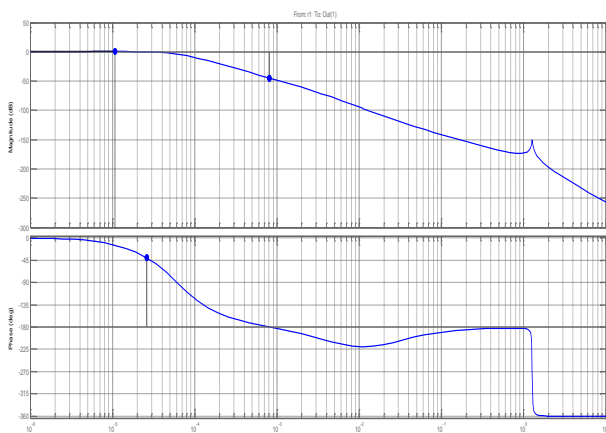


Fig. 7: Bode diagram of the system with correction

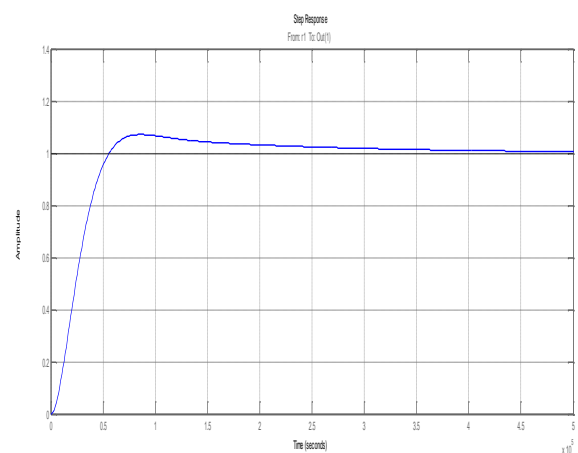


Fig. 8: Step response of the system

4 Results and discussion:

The simulation of the system was designed, in Matlab/ Simulink/ SimPowerSystems, they were performed on a wind farm consisting of six DFIG; with a rated output of 1.5 MW each; to verify the performance of the proposed

control of the power exchanged between DFIG and grid. The optimal parameters of the used controllers are tuned, to ensure good dynamic response for our system:

Table 1- The optimal parameter of the converter dc-dc and the data of the DFIG.

Wind turbine DFIG	value
Rated Generator Power	1.5MW
Rated Terminal stator voltage	690V
Rated frequency	50Hz
Stator Resistance R_s	0.0048 m Ω
Stator leakage inductance L_s	0.1386 mH
Rotor Resistance R_r	0.00549 m Ω
Rotor leakage inductance L_r	0.1493 mH
DC bus voltage	1150 V
DC-DC Converter	value
Capacitance C_{in}	0.0000815 μ F
Inductance L_f	3.833mH
Capacitance C_f	160 μ F
Switching frequency	10KHz
Parameter of the battery	value
Battery Nominal Voltage	1150 V
Rated Capacity	65 Ah

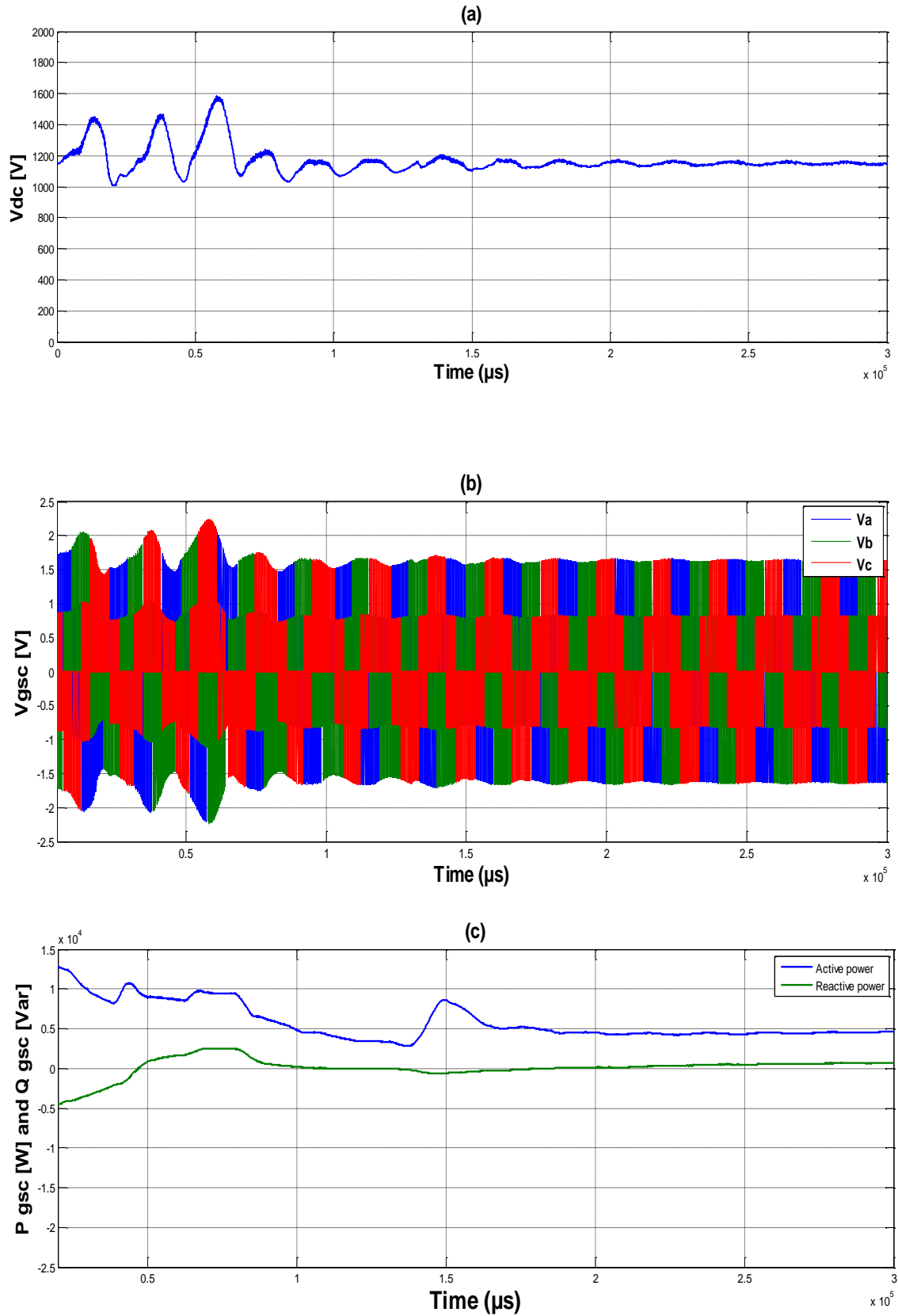


Figure 6: (a) DC bus voltage, (b) Output Voltage of the GSC and (c) active and reactive power injected to grid without control.

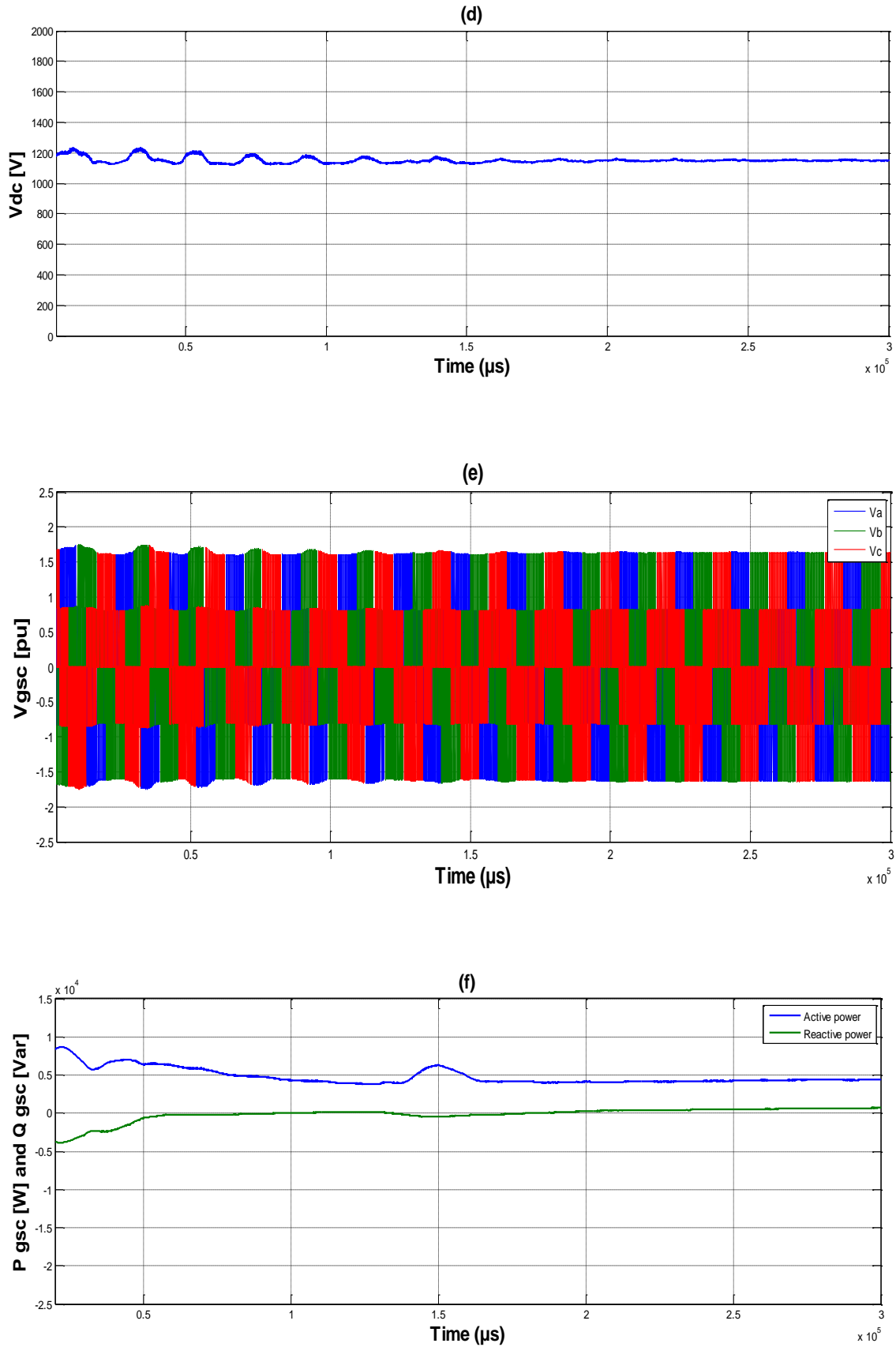


Figure 7: (d) DC bus voltage, (e) Output Voltage of the GSC and (f) Active & reactive power injected to grid with the robust control

During the fault, the fluctuations of the rotor currents will be transferred to the DC bus via the rotor side converter, which will cause overflow at the DC bus voltage as shown in Figure (a). the voltage reaches 1.37 pu could, in this case we will stress the components of the DC bus and power converters, the transition from the DC bus voltage causes a fluctuated voltage in the output grid side converter as it is shown in the figure (b) and therefore the power exchanged by the GSC and the network is varied as it is shown in Figure (c). with the new robust control, the overflow affecting the DC bus voltage is suppressed by the outer loop

5 CONCLUSION:

in this paper a robust control of the power exchanged between the rotor and the power grid during the fault has been proposed based on the voltage and current in the DC bus system, an outer loop to maintain the stability of the DC bus and a inner loop control the current flowing in the DC bus, the protection of converters during the fault which generates a surplus power and smoothing of the active power injected to the grid are provided by a battery (BESS), both theoretical and the simulations done on Matlab / Simulink / SimPowerSystems validate the efficiency of the proposed robust control.

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voltage and the inner loop is responsible of the current through the coil, the stability of the DC bus voltage ensures good waveform of the converter output voltage of the network side, the existence of system energy storage battery (BESS) provides smoothing of the active power injected by the network-side converter to the grid, the first primary role is to store the excess energy passing through the DC bus in the battery (BESS), keep the DC bus voltage and the supply of constant reactive power requested by the grid.

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