

Research Paper

DFIG WTG PLANT ELECTRICAL FAULTS ANALYSIS AND THE ROTOR SIDE CONVERTER OVER-CURRENT SOLUTION APPROACH

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With the rapid increase of the modern high power wind plants all over the world, a new problem associated with the response of wind turbines to temporary low-voltages has arisen. Today, this problem has become the topic of discussion because of the stability of the power grids at which these farms are connected. A majority of wind turbines use voltage source converters with a DC-link, especially those using Doubly Fed Induction Generators (DFIG). When the grid voltage exceeds a certain limit, the current flowing through the converters critically increase, resulting in an instantaneous release of protection equipments to avoid the destruction of the power system installations. One of the widely used protection system in DFIG plant is the crowbar system which when triggered satisfies the over-current problem, but is not enabled to feed the plant with the required reactive power as imposed in the new (FRT) requirements. To handle such situations, special countermeasures are required. This paper identifies and outlines the problem and analyzes a possible measure to ride through the low voltage safely. Additionally, fault current flow level control is announced without being developed.

Keywords: DFIG, WTG, Wind power plant, Voltage source converter, Doubly fed induction generator, FRT

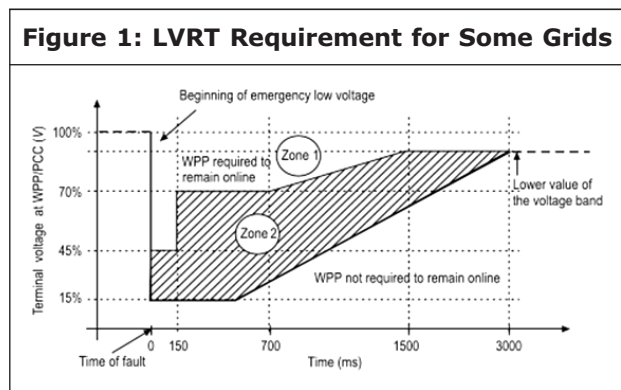
INTRODUCTION

The renewable energy (hydro, solar, wind, geothermal, bio-power, ocean) represents about 21.7% of the worldwide global electricity production. According to the Global Wind Energy Council (GWEC), a total of 282,587 MW was installed in 2012 representing about 60% of the total renewable energy, excluding hydropower [1]. The instability of these plants due to the wind flow and the used technology constitute a major problem in grid exploitation; also the faults in the grid influence the plant due to critical variation in the current, voltage and the torque. Therefore,

many requirements are imposed on the plant energy production like fault ride through requirements for grid-connected wind plant. Many procedures are being used to solve this problem but the efforts are often half rewarded. For a plant using Doubly Fed Induction Generator (DFIG), a system called crowbar is often used but this does not satisfy 100% of the requirements and is not without a negative consequence on the installed electronics. In this paper, we analyze some critical faults of the DFIG wind plant and present a simple approach to ride through a fault causing an over-current in the rotor circuit. During a fault, the

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disconnection of the wind power plant helps in protecting the incorporated power electronics from damage due to thermal overload; however a quick disconnection is not desirable as it can provoke the release of other plants in the grid and lead to loss of large amount of energy generation by cascading effect. The WPP (Wind Power Plant) must support the voltage in case of three-phase short circuit in the grid. If the fault is close to the WPP, there should neither be instability of the WPP nor disconnection from the grid for voltage-time values exceeding the bold line (see Figure 1). This procedure called Fault Ride Through (FRT) generally known as Low Voltage Ride Through (LVRT) and High Voltage High Through (HVHT) is now almost a mandatory requirement in many grid codes for modern grid-connected WPP. The voltage level and the FRT time delay is not the same for all the grid codes.

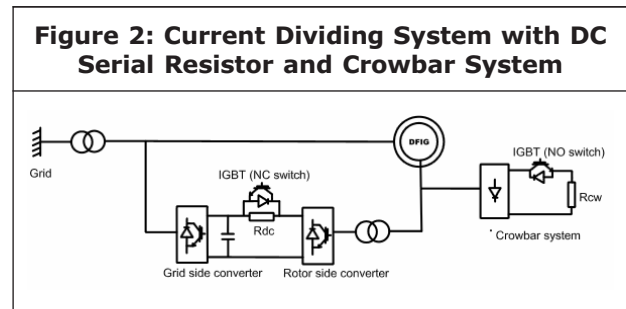


- In zone 1, active power generation capacity must be recovered after the indication of the fault and must be increased at a gradient of 20% of the rated power per second.
- In zone 2, instead, a short disconnection of the WPP from the grid is allowed; however, a quick resynchronization should follow after the fault clearing and it must return to the pre-fault standard generation conditions so that the outage lasts for not more than 10s. Therefore, the plant must return to supplying active power within 2s after the fault is cleared at a gradient of 10% of the rated active power per second.
- If the short circuit is far from the plant, it should not be disconnected from the grid

because fault is generally eliminated by the network protection in 5s. [2]

IMPLEMENTATION OF OUR SYSTEM

We will simulate a grid side fault with Matlab DFIG detailed model [3].



During an over current fault it is used to block out the switches of the IGBT of the rotor side converter and used a crowbar system to drive the current between the crowbar resistor and the rotor windings. When the contacts of the converter IGBT are opened, a very high voltage appears at their pins and they can be damaged [4]. And when all the short-circuit current needs to be directed into the crowbar, a special dimensioning is necessary. Our idea is to fix the current in the converter and lead the rest to the crowbar reducing the dimension of the latter.

As meant above, when the circuit is opened, the voltage is so high, and according to the grid requirements, during a low voltage problem, the plant must still be connected to the grid at least for a fixed time and be able to produce a reactive power to support the grid as indicated in LVRT requirements [4].

Principle: Fix the rotor side current at a maximum value when the rotor is in over-current situation. A resistor will be put in the DC circuit during the fault to limit the DC bus current thus limiting the current in the rotor side convertor. When the fault occurs, the DC side resistor and the crowbar are triggered (Figure 2).

To evaluate the resistances, we will simplify all the computing (Figure 3).

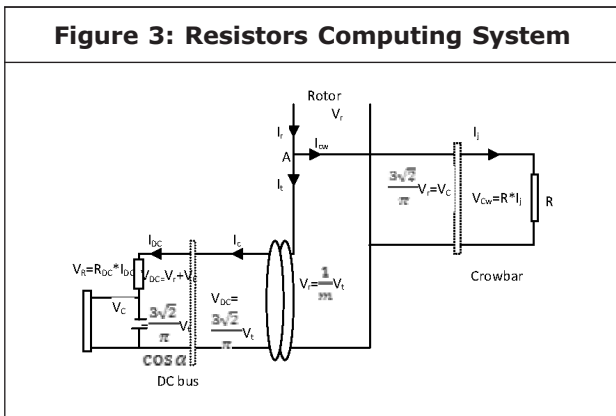


Figure 3: Resistors Computing System

- For the rotor side converter circuit

$$\left\{ \begin{array}{l} V_R + V_C = V_{DC} \\ V_{DC} = \frac{3\sqrt{2}}{\pi} V_t \cos\alpha \\ V_R = R_{DC} * I_{DC} \\ I_c = \sqrt{\frac{2}{3}} I_{DC} \\ V_t = m * V_r \\ I_t = m * I_c \\ m = \frac{V_t}{V_r} \end{array} \right. \dots(1)$$

From (1):

$$R_{DC} * \sqrt{\frac{3}{2}} * \frac{I_t}{m} = \frac{3\sqrt{2}}{m} * m * V_r \cos\alpha - V_C \dots(2)$$

and

$$I_t = \sqrt{\frac{2}{3}} * \frac{m}{R_{DC}} * \left(\frac{3\sqrt{2}}{\pi} * m * V_r \cos\alpha - V_C \right) \dots(3)$$

$$R_{DC} = \sqrt{\frac{2}{3}} * \frac{m}{I_t} * \left(\frac{3\sqrt{2}}{\pi} * m * V_r \cos\alpha - V_C * m * V_r - V_C \right) \dots(4)$$

With Equation (4) we can determine a value for RDC, with $I \leq I_{tmax}$, the rotor maximum current in

the steady case, and $V_r = V_{rfault} * V_{rfault}$ is the approximate value for the rotor voltage during the transient fault.

From Equation (4), we have

$$R_{DCmin} \geq \sqrt{\frac{2}{3}} * \frac{m}{I_{tmax}} * \left(\frac{3\sqrt{2}}{\pi} * m * V_{rfault} \cos\alpha - V_C \right) \dots(5)$$

- At the point A,

$$I_r^2 = I_t^2 + I_{cw}^2 \dots(6)$$

- For the crowbar circuit:

$$\left\{ \begin{array}{l} \frac{3\sqrt{2}}{\pi} V_r = V_{Cw} \\ V_{Cw} = R * I_j \\ I_{cw} = \sqrt{\frac{2}{3}} I_j \end{array} \right. \dots(7)$$

$$R = \sqrt{\frac{2}{3}} * \frac{3\sqrt{2}}{\pi} * \frac{1}{I_{cw}} * V_r = \frac{4\sqrt{3}}{\pi} * \frac{V_r}{\sqrt{I_t^2} * \left(\frac{3\sqrt{2}}{\pi} * m * V_r \cos\alpha - V_C \right)^2} \dots(8)$$

During the fault $I_r = I_{rfault}$ the rotor current during the fault, RDC the admitted resistance for the DC bus, $V_r = V_{rfault}$

We can then get the curve R(I_r).

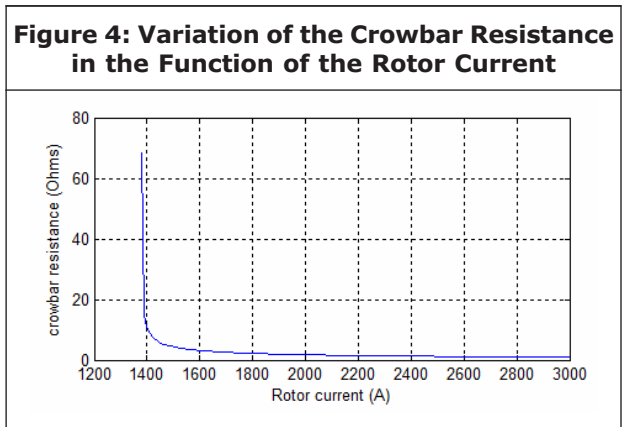


Figure 4: Variation of the Crowbar Resistance in the Function of the Rotor Current

We will use Matlab DFIG detailed model for our simulation. We can observe that the voltage of the rotor during the fault when the converter is connected through a resistance and the crowbar is triggered, is about 2 times the nominal value.

$$V_{r\text{fault}}=2V_r = 1150V \text{ and } V_c = 1150V.$$

Estimation of the current:

The power of the plant is 1.5MW,

The rotor nominal voltage is 575V

If we suppose that the rotor is dimensioned for 60% of the power during the fault, and if $\cos\phi=0$ then the nominal current in the rotor is:

$$I_r = I_{t\text{max}} = \frac{1.5 * 10^6}{575} * 60\% = 1565A,$$

$$m = \frac{1975}{575} = \frac{79}{23}$$

If we fix the current of the rotor circuit at $I_r=1500A$, we have the converter current:

$$I_c = 1500 * 23 / 79 = 437A$$

Note: The value of the rotor circuit and the converters depend on the dimensioning. Here we just fix a theoretical value for our simulation. There are IGBTs which support more than 3000A, the value of I_r will depend on the project requirements (cost and power).

With Equation (5),

$$R_{DC\text{min}} \geq \frac{\sqrt{2}}{3} * \frac{m}{I_t \text{max}} * \left(\frac{3\sqrt{2}}{\pi} * m * V_{r\text{fault}} * \cos\alpha - V_c \right) \text{ and}$$

$$\cos\alpha = \frac{V_{DC}}{V_t} * \frac{\pi}{3\sqrt{2}} = \frac{\pi * 1150}{1975 * 3\sqrt{2}} = 0.43, \text{ let fix}$$

$$\cos\alpha = 0.4$$

$$R_{dc} \geq 1.84\Omega$$

Let fixe $R_{DC}=2 \Omega$, compute the new

$$I_t = \sqrt{\frac{2}{3}} * \frac{m}{R_{DC}} * \left(\frac{3\sqrt{2}}{\pi} * m * V_{r\text{fault}} * \cos\alpha - V_c \right)$$

$$I_t = \frac{2759}{R_{DC}} = 1379.5A$$

Let us analyze the rotor current during the fault:

From 0.11S the current has a pick of 5 times, at 0.12S it decreases to 3 times and stays at 1.8 times from 0.14S till the end of the fault. With $I_r=1500A$, we have the following table

$$R = \frac{4\sqrt{3}}{\pi} \frac{V_r}{\sqrt{I_t^2} * \left(\sqrt{\frac{2}{3}} * \frac{m}{R_{DC}} * \left(\frac{3\sqrt{2}}{\pi} * m * V_r * \cos\alpha - V_c \right) \right)^2}$$

$$= \frac{4\sqrt{3}}{\pi} \frac{V_r}{I_r^2 - I_t^2} = \frac{4\sqrt{3}}{\pi} \frac{1150}{\sqrt{I_r^2} - 1379.5^2}$$

$$= \frac{2536}{\sqrt{I_r^2} - 1379.5^2}$$

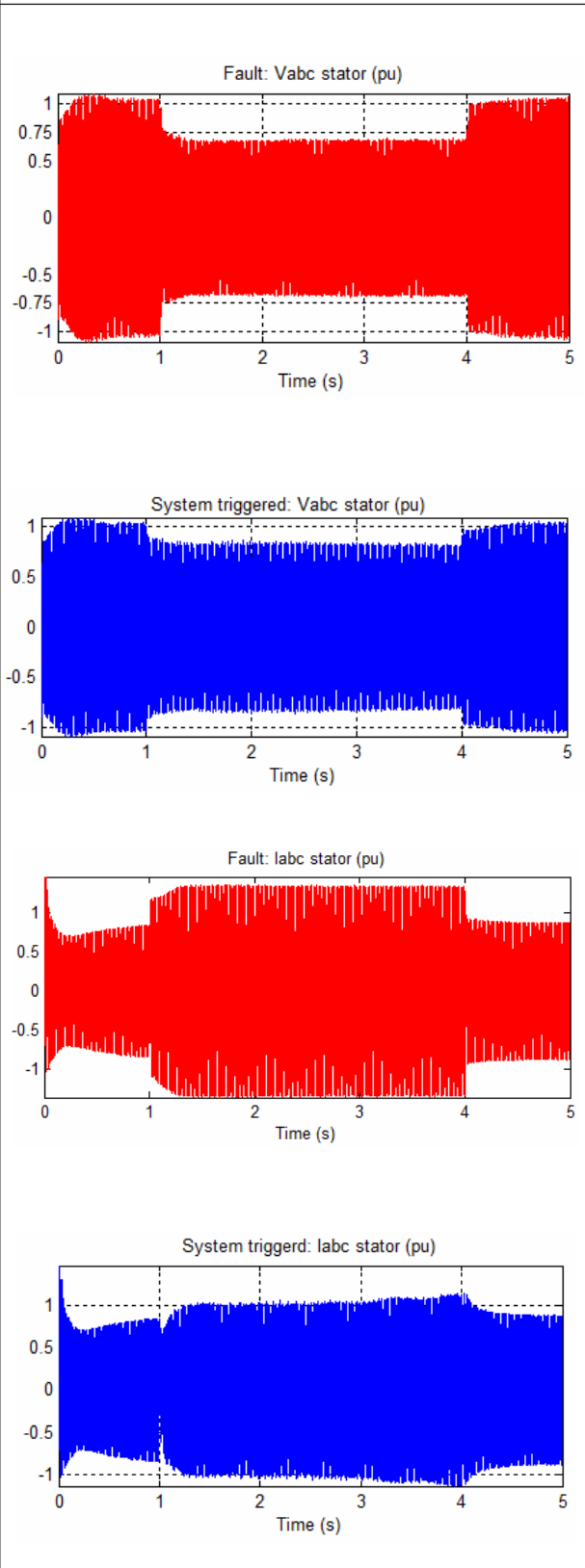
Table 1: Variation of the Resistance During the Fault

T(s)	0.201	-	0.21	-	0.22	-
	0.21		0.22		0.501	
R(Ω)	0.344		0.592		1.1	

For our simulation, as the model of the wind plant is not built by us, we do not have all the parameters and nominal values. We also do not change any of the parameters of the original system (Matlab DFIG wind plant detailed model), except removing the fault which initially was introduced in the grid. We simulate a new fault in the stator circuit to make high current flows in the rotor circuit. The results of our simulations are as shown in the following figures. The duration of the simulation is 5s with 3s delay time for fault simulation:

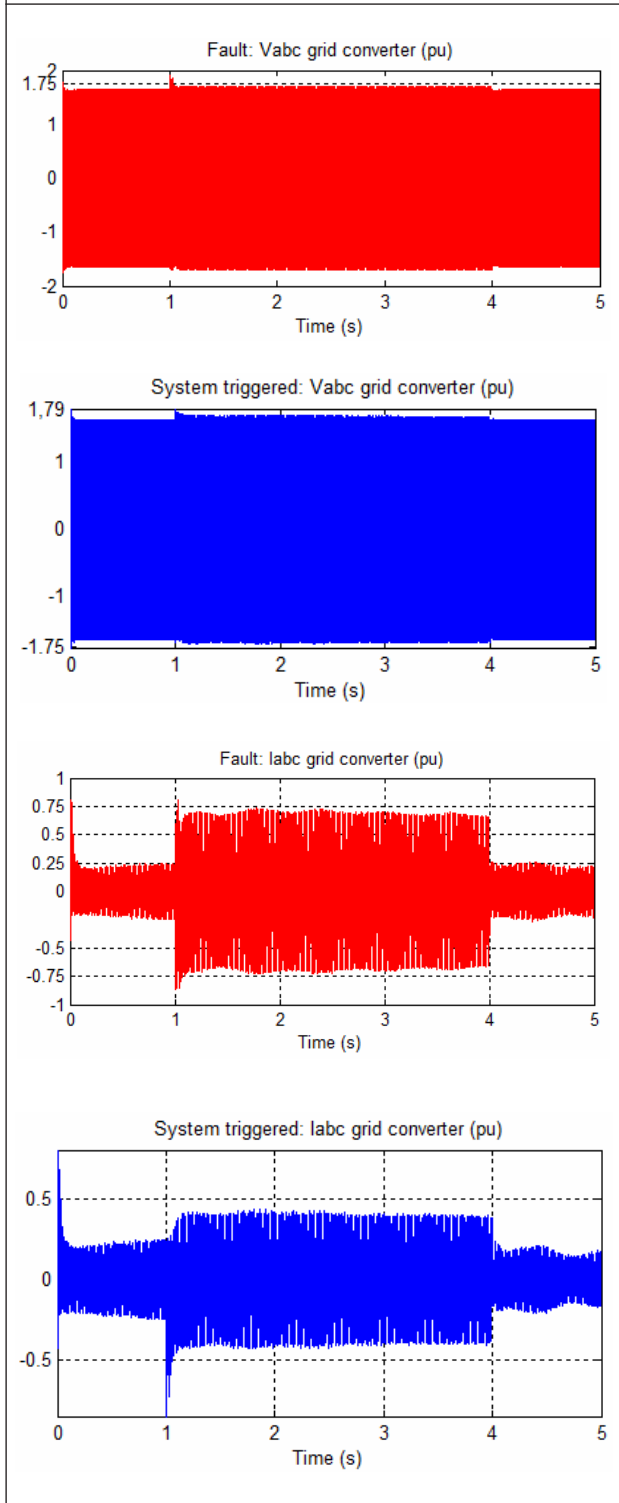
- As the requirement for most of the grids is around 2s delay for fault simulation, we will extend our fault delay to 3s with a 5s simulation time. The results are as follows:

Figure 5: Stator Voltage and Current

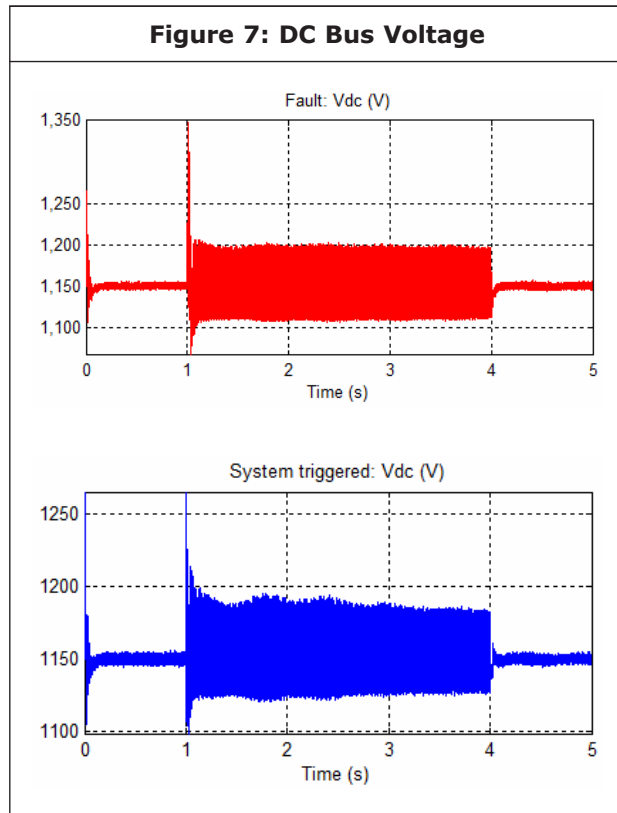


With 3s fault simulation, we can see good amelioration of voltage and current in the stator circuit.

Figure 6: Grid Converter Voltage and Current



The current in the grid converter which was 3times the steady value is ameliorated to 1.75 times.



The DC voltage during a fault oscillated between 1100 and 1200V with starting peak voltage of 1350V; with our system, the peak is low and the voltage oscillates between 1120 and 1180V.

The problem of the rotor voltage remains; it is practically 2.5 times the steady value. However the over-current is corrected a little-1.8 times instead of 2 times.

Our dimensioning had a limit because we do not have all the characteristics of the model we used, because it was not built by us due to our limited knowledge in model-building.

With 3s fault simulation, the power produced when the system is triggered is about the half without the system during the fault; however, the reactive power is produced instead of consuming without the system application during the fault.

Figure 8: Rotor Converter Voltage and Current

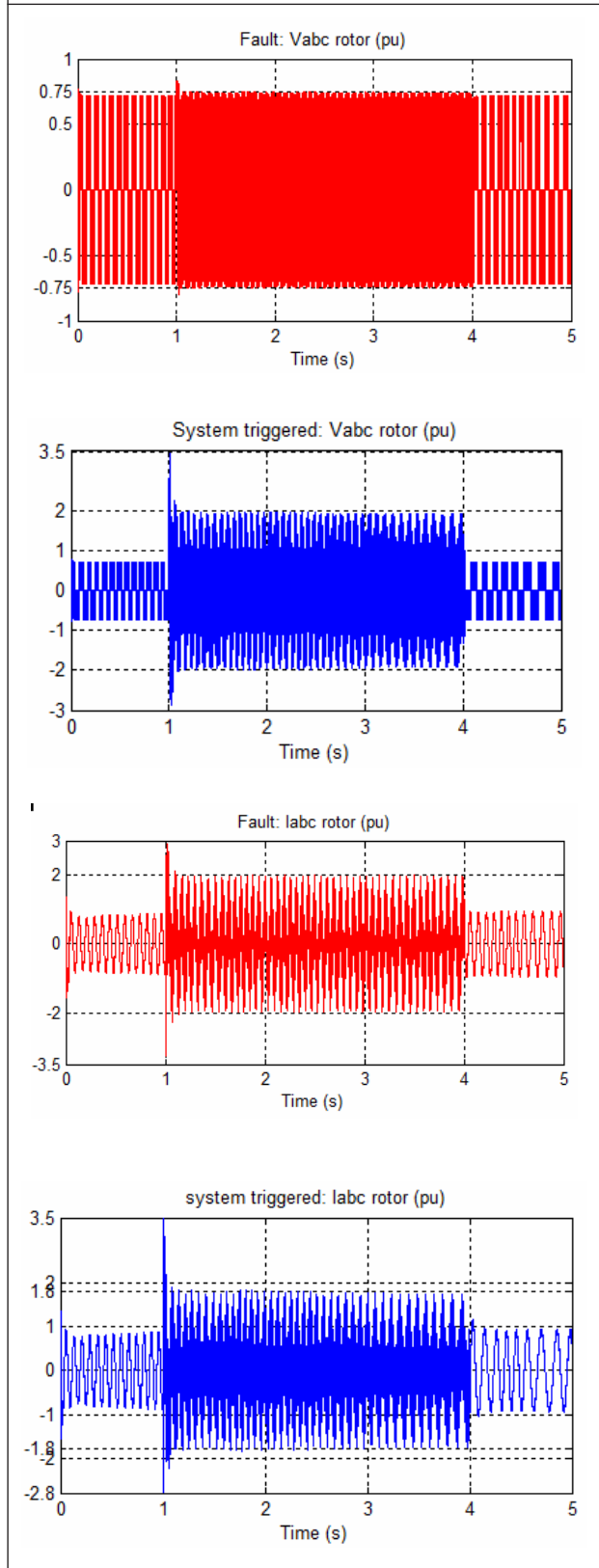


Figure 9: Crowbar Voltage and Current

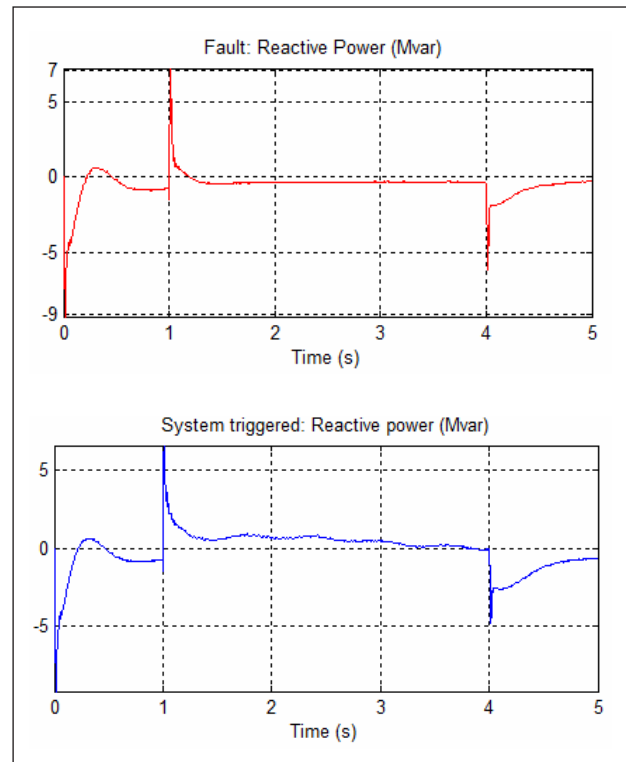
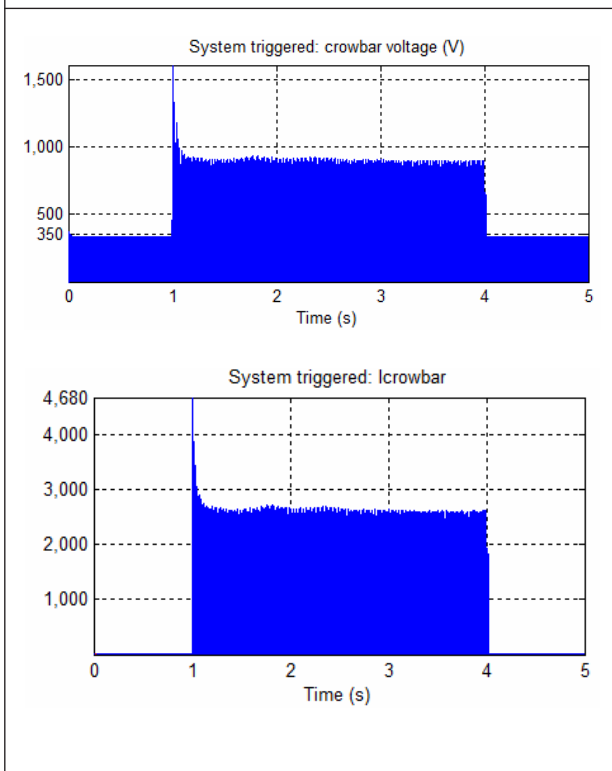
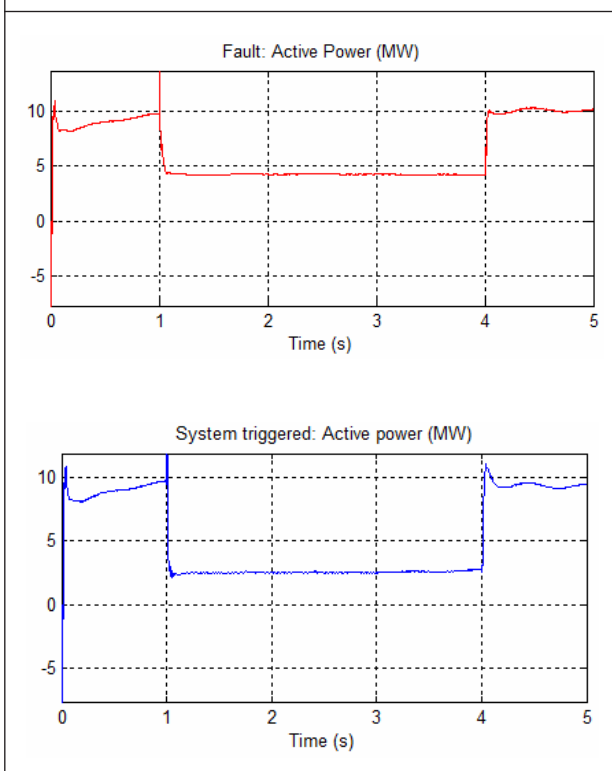


Figure 10: Active and Reactive Power



SUMMARY

The DFIG system applied to wind power generation has gained considerable academic attention and industrial application during the past 10 years and is still the actual topic in view of the growth in wind power in the worldwide energy generation every year. In the present situation, the wind power is one of the best solutions to palliate the dependence on fossil energies; however, with transient faults, wind power is still the black beast for the research field. In our work, we have presented the fault ride through requirements and give an approach to ride through a low voltage for existing DFIG wind turbine. Even though this is not a full solution, it can lead to deep practical researches. Our work will continue by implementing a variable ‘resistance’ in the crowbar system.

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