International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 7 (2020) pp. 695-699

Control of Wind driven Doubly Fed Induction Generator Under Unbalanced Grid Voltage Conditions

T.Samina
Associate professor
College of Engineering Trivandrum
Thiruvananthapuram, India.

A.Bisharathu Beevi
Professor
College of Engineering Trivandrum
Thiruvananthapuram, India.

S.RamaIyer
Retd.Dean
College of Engineering Trivandrum
Thiruvananthapuram, India.

Abstract

Wind energy system based on Doubly Fed Induction Generator (DFIG)are very sensitive to grid disturbance such as voltage sag. The Low Voltage Ride through capability during grid disturbance is one of the core requirements to ensure stability in power grid during transient condition. In this paper the authors analyse system under abnormal grid voltage situation and proposes a control strategy enabling the DFIG to ride through sudden variation in grid voltage. These control schemes include the generator-side converter control, Rotor -side converter control, and crow bar protection.

Keywords: Doubly Fed Induction Generator,Vector Control,Active power,Wind Power Generation.

NOMENCLATURE

DFIG	Doubly Fed Induction Generator
MPPT	Maximum Power Point Tracking
s , *r*	Stator, Rotor variable
F_{ij}	Flux linkage ($i=d$ or q and $j=s$ or r)
V_{qs} , V_{ds}	q and d axis stator voltages
V_{qr} , V_{dr}	q and d axis rotor voltages
R_s , R_r	Stator, Rotor resistance
X_{ls} , X_{lr}	Stator, Rotor leakage reactance
i_{qs} , i_{ds}	q and d axis stator currents
i_{qr} , i_{dr}	q and d axis rotor currents
p	Number of poles
T_e	Electromagnetic torque
T_l	Load torque
ω_e	Stator angular electrical frequency
ω_b	Base frequency
ω_r	Rotor angular electrical speed
P_s , P_r	Stator and Rotor active power
Q_s , Q_r	Stator and Rotor reactive power

I. INTRODUCTION

Wind energy is one of the most important and prominent renewable energy which attracts more and more concerns. The Doubly Fed Induction Generator (DFIG) based wind turbine with variable speed variable-pitch control scheme is the most popular wind power generator in the wind power industry. A drop of one or more phase voltage can be especially damage the power electronic converter. For Symmetrical fault the drop is the same for three phases. Such a dip may be caused by inrushing current at a motor start up or by a near short circuit and ground. Unbalanced magnetic loading of the machine can lead to unexpected magnetic saturation and excessive heating which in turn can reduce the life time of DFIG. Since the negative sequence component of stator field rotates in the same direction as that of the rotor field the resulting torque and field will appear with double of the stator frequency. This is the second harmonic behavior of DFIG operating under unbalanced condition.

The objective of the paper is to analyze the behavior of DFIG under unbalanced grid voltage conditions. This paper is organized as follows, Section I gives the introduction, Section II give an overview of the working of DFIG, Section III gives the dynamic DFIG system modeling including rotor side converter control and grid side converter control. Analysis of DFIG during Symmetrical and Asymmetrical Voltage dip is conducted in section IV and section V gives the conclusion.

II. OVERVIEW

The typical configuration of the DFIG wind turbine system is shown in Fig. 1. The Stator is directly connected to the grid, and rotor is connected through a back to back PWM converter. This kind of wound rotor slip-ring machine can be fed from both the rotor and stator sides. The converter system includes two AC/DC Insulated-Gate Bipolar Transistors (IGBTs) based Voltage Source Converters (VSCs) connected by a DC bus.

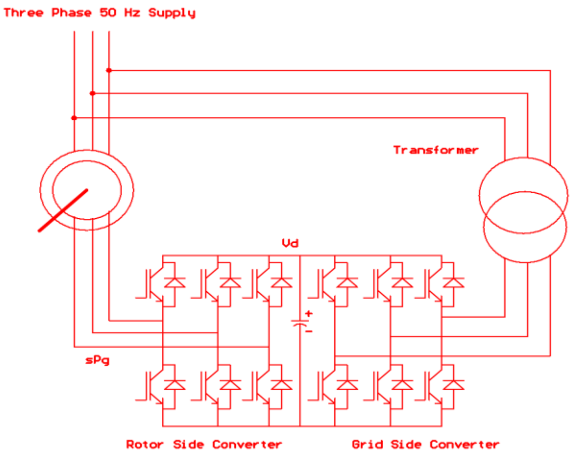
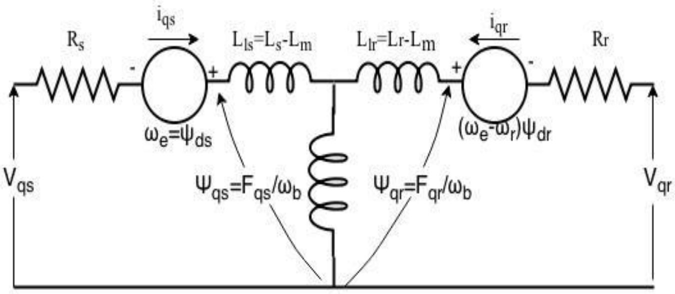


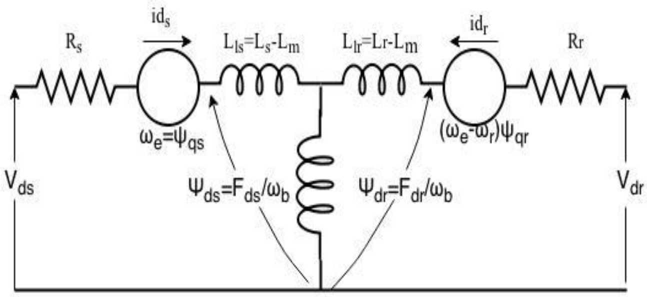
Fig. 1. Doubly fed induction machine

III DYNAMIC MODELING

The induction machine *d q* axis model, i.e. dynamic model is given in Fig.2. A synchronously rotating reference frame is used with direct axis oriented along with the stator flux position, so the decoupled control between torque and excitation current is obtained[1]. The wound rotor induction machine equations in flux linkage form are given from equation (1) to (18). Vector control technique is used for the analysis which include (a) Rotor side control and (b) Grid side control.



(a)



(b)

Fig. 2. Dynamic or *q- d* equivalent circuit of an induction machine

$$\frac{dF_{qs}}{dt} = \omega_b \left[v_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{x_{ls}} \left(F_{mq} + F_{qs}\right)\right] \tag{1}$$

$$\frac{dF_{ds}}{dt} = \omega_b \left[v_{ds} - \frac{\omega_e}{\omega_b} F_{qs} + \frac{R_s}{x_{ls}} \left(F_{md} + F_{ds}\right)\right] \tag{2}$$

$$\frac{dF_{qr}}{dt} = \omega_b \left[v_{qr} - \frac{(\omega_e-\omega_r)}{\omega_b} F_{dr} + \frac{R_r}{x_{lr}} \left(F_{mq} + F_{qr}\right)\right] \tag{3}$$

$$\frac{dF_{dr}}{dt} = \omega_b \left[v_{dr} - \frac{(\omega_e-\omega_r)}{\omega_b} F_{qr} + \frac{R_r}{x_{lr}} \left(F_{md} + F_{dr}\right)\right] \tag{4}$$

$$F_{mq} = X_{ml} \left[\frac{F_{qs}}{x_{ls}} + \frac{F_{qr}}{x_{lr}}\right] \tag{5}$$

$$F_{md} = X_{ml} \left[\frac{F_{ds}}{x_{ls}} + \frac{F_{dr}}{x_{lr}}\right] \tag{6}$$

$$i_{qs} = \frac{1}{x_{ls}} \left[F_{qs} - F_{mq}\right] \tag{7}$$

$$i_{ds} = \frac{1}{x_{ls}} \left[F_{ds} - F_{md}\right] \tag{8}$$

$$i_{qr} = \frac{1}{x_{lr}} \left[F_{qr} - F_{mq}\right] \tag{9}$$

$$i_{dr} = \frac{1}{x_{lr}} \left[F_{dr} - F_{md}\right] \tag{10}$$

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\frac{1}{\omega_b}\left(F_{ds} i_{qs} - F_{qs} i_{ds}\right) \tag{11}$$

$$\frac{d\omega_r}{dt} = \frac{P}{2J}\left(T_e - T_L\right) \tag{12}$$

$$v_{qr} = \frac{1}{\omega_b}\left[R_r i_{qr} - (\omega_e - w_r) F_{dr} + \frac{dF_{qr}}{dt}\right] \tag{13}$$

$$v_{dr} = \frac{1}{\omega_b}\left[R_r i_{dr} - (\omega_e - w_r) F_{qr} + \frac{dF_{dr}}{dt}\right] \tag{14}$$

$$P_s = \frac{3}{2}\left[V_{ds} I_{ds} + V_{qs} I_{qs}\right] \tag{15}$$

$$Q_s = \frac{3}{2}\left[V_{qs} I_{ds} - V_{ds} I_{qs}\right] \tag{16}$$

$$P_r = \frac{3}{2}\left[V_{dr} I_{dr} + V_{qr} I_{qr}\right] \tag{17}$$

$$Q_r = \frac{3}{2}\left[V_{qr} I_{dr} - V_{dr} I_{qr}\right] \tag{18}$$

(a) Rotor side controller

Vector control is used in synchronously rotating reference frame, '*d*' axis is aligned with stator flux space vector. Direct rotor current is proportional to stator reactive power and quadrature rotor current is proportional to active power or torque. Fig 3 shows the block diagram of Rotor side controller.

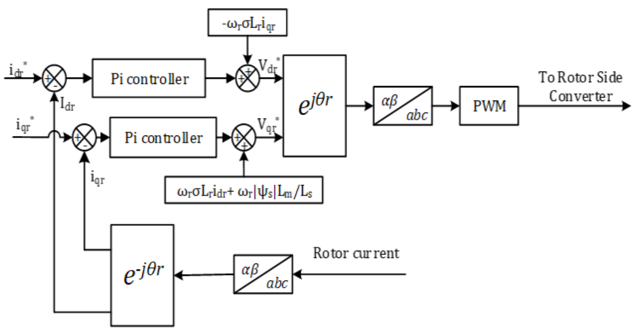


Fig. 3. Rotor side control of DFIG

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 7 (2020) pp. 695-699

(b) Grid side controller

The function of grid side controller is to keep the dc link voltage constant. Here also grid side vector control is used with reference frame oriented along the stator voltage vector position. The direct axis current is used to regulate the dc link voltage and quadrature axis current is used to regulate the reactive power[2]. Fig 4 shows the block diagram of Grid side controller.

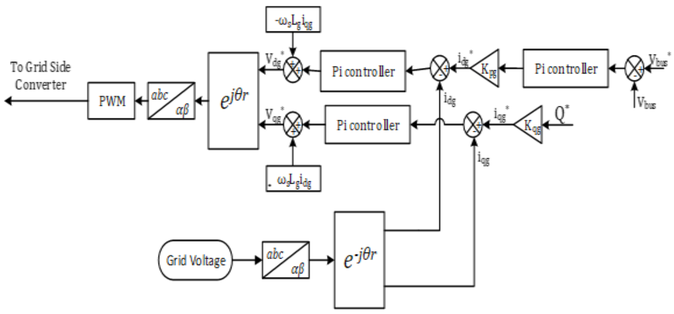


Fig. 4. Grid side control of DFIG

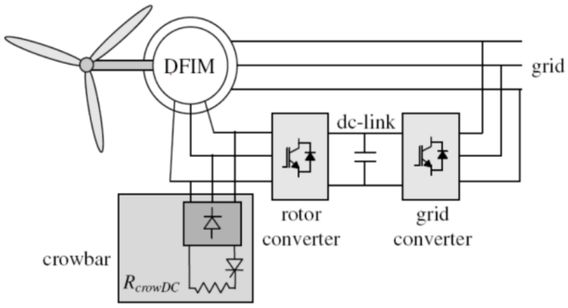


Fig. 5. DFIG with crow bar protection.

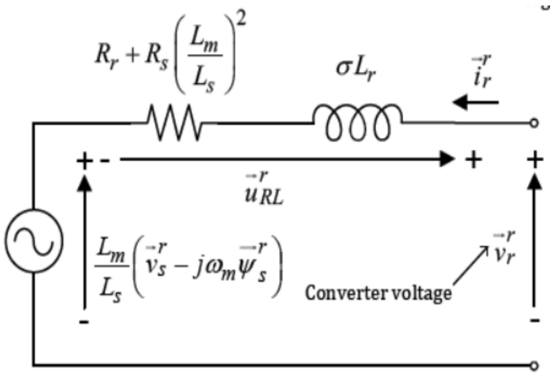


Fig. 6. DFIG Simplified Equivalent circuit.

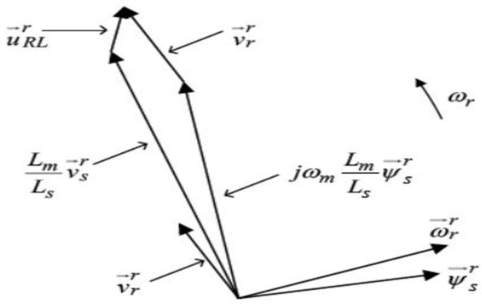


Fig. 7. DFIG Voltage Vector diagram

VI ANALYSIS 0F DFIG DURING VOLTAGE DIP

If there are unbalance in the grid voltage, this unbalance situation will be imposed on the stator winding of the DFIG. Under this condition even if balanced load is connected, across the Machine terminals, unbalanced set of current will be taken which can result in the occurrence of negative, positive and zero sequence magnetic field in the air gap of DFIG which result in reduction in torque and increase in torque pulsation. This unbalanced field decomposes in to symmetrical component can initiate a positive and negative sequence rotating field. Positive sequence result in the similar behavior as that of the balanced mode operation, the negative sequence result in the motoring action which will result in overall increase in torque pulsation. Crowbars are used to protect the power electronic converter from the flow of over current from the rotor. During the operation of crowbar the RSC is disabled and the rotor winding is short circuited by shunt resistors. The problem with a DFIG when a voltage dip occurs is that stator flux cannot follow the sudden change in the stator voltage [3]. Fault create higher over current and over voltage in the rotor, because a negative sequence component exists in the stator voltage and slip of the negative sequence is very high.

$$\frac{d\varphi_s}{dt} = V_s - \frac{R_s}{L_s}\varphi_s + R_s\frac{L_m}{L_s}i_r \quad (19)$$

$$V_r = \frac{L_m}{L_s}(V_s - j\omega_m\varphi_s) + \left[R_r + \left(\frac{L_m}{L_s}\right)^2 R_s\right] i_r + \sigma L_r\frac{di_r}{dt} \quad (20)$$

The stator flux is given by Eqn.19,when sudden voltage dip occures the stator flux cannot evolve to its final steady state value like stator voltage.Each phase of the stator flux evolves as the sum of a sinusoid and an exponetial with time constant $\frac{L_s}{R_s}$.When a sudden dip in the stator voltage occures a sudden rotor voltage change is occurred inorder to prevent high increase in rotor current.Inorder to not to lose control,keeping the rotor current within the safe limit it is needed to have a rotor voltage.But rotor can provide a 1/3 (Slip=3%) of stator voltage.Due to rotor voltage limitaion these type windturbine cannot guarantee that during severe voltage drop rotor currrent will be maintain within safe limit.Because of this limitation wind turbine based on DFIG incorporate additional crow bar protection[4].The crow bar is installed at the rotor terminals which prevents damage to the rotor converter.It is activated if a voltage sag is detected,entire rotor current circulates through the crowbar ,keeping the rotor converter in a safe mode[5].Once the flux has decayed,and the available converter voltage can control the machine,the crow bar is disconnected and the rotor converter is acivated again.

(A) Symmetrical voltage dip

The analysis is conducted by means of simulation using MATLAB based on 2MW Wind turbine based DFIG.Here the Voltage dip occures at t=3 seconds,as shown in Fig. 9,when the dip occures the grid voltage is only 10% of rated voltage.The crowbar is activated at the same time,connecting the additional resistance path in the machine.During the first instant of the dip,peak stator and rotor current and large torque occures as in Fig.10, Fig.11, and Fig.12. During sag period,entire rotor current circulates through the crow bar.

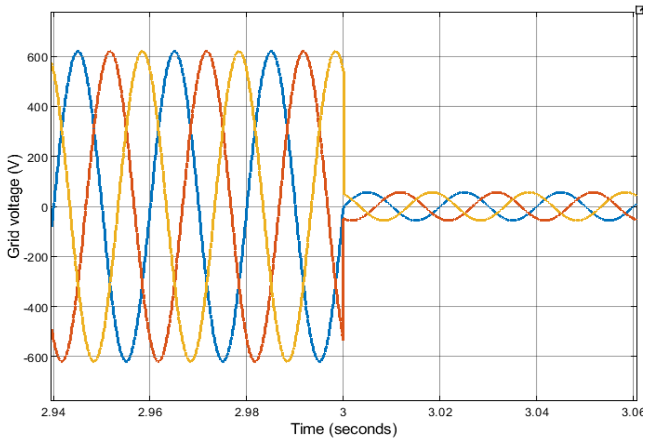


Fig. 9. Grid voltage with Symmetrical voltage sag.

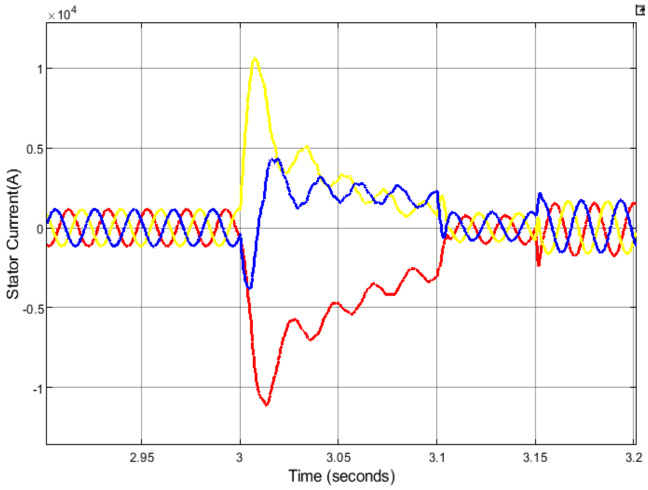


Fig.10 DFIG stator current Symmetrical voltage sag.

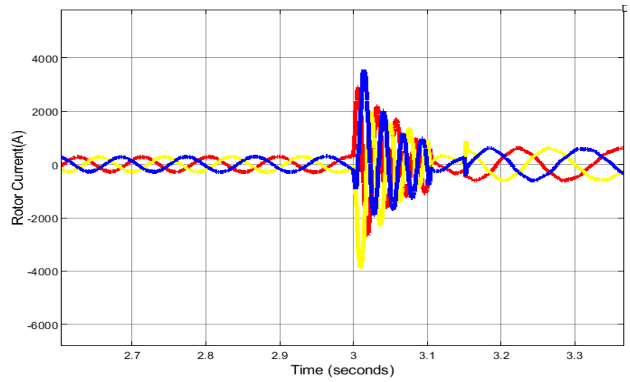


Fig. 11. DFIG Rotor current with Symmetrical voltage sag.

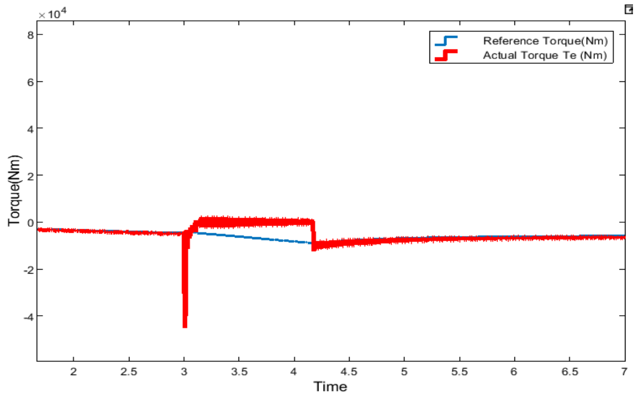


Fig. 12 Torque developed with Symmetrical voltage sag .

(B) Asymmetrical Voltage sag.

When the sudden voltage dip occures the stator flux cannot evolve to its final value and consequently the negative sequence of the stator flux is not zero. The negative fluxes due to the unbalance causes the powers and the torque to oscillate at twice the grid frequency,under unbalanced condition a negative sequence is added to the stator fluxes,as a consequence a large amount of negative current flows through the rotor,and stator.These currents are caused by the emf induced by the negative flux,and there amplitude depends on the current regulator rejection to a perturbation at thrice the grid frequency.

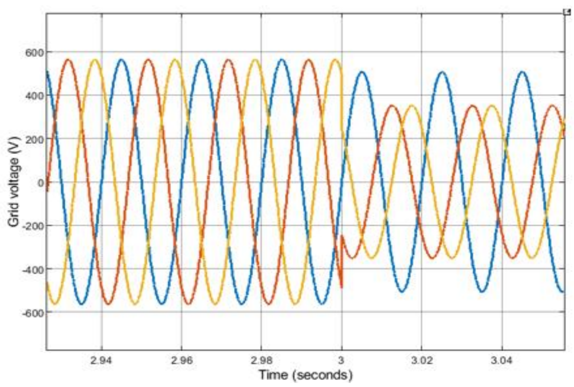


Fig. 13. Grid voltage with Asymmetrical voltage sag.

The unbalance occures at t=3 seconds,as shown in the Fig.13,The voltage unbalance is asymmetric,The stator current is shown in Fig.14 and the rotor current is shown in Fig.15. The Fig.16 gives the variation of torque due to the asymmetrical voltage unbalance.

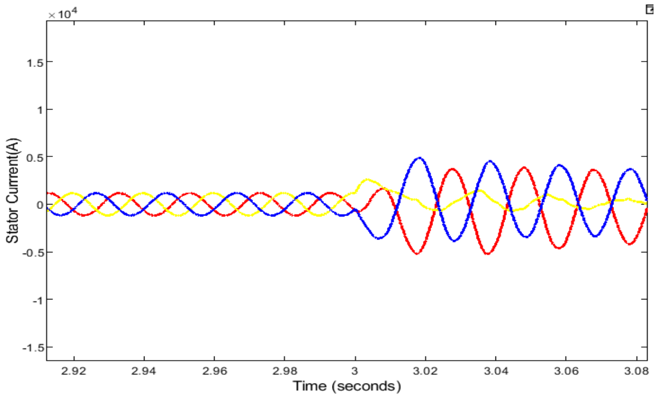


Fig.14 DFIG Stator current with Asymmetrical voltage sag

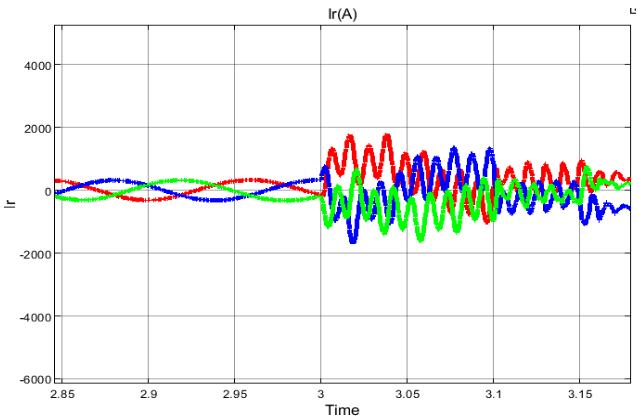


Fig. 15. DFIG Rotor current with Asymmetrical voltage sag.

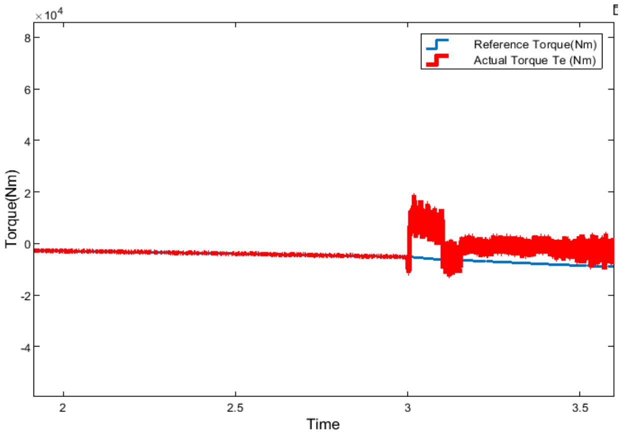


Fig.16. Torque developed with Asymmetrical voltage sag

V CONCLUSION

This paper gives a detailed investigation on the behavior of grid connected Doubly Fed induction Generator under unbalanced network conditions. To show the complete behavior of DFIG, during grid voltage disturbances, simulation result of 2 MW system are presented, as shown high rotor currents are the main issue during unbalanced grid voltage. Introducing crowbar we can effectively reduce the fault current.

APPENDIX

2 kW, 690V, 50Hz generator parameters

R_s = 0.19Ω R_r = 0.39Ω

P = 4

n = 1

L_m = 4 mH

L_{ls} = 0.21 mH L_{lr} = 0.6 mH

L_s = 4.21 mH L_r = 4.6 mH

J =0 .0226 Nm/(rad s)

B = 0.2 Nm/(rad s^2)

REFERENCES

[1] Singh, Bhim, Shiv Kumar Aggarwal, and Tara Chandra Kandpal. "Performanceof Wind Energy Conversion System Using a Doubly Fed Induction Generator for Maximum Power Point Tracking", *IEEE Industry Applications SocietyAnnual Meeting*, vol. 139, no. 5, pp. 429-442, July 2010.

[2] Bimal K Bose,"Modern Power electronics and ac drives"PHI Learning Private Limited.

[3] Noël A. Janssens "Active Power Control Strategies of DFIG Wind Turbines" *IEEE Power Tech 2007*, Lausanne (Switzerland), 1-5 July 2007.

[4] Ned Mohan, Ted K. A. Brekken "Control of a Doubly Fed Induction Wind Generator Under Unbalanced Grid Voltage Conditions" *IEEE Transaction Energy conversion*, vol.no22. 1, March 2007 page 129-135

[5] Heng Nian, Member, IEEE, and Yipeng Song," Direct Power Control of Doubly Fed Induction Generator Under Distorted Grid Voltage" *IEEE Transactions on Power Electronics*, vol. 29, no. 2, February 2014