

Wind Turbine Driven Doubly-Fed Induction Generator with Grid Disconnection

B.Chitti Babu^{#1}, K.B.Mohanty^{#2} and C.Poongothai^{*3}

[#] Department of Electrical Engineering, National Institute of Technology Rourkela
Rourkela-769008 (India)

¹ bcbabunitrkl@ieee.org

² kbmohanty@nitrkl.ac.in

^{*} Department of Electrical Engineering, Indian Institute of Technology Madras
Chennai-600036 (India)

³ ee08d002@smail.iitm.ac.in

Abstract—This paper describes the transient behaviour of a doubly-fed induction generator (DFIG) driven by wind turbine after its disconnection from the grid. The induction machine runs at a specific speed with the stator disconnected from the grid ($I_s=0$), the rotor is suddenly excited with slip-frequency voltages derived from voltage regulators so as to produce commended open-circuit stator terminal voltage. Behaviour under varying rotor speed typically observed in wind turbines is also reported. A MATLAB computer simulation study was undertaken and results on 1.5 kW wind turbine are presented.

Index Terms—Doubly-Fed Induction Generator (DFIG), Variable-speed wind turbine, Dynamic Modeling, Grid Disconnection, Transient Analysis

I. NOMENCLATURE

V_{qs} , V_{ds} are the three-Phase supply voltages in d-q reference frame, respectively
 i_{qs} , i_{ds} are the three-Phase stator currents in d-q reference frame, respectively
 λ_{qs} , λ_{ds} are the three-Phase stator flux linkages in d-q reference frame, respectively
 V_{qr} , V_{dr} are the three-Phase rotor voltages in d-q reference frame, respectively
 i_{qr} , i_{dr} are the three-Phase rotor currents in d-q reference frame, respectively
 λ_{qr} , λ_{dr} are the three-Phase rotor flux linkages in d-q reference frame, respectively
 r_s , r_r are the stator and rotor resistances of machine per phase, respectively
 L_{ls} , L_{lr} are the leakage inductances of stator and rotor windings, respectively
 ω_e , ω_r are the supply and rotor angular frequency (electrical speed), respectively
 T_e is the electromagnetic torque
 P_s , Q_s are the stator-side active and reactive powers, respectively
 P is the Number of poles

II. INTRODUCTION

For stand alone or autonomous operation, mostly single induction generator or parallel operated induction generators are focused according to available analysed references. These induction generator driven by the individual prime movers employed excitation capacitor bank to build up desired voltage via self-excited phenomena. Hence the value of the excitation capacitor bank and the rotor speed determine the magnitude of the generated voltage and its frequency. Both voltage and frequency need to be controlled to feed the power to the load. But for grid connected operation, there are two types of generators are used. (i.e., single output and double outputs). In order to feed the active power to the grid, the machine should run at a speed greater than the synchronous speed of the revolving magnetic field. (i.e. slip should be negative). The single output generator feeds active power to the grid via only stator side and double output generator feeds electrical power to the grid via both stator as well as rotor side. The latter is also called static Kramer, double-fed or double outputs induction generators. This is only the generator which generates the power more than rated power without overheating. Besides, this kind of power generation usually causes problems in the utility grid system. Because the control on active and reactive power of the machine is complex one. Wind turbines often do not take part in voltage and frequency control and if a disturbance occurs, the wind turbines are disconnected and reconnected when normal operation has been resumed. As the wind power penetration continually increases, power utilities concerns are shifting focus from the power quality issue to the stability problem caused by the wind power connection. In such cases, it becomes important to consider the wind power impact properly in the power system planning and operation. This paper will focus on the grid-connected induction generator feeding power with DOIG during steady state and transient conditions.

This paper describes the transient behaviour of a doubly-fed induction generator (DFIG) driven by wind turbine after its disconnection from the grid. The induction machine runs at a specific speed with the stator disconnected from the grid ($I_s=0$), the rotor is suddenly excited with slip-frequency voltages derived from voltage regulators so as to produce

commended open-circuit stator terminal voltage. Behaviour under varying rotor speed typically observed in wind turbine is also reported. A MATLAB computer simulation study was undertaken and results on 1.5 kW wind turbine are presented.

III. DFIG DYNAMIC MODELLING

A commonly used model for induction generator converting power from the wind to serve the electric grid is shown in Fig.1. The stator of the wound rotor induction machine is connected to the low voltage balanced three-phase grid and the rotor side is fed via the back-to-back IGBT voltage-source inverters with a common DC bus. The network side converter controls the power flow between the DC bus and the AC side and allows the system to be operated in sub-synchronous and super synchronous speed. The proper rotor excitation is provided by the machine side power converter.

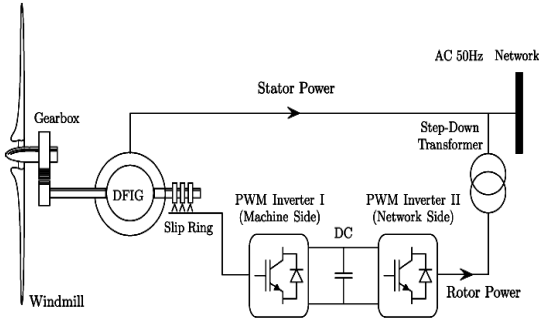


Fig. 1. Model of DFIG Wind Turbine

The general model for wound rotor induction machine is similar to any fixed-speed induction generator as follows.

A. Stator Voltage Equations

$$\begin{aligned} V_{qs} &= p\lambda_{qs} + \omega\lambda_{ds} + r_s i_{qs} \\ V_{ds} &= p\lambda_{ds} - \omega\lambda_{qs} + r_s i_{ds} \end{aligned} \quad (1)$$

B. Rotor Voltage Equations

$$\begin{aligned} V_{qr} &= p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} + r_r i_{qr} \\ V_{dr} &= p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} + r_r i_{dr} \end{aligned} \quad (2)$$

C. Power Equations

$$\begin{aligned} P_s &= \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs}) \\ Q_s &= \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) \end{aligned} \quad (3)$$

D. Torque Equation

$$T_e = -\frac{3}{2} \frac{P}{\omega} (\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad (4)$$

E. Stator Flux Linkage Equations

$$\begin{aligned} \lambda_{qs} &= (L_{ls} + L_m) i_{qs} + L_m i_{qr} \\ \lambda_{ds} &= (L_{ls} + L_m) i_{ds} + L_m i_{dr} \end{aligned} \quad (5)$$

F. Rotor Flux Linkage Equations

$$\begin{aligned} \lambda_{qr} &= (L_{lr} + L_m) i_{qr} + L_m i_{qs} \\ \lambda_{dr} &= (L_{lr} + L_m) i_{dr} + L_m i_{ds} \end{aligned} \quad (6)$$

IV. TRANSIENT ANALYSIS DURING GRID DISCONNECTION

Fig (2) shows the three phase stator voltages under normal operating conditions. When the induction machine is running at a particular speed while the stator disconnected from the grid. So the rotor is suddenly got excited due to slip frequency rotor voltages from the voltage regulators in order to produce the commended stator terminal voltage. Since the variation of speed of the rotor, torque could also be varied on the machine. Fig (3) shows the transient response of the stator voltage of induction generator under torque disturbance. It is found that the voltage of the stator becomes slightly small value after disturbance. Fig (4) shows the transient response of the rotor voltage of induction generator under torque disturbance. Fig. (5) shows the transient response of the active power of the induction generator during disconnection. When induction generator is disconnected from the grid, the active powers supplied from induction generator decreases and quickly recover to original value after re-closed to the grid. The changes in a reactive power are also shown in Fig. (6). It is observed that the reactive power absorbed by the induction is also decreases rapidly, but the part of reactive power would be supplied by rotor side converter for compensation during re-closed to the grid. Negative values of active and reactive power indicate the machine working in generating mode.

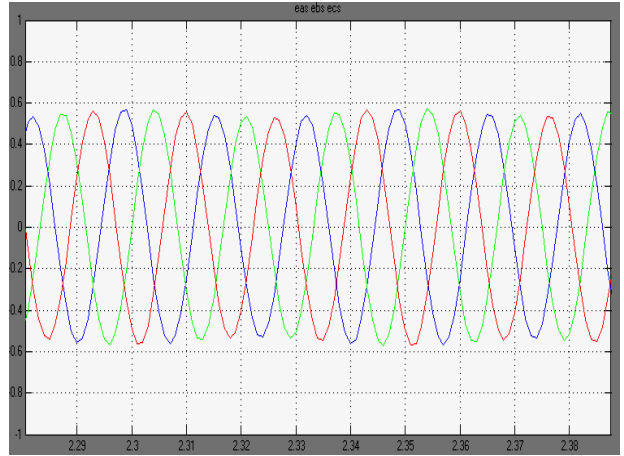


Fig. 2. Response of Three phase Stator voltages of DFIG

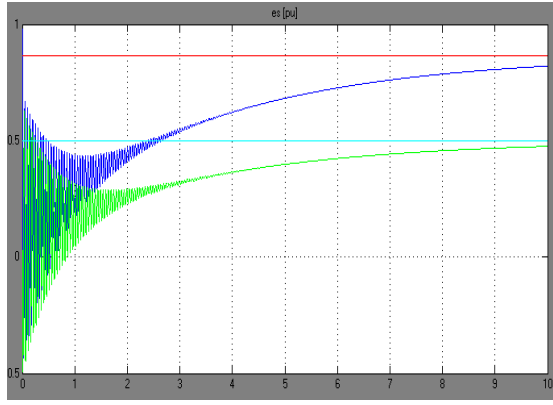


Fig. 3. Transient Response of Stator voltage During Grid Disconnection

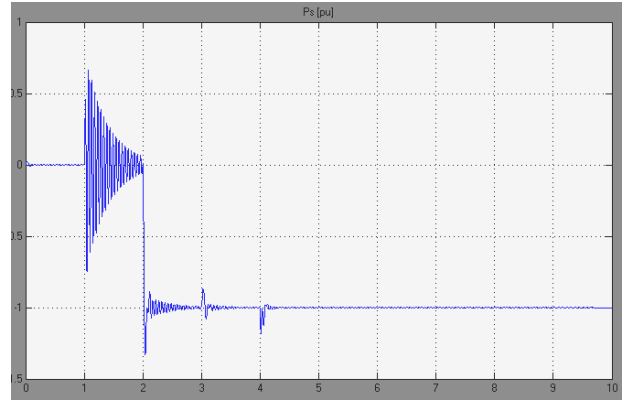


Fig. 6. Transient Response of Reactive power During Grid Disconnection

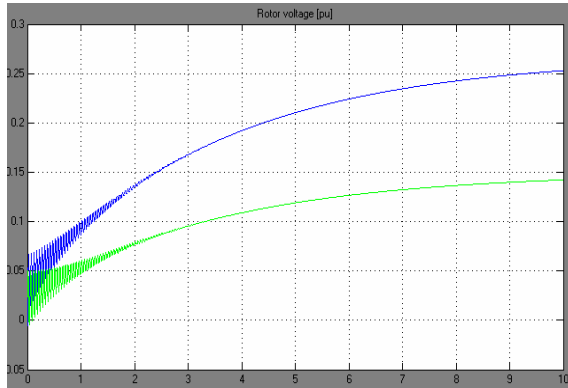


Fig. 4. Transient Response of Rotor voltage During Grid Disconnection

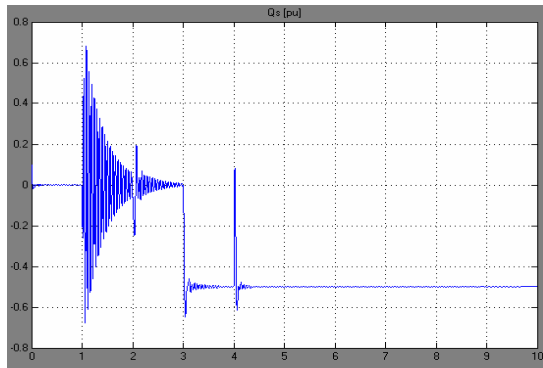


Fig. 5. Transient Response of Active power During Grid Disconnection

IV. CONCLUSION

In this paper, dynamic characteristics of double-fed induction generator has been studied during abnormal conditions of the grid. For this, dynamic d-q model was used to derive the dynamic equations of such machine in a synchronous reference frame. The choice of synchronous rotating reference frame makes it particularly favourable for the simulation of double-output configuration in transient conditions. When the stator is disconnected from the grid, the rotor is suddenly got excited due to slip frequency rotor voltages from the voltage regulators in order to produce the commended stator terminal voltage. So active and reactive power of the machine have been decreasing rapidly. For reactive power compensation during these conditions, rotor side converter has to supply necessary reactive power.

REFERENCES

- [1] A.Tapia, G.Ostolaza and J.X. Saenz, "Modeling and control of a wind turbine driven doubly fed induction generator," *IEEE Energy Conversion*, vol. 18, pp. 194–204, June. 2003.
- [2] Yazhou Lei, Alan Mullane, Gordon Lightbody, and Robert Yacamini, "Modeling of the Wind Turbine With a Doubly Fed Induction Generator for Grid Integration Studies," *IEEE Energy Conversion*, vol. 21, pp. 257–264, Mar. 2006.
- [3] C. S. Demoulias and P. S. Dokopoulos, "Transient behaviour and self excitation of wind-driven induction generator after its disconnection from the power grid," *IEEE Energy Conversion*, vol. 5, pp. 272–278, 1990.
- [4] P. S. Nagendra Rao and S. S. Murthy, "Performance analysis of grid connected induction generators driven by hydra/wind turbines including grid abnormalities," in *Proc. 24th Intersociety on Energy Conversion Engineering Conference*, 1989, pp. 2045-2050.
- [5] L. Wang, Ya-Feng Yang and Sung-Chun Kuo, "Analysis of Grid-connected Induction Generators Under Three-phase Balanced Conditions," in *Proceedings of IEEE 2002*, pp. 413-417.
- [6] J.G.Slootweg, H. Polinder, and W.L.Kling. "Dynamic modeling of wind turbine with doubly fed induction generator," in *Proc. IEEE Power Eng. Soc. Summer meeting*, Vancouver, BC, Canada, Jul. 15-19, 2001.
- [7] B.H.Chowdhary, Srinivas Chellapilla, "Doubly-fed induction generator for variable speed wind power generation" *Transactions on Electric Power System Research*, Vol. 76, Jan 2006. pp. 786-800. S.N.Bhadra, S.Banerjee, "Wind Electrical Systems", Oxford University Press.