JAUES

JOURNAL OF AL AZHAR UNIVERSITY ENGINEERING SECTOR

Vol. 13, No. 48, July 2018, 1110-1116

PERFORMANCE OF DOUBLY-FED INDUCTION GENERATOR BASED ON WIND TURBINE

Salama Abu-Zaid

Electrical Engineering Department, El-Azhar University, Cairo, Egypt.

ABSTRACT

The doubly-fed induction generator driven by a Wind Turbine has received attention from the industrial and scientific communities, due to fixed frequency voltage from the stator windings when the rotor is driven at variable speed and excitation of power electronics converter feeding through rotor windings can be less than other types at nominal power of the generator. This paper give the design and study of doubly-fed induction generator (DFIG) for wind energy systems, this model is proposed for the seamless operation. The control on Grid side converter (GSC) and Rotor side converter (RSC) through detailed simulation will be studied on a 1.5-MW wind generator.

1. INTRODUCTION

The doubly fed induction generator (DFIG) using wind turbines are widely used in large wind farms.

The majority of a large capacity machines are available for General Electric-Wind. The power electronic converters enable control over the generator operating characteristics such as speed and reactive power. [1]

A speed controller is used to vary the pitch of the wind turbine blades during high wind speeds to reduce the power intake and protect the wind turbine.

By optimizing a term called tip speed ratio we can optimize the ratio of wind speed to rotor speed: $\lambda = \frac{V_{tip}}{V_{wind}}$ (1)

where V_{tip} is the velocity of the blade tip and V_{wind} is the wind velocity. The tip velocity can be calculated from: $V_{tip} = \Omega . r$ (2)

Where Ω is the mechanical speed of the wind turbine and r is radius of the circle of rotation.

2. MATHEMATICAL MODEL OF THE DFIG

The voltage and flux equations of the induction machine stator in d-q reference frame can be written as follows:

$$Vsd = Rs * Isd + \frac{d\varphi sd}{dt} - \omega * \varphi sq \quad (3)$$

$$Vsq = Rs * Isq + \frac{d\varphi sq}{dt} + \omega * \varphi sd \quad (4)$$

$$Vrd = Rr * Ird + \frac{d\varphi rd}{dt} - (\omega - \omega r)\varphi rq \quad (5)$$

$$Vrq = Rr * Irq + \frac{d\varphi rq}{dt} + (\omega - \omega r)\varphi rd \quad (6)$$

$$\varphi sd = Ls * Isd + Lm * Ird \quad (7)$$

$$\varphi sq = Ls * Isq + Lm * Irq \quad (8)$$

$$\varphi rd = Lr * Ird + Lm * Isd \quad (9)$$

$$\varphi rq = Lr * Irq + Lm * Isq \quad (10)$$

The q axis is aligned with the stator voltage. This implies that vsd = 0 and vsq = vs . This approach is useful for doubly fed machines where the control is performed by a means of the rotor voltage. The stator voltage is the grid voltage, which is approximately constant in a stable grid. The rotor voltage is referred to the same frame. It consists in general of two non-zero d–q components. This d–q frame orientation decouples the active power from reactive power and they can be con- trolled independently. The stator active power Ps and reactive power Qs are expressed as follows:

$$P_s = V_{0sq} I_{sq} \quad (11) \qquad Qs = V_{sq} I_{dq} \quad (12)$$

3. WIND TURBINE MODEL

3.1 The Aerodynamic Model

The mechanical and wind power output that a turbine can produce is given by:

$$Pm = Cp\,(\lambda, \beta) \cdot Pw \quad (13) \qquad Pw = \frac{1}{2}\rho\pi R^2 Vw^3 \quad (14)$$

Where:

Pm : Mechanical output power of the turbine (W).

Cp : Performance coefficient of the turbine.

ρ : Air density (kg/m3)

A : Turbine swept area (m2).

Vwind : Wind speed (m/s).

λ : Tip speed ratio of the rotor blade tip speed to wind speed.

β : Blade pitch angle (deg).

$$Cp\,(\lambda, \beta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\,\beta - 5\right)e^{-12.5/\lambda_i} \quad (15) \qquad \frac{1}{\lambda_i} = \frac{1}{\lambda_i + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (16)$$

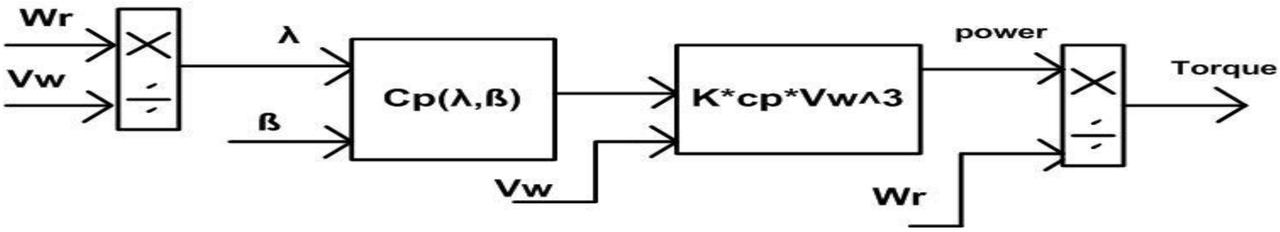

Fig .1. Turbine model.

3.2 Pitch angle controller.

The conventional pitch angle controller is used. The minimum pitch angle min is 0◦ and the maximum pitch angle is 27◦ . Accordingly, for a more realistic simulation, a rate limiter is implemented in the pitch controller model. the maximum pitch angle rate is set at 2 degrees/second. The purpose of using the pitch controller is to maintain the output power of wind generator at rated level by controlling the blade pitch angle of turbine blade when wind speed is over the rated speed.

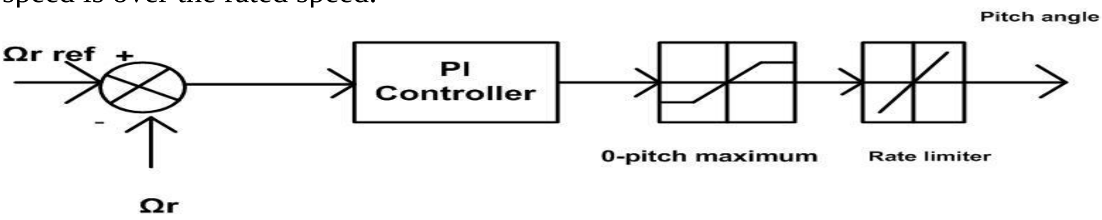

Fig.2. The rotor speed control diagram.

3.3 WIND FARM MODEL SYSTEM

The power system model used of DFIG based wind farm is as shown in Fig. 9. Here, a 9 MW wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 30 km, 25 kV feeder. are connected at the 575 V generation bus . Wind turbines using a doubly-fed induction generator consist of a wound rotor induction generator and an AC/DC/AC converter. The switching frequency is 1620 Hz. The stator winding is connected directly to the 60 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed.

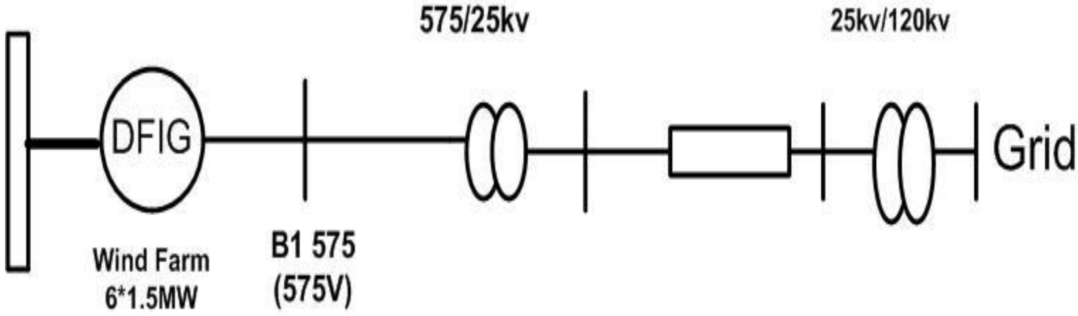

Fig .3. The model system.

3.4 Operation and Control of DFIG

The DFIG-WT allows control active and reactive power using rotor and grid side converters. In super-synchronous operation, both the rotor and stator supply power. Which can be shown as $p_r = -s p_s$. In normal operation, the rotor power is supplied to the dc-link through (RSC), and then injected to grid (GSC). [3]

3.5 ROTOR SIDECONVERTER CONTROLLER

The stator of DFIG is connected directly to the grid. The rotor of DFIG is connected to the grid through AC/DC/AC converter. The simulation program is carried out using one of Matlab toolboxes, Simulink. All the system components are simulated using this program blocks. Control the reactive power produced by DFIG, in normal mode of operation RSC is controlled in a synchronously rotating d-q reference frame with d-axis aligned to stator flux vector. [4]

The rotor-side converter provides a variable rotor voltage, which is controlled in its d- and q component and is used for independent active and reactive power control. [5]

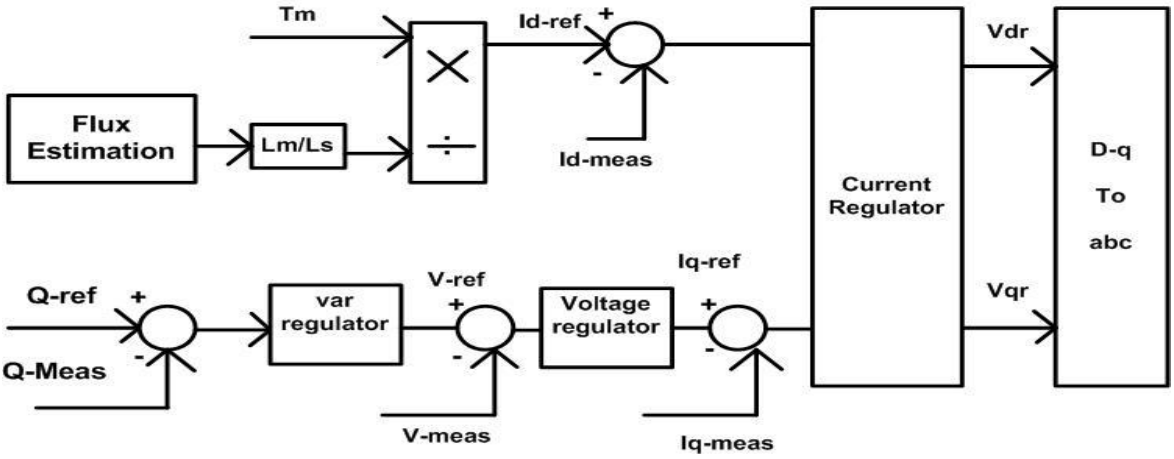

Fig .4. rotor side converter control.

3.6 Grid SIDE CONVERTER CONTROLLER

In the grid side converter controller, the voltage of bus B1 Vabc and the grid converter currents Iabc-grid-conv are transformed into the d–q quantities Vdq and Idq respectively. A dc bus voltage regulator is used to produce Idref . The inputs of the dc bus voltage regulator are the reference

dc bus voltage Vdcref and the actual value of dc bus voltage Vdc . Vdc is compared with Vdcref to yield the voltage error which feeds a PI controller to get Idref . A current regulator is used to produce the reference voltages

V^*_{dq} . These d–q voltages can be transformed into abc quantities to produce the control signals of the grid converter. These control signals feed three phase PWM generator to produce the firing pulses to the grid converter.

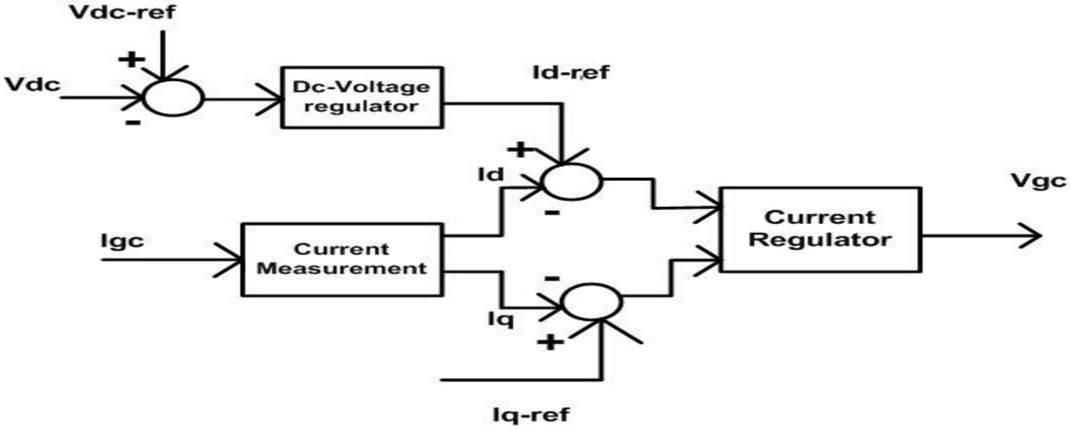

Fig .5. grid side converter control.

4. SIMULATION OF DOUBLY-FED INDUCTION GENERATOR

4.1 Model and Parameters

TABLE I. Parameters for Doubly-fed induction generator data

number of units	active power for each unit (MW)	total active power (MW)	stator voltage (V)	rotor voltage (V)	nominal frequency (HZ)	stator resistance (Pu)
6	1.5	9	575	1975	60	0.023

TABLE II. parameters for wind turbines data

stator inductance (Pu)	rotor resistance (Pu)	rotor inductane (Pu)	mutual inductance (Pu)	Number of pole pairs	Inertia constant	Friction factor (Pu)
0.18	0.016	0.16	2.9	3	0.685	0.01

4.2 SIMULATION RESULTS

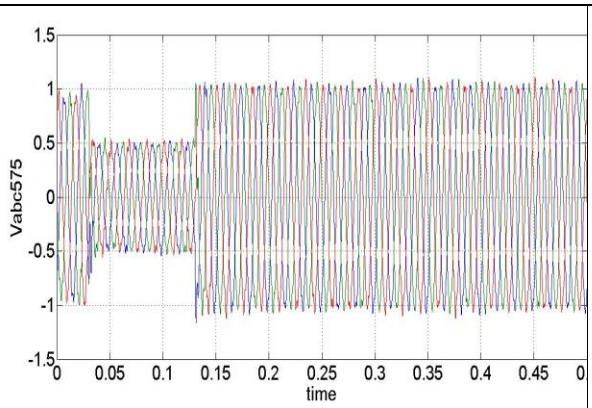

Fig .6. The voltage Vabc- B575 (pu).

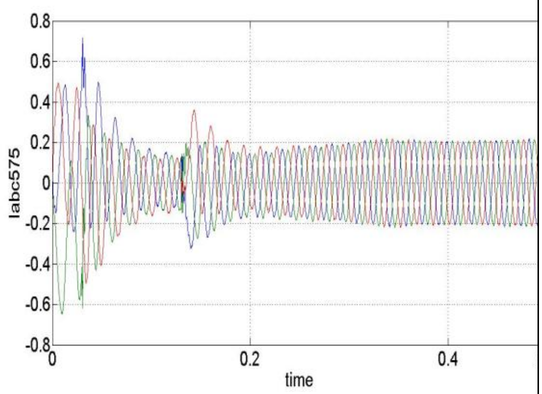

Fig.7. The current Iabc- B575 (pu).

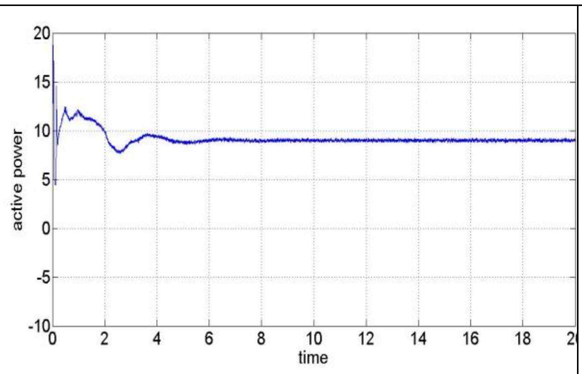

Fig .8. active power of DFIG (MW)

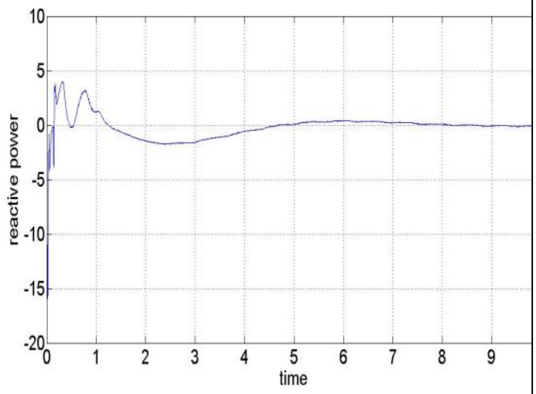

Fig.9. reactive power of DFIG (MW).

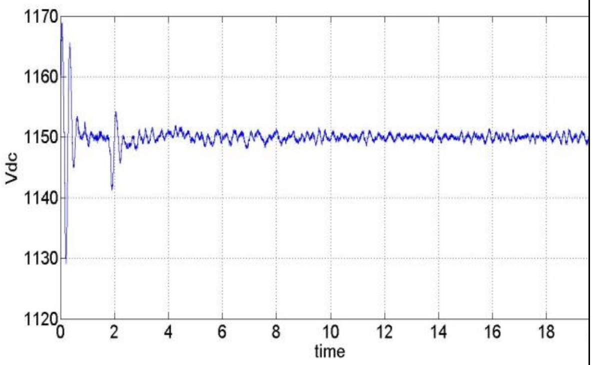

Fig .10. The DC link voltage Vdc.

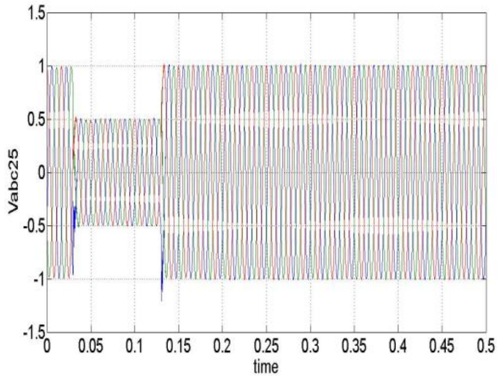

Fig .11. The voltage Vabc- B25 (pu).

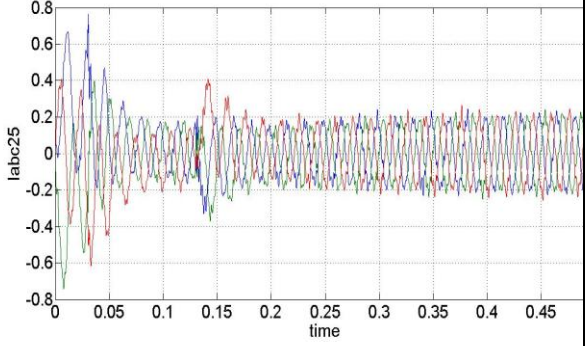

Fig.12. The current Vabc- B25 (pu).

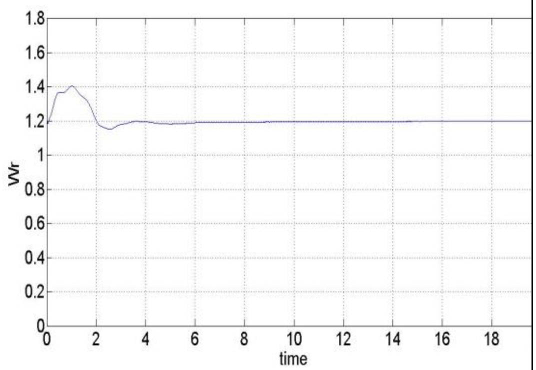

Fig.13. The generator speed ω_r (pu).

The result show the performance of the DFIG as the voltage and current after the DFIG and the voltage and current at bus 25kv. The voltage is stable at (1pu).the result also show the active power of the wind farm(9MW).and reactive power of the DFIG (0MVAR). the result also show the DFIG speed (1.2pu) and the dc voltage (1150v).

4.3 Result using Fuzzy Logic Control:

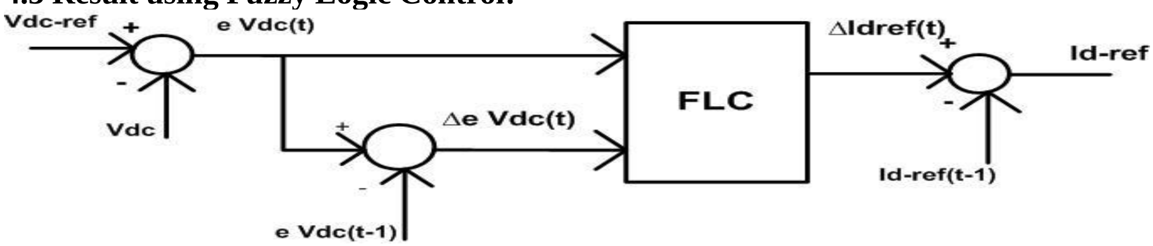

Fig.14. The Fuzzy Logic Control.

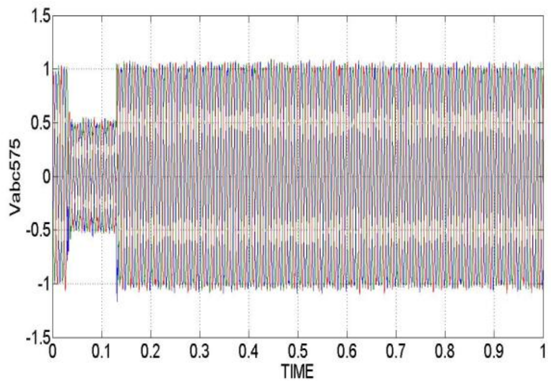

Fig .15. The voltage Vabc- B575 (pu).

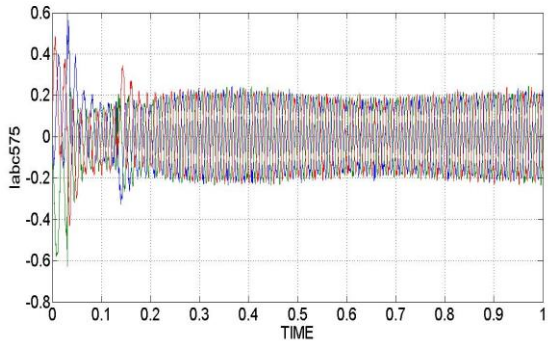

Fig.16. The current Iabc- B575 (pu).

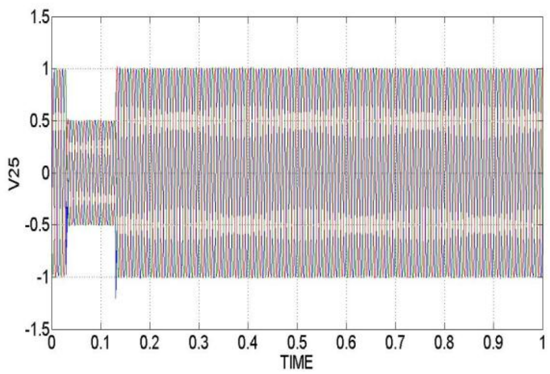

Fig .17. The voltage Vabc- B25 (pu).

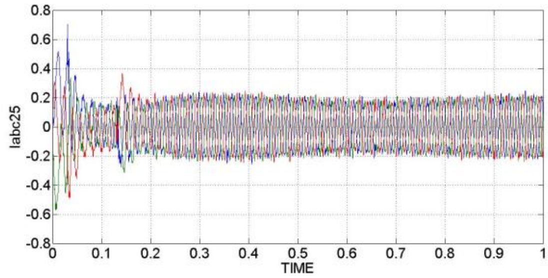

Fig.18. The current Vabc- B25 (pu).

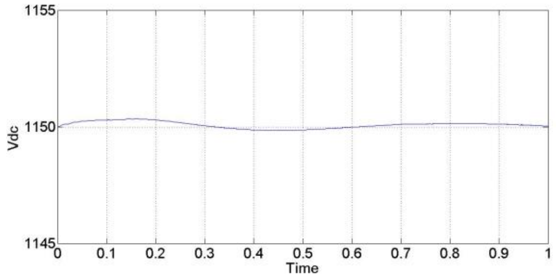

Fig .19. The DC link voltage Vdc.

The fuzzy logic controller is found to enhance the performance of DFIG based wind farm. The dc voltage is enhance the performance comparing by conventional PI controller. The response is fast with minimum overshoots. Moreover, the steady state error after the clearance of fault is rigorously reduced when the fuzzy logic controllers are used.

TABLE IV. Transient of dc voltage

	Maximum value	**Minimum value**	**Ripple**
Conventional controller	1168v	1131v	35v
Fuzzy logic control	1150.4	1149.9	0.5v

TABLE V .Steady state of dc voltage

	Maximum value	**Minimum value**	**ripple**
Conventional controller	1154v	1142v	12v
Fuzzy logic control	1150.5v	1149.5v	1v

CONCLUSION

This paper has presented the modeling and simulation of wind turbine driven DFIG which feeds power to the utility grid. Wind turbine modeling, back-to-back converter system and basic vector-control has been described in order to extract maximum possible mechanical power from the wind according to the wind velocity.

The results show that DFIG fed by wind turbines are necessary when output power becomes higher than 1 MW to reduce cost.

A dynamic model of the DFIG was derived to develop a vector controller to decouple dynamically active and reactive power control. Simulations show excellent response of the DFIG independent of speed, and the performance of DFIG has been improved using FLC technique.

REFERENCES

[1] Chad Abbey "A DOUBLY-FED INDUCTION GENERATOR AND ENERGY STORAGE SYSTEM FOR WIND POWER APPLICATIONS " Master in Engineering Department of Electrical and Computer Engineering, McGill University, Montréal, Québec, Canada August 2004.

[2]staff of Lab-Volt Ltd. “Principles of Doubly-Fed Induction Generators (DFIG) “Canada May 2011.

[3] Surour Alaraifi, , Ahmed Moawwad, Student, Mohamed Shawky El Moursi, and Vinod Khadkikar “Voltage Booster Schemes for Fault Ride-Through Enhancement of Variable Speed Wind Turbines” IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 4, NO. 4, OCTOBER 2013.

[4] Parag Kanjiya, Bharath Babu Ambati, and Vinod Khadkikar “A Novel Fault-Tolerant DFIG-Based Wind Energy Conversion System for Seamless Operation During Grid Faults” IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 29, NO. 3, MAY 2014.

[5] Gabriele Gail, Anca D. Hansen, Thomas Hartkopf "Controller design and analysis of a variable speed wind turbine with doubly-fed induction generator" University of Technology Darmstadt, Department of Renewable Energies, Institute for Electrical Power Systems, Landgraf-Georg-Straße4,64283 Darmstadt, Germany

[6] Hany M. Hasanien , Essam A. Al-Ammar" DYNAMIC RESPONSE IMPROVEMENT OF DOUBLY FED INDUCTION GENERATOR{BASED WIND FARM USING FUZZY LOGIC CONTROLLER" Journal of ELECTRICAL ENGINEERING, VOL. 63, NO. 5, 2012.