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DEVELOPMENT OF FUZZY CONTROLLER FOR DFIG CONNECTED TO WIND TURBINE

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ABSTRACT

In present context electrical energy is playing a crucial role in development of any nation. Enormous consumption of resources like coal, oil etc. has created demand for renewable energy. Due to the current requirements for the expansion of renewable energy as sources of electrical energy, wind energy conversion is getting much interest all over the world. In present scenario the variable speed doubly fed induction generator is the most prolific concept. This paper develops simple doubly Fed Induction generator (DFIG) coupled with wind turbine using fuzzy control.

KEYWORDS: Doubly-Fed Induction Generator (DFIG), Wind Turbine, Wind Energy, Wind Energy Conversion System, Fixed Speed Wind Turbine, Variable Speed Wind Turbine, Fuzzy Control, Membership Function

INTRODUCTION

Today most of the researches in power system are going on the development of conventional energy based power generation. But the issues like international oil crisis, limited availability of conventional sources and environmental pollution effect forced the researcher to think about an alternative source of energy that can be the solution for the above issues. The various forms of renewable energy sources like wind energy, solar energy; tidal energy etc. can be a possible solution to this. All these sources of renewable energy are plentifully available in nature, are recyclable and almost available free of cost.

Wind power, as an alternative to fossil fuel is available plentifully, renewable, widely distributed, clean, produces zero greenhouse gas during operation and uses little land for its installation. Wind energy is not new to the human beings. Wind based power station can work in both in isolated mode as well as grid connected mode. These large wind turbines are all based on variable-speed operation with pitch control using a direct driven synchronous generator (without gearbox) or a doubly-fed induction generator (DFIG). Fixed-speed induction generators with stall control are regarded as unfeasible for these large wind turbines. Doubly-fed induction generators are commonly used by the wind turbine industry for larger wind turbines.

In the 1960s, the concept of fuzzy control was put forward by Professor Charles (L. A. Zadeh) of California University, as an intelligent control method, its advantages lie in without needing precise mathematical model, and using language rules to describe knowledge and experience. Its advantages also lie in that it is a senior control strategy using fuzzy reasoning for verdict combining advanced computer technology. This paper designed fuzzy controller based on stator flux-oriented vector control.

Doubly Fed Induction Generator (DFIG)

If a wound rotor induction machine (WRIM) works as a generator and fed power from both stator and rotor side, it is termed as Doubly Fed Induction Generator (DFIG). DFIG scheme is used as a variable speed fixed frequency topology. In this scheme, stator is directly connected to the grid & the rotor circuit is connected to grid with the help of an AC/DC/AC back to back frequency converter. The rating of this converter is typically 24-29% of the total power rating of the generator. This is a pivotal advantage of DFIG over other variable speed topologies because it provides same features at lesser cost and good efficiency. The figure 1 shows a typical DFIG configuration.[1]-[2]

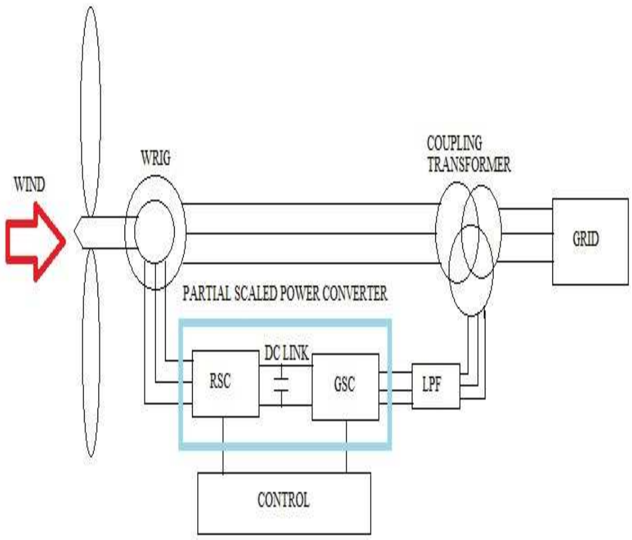

Figure 1: Doubly Fed Induction Generator

Doubly fed induction machine can be operated in generating mode in both sub-synchronous and super-synchronous modes [3]. The SCIG controlled over a range of sub-synchronous and super-synchronous speeds, using the novel secondary EMF signal generator, shows considerable advantage over sub-synchronous systems based on the Kramer technique [4] and does not have the stability problems associated with doubly fed machines [5]. The steady-state analysis of a wound-rotor induction generator, by control of both the magnitude and direction of slip power and operated at varying shaft speeds in the sub-synchronous and super-synchronous regions is studied [6].

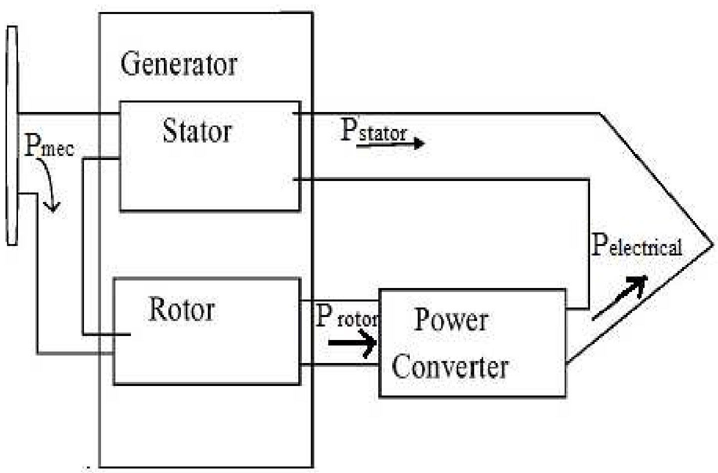

Figure 2: Super Synchronous Operating Mode of DFIG

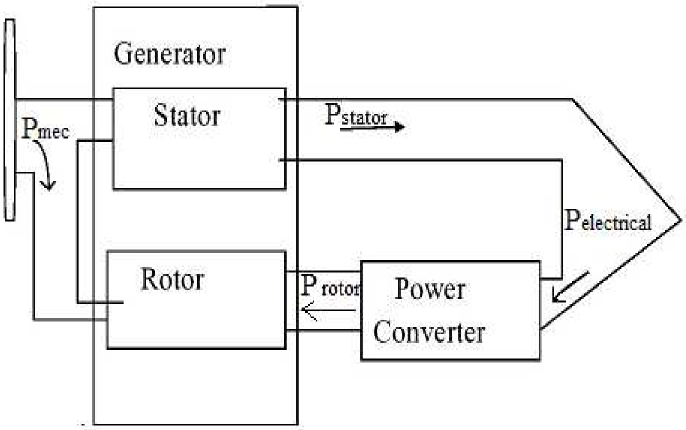

Figure 3: Sub-Synchronous Operating Mode DFIG

As compared to rotor resistance method the reduced capacity Kramer technique provides better performance, but its cost of converter switches and firing circuits is more. Due to the requirement of better operating systems which is assisted by reduced cost of converter switches in 2000s, the variable speed wind turbine based system became very popular. With the Kramer technique based wound rotor configuration or DFIG Wind turbine, decoupled active and reactive power control of the generator could be attained, with more efficient energy production, improved power quality as well as improved dynamic performance [2,7].

The concept of a variable speed wind turbine driving DFIG is receiving increasing attention because of its noticeable advantages over other Wind Turbine Generating systems. DFIG-based WT are used on the basis of their favorable cost/performance attribute resulting primarily from the need for a much smaller converter rating compared to the machine rating.

DFIGs are widely used in modern Wind turbine due to their power control capability; variable speed operation, low converter cost, and reduced power loss and these characteristics are compared to fixed speed induction generators and fully rated converter systems [12]. In the rotor circuit of DFIM the converter design and control technique using an ac/dc/ac converter is studied. For high power applications involving a limited speed range, it was a standard drive option.

The power converters only need to handle the rotor side power (25% of rated). The power circuits and control system required for a rectifier are examined, and closed loop regulation through d.c. link voltage for four quadrant operation in order to control power feedback to the supply with required power factor is attained. The complete design of the DFIG [13] using back-to-back PWM voltage source converters in the rotor circuit is validated experimentally by considering a grid connected system. Also it was found DFIGs and a four-quadrant ac-to-ac converter connected to the rotor windings increases the transient stability margin of the electrical grids, when compared with the case where the fixed speed wind systems with cage generators are used [10].

DQ Modeling of DFIG

The general model for wound rotor induction machine is similar to fixed speed induction generator

A. Stator Voltage Equations

$$V_{qa} = R_a I_{qa} + \frac{d\omega_{qa}}{dt} + \omega_e \phi_{da} \tag{1}$$

$$V_{da} = R_a I_{da} + \frac{d\omega_{da}}{dt} + \omega_e \phi_{qa} \tag{2}$$

Where

V_{qa} and V_{da} = stator voltage of quadrant and direct axis

ϕ_{qa} and ϕ_{da} = stator flux of quadrant and direct axis

R_a =stator resistance

B. Rotor Voltage Equations

$$V_{qb} = R_b I_{qb} + \frac{d\omega_{qb}}{dt} + (\omega_e - \omega_b)\phi_{db} \tag{3}$$

$$V_{db} = R_b I_{db} + \frac{d\omega_{db}}{dt} + (\omega_e - \omega_b)\phi_{qb} \tag{4}$$

Where

V_{qb} and V_{db} = rotor voltage of quadrant and direct axis

ϕ_{qb} and ϕ_{db} = rotor flux of quadrant and direct axis

R_b = rotor resistance

C. Power Equation

$$P_a = \frac{3}{2}(V_{da} I_{da} - V_{qa} I_{qa}) \tag{5}$$

$$Q_a = \frac{3}{2}(V_{qa} I_{da} - V_{qa} I_{qa}) \tag{6}$$

Where

P_a and Q_a stator active and reactive power

I_{da} and I_{qa} = stator current of direct and quadrant axis

D. Torque Equations

$$T_e = -\frac{3}{4}(\phi_{da} I_{qa} - \phi_{qa} I_{da}) \tag{7}$$

Where

T_e = electromagnetic torque

E. Flux Linkage Equations

$$\phi_{qa} = L_{la} I_{qa} + L_m (I_{qa} + I_{qb}) \tag{8}$$

$$\phi_{da} = L_{la} I_{da} + L_m (I_{da} + I_{db}) \tag{9}$$

$$\phi_{qr} = L_{lb} I_{qb} + L_m (I_{qa} + I_{qb}) \tag{10}$$

$$\phi_{db} = L_{la} I_{qb} + L_m (I_{da} + I_{db}) \tag{11}$$

Where

L_m = magnetizing inductance

L_{la} And L_{lb} = stator and rotor leakage inductance

For doubly fed inductance generator in steady state ,then the desired amount of reactive power flows in to the stator can be controlled by controlling I_{ds} as indicated in equation (5) and (6).[9]

Fuzzy Logic Controller for DFIG wind Power System

This section describes the fuzzy controller used for DFIG based System .There are two converter connected back to back hence we need to control both side .These controller are known as rotor side converter (RSC) and grid side converter (GSC) controller. The mathematical model of DFIG is nonlinear and multivariable time-varying system [12]. Fuzzy logic control has ability to control nonlinearity of system. Fuzzy control does not need any mathematical model of plant. Its rule can be qualitatively based on logic language variation. In this paper fuzzy logic control is applied to both rotor side and grid side converter, which ensure precision and robustness of control. Fuzzy controller has two input signals, error E and change in error CE, which is related to the derivative of dE/dt of error. These two signals are converted to the respective scale factor and then controller output is given to the vector control block. The figure 3 shows the basic function of fuzzy logic controller.[10],[11]

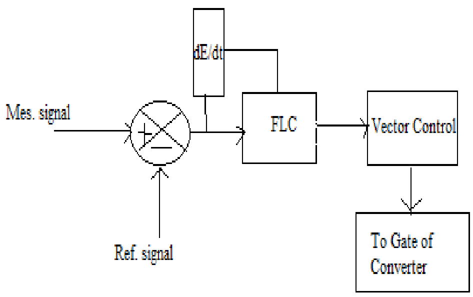

Figure 4: Basic Fuzzy Logic Controller

A. Rotor Side Converter Controller (RSC)

To control the wind turbine active and reactive power the rotor side converter control is used and measured at grid terminals. The control is made in such a way that it basically follows the pre-defined power speed characteristics. The speed of the turbine is measured and corresponding mechanical power of tracking characteristics is used as reference power for power control loop. The main objective of the fuzzy controller is to achieve more accurate control then conventional controller. Figure 4 shows the rotor side control of DFIG [14]

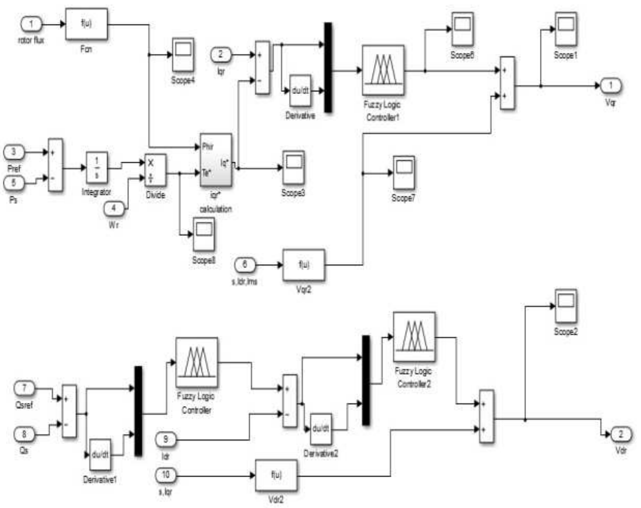

Figure 5: Over All Vector Control of RSC

Table-1 shows the rule table for the rotor side converter control. The top row and left column of the matrix indicate the fuzzy sets of the variable E and CE respectively and membership function output shown in body of the matrix.

The fuzzy sets are defined as follow: NL= Negative Large, NM= Negative Medium, NS= Negative Small, ZR= Zero, PS= Positive Small, PM= Positive Medium, PL= Positive Large.

Table 1: Rule Matrix for Rotor Side Converter Control

E / CE	NL	NM	NS	ZR	PS	PM	PL
NL	PL	PL	PM	PM	PS	PS	ZR
NM	PL	PM	PM	PS	PS	ZR	NS
NS	PM	PM	PS	PS	ZR	NS	NS
ZR	PM	PS	PS	ZR	NS	NS	NM
PS	PS	PS	ZR	NS	NS	NM	NM
PM	PS	ZR	NS	NS	NM	NM	NL
PL	ZR	NS	NS	NM	NM	NL	NL

B. Grid Side Converter Control (GSC)

Grid side converter control is used to regulate the voltage across the DC link and sometime also to compensate harmonics. This is a two stage controller scheme which is achieved by grid voltage oriented vector control scheme. the GSC control scheme is also designed to regulate the reactive power. This should be required to keep the voltage within the desired range, when the DFIG feeds into a weak power system without any local reactive compensation. When DFIG feeds into a strong power system, the reactive power command of Q_g can be set to zero. Figure 5 shows the overall control scheme of the GSC [13],[14].

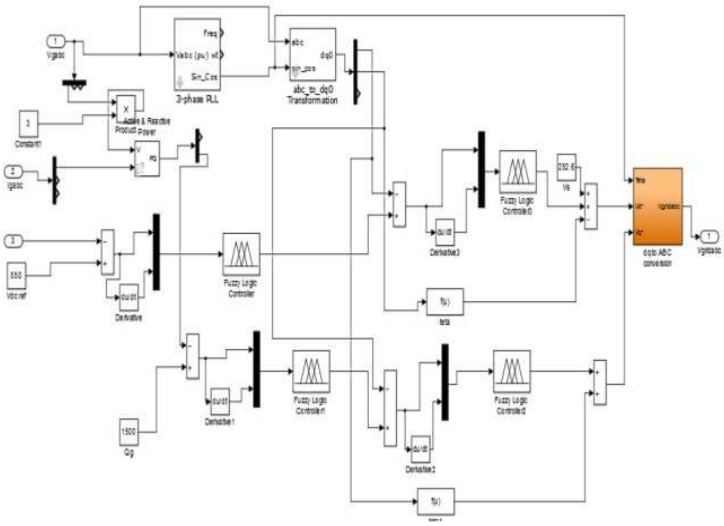

Figure 6: Over All Vector Control of GSC

Table-2 shows the rule table for the rotor side converter control. The top row and left colum of the matrix indicate the fuzzy sets of the variable E and CE respectively and membership function output shown in body of the matrix.

NB= Negative Big, NVS= Negative very Small NM= Negative Medium, NS= Negative Small, ZR= Zero, PS= Positive Small, PM= Positive Medium, PB= Positive Big.

Table 2: Rule Matrix for Grid Side Converter Control

E / **CE**	**NB**	**NM**	**NS**	**ZR**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NS	NVS	ZR
NM	NB	NB	NM	NS	NVS	ZR	PS
NS	NB	NM	NS	NVS	ZR	PS	PM
ZE	NB	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PM	PB	PB
PM	NS	ZR	PS	PM	PM	PB	ZR
PB	ZR	PS	PM	PB	PB	PB	PB

In this paper, the triangular membership function and centroid method of de-f **Figure** uzzification are used, as these methods are most frequently used in many literatures.

Simulation Result and Discussions

The fuzzy controller was implemented in DFIG DC voltage control and power control, in MATLAB. The parameters of wind turbine with DFIG are given in Appendix. The effectiveness of proposed control scheme is checked by simulation study in MATLAB/Sim Power system environment. Figure VI show the wind speed varies between 8m/s to 14m/s.

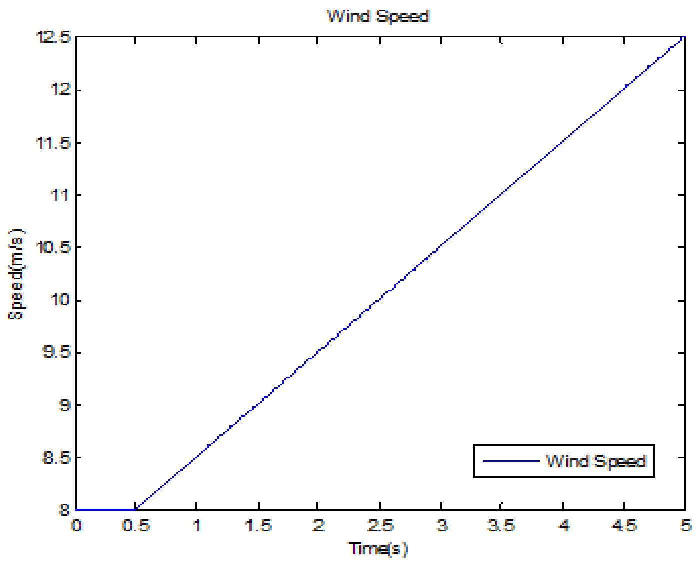

Figure 7: Wind Speed

Figure VII shows the DC link voltage at variable wind speed, initially the it rise linearly but after 0.5sec rate of rise is slow and after few instant it attain the constant value which is the desired link voltage.

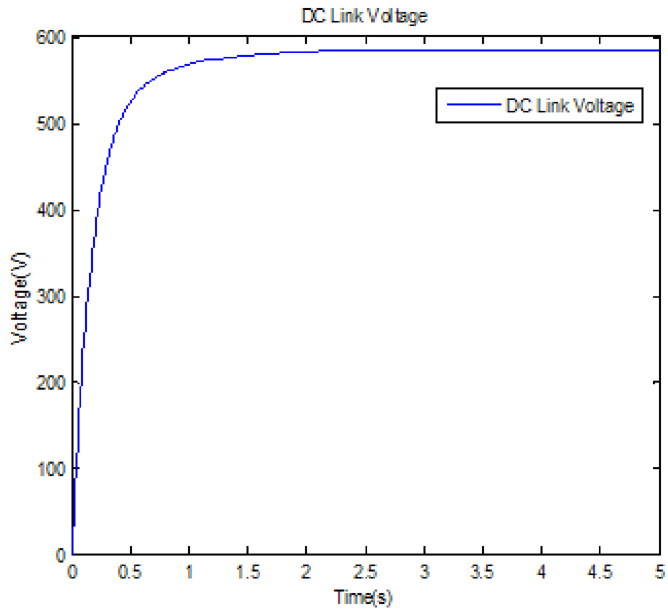

Figure 8: DC Link Voltage

Figure VIII show the inverter side voltage of DFIG in initial few seconds it start increasing and after 0.4seconds the voltage attain its maximum value.

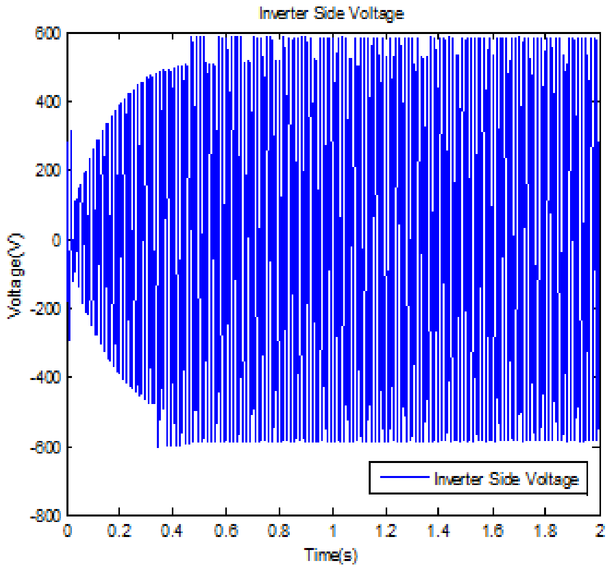

Figure 9: Inverter Side Voltage

Figure IX, and X shows the stator active and reactive power respectively. It is clear from the figure that both the power are smoothed very fast in initially

Few second due to control action of fuzzy controller so it enhances the overall performance of DFIG.

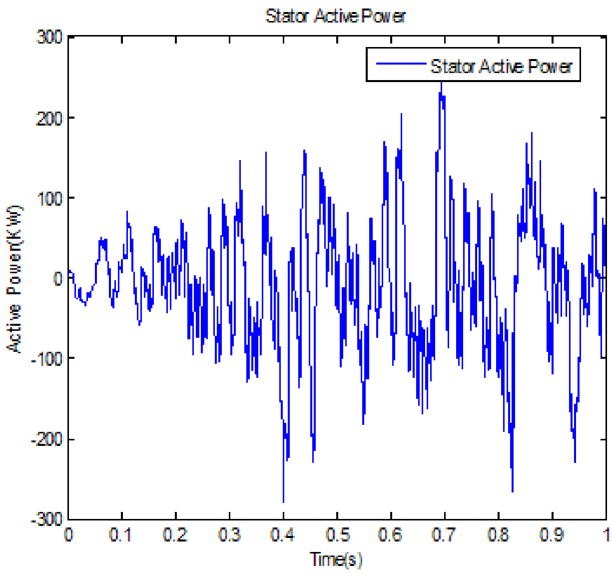

Figure 10: Stator Active Power

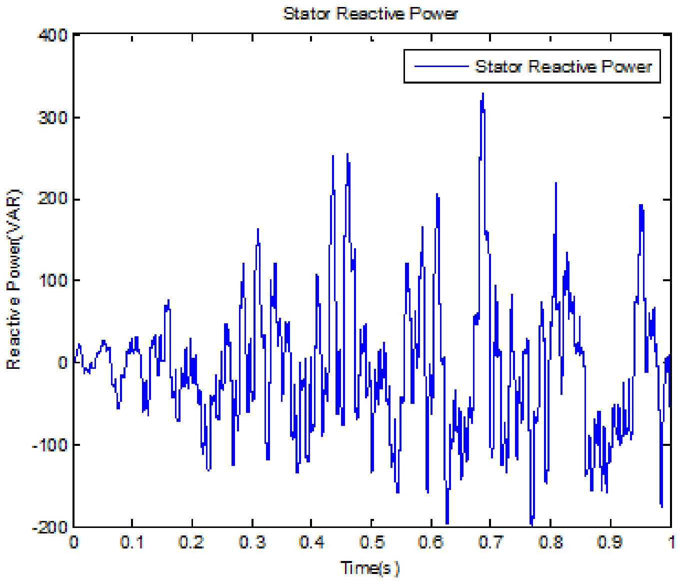

Figure 11: Stator Reactive Power

CONCLUSIONS

In this paper first review the electric equations of the induction machine in the case where the rotor voltage is not equal to zero. After that on basis of these equations a DFIG model is developed, which is compatible with transient analysis. Using fuzzy logic control on these model, independent control of active, reactive power and DC link voltage is possible in simple way. The simulation study made on DFIG and there results show good static and dynamic performance of system. The simulation results are highly consistent with theoretical analysis and verify correctness of the proposed simulation system.

APPENDIX

Wind Turbine Rating

Power = 7.4 KW

Pitch angle = 0 deg.

Wind speed = 8m/s to 14m/s.

Wound Rotor Induction Machine

Power, P = 7.4 KW

Voltage Line - Line = 415 V

Pole, P = 3

Stator Resistance, R_s = 1.06 ohm

Stator Inductance, L_s = 0.206 H

Rotor Resistance, R_r = 0.8 ohm

Rotor Inductance, L_r = 0.0810 H

Mutuak Inductance, L_m = 0.064 H

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