Rotor Side Power Controlling Strategy of Doubly Fed Induction Motor for Wind Energy Conversion System

Vasamsetti Durga Prasad[1], G V Ram Mohan[2]
[1]*M.Tech Student, EEE,Kakinada institute of Engineering and Technology, Korangi, India*
[2]*Assistant Professor, EEE,Kakinada institute of Engineering and Technology, Korangi, India*

Abstract— **Recently, renewable energy resources like wind power have been spread rapidly. Nowadays, wind energy plays an important role in generating green and cheap electrical power. A doubly fed induction motor (DFIM) becomes a necessary part of the wind turbine generation system due to its good efficiency of using the wind power and controlling the reactive power. Due to irregular obtainability of the wind, a power system is intended to extract a maximum power from the wind. The purpose of this project is to introduce a Power control strategy of DFIM for a wind turbine and to study its steady state behaviour by using MATLAB/SIMULINK. This modelling algorithm gives the asynchronous machine a possibility to trace and follow the path of maximum power extraction and support the optimal operation points of the power coefficient curve over different wind circumstances, also simulating the wind turbine (WT) model and studying the steady state condition for the reference value and actual value for the rotor speed, electromagnetic torque, the two components of rotor current, rotor voltage, stator voltage and the value of currents for the rotor and stator sides. To avoid complexity, the whole model is considered as a collection of subsystems which are modelled individually and then assembled to get wind turbine model. PWM control method is implemented for decoupled control of active and reactive power.**

Index Terms— **Doubly fed induction motor (DFIM), Modelling of Wind turbines, Rotor side controlling, MATLAB/SIMULINK programming of Wt model**

1. INTRODUCTION

The bulk power system was called “the largest, most complex machine ever devised by man” by Charles Steinmetz in the early 1900s, and its complexity has increased considerably since then. The basic characteristics of the power system in the 20th century were that they were comprised of 3-phase AC systems at constant voltage, synchronous AC machines (alternators) running at constant frequency for generation, and transmitted power over significant distances. Our understanding of the power system has been based on these underlying characteristics. However, in the 21st century, these characteristics no longer apply universally and our understanding of power system concepts is no longer quite as firmly entrenched. After notable development in the field of renewable system in 21st century, modern power grid is mostly integrated with different renewable and sustainable energy sources in transmission and distribution areas. Again, necessity for a large centralized power system as a “one-size- fits-all” solution for every energy need is being questioned, and distributed generation and micro grids are gaining importance in niche applications. In all developed and developing countries, wind power along with other renewables being interconnected and being planned for interconnection is increasing at a sharp rate. This trend is expected to continue due to increased concerns about environmental issues such as carbon emissions and global climate change, energy security in a less-than-unipolar world, and job creation in a recession environment. Out of all renewable sources, wind power has been the most successful but poses various integration challenge. Another important renewable energy i.e. solar is more practical option for residential energy production but not as popular as wind on utility scale. According to a recent survey, “Out of all the renewable energy produced in the U.S. in 2017, 21% came from wind, while just 7% came from solar power”. Variable speed wind turbines which uses power electronic converters such as doubly-fed induction generator (DFIG) wind turbines and permanent magnet synchronous generator (PMSG) wind turbines, provide flexible control on rotor speed and generated power. Because of that, these turbines are more grid-friendly compared to fixed speed wind turbines. In recent time, DFIG is getting market penetration more rapidly than PMSG system which is equipped with full-rated power converters.

In order to analyse system stability and to develop new operation strategies with an increased share of renewable energy for the grid, there is a need for reliable models to simulate the response of wind turbines following an event in the grid. The should be valid to study both short term events like grid faults and conditions that take up to several minutes like the analysis of a voltage collapse. Manufacturers of wind turbines commonly have very detailed wind turbine models. But there are several drawbacks for the use of such models by system operators. Since these are usually 'black-box' models, the grid operator does not have a full understanding of the model and has to rely on the manufacturer in case questions arise. A change or an update of the simulation environment may even render the model unstable. A model update could then only be performed by the manufacturer, but the result may not be available within the time scale desired by the grid operator.

Wind is formed by the uneven heating of the atmosphere by sun rays. There is formation of pressure gradient because of the formation of hot and cold air regions. This results in the flow of air from high pressure to low pressure region

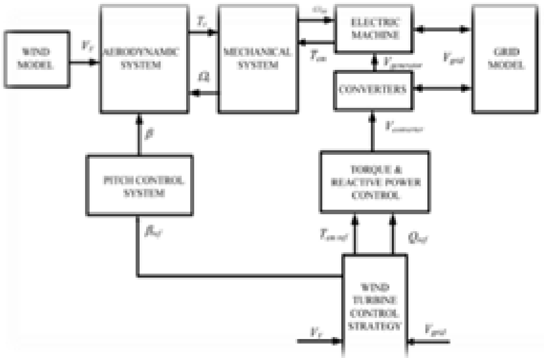

Fig 1 Block diagram of Wind Energy Conversion System

The kinetic energy of air in motion is called as wind. The block diagram of the wind energy conversion system is shown in Fig 1. This kinetic energy hits on the aerodynamically designed blades which results in the rotation of the wind turbine. Sometimes the wind speed is not sufficient to rotate the blades at the speed where power generation is not possible. To increase the speed of the rotor shaft, gearbox is required in some of the topologies of WECS. The mechanical energy of the shaft is converted into electrical energy by the use of generators. The electrical energy generated is supplied to the connected grid. The advantage of DFIG based WT is that only a fractional power size converter (typical size is 30% of the generator power rating) is enough in order to regulate the system in the overall operation range. This is because the converter only need to control the "slip" power of the rotor. In this report we will discuss about type-3 WT in details.

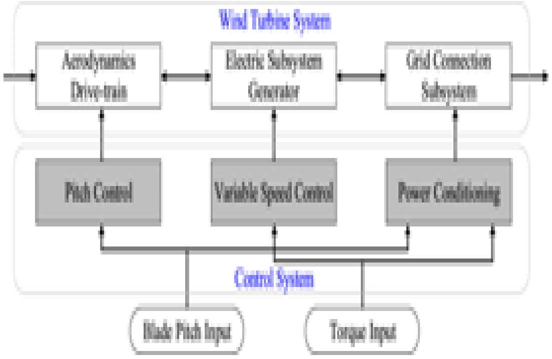

Fig.2 Different Subsystems in wind turbine and interconnection between them

Fig.2 shows the interaction between the different subsystems and how they form the complete wind turbine model. In subsequent subsections all subsystems are explained in details.The aerodynamic model represents the power extraction of the rotor, calculating the mechanical torque as a function of the air flow on the blades.

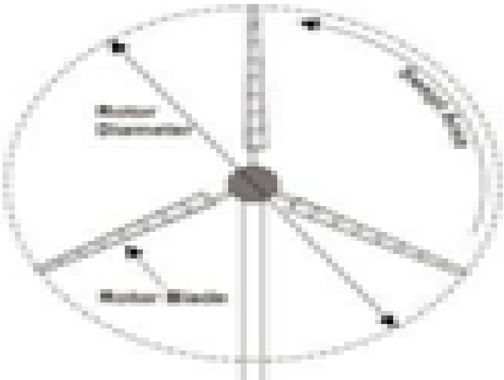

Fig 3 Swept area of Rotor

The power contained in the form of kinetic energy in the wind crossing at a speed s , surface area a is denoted by,

$$p=\frac{1}{2}\rho a s^{3}$$

The wind turbine can recover only a part of that power:

$$p=\frac{1}{2}\rho a s^{3}c_{p}$$

Cp is known as 'Power co-efficient' and it is a function of Tip-Speed Ratio and pitch angle, where tip-speedratio,

$$\lambda=\frac{R\omega}{s}$$

$$c_{p}=k_{1}(\frac{k_{2}}{\lambda}-k_{3}\beta-k_{4}\beta^{k_{5}}-k_{6})(e^{k_{7}/\lambda_{i}})$$

$$T=\frac{p}{\omega}$$

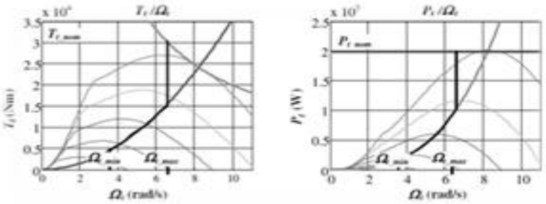

Fig. 4. Curves of power and torque of a 200 kW wind turbine

Considering the designing aspect, the mechanical representation of the entire wind turbine is complex. Wind Turbine drivetrain can be considered as a two-mass system coupled through gear train. The power transmission train is constructed by the blades linked to the hub, coupled to the slow shaft, which is linked to the gearbox, that multiplies the rotational speed of the shaft connected to the generator. The 'Two-mass model' used for this purpose is shown in Fig. 5.

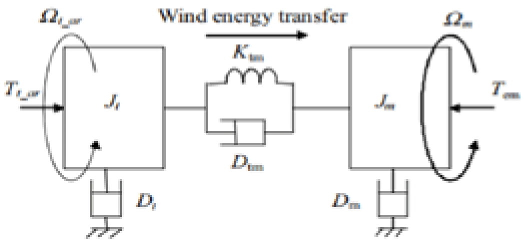

Fig 5 Mechanical Drivetrain Model

Wind turbine control block is responsible for generating the reference signal for the RSC control circuit which enables the system to optimise the capture of wind energy in different regions. These regions are shown in Fig 6.

Region A-B : Rotor speed is limited to wrot min at very low wind speed.

Region B-C: Maximum Power Point tracking (MPPT) is followed to control rotor speed in order to generate maximum power.

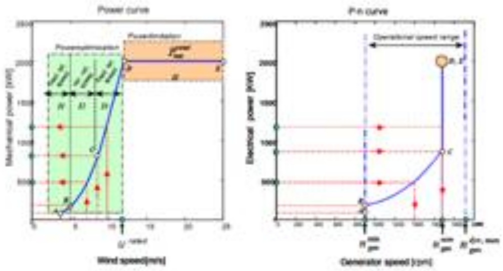

Fig .6 Static curves used in the control of DFIG

Region C-D: Limit the maximum speed to wrot nom at partial load operation.

Region D-E: Limit the maximum operating speed to maintain rated power output at higher

Rotor Side Control

Rotor side DFIG is connected to grid through bi-directional AC-DC-AC converters. Fig. 11 shows simplified model for the rotor side.

The main function of rotor side converter is to achieve decoupled control of active and reactive power. The vector control of the DFIM is executed in a synchronously rotating dq frame, shown in Fig.12, in which the d-axis is aligned with the stator flux space vector.

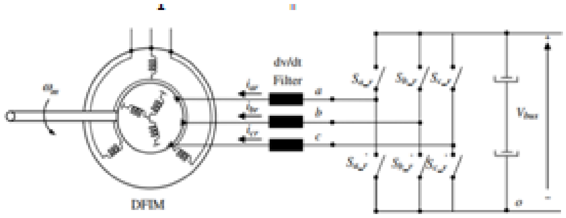

Fig .7 Simplified converter, filter and rotor model

Therefore, because of the orientation chosen, it can be seen that both rotor current components independently allow us to control the torque and reactive stator power. In this way, based on above expressions, Fig.8 illustrates the complete vector control of the DFIG.

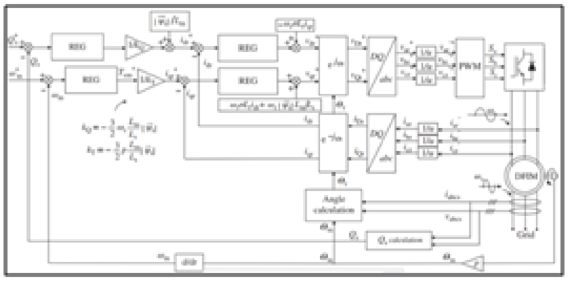

Fig.8 Rotor Side Control in DFIG

Based on the basic model equations for a three-blade wind turbine equations. A simulation of 2.4 megawatt wind turbine model can be implemented using MATLAB/SIMULINK. By taking the gearbox ratio N=100, the radius of the turbine rotor (length of the blades) Radio=42 meters and the air density ro=1.225. below figure shows the torque coefficient Ct versus speed ratio lambda curve.

Rotor Side Control

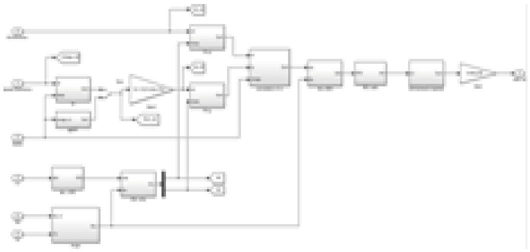

Fig. 9 Rotor side control block

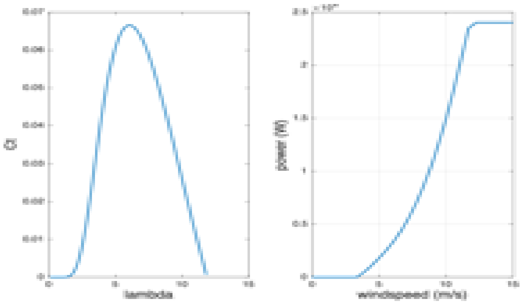

Fig.10 Ct versus tip speed ratio lambda curve

2. SIMULATION OF WIND TURBINE MODEL

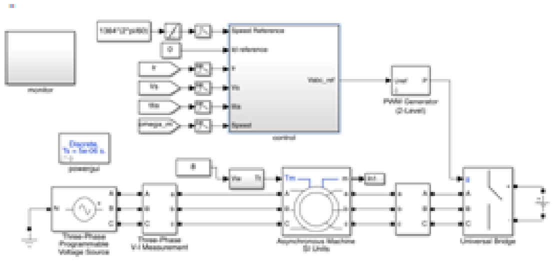

Fig. 11 Complete simulink model for DFIG based wind turbine

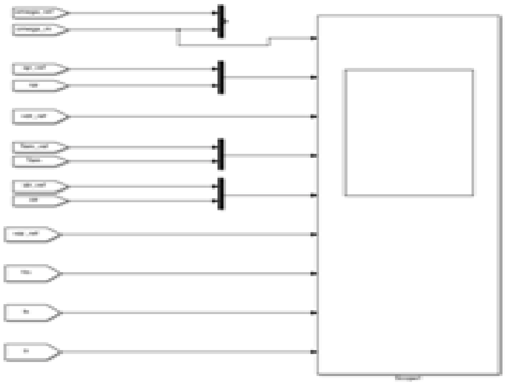

Fig. 12 Monitor to get waveforms

3. RESULT

The algorithm simulation requires the values of wind speed in (m/s), generator speed reference in(rad/s), rated stator voltage in v and rated stator current in *A*as an input which already given by the initialization file. Thus, the wind speed is directly fed into the algorithm of the simulation from external mat file or by feeding the wind speed value by value and observe the simulation result since the algorithm monitors the wind speed and computes the tip speed ratio (TSR). The generator speed input reference allows the algorithm to define whether the generator speed has reached the reference speed level as desired. The output voltage and current together supply the algorithm with the knowledge of the output power.

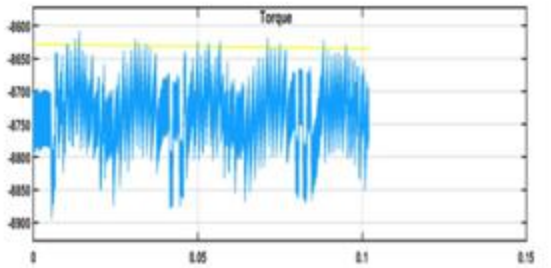

fig. 13 The rated torque at maximum power point for 10 (mm/ss).

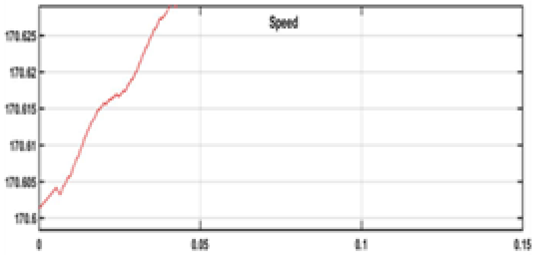

fig. 14 The turbine speed at maximum power point for 10 (mm/ss).

Figure 15 and Figure 16 show the stator voltage at steady state and the rotor current response respectively. The stator currents are illustrated in Figure 17.

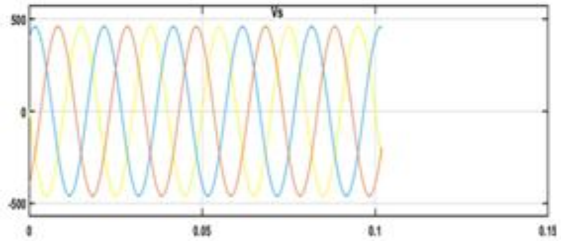

Fig. 15. The stator voltage at steady state respons

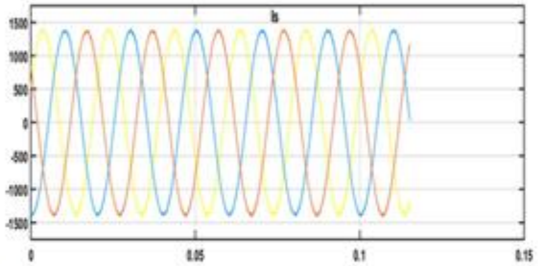

Fig. 16 The Stator current at steady state response

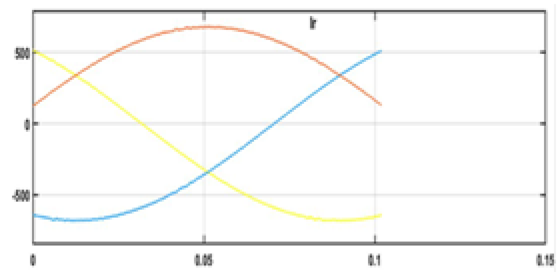

Fig. 17 The rotor current at steady state responce

4. CONCLUSION

A successful Wind Energy Conversion system possesses the ability to transform mechanical energy delivered by the wind into electrical energy that can be used to power any electrical grid. This project has addressed the modelling and control of variable speed type-3 wind turbine (DFIG based). The development of this model is part of an effort to develop generic manufacturer-independent wind turbine models capable of being used for power systems studies. To maintain generality, various approximations and simplifications have been used in the modelling process and despite all the simplifications, the developed time-domain model performs admirably and is able to approximate the behaviour of a real-world WPP in normal condition. Aspects of the theory behind DFIG technology have also been discussed in this chapter, and the necessary mathematical foundation has been presented. The decoupling of real and reactive power control, and the extraction of maximum extractable power from the wind, are the defining aspects of DFIG technology, and a discussion of these concepts is also presented. The modelling procedure has been discussed in detail, with the salient points being the development of sub-models for the generator, converter, mechanical turbine, and pitch control, the theory behind the operation of these sub-models, and the combination of these sub-models into a complete time-domain DFIG WPP model. Details of model parameters have been provided to allow reproduction of the results shown here. The modelling of wind turbine generators for bulk power system stability studies is the focus of intense activity in many parts of the industry. This model is expected to give realistic and correct results when used for bulk system performance studies. It is expected that these model components will continue to evolve, in terms of parameter values and structure, as experience and additional test data are obtained.

5. ACKNOWLEDGEMENT

I would like to articulate my sincere gratitude to Assistant Prof. G V Ram Mohan, kakinada institute of engineering and Technology, korangi for his guidance and constant encouragement during the course of my research work. I truly appreciate and value his esteemed guidance and support, his knowledge and accompany from the beginning to the end of this work. My special thanks to all my friends and staff members of Power electronics Lab, Department of Electrical and Electronic Engineering for their assistance and constant co-operation throughout my project work. Also I would like to thank all those who have directly and indirectly supported and helped me towards the completion of my project.

REFERENCE

[1] Y.K. Wu, W.H. Shu, H.Y. Cheng, G.T. Ye and D.C. Jiang, " Mathematical modelling and simulation of the DFIG-based wind turbine", CACS International Automatic Control Conference (CACS 2014), 2nd ed., vol.3, 2014, pp. 15-64

[2] H. Altun and S.Sünter, "Modeling, simulation and control of wind turbine driven doubly-fed induction generator with matrix converter on the rotor side", Electrical Engineering, vol. 95, no. 2, 2012 ,pp. 157-170

[3] J.B. Ekanayake, L. Holdsworth, XueGuang Wu and N. Jenkins, "Dynamic modeling of doubly fed induction generator wind turbines", IEEE Transactions on Power Systems, vol. 18, no. 2,2003, pp. 803-809

[4] A. Petersson and L. Harnefors, T. Thiringer, "Evaluation of Current Control Methods for Wind Turbines Using Doubly-Fed Induction Machines", IEEE Transactions on Power Electronics, vol. 20, no. 1, 2005, pp. 227-235

[5] B.Chitti Babu and K.B. Mohanty, "Doubly-Fed Induction Generator for Variable Speed Wind Energy Conversion Systems- Modeling & Simulation", International Journal of Computer and Electrical Engineering, 2010,pp. 141-147

[6] Y. Majdoub, A. Abbou, M. Akherraz, M. El Malah and R.El Akhrif, 2016, "Design of an MPPT control under asymmetrical grid faults of DFIG wind turbine", 2016 Interational Conference on Electrical and Information Technologies (ICEIT)

[7] P. O. Ochieng, A. W. Manyonge, and A.O. Oduor"Mathematical Analysis of Tip Speed Ratio of a Wind Turbine and its Effects on Power Coefficient", International Journal of Mathematics and Soft Computing, vol. 4, no. 1,2014, pp. 61

[8] Sabah Louarem, Saad Belkhiat, Djamel Eddine Chouaib Belkhiat, 2013, "A control method using PI/fuzzy controllers based DFIG in wind energy conversion system", 2013 IEEE Grenoble Conference