Interfacing of Grid Connected Wind Energy Conversion System Based on PMSG through NPC Inverter

Anita
M.Tech Scholar, Electrical Engineering Department
RPIIT, Karnal, India

Satish Kumar
Professor, Electrical engineering Department
RPIIT, Karnal, India

ABSTRACT

Wind energy is a prominent area of application of variable-speed generators operating on the constant grid frequency. This paper describes the simulation, operation and control of one of these variable-speed wind generators: the direct driven permanent magnet synchronous generator (PMSG). This generator is connected to the off-grid load. The generator is controlled to obtain maximum power from the incident wind with maximum efficiency under different load conditions. Pitch angle control is designed to extract the power from the wind when speed is more than the base speed. This paper shows the dynamic performance of the complete system. Different tests in a 8.5-kW prototype have been carried out to verify the benefits of the proposed system.

Keywords: *Permanenet magnet synchronous generator; wind turbine; pitch angle controller; Wind energy conversion system; variable load*

I. INTRODUCTION

THE ELECTRICITY industry worldwide is turning increasingly to renewable sources of energy to generate electricity. Environmental concerns about fossil-fueled conventional generators, the desire to increase the diversity and security of fuel supply, and increasing fossil fuel costs are all motivating factors behind this upward trend. Global targets for the reduction of carbon dioxide (CO2) and other greenhouse gases have been introduced [1] and separate targets for minimum quantities of electricity generated from renewable energy sources have also been established in many parts of the world [2]. Wind is the fastest growing and most widely utilized of the emerging renewable energy technologies in electricity systems at present, with a total of approximately 54 GW installed worldwide at the beginning of 2016 [3]. However, the majority of wind resources are still untapped, and the potential for energy from wind generation is vast. Constant advances in technology and the relatively low capital costs when compared with other forms of renewable energy are significant contributing factors to the ongoing rapid growth in the proportion of electricity being generated from wind.

The ease with which wind generation is integrated into existing electricity systems depends on a number of factors, both technical and regulatory [3]. Technical aspects that need to be considered include the amount and location of wind generation, wind turbine technology, and the size and characteristics of the electricity system. Regulatory issues, such as compliance with existing system operator rules and regulations, also arise. Of the technical aspects that need to be considered, system inertia plays an extremely important role as it determines the sensitivity of system frequency to supply demand imbalances. The lower the system inertia, the faster the frequency will change if a variation in load or generation occurs. Large interconnected electricity systems generally have sizeable system inertia and large frequency deviations from nominal are rare. However, frequency deviations on small, isolated electricity systems, when they occur, tend to be more

sizeable. When connecting wind turbines to small isolated power systems, their contribution to system inertia must be considered. The addition of synchronous generation to a power system intrinsically increases the system inertial response. This intrinsic increase does not necessarily occur with the addition of wind turbine generators due to their differing electromechanical characteristics. Therefore, the displacement of conventional synchronous generation with wind generation may result in an erosion of system inertial response resulting in increased rates of change of frequency (ROCOF) and larger frequency excursions. In small isolated systems, these phenomena are particularly challenging due to low system inertia. Where wind turbines are found to severely impact on system inertial response, system operators need to consider altering their frequency control strategies to avoid large rates of change of frequency and/or large frequency excursions. Wind turbine generators (WTGs) can be divided into two basic categories: fixed speed and variable speed. A fixed-speed WTG generally uses a squirrel-cage induction generator to convert the mechanical energy from the wind turbine into electrical energy. During a frequency excursion, the relationship between the system frequency and the electromagnetic torque of any induction machine will determine the inertial response. As there is a strong coupling between the squirrel-cage induction generator stator and the power system, and due to the low nominal slip of 1%−2% [7], any deviations in system speed will result in a change in rotational speed. This linking of rotor speed with system speed gives rise to an inertial response from the fixed-speed WTG when the system frequency falls.

II. Wind Turbine Technology

Wind turbine generators (WTGs) can be divided into two basic categories: fixed speed and variable speed. A fixed-speed WTG generally uses a squirrel-cage induction generator to convert the mechanical energy from the wind turbine into electrical energy. During a frequency excursion, the relationship between the system frequency and the electromagnetic torque of any induction machine will determine the inertial response. As there is a strong coupling between the squirrel-cage induction generator stator and the power system, and due to the low nominal slip of 1%−2% [7], any deviations in system speed will result in a change in rotational speed. This linking of rotor speed with system speed gives rise to an inertial response

from the fixed-speed WTG when the system frequency falls.

Variable-speed WTGs can offer increased efficiency in capturing the energy from wind over a wider range of wind speeds, along with better power quality and the ability to regulate the power factor, by either consuming or producing reactive power. Doubly fed induction generator (DFIG) and multi-pole synchronous generator are popular types of variable speed WTGs. Both forms of generator have power electronic converters between the electrical machine and the power system. The multi-pole synchronous generator allows variable-speed operation by employing a back-to-back ac/dc/ac converter attached to the stator of the synchronous machine. As a result, the stator is isolated from and, consequently, unaffected by any changes in the frequency of the power system. Therefore, the power output from the WTG does not change and no inertial response is obtained during a frequency event.

The power electronic converter in the DFIG, on the other hand, is attached to the rotor. The rotor is connected to the power system through this back-to-back ac/dc/ac converter, while the stator is connected directly to the power system. The net power output from the DFIG is the sum of the power outputs from both the stator and the rotor [8], [9]. During a system frequency excursion, any inertial response provided by the DFIG depends on the relationship between the electromagnetic torque of the machine and system frequency. This relationship, in turn, depends upon the type of controllers used in the converter and the parameters of the controllers [10].

## III. Modeling of PMSG Based WECS

A. Wind Turbine Modelling

The output power P_a, developed by wind turbine with blade radius 'r' can be expressed as under:

$$P_a = \frac{1}{2}\rho\pi r^2 C_p(\lambda, \beta)V_w^3 \qquad (1)$$

where, πr^2 is the rotor swept area, C_p is the power co-efficient, λ is the tip speed ratio, β is the pitch angle while V_w being the wind speed. The tip speed ratio λ can be described as:

$$\lambda = \frac{r\Omega}{V_w} \qquad (2)$$

Where, Ω is the turbine rotor speed. The relevant wind turbine characteristics are depicted in Fig. 1.
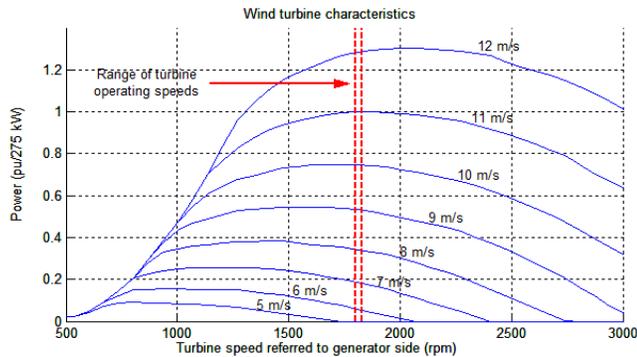
Fig.1: Mechanical power versus turbine speed characteristics.

The wind turbine is designed for 8.5 kW and base speed of 12 m/sec.

There are different parameters on which it depends and they are given as following.

➢ Base power of the electrical generator is given as: 8.5e3/0.9 W
➢ Mechanical output power of the model: 8.5e3 W
➢ Base wind speed of system : 8 m/sec
➢ Maximum power at base wind speed: 0.8 pu
➢ Base rotational speed :1 pu.

B. Two Mass Driven Model

In this paper a two mass driven model for coupling is used and it has the equation:

$$T_{sh} = K_{sh}\theta_{sh} + D_t \frac{d\theta_{tw}}{Dt} \qquad (3)$$

Where T_{sh} is shaft torque, K_{sh} is shaft stiffness, θ_{tw} is shaft twist angle, D_t is damping coefficient, H_t is inertia constant of the turbine, H_g is inertia constant of the PMSG.
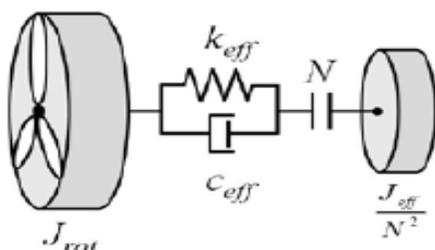
Fig 2: Two mass driven model.

C. PMSG Modelling

Due to many advantages of PMSG over induction generator it is used in designed model of wind energy conversion system. The dynamic model of the PMSG is derived from the two phase synchronous reference frame, which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. The mathematical model of the PMSG in the synchronous reference frame (in the state equation form) is given by:

$$\frac{di_d}{dt} = \frac{1}{L_d}(-R_s i_d + \omega_e L_q i_q + u_d) \qquad (4)$$

$$\frac{di_q}{dt} = \frac{1}{L_q}[-R_s i_q - \omega_e(L_d i_d + \varphi_d) + u_q] \qquad (5)$$

The above equations are used to model the PMSG.

IV. Control, Simulations and Results

The grid connected WECS through NPC inverter is modelled and simulated in MATLAB/Simulink environment. The proposed system is subjected variable and constant wind speed. The effectiveness of NPC inverter is verified at different load. The main aim of this work is to maintain the voltage at point of common coupling constant whatever may be the wind speed and connected load. This is done by Neutral Power Clamped (NPC) inverter. A PI based regulator is used for generating the control pulses for the NPC inverter. This will help in maintain the system voltage constant at different perturbances. In this work the wind speed is supposed to be varied between 7 m/sec to 12 m/sec.

The simulation is done for the variable wind speed and as expected the NPC inverter will come in to action for maintaining the voltage constant.
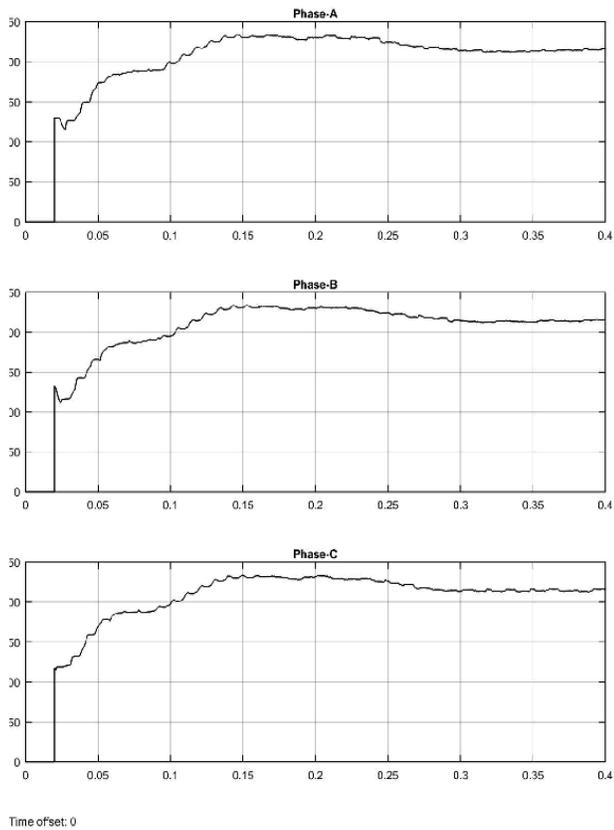
Fig.3: Each Phase Voltage at PCC.
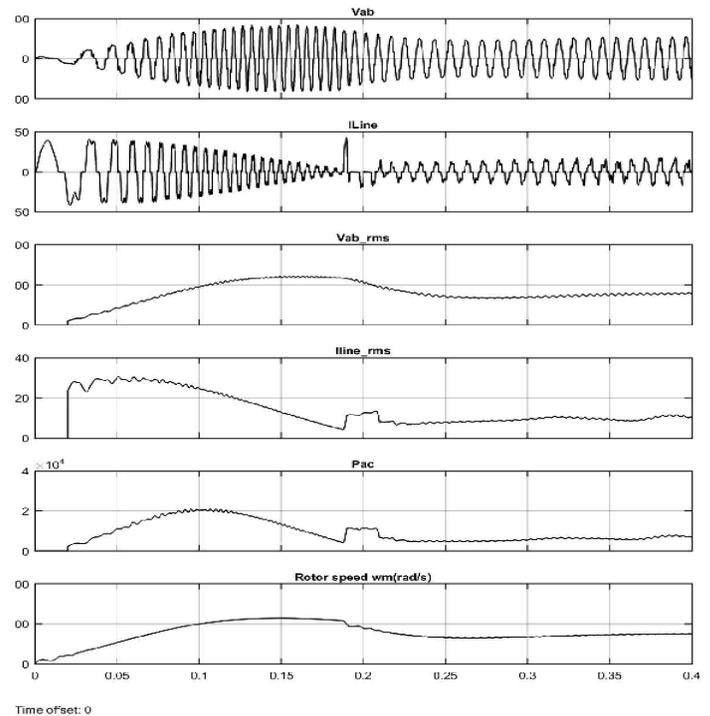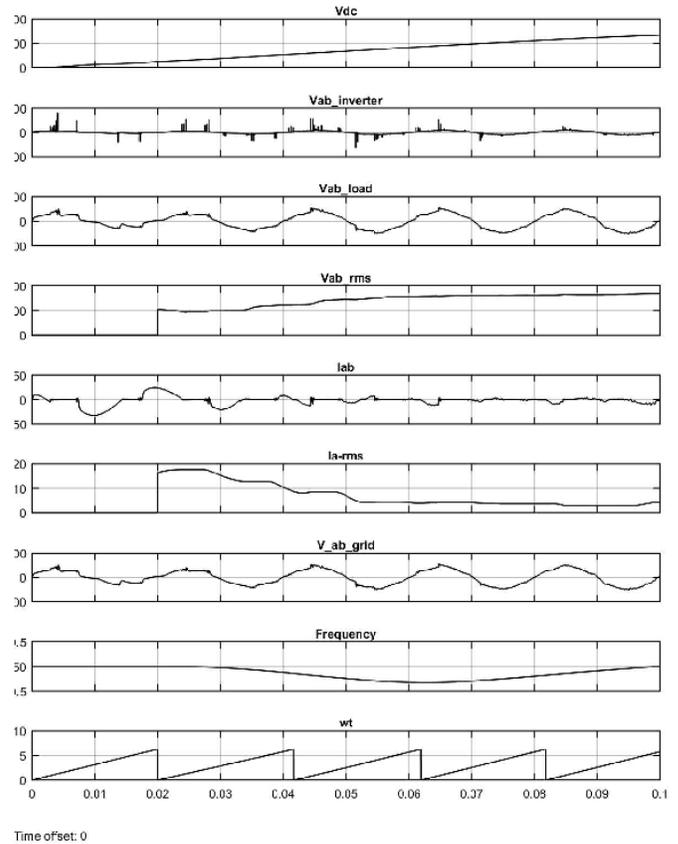
Fig 4: Different parameters of WECS.

When the wind turbine speed reaches to the cut-in speed, the PMSG start producing power at time 0.018 seconds. This can be seen in fig.3. The phase voltage starts building up at that moment.

As the wind speed varies the output power of the wind turbine also changes. The power quality is generally related to the frequency and voltage stability. These two parameters determine the power quality. In this work the voltage and frequency variations are in the prescribed limits. With the variations of the wind speed the phase voltage is held constant with the help of NPC inverter. When there is need for voltage boost the reactive power is injected in to the system and vice-versa.

V_{dc} is the DC link voltage which is to be maintained 1 pu, this is done by the inverter control. In the fig.4, it can be seen that PI based voltage controller, able to control the V_{dc} after the drop in speed and rise in speed.

Conclusions

In this thesis work, the scheme of voltage control (i.e. using pitch angle control and PI based voltage controller) for PMSG based WECS have been investigated. Firstly basic components of wind energy conversion system has been discussed like turbine, generation part used, coupling part used. It is concluded that when there is a change in wind speed voltage dip or rise occur, there is change in voltage level. Further there is effect of variable load on the profile of the output voltage of the wind turbine driven PMSG when there is no control scheme is employed in the system.

An NPC inverter is used, which is able to maintain the system voltage constant when there is change in the wind speed and variation in the load. The NPC gate pulses are produced a PI based controller which helps in maintaining the voltage as per the prescribed limits.

REFERENCES

[1] The United Nations Framework Convention on Climate Change. (1997) The Kyoto Protocol. [Online]. Available: http://unfccc.int/resource/docs/convkp/kpeng.pdf.

[2] "Directive 2016/77/EC of the European Parliament and the Council of 27 September 2016 on the promotion of electricity produced from renewable energy sources in the internal electricity market," Official J. Eur. Communities, L283, pp. 33–40, Oct. 2001.

[3] The European Wind Energy Association (EWEA) and the European Commission's Directorate General for Transport and Energy DG TREN). (2016) Wind Energy—The Facts. [Online]. Available: http://www.ewea.org/06projects_events/proj_WEfacts.htm.

[4] Commission for Energy Regulation (CER). (2016) Wind Farm Transmission Grid Code Provisions. [Online]. Available: http://www.cer.ie/CERDocs/cer04237.pdf.

[5] Commission for Energy Regulation (CER). (2015) Wind Generation Distribution Code Provisions. [Online]. Available: http://www.cer.ie/CERDocs/cer04318.pdf.

[6] ELTRA. (2015) Specifications for Connecting Wind Farms to the Transmission Network. [Online]. Available: http://www.eltra.dk/composite- 837.htm.

[7] [A. P. Mullane, "Advanced control of wind energy conversion systems,"

[8] Ph.D. dissertation, Nat. Univ. Ireland, Univ. College Cork, Cork, Ireland, 2004. J. B. Ekanayake, L. Holdsworth, X. Wu, and N. Jenkins, "Dynamic modeling of doubly fed induction generator wind turbines," IEEE Trans. Power Syst., vol. 18, no. 2, pp. 803–809, May 2003.

[9] P. Pourbeik, R. J. Koessler, D. L. Dickmander, and W. Wong, "Integration of large wind farms into utility grids (Part 2—Performance issues)," in Proc. IEEE Power Eng. Soc. Gen. Meeting, vol. 3, Toronto, ON, Canada, Jul. 2003, pp. 1525–1528.

[10] A. Mullane and M. O'Malley, "The inertial-response of induction-machine based wind-turbines," IEEE Trans. Power Syst., vol. 20, no. 3, pp. 1496–1503, Aug. 2005.