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Simulation of Standalone Wind Energy Conversion System using PMSG

Arpit Varshnry, Smrati Singh, Deepti Gupta

***Abstract**: In this paper a wind energy conversion system (WECS) is designed to supply power to a standalone system consisting of permanent magnet synchronous generator (PMSG), a rectifier system, and inverter system to get the desired constant ac voltage respectable of variable wind speed to extract power from the fluctuating wind, controlling of the wind turbine is done by controlling the pitch angle of turbine. This power is transferred to dc link capacitor through controlled rectifier. This constant dc link voltage is converted into ac of desired amplitude and frequency. Based on extensive simulation results using MATLAB/SIMULINK, it has been established that the performance of the controllers both in transient as well as in steady state is quite satisfactory and it can also maintain maximum power point tracking*

***Index Terms**: PMSG, WECS, Inverter, Rectifier, Pitch controller, Variable speed wind turbine*

I. INTRODUCTION

In wind energy application, variable speed wind turbines are popular mainly because of their capability to capture more power from the wind using the maximum power point tracking (MPPT) algorithm and improved efficiency [1]. Presently, doubly feed induction generators (DFIGs) are widely used as the generator in a variable speed wind turbine system. In case of DFIG, there is a requirement of the gearbox to match the turbine and rotor speed. The gearbox many times suffers from faults and requires regular maintenance [2], making the system unreliable. The reliability of the variable speed wind turbine can be improved significantly using a direct drive-based permanent magnet synchronous generator (PMSG). PMSG has received much attention in wind energy applications because of its self-excitation capability, leading to a high power factor and high efficiency operation [3].

There are two common types of interfaces between PMSG and the load. The first configuration is designed as back-to-back PWM converter [4, 5], the second configuration is a single switch mode rectifier and an inverter [6, 7]; the former is commonly considered as the technical ultimate operation but may be more expensive and complex, it has a lot of switches which cause more losses and voltage stress in addition to presence of Electromagnetic Interface (EMI). The latter, which is adopted in this paper, is usually used in the stand-alone or small scale wind farms for its simple topology and control, and most importantly, low cost.

In many countries, there are remote communities where connection with the power grid is too expensive or impractical and diesel generators are often the source of electricity. Under such circumstances, a locally placed small-scale standalone distributed generation system can supply power to the customers. Autonomous wind power systems are among the most interesting and environment friendly technological solutions for the electrification of remote consumers.

The control of an inverter to present the customers with a balanced supply voltage is the main challenge in a standalone system. Moreover, voltage variations, flickers, harmonic generation, and load unbalance are the major power quality (PQ) problems that occur in the wind energy conversion system (WECS). The voltage variations are mainly due to the change in load. Flicker or voltage fluctuations are primarily caused by variations in the power from WECS which comes into existence, owing to the fluctuations in the wind speed. Unwanted harmonics are generated due to the power electronics interface (rectifier, inverter and dc–dc converter) between the wind generator and the load. Those power quality problems may not be tolerated by the customers and hence require mitigation techniques.

In this paper a small scale standalone power supply system based on wind energy is considered. Our objectives are:

- Implementation of Pitch angle control of wind turbine for control of generator under higher wind speeds.
- Converting variable ac voltage into a constant ac voltage for the use of household.

The schematic of the standalone system using PMSG-based wind turbine is shown in Fig. 1

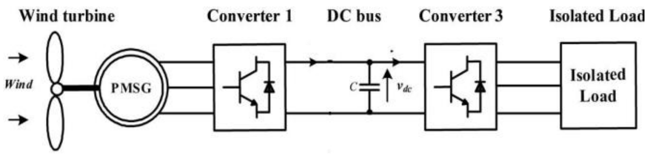

Fig1: Standalone WECS

II. MODELLING OF WIND TURBINE

The power in the wind is proportional to the cube of the wind speed and may be expressed as [8]:

$$P = 0.5\rho A v_w^{\ 3} \quad (1)$$

Where ρ is air density, A is the area swept by blades and Vw is wind speed. A wind turbine can only extract part of the power from the wind, which is limited by the Betz limit (maximum 59%). This fraction is described by the power coefficient of the turbine, Cp, which is a function of the blade pitch angle and the tip speed ratio.

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Therefore the mechanical power of the wind turbine extracted from the wind is

$$P_w = 0.5C_p(\beta,\lambda)\rho A v_w^{\ 3} \quad (2)$$

Where C_p is the power coefficient of the wind turbine, β is the blade pitch angle and λ is the tip speed ratio. The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed V_w,

$$\lambda = \frac{\Omega R}{v_w} \quad (3)$$

Where Ω is the turbine rotor speed, R is the radius of the wind turbine blade. Fig. 2 shows that the mechanical power converted from the turbine blade is a function of the rotational speed, and the converted power is maximized at the particular rotational speed for various wind speed.

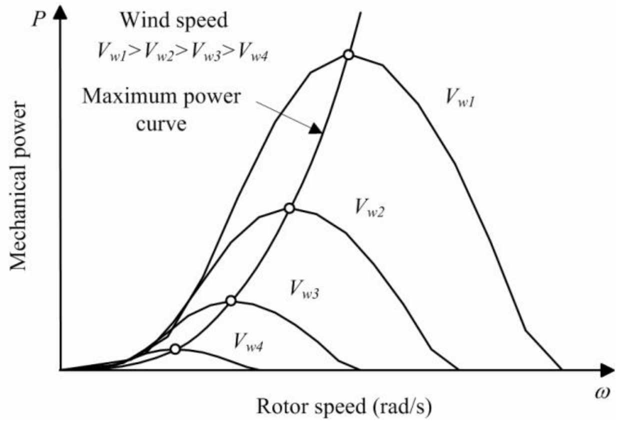

Fig 2: Mechanical Power versus Rotor Speed Characteristics

The typical power control regions of wind turbine are shown in Fig. 3. The turbine starts operating when the wind speed exceeds cut-in wind speed. The power captured by the turbine increases with the wind speed increasing. At the set point of wind speed, the generating power reaches the rated power of the turbine. If the wind speed continues to rise, the generator output power remains constant at the design limit. Due to safety consideration, the turbine is shut down at speeds exceeding cut-out wind speed.

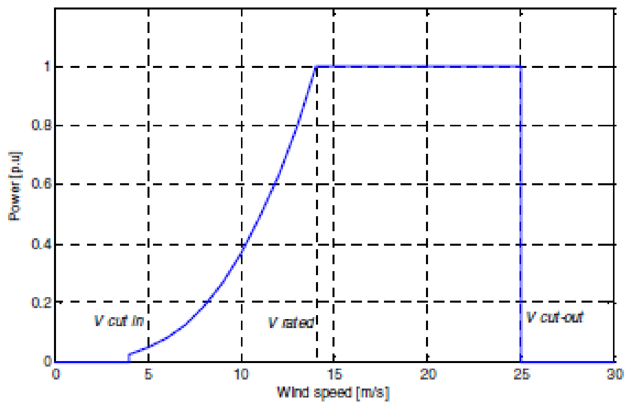

Fig 3: Power versus Wind Speed

III. MODELING OF DRIVE TRAIN

The drive train of a wind turbine generator system consists of the following elements [9]: a blade-pitching mechanism with a spinner, a hub with blades, a rotor shaft and a gearbox with breaker and generator. The acceptable way to model the drive train is to treat the system as a number of discrete masses connected together by springs defined by damping and stiffness coefficients (Fig. 4).

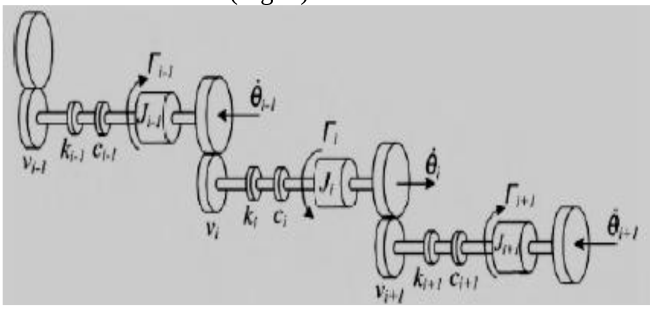

Fig 4: Transmission Model of N Masses Connected Together

Therefore, the equation of ith mass motion can be described as follows:

$$\frac{d^2\theta_i}{dt^2} = \frac{v_i c_i}{J_i}\frac{d\theta_{i-1}}{dt} - \frac{v_{i+1}^2 c_{i+1} + c_i}{J_i}\frac{d\theta_i}{dt} + \frac{v_{i+1}c_{i+1}}{J_i}\frac{d\theta_{i+1}}{dt} + \frac{v_i k_i}{J_i}\theta_{i-1} - \frac{v_{i+1}^2 k_{i+1} + k_i}{J_i}\theta_i + \frac{v_{i+1}k_{i+1}}{J_i}\theta_{i+1} + \frac{\tau_i}{J_i} - D_i\frac{d\theta_i}{dt} \quad (4)$$

where v_i, is the transmission rate between i and i-l masses, ci is the shaft viscosity [kg/(m-s)], k_i is the shaft elastic constant [N/m], J is the moment of inertia of the ith mass [kg-m2] ,τ_i is the external torque [N-m] applied to the ith mass and D_i is the damping coefficient [N-m/s], which represents various damping effects . For the purposes of the present research, neither viscosity nor damping effects have been considered.
When the complexity of the study varies, the complexity of the drive train differs. For example, when the problems such as torsional fatigue are studied, dynamics from all parts have to be considered. For these purposes, two-lumped mass or more sophisticated models are required. However, when the study focuses on the interaction between wind farms and loads, the drive train can be treated as one-lumped mass model for the sake of time efficiency and acceptable precision. The last approximation has been considered in the present study and it is defined by the following equation

$$\frac{d\omega_g}{dt} = \frac{\tau_e - \tau_{w\_g}}{J_{eq}} - \frac{B_m}{J_{eq}}\cdot\omega_g \quad (5)$$

Where the sub-index g represents the parameters of the generator side, wg is the mechanical angular speed [rad/s] of the generator; τ_e is electromechanical torque [Nm], τ_{w_g} is the aerodynamic torque that has been transferred to the generator side, which is equal to the torque produced in the rotor side because there is no gearbox, and J_{eq} is the equivalent rotational inertia of the generator [kg-m2], which is derived from,

$$J_{eq} = J_g + \frac{J_w}{n_g^2} \quad (6)$$

Where J_g and J_w; are the generator and the rotor rotational inertias [kg-m2] respectively, n_g is the gear ratio, which is equal to I, because no gearbox is utilized. The model of the two mass drive train implemented in Simulink is depicted in Fig.5.

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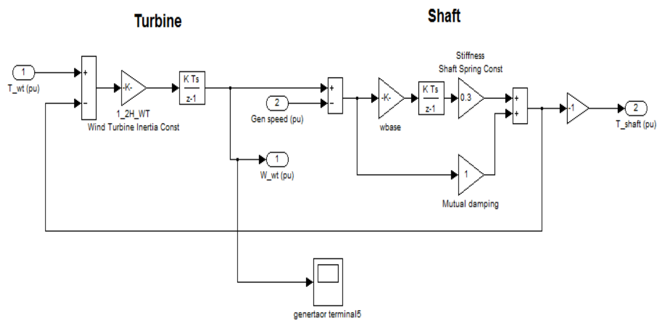

Fig 5: Simulink Model of Drive Train

IV. PITCH ANGLE CONTROL OF WIND TURBINE

Pitch angle control is the most common means for adjusting the aerodynamic torque of the wind turbine when wind speed is above rated speed and various controlling variables may be chosen, such as wind speed, generator speed and generator power. As conventional pitch control usually use PI controller, the mathematical model of the system should be known well. Pitch angle regulation is required in conditions above the rated wind speed when the rotational speed is kept constant. Small changes in pitch angle can have a dramatic effect on the power output. The purpose of the pitch angle control might be expressed as follows [10]:

Optimize the power output of the wind turbine. Below rated wind speed, the pitch setting should be at its optimum value to give maximum power. Preventing input mechanical power to exceed the design limits. Above rated wind speed, pitch angle control provides a very effective means of regulating the aerodynamic power and loads produced by the rotor.

Minimizing fatigue loads of the turbine mechanical component. It is clear that the action of the control system can have a major impact on the loads experienced by the turbine. The design of the controller must take into account the effect on loads, and the controller should ensure that excessive loads will not result from the control action. It is possible to go further than this, and explicitly design the controller with the reduction of certain fatigue loads as an additional objective.

A. Conventional Pitch Angle Control: Adjusting the pitch angle of the blades provides an effective means of regulations or limiting turbine performance in strong wind speeds. To put the blades into the necessary position, pitch servos are employed which may be hydraulic or electrical systems. During normal operation, blade pitch adjustments with rotational speeds of approximately 5-10% are expected. Here the chosen pitch rate is 8% which avoids excessive loads during normal regulation procedures.

In the proposed system the pitch angle is controlled by comparing the actual generator speed with the reference speed to control it. When the generator speed exceeds due to the increase of wind speed the controller will vary the pitch angle of the wind turbine. Pitch angle variation will result in the control of aerodynamic torque of the wind turbine and the speed control will be achieved through it.

V. COMPENSATION OF LOAD VARIATION

In distribution systems, as the loads are mostly single phase in nature, the current in different phases will not be the same in magnitude and the phase difference between them may not be 120. The detrimental effects of this unbalanced current on the generating system are [11]

Electrical torque pulsation Unbalanced voltages at PCC. The effect and control of the above-mentioned two quantities are discussed below.

A. Effect on the Generator Torque and Its Compensation

When an inverter supplies unbalanced load current, the time variation of the dc link current (I_{dc}) and dc link voltage (V_{dc}) can be expressed as a dc component superimposed with a second harmonic component. Due to the second-harmonic component present in the dc current, the electrical torque of the generator will oscillate and the life of the turbine shaft will reduce.

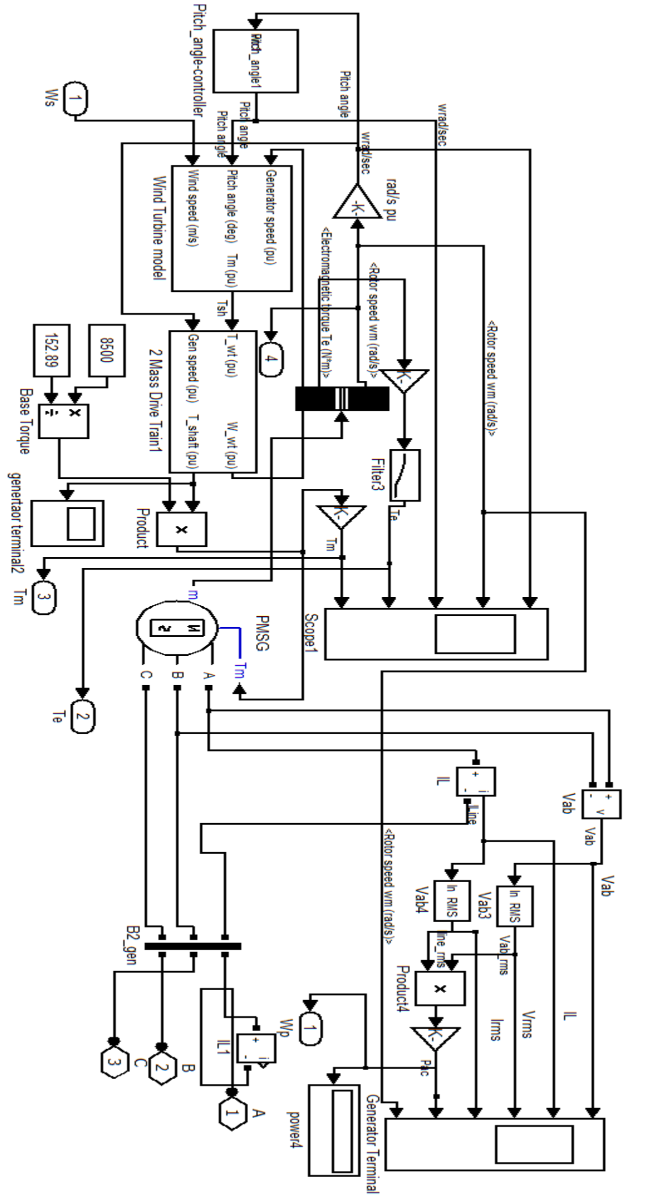

Fig 6: Simulink Model of Pitch Angle Controller

B. Effect on Voltage at PCC and Its Compensation

Due to unbalanced load being connected to the inverter, the current in each phase will not be equal, leading to unequal voltage drop across each phase. This unbalanced voltage drop will cause the line voltages at PCC to become unbalanced and the voltage unbalance factor may not be within permissible limit (i.e., below 1%).

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Hence, it is necessary to compensate the voltage unbalance at PCC. To achieve this goal the error between the rms (or peak) value of the phase voltages at PCC and the reference phase voltage is given to a PI controller. The output of the PI controller is multiplied with a unit sine wave generator to get the reference phase voltages (Va_ref, Vb_ref, and Vc_ref) PWM pulses are generated to switch ON/OFF the load side inverter. The schematic of the control scheme used for unbalanced voltage compensation is shown in Fig. 7. Through the controller shown in Fig. 7, our aim is to get different modulation index for three phases so as to balance out the unbalanced PCC voltages. The controller requires the information about the actual voltage. The actual voltage can be detected by different algorithms. The detection time of both the peak detection method and dq0 transformation-based approach is faster than the rms measurement approach. The dq0 values of the actual signals are acquired using abc to dq transformation blocks in the Simulink browser.

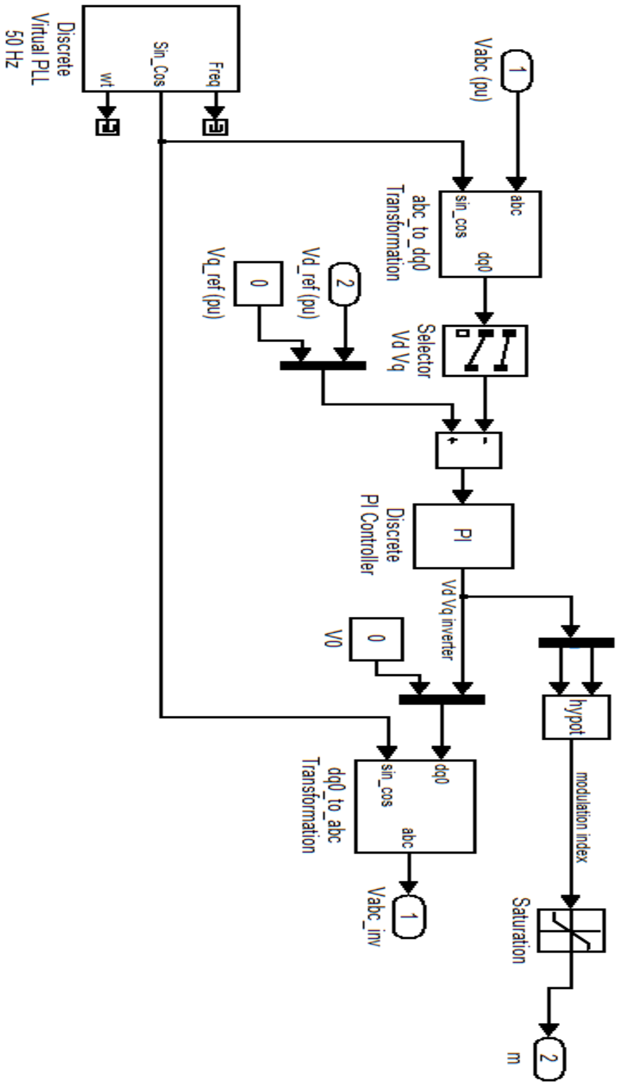

Fig 7: PWM Inverter Controller for Unbalanced Load Compensation

VI. SIMULATION RESULTS DISCUSSIONS

The simulation is done considering the system is always connected to the load, (i.e.) the wind is always present and no backup storage devices are used as shown in fig 8.

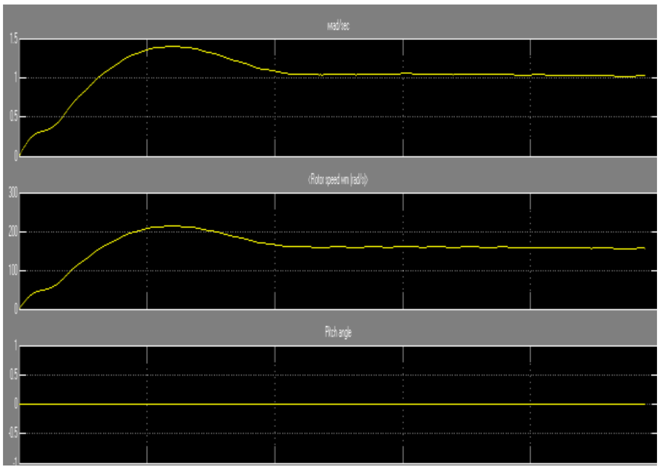

Fig 9: Pitch control output

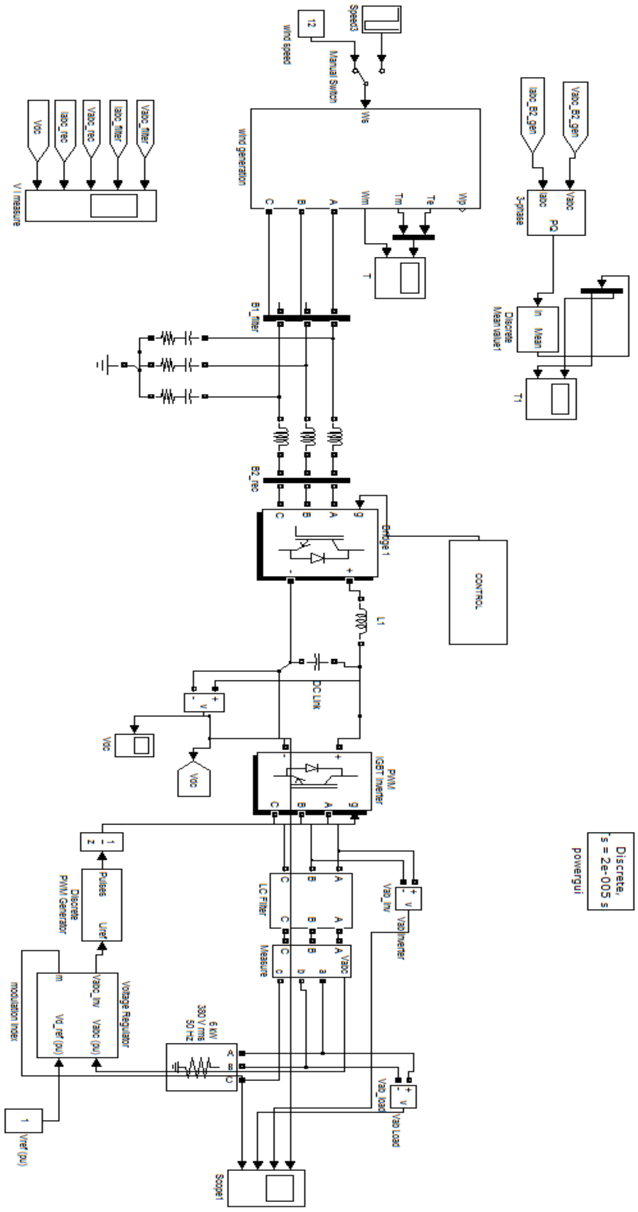

Fig 8: Simulated model of Standalone Wind Energy conversion System using PMSG

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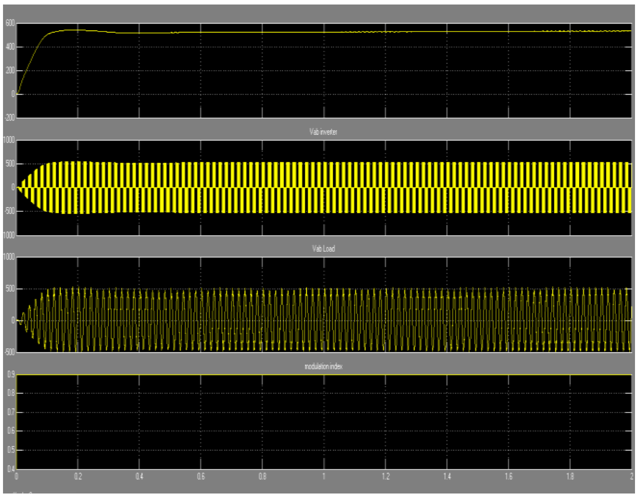

Fig 10: Output of Inverter

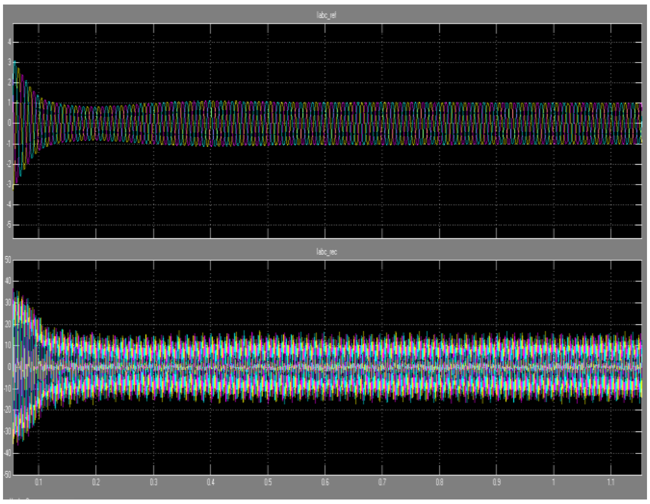

Fig 11: Output of Rectifier

VII. CONCLUSION

Control strategy for a direct drive stand alone variable speed wind turbine with a PMSG is presented in this paper. A pitch control strategy of wind turbine is implemented using simpower dynamic system simulation software. Also a simple control strategy for the generator side converter to extract power is discussed and implemented. The load side PWM inverter is controlled to maintain the amplitude and frequency of the inverter output voltage. It is seen that the controller can maintain the load voltage and frequency quite well. The generating system with the proposed control strategy is suitable for a small scale standalone variable speed wind turbine installation for remote area power supply. The simulation results demonstrate that the controller works very well.

APPENDIX

Parameters of PMSG

Number of poles	10
Rated speed	153 rad/s
Armature resistance (R_s)	0.425 Ω
Magnetic flux linkage	0.433 Wb
Stator inductance (L_s)	8.4 mH
Rated torque	40 Nm
Rated power	6 kW

Parameters of Two Mass Drive Train

H_t ; H_g	4s ; 0.1H_t
K_{sh}	0.3 p.u./el.rad
D_t	0.7 p.u.s/el.rad

REFERENCES

1. S. Müller, M. Deicke, and W. De DonckerRik, “Doubly fed induction generator system for wind turbines,” IEEE Ind. Appl. Mag., vol. 8, no.3, pp. 26–33, May/Jun. 2002.
2. H. Polinder, F. F. A. van der Pijl, G. J. de Vilder, and P. J. Tavner, “Comparison of direct-drive and geared generator concepts for wind turbines,” IEEE Trans. Energy Convers., vol. 21, no. 3, pp. 725–733, Sep. 2006H. Poor, An Introduction to Signal Detection and Estimation. New York: Springer-Verlag, 1985, ch. 4.
3. T. F. Chan and L. L. Lai, “Permanent-magnet machines for distributed generation: A review,” in Proc. 2007 IEEE Power Engineering Annual Meeting, pp. 1–6.
4. Chinchilla, M.; Arnaltes, S.; Burgos, J.C. Control of permanent-magnet generator applied to variable-speed wind-energy system connected to the grid. IEEE Trans. Energy Convers. 2006, 21, 130–135.
5. Thongam, J.S.; Bouchard, P.; Ezzaidi, H.; Ouhrouche, M. Wind Speed Sensorless Maximum Power Point Tracking Control of Variable Speed Wind Energy Conversion Systems. In Proceeding of the IEEE International Conference on Electric Machines and Drives, Miami, FL, USA, 3–6 May 2009; pp. 1832–1837.
6. Tan, K.; Islam, S. Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors. IEEE Trans. Energy Convers. 2004, 19, 392–399.
7. Rolan, A.; Luna, A.; Vazquez, G.; Aquilar, D.; Azevedo, G. Modeling of a Variable Speed Wind Turbine with Permanent Magnet Synchronous Generator. In Proceeding of the IEEE International Symposium on Industrial Electronics, Seoul, Korea, 5–8 July 2009; pp. 734–739.
8. Janardan gupta, Ashwani kumar “Fixed pitch wind turbine based permanent magnet synchronous machine model for wind energy conversion” www.onlinejet,net
9. Alejandro Rolan', Alvaro Luna, Gerardo Vazquez,Daniel Aguilar, Gustavo Azevedo “Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator” IEEE International Symposium on Industrial Electronics (ISlE 2009) Seoul Olypic Parktel, Seoul, Korea July 5-8, 2009
10. Jianzhong Zhang, Ming Cheng, Zhe Chen, Xiaofan Fu” Pitch Angle Control for Variable Speed Wind Turbines” DRPT2008 6-9 April 2008 Nanjing China
11. C. N. Bhende, S. Mishra, Senior Member, IEEE, and Siva Ganesh Malla “Permanent Magnet Synchronous Generator-Based Standalone Wind Energy Supply System” IEEE Transactions on Sustainable Energy, VOL. 2, NO. 4, October 2011 361

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