

# Design of Permanent Magnet Synchronous Generator for Wind Energy Conversion System

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**Abstract** It describes about the power and potential of wind energy that can be used to meet energy demand in future. The detailed illustration of generator and wind turbine has focused on interconnection of the generators and the troubles allied with it. For the generation of power from the wind, wind turbine, and PM synchronous generator are designed using MATLAB/Simulink. The results of this simulation authenticate the validity of developed WECS.

**Keywords** AC/DC and DC/AC converter · PMSG · Pitch controller  
2-mass drive train · Wind turbine and WECS

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**Table 1** All renewable energies installed capacity in India (till 31 Dec 2014)

S. No.	Source power	Total install capacity (MW)
1	Wind	22465.03
2	Solar (SPV)	3062.68
3	Small hydro power	3990.8
4	Biomass	1365.2
5	Biogases cogeneration	2800.35
6	Waste to power	107.58
	Total	33791.74

## 1 Introduction

Recently, the injurious effect of global warming and emission of carbon is considerably augmented. Due to which clean and extensive renewable sources such as wind, sun, ocean, and biomass energy come in more demand. Among all sources, wind energy has the maximum growth in the last decade. The reason that wind energy is free from toxic waste and continuously available natural source of energy, which is endless source and having great potential [1–4].

There are two factors which stimulate interest for the research in PMSG technology for wind turbine. First one is the significant growth trend of wind generation demonstrates its importance in meeting global requirements for electrical power in future and second, as wind generation technology progresses, the PM synchronous generator has potential to supplant this technology as primary means to the generation of electricity for large scale wind turbines [5–8].

This paper aims to simulate the controller of three-phase PMSG system, which will be built-in in a small wind turbine of fixed pitch variable speed. The wind turbine will be used to provide electricity for farm, business industries with the main electric supply in the India. The whole system consists PMSG, AC/DC convertor, DC link, PWM inverter and LC filter, and 3-phase load, and objective of the system is to develop the simulation model (Table 1).

## 2 Proposed Methodology

Figure 1 explains the main components of wind energy conversion system (WECS) such as Wind turbine system, generation system, DC/AC converter, and the load. Figure 2 shows PMSG system.

1. Wind turbine system: it converts the potential of wind energy into the rotation of the turbine, which is responsible for generating mechanical energy.
2. Generation system: the generation system converts the mechanical energy output into electric energy.

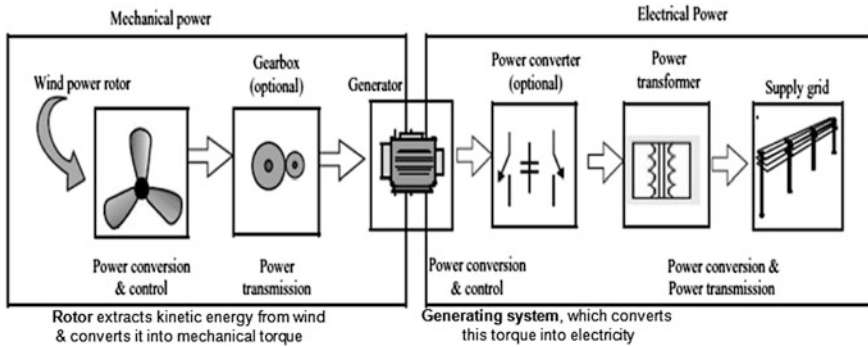


Fig. 1 Main components of a WECS

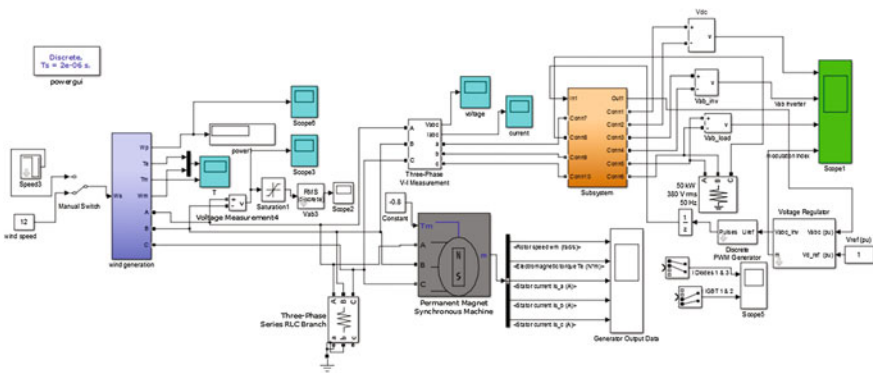


Fig. 2 Proposed system of a variable speed PMSG-based WECS

3. AC/DC converter: this AC/DC converter, i.e., rectifier is a full-bridge converter circuit.
4. DC/AC inverter: the PWM is selected to implement DC/AC converter. The controller takes voltage signal and current signal, in order to generate a signal to control the IGBT to attain a closed loop full-bridge voltage source inverter.
5. The load: a three-phase load is connected to the output end to measure the output results.

### 3 Modeling of the System

The turbine blades of wind extract kinetic energy and convert it into mechanical energy. Hence, the kinetic energy associated with an object having mass  $m$  rotating with velocity  $v$  is equal to the following:

$$E = \frac{1}{2}mv^2 \quad (1)$$

$$P_m = \frac{dE}{dt} = \frac{1}{2}\rho Av^3 \quad (2)$$

where

$P_m$  mechanical power

$T_w$  mechanical torque

$A$  rotor area;  $A = \pi r^2$

$v$  wind speed in m

$C_P$  coefficient of power

$\alpha$  speed ratio of tip

$\beta$  pitch angle of rotor blade in radian

Air density  $\rho = \rho_0 - 1.194 * 10^{-14}$  (where  $\rho_0 = 1.225 \text{ kg/m}^3$  known as the air density at  $T = 298 \text{ K}$ ).

### 4 Extraction of the Power from Wind

The power that contained by the wind can be calculated as

$$P_{\text{wind}} = \frac{1}{2}\rho_{\text{air}}\pi R^2 V_{\text{wind}}^3 \quad (3)$$

where  $\rho_{\text{air}} = 1.225 \text{ kg/m}^3$  is the density of air.

The extracted power from the wind is

$$P_{\text{blade}} = C_P(\alpha, \beta)P_m \quad (4)$$

$$P_{\text{blade}} = \frac{1}{2}C_P(\alpha, \beta)\rho Av^3 \quad (5)$$

The rated speed is the point on power curve, wherever the power output begins to level out. Typical height of turbine is around 50 m, now increased up to 80–100 m. The manufacturers are also trying to increase the length of blades of

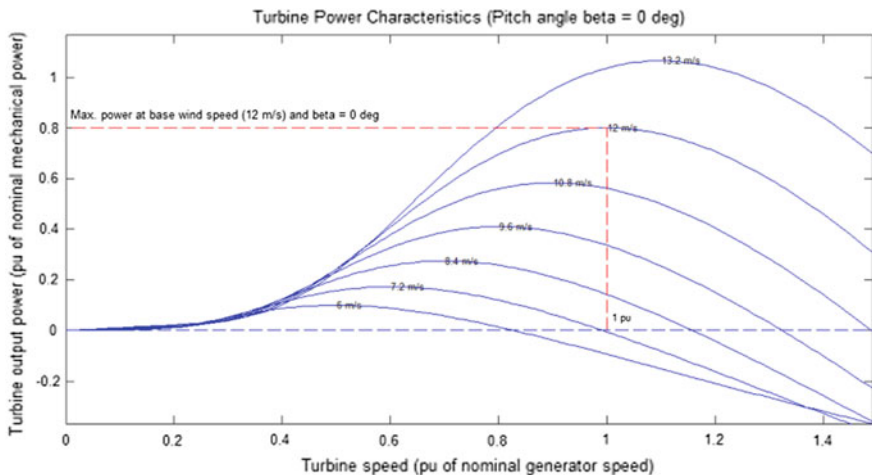


Fig. 3 Typical power curve between turbine output power versus turbine speed

rotor. The motive for this is the indirect relationship between the output mechanical power and tip-speed ratio ( $\lambda$ ) of the rotor which is shown in Fig. 3.

$$\lambda = \frac{\omega_{\text{turb}}R}{v_{\text{wind}}} \tag{6}$$

$$P_{\text{mech}} = C_p^{1/2} \rho_{\text{air}} \pi R^2 (\omega_{\text{turb}}R/\lambda)^3 \tag{7}$$

where  $\omega_{\text{turb}}$  is the turbine rotational speed, as the turbine’s rotor radius increases, the tip-speed ratio decreases, allowing for better output. After this stage, the output has given to the power convertor. AC voltage at fundamental frequency is related with DC voltage by Eq. (8)

$$V_B = \frac{1}{2\sqrt{2}} m_B V_B \angle \delta_B \tag{8}$$

$m_g$  modulation index.  
 $\angle \delta$  Phase angle.

The primary stage is rectification, also known as AC to DC conversion. The essential form of a rectifier is three-phase diode bridge, in which upper group diode will pass the positive cycle of a sine wave, and the lower group diode will pass negative cycle of a sine wave. A one-phase DC output can be calculated as given in Eq. (9). In the stage of inversion the output of DC link converted back into

alternating current output, which is achieved by three-phases switching circuits, (MOSFET or IGBTs).

$$V_{dc} = \frac{2V_{peak}}{\pi} \tag{9}$$

For a three-phase bridge converter, this will have to be multiply by three.

### 5 Results and Discussion

The WECS is built via MATLAB/Simulink with base wind speed is supposed as 8–12 m/s. The simulation results for the proposed system are given in Figs. 4 and 5. The output voltage wave forms of wind turbine are shown in Figs. 6 and 7. The output voltage waveforms of the wind turbine are shown in Fig. 8. The output waveforms of the AC-DC-AC convertor subsystem are shown in Fig. 9, which

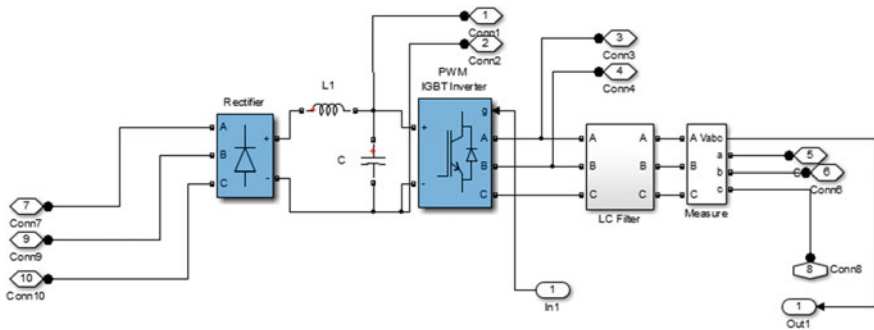


Fig. 4 AC-DC-AC converter model subsystem

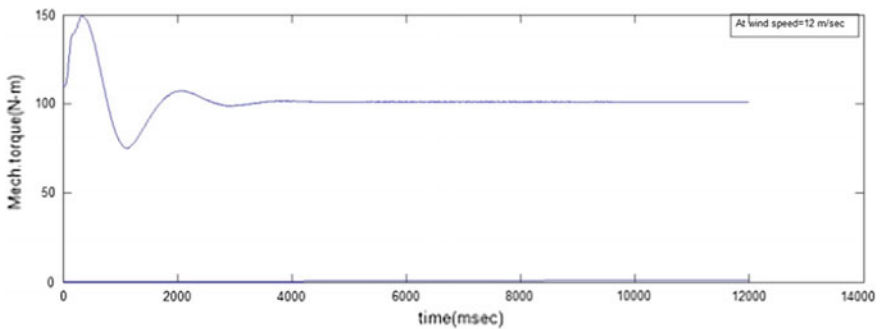


Fig. 5 Mechanical torque at wind speed 12 m/s

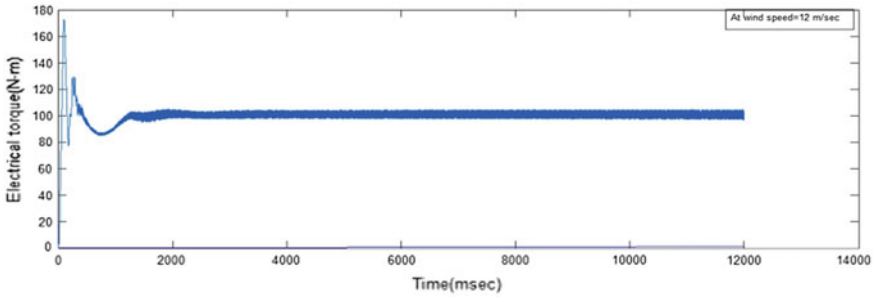


Fig. 6 Electrical torque of the generator at 12 m/s

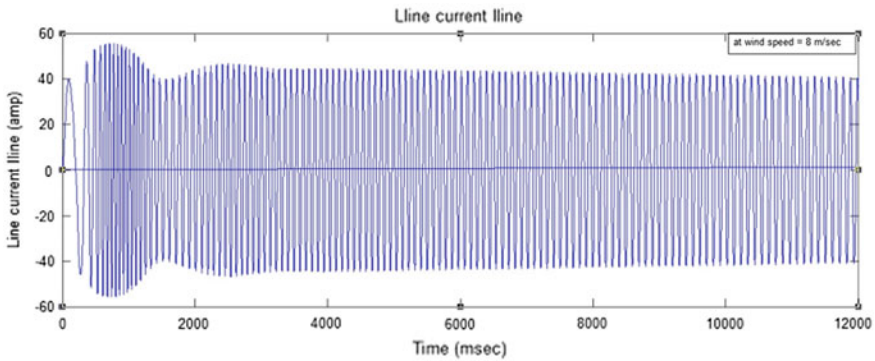


Fig. 7 Output current  $I_a$  of the generator at wind speed 8 m/s

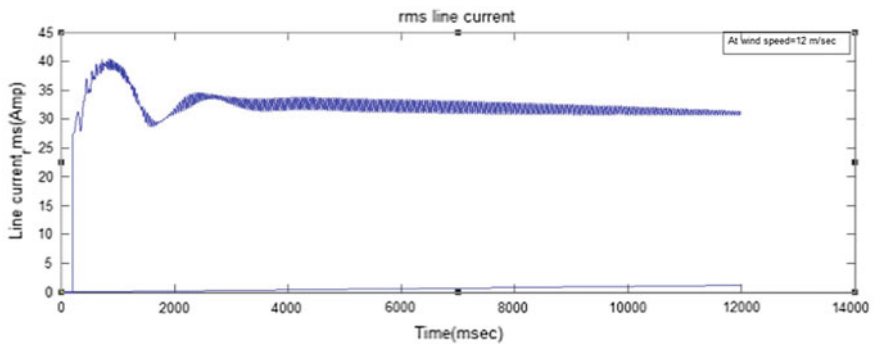


Fig. 8 RMS line current at 12 m/s

shows the RMS output voltage at wind speed 10 m/s. Also Figs. 10 and 11 show output line current at wind speed 12 m/s and three-phase output voltage on load (Fig. 12), respectively. Figure 13 describes the output RMS current on load at wind speed 12 m/s, and Fig. 14 shows the modulation index.

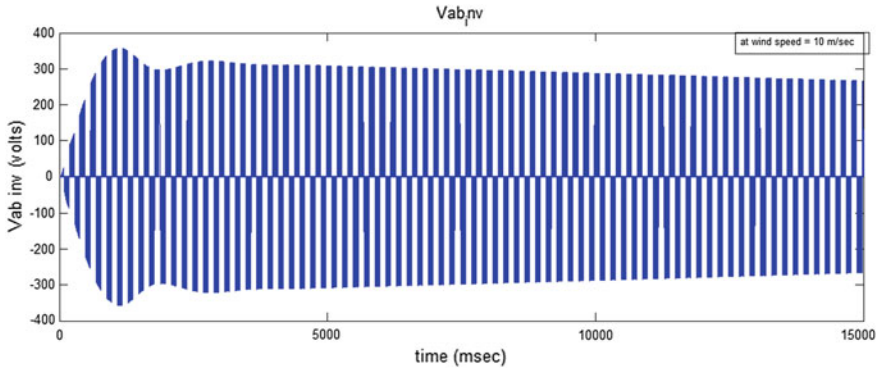


Fig. 9 Inverter output voltage  $V_{ab}$  at wind speed 10 m/s

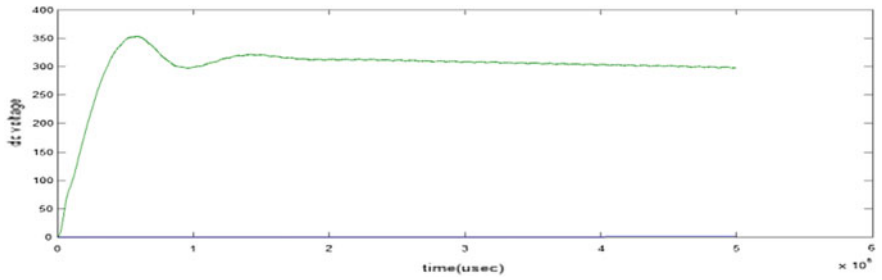


Fig. 10 RMS output voltage at wind speed 10 m/s

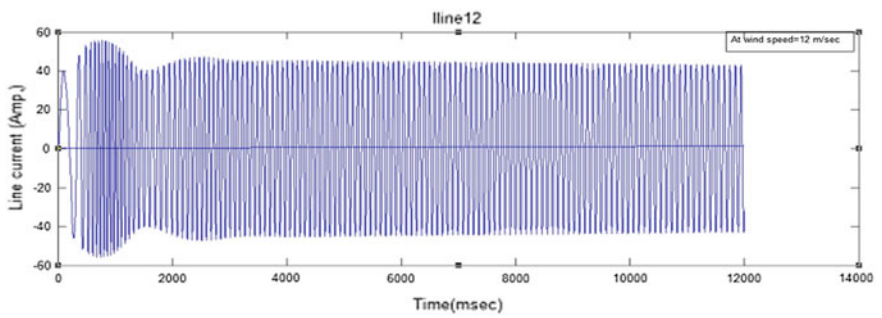


Fig. 11 Output line current at wind speed 12 m/s



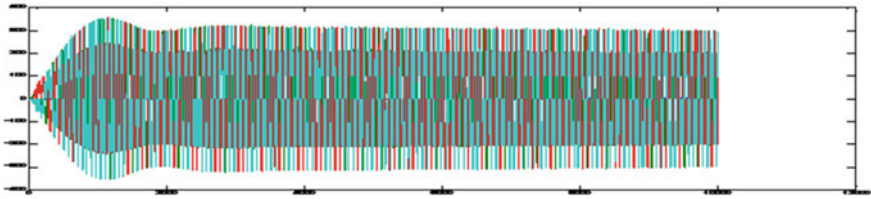


Fig. 12 Three-phase output voltage on load

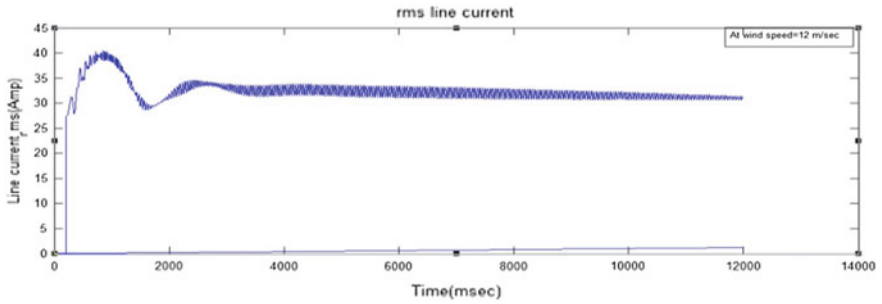


Fig. 13 Output RMS current at load at wind speed 12 m/s

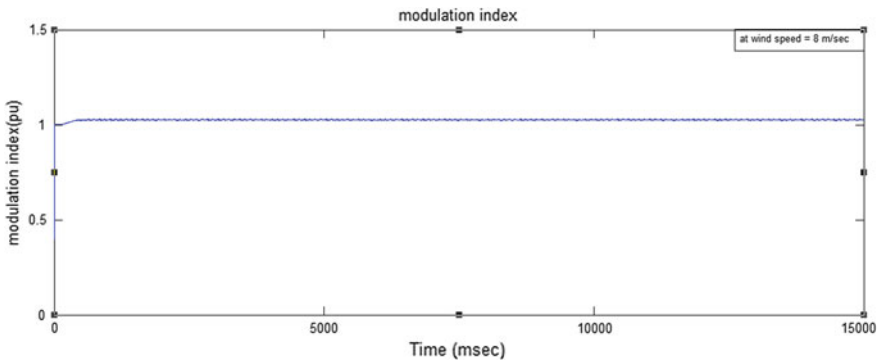


Fig. 14 Modulation index

## 6 Conclusions

This paper tries to maximize the yield of wind turbine by means of PMSG. The variable speed has been selected because of higher energy gain to reduce stress. A variable speed WECS has been developed using the MATLAB/SIMULINK. PMSG generator along with its controls has been discussed. The wind turbine

model is changed to a stall wind turbine model by adding a controller for strike angle. All results prove that the model is developed, and controllers demonstrate the effectiveness to obtain the maximum power output.

## References

1. Pinto, A., Carvalho, B., Oliveira, J., Guimaraes, G., Moraes, A.: Analysis of a WECS connected to utility grid with synchronous generator. In: IEEE 2006 IEEE PES Transmission & Distribution Conference and Exposition, Latin America, Caracas doi:[10.1109/TDCLA.2006.311373](https://doi.org/10.1109/TDCLA.2006.311373), pp. 1–6 (2006)
2. Mesemanolis, A. Mademlis, C. Kioskeridis, I.: Maximum efficiency of a wind energy conversion system with a PMSG. In: IET 7th Mediterranean Conference and Exhibition on Power Generation, Transmission, Distribution and Energy Conversion. ISBN: 978-1-84919-319-1, pp. 1–9 (2010)
3. Ni, B., Sourkounis, C.: Energy yield and power fluctuation of different control methods for wind energy converters. *IEEE Trans. Ind. Appl.* **47**(3), 1480–1486 (2011)
4. Zahedi, A.: Current status and future prospects of the wind energy. In: IEEE 2012 10th IPEC Conference, Ho Chi Minh City (2012.12.12–2012.12.14) (2012)
5. Parikh, K., Maheshwari, A., Agarwal, V.: Modelling, simulation and performance analysis of AC-DC-AC PWM converters based WECS **2**(4) (2013)
6. Ahmed, A.A., Abdel-Latif, K.M., Eissa, M.M., Wasfy, S.M., Malik, O.P.: Study of characteristics of wind turbine PMSG with reduced switches count converters. In: 26th IEEE Canadian Conference of Electrical and Computer Engineering, doi:[10.1109/CCECE.2013.6567673](https://doi.org/10.1109/CCECE.2013.6567673), pp. 1–5 (2013)
7. Jayalakshmi, N.S., Gaonkar, D.N., Sai Kiran Kumar, K.: Dynamic modeling and performance analysis of grid connected PMSG based variable speed wind turbines with simple power conditioning system. In: 2012 IEEE International Conference on Power Electronics, Drives and Energy Systems, 16–19 Dec 2012, Bengaluru, India doi:[10.1109/PEDES.2012.6484474](https://doi.org/10.1109/PEDES.2012.6484474), pp. 1–5 (2012)
8. Research on the directly driven permanent magnet synchronous generator connected to DC grid. doi: [10.1049/cp.2013.1830](https://doi.org/10.1049/cp.2013.1830). ISBN: 978-1-84919-758-8, pp. 1–4 (2013)