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Performance Analysis of Small Scale PMSG Based WEC Systems Coupled With PWM Load Side Inverter

P.SELVARAJ[1], K.SEETHA DEVI[2]

1. AP/EEE Department of EEE, Adhiparasakthi Engineering, Melmaruvathur, India
2. PG Scholar Department of EEE, Adhiparasakthi Engineering, Melmaruvathur, India

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P.SELVARAJ

K.SEETHA DEVI

ABSTRACT

Now a days in wind Energy conversion systems, various technologies are used to extract maximum power from the wind. Implementing such technologies are more suitable for the permanent magnet synchronous generator based wind energy conversion systems due to some important features of PMSG like less weight, more efficiency and absence of gear box arrangement. In this paper a standalone PMSG coupled with the 3 phase PWM inverter is proposed to supply more power to load. By using the pulse width modulation techniques effective voltage control is achieved. This Proposed method is simulated in Matlab-Simulink and results are verified using developed 5 KW Horizontal axis wind turbine Model.

Index Terms- Permanent magnet Synchronous Generator, Renewable Energy, Wind Power Conversion, Direct Drive Wind Turbine.

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INTRODUCTION

Recently Permanent Magnet Synchronous generators (PMSG) are mainly used in the variable Speed wind Energy conversion systems due to the capability of Extracting More Power from the Wind and this system produces more efficiency. Doubly Feed Induction generator based WEC systems needs Gear box arrangement to match the turbine speed with the rotor speed. This system produce less efficiency due to the Presence of gear box which require regular maintenance. This will leads to the unreliable operation [1]. The reliability of the WEC system is improved by replacing the DFIG by PMSG. The power factor and efficiency of this PMSG based systems are also high since the it has require no separate field excitation to create the magnetic field.

Supplying Electric Power to the remote areas through Power grid is expensive and complicated. The alternative source of Power generation in this area is diesel generator set which is costlier. This draw backs can be replaced by the Stand alone PMSG based wind Energy conversion systems and This environment friendly system makes the electrification of remote area as easy.

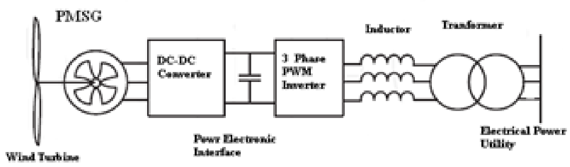


Fig.1.Proposed PMSG based WEC

The Main task in the PMSG based Wind energy conversion system is maintaining balanced supply voltage at the load side [2]. The main power quality problems such as voltage sag, voltage swell, voltage flicker, harmonics Presence in the WEC affects the Performance of various equipments connected with it.[3] These Power quality issues should be mitigated for effective operation of the Wind energy system. Due to the frequently varying load, voltage sag and voltage swell occur. Power variations leads to flickering and voltage fluctuations in the supply system. Power Electronic Converters Produce harmonics.[4]-[6].

The already Existing PMSG based wind energy conversion systems Produce unbalanced Load in the in the Electric network.[7]. This unbalanced load makes the voltages un equal at the point where the load is connected . It also produces variations in the generated torque which affect the wind turbine shaft.[8]. Fig.1.Shows the schematic diagram of the Proposed WEC system.

The Main objectives of this paper are to simulate PMSG Based Wind Energy Conversion Systems Coupled With PWM Load Side Inverter in Matlab Simulink and verify the results ,using the developed 5KW PMSG based wind turbine model , control the magnitude and frequency of ac output voltage using PWM techniques., maintain the constant and balanced voltages at the load side.

II. PMSG BASED WEC SYSTEM.

The Proposed method consists of direct driven 3 phase PMSG followed by 3 Phase uncontrolled Bridge rectifier. The output of the Bridge rectifier is given to the PWM inverter. This inverter feeds the controlled AC voltage at required frequency to the load

A. Wind Turbine

Wind turbine converts the linear motion of the wind into rotational motion. This rotational motion rotates the shaft of the permanent magnet Synchronous generator. In such a way the wind power is converted into Electrical Power.[9].

The Power collected from the wind is calculated using,

$$P = 0.5\rho A V^3 \qquad (1)$$

Where ρ = wind density

A=Area swept by the wind turbine

V= Wind speed.

The mechanical power produced by the wind turbine is given by[10].

$$P_m = C_p\ (\lambda,\beta)\ \rho \qquad (2)$$

Where, C_p= function of tip speed ratio λ and pitch angle β.

For constant pitch angle

$$C_p\ (\lambda) = 0.5\left(\frac{116-9(\lambda-0.2)}{(\lambda-0.2)}\right)e^{-\frac{21}{(\lambda-0.2)}} + 0.007\lambda \qquad (3)$$

Where λ can be expressed as,

$$\lambda = R\left(\frac{\omega_r}{V_w}\right) \qquad (4)$$

Where R is the radius of the wind turbine aero dynamic rotor in meter.

ω_r is speed of the turbine in radian/second

If the turbine operating point is fixed by the power co efficient C_P(max).[11]. Then the turbine will produce Maximum Power.

The maximum rotor speed can be expressed as,

$$\omega_r\,(\max) = V_w\left(\frac{\lambda(\max)}{R}\right) \qquad (5)$$

Fig 2 shows the relationship between torque and speed of the wind turbine for various wind speed.[12] Whenever the wind speed changes, the rotor speed is to be adjusted to get the maximum Power .This is achieved by maintaining the $\lambda(\max)$ and C_P(max) values.

In such cases the P_W(max) can be calculated using the following expression

$$P_w(\max) = 0.5\rho A\, C_P(\max)\left(\frac{\omega_r(\max)R}{\lambda(\max)}\right)^3 = K(\max).\omega_r^{\ 2} \qquad (6)$$

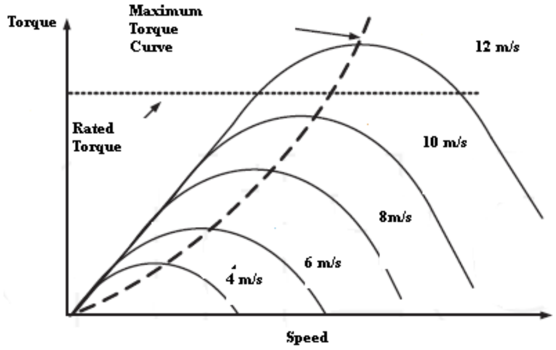


Fig.2.Torque speed curves of wind turbine

B .Permanent Magnet Synchronous generator

Now a days, PMSG is mostly used in all Wind Energy Conversion Systems Due to its simple construction and simple field excitation systems. It can generate more power from the various range of wind speed.[13]. The Magnetic field formed by the permanent magnet can be easily modeled as current source. From this simplified model we can derive the no load voltage equation E_g of the PMSG.

The no load voltage, $E_g(t)= 0.5\,\omega_r P\psi_f \sin(2\pi f_g t)$ (7)

$f_g = \omega_r \frac{P}{4\pi}$ (8)

Where P is the number of rotor poles

ψ_f = voltage flux constant of the Permanent Magnet

f_g = frequency of the generated voltage

III. POWER ELECTRONIC CONVERTERS

A. Generator side 3phase un controlled Rectifier

For a particular rotor speed ,the DC output voltage of the Bridge rectifier can be calculated using the following equation[4]-[6].

$V_d(\omega_r) = 1.6548\{(E_g(\omega_r))_{max} - I_s(\omega_r)_{max} Z_s(\omega_r)\}$(9)

Where $I_s(\omega_r)$ is the stator current of PMSG.

$Z_s(\omega_r)$is the stator impedance of PMSG and it is given by

$Z_s(\omega_r) = (R_s^{\,2} + (2\pi f_r L_s)^2)^{1/2}$ (10)

The capacitor C_d at the output of the generator side 3 phase rectifier can be chosen as

$C_d = (I_d\ avg) / f_s \Delta V_d$ (11)

Where, ΔV_d is the ripples Presence in the rectifier output voltage,

An uncontrolled rectifier employing diodes converts the AC Power in to DC Power. It Produce the constant dc output voltage. This 3 phase bridge rectifier arrangement consists of DC link capacitor C_d and inductor L_d Which forms the filter circuit. Generator inductance is denoted by L_s. To achieve the smooth DC output voltage, the values of L_d and L_s must be small and C_d will be high value. In this type of rectifier the ripple content in the output voltage is low and the ac side current contains spikes.[3].This Spikes produce the high level current harmonics in the ac source. In the absence of L_d and L_s, the current spikes are more .The inductance minimizes the surge current as a result we get the smooth supply current.[7]. The main draw backs of the rectifier with the large capacitor are low power factor and increase in generator load. The Power conversion stage of this method is shown in Fig 3.

At no load the capacitor voltage is expressed as

$V_c = 1.414 V_{LL}$ (12)

The minimum value of L_d can be calculated using the following Expression

$L_d\,(\text{min}) = \frac{P0.013V_{LL}}{\omega I_d}$ (13)

Where $\omega =$ the value of Supply frequency in rad/sec.

If the value of inductor L_d is large,the bridge rectifier Produce the less current. We can get the symmetrical and quasi square wave shape ac supply current in the absence of Ls .[12], [13].The generator inductance Ls decrease the current flow through the outgoing diode. and increase the current flow through the incoming diode

We can determine the value of overlap angle γ associated with this rectifier, using the following expression

$X_s I_d = \frac{V_{LL}}{1.414}(1 - \cos\gamma)$ (14)

The average value of DC output voltage can be expressed as

$V_L = 1.35 V_{LL} - 0.955 X_s I_d$ (15)

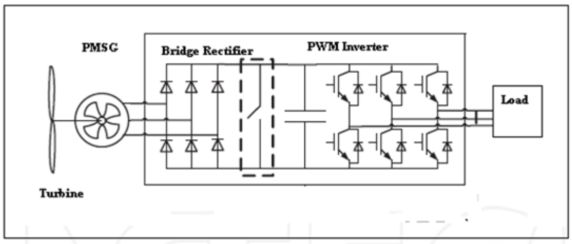


Fig.3.PMSG system with Power converters.

B. Load side3 Phase PWM Inverter

Three phase bridge rectifier output is connected with the 3 phase PWM inverter. This converters the DC Power in to AC Power.[5]. The aim of connecting the inverter at load side is to control the DC Link voltage and terminal voltage at the load side.

The charge and discharge power of the DC Link capacitor can be expressed as

$\Delta P_{dc} = P_c - P_g$ (16)

Where P_c is the smooth output Power

P_g is the output power of generator side inverter

The smoothing index can be calculated using

$\Delta V_{dc} = \frac{\delta P_{dc}}{I_d}$ (17)

To Prevent the damage of the DC link capacitor, the high frequency components of P_g are eliminated by employing a low pass filter. Active power control and reactive power control are achieved using the DC link capacitor [6]. These controls are achieved using PWM inverter. For choosing the control region of the DC link voltage, ratings of Power converters, THD value and voltage stress of power devices are considered.

The inverter output voltage is adjusted by controlling the DC link voltage and the output frequency is varied by changing the time interval between the control signals to the devices.

Pulse width modulation technique is used in the inverter. By using this technique the line to line RMS voltage at fundamental frequency can be obtained using the following equation

$V_{LL} = 1.22 m_a (V_{dc}/2)$

$= 0.612 m_a V_{dc}$ (18)

Where $m_a = \frac{V_m}{V_r}$ (Modulation Index: Ratio of carrier wave frequency to the modulating wave frequency).

IV. SIMULATION

In this paper PMSG based wind energy conversion system circuit was simulated. For this wind turbine two masse model drive train was used. WEC output is converted in to DC using universal AC to DC Bridge. Finally the DC output is converted into AC using 3 phase PWM inverter circuit and fed to the three phase load.

Table: 1.PMSG Parameters:

S.NO	Parameter	Value
1	Stator Phase Resistance	0.5 Ω
2	Armature Inductance	0.9mH
3	Flux linkage established by Magnets	0.45VS
4	Voltage constant	393(V Peak LL /Krpm)
5	Torque constant	3.5 Nm/A

Table: 2.Wind turbine Parameters:

S.NO	Parameter	value
1	Mechanical output power	5KW
2	Base power of electrical generator	5.55KW
3	Base wind speed	10 m/s
4	Maximum power at base wind speed	0.7 (p u)
5	Base rotational speed	1 (p u)

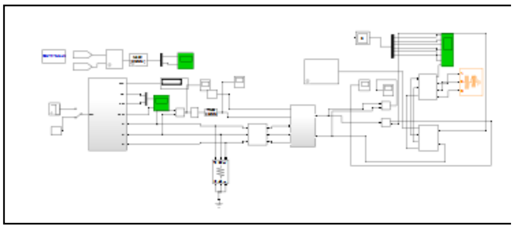


Fig 4 Simulink model of the PMSG based System

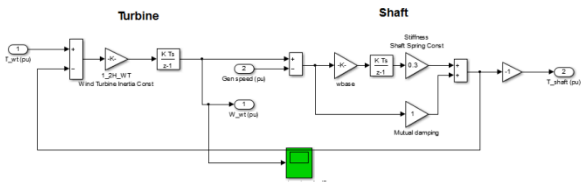


Fig .5 Wind turbine drive train based on two masse model

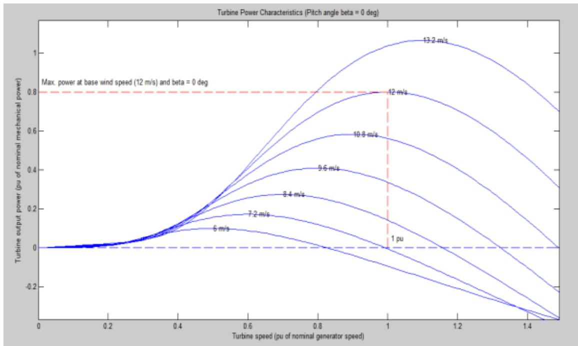


Fig .6. Wind turbine Power Characteristics(Pitch angle β=0°

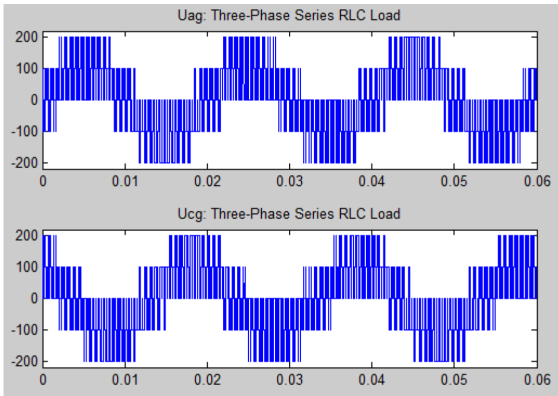
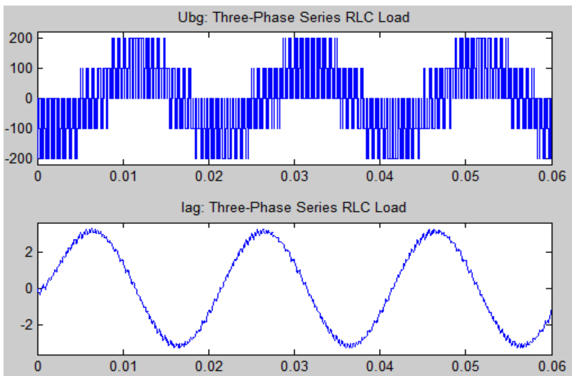


Fig .7 Three phase PWM inverter phase voltages and Phase current



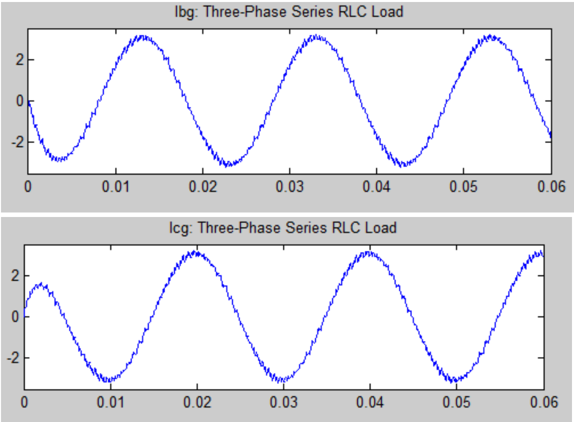


Fig 9 Three phase PWM inverter phase voltages and Phase current

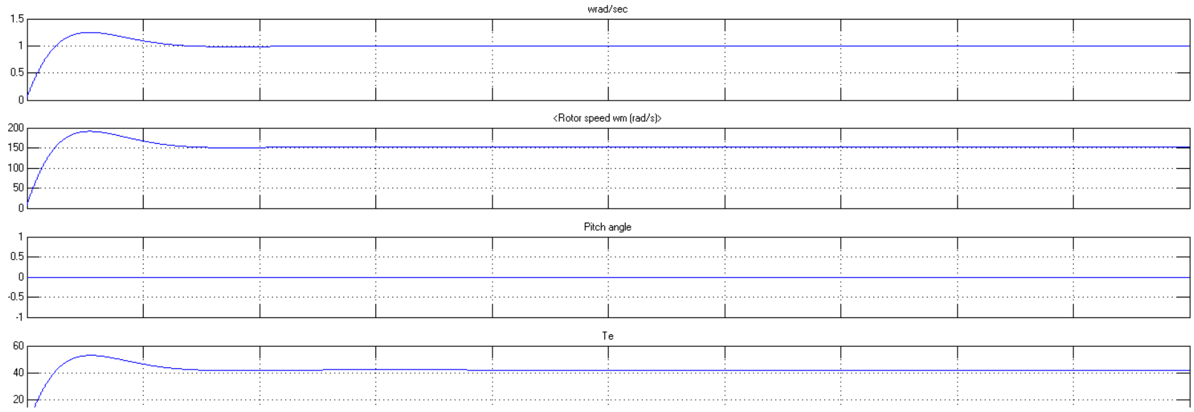


Fig .8various Wind turbine Parameters curves (in Per unit)

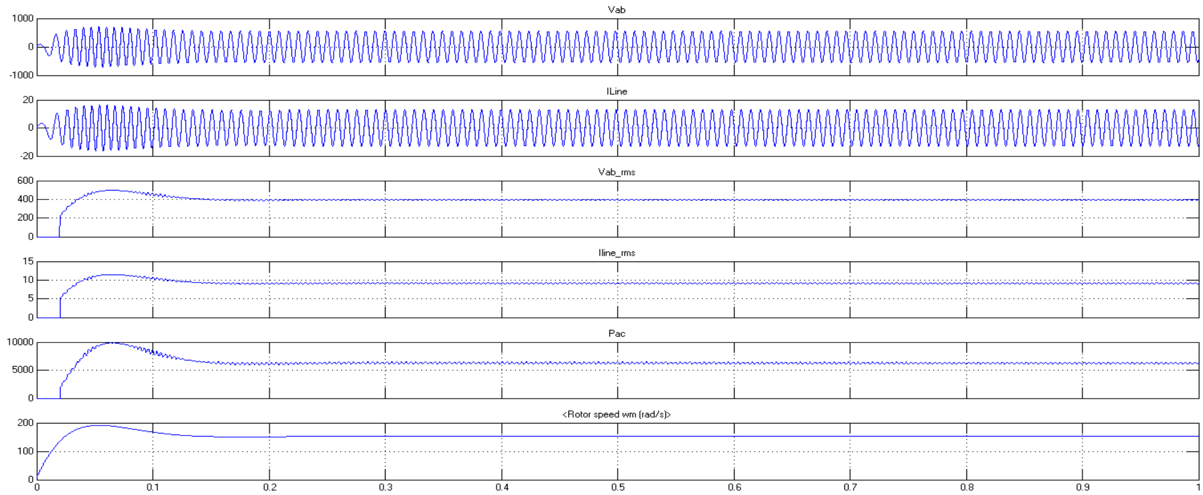


Fig .10 Various Wind Generators Parameters curves

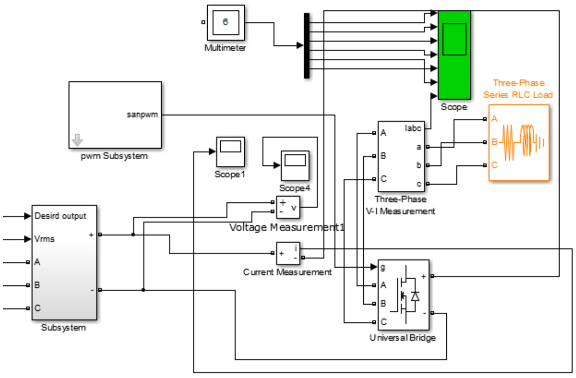


Fig 11. Simulink model of the DC to AC Inverter system

CONCLUSIONS

The paper provides performance curves of PMSG based Wind energy system coupled with 3 phase PWM inverter. Wind turbines are normally connected with asynchronous generators which require the speed multiplier to produce the desired electrical power. But Permanent magnet synchronous generators are very compact and it does not require gear box arrangement. The gear arrangement requires more maintenance A direct driven permanent magnet synchronous generator is lighter and more reliable than asynchronous generators. In variable-speed wind energy conversion system, controlling wind speed is important to extract more power from the wind for which PMSG is suitable one.

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About authors

Mr. P. Selvaraj was born in 1979 in Tamilnadu. He received his BE degree in Electrical and Electronics Engineering from Manonmaniam Sundaranar university and M.E Degree in Power Electronics and drives from Sathyabama University. He is currently working as Assistant Professor in EEE department in Adhiparasakthi Engineering College, Melmaruvathur and pursuing Ph.D degree in Faculty of Electrical Engineering at Anna University, Chennai, India. His current research includes PMSG based wind Energy systems and renewable Energy.

Miss.K.Seetha Devi is pursuing her M.E degree in Power Electronics and Drives from Adhiparasakthi Engineering College, Melmaruvathur, tamilnadu. She obtained her bachelor's degree in Electrical and Electronics Engineering from Arulmigu Meenakshi Amman College of Engineering. Her research interest is primarily in Power electronics and Renewable energy system.