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Wind Turbine System Connected to a Permanent Magnet Synchronous Generator

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Abstract - *In today's world electricity generation using renewable sources are more popular. It includes sunlight, wind, biomass, rain, tides, waves and geothermal heat etc. This paper presents a mathematical modelling and simulation of a small wind turbine for extracting wind power and convert the kinetic energy of wind to electrical energy using permanent magnet synchronous generator (PMSG) without using gear box.*

For implementing the model of wind turbine system, basic mathematical equations are carried out and the tool used is Simulink/MATLAB. The technique used is Zero d-axis control.

The simulation results here demonstrate the effectiveness of proposed mathematical model of the small wind turbine to determine its dynamic behaviors.

Key Words: Doubly fed induction generator (DFIG), Maximum power point tracking (MPPT), Permanent magnet synchronous generator (PMSG), and Wind turbine generator (WTG).

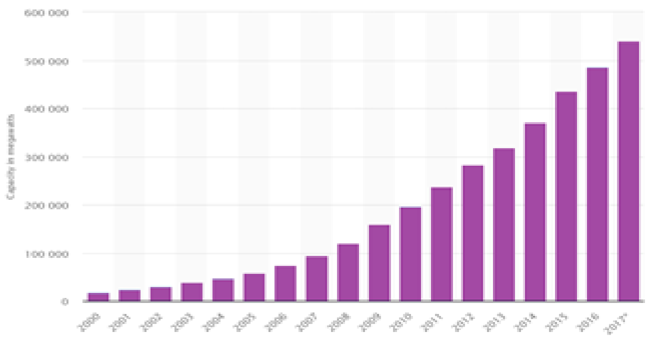
1. INTRODUCTION

Power generation by renewable energy sources is becoming more popular and economical than the traditional generation system to supply reliable power in areas not served by conventional power grids. The demand of global energy in 2040 will expand to be about 30% higher than in 2010[1].

In the last fifteen years the penetration of the wind turbine power generation is dramatically increased world-wide [2]. The wind turbine system is one of the most known and used source of renewable energy. It has not only a several environmental and economic advantages, but also, it can be installed in all regions. Around 83% of wind capacities are located in these five countries, German, United State of America, Denmark, India and Spain [3-4]. The wind turbine system produces the electrical energy from the wind speed after converting it to mechanical energy by the generator. For this purpose, we can find several types of generators such as the permanent magnet synchronous generator (PMSG) [5] [6], squirrel-cage induction generator (SCIG) [7] [8], doubly fed induction generator (DFIG) [9] [10] [11] [12], and wound rotor induction generator (WRIG). PMSG has received much attention in wind energy application because of their property of self-excitation, which allows an operation at a high power factor and high efficiency. There are so many researchers whose main focus is on the dynamic modelling and simulation of the small wind turbine system so as to get its dynamic physical model and the appropriate outputs such as the current, the voltage, and the power. Further, many control strategies can be applied to control the permanent magnet synchronous generator in order to achieve good results. In [13], a novel control strategy for the extraction of maximum power and operation of direct driven PMSG based stand-alone variable speed wind turbine system is shown. In some papers the wind turbine model deals with the mechanism of variable speed operation of the turbine by a pitch control. As in [14], the modelled system consists of a PMSG model, a pitch-angled controlled wind turbine model and a drive train model. The control scheme include a pitch angle control and a speed control of the generator. The pitch angle control uses wind speed signals and power output of the generator as the inputs and vector control is implemented for the speed control of the generator in the dq-synchronous rotating reference frame. The field orientation is realized by setting id (ref) =0 and q-axis component of the current iq controls the rotational speed.

In [15] a dynamic modelling and simulation of wind turbine connected to PMSG generator is shown and two different control techniques are compare: the fractional-order and the classical control.

This paper consists of four sections, in which section II shows the aerodynamic and the electrical dynamics of a PMSG generator with control technique i.e. Zero d-axis current control (ZDC). Section III and IV shows the simulation results of mathematical model and the overall conclusion.



Installed capacity of wind turbine system from 2000-2017

2. AERODYNAMIC MODEL OF SMALL WIND TURBINE SYSTEM

In this part we are going to study the mathematical model of a wind turbine system connected to PMSG generator and an AC load.

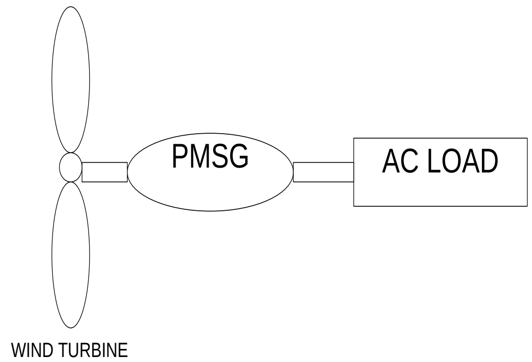


Fig.2.Wind turbine system connected to PMSG generator.

The whole wind turbine system consists of:

- Wind turbine.
- PMSG generator.
- AC load.

Generally in grid connected wind turbine system, power electronic converters are required but here in this paper the wind turbine system is directly connected to AC load without the power electronic converter. (Fig 2)

2.1 MODELLING OF THE WIND TURBINE

The mechanical power captured by the wind turbine is given by Eq (1)

$$Pw = \frac{1}{2}\rho\pi R^2 (Vw)^3 Cp \quad \text{..................... (1)}$$

Where, p = 1.225 is the air density, R (m) is the blade radius and Vw (m/s) is the wind speed.

Cq represents the torque coefficient. It can be computed using Eq (2)

$$Cq = C1\left(\frac{C2}{\lambda i - C3 * \beta - C4}\right) * \exp\left(-\frac{C5}{\lambda i}\right) + C6 * \lambda \quad \text{......... (2)}$$

Where,

$$\lambda i(\lambda, \beta) = 1/(\frac{1}{\lambda + 0.08 * \beta} - \frac{0.035}{\beta^3 + 1}) \quad \text{.............................. (3)}$$

The following coefficients were obtained:

C1=0.5176, C2=116, C3=0.400, C4=4, C5=21, C6=0.0068

Where is the pitch angle and is the tip speed ratio, and given as Eq (4)

$$\lambda = \frac{Ww.R}{Vw} \quad \text{... (4)}$$

Ww (rad/s) is the rotor speed.

The power coefficient Cp can be given by Eq (5)

$$CP = Cq.\lambda \quad \text{.. (5)}$$

The torque of the turbine Tw (N.m) can be obtained by Eq(6)

$$Tw = \frac{1}{2}\rho\pi R^3 (Vw)^2.Cq \quad \text{........................... (6)}$$

2.2 MODELING OF THE PMSG GENERATOR

The electromagnetic torque produced by the PMSG generator is given by Eq (7):

$$Te = \frac{3P}{2}(\lambda r.iqs - (Ld - Lq)ids.iqs) \quad \text{.............. (7)}$$

Where, P is the number of pole pairs, Ld (H) and Lq (H) are the dq-axis self-inductance of the synchronous generator and λr (Wb (rms)) is the rotor flux linkages.

ids And iqs present the dq-axis stator current of the PMSG generator:

$$\frac{dids}{dt} = -\frac{Rs}{Ld}ids + \frac{Lq}{Ld}\omega r.iqs - \frac{1}{Ld}vds \quad \text{......................... (8)}$$

$$\frac{diqs}{dt} = -\frac{Rs}{Lq}iqs + \frac{Ld}{Lq}\omega r.ids - \frac{1}{Lq}\omega r.\lambda r - \frac{1}{Lq}vqs \quad \text{......... (9)}$$

Rs is the stator winding resistance of the PMSG generator. vds and vqs present the dq-axis stator voltage:

$$vds = -Rs.ids + \omega r.Lq.iqs - Ld.\frac{dids}{dt} \quad \text{....................... (10)}$$

$$vqs = -Rs.idqs - \omega r.Lq.ids + \omega r.\lambda r - Lq.\frac{diqs}{dt} \quad \text{....... (11)}$$

Where, ωr (rad/s) is the rotor speed. It can be written by using Eq (12).

$$\omega r = \frac{P}{J}(Tw - Te) \quad \text{.............................. (12)}$$

J is the moment of inertia.

2.3 CONTROLLING SCHEME (ZERO D-AXIS CURRENT CONTROL)

here are several control schemes are used to control PMSG generator. In this paper a zero d-axis current (ZDC) control is applied, where the d-axis stator current of the generator ids is set to zero.

The electromagnetic torque is given as (13):

$$Te = \frac{3P}{2}\lambda r.iqs \quad = \quad \frac{3P}{2}\lambda r.is \quad .... (13)$$

Where, the stator current is calculated as:

$$is = \sqrt{ids^2 + iqs^2} \quad .... (14)$$

The dq-axis stator reference current of the PMSG generator is given as:

$$iqs* = \frac{2}{3P\lambda r}Te* \quad .... (15)$$

$$ids* = 0 \quad .... (16)$$

Where, Te* is the torque reference and given as:

$$Te* = K\omega r^2 \quad .... (17)$$

The dq-axis stator current and voltage of the PMSG generator can be written, by the following equation.

$$vds = -Ld(\frac{Lq}{Ld}\omega r.iqs + vds*) \quad .... (18)$$

$$vqs = -Lq(-\frac{Ld}{Lq}\omega r.ids - \frac{1}{Lq}\omega r.\lambda r + vds*) \quad .... (19)$$

$$\frac{diqs}{dt} = -\frac{Rs}{Ld}ids + vds* \quad .... (20)$$

$$\frac{diqs}{dt} = -\frac{Rs}{Lq}iqs + vqs* \quad .... (21)$$

Rs (ohm) is the stator winding resistance of the PMSG generator.

The mechanical power of the PMSG generator is given by the Eq (22).

$$Pm = Tm.\omega m \quad = \frac{Tw.\omega r}{P} \quad .... (22)$$

Tm is the mechanical torque and ωm is the rotor mechanical speed. Here the mechanical speed is equal to the rotor electrical speed ωr because of no gearbox.

The active power delivered to the load:

$$Pl = Pm - Pcu,s \quad .... (23)$$

$$Pl = 1.5(vds.ids + vqs.iqs) \quad .... (24)$$

Where Pcu,s is the stator winding loss:

$$Pcu,s = 3Is^2Rs \quad .... (25)$$

The reactive power delivered to the load is determined by using Eq (26).

$$Pq = 1.5(vqs.ids + vds.iqs) \quad .... (26)$$

Is and Vs are rms stator current and voltage:

$$Is = \sqrt{\frac{ids^2 + iqs^2}{2}} \quad .... (27)$$

$$Vs = \sqrt{\frac{vds^2 + vqs^2}{2}} \quad .... (28)$$

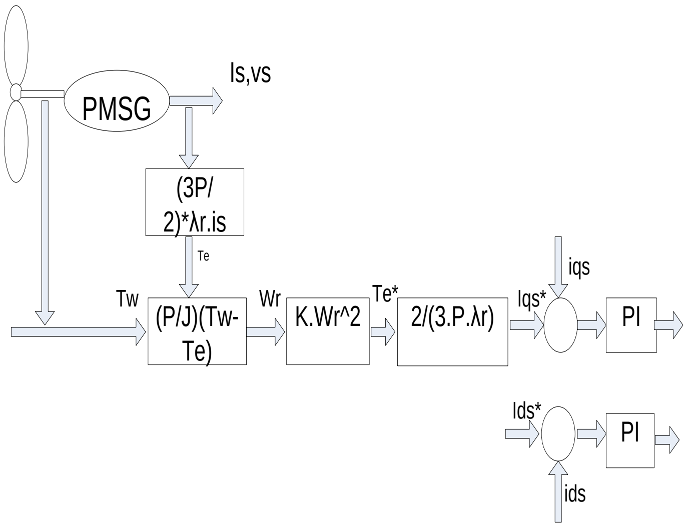


Fig 3.ZDC control scheme of PMSG generator.

In this paper ZDC control strategy is used, in which d-axis stator current is made zero to get maximum torque with a minimum stator current. The ZDC control scheme of the PMSG generator is shown in fig.3.

3. SIMULATION RESULTS

The model Simulink of the wind turbine system connected to a PMSG generator during 10 s is shown in fig.4. It is carried out using MATLAB/Simulink.

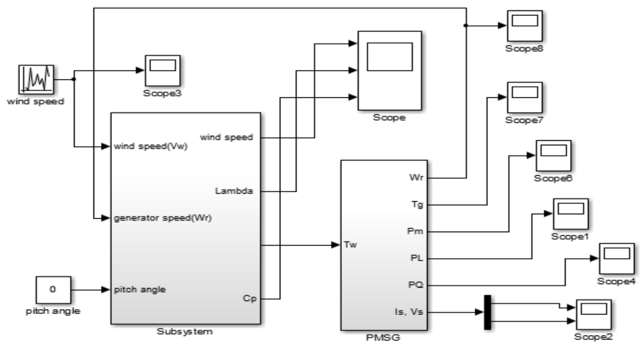


Fig.4. Model Simulink of wind turbine system.

Figure 5 presents the model Simulink showed below the block "wind turbine" where its input parameters are the wind speed, pitch angle, which is equal to zero, and the generator speed which is equal to the rotor speed generated by the PMSG generator.

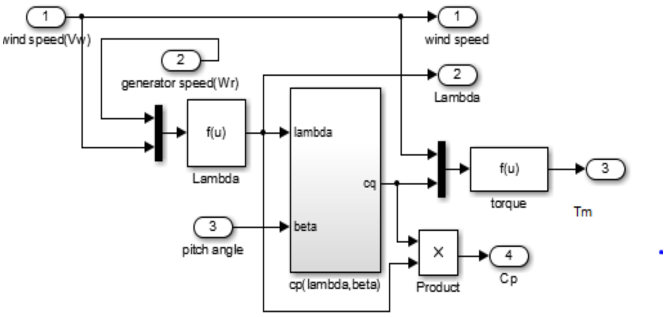


Fig.5. Model Simulink under block "wind turbine".

The model Simulink below the block "PMSG" generator is plotted in Fig.6. Its Input parameter is the torque generated by the wind turbine and the output parameter are the rotor speed, electromagnetic torque, current, voltage, and mechanical, active and reactive power.

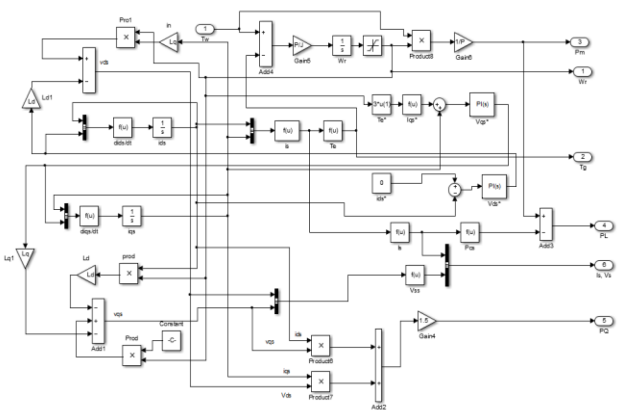


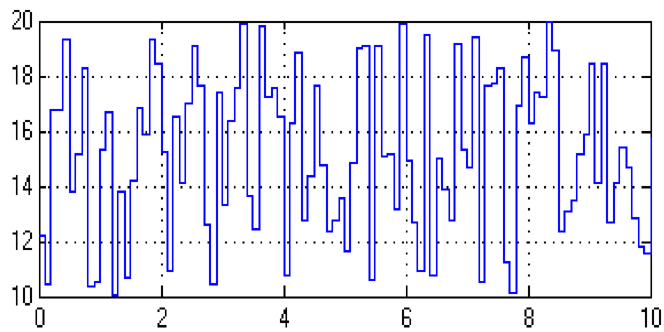
Fig.6. Model Simulink under block "PMSG"

The parameters of the wind turbine system are summarized in Table 1.

Table -1: Parameters of Wind Turbine System

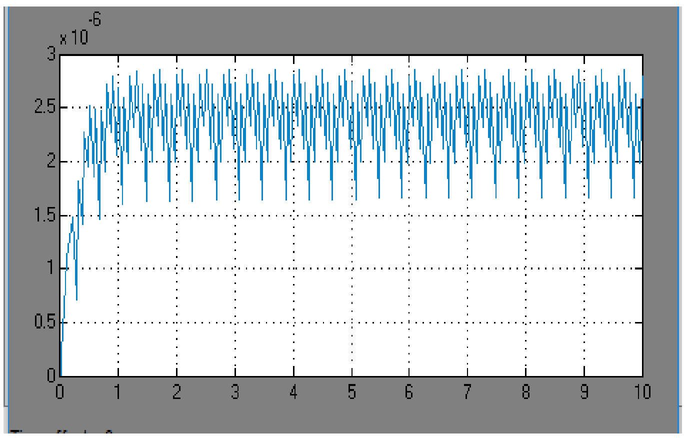
Maximum wind speed	18.73 (m/s)
Pitch angle	0 deg
C	2.245 m
Stator winding resistance of synchronous generator	2.87 ohm
dq-axis self-inductance of synchronous generator.	0.05297 H
Number of pole pairs	2
Rotor flux linkages	6.7302 Wb rms)
Moment of inertia	0.1278

The most important parameter of wind turbine system is wind speed. Its variation is shown in Fig.7.

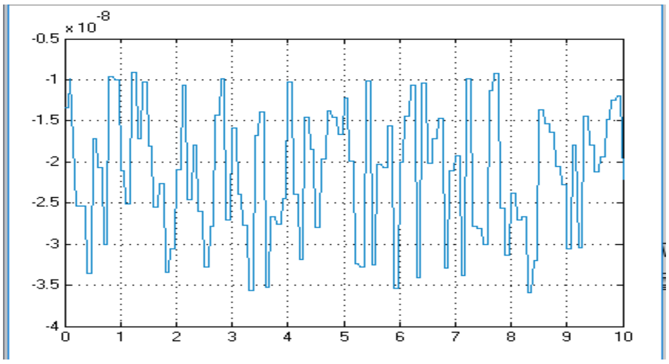


Time (second)
Fig.7.variation of wind speed.

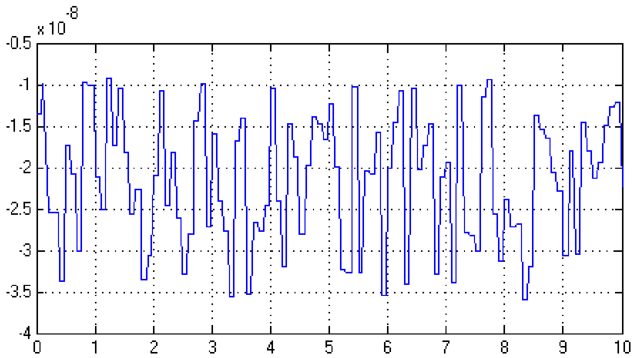
Fig.8 shows the variation of torque Tw (Nm) generated by wind turbine system.



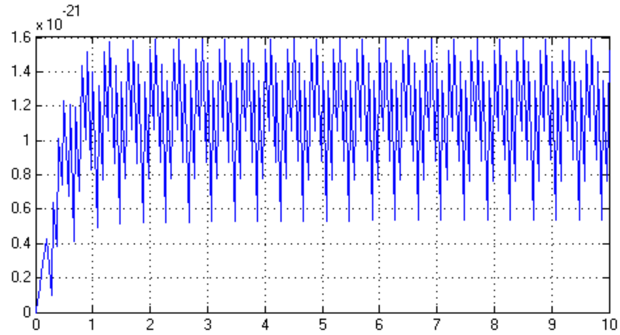
Time (second)
Fig .8. Variation of torque generated by wind turbine



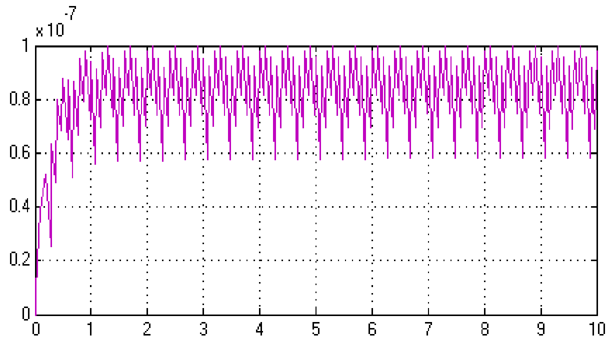
Time (second)
Fig.9. Variation of mechanical power



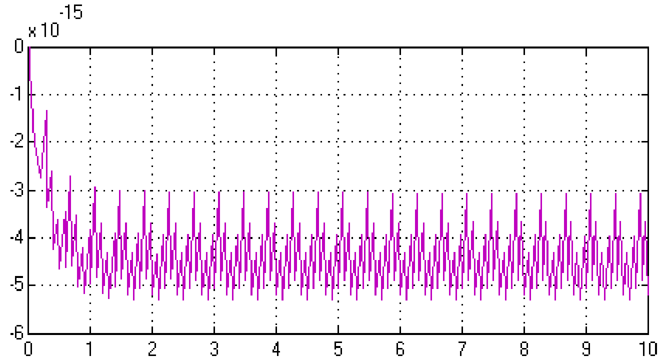
Time (second)
Fig.10. Variation of active power



Time (second)
Fig.11. Variation of reactive power



Time (second)
Fig.12. Variation of current



Time (second)
Fig.13. Variation of voltage

The simulation result show that the mechanical and active power vary according to the variation of wind speed. The maximum wind speed is 18.7 m/s.

3. CONCLUSION

Simply, the enhancement of the renewable energy is the intension of numerous studies concerning its advantages in terms of efficiency, reliability and cost. The wind system is considered one of several power supplies which is used to supply energy with reduced pollution. This papers objective is to expand a dynamic model of a small wind turbine system primarily based on PMSG generator. The simulation results display the efficiency of shown mathematical model to decide the expected dynamic behaviors along with: voltage, current and electricity using MATLAB/simulation.

REFERENCES

[1] J. Dashwood, "Australia's Energy Options: Renewables and efficiency," Aust. Energy Options Renewables Effic., no. May, pp. 45–52, 2012.

[2] J. S. Thongam, P. Bouchard, R. Beguanne, A. F. Okou, A. F. Merabet, "Control of variable speed wind energy conversion system using a wind speed sensorless optimum speed MPPT control method", in Proc. 37th Annual Conference on IEEE Industrial Electronics Society, IECON 2011, Melbourne, Australia, 70-10 Nov., 2011, pp. 855-860.

[3] T. Ackermann. "Wind Power in Power Systems. New York: John Wiley &Sons, 2005.

[4] The American Wind Energy Association. (2004 March). "Global Wind Power Growth Continues to strengthen [online]. Available: http://www.ewea.org.

[5] M. A. Badr, A. M. Atallah, and M. A. Bayoumi, "Comparison between Aggregation Techniques for PMSG Wind Farm," Energy Procedia, vol. 74, pp. 1162–1173, 2015.

[6] X. Yang, X. Gong, and W. Qiao, "Mechanical sensorless maximum power tracking control for direct-drive PMSG Wind turbines," 2010 IEEE Energy Convers. Congr. Expo. ECCE 2010 - Proc., pp. 4091– 4098, 2010.

[7] B. Wu, Y. Lang, N. Zargari, and S. Kouro, Power Conversion and Control of Wind Energy Systems. 2011.

[8] M. Quan, F. Grimaccia, S. Leva, M. Mussetta, and E. Ogliari, "Pitch angle control using hybrid controller for all operating regions of SCIG wind turbine system," Renew. Energy, 2014.

[9] J. J. Justo, F. Mwasilu, and J.-W. Jung, "Doubly-fed induction generator based wind turbines: A comprehensive review of fault ridethrough strategies," Renew. Sustain. Energy Rev., vol. 45, pp. 447– 467, 2015.

[10] A. El-Naggar and I. Erlich, "Analysis of fault current contribution of Doubly-Fed Induction Generator Wind Turbines during unbalanced grid faults," Renew. Energy, vol. 91, pp. 137–146, 2016.

[11] S. A. A. Shahriari, M. Raoofat, M. Mohammadi, M. Dehghani, and M. Saad, "Dynamic state estimation of a doubly fed induction generator based on a comprehensive nonlinear model," Simul. Model. Pract. Theory, vol. 69, pp. 92–112, 2016.

[12] G. Sarwar, J. Wang, and M. Hussain, "Active and reactive power control of the doubly fed induction generator based on wind energy conversion system," Energy Reports, vol. 2, pp. 194–200, 2016.

[13] R. Melício1, V.M.F. Mendes2, J.P.S. Catalão1, "Dynamic Stability of Wind Turbines with Permanent Magnet Machines and Power-Electronic Converters,"IEEE 2009.

[14] A.G.Sanchez, M.G.Molina, A.M Rizzato Lede, "Dynamic model of wind energy conversion systems with PMSG-based variable –speed wind turbines for power system studies," International journal of hydrogen energy (2012).

[15] M.Seixas,R. melicio, and V.M.F.Mendes, "simulation by discrete mass modeling of offshore wind turbine system with DC link,"int.J.Mar.energy,vol.14,pp.80-100,2016.