

# PMSG Based Wind Power Regulator Using Fuzzy Logic Controller

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**ABSTRACT:** This paper presents a system in which a wind Permanent Magnet Synchronous Generator feeds an isolated load through a Boost Converter and an inverter. The output voltage and frequency of the PMSG is variable in nature due to non uniform wind velocities. The fluctuating output is rectified and kept constant by means of a boost converter. A fuzzy logic controller is designed to set the duty ratio of the boost converter is varied to maintain a constant DC output voltage. Also to choose the moment to charge/discharge the battery and the moment to dissipate excess energy in a non linear resistance. This converter output is converted to three phase ac using a three phase PWM inverter, which employs hysteresis current control to control the output voltage. The power converters together with independent control systems can effectively improve the output voltage and frequency of the wind PMSG feeding an isolated load. The model has been demonstrated using MATLAB Simulink based simulations.

**KEYWORDS:** Battery, Boost Converter, Fuzzy logic control, Hysteresis current control, Permanent Magnet synchronous Generator

## I. INTRODUCTION

Under the pressure of limited available renewable energy resources and environmental policies, electrical power using renewable energy has rapidly increased in recent years [1]. In India, a large number of remote rural or mountainous inhabitants have no access to the main electricity supply network so it is important to explore the local natural renewable energy resources such as wind or solar [2] for power generation, mainly for local consumptions. Due to the nature of intermittence of renewable energy, the use of the secondary energy storage such as batteries become inevitable which will compensate the fluctuations of power generation [3]. The use of a small size wind turbines could enable more households to have accesses to electricity. A permanent magnet synchronous generator (PMSG) based variable speed wind turbine has received much attention in a standalone mode because of its simplicity, less maintenance, leading to a higher power factor and high efficiency [4]. The wind turbine alone cannot meet the load demand due to its nature. Some additional sources and sinks are in order to balance the fluctuating nature of the wind. Different and local bodies are connected at a Cbus, which can operate in both grid and off-grid conditions, is formally called AC microgrid [5]. With the rapid development of renewable energy and power electronics technology, cost reduction in energy storage and wider applications of microgrid system, different control strategies and energy management systems have been proposed for wind integration [4]. Normally, microgrid is intentionally operated in off-grid mode in rural areas where the availability of grid is impossible due to technical, geographical and social reasons [5]. In this kind of micro grid, diesel generator is the common controlled source. However, the off grid micro grid can be also used in urban areas to reduce the load stress and power congestion in weak grid and large demand power systems. Especially, in developing countries, where the load-shedding occurs due to extreme weathers, societal involvement and limited resources with increasing demand [6]. Similarly, in developed countries, the high penetration of unequal distribution of electric vehicle (EV) has created lots of challenges to the grid and ultimately affects the rating of the components and the peak load of the existing grid [7]. This problem can be reduced by charging EV

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Vol. 4, Special Issue 6, May 2015

independent of the grid. Therefore, the scattered microgrid forming with some renewable energy like wind, energy storage, dump loads and loads can be used in these urban areas to solely provide power to residential or commercial areas in the vicinity of grid. The control of an inverter to present the customers with the balanced supply voltage is the main challenge in the stand-alone system. Moreover, voltage variations, flickers, harmonic generation, and load unbalance are the major power quality problems that occur in the wind energy conversion system. The voltage fluctuations are primarily caused by variations in the power from WECS due to the fluctuations to the wind speed. Unwanted harmonics are generated due to the power electronic interface (rectifier, inverter and dc-dc converter) between the wind generator and load. Those power quality problems may not be tolerated by the customers and require controllers. Unbalanced load will create pulsation in generator torque which will reduce the life of the turbine shaft. To meet the amplitude and frequency requirements of conventional loads, the amplitude and frequency output of PMSG requires additional conditioning. Few papers have been published on maintaining DCL voltage in a standalone PMSG based VSWT [9-12]. Recently, M. Dali worked on the duty cycle of a boost converter, managed in the same time the MPPT control and the load voltage by using a PI controller for current and voltage [4].

Although conventional PI controller have been well developed and applied for industrial automation and process control due to their simplicity of operation, ease of design and effectiveness for most linear systems, it generally does not work well for nonlinear systems, higher order and time-delayed linear systems, and particularly complex and vague systems that have no precise mathematical models [7]. To overcome these difficulties, various types of controllers using artificial intelligent such as fuzzy logic, genetic algorithm... were developed lately [8].

In this paper, we propose a wind energy conversion system for remote site using a variable speed PMSG, a battery bank and a fuzzy controller to optimize the operation of both the wind turbine and the battery according to wind speed and load demand. we use fuzzy controller to set the duty ratio of the second boost converter (DC/DC) in order to

- (i) adjust the DC output voltage to choose the moment to charge/discharge the battery
- (ii) The moment to dissipate excess energy in a dumb resistance.

## II. WIND ENERGY CONVERSION SYSTEM

Wind turbines convert aerodynamic power into electrical energy. In a wind turbine two conversion processes take place. First the aerodynamic power (available in the wind) is converted into mechanical power. Next the mechanical power is converted into electrical power.

The conversion of the wind power to mechanical power by the wind turbine rotor can be simulated by the static relation:

$$P_w = 0.54 C_p A V_w^3 \dots \dots \dots (1)$$

The rotor mechanical torque can be calculated from  $P_w$  by

$$T_w = \frac{P_w}{\omega_R} \dots \dots \dots (2)$$

The rotor aerodynamic power coefficient,  $C_p$ , is the percentage of the kinetic energy of the incident air mass that is converted to mechanical energy by the rotor, and it is expressed as a function

$$C_p = C_p(\lambda, \beta) \dots \dots \dots (3)$$

where  $\beta$  is the blade pitch angle and  $\lambda$  the tip speed ratio of the blade, and defined as

$$\lambda = \frac{R \omega_R}{V_w} \dots \dots \dots (4)$$

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Using the above relations and the rotor  $C_p(\lambda)$  characteristic, the rotor aerodynamic torque and power curves can be calculated.

Basically, the mass model of a PMSG is the same as that of a permanent magnet synchronous motor (PMSM). The voltage and torque equations the PMSM in the d-q reference frames are given by the following equations

$$v_d = (R_s + PL_d)i_d - \omega_e L_q i_q \dots \dots \dots (5)$$

$$v_q = \omega_e L_d i_d + (R_s + PL_q)i_q - \omega_e K \dots \dots \dots (6)$$

$$T_e = K(i_q + (L_d - L_q) i_d i_q) \dots \dots \dots (7)$$

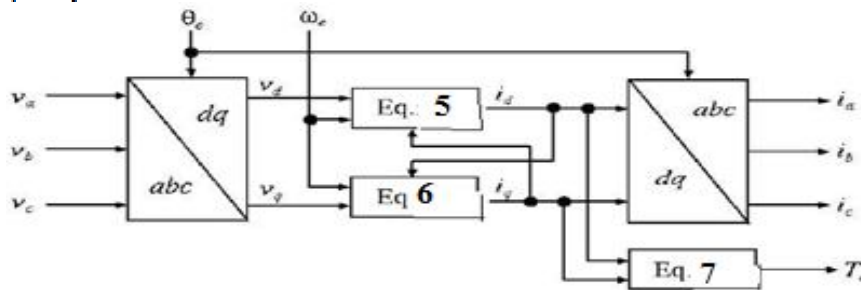


Figure 1. Model of drive train.

Where

$v_d$  and  $v_q$  are dq-axis voltage,

$i_d$  and  $i_q$  are dq-axis current,

$R_s$  is stator resistance,

$L_d$  and  $L_q$  are dq-axis inductance,

$\omega_e$  is electrical rotational speed,  $K$  is permanent magnetic flux, and  $P$  is differential operator.

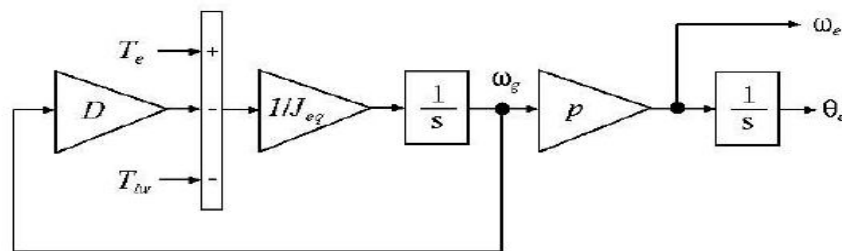


Figure 2. Model of PMSG.

Generating operation starts when the electromagnetic torque  $T_e$  is negative.

In addition, the motion equation of the PMSG is given by the following equation:

$$T_e = J_{eq} \frac{d\omega_g}{dt} + D\omega_g + T_{mv} \dots \dots \dots (8)$$

Where  $J_{eq}$  is the equivalent inertia &  $\omega_g$  is the rotational speed.

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

## III. SYSTEM DESCRIPTION

Our system consists of a PMSG (12 KW) to power a 2kW pump, a 3kW induction machine, a 4kW water heater, and a lead acid battery for backup storage. A diode bridge rectifier and a boost converter are used for MPPT purpose and for electrical production management.

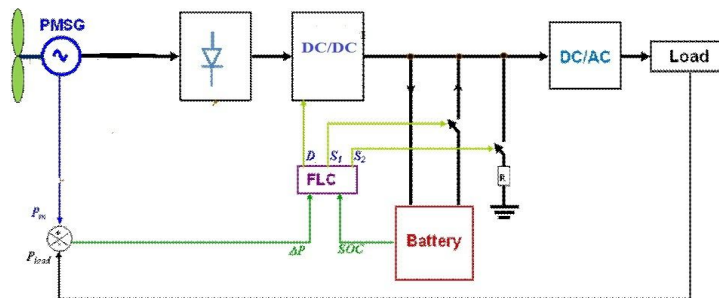


Figure 3. Block diagram

A fuzzy logic controller (FLC) is designed to adjust the DC voltage to a value suitable for battery charging and also suitable for the proper operation of the PWM inverter. If wind conditions are favorable, the wind turbine will be the main supplier for load. If the wind does not give enough power to load, and the battery capacity is sufficient, the battery will start to provide the necessary power. If the power of the wind turbine exceeds the load demand, the surplus is stored in the battery and if the battery is full, the surplus will be dissipated in a resistor. Thus, the battery is not the main supplier, so that the number of charge/discharge rate is reduced, and consequently the life of the battery is extended.

### Fuzzy controller for the production process

Inputs for this controller are the battery state of charge (SOC) and the error power DeltaP (difference between wind power and load power). The outputs are the duty ratio D2 applied to the second boost converter for charging the battery (ensuring a safe and effective) and ensure that the input voltage is sufficient for the PWM inverter, the time to charge/discharge the battery and the time to dispel the surplus to a discharge resistor. The linguistic term sets used for:

- Power error DeltaP [Negative, Small Positive, Positive, Very Positive].
- Battery's state-of-charge SOC [Empty, Average, Full].
- Duty cycle D2 [Very Small, Small, Medium, Big, Very Big].
- Switch S1 and S2 [Opened, Closed].

The method of inference rules is also the min-max inference and the implementation of the rules was based on fuzzy rules of Mamdani type [17]. Example: "If the error between wind power and load demand is Positive and battery state-of-charge is Full, then, switch 1 should be Opened and switch 2 should be Closed".

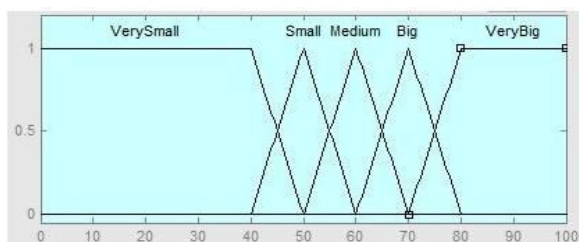


Fig. 4 Five terms of variable D

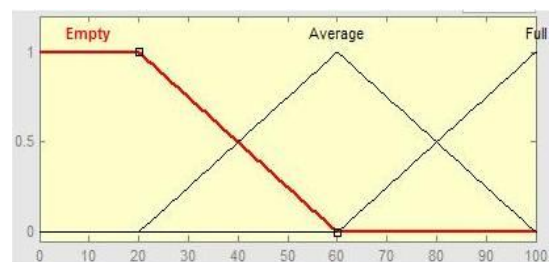


Fig. 5 Three terms of variable "SOC"

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Vol. 4, Special Issue 6, May 2015

The fuzzy rules used in our FLC 2 are summarized in table 1,2 and 3

D <sub>2</sub>		SOC		
		Full	Average	Empty
DeltaP	N	Big	Big	Small
	SP	Very Big	Big	Small
	P	Very Big	Very Big	Medium
	VP	Very Big	Very Big	Medium

S <sub>1</sub>		SOC		
		Full	Average	Empty
DeltaP	N	Close	Close	Open
	SP	Open	Open	Open
	P	Open	Open	Open
	VP	Open	Open	Open

Table 1. Rules of D

Table 2. Rules of S1

S <sub>2</sub>		SOC		
		Full	Average	Empty
DeltaP	N	Open	Open	Open
	SP	Open	Open	Open
	P	Open	Open	Open
	VP	Close	Open	Open

Table 3. Rules of S2

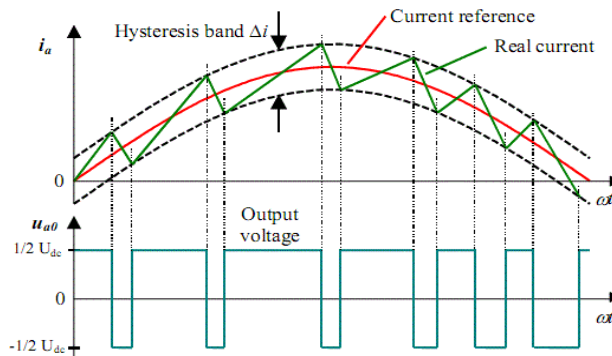


Figure 6. Control Strategy for Inverter

When the error exceeds the upper hysteresis band, the inverter output is switched low, and when the error falls below the lower hysteresis band, the inverter output switches high. The advantages of this technique are high simplicity, good accuracy, outstanding robustness and a response speed limited only by switching speed and load time constant.

## IV. SIMULATION RESULT

The proposed model is simulated using MATLAB 7.14 and the simulation model is shown in Fig 7. The voltage is measured at different points in the simulation circuit. The generated output is converted to DC and it will vary with the wind speed.

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Vol. 4, Special Issue 6, May 2015

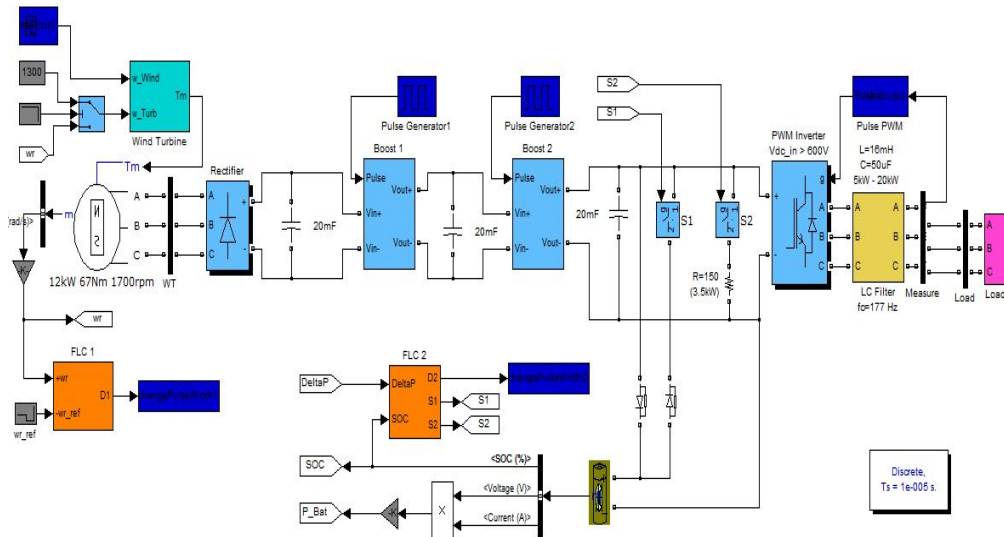


Figure 7. MATLAB/Simulink Simulation model

The output voltage of rectifier shown in figure 8

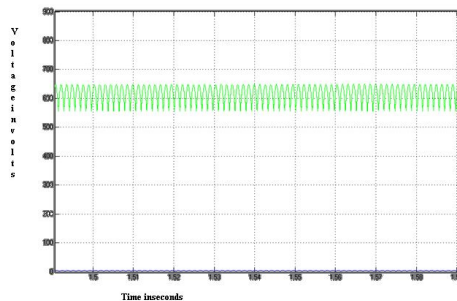


Figure 8. Output voltage of rectifier

The DC voltage is then boosted with the closed loop boost converter (CLBC). The output of closed loop boost converter is shown in figure 9

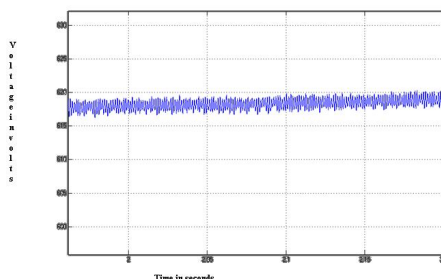


Figure 9. Output voltage of closed loop boost converter

Thus the output at the CLBC is fed to the three phase inverter, output of inverter shown in Fig 10

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

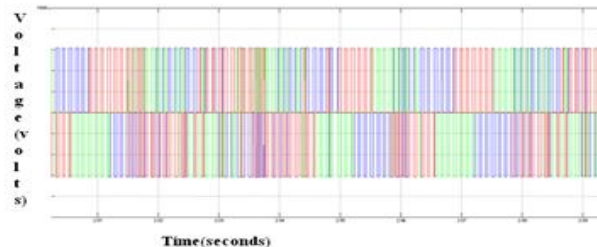


Figure 10. Expanded view of output voltage

## V. CONCLUSION

This paper presents an efficient control method for PMSG based wind energy conversion system. In the proposed system, the output of the PMSG is converted to constant DC using a full bridge rectifier and it is regulated using a PI controller based CLBC. The constant DC is converted to AC and it is fed to the load. From the simulation results, we can conclude that, even at low wind speed and low power generation, the required voltage and frequency can be obtained at the output. The main advantage of this system is its minimum wind speed requirements and reduced generator power ratings.

## REFERENCES

- [1] T. Senjyu, R. Sakamoto, N. Urasaki, T. Funabashi, H. Fujita, and H. Sekine, "Output power leveling of wind turbine generator for all operating regions by pitch angle control" *IEEE Transactions on Energy Conversion*, volume 21, no. 2, pp. 467–475, June 2009
- [2] B. G. Rawn, P. W. Lehn, and M. Maggiore, "Control methodology to mitigate the grid impact of wind turbines," *IEEE Transactions on Energy Conversion*, volume 22, no. 2, pp. 431–438, June 2007.
- [3] C. Luo, H. Banakar, B. Shen, and B-T. Ooi, "Strategies to smooth Wind power fluctuations of wind turbine generator," *IEEE Transactions on Energy Conversion*, volume 22, no. 2, pp. 341–349, Jun. 2007.
- [4] L.-R. Chang-Chien and Y.-C. Yin, "Strategies for operating wind power in a similar manner of conventional power plant," *IEEE Transactions on Energy Conversion*, volume 24, no. 4, pp. 926–934, Dec. 2009.
- [5] N. A. Schinas, N. A. Vovos, and G. B. Giannakopoulos, "An autonomous system supplied only by a pitch-controlled variable-speed wind turbine," *IEEE Transactions on Energy Conversion*, volume 22, no. 2, pp. 325–331, Jun. 2007.
- [6] F. D. Kanellos and N. D. Hatziaargyriou, "Control of variable speed wind turbines in isolated mode of operation," *IEEE Transactions on Energy Conversion*, volume 23, no. 2, pp. 535–543, Jun. 2008.
- [7] W. Qiao, L. Qu, and R. G. Harley, "Control of IPM synchronous generator for maximum wind power generation considering magnetic saturation," *IEEE Transactions on Industrial Applications*, volume 45, no. 3, pp. 1095–1105, May/June 2009.
- [8] J. M. Mauricio, A. Marano, A. G. Exposito, and J. L. M. Ramos, "Frequency regulation contribution through variable-speed wind energy conversion systems," *IEEE Transactions on Power Systems*, volume 24, no. 1, pp. 173–180, Feb. 2009.
- [9] S. Morimoto, H. Nakayama, M. Sanada, and Y. Takeda, "Sensor less output maximization control for variable-speed wind generation system using IPMSG," *IEEE Transactions on Industrial Applications* volume 41, no. 1, pp. 60–67, Jan./Feb. 2005.
- [10] P-K. Keung, P. Li, H. Banakar, and B. T. Ooi, "Kinetic energy of wind turbine generators for system frequency support," *IEEE Transactions on Power Systems*, volume 24, no. 1, pp. 279–287, Feb. 2009.
- [11] Meghdad Fazeli, Greg M. Asher, Christian Klumpner, and Liangzhong Yao, "Novel Integration of DFIG-Based Wind Generators Within Micro grids" *IEEE Transactions on Energy Conversion*, volume 26, no. 3, pp. 840–850, September 2011
- [12] Md. Enamul Haque, Michael Negnevitsky, and Kashem M. Muttaqi, "A Novel Control Strategy for a Variable-Speed Wind Turbine With a Permanent-Magnet Synchronous Generator" *IEEE transactions on industrial electronics*, volume 53, no. 5, pp. 331–340, January 2010
- [13] Juan Manuel Mauricio, Alejandro Marano, Antonio Gómez-Expósito, and José Luis Martínez Ramos, "Frequency Regulation Contribution Through Variable-Speed Wind Energy Conversion Systems" *IEEE transactions on power systems*, Volume. 24, no. 1, pp. 173–180, February 2009
- [14] Frede Blaabjerg, Remus Teodorescu, Marco Liserre, and Adrian V. Timbus, "Overview of Control and Grid Synchronization for Distributed Power Generation Systems" *IEEE transactions on industrial electronics* volume 53, no. 5, pp. 1398–1410, October 2009