

Control Techniques and Low-Cost Permanent Magnet Synchronous Generator Design for Small Wind Power Generation Plant

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ABSTRACT

Designing a low-cost power converter for small-scale wind turbine systems using permanent magnet synchronous generators (PMSG) is one of the hot topics in the wind power generation research. Using minimum number of switches with high efficiency is the target of this proposal. The proposed converter consists of six switches in the generator and grid side. The DC-link side is divided into two capacitors with mid-point to connect the third phase of the PMSG to this point. The topology and the control strategy are implemented and the validity of this topology is validated by using PSIM software.

Keywords: Photovoltaic, Maximum Power Point, Support Vector Regression.

I. INTRODUCTION

The world's population is forecasted to grow by 2.5 billion by 2050, reaching a total of some 9.2 billion. In addition, many economies are currently experiencing rapid expansion and industrialization. As population grows and industry expands, so does the demand for energy. If governments around the world maintain their current policies, the world's energy needs may increase by 50% or more by 2030. In the past, these needs have been satisfied largely by finite energy sources. Satisfying the growing demand for energy with the help of fossil fuels and nuclear power is becoming increasingly difficult. The wind energy use has been drastically improved because of energy prices, environmental concerns, and enhanced efficiency of composite wind turbines. The wind installation capacity has been growing at an average rate of 35% per year [1]. On the other hand, the 4th Assessment Report of the IPCC predicts that temperatures will rise between 1.8°C and 4°C by the end of the twenty-first century. To limit global warming to no more than two degrees – as agreed at the UN Climate Change Conference in Bali in 2007 – we must reduce global greenhouse gas emissions by at least 50% compared to their 1990 level by 2050. The Stern Report estimates that, without swift action, economic losses due to climate change could amount to 20% of global GDP each year. The international wind energy market

showed a new record in 2003 with a growth rate of 15%.

Globally, a total power of 8.3 GW was installed. The total installed wind energy power has now reached more than 40 GW, and the average growth in the market during the past five years has been 26% per year. This illustrates how during the past 25 to 30 years the use of wind turbines for electricity generation has grown from a grass-root initiative to an efficient alternative energy resource. The capacity of a commercial wind turbine has today reached the range of 2–5MW, with large plants being built world-wide on land and offshore. This status illustrates the increasing concern in the world, and perhaps in Europe in particular, about the supply and consumption of energy in a modern and civilized society. Over the centuries, energy has been supplied by wood, coke, coal, oil, and natural gas, as well as by uranium (nuclear energy). The early sources were natural in the sense that they renewed themselves over a short time period (years), while the later energy supplies were tapped from sources established millions of years ago. The increasing energy demands in the world today, owing to improved and expanded civilizations and to increasing populations, have led to concerns over the limited energy resources in storage on the earth. Two major technological developments have recently taken place in the field of wind power technology, the first is a substantial scaling up has taken place to further

reduce the cost of wind power. Secondly, the individual turbine has become larger and so has the typical project scale. For modern wind turbines of the multi-MW class, both the nacelle height and the rotor diameter are in the order of 100 m. Thus, at the vertical position, the blade tip can reach heights of up to 150 m. The development of the scale of individual wind turbines introduced on the market is depicted in Fig. 1

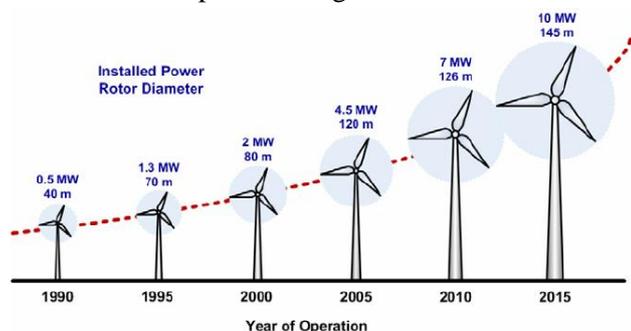


Figure 1. Size and rating of wind turbines at market introduction

The variable speed wind turbine with a permanent magnet synchronous generator (PMSG) and full-scale voltage source converters is a promising configuration, but still not used popularly [1]. The advantages of such configuration are 1) no gear; 2) no dc excitation system [2]; and 3) robust control systems for maximum wind power extraction and grid interface. So, the reliability and efficiency of a voltage source converters-based PMSG wind turbine is considered to be higher than that of a doubly-fed induction generator wind turbine [3]. Due to the tough grid codes, a PMSG wind turbine with a back-to-back converter is becoming more and more implemented by the wind power sector [1]–[3] as Figure 2 shows.

The main features of the back-to-back converter are that the converter uses active devices at both the generator side for the converter and the grid side for the inverter the advantages of this converter are as follows:

- ✓ The rectifier is fully controllable, and
- ✓ Both converter and inverter bridges are built of active IGBT devices, with the current ability to flow from
- ✓ either the generator side to the grid or the grid side to the generator.
- ✓ The major disadvantage of back-to-back converter is:
- ✓ The controller is complex and expensive because it requires 12-channel Pulse Width Modulation (PWM)
- ✓ signals for the converter and the inverter.

For this reason, in a practical application, the control system requires Digital Signal Processor (DSP) to control the chips on the board. A simple topology for wind turbine generation which consists of a diode bridge rectifier, with a DC link to an active IGBT inverter. Nowadays, commercial PMSG technology mainly uses this topology for its low cost and simplicity.

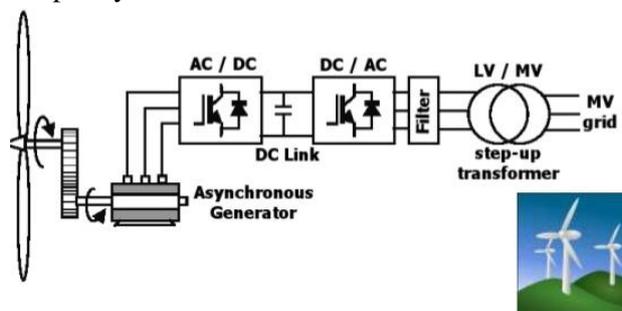


Figure 2. Conventional Back-to-Back System

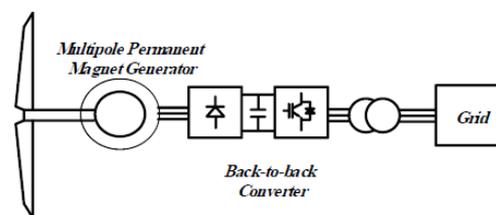


Figure 3. PMSG Wind Power System with diode rectifier.

In this paper, a low-cost power converter for small-scale wind turbine systems using permanent magnet synchronous generators (PMSG) is proposed. Using minimum number of switches with high efficiency is the target of this proposal. The proposed converter consists of six-switches in the generator and grid side. The DC link side is divided into two capacitors with mid-point to connect the third phase of the PMSG to this point. The topology and the control strategy will be implemented by using PSIM software.

II. METHODS AND MATERIAL

1. System Description

In this proposal, a converter of two-leg PWM converter and the single-phase half-bridge inverter can be used for the three-phase PMSG to be connected to the single-phase utility grid. The vector control of the PMSG is possible and the dynamic control performance becomes fast.

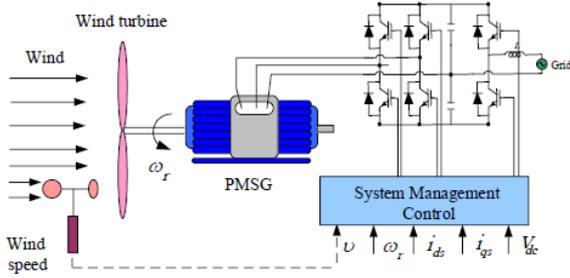


Figure 4. Basic configuration of the proposed system.

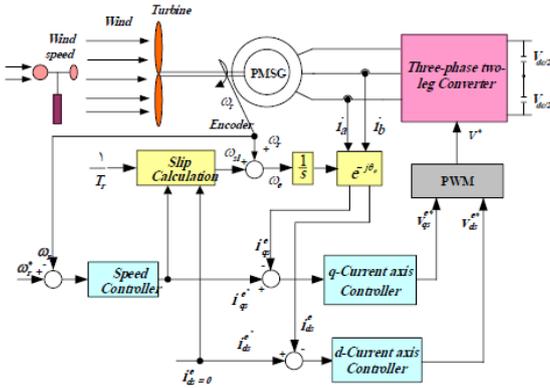


Figure 5. Control block diagram of PMSG

2. Single-phase half-bridge inverter

A half bridge inverter of a three wire dc source in which $V_{dc}/2$ voltage is obtained across the C+ capacitor terminals as shown in Fig. 6. When T1 is turned on T2 is turned off, the instantaneous voltage across the load is $V_{dc}/2$ as seen in Fig.6. On the other contrary, if T2 is turned on and T1 is turned off, the instantaneous voltage across the load is $-V_{dc}/2$. The power topology of a half-bridge VSI, where two large capacitors are required to provide a neutral point N, such that each capacitor maintains a constant voltage = $V_{dc}/2$. Because the current harmonics injected by the operation of the inverter are low-order harmonics, a set of large capacitors is required. It is clear that both switches T1 and T2 cannot be on simultaneously because short circuit across the dc link voltage source VI would be produced. There are two defined (states 1 and 2) and one undefined (state 3) switch state as shown. In order to avoid the short circuit across the dc bus and the undefined ac output voltage condition, the modulating technique should always ensure that at any instant either the top or the bottom switch of the inverter leg is on.

3. PMSG Model

Figure 5 shows the d-q equivalent circuits of the PMSG. The voltage equation of the PMSG is expressed at Synchronous reference frame:

$$v_q = -R i_q + L_q \frac{di_q}{dt} - \omega_r L_d i_d + \omega_r \lambda_m$$

$$v_d = -R i_d + L_d \frac{di_d}{dt} + \omega_r L_q i_q$$

Where, R and L are the per phase machine resistance and inductance; v_d and v_q are the dq-axis machine voltages; i_d and i_q are the dq-axis machine currents; λ_m is the amplitude of the flux linkages established by the permanent magnet and ω_r is the angular frequency of the stator voltage. The expression for the electromagnetic torque in the rotor is written as:

$$T_e = \left(\frac{3}{2} \right) \left(\frac{P}{2} \right) \left[(L_d - L_q) i_q i_d - \lambda_m i_q \right]$$

The relationship between ω_r and ω_m may be expressed as:

$$\omega_r = \frac{P}{2} \omega_m$$

The q-axis current component can be used for the speed control of the generator, and the d-axis current is controlled to be zero. So, for particular wind speed v , the Maximum wind power ω_r^* is obtained as,

$$\omega_r^* = \frac{\lambda_{opt}}{R} v$$

III. RESULTS AND DISCUSSION

Simulation Results

To demonstrate the performance of the proposed topology, the simulation work was carried out. Figure 8 shows the simulation configuration of the proposed system. The wind turbine was simulated to provide the real characteristics of wind turbine at different conditions. The PMSG is connected to low-cost converter, DC-link capacitor, inverter and utility-grid.

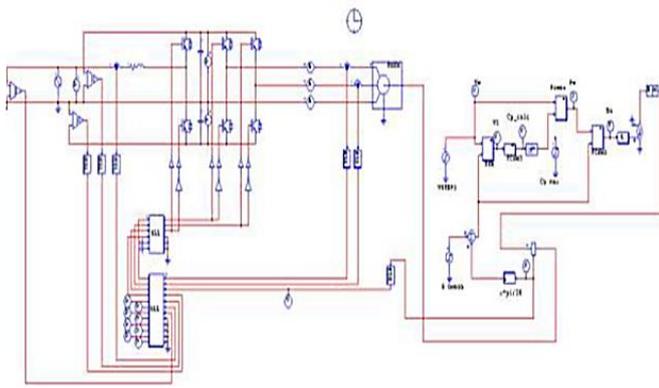
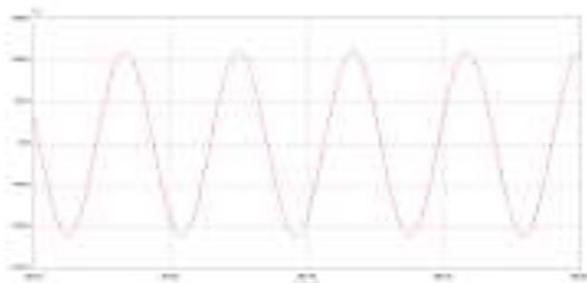
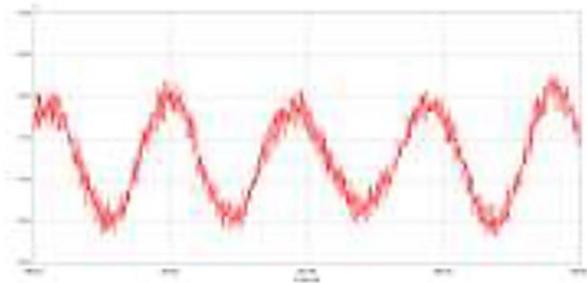


Figure 6. PSIM Simulation Block

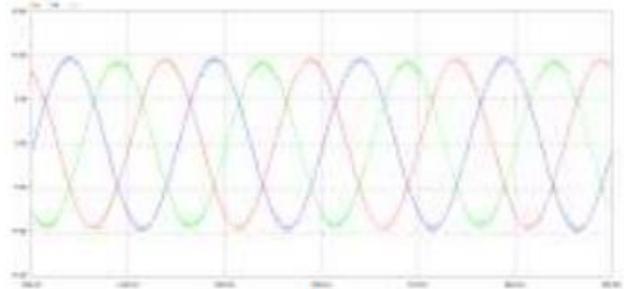


(a)

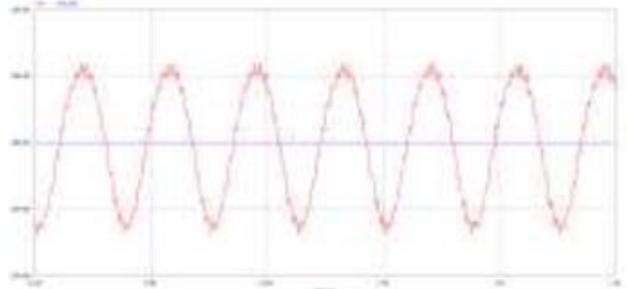


(b)

Figure 7. Inverter performance: (a) grid voltage, (b) Grid current

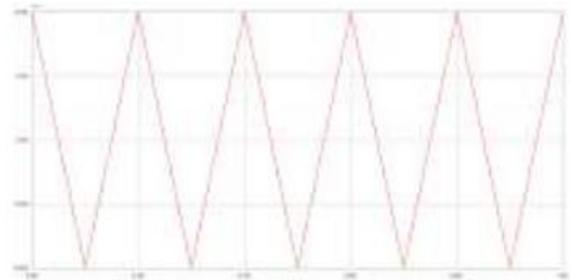


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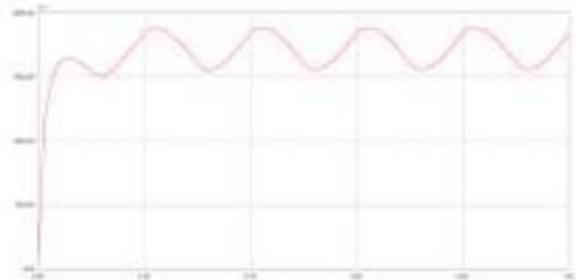


(b)

Figure 8. (a) Generator current (b) DC-link voltage



(a)



(b)

Figure 9. (a) Wind speed, (b) Generator speed

V. REFERENCES

- [1] J'ockel, "High energy production plus built in reliability—The new Vensys 70/77 gearless wind turbines in the 1.5 MW class," presented at the 2006 Eur.Wind Energy Conf., Athens, Greece, Feb. 27– Mar. 2, 2006.
- [2] H. Polinder, S.W. H. de Haan, M. R. Dubois, and J. Slootweg, "Basic operation principles and electrical conversion systems of wind turbines," presented at the Nordic Workshop Power Ind. Electron., Trondheim, Norway, Jun. 14–16, 2004.
- [3] A. Grauers, "Efficiency of three wind energy generator systems," *IEEE Trans. Energy Convers.*, vol. 11, no. 3, pp. 650–657, Sep. 1996.
- [4] K. Tan and S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors," *IEEE Trans. Energy Convers.*, vol. 19, no. 2, pp. 392–399, Jun. 2004.
- [5] F. Velenciaga and P. F. Puleston, "High-order sliding control for a wind energy conversion system based on a permanent magnet synchronous generator," *IEEE Trans. Energy Convers.*, vol. 23, no. 3, pp. 860–867, Sep. 2008.
- [6] North American Electric Reliability Corporation. (2009 Apr.) Accommodating High Levels of Variable Generation [Online]. Available: http://www.nerc.com/files/IVGTF_Report_041609.pdf
- [7] Clipper Windpower, The Liberty 2.5 MW Wind Turbine: Clipper Design. (Dec. 2011). [Online]. Available: <http://www.clipperwind.com/productline.html>
- [8] J. Belhadj and X. Roboam, "Investigation of different methods to control a small variable-speed wind turbine with PMSM drives," *J. Energy Resources Technol.*, vol. 129, pp. 200–213, Sep. 2007.
- [9] M. Chinchilla, S. Arnaltes, and J. C. Burgos, "Control of permanent - magnet generators applied to variable-speed wind-energy systems connected to the grid", *IEEE Trans. on Energy Conversion*, Vol. 21, No. 1, pp. 130-135, March 2006.

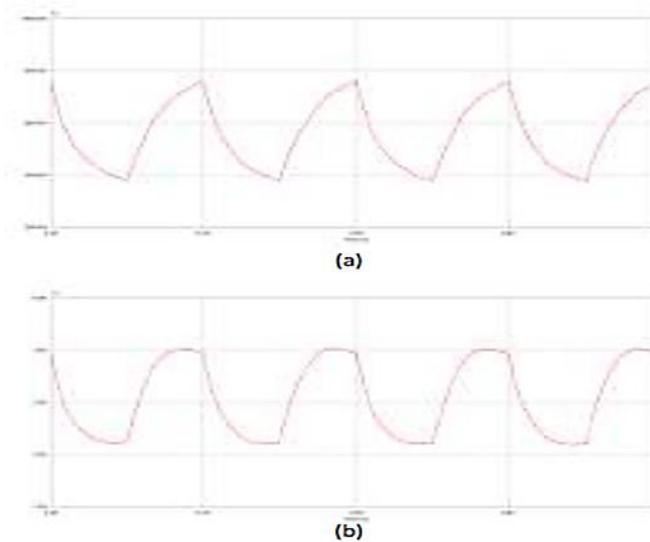


Figure 12. (a) Generator Power, (b) Turbine torque

Figure 9 (a) and (b) show the inverter performance in steady state condition. It is clear that the output current is out of phase with the grid voltage. The generator current is shown in Fig 10 (a). The dc-link control is shown in Fig. 10(b). The dc-link voltage fluctuates around the reference value due to the fluctuation in the two capacitors. The generator speed changes with changing the wind speed as seen in Fig. 11 (a) and (b). Fig. 12 shows the turbine and generator performance at a variable wind speed. The generator power and torque change continuously when the wind speed changes as seen in Fig. 13 (a) and (b).

IV. CONCLUSION

In this paper, a simple topology and controller for small-scale PMSG power generation system has been presented. The system consists of two-leg three-phase PWM converter and a half-bridge single-phase inverter. With this proposal, the PMSG has been controlled to extract the maximum power point by controlling the d-axis current component during the constant or variable wind speeds. The simulation results have shown that the advantage of this system is fast response and good transient performance.