Performance Analysis of Power Converter for Stand-alone Wind Power Generation

Raghunath.M.J

Abstract— **This paper analyses the operation of a power converter for a small wind turbine system with variable speed Permanent Magnet Synchronous Generator supplying power directly to the single phase load. Here a system consisting of wind turbine, Permanent Magnet Synchronous Generator and power converter is designed and analyzed. The power converter consists of three-phase diode rectifier, boost converter and a single-phase full-bridge inverter. Boost converter keeps the voltage level nearly constant over the whole wind speeds. The studies carried out in this paper are based on simulation made with MATLAB/ Simulink software. Considering an output voltage of 230V, 50Hz, the results show that it is possible to implement this system to increase the efficiency of stand-alone wind turbine system and has an advantage due to the boost converter DC link have more control on the voltage levels and the output power that is supplied to single phase load.**

Index Terms— **Permanent Magnet Synchronous Generator (PMSG), Wind Turbine(WT), Pulse Width Modulation (PWM), Voltage Source Inverter (VSI), Insulated-Gate Bipolar Transistor(IGBT) .**

I. Introduction

Research on performance improvement, cost reduction of non–conventional energy conversion systems is being accorded the highest priority [1]. Wind energy is one of the important renewable energy sources used for power generation for isolated, as well as grid connected applications. Powering remote equipment using a small renewable energy system that is not connected to the electricity grid, called a non-grid connected system, makes economic sense and has limited environmental impact. In remote locations, non-grid-connected systems can be more cost effective than extending a power line to the electricity grid [2].

Wind energy systems have a fluctuating power output due to the wind speed variations. Permanent magnet synchronous machines (PMSG) are widely used in many applications as high-performance variable speed drives. Integrating an appropriate power converter with a PMSG wind system removes fluctuations and stabilizes the load power supply.

This paper deals with the power converter used to control the variable voltage and frequency of the power generated from stand-alone wind power generation system. The power converter consists of a boost converter controlled in current control mode to maintain the voltage constant over all the wind speeds. The excellent performance of the power converter scheme is demonstrated under different dynamic conditions using the SimPowerSystem toolbox of MATLAB/SIMULINK.

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II. COMPONENTS OF WIND ELECTRIC SYSTEM

The schematic of a PMSG based standalone variable speed wind turbine is sown in Fig 1. The standalone system consists of the following:

- Wind turbine
- Permanent magnet synchronous generator, which is directly driven by the gearless wind turbine.
- A three-phase diode bridge rectifier,
- A boost converter to control the amplitude of the generated voltage.
- A PWM voltage source IGBT-inverter to control the frequency of the supply voltage.

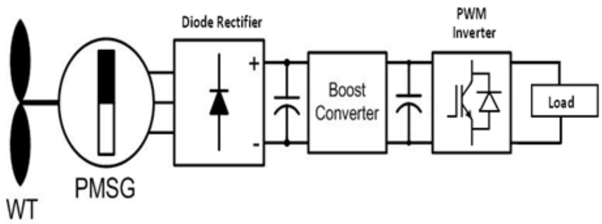

Fig.1: Stand-alone wind system configuration.

Since the wind power fluctuates with wind velocity, the generator output voltage and frequency vary continuously. The varying AC voltage is rectified into DC in a diode bridge rectifier and the DC voltage is then regulated to obtain constant voltage by controlling the duty ratio of a DC/DC boost converter. The DC voltage is inverted to get the desired AC voltage and frequency employing a PWM inverter.

A. Wind Turbine

The proposed wind stand-alone system is a 1kw wind turbine system with the wind turbine power characteristics as shown in Fig 2.

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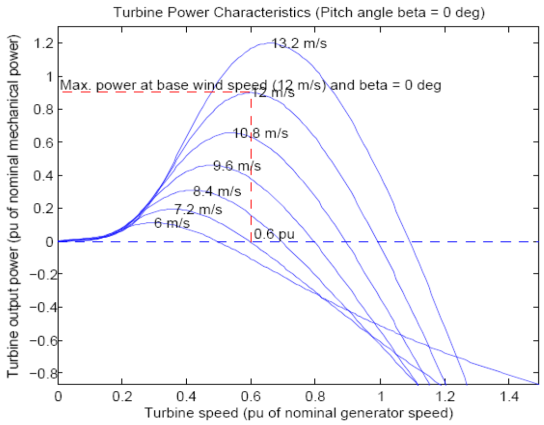

Fig.2: Wind turbine power characteristics

B. The PMSG Model

The electrical parts of the machine are each represented by a second-order state-space model. The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal. The generator is equipped with permanent magnets and has no damper winding. Fig. 3 shows the *d*- and *q*- axis equipment circuits of PMSG in the *dq* coordinate that rotates synchronously with an electrical angular velocity.
The PMSG model in a synchronous reference frame (Park) in the *dq* coordinate is expressed as (1) from Fig 3, [3].

$$\begin{cases} v_d = -R_s i_d + \omega \psi_q - \frac{d\psi_d}{dt} \\ v_d = -R_s i_q - \omega \psi_d - \frac{d\psi_q}{dt} \end{cases} \quad (1)$$

The induced flux linkage in the stator (*dq* frame) is described in (2):

$$\begin{cases} \psi_d = L_d \cdot i_d - \psi_{PM} \\ \psi_q = L_q \cdot i_q \end{cases} \quad (2)$$

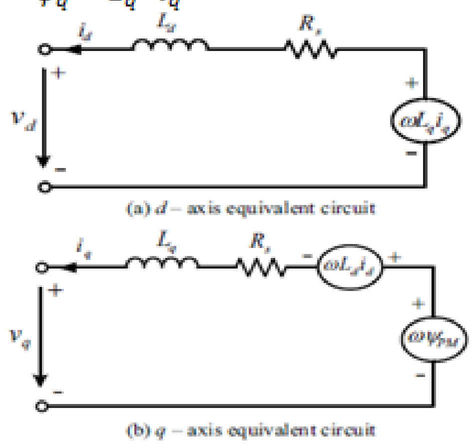

Fig.3: Equivalent circuit of a PMSG in the synchronous reference frame

The PMSG torque is expressed as:

$$T_G = \left(\frac{3}{2}\right) \cdot \left(\frac{P_n}{2}\right) \cdot \left[\left(L_d - L_q\right) i_d i_q - \psi_{PM} i_q\right] \quad (3)$$

C. Boost Converter

The Boost converter topology is used as a voltage regulator and it is controlled using a current mode control algorithm. The basic idea of the control scheme is to estimate the required value of the duty ratio based on the measured samples of the voltage signals in order to make the average value of the inductor current track the input control signal[4][5].

Fig. 4 depicts the topology of the used Boost converter in this case is proposed an IGBT as switch.

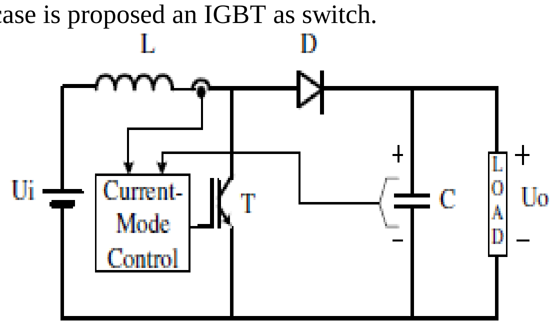

Fig 4: Boost converter.

By assuming that the frequency of the ripple of the input voltage U_i is less than the switching frequency of the IGBT and the output voltage U_o is constant, it is possible to write

$$I_{max} = t_{on} T m_1 \quad (4)$$

$$(1 - t_{on})T = I_{max}/m_2 \quad (5)$$

Where $m_1 = U_i/L$, $m_2 = (U_o\text{-}U_i)/L$ and T is the switching period. The average value of the diode current is indeed load current. By combining (4) and (5) and using the definition of m_1 and m_2, the average value of the diode current in one switching interval can be calculated as [6].

$$i_{LOAD} = i_{D(AV)} = \frac{T}{2L}\left(\frac{U_i^2}{U_o - U_i}\right) t_{on}^2 \quad (6)$$

The solution for t_{on} is

$$t_{on} = \sqrt{\frac{2L}{T}} \frac{1}{U_i} \sqrt{i_{D(AV)}(U_o - U_i)} \quad (7)$$

This relationship is used to calculate the on-time duration in a way that the average current of the diode follows the desired current command signal. In this case the current command signal is the output of a PI voltage controller..

C. Single-phase full bridge inverter

The DC/AC converter consists of a single-phase full bridge inverter which is shown in Fig. 5. Normally, IGBT's T1 and T2 are switched on and off for alternate 180 degree intervals by supplying and removing forward base current. Neglecting on state voltage drop, load terminal A is therefore connected alternately to the positive and negative sides of the supply. Likewise, IGBT's T3 and T4 are switched alternately to connect load terminal B to the positive and negative DC rail. When T1 and T4 conduct simultaneously, the DC supply

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voltage UDC appears across the load (RL). Similarly, when T2 and T3 conduct, the supply voltage is applied across the load with reverse polarity.

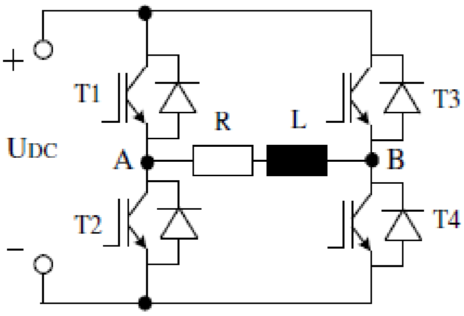

Fig.5:Single-phase full bridge inverter

If the Voltage Source Inverter (VSI) is controlled as above explained, the inverter delivers a square-wave output voltage of amplitude U_{DC}. However, if the firing of T3 and T3 is advanced by an angle Φ, equal to 120 degrees. The resulting load voltage U_{AB} will have a quasi-square wave having zero-voltage internals of 120 degrees of duration in each half-cycle. These intervals obviously correspond to the times when terminals A and B are connected simultaneously to the same DC supply rail.

The importance of this technique is that the fundamental output voltage can be varied from a maximum value to zero by advancing the firing of T3 and T4 from zero to 180 degrees. This general method of voltage control is termed Pulse-Width Modulation (PWM).

For the single-phase full-bridge inverter the sinusoidal PWM pulses are generated by using a high frequency (10 KHz) triangular carrier wave and it is compared with a sinusoidal reference wave of the desired frequency (50 Hz), and the crossover points are used to determine the inverter switching instants. In this case the modulation index has been selected equal to $M_{In}=0.7$

III. SIMULATION AND RESULTS

The simulation of the proposed power converter and its control is done using MATLAB/SIMULIK software in order to simulate the behavior of the whole system. The system includes: Wind turbine, PM generator, AD/DC rectifier, DC/DC Boost converter, DC/AC inverter and RL single-phase load is programmed with parameters. The topology of the Simulink model with the whole system implemented is shown in Fig.6.

Fig. 7 shows how the generator voltage varies with the wind speed which is varying from 7 to 9m/s and from 9 to 11m/s. Also the variation in the rectifier output voltage as the wind speed varies from 7 to 9m/s and from 9 to 11m/s is shown in figure 8.

The variation of generated line-line voltage from PMSG and the boost converter output voltage at variable wind speeds are shown in Table I.

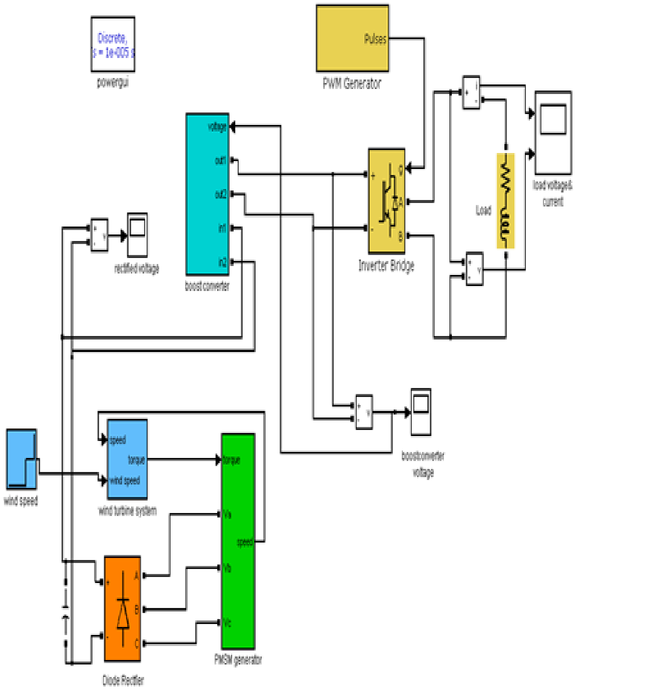

Fig 6: Simulink model of the wind power generation system

Table I: PMSG line-line voltage values for different wind speed

Wind Speed in m/s	Rotor speed in rad/sec	PMSG line-line voltage in volts	Boost converter output voltage in volts	Duty ratio D
6	143.2	70	230	0.695
7	171.1	85	230	0.63
8	199.8	100	230	0.565
9	228.5	120	230	0.478
10	255.4	135	230	0.413
11	282.5	150	230	0.347
12	308.2	165	230	0.282

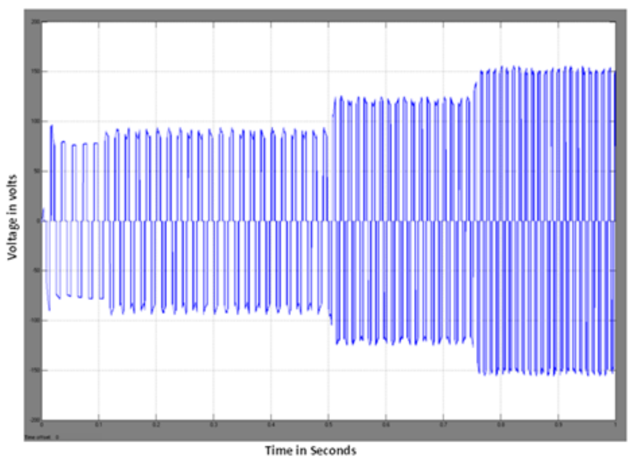

Fig 7: Generator line-line voltage at wind speed variations from 7to 9m/s and from 9 to11m/s.

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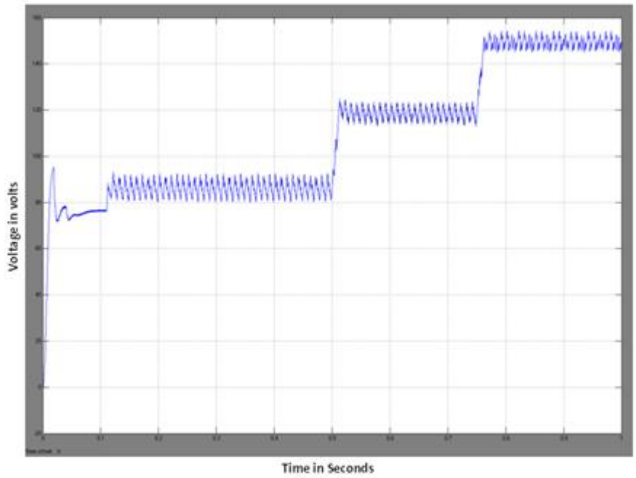

Fig 8: Rectifier output voltage at wind speed variations from 7to 9m/s and from 9 to11m/s.

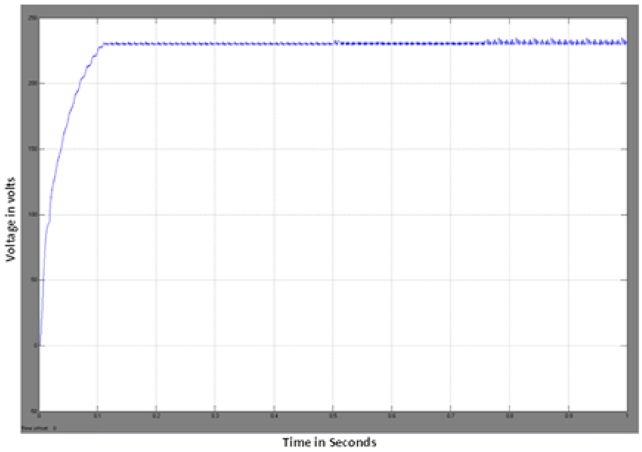

Fig 9: Boost converter output voltage at wind speed variations from 7to 9m/s and from 9 to11m/s

Fig.9 shows the DC output voltage waveform of the boost converter which shows that the boost converter output voltage is maintained constant at 230V even though the generated voltage varies with the variation in the wind speed.

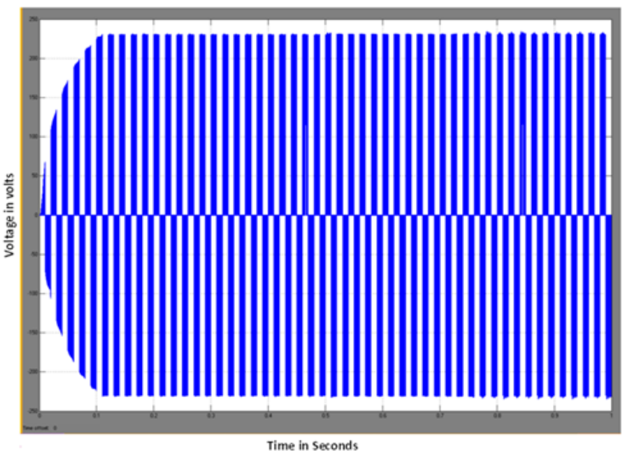

Fig 10: Load voltage

Fig.10 shows the voltage at the load. This voltage is a modulated by the inverter and performs at constant switching frequency of 10 KHz.

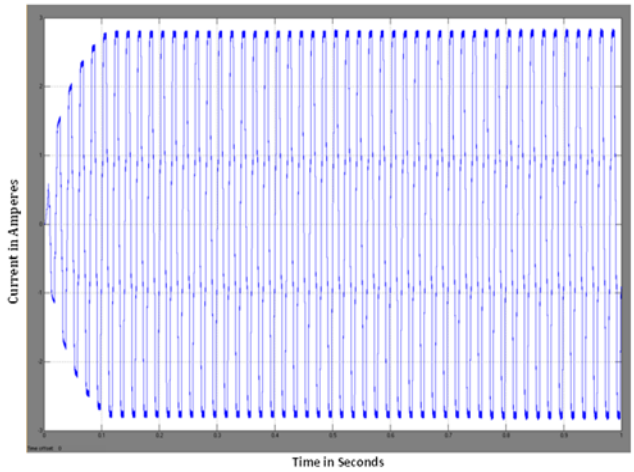

Fig 11: Load current

The input and output magnitude will be constant for constant load although wind speed changes from 7to 9m/s and from 9 to11m/s. Fig. 11 shows the current at the load. It can be seen, that the frequency of this load is constant (50 Hz) and its magnitude will be constant for constant load although wind speed changes. In this way, it has been verified that the design of the proposed control strategy for the power converter works very well.

The simulation of the whole system is carried out for different wind speeds and the performance of the boost regulator is found to be satisfactory.

IV. CONCLUSIONS

In this paper, a stand-alone wind energy conversion system using the AC/DC-DC/DC-DC/AC power converter to stabilize the output voltage and frequency is presented. As generator a PM synchronous machine is proposed. Boost converter and inverter are used to maintain constant voltage and frequency at different wind speeds. The functionality of the proposed power converter has been demonstrated by simulation and the obtained results are satisfactory.

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