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Modeling & Simulation of Permanent Magnet Synchronous Wind Generator Based Stand-alone System

Smitkumar S. Tandel[1], Jay S. Tandel[2], Krishnakant D. Tandel[3]
[1]P.G. Student, Department of Electrical Engineering, MGITER, Navsari, Gujarat, India
[2]Assistant Professor, Department of Electrical Engineering, MGITER, Navsari, Gujarat, India
[3]P.G. Student, Department of Electrical Engineering, L. D. Collage of Engineering, Ahmedabad, Gujarat, India

ABSTRACT

This paper uses a suitable power converter topology for a Wind Energy Conversion system with Permanent Magnet Synchronous Generator (PMSG) for stand-alone operations. The present work presents the system in which a PMSG feeds an isolated load through a closed loop boost converter. The output voltage and frequency of the PMSG is variable in nature due to non-uniform wind velocities. The variable ac output is rectified by a diode rectifier and maintained constant by a boost converter. The boost converter is provided with a closed loop feedback control, which is designed using PID controller. In this controller the output voltage is continuously sensed and duty ratio of the switch is varied to maintain the DC link voltage constant. The converter output is fed to three phase inverter which employs a sine PWM technique, the output of which is fed to the load. The power converters and together with independent control systems can effectively improve the output voltage and frequency of the wind PMSG feeding an isolated load. The whole system is simulated using MATLAB/ Simulink and the results are presented to demonstrate the veracity of the developed control scheme.

Keywords : Permanent Magnet synchronous Generator (PMSG), Closed loop boost converter, Three phase inverter, Three phase diode bridge rectifier.

I. INTRODUCTION

Recent trend indicates that wind energy will play a major role to meet the future energy target worldwide to reduce reliance on fossil fuel and to minimize the adverse impact of climate change. Wind energy is the fastest growing generation technology among the renewable energy sources. Over the last decade, the global wind energy capacity has increased rapidly and wind is an important competitor to the traditional sources of energy. In 2013, more than 35 GW of wind power capacity was added to the global wind generation capacity which became 318 GW. Since 2008, annual growth rates of cumulative wind power capacity have averaged 21.4%, and global capacity has increased eightfold over the past decade [9].

The small scale wind energy conversion systems are more efficient and cost effective. Among AC type generation systems, those based on Permanent magnet synchronous generator (PMSG) is one of the most favourable and reliable methods of power generation for small and large scale wind turbines. Advantages of PMSGs are highest energy yield, higher active/reactive power controllability, absence of brush/slip ring, low mechanical stress, absence of copper losses on rotor, high power density, lower rotor inertia, robust construction of the rotor and low level of acoustic noise. Considering the usage of permanent magnet synchronous generators, three-phase diode rectifiers followed by dc–dc choppers are more economical than three-phase insulated gate bipolar transistor (IGBT) converters. The dc-distribution system involves a better integration of distribution generators and the storage systems, compared with the ac-grid with respect to bi-directional power exchange and power quality Whereas the protection schemes were proposed for permanent magnet synchronous generator (PMSG) wind turbines farm connected in parallel to dc-link. In variable speed wind turbine technologies, the PMSG has received increased attention because of its operation at high power factor, high efficiency and increased reliability due to its self-excitation property Three-phase six switch rectifier is of wide interest to be used as generator side converter [1].

Stand-alone system power system is also known as remote area power supply is an off-the grid electricity system for locations that are not fitted with an electricity distribution system. Typical stand-alone power system include one or more methods of electricity generation, energy storage and regulation. The electricity is typically generated by following methods:

1. Photovoltaic system using solar panels
2. Wind turbine
3. Geothermal source
4. Diesel or bio-fuel generation
5. Micro hydro generation [2].

Stand-alone (off-grid) power system (SAPS) is the small-scale power system which is suitable for the rural (remote) areas where grid connectivity is not possible and/or where independent power supply is needed [2].

II. BLOCK DIAGRAM OF THE SYSTEM

The wind turbine is the prime mover of the Permanent magnet synchronous generator. As the wind velocity is non-uniform in nature, the output of PMSG will be fluctuating. Therefore it cannot be interfaced directly to the load. The output of PMSG is converted to DC using a full bridge rectifier and the variable DC is converted to constant DC by a closed loop Boost converter. This constant DC output is converted to AC using an inverter. This inverter is operated with Sine PWM technique and fed to the load [1].

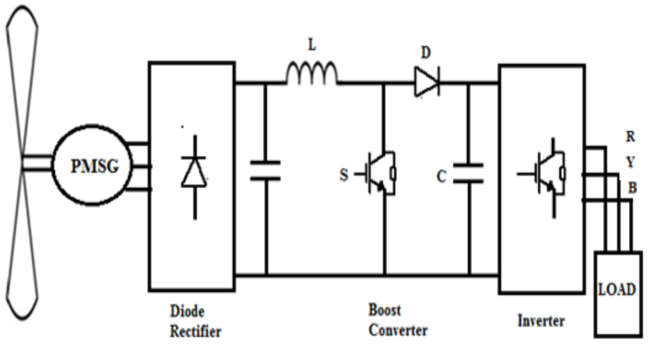

Figure 1. Basic Block Diagram of PMSG Based Stand-alone System [1].

A. Permanent Magnet Synchronous Generator

The Permanent magnet synchronous generators are being used in many small generating systems, particularly wind power system. The PMSG is typically constructed with magnets attached to the rotor and a three phase winding in the stator core. It is particularly an attractive option in renewable energy applications, because it has high conversion efficiency. It is of simple design, robust and reliable. PMSG do not require an additional DC supply for the excitation circuit.

According to the flux direction permanent magnet, generators can be classified as radial, axial & transversal flux machine [1].

B. Three Phase Diode Rectifier

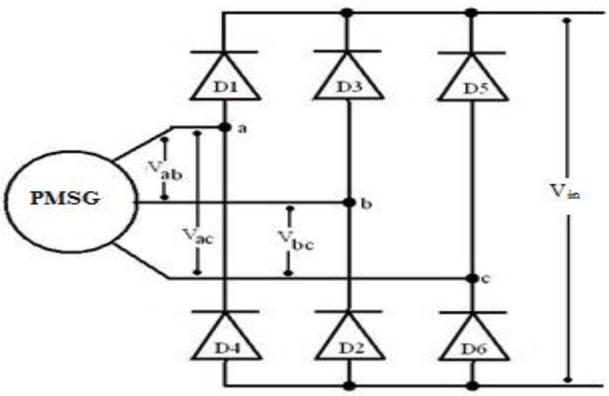

Figure 2. Three Phase Diode Rectifier [1].

The diode rectifier is the most simple, cheap, and rugged topology used in power electronic applications. The most disadvantage of this diode rectifier is its disability to work in bi-directional power flow. The variable output dc voltage from three-phase diode bridge rectifier can be obtained[1].

C. Boost Converter

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor or a MOSFET or an IGBT or a BJT) and at least one energy storage element [1].

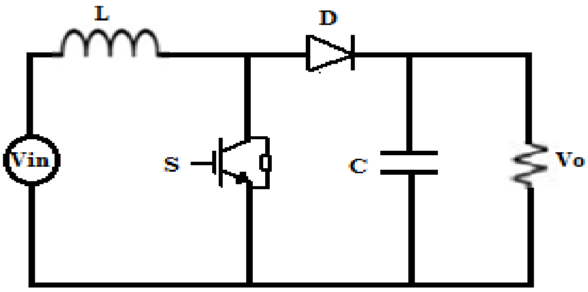

Figure 3. Basic Schematic Diagram of Boost Converter [1].

A boost converter is sometimes called a step-up converter since it “steps up” the source voltage. The output voltage of the boost converter is given by

$$\frac{V_0}{V_{in}} = \frac{1}{(1-D)}$$

Where,

Vin = input voltage of boost converter
Vo = output voltage of boost converter
D = duty cycle [1].

D. Closed Loop Control of Boost Converter

The closed system of boost converter is obtained by using a Voltage mode PWM Scheme. The block diagram of which is shown in the figure 3.8. In this technique the output of the boost converter is kept constant by using the duty ratio as the control variable [1].

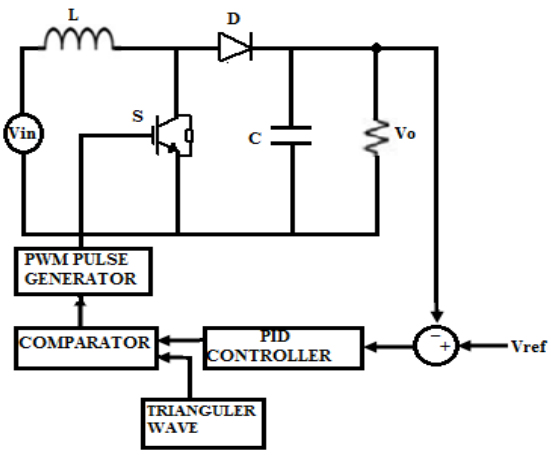

Figure 4. Closed Loop Boost Converter [1]

The error amplifier compares the output voltage Vo with the reference voltage and generates the error signal. This error signal is given as the input to the PI controller. The output of the PI controller is compared with the saw-tooth signal and the pulses are generated. The output pulses are functions of duty cycle [1].

The boost converter operate in Continuous conduction mode for L > Lb, where

$$L_b = \frac{D.R.(1-D^2)}{2.f}.$$

The value of the filter capacitor required is more to limit the output voltage ripple. The minimum value of filter capacitor needed is given by

$$C_{min} = \frac{D.V_0}{R.f.V_r}$$

Where,

D is the duty ratio
f is the switching frequency
R is the load resistor
V_r is the ripple voltage [1].

E Three Phase Inverter

An inverter is a circuit that converts DC to AC. Pulse Width Modulation (PWM) is a switching technique that is used to decrease the total harmonic distortion in the inverter circuit. The output of the boost converter is fed to a three phase inverter which converts the constant DC to constant AC having a frequency of 50 Hz. The schematic diagram of a three phase inverter is shown in the fig. 5 [1].

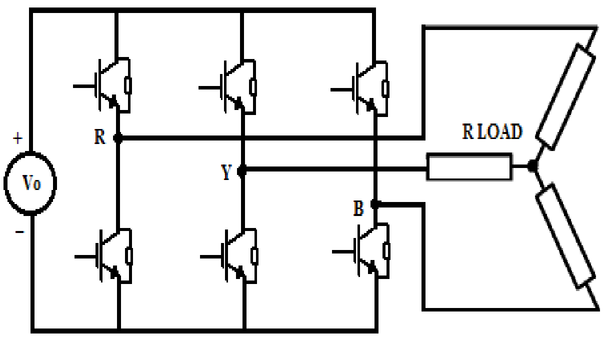

Figure 5. Three Phase Inverter [1]

The objective in pulse-width modulated three-phase inverters is to shape and control the three-phase output voltages in magnitude and frequency with an essentially constant input voltage Vo. To obtain balanced three-phase output voltages in a three-phase PWM inverter, the triangular voltage waveform is compared with three sinusoidal control voltages that are 120 deg out of phase [1].

III. SIMULATIONS & RESULTS

The simulation result of the proposed work in open loop and in closed loop is discussed for the variations in the PMSG speed and for variations of wind speed.

A. Open Loop Simulation

The simulation model of PMSG with Boost converter for open loop mode is shown in fig.6

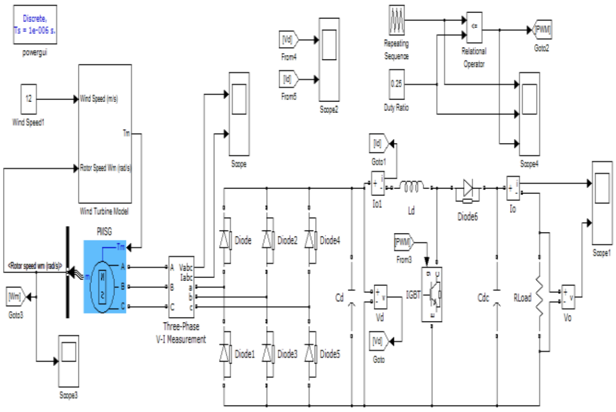

Figure 6. Open Loop Simulation of PMSG with Boost Converter.

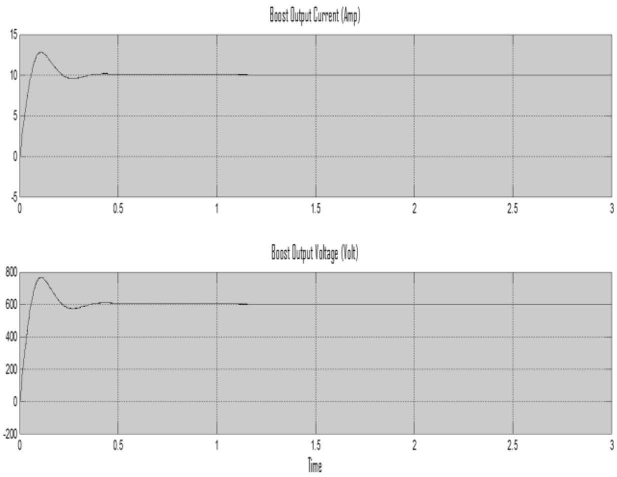

Figure 7. Waveform of Boost Converter Output voltage & Current at wind speed 12 m/s.

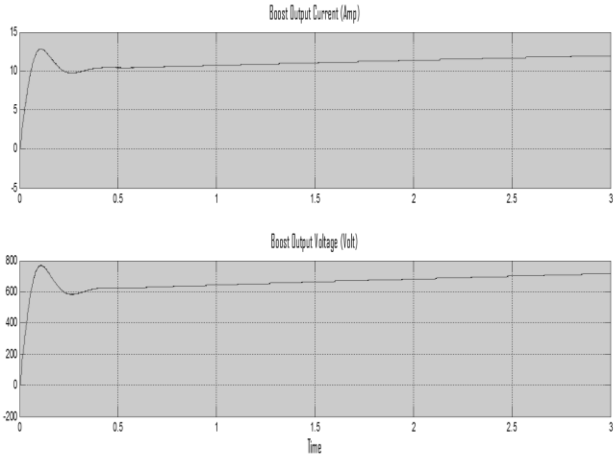

Figure 8. Waveform of Boost Converter Output voltage & Current at wind speed 16 m/s.

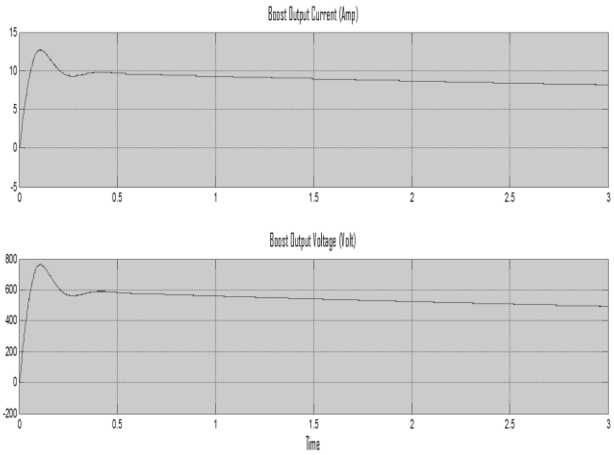

Figure 9. Waveform of Boost Converter Output voltage & Current at wind speed 8 m/s.

B. *Closed Loop Simulation*

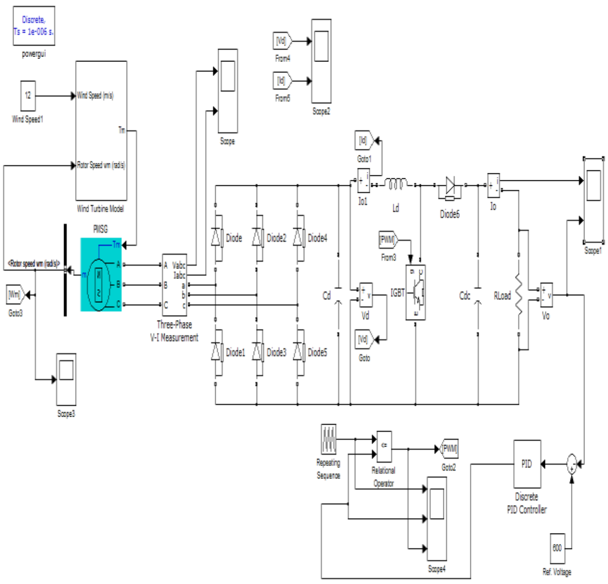

Figure 10. Closed Loop Simulation of PMSG with Boost Converter.

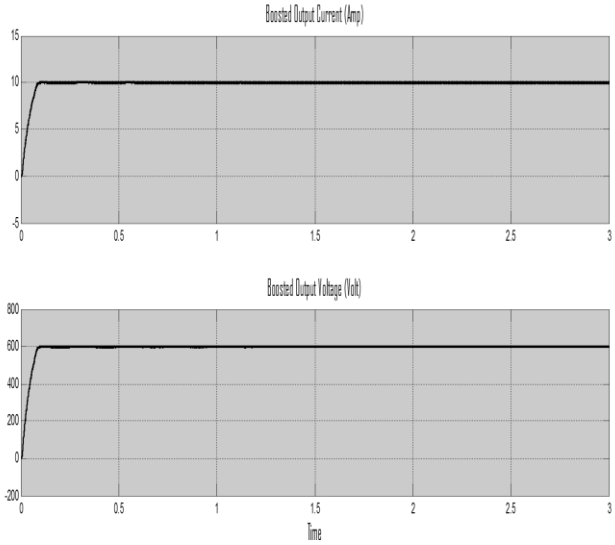

Figure. 11 Waveform of Boost Converter Output voltage & Current at wind speed 12 m/s.

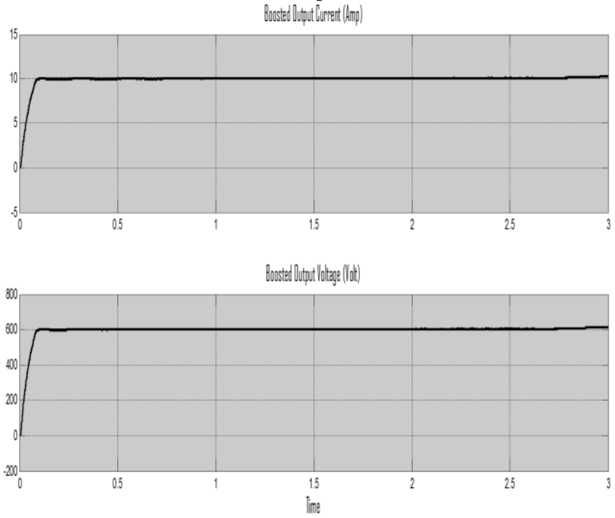

Figure 12. Waveform of Boost Converter Output voltage & Current at wind speed 16 m/s.

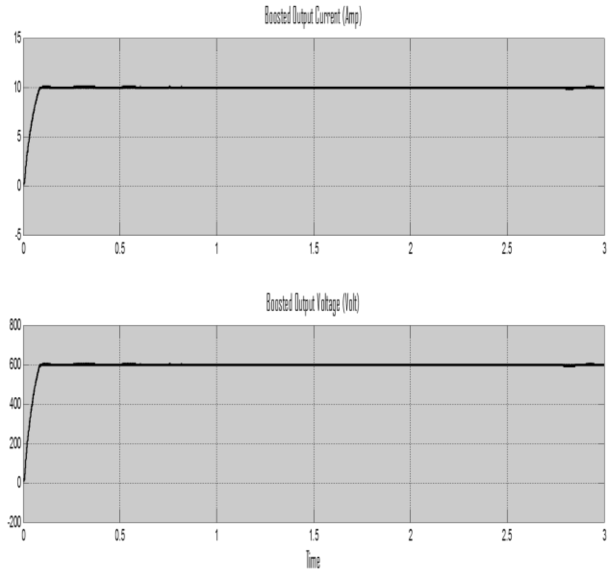

Figure 13. Waveform of Boost Converter Output voltage & Current at wind speed 8 m/s.

IV. CONCLUSION

In this paper, the power electronic topology comprising of diode rectifier, DC to DC boost converter and inverter for a variable wind energy conversion system with PMSG for a standalone application is presented. The state space averaging technique employed for obtaining transfer function of the boost converter and the subsequent design of PID controller using trial & error technique for the dc-dc boost converter for maintaining the required dc link voltage constant is given in detail. The analysis and dynamic response with the designed controller is carried out for varying wind speed and load and the simulation results are given to validate the design. Further investigations are carried out for obtaining the range of wind speed and load variation that the designed controller can work in isolated mode with regulated voltage at the load is presented.

V. ACKNOWLEDGMENT

The parameters of wind turbine & PMSG are given by table I.

TABLE I.
PARAMETERS OF WINDD TURBINE & PMSG

Wind turbine	
Density of air	1.225 Kg/m3
Area swept by blades, A	1.06 m2
Optimum coefficient, Kopt	1.67×10^{-3} Nm/(rad/s)2
Base wind speed	12 m/s
PMSG	
No. of poles	10
Rated speed	153 rad/sec
Rated current	12 A
Armature resistance, Rs	0.425 Ώ
Magnet flux linkage	0.433 Wb
Stator inductance, Ls	8.4 mH
Rated torque	40 Nm
Rated power	6KW

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