Analysis of Permanent Magnet Synchronous Generator based Wind Generation System using Matlab/Simulink

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Abstract— This paper deals with the Dynamic modeling and performance analysis of Permanent magnet synchronous generator (PMSG) based Wind Generation System (WGS). This system consists of Wind Turbine, PMSG, Diode Rectifier, Buck- Boost converter, Voltage source Inverter (VSI). PMSG and Buck Boost converter are employed in WGS to get efficient output according to the load requirement without damaging the system. The output of the VSI is injected to the grid and used for Home Application. The proposed model dynamic simulation results are tested in MATLAB Simulink.

Keywords— *PMSG, WGS, Buck-Boost converter, VSI, Diode rectifier, Wind turbine, MATLAB Simulink.*

I. INTRODUCTION

Wind generation system is one of the effective and innovative technologies in the field of renewable energy resource. Wind is a clean, infinite, non conventional and immune to disturbances and volatile to fossil fuel industries.The aim of this paper is to build a wind generation system in the geography which have major wind source. The system mainly consists of Generator, Rectifier, Energy storage system and Inverter. The most commonly used generators are DFIG (Doubly fed Induction Motor), Synchronous motor and PMSG. Permanent Magnet Synchronous generator has more advantages compare to other generators and it is stable, secure, not require DC supply, and operates at low wind speed. The MPPT control technique is used to capture more energy from the source.

The diode rectifier is used to convert AC/DC and VSI is used to DC/AC. In conventional WGS, Energy storage device is connected in between Rectifier and inverter. Energy storage device such as battery is not preferable due to environmental concern and it is very expensive and also bulky [1].

Two main topologies connects the PMSG and Grid, First topology composed of Rectifier, Boost converter, VSI, second topology consists of Diode rectifier, Buck-Boost converter[2] and VSI. The first topology causes damage to the system because of its Boosting nature, when the load requirement is less than the generated or supplied input. Second topology achieves more efficiency and it will not cause any damage to the system and the energy losses will be less. Buck-Boost converter acts as either Buck converter or Boost converter depends on the duty cycle. To obtain the desired output the duty cycle of the Buck-Boost converter is varied.

II. CONVENTIONAL SYSTEM

The conventional wind generation system consists of Energy storage device (Battery) is connected in the middle of AC/DC and DC/DC converter. The excess energy can be stored in the battery and used when the load requirement is higher than the generated wind energy. It is very expensive, bulky in nature and Limited Life cycle.

By employing battery in the wind generation system we get a fixed voltage to the converter and controlling is easy but this makes the system bulky with the constraint weight. Battery is also not preferable from environment concern. Conventional Wind generation system as shown in Fig.1

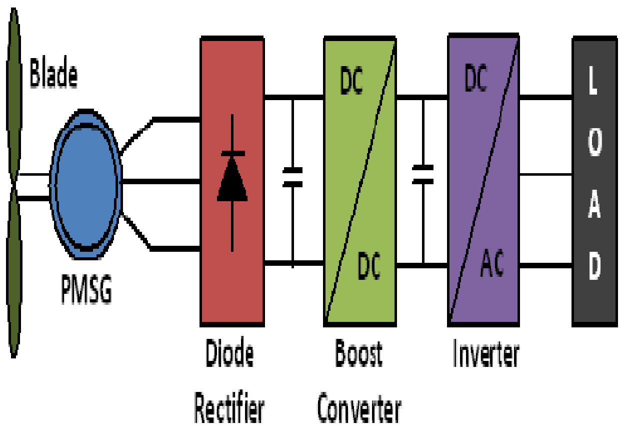

Fig 1: Conventional WGS topology

III. PROPOSED WGS AND DESCRIPTION

The Proposed PMSG based wind generation system as shown in the Fig 2. The battery is substituted by Buck-Boost converter to get an efficient output voltage and to reduce the weight, cost and bulkiness of the system [3].

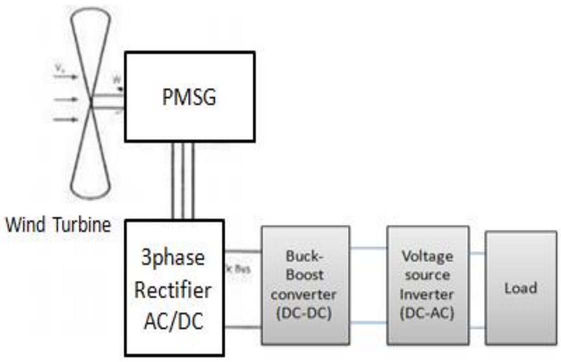

Fig 2: Proposed PMSG based WGS system

A) Wind Turbine

Wind turbine converts kinetic energy into mechanical energy. It uses large blades to catch the wind when the wind blows, it strikes to blades and the blades forced to rotate by driving a turbine which generate electricity [5].

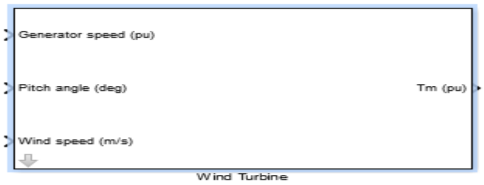

Fig 3: Wind turbine in MATLAB Simulink

Energy conversion from wind turbine

$$K.E = E = \frac{1}{2}mv^2 \quad (1)$$

$$m = \rho vs \quad (2)$$

Where, m = air mass (kg)

v = wind speed (m/s)

s = Swept area of turbine.

ρ = Air density.

$$P_w = Ec = \frac{1}{2}mv^2 = \frac{1}{2}\rho vs \quad (3)$$

P_m is inferior to P_w and the power coefficient is given by

$$c_p = \frac{P_m}{P_w} \quad ; \quad c_p < 1 \quad (4)$$

P_m = Mechanical power

P_w = Wind power

From equation (4) $P_m = C_p P_w$ (5)

$$P_m = \frac{1}{2}\rho\pi R^2 V^3 C_p \quad (6)$$

Where R= radius of the rotor

$$C_p = C_p(\lambda, \beta) \text{ With } \lambda = \frac{R\omega}{V} \quad (7)$$

Cp depends on λ *and* β

Where, λ is tip speed ratio of the wind turbine.

β is the pitch angle of blades.

ω is the rotation speed of the rotor.

Wind turbine Torque equation is

$$T_m = \frac{P_m}{\omega} \quad (8)$$

From (6) and (8)

$$T_m = \frac{P_m}{\omega} = \frac{1}{2}\rho\pi R^2 \frac{V^3}{\omega} C_p \quad (9)$$

From (9) and (7)

$$T_m = \frac{1}{2}\rho\pi R^3 V^2 \frac{C_p}{\lambda} \quad (10)$$

The torque coefficient can be expressed as

$$C_r = \frac{C_p}{\lambda} \quad (11)$$

From (10) and (11)

$$T_m = \frac{1}{2}\rho\pi R^3 V^2 C_T \quad (12)$$

B) PMSG

Permanent magnet synchronous generator converts mechanical energy into electrical energy, the magnetic field of rotor is produced by permanent magnets and it do not requires DC supply for the excitation. PMSG is stable, Secure and operates at low speed and it does not require a gear box [4- 6].

The electrical equation of PMSG in a reference frame linked to the rotor flux vector.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} r_s & 0 \\ 0 & r_s \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \emptyset_d \\ \emptyset_q \end{bmatrix} + \omega_r \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \emptyset_d \\ \emptyset_q \end{bmatrix} \quad (13)$$

For sinusoidal distribution of the back e.m.f, the flux and current phasors are linked by the below equation

$$\left.\begin{aligned} \emptyset_d &= L_d i_d + \emptyset_r \\ \emptyset_q &= L_q i_q \end{aligned}\right\} \quad (14)$$

Where, $\emptyset_r$ is the rotor flux.

Substituting (14) in (13) and by applying Laplace transform

$$\left.\begin{aligned} V_d &= (r_s + L_d P) i_d - e_d \\ V_q &= (r_s + L_q P) i_q + e_d \end{aligned}\right\} \quad (15)$$

d and q components back e.m.f expressed as

$$\begin{aligned} e_d &= \omega_r L_q i_q \\ e_q &= \omega_r L_d i_d + \omega_r \varphi_r \end{aligned} \quad (16)$$

The stator active and reactive power is

$$P_s = \frac{3}{2}(V_d i_d + V_q i_q)$$

$$Q_s = \frac{3}{2}(V_q i_d - V_d i_q) \quad (17)$$

The electromagnetic torque can be expressed in the reference frame

$$T_{em} = \frac{3}{2} n_p \left(\emptyset_r - (L_q - L_d) i_d\right) i_q \quad (18)$$

C) Diode Rectifier

Three phase diode rectifier is fed by the PMSG, Diodes are used in the rectifier and it is not require control. And diodes are not expensive and made the circuit simple. This converts AC/DC.

D) Buck- Boost converter

Buck- Boost converter is a converter which converts DC/DC, The output of the converter depends on the duty cycle of the converter. It acts as both buck and Boost converter depends on the duty cycle (d).

By substituting Battery or Boost converter by Buck-Boost converter we can increase the efficiency and reduces the chances of system damage. If the load demand is less than the generated voltage, the buck-boost converter acts as Buck converter by varying d. If the load demand is greater than the generated voltage the converter circuit operates as Boost by varying d. If d < 0.5 it acts as Buck Converter, d > 0.5 it acts as Boost converter.

E) Voltage Source Inverter

Voltage source inverter is fed by the Dc output of the Buck-Boost converter, It converts DC/AC. VSI is commonly used Inverter in renewable energy generation system because it is very simple at design, good speed range and having the capability of controlling multiple motor control from single unit. IGBT switches are employed in inverter, these switches reduces the loss, greater power gain, high voltage capability, low on resistance, fast switching speed and it is a voltage controlled device.

IV. PROPOSED CIRCUIT TOPOLOGY

Fig 4 shows the circuit topology of PMSG based wind generation system, the load is grid and we can use it for home appliances. Battery is replaced from conventional Wind energy generation system by Buck-Boost converter and is fed by the Rectifier and injects its output Dc voltage into Voltage source inverter, this inverter converts DC voltage into AC voltage that output voltage is used for house appliances. MPPT technique involved to track maximum energy from the source [7].

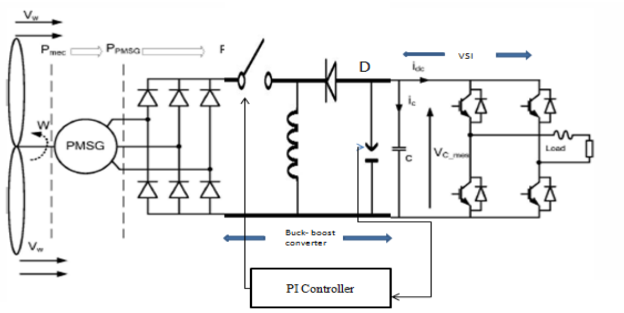

Fig 4: WGS topology and control

PI controller is connected at the feedback control loop to control the error. It calculates the error by comparing the output and reference point and attempts to minimize the error by adjusting the process control output.

V. MATLAB SIMULINK SIMULATION

The Matlab Simulink software tool is used to test the results. FPGA hardware implementation is used and it is programmed by Higher Description Language.Fig 5 to 8 shows the matlab simulation results, As shown Fig 5, the wind is varying throughout the day and the generate output voltage of the PMSG varying with respect to Wind speed. Based on the load requirement the converter acts as buck or Boost converter.

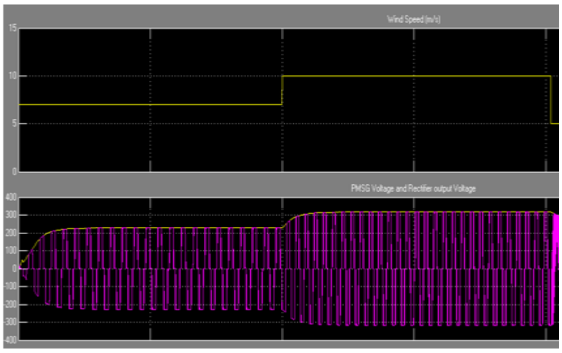

Fig 5: Wind speed and PMSG Rectifier output voltage

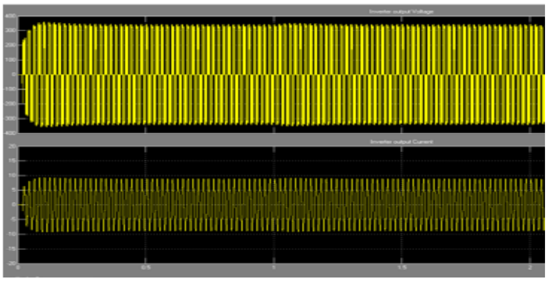

Fig 6: VSI voltage and current output

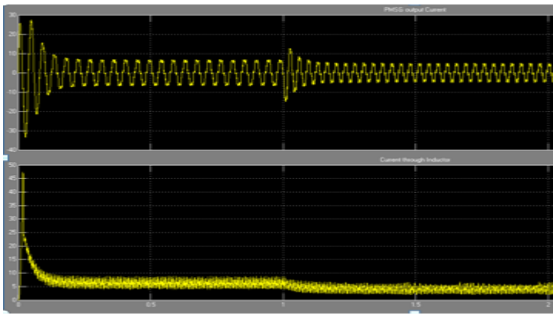

Fig 7: PMSG and Inductor Current

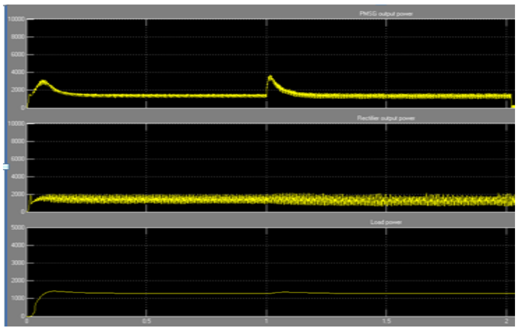

Fig 8: Power transfer from PMSG to load

By using the PI controller feedback loop, the required output is obtained.

Fig 6 shows the VSI output voltage and current, the output frequency is fixed. Fig 7 shows PMSG and Inductor current and Fig 8 shows the power transfer from PMSG to load and we can observe the constant power delivered at the load.

VI. CONCLUSION

The proposed system is more Compact, simple and efficient and this delivers constant power to the load. It meets the load requirement by acting as Buck Converter or Boost converter and it depends on the Duty cycle and it increases the system performance. By employing Buck-Boost converter the system damage chances are reduced and the system efficiency increased, and the Transmission and conversion losses are decreased and it reduces the overall system cost.

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