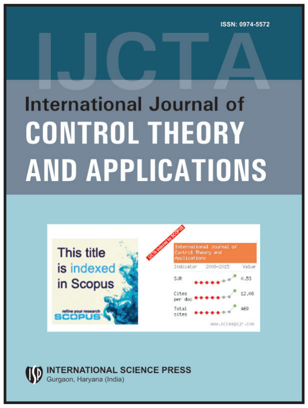

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 16 • 2017

Power Control Approach for a Variable-Speed Wind Turbine with PMSG

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Abstract: In this paper, Variable Speed Wind energy Conversion system, consisting of Wind Turbine, PMSM (Permanent Magnet Synchronous Machine) connected to a grid via power converter station is implemented. Here the DC link sustains the voltage between the two converters Here the power converter station is controlled individually i.e., using rectifier control strategy and inverter control strategy with the PI controller. Using the SPWM (Sinusoidal Pulse Width Modulation) method the PWM inverter is restrained. This technique is inbuilt of inverter strategy. The main desire is to analyze and improve the power quality by doing FFT analysis with THD. The above mentioned scheme is implemented using MATLAB/SIMULINK.

Keywords: PMSM (Permanent Magnet Synchronous Machine), PMSG (Permanent Magnet Synchronous Machine, Variable Speed Wind Energy Conversion System (VSWECS), wind turbine, Filter, PWM converter, SPWM technique, PI controller, FFT analysis, Grid.

1. INTRODUCTION

In last decade, because of several restrictions of non-renewable resources like high cost of fossil fuels such as Thermal, Coal, Gas, Diesel, Nuclear etc., increases contaminated air in the environment this leads to the damage and insufficiency of resources. Hence, to negate these effects there is an urge for the employment of renewable sources like solar, wind, tidal power etc., for the propagation of power. Among all forms of renewable sources, wind absorbs a particular place due to its vast advantages like cost effective, used for wide range of power generation, technically improved etc. with the usage of nonconventional sources like solar, wind, tidal, hydro etc, we can deliver the energy consumption to the forth coming generation. Among the various energy sources, wind and solar can be considered as viable options for future electricity. The wind energy plays a prominent role in providing emission free power generation. Electricity generation through wind energy is considered as beneficial and economical for several applications [1]. The main components for distributed generation system are photovoltaic cells, turbines and small scale wind turbines. In many areas the combination of PV system with wind energy system forms a hybrid power system to supply power to the loads as per the requirement. [2]Therefore in order to generate power wind energy conversion system (WECS) can either be driven in fixed speed mode or in variable speed mode. Compared to fixed speed wind turbines the variable speed wind turbines, are simple in design, mechanically robust, cost effective, need lower level of maintenance and are very reliable. In fixed speed mode any change noticed in wind speed results in power fluctuation of the grid. The variable speed operation leads to higher energy yield and lower level of power fluctuation compared to fixed speed operation[3].

In this paper, modeling of the Variable Speed Wind Energy Conversion System (VSWECS) based PMSG (permanent magnet synchronous generator) is integrated to the grid via power converter station.[4-5].Generally, a direct driven wind energy conversion system can't operate a low torque machines therefore, an electrical machine must designed for high torque density. Thus PMSG is opted.

A wind turbine can be integrated with the three phase synchronous generator either it can be WRSG or PMSG. On correlating both, the WRSG has the prejudices like field losses, desires additional exciter, higher maintenance therefore higher cost. Thus, obviously it proves that PMSG contributes better features like:

- Gear box requirement is not necessary.
- Minor losses, provides high efficiency and sophisticated power factor.
- Small size in construction.
- Rotor copper losses can be eliminated.
- Lower maintenance and thus less cost.

Because of above reasons PMSG is preferable.

The wind energy conversion system can be classified into two types:

1. Fixed Speed Wind Energy Conversion System
2. Variable Speed Wind Energy Conversion System

The prime theme of this work is to upgrade the power quality along with the THD, and voltage. This will not be feasible with the fixed speed WECS means it cannot control the reactive power as well as grid voltage.[6]

Consequently the Variable Speed wind energy conversion system is more suitable than Fixed speed wind energy conversion system because of the following advantages[7]:

- It can capture maximum efficiency.
- Improves dynamic behavior.
- Improves power quality.

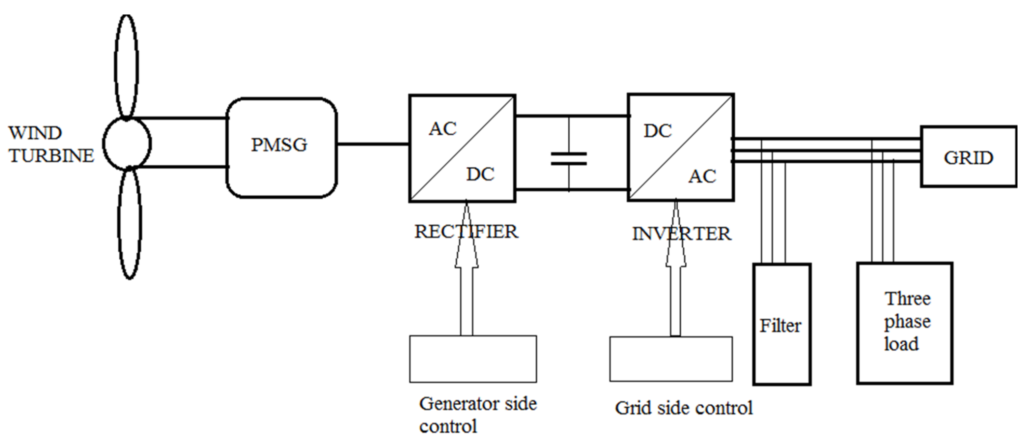

Figure 1: Block diagram of WECS with PMSG

In Figure 1 we can observe the main Figure of WECS which contains the components like a generator, a Back to back converter, filter, three phase load and a transformer for grid connection [8]. The function of the wind turbine is to capture the power from the wind with help of its blades and then convert it to mechanical power. This power will be later changes as electrical power with the help of PMSG[9].

2. DESIGN OF WIND TURBINE

According to the function of the wind turbine they can be classified as two types:

- Fixed speed wind turbine (FSWT)
- Variable speed wind turbine (VSWT)

Wind is the movement of air, which has a kinetic energy. Power = work/time

= kinetic energy/time

The wind energy is captured by the blades and then converts it to mechanical power[10].

The Kinetic energy can be written as = $\frac{1}{2} m v^2$ therefore,

$$\text{Power} = \frac{1}{2} m v^2 / t$$

where, m = mass (kg) = $\rho A d$ (1)

$$\text{Power} = \frac{1}{2} \rho A d \, (v^2/t) \tag{2}$$

Total wind power

$$P_w = \frac{1}{2} \rho A v^3 \tag{3}$$

Considering the power of the actuator disc can be written as:

$$\text{Power} = \frac{1}{2} \rho A v^3 \; 4x\,(1-x)^2$$

where, $x = \frac{1-v}{v_u}$ (4)

Mechanical torque is the ratio of total wind power to thee speed

$$T_m = \frac{P_\omega}{\omega}$$

where, $\omega = \frac{2\pi N}{60}$

N is representing the speed of the wind turbine

Coefficient of power can be defined as the ratio of the power captured by the turbine to the total power is dimensionless.[11, 12] The power extraction efficiency can be written as:

$$C_p = \frac{P}{P_\omega} = \frac{0.5\,\rho A v^3 4x(1-x)^2}{0.5\,\rho A v^3} \tag{5}$$

where, C_p is the power coefficient,

P is the power of actuator disk,

P_w is the wind power,

ρ is the Air density,

A is the area, and

v is the wind speed.

2.1. Characteristics of the Wind Turbine

A wind turbine can be known as a power extracting device.

The *tip speed ratio* (λ) is the tangential speed, it characterizes the power conversion efficiency

$$\lambda = \frac{R\Omega_t}{v} \tag{6}$$

where, Ω_t is the rotor speed

R is the blade length

It is used to define auditory noise levels.

The power extracted by wind turbine,

$$P = 0,5\rho\pi R^2 v^3 C_p(\lambda) \tag{7}$$

For the designed system, the Figure 3 shown below is the power characteristics of wind turbine. The different color at 12 m/s represents the base speed of it. The maximum value of C_p occurred at 0.5.

The wind turbine power characteristics for the designed system are appeared as follows:

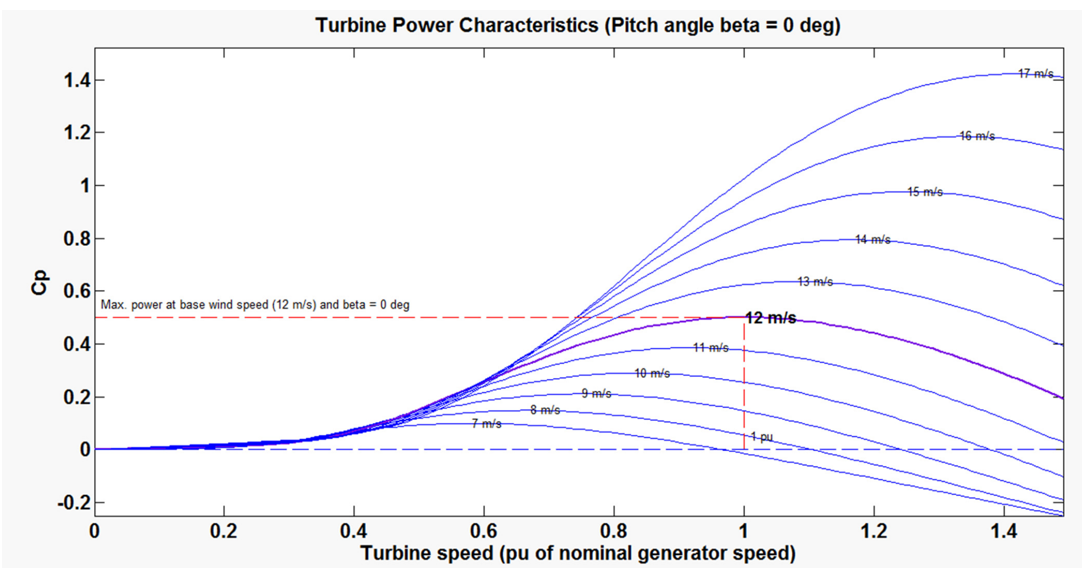

Figure 2: Power Characteristics of Wind turbine

3. MODELING OF PMSG

A permanent magnet synchronous generator has a stator and rotor. The rotor consists of a permanent magnet whereas the stator is armature which is coupled to a load. There are three conductors which are placed by 120 deg for providing uniform torque[13]. The two fields stator magnetic and rotator fields are move in synchronicity and also twist with the same frequency. In PMSG based wind energy conversion system the voltage is proportional to the rotor speed[14]. The PMSG is more preferable because of its advantages:

3.1. General Mathematical Equations Of PMSG:

The mathematical modeling of a PMSM drive based on *d*-*q* reference frame given below[18].

d-axis and *q*-axis stator voltage

$$V_d = RI_d + L_d \frac{dI_d}{dt} - L_q W_e I_q \tag{8}$$

$$V_q = RI_q + L_q \frac{dI_q}{dt} + L_d W_e I_d - W_e Y_{af} \tag{9}$$

with

$$V_d = L_d I_d + Y_{af} \tag{10}$$

$$V_q = L_q I_q \tag{11}$$

The electromagnetic torque is represented with the negative sign as it indicates the motor working as a generator

$$-T_e = J \frac{d}{dt} W_r + BW_r + T_l \tag{12}$$

$$T_e = -\frac{3}{2} P\left(Y_{af} I_q + \left(L_d - L_q\right) I_d I_q\right) \tag{13}$$

where, $W_r = \frac{2}{P} W_e$

$$W_e = \int \frac{1}{W_r}\left[\frac{1}{J}\frac{P}{2}\left(T_e - T_m - B\frac{2}{P} W_e\right)\right] \tag{14}$$

Here, V_d, V_q = *d* and *q* axes stator voltage

I_d, I_q = *d* and *q* axes stator current

V_d, L_q = *d* and *q* axes inductances

R = stator resistance

T_e, T_l = electromagnetic and load torque

J = moment of inertia of motor and load

B = friction coefficient of the motor

P = number of pole pairs

W_e = rotor speed in angular frequency

Y_{af} = rotor magnetic flux linking the stator

4. BACK TO BACK PWM CONVERTER WITH CONTROL STRATEGY

Basically, the Back to back converter is a combination of two hence, it is also named as Two level converter i.e, Generator side rectifier and Grid side inverter. The two converters are linked with a capacitor known to be decoupling capacitor.[15] The basic operation is based on AC/DC/AC conversion with the help of converter valves. These converters are practically used for:

- Stabilizing the weak AC links.
- For supplying more Active power
- Controlling the Grid power within a synchronous system. High frequency harmonics.

Controlling theory: A three phase transformer is connected to the rectifier. From the rectifier I_d(direct axis current) and V_d(direct axis voltage) are generated. Here the rectifier has a special control strategy to control itself. The rectifier control strategy receives the three phase voltage, d axis reference current, and I_d(pu) the ripples in current which are controlled with the help of inserting filter[16]. Hence, whatever the error obtained from the filter is then goes to PI controller where it gets multiplied by the proportional and integral constant. This will be given to the 6 pulse firing control which comprises of PLL and discrete synchronized 6 pulse generator[17].

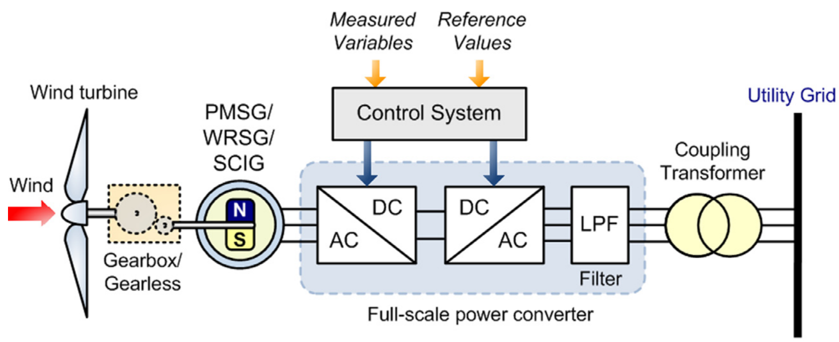

Figure 3: Basic Figure of wind system connected to a Grid

The inverter also generates the direct axis voltage (V_d) and direct axis current (I_d). Same as rectifier, the inverter has a special control strategy with gamma control. The current and voltage retrieve from the inverter are acts as input to the inverter controller and I_d ref is taken from the rectifier. Therefore, the outcomes of inverter are nothing but conclusion of gamma control and discrete synchronized 6 pulse generator.

5. RESULTS AND DISCUSSIONS

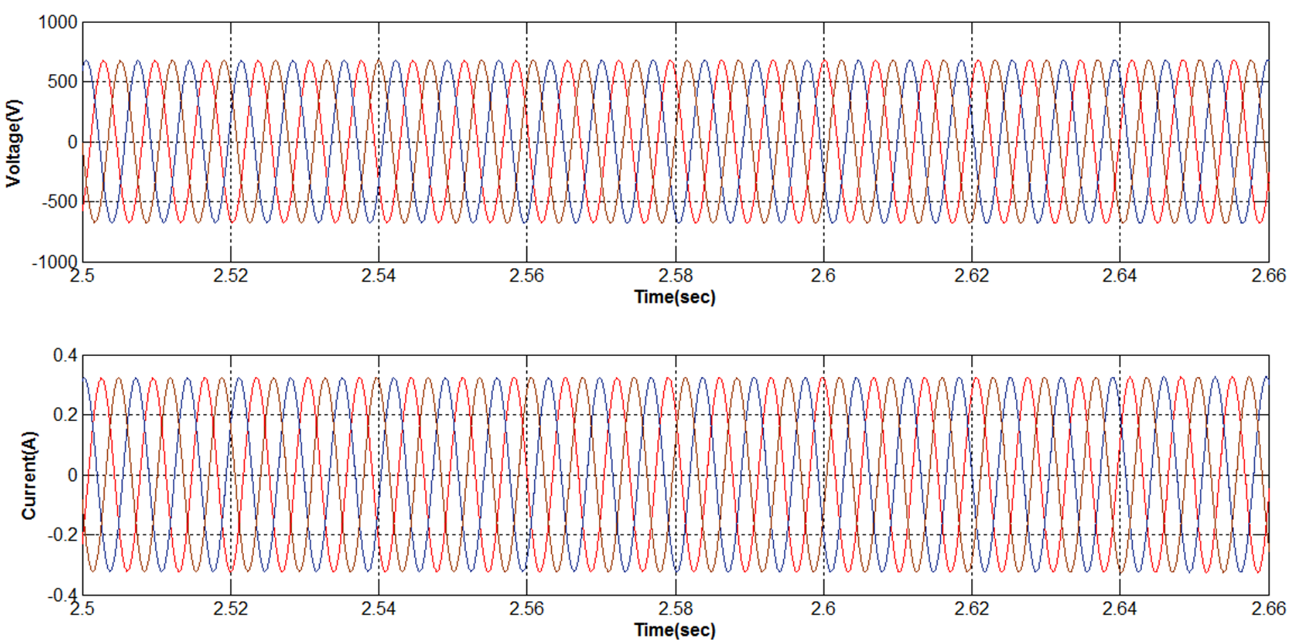

Figure 4: Three Phase Voltage and Current of wind generator

The three phase voltage and current generated by the wind generator for RL load is shown in above Figure 4. Here the voltage is approximately settled to the 630 volts and the current reaches nearly 0.3 amps.

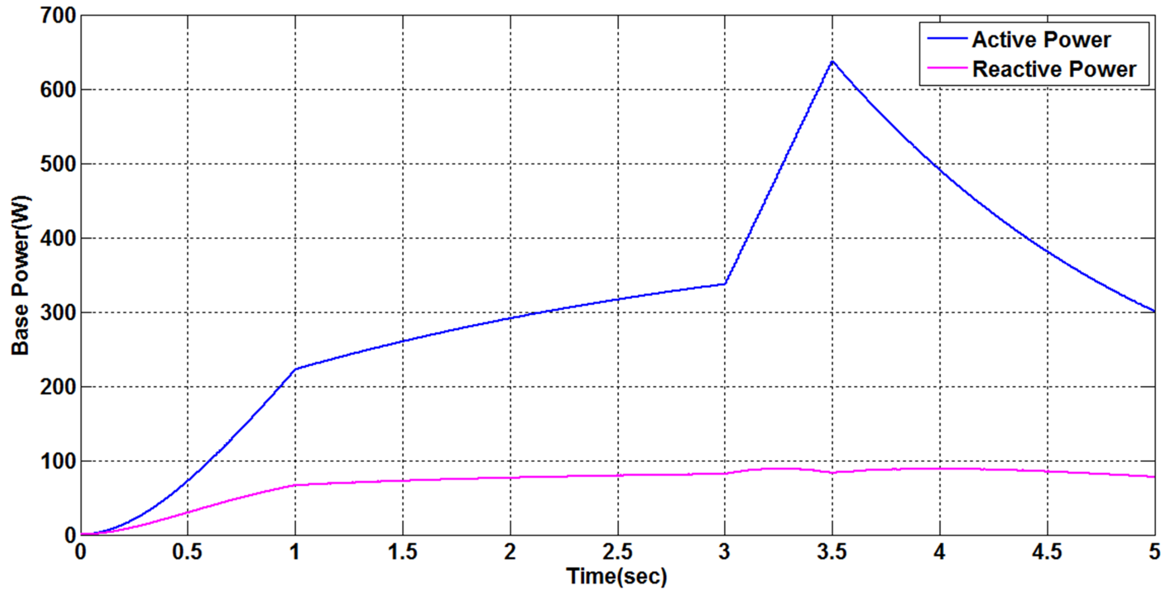

Figure 5: Active and Reactive power of PMSG

From the Figure 5 it is observable that Active power and reactive power curves hence, active power is varying for the different periods 0 to 1, 1 to 2, 2 to 3, and 3 to 4 it is raised to the peak 650 W therefore again it slightly decreased.

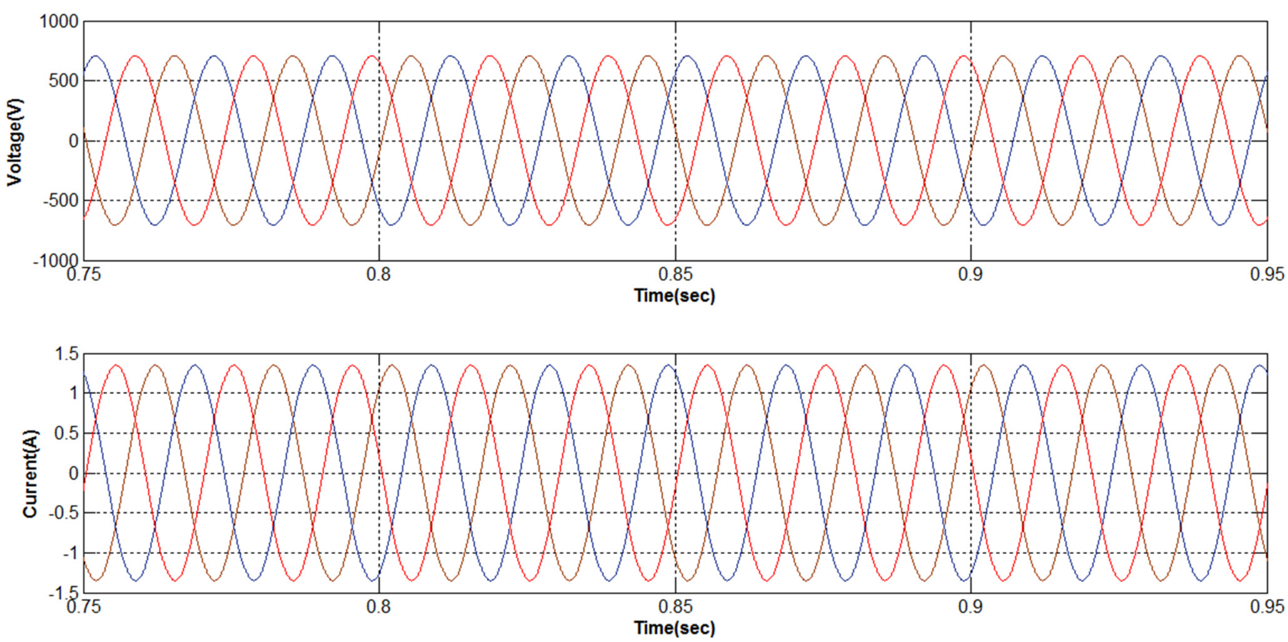

Figure 6: Voltage and Current at load side

Figure 6 shows voltage at load side approximately reaches to 630 volts as at wind generator and the current is improved than before it attains to nearly 1.3 amps. The entire results can be taken using RL load.

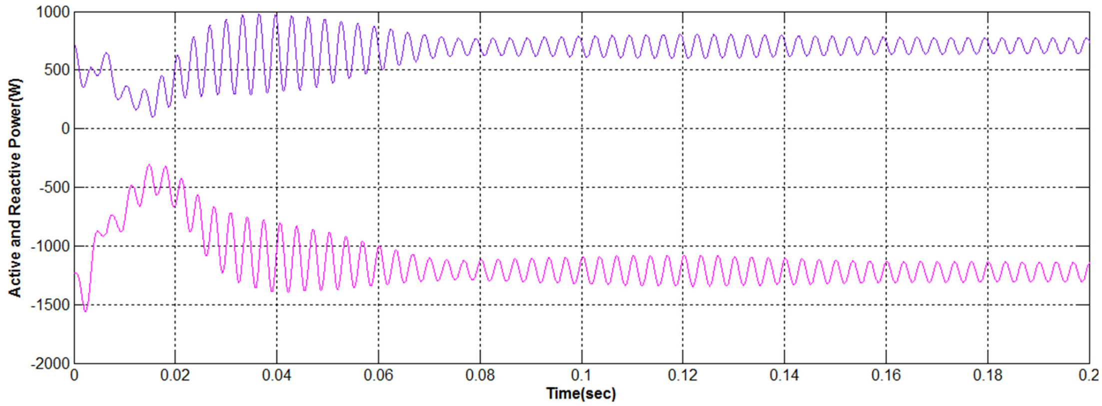

Figure 7: Active and Reactive power at load side

In Figure 7 the active power is shown at positive side which is assumed as the power generating whereas the reactive power can be observed on the negative scale it is considered as consuming power.

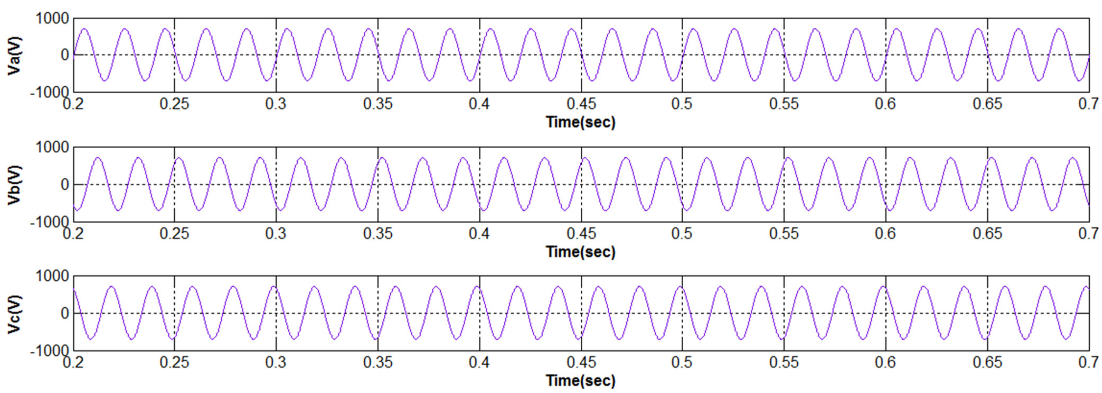

Figure 8: Three phase voltage at load side

The three phase voltages V_{ab}, V_{bc}, and V_{ca} are shown above in Figure 8 generated at load these voltages are attained to approximately 630 volts.

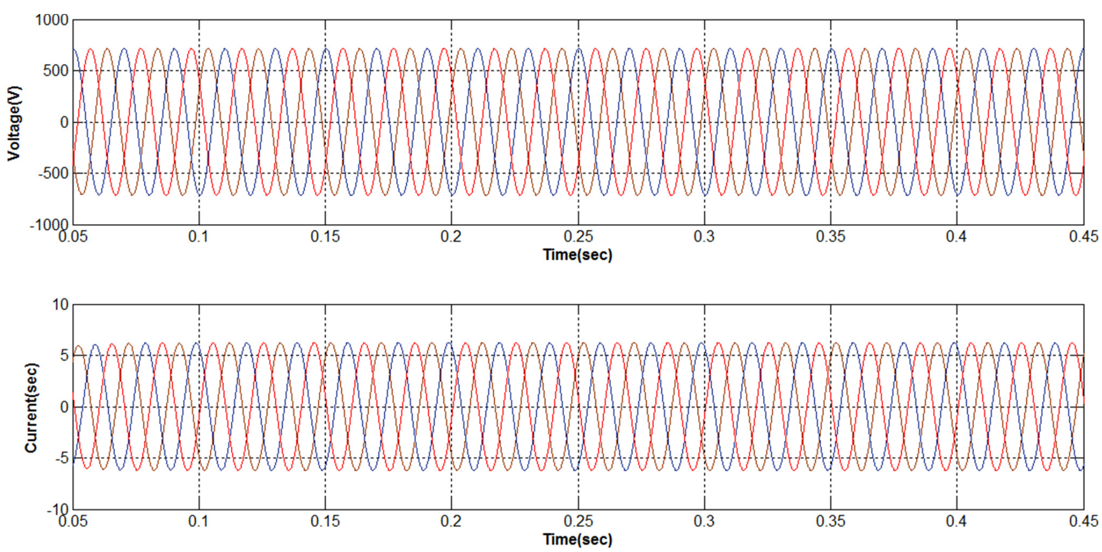

Figure 9: Voltage and Current at grid side

Figure 9 shows three phase voltage and current at grid side. The voltage doesn't changed means it reaches to the 630 volts whereas the current attained to 6 amps.

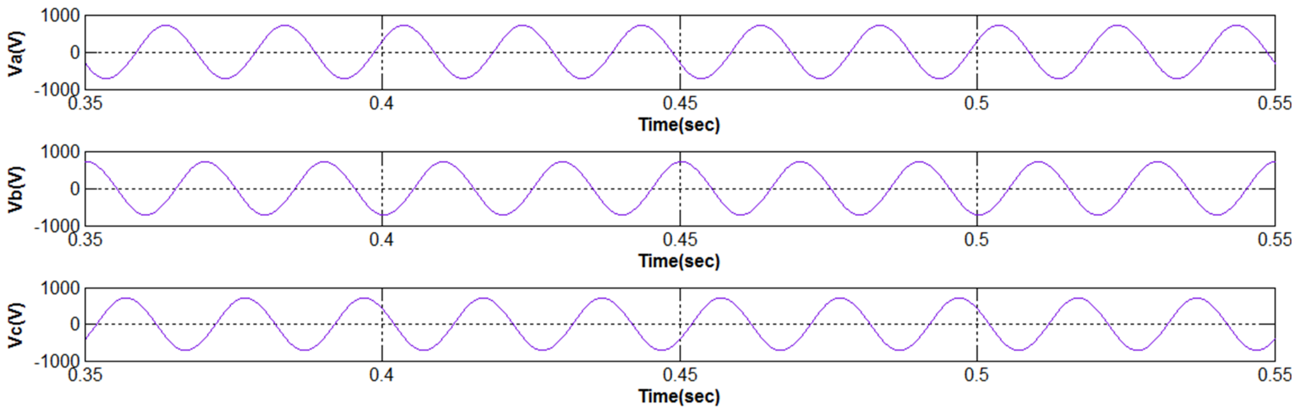

Figure 10: Three phase voltage at grid side

The three phase voltages at grid can be observed in Figure 10.

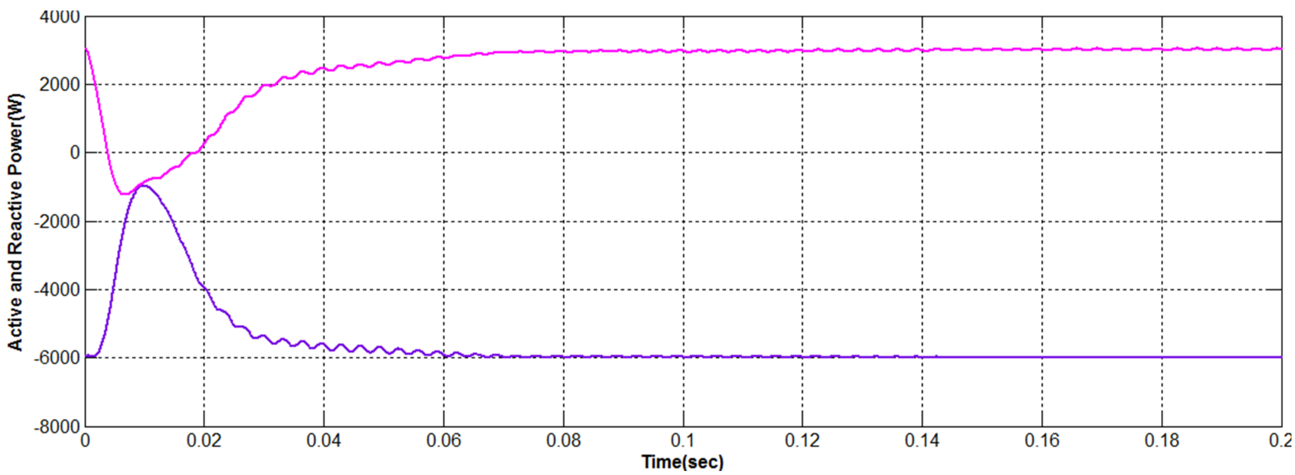

Figure 11: Active and Reactive power at grid side

The active power which is shown in Figure 11 is generated the power to nearly 3500 W and the reactive power is settled at –6000 W and this is consuming power from the system.

6. FFT ANALYSIS

Figure 12(a) and Figure 12(b) shows the voltage is approx 630 volts of wind generator and the THD of Voltage is observed as 7.97%.

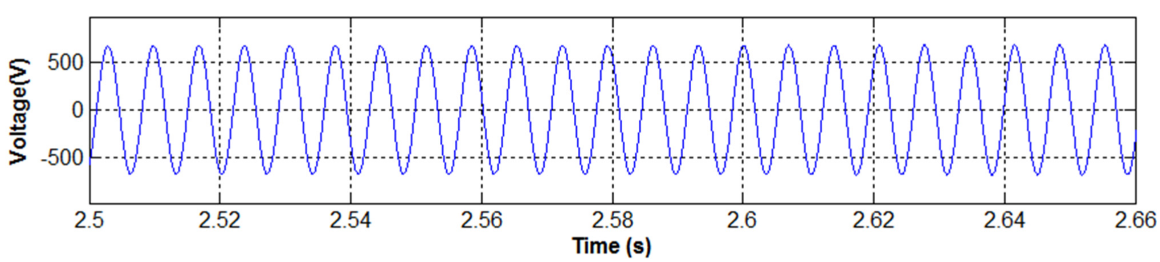

Figure 12: (a) Voltage at wind turbine

The current is 0.3 amps and its THD is 5.86% of wind turbine as shown in Figure 13(a) and Figure 13(b).

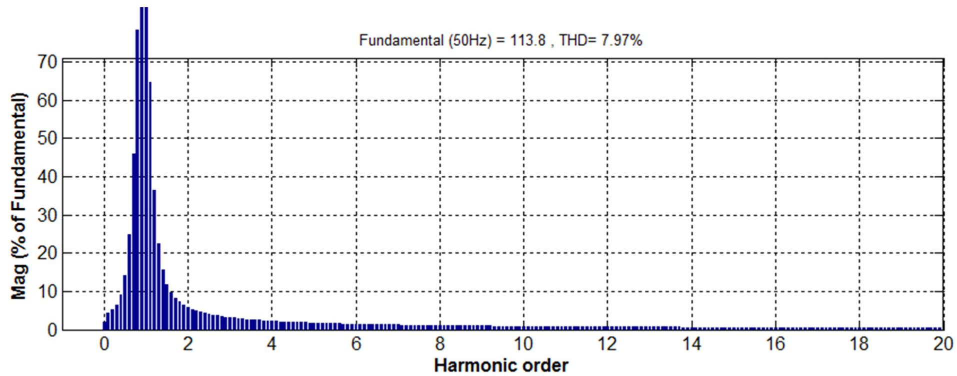

Figure 12: (b) FFT of Voltage at wind turbine

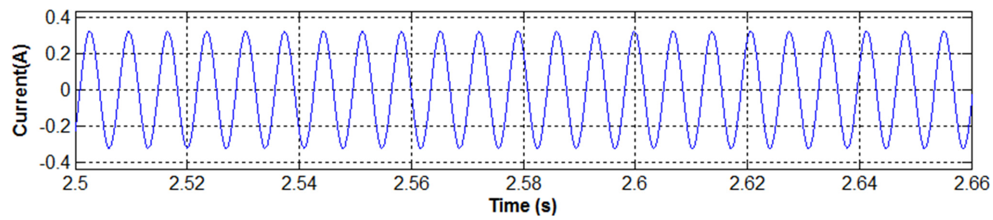

Figure 13: (a) Current at wind turbine

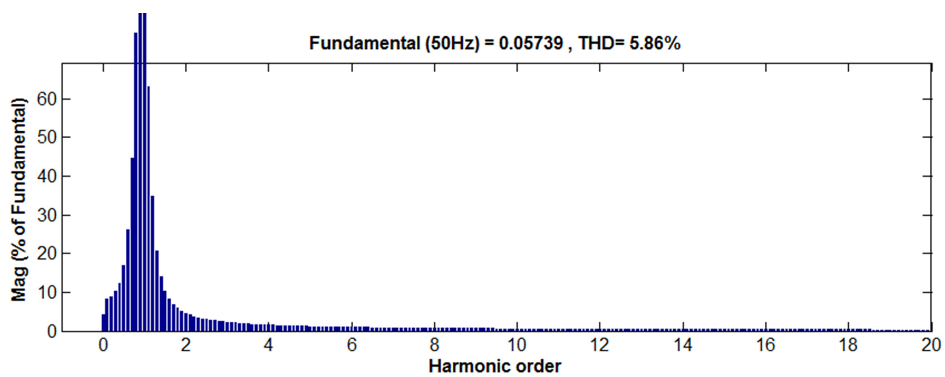

Figure 13: (b) FFT of Current at wind turbine

From the Figures 14, and 15 it is observable that the THD for voltage is 0.25% and current is 4.19% at load side.

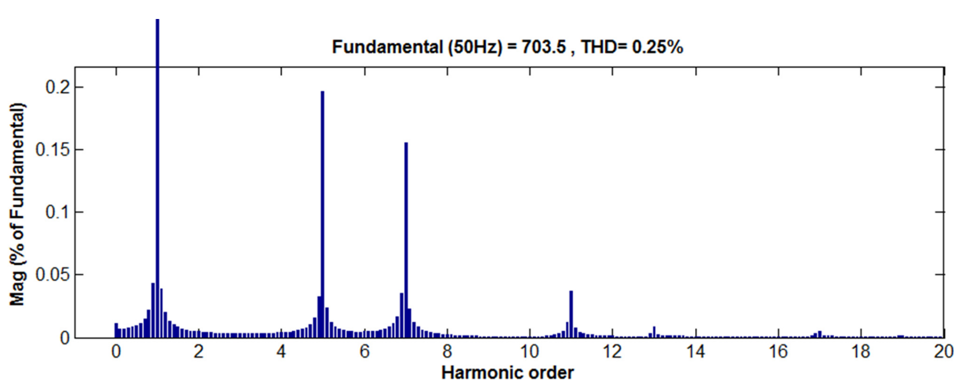

Figure 14: FFT of Voltage at load

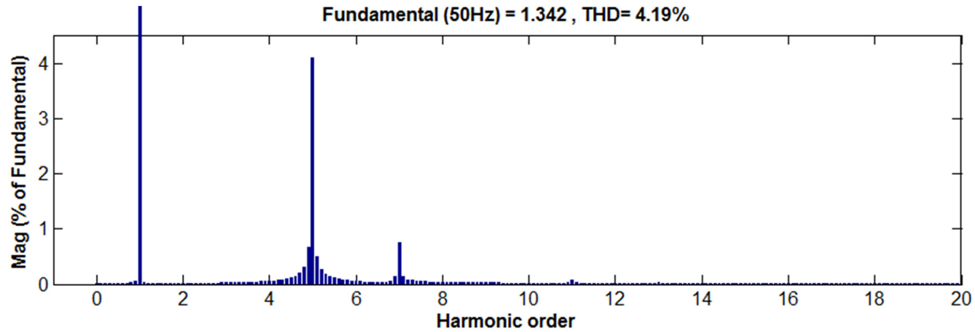

Figure 15: FFT of Current at load

In Figure 16(a) and Figure 17(b) we can see some variation in the waveforms with some different color because it is calculating the THD for that particular part therefore FFT for voltage and current is 0.14% are shown in Figures 16(b) and Figure 17(a).

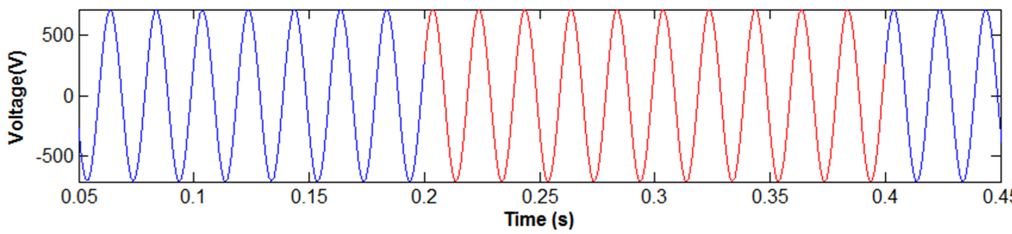

Figure 16: (a) Voltage at grid

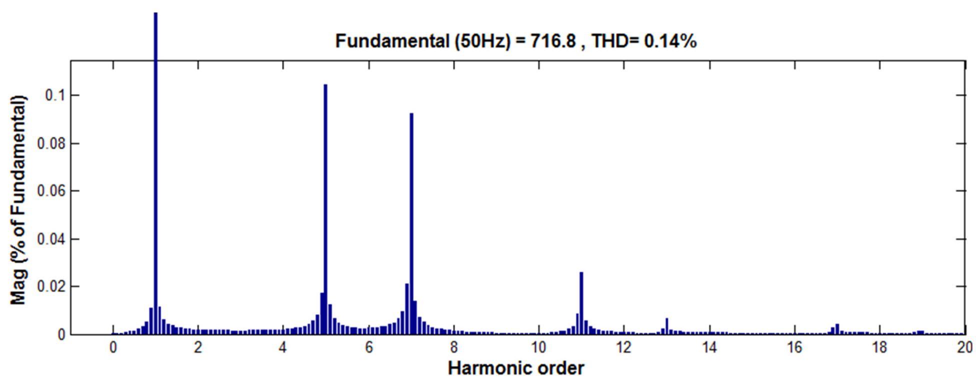

Figure 16: (b) FFT analysis of Voltage at grid

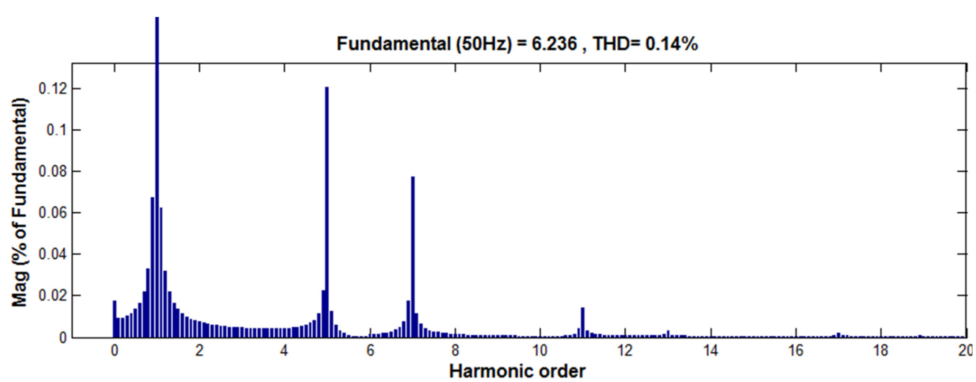

Figure 17: (a) FFT of Current at grid

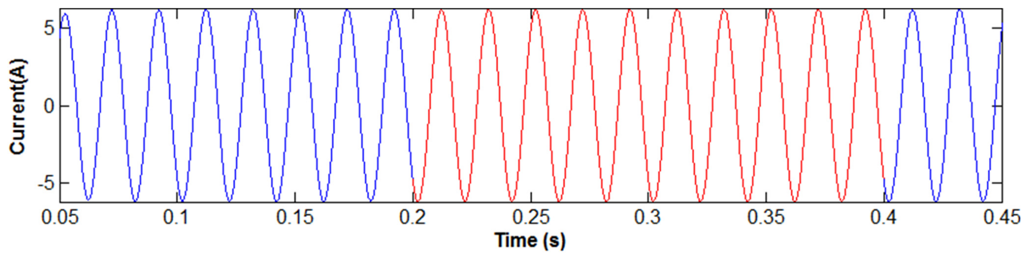

Figure 17: (b) Current at grid

7. CONCLUSION

In this paper, the SIMULINK model of a Variable Speed Wind Energy Conversion System (VSWECS) with PMSG has been implemented via using a PWM converter station. The two converters are linked by a DC voltage bus. The first one has its own controller as well as the rectifier is also under the control of inverter controller. The SPWM technique and PI controller operation is described in the inverter strategy and also Gamma control plays a vital role in this strategy. The performance of this work had done using MATLAB / SIMULINK. It also evaluated the active and reactive power along with the voltage, current and harmonic distortion waveforms for various loads. FFT analysis also presented in this paper with and without filter.

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