Grid Connected Wind Turbine Generator with Real and Reactive Power control

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Abstract - *This paper proposes the use of power electronic converters to extract power from variable speed wind turbines and feed it into the grid. A permanent magnet synchronous generator is coupled to the wind turbine due to its better performance of higher efficiency, less maintenance and it can be used without a gearbox, which implies a reduction of the weight of the nacelle and reduction of costs. The pitch angle of the wind turbine is varied according to the varying wind speeds for the maximum power extraction using voltage controlled MPPT technique. An uncontrolled diode bridge rectifier converters the ac voltage from the generator to dc and is fed to a smooth control of the Boost dc-dc converter. The output of the boost converter is fed to a three phase inverter. An enhanced dynamic behavior is achieved using a feedback control with grid current and grid voltage samples resulting in a desired real and reactive power using PI controllers. The performances of the above operations are explained by simulation results using MATLAB/SIMULINK.*

***Key Words*: PMSG, WTG, MPPT CONTROL, CCVSI, VSI**

1. INTRODUCTION

The realization of a wind turbine as a source of clean, non-polluting and renewable energy may depend on the optimum design of the system and the control strategies of the different possible parameters that can operate efficiently under extreme variations in wind conditions. The general goal of this paper is to optimize the electromechanical energy conversion of the wind turbines, developing suitable strategies of control [1].Both induction and synchronous generators can be used for wind turbine systems [3]. Mainly, three types of induction generators are used in wind power conversion systems: cage rotor, wound rotor with slip control and doubly fed induction rotors. The last one is the most utilized in wind speed generation

because it provides a wide range of speed variation. However, the variable-speed directly-driven multi-pole permanent magnet synchronous generator (PMSG) wind architecture is chosen for this purpose and it is going to be modelled: it offers better performance due to higher efficiency and less maintenance because it does not have rotor current. What is more, PMSG can be used without a gearbox, which implies a reduction of the weight of the nacelle and reduction of costs. Optimum wind energy extraction is achieved by running the Wind Turbine Generator (**WTG**) invariable speed because of the higher energy gain and the reduced stresses. Using the Permanent Magnet Synchronous Generator (**PMSG**) the design can be even more simplified. However, the recent advancements in power electronics and control strategies have made it possible to regulate the voltage of the PMSG in many different ways. In the proposed system a **VSI** converter is preferable [3,4]. Once the model is made and tested sufficiently, the controller for an optimal command strategy is developed so the wind turbine can perform always in the maximum power point.

SMALL-SCALE wind turbines interfaced to an ac grid via grid-connected inverters have wide-spread applications in household and community level power generation. The advantages of this arrangement are that it eliminates the need for batteries, as all the generated power can be fed to the power grid. Major issues with existing grid-connected inverter systems for small wind turbines are as follows.

1) *Limited speed range*: Limitations with existing grid connected inverters have limited dc voltage window, which limits power extraction in both low and high wind speed regimes.

2) *High cost*: Existing grid-connected inverters adapted from the more common photovoltaic inverters require additional front end ac/dc conversion and voltage limiting power electronic circuitry and control algorithms. [2] and [3] put forward block diagrams of a grid-connected wind turbine with a permanent magnet synchronous generator that uses a back-to-back full-scale pulse width modulation (PWM) converter connected to the grid. [4] This increases the system cost and has prevented the more widespread use of small grid-connected wind turbines. Considering the usage of permanent magnet (PM) synchronous generators, three-phase diode rectifiers followed with dc–dc choppers are more economical than three-phase insulated gate bipolar transistor (IGBT) converters. In [5]–[6], a simple ac–dc–ac converter for grid-connected wind power generation systems is used with advantages that include inexpensive cost and easy control of the generator load.

In this paper, a power conversion circuit such as in [4] is designed for a small-scale grid-connected wind generator system. The system consists of a permanent magnet wind turbine generator, a 3-phase uncontrolled diode rectifier, a boost dc/dc converter, and a grid-connected inverter. The output voltage of a PM generator is rectified to provide a dc voltage that will vary in magnitude to reflect the turbine speed. The boost converter makes it possible for inverters operating at low wind speed

2. PROPOSED SYSTEM

2.1 System Principle

The configuration of the wind source converter is shown in Fig. 2. A, B, and C are the ac output voltage ports of a wind turbine. The rectifying circuit (*D*1–*D*6) transforms the ac voltage of a wind turbine into dc voltage. The function of the boost circuit (L_0, D_0, V_0) is to make the dc bus voltage stable. The current control voltage source inverter (CCVSI) (*V*1–*V*4) offers sine wave current to mains. Considering the isolated characteristic of turbine winding, the system is connected to mains without the isolated transformer.

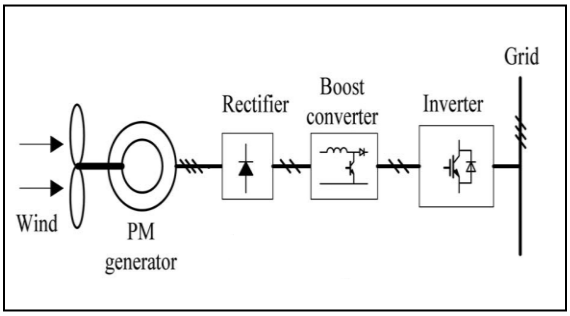


Fig-1: Block diagram

The control of the proposed system can be separated into two parts: dc voltage control and grid-connected current control as illustrated in Fig. 2. The input voltage of the boost circuit *V*re is controlled by grid-connected power including MPPT, while the output voltage of the boost circuit Vdc is stably controlled by the dc voltage loop. As a result, the boost circuit control power switch can transit to switch off smoothly during all wind speeds. Introducing *i*ac feedback and current inner loop forces the current waveform to be sinusoidal at all wind speeds, which ensures that the current injected to the grid satisfies International Electro technical Commission (IEC) standards.

In this system, two strategies are used to improve the output current quality. On one hand, since the converter is transformer less, decaying dc component of the output current injected to the grid is very necessary. This control system computes the dc component of *i*ac by using the grid current sample, and then compensates the dc component in the current loop. On the other hand, in CCVSI, for avoiding *V*1 and *V*2 (or *V*3 and *V*4) be open at the same time, a delay time *Td* is normally used for the switch that be about to open. The presence of *Td* results in the output voltage PWM pulse not equal to the command voltage pulse. The higher the carrier frequency, the more distortion of the output voltage, which causes non sinusoidal, output current waveform. The introduction of the current loop, to a certain extent, can reduce the impact of Td*,* and in theory, *Td* can be fully compensated when the current regulation loop achieves no difference. But i∗ac tracking is some difficult to achieve no difference, so this control system modified the PWM trigger pulse by software to compensate for the output current waveform. The strategy called current feedback compensation method detects zero-crossing of the output current *i*ac and then generates a synchronous square wave voltage added to the corresponding phase modulation wave, to eliminate the dead zone in the fundamental output voltage of H-bridge. Compared with the inverter with frequency transformer, the efficiency of a transformer less inverter is higher.

2.2 Mppt Control:

In variable speed wind turbine, MPPT technique is used for maximum power production. In this paper **perturb and observe method** is employed by controlling the turbine blade pitch angle of the turbine. The output voltage (440V) of the generator is taken as the reference and the pitch angle is either increased or decreased continuously till the voltage (V_0>=440V) is reached. Initially, the output voltage of the PMSG is taken as reference, and check whether the voltage is in the expected range, if it satisfies the above condition then decide output(P=1)1.If it does not exist within the range, then display output as(P=0). In the next step, we have sense the voltage to satisfy the condition of (V>=440). A lot of samples are taken as reference and if the above condition matches then the blade pitch angle of the turbine is varied till maximum power is reached. If the above condition does not occur then the previous sample is considered.

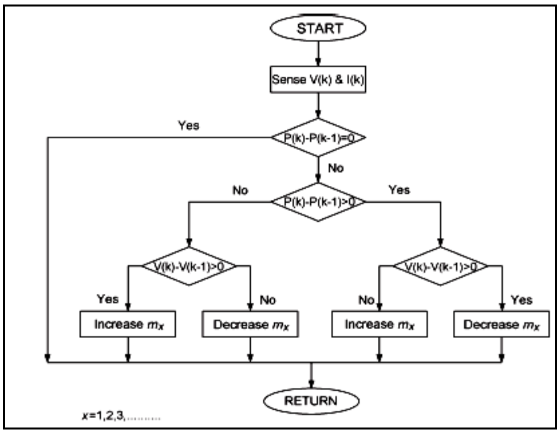


Fig-2: MPPT flow chart

2.3 Smooth Control Of The Boost Converter:

For the voltage characteristics of small-scale low and wide range wind turbines, a boost converter [5], [8] is often added before the grid-connected inverter. The boost converter serves to control the input dc voltage of inverters.

Regardless of the dc voltage output range the diode rectifier is, the input dc voltage of inverter remains steady. Meanwhile, the boost circuit increases the output power of the wind turbine. The output of the PI1 compensator changes the pulse signal, which corresponds to the duty ratio of the power switch V_0. For low, medium, and high wind speeds, the dc voltage is controlled by the boost converter as follows.

1) *Low wind speed*: The converter will increase the dc voltage

So that Vdc>Vg (assuming modulation is equal to 1). During that time, because of Vdc<$V*$dc, the PI1 compensator output is saturated so the switch $V0$ gains the maximum duty ratio.

2) *Medium wind speed*: The function of the converter is to regulate the inverter dc voltage as a constant. The PI1 compensator will cease saturation to keep Vdc near the referenced voltage $V*$dc.

3) *High wind speed*: When Vdc is higher than $V*$dc constantly, the duty ratio of the switch V_0will decrease and the switch V_0will then be turnoff. Therefore, the boost circuit switch can transit to be off smoothly at all wind speeds.

2.4 Current Controlled VSI:

A current controlled voltage source inverter is connected to the output of dc-dc boost converter. It consists of six MOSFET switches, to which the pulses are provided by the feedback control of grid current. The output voltage and current is transferred to direct and quadrature axis using (abc-dq) transformation. The reference current id1 and iq1 are calculated using the below formula. In the three phase inverter, the sinusoidal PWM technique is used for pulse formulation of the 6 MOSFET switches. Abc-dq transformation is performed to transform the voltage (Vabc - Vd, Vq) and current (iabc-id, iq). The voltage is kept constant and the output current of the inverter is given as feedback (id, iq) and compared with a reference current (id1, iq1) calculated from the reference real and reactive power and voltage using the following relation;

$$I_{d1}(t) = 2/3\prod [v_d(t).P(t) + v_q(t).Q(t)] \quad (1)$$

$$I_{q1}(t) = 2/3\prod [v_q(t).P(t) + v_d(t).Q(t)] \quad (2)$$

The PI controller is used to compensate the current error values and inverse transformation (dq-abc) is performed and used for the pulse formulation in inverter.

The real and reactive power requirement is not continuous and it varies periodically in the grid. Hence the power produced in the wind generators must be compensated to the requirements for better grid connection. Therefore grid synchronization has become the most important factor for better efficiency. The three phases to two phase transformation is performed by park's transformation (abc-dq) and followed by inverse Clark's transformation (dq-abc) is used finally after the compensation and power is calculated. The active and reactive powers for the three phases balanced system can be written in d-q coordinates as follows:

$$\text{Real power, } P=3/2[v_d*I_d + v_q*I_q] \quad (3)$$
$$\text{Reactive power, } Q=3/2[v_q*I_d - v_d*I_q] \quad (4)$$

Where Vd, Vq, Id and Iq are the voltages and currents in d-q coordinates.

3. SIMULATION AND RESULTS

3.1 Wind Turbine Modelling

In order to extract power from the wind, energy must be transferred from the flow of the fluid of the air to the blades of the turbine gives the theoretical power available in the wind (Pwind), where r is the density of the air, A is the area swept by the rotor, v is the wind velocity and R is the blade radius. PMSG can be used without a gearbox, which implies a reduction of the weight of the nacelle and reduction of costs. The Output mechanical power generated by the wind turbine is given by, The wind turbine exhibits a nonlinear characteristic and the output mechanical power generated by the wind turbine is given by [4], [10]

$$Pw = 0.5\rho AwCpV w^3 \quad \text{-- (5)}$$

Where

ρ -air density (kg/m³);

A_w- area covered by the wind turbine (m²);

Cp -performance coefficient;

Vw -wind speed (m/s).

The performance coefficient is a function of tip speed ratio **λ** and pitch angle **β**

$$C_p = f(\lambda, \beta) = 0.5 (98/ \lambda i - 0.4\beta - 5) \_ e^{-(16.5/\lambda i)} \quad (6)$$

λ is given by,

$$\lambda = \omega rR/ V_w \quad (7)$$

where ωr is the turbine rotational speed (in rad/s) and R is the radius of the turbine blades (in m). By substituting ωr from (7) into (5), we get

$$Pw = 0.5\rho AwCp (\omega rR/\lambda)^3 \quad (8)$$

There exists a particular value λopt, which results in the point of optimal efficiency where the maximum power is captured from wind by the wind turbine [11]. The mechanical power–rotational speed curves of wind turbine at various wind speeds, which indicates that the wind turbine. Maximum power point for each of the wind speed. And its MPP varies with changing atmospheric conditions

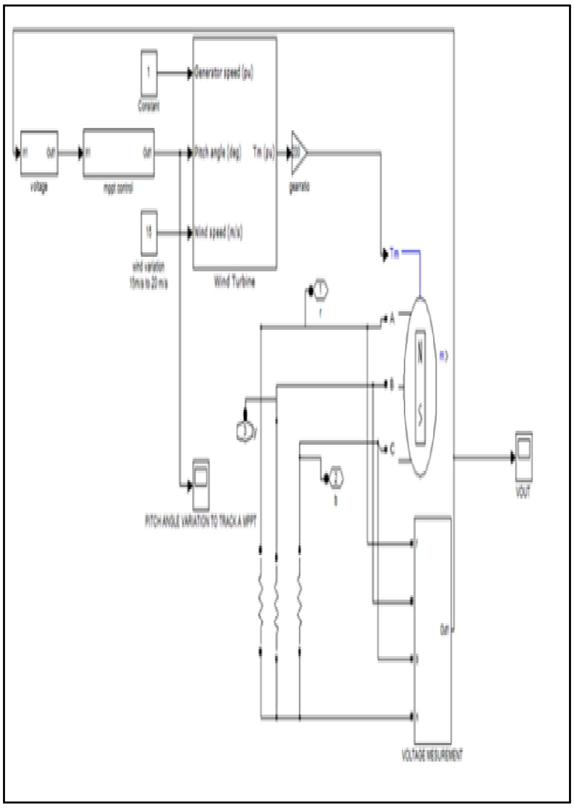


Fig -3: Modelling of wind turbine with PMSG

3.2 *Mppt Control:*

In variable speed wind turbine, MPPT technique is used for maximum power production. In this project perturb and observe method is employed by controlling the blade pitch angle of the turbine. The output voltage (440V) of the generator is taken as the reference and the pitch angle varies continuously till the voltage (V_0>=440V) is reached. The output voltage of a PMSG (440V) is fed through an uncontrolled diode bridge rectifier and converted into dc. The smooth control of closed loop boost dc-dc converter makes it possible for the input voltage of the inverter operating at different wind speeds It is not easy to measure the wind speed in the rotor of turbine, so an indirect approach is implemented. According to the theory of power balance of the system, the maximum power point of the wind turbine can be tracked by judging the grid-connected power. This strategy has a simple structure and needs no additional measurements.. The compensator of the rectify voltage loop is proportional and integral for realizing zero difference. Therefore, MPP tracking can be achieved by incorporating it with grid-connected power control without any information of wind speed. The control algorithm adopts a regular perturbation and observation (P&O) method by increasing or decreasing Ure constantly to track the maximum power. The method can be expressed as follows:

$$P : V(n) = V(n-1) + s|\Delta V| \qquad (9)$$

$$O : \Delta Pg = Pg(n) - Pg(n-1) \qquad (10)$$

where

$V(n)$ -actual rectified voltage sampling;

$V(n-1)$ - previous rectify voltage sampling;

S -disturb direction;

$|\Delta V|$ -| step of voltage disturb; $Pg(n)$ actual power sampling;

$Pg(n-1)$ - previous power sampling;

ΔPg - difference of power.

The P&O method disturbs voltage Ure first, and then compares the actual output power $Pg(n)$ with the previous sample $Pg(n-1)$. If the power is increasing, the perturbation direction s will be in the same direction; otherwise, s would be inverted. ΔPg avoids the false comparison between $Pg(n)$ and $Pg(n-1)$.A 3-phase inverter is used for dc-ac conversion and connected to the utility grid using sinusoidal pulse width modulation. The wind energy conversion system is incorporated with grid synchronisation to compensate the power variations using power controllers.

The actual power is calculated from the above formula (1) and(2)with the reference power used in simulation shown in the following table.1. rom the results, we observe that the actual power calculated from the system compensates the reference values there by improving the performance of grid synchronisation

Table-1: Reference Power For Simulation

S.N0	TIME RANGE (SEC)	REFERENCE ACTIVE POWER (KW)	REFERENCE REACTIVE POWER (Kvar)
1.	0-0.25	25	-2.5
2.	0.25-0.5	13.5	1.35
3.	0.5-0.75	40	4
4.	0.75-1	2.5	-5

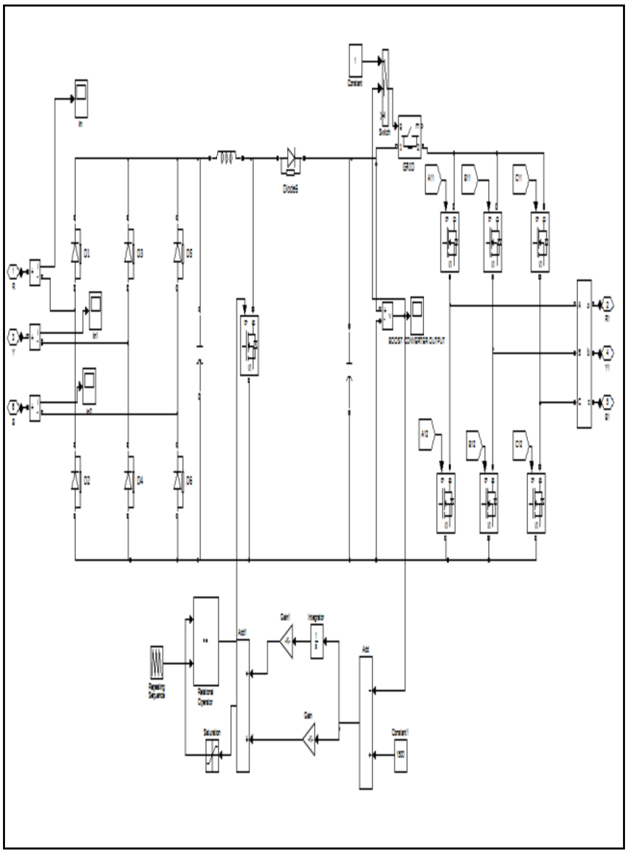


Fig- 4: power converters (ac-dc-ac)

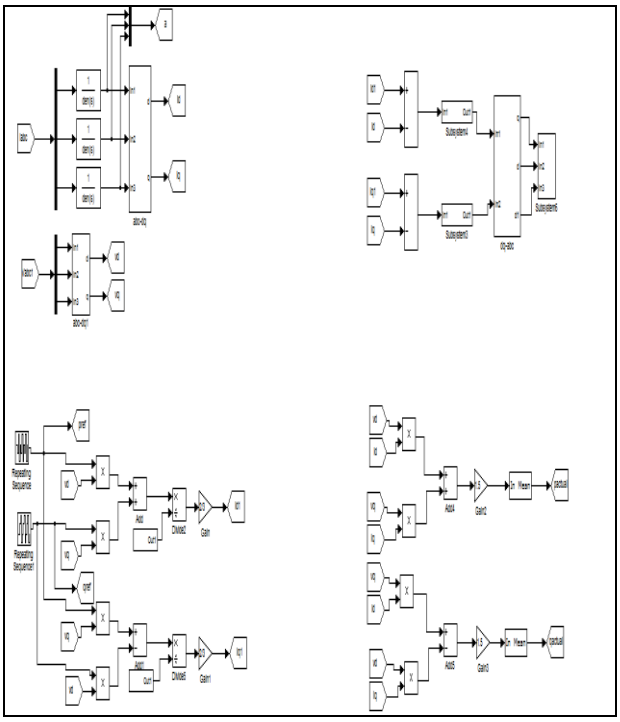
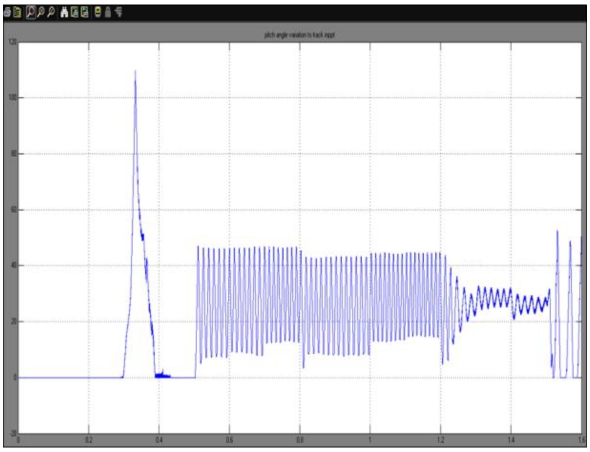
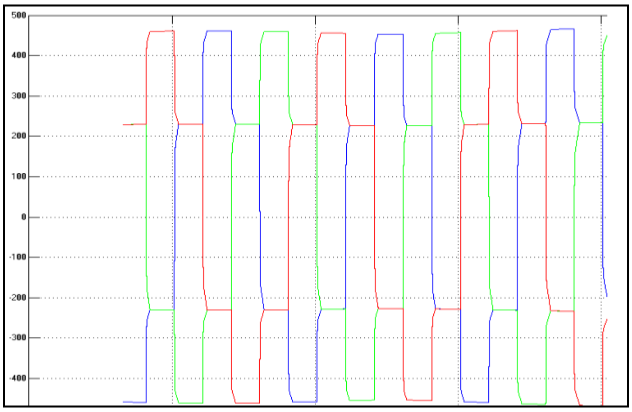


Fig-5: power controllers



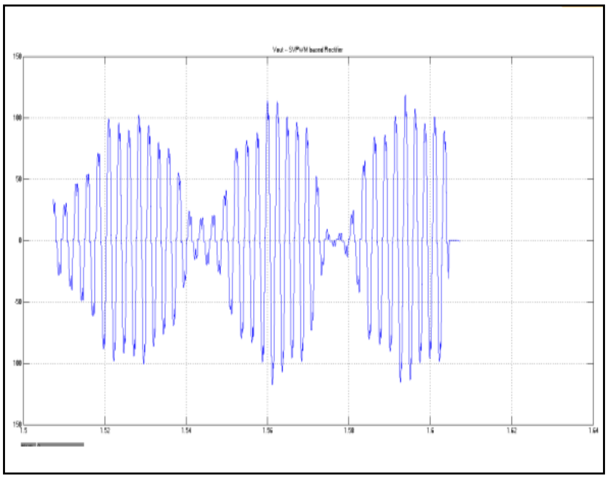
⟶ Time

Fig-6: pitch angle variation due to MPPT



⟶ time

Fig-7: wind generator output voltage



⟶ time

Fig-8: rectifier input current

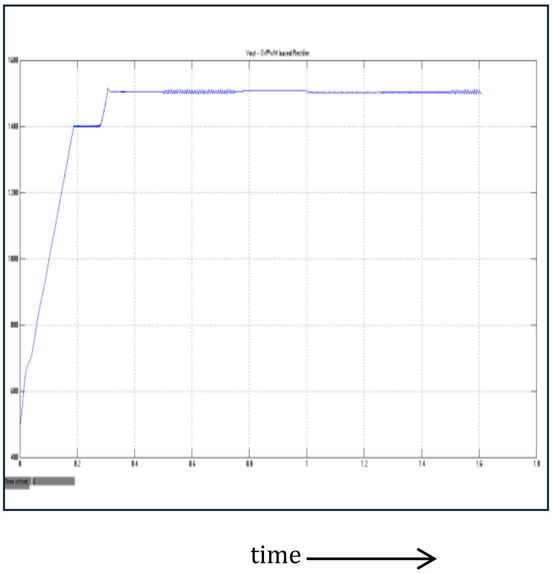


Fig-9: output dc voltage of Boost Dc-Dc converter

4. CONCLUSION

In this paper a variable speed wind turbine is coupled with permanent magnet synchronous generator and used to produce power and feed it into the grid using power electronics converters. A MPPT technique based on perturb and observe method is used for maximum power production by controlling the pitch angle of the wind turbine.

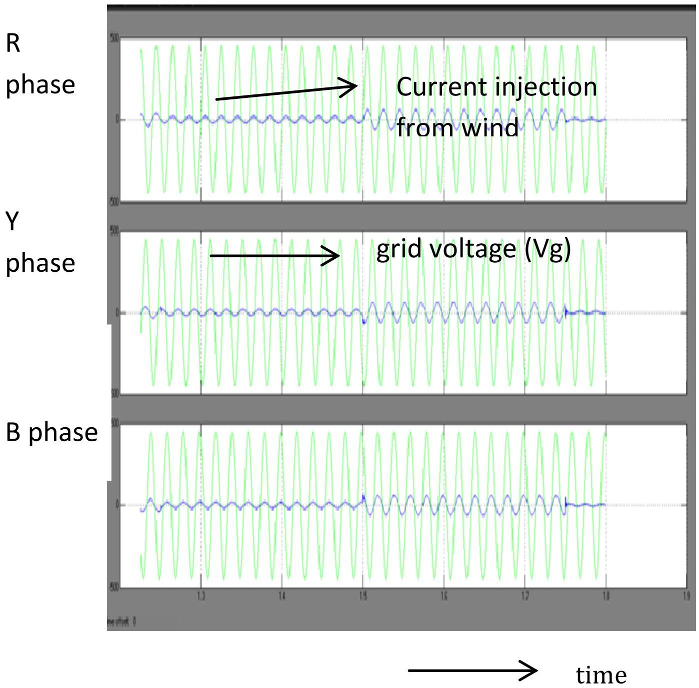


Fig-10: per phase output voltage and current

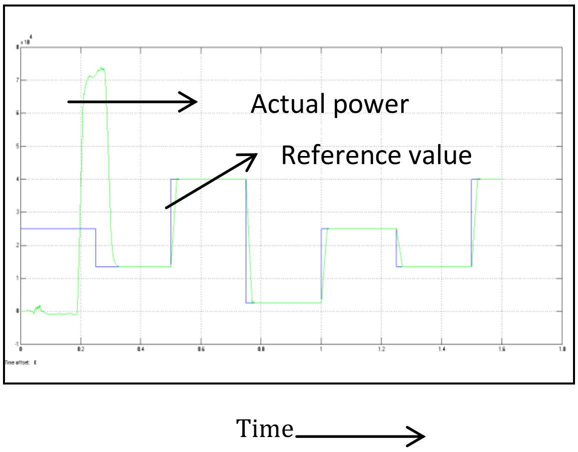


Fig-11: active power (reference & actual)

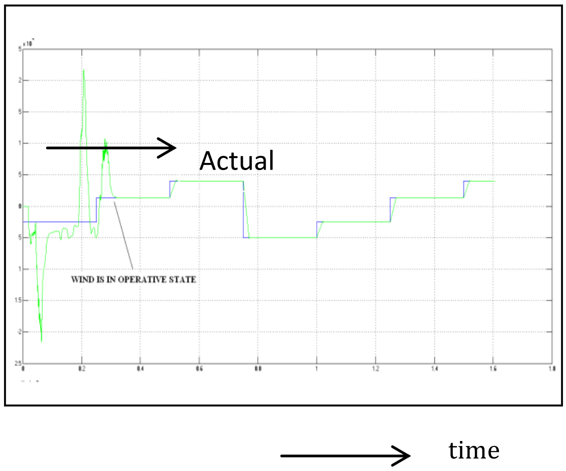


Fig-12: reactive power (reference & actual)

The closed loop control of boost converter and current controlled voltage source inverter is performed using PI controllers. The stable real and reactive power flow is achieved using feedback controllers for the grid synchronization. The grid connection of wind energy system was verified by the simulation results.

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