Simulation and Control of DC/DC Converter for MPPT Based Hybrid PV/Wind Power System

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Abstract- The Hybrid PV/Wind power system is the best renewable energy sources due to their complementary nature. In this paper explains the simulation and control of DC/DC converter for a prototype of 3kW PV and 3.2kW PMSG based wind energy conversion system. The perturbation and observation algorithm fused with the proposed converters is used for drawing maximum power from the input sources. So power from the two sources can be delivered either independently or simultaneously depending on their availability. The single phase sinusoidal pulse width modulation (SPWM) inverter which is based on PQ control strategy supplied total power to the grid and maintained DC link voltage constantly at 400V. The LCL filter at the output of the inverter kept THD of grid current within the standard limit, and we have found that power fluctuation has been completely reduced using battery bank.

Keywords- PV system, WECS, Two Mass Drive Train, , PMSG, MPPT,SPWM, THD.

1. Introduction

Growth of power electronics lead to a significant development in photovoltaic and wind energy system. Most of the researchers consider only one source either wind or PV.The major drawback of single source is its intermittent nature which makes the output power fluctuating. Varying wind speed affects the amount of power generated by WECS, similarly, power generated by solar system is affected by the variation in solar irradiation and temperature. Hybrid Wind/PV generation system is more efficient and reliable compared to single source since wind speed is high during night or cloudy days and calm wind occurs on sunny days.

Different hybrid Wind/PV generation system is proposed and discussed in works [1]-[4], these systems use MPPT based DC/DC converters to achieve maximum power from both the energy sources [1]-[3]. A dual input inverter is recommended by [1], where a multi input buck/buck boost converter is used and MPPT is accomplished for both wind and PV system. A grid tied wind energy conversion/PV/Fuel cell hybrid system is proposed by [2], this system can lead to maximum output energy and minimum output power fluctuation for stand alone mode. An alternative multi input converter structure is suggested for hybrid wind – PV energy systems by [4]. Where a Cuk/SEPIC fused converters are used to eliminate the separate input filters.

In this paper two separate boost converters are used to transfer maximum power from the solar array and WECS. The boost converter is simple, easy to be controlled by varying the duty cycle with minimum power fluctuation and high efficiency. Since the boost converter output is always greater than the input, it is useful to connect to grid later.

2. Hybrid System Configuration

The proposed hybrid system is a combination of PV, PMSG based WECS and Battery with two separate MPPT based boost converters connected at the output of solar and WECS as shown in the “ Fig.1”. The boost converter is simple, easy to controle by varying the duty cycle with minimum power fluctuation and high efficiency. The output of the two boost converters are connected to a common DC bus. This eliminates the use of two separate DC/AC inverters. The power rating of the inverter in a common DC bus system is less. Moreover this reduces the cost and makes system more compact. Through the control strategy of the single phase pulse width modulated inverter, it is possible to achieve DC link voltage stabilization at the inverter input, and to supply a minimum power to the grid even if only one energy source is present.

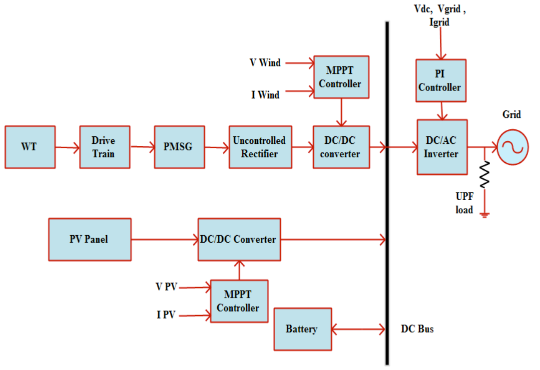


Fig.1. General block diagram of the hybrid system

3. Modelling of Photovoltaic Cell

Considering only a single solar cell, it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell as shown Fig.2. and Table 1.

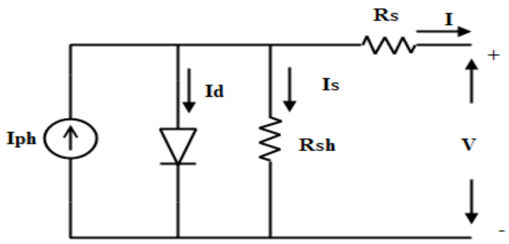


Fig.2. Equivalent circuit of PV cell

The V-I characteristic equation of PV cell is given by

I=Iph - Id - Ish (i)

$$= I_{ph} - I_s\{exp\left[\frac{q}{AkTc}(V + IR_s\right] - 1\} - \frac{V + IR_s}{R_{sh}} \quad (ii)$$

$$Where,\ I_{os} = I_{rs}\left[\frac{T_c}{T_{ref}}\right]^3\left[\frac{qE_g}{Bk}\left(\frac{1}{T_{ref}} - \frac{1}{T_c}\right)\right. \quad (iii)$$

$$I_{ph} = [I_{sc} + Kl(T_c - 298) \quad (iv)$$

Table 1. Parameters of PV module

Parameter	Variable	Values
Maximum current	I_m	4.39 A
Maximum voltage	V_m	17.1 V
Open circuit voltage	V_{oc}	21.4 V
Short circuit current	I_{sc}	4.76 A
Internal series resistance	R_s	0.4 Ω
Reference solar irradiation	S_{ref}	1000 W/m^2
Reference temperature	T_{ref}	25 ^{o}C

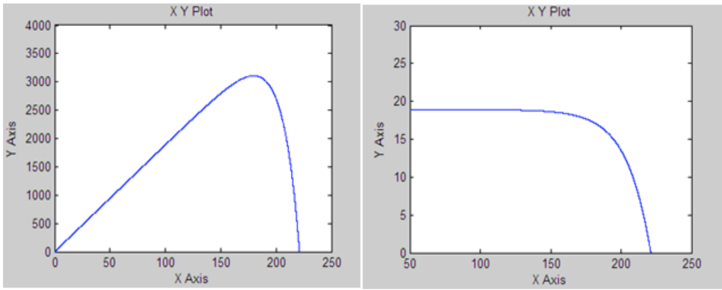


Fig.3. P-V and I-V characteristics of PV system

4. Design of Wind Turbine

The fundamental equation governing the mechanical power captured by wind turbine is given by equation.

$$P_m = \frac{\rho A V^3 C_p}{2} \quad (v)$$

Where, ρ is the air density (Kg/m^3), A is the area swept by the turbine blades (m^2), V is the wind speed (m/s) and C_p is the power coefficient of the wind turbine. The output power of the wind turbine is a function of power coefficient which in turn depends on pitch angle β and tip speed ratio λ.

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda 1} - 0.4\beta - 5\right) exp\left(\frac{21}{\lambda 1}\right) - 0.0068\lambda \quad (vi)$$

$$\lambda = \frac{WtR}{V}$$

Where W_t is the turbine speed

$$\lambda 1 = f(\lambda, \beta)$$

is given by,

$$\frac{1}{\lambda 1} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (vii)$$

Table 2. Wind turbine Parameters

Parameter	Value
Mechanical power output (Kw)	3.5
Wind Turbine power coefficient	0.48
Tip Speed ratio, (λ)	8.1
wind speed (m/s)	12
Pitch angle, (β)	0

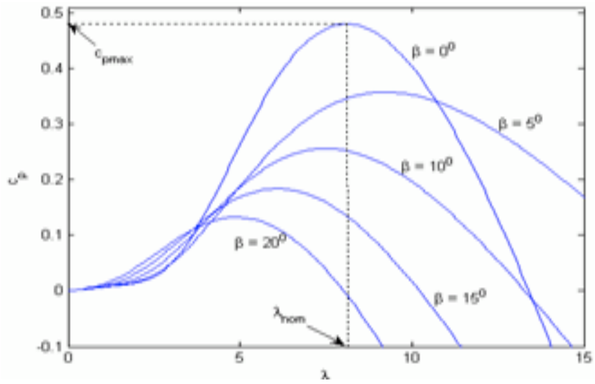


Fig.4 .$C_p V_s λ$ characteristics of wind turbine

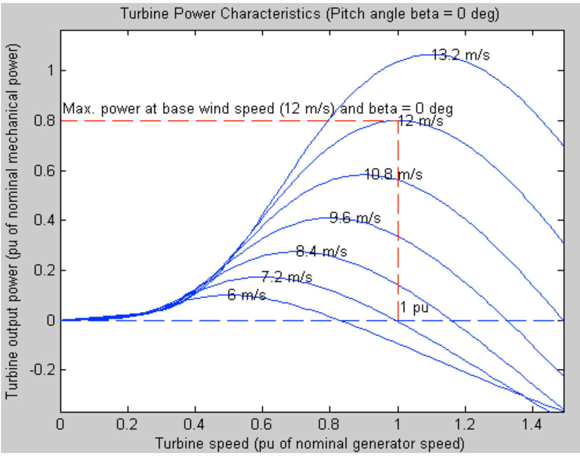


Fig.5. of wind turbine Torque-Speed characteristics

5. Design and Modelling of Two Mass Drive Train

By applying Newton's second law of rotation, the mathematical model will be shown below

$$J_r W_t^{\cdot} + B_r W_t = T_a - T_{ls} \qquad \text{(viii)}$$

Where J_r = rotor moment of inertia, *Wt* = rotor angle speed, *Br* = rotor damping effect, *Ta* = applied torque on the rotor, Tls = low speed shaft torque, similarly

$$J_{ls} W_{ls}^{\cdot} + B_{ls}(W_t - W_{ls}) + K_{ls}(\Theta_t - \Theta_{ls}) = T_{ls} \qquad \text{(ix)}$$

Where *Jls* = drive moment of inertia, *Wls* = Angular speed of shaft (low speed), *Bls* = Damping effect(low speed), Kls = Stiffness of shaft, θt = rotor angular displacement, θls = low speed angular displacement. When drive moment of inertia is cancelled it becomes:

$$T_{ls} = B_{ls}(W_t - W_{ls}) + K_{ls}(\Theta_t - \Theta_{ls}) \quad \text{(x)}$$

As shown in the Fig.4. CpVs λ, it is understood that Cp is maximum for pitch angle, β = 0, so the pitch controller continuously sense the rotor speed and produces zero pitch angle, thus Cp will be kept maximum and in turn output power of the turbine will be maximum. PMSG is having large air gap thus leakage flux is low for machines with more number of poles. In PMSG the rotor windings are replaced with permanent magnet which eliminates rotor excitation losses, thus wind energy can be better utilized for production of electric power. The generator armature current can be related to armature voltage and torque to rotor speed as follows:

*T = Kt*Ia, E = Ke*Wm*

6. Boost Converter

Two separate boost converters are used to transfers maximum power from the solar array and WECS to the common DC bus, in a coordinated way and at a voltage always greater than the input magnitude

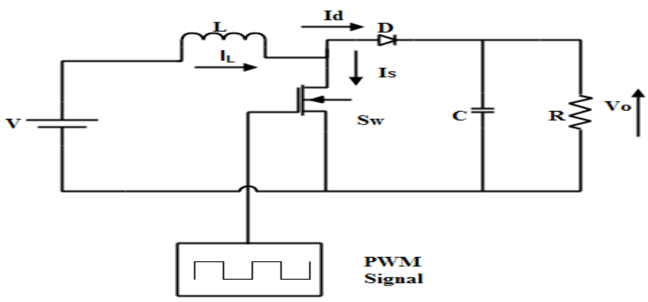


Fig.6. A boost converter

The control strategy is achieved by varying the duty cycle of the switch, in this project boost converter is designed for 50% duty cycle that is for 200V to 400V conversion. When the switch is closed, the inductor will charge energy and it will discharge the accumulated energy when the switch is opened.

$$\frac{di_l}{dt}(closed) = \frac{V_S}{L} D,$$
$$\frac{di_l}{dt}(opened) = \frac{V_S - V_O}{L} D'$$

Where D is the duty cycle and $D + D^1 = 1$

$$\frac{di_l}{dt}(closed) + \frac{di_l}{dt}(opened) = 0$$

$$V_O = \frac{V_S}{D'} = \frac{V_S}{1-D} \qquad \text{(xi)}$$

since

$$\frac{1}{1-D} \geq 1,$$

The output voltage is always greater than the input.

$$L = \frac{DD'^2 R}{2f},$$

$$C = \frac{V_o}{dV_o R f} D,$$

7. MPPT Algorithm

In this project the perturbation and observation (P & O) algorithm is used, it is simple, cost effective and easy to implement. Fig.7. shows the flow chart of P & O MPPT. The system continuously perturbs the operating voltage after comparing the output power with its previous value. If the output power is increasing the operating voltage is perturbed in the same direction as that of the previous cycle otherwise it is changed in the opposite direction.

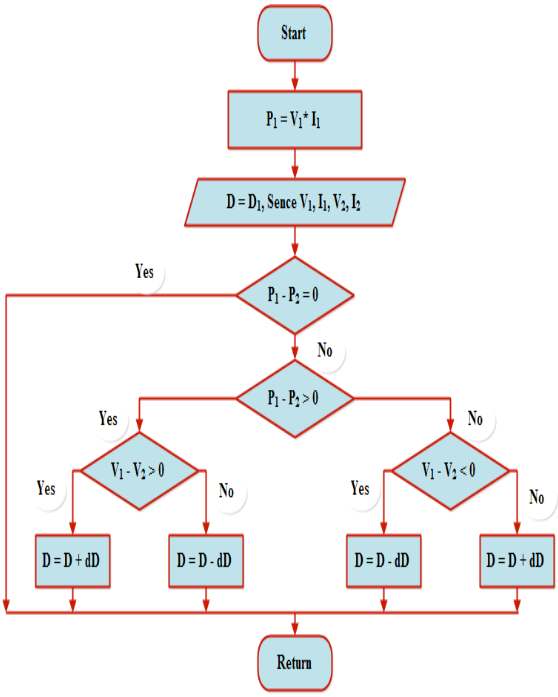


Fig. 7. Flow chart of P & O method

8. Inverter

In this paper a single phase SPWM deadbeat PI controller used. Dead beat PI controller is one of the most attractive control technique which results in fast dynamic response and steady state response is excellent with low total harmonic distortion. It will produce the output in finite time or dead time after the signal is received by the system. This can maintain constant rms output voltage for various type of loads, but the modulation index keeps changing due to the presence of deadbeat based PI controller. Here the control system has two closed loop control which has an outer voltage loop and an inner current loop. Outer voltage loop stabilizes the system that is it regulates the DC link voltage. The inner current loop generates the PWM signal based on PQ control. The reference signal is at a frequency of 50Hz and carrier signal is at a frequency of 5 kHz.To make the perfect sinusoidal waveforms LCL filter is used.To maintain the DC link voltage constant baterry is used.

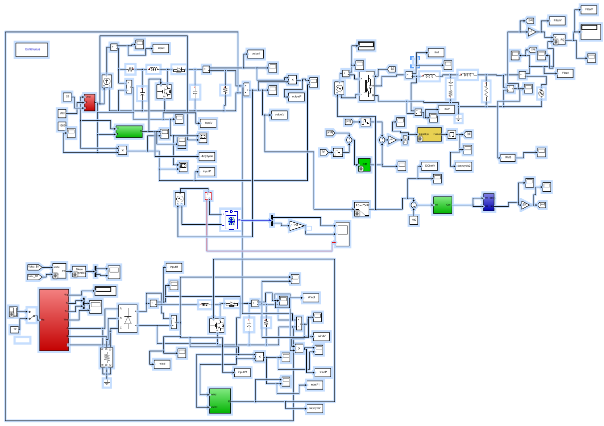


Fig. 8. Simulink model of hybrid PV/Wind hybrid system

9. Results and Discussion

This paper tries to describe the , simulation results of Hybrid PV/Wind power system under different conditions such as constant temperature, constant solar irradiation, constant wind speed and for variable temperature, variable solar irradiation and variable wind speed.

CaseI: When solar irradiation changes from 200W/m^2 to 1000W/m^2 at t=0.6s, temperature constant at 25^{o}C.

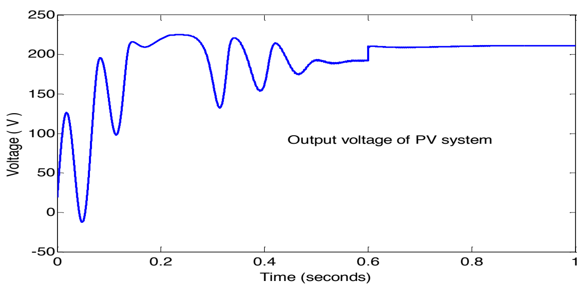


Fig. 9. Output Voltage of solar panel

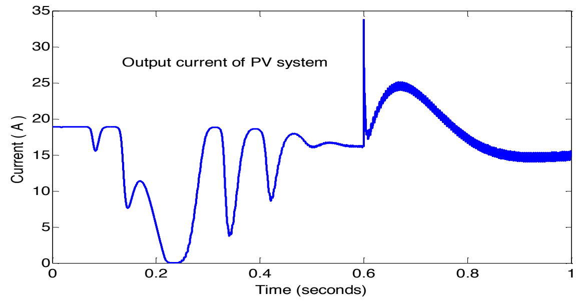


Fig.10. Output current of Solar panel

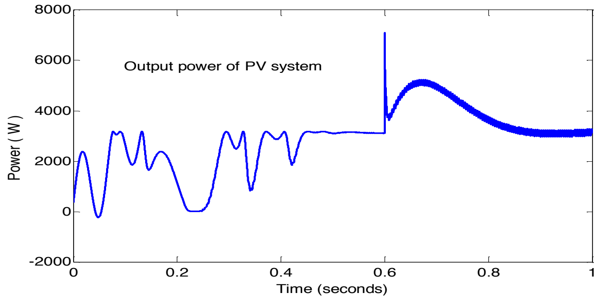


Fig. 11. PV output power

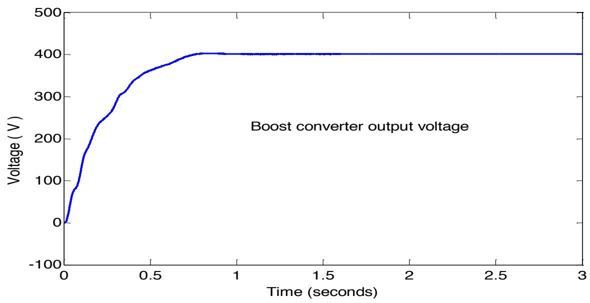


Fig.12. Output Voltage of Boost converter1

Case II: When solar irradiation constant at 200W/m,^{2} temperature changes from85^{o}C to 25^{o}C at t=0.8s

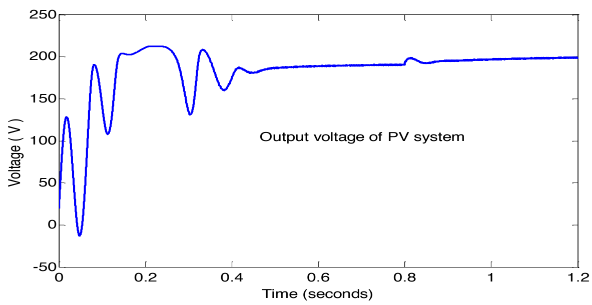


Fig. 13. Output voltage of Solar panel

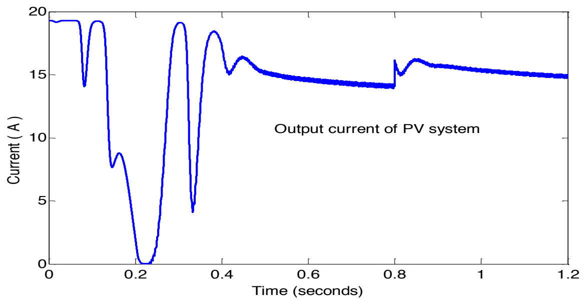


Fig.14.Output current of Solar panel

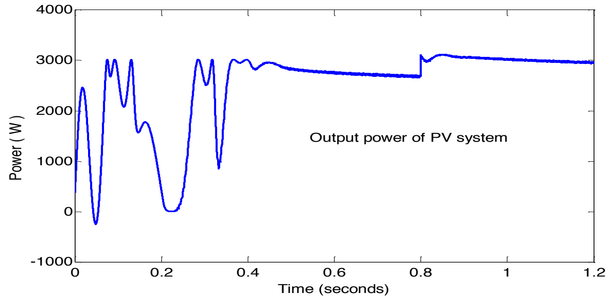


Fig.15. PV output power

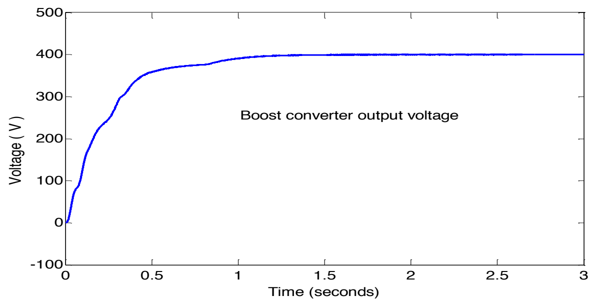


Fig.16. Output Voltage of Boost converter1

CaseIII: When solar irradiation changes from 200W/m^{2}to 1000W/m^{2}at t=0.6s temperature changes from 85^{o}C to 25^{o}C at t=0.8s

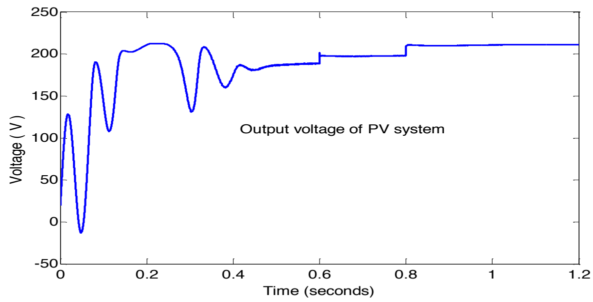


Fig. 17. PV output voltage

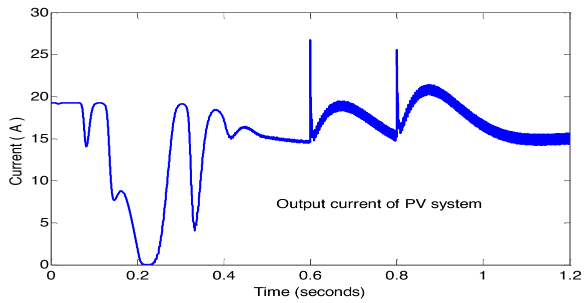


Fig. 18. PV output current

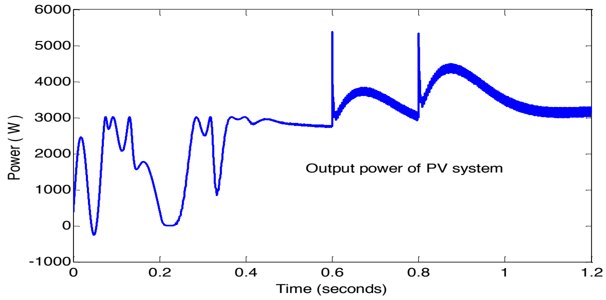


Fig. 19. PV output power

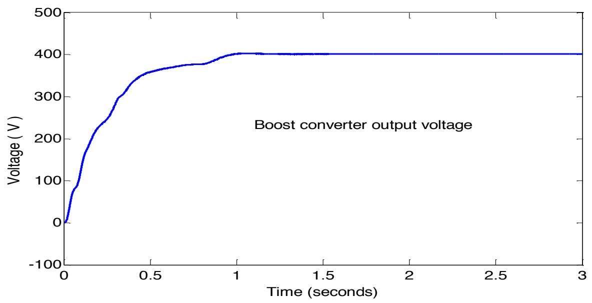


Fig. 20. Boost converter-I output voltage

Case-I Wind speed is constsnt at 12m/s

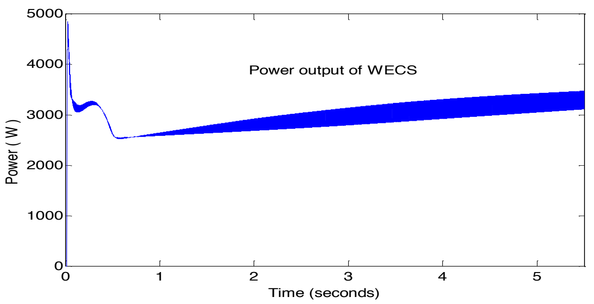


Fig. 21. WECS output Power(3.2Kw)

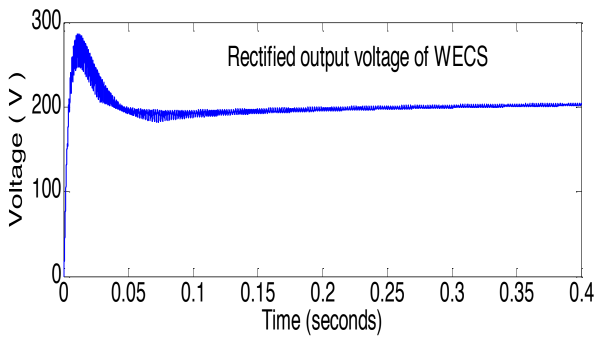


Fig.22. Rectified output voltage of WECS

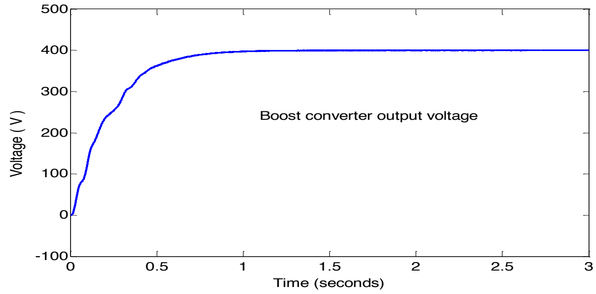


Fig. 23. Boost converter-II output voltage(400V)

Case II: Wind speed changes from12m/s to 7m/s at t=3s and then to 12m/s at t=5s

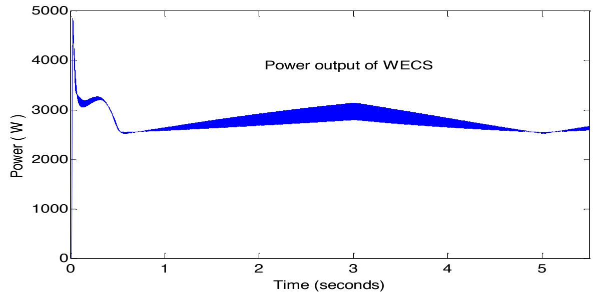


Fig. 24. WECS output Power

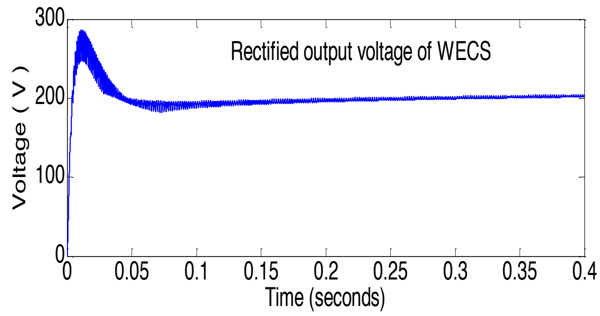


Fig. 25. Rectified output voltage of WECS

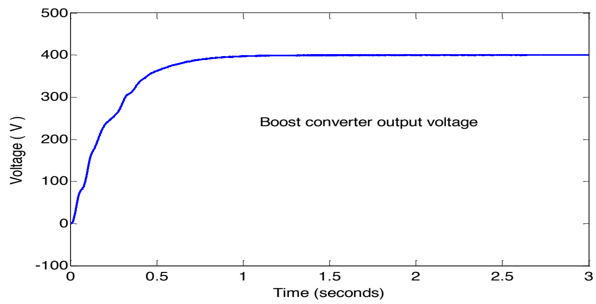


Fig. 26. Boost converter-II output voltage

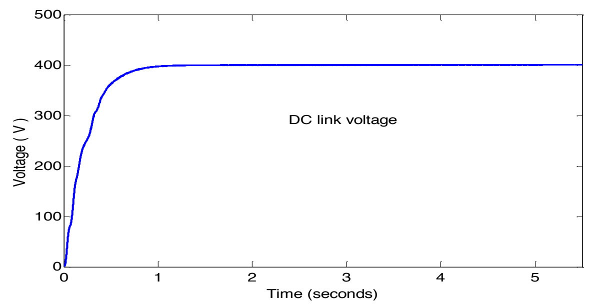


Fig. 27. DC link voltage

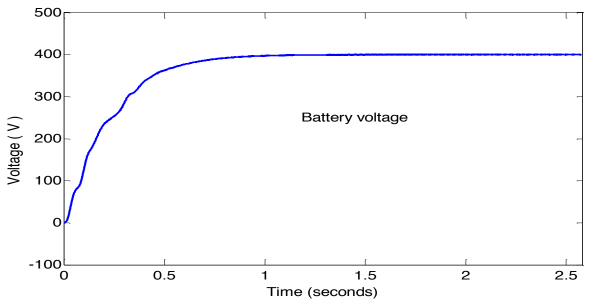


Fig. 28. Battery voltage

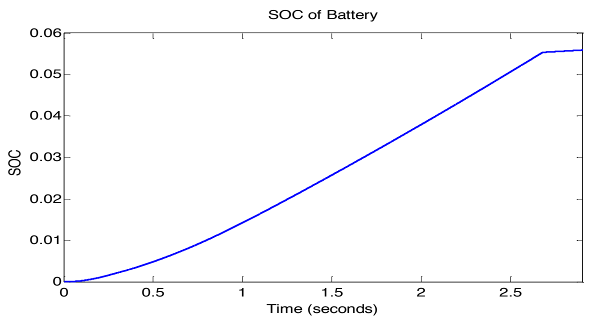


Fig. 29. SOC of Battery

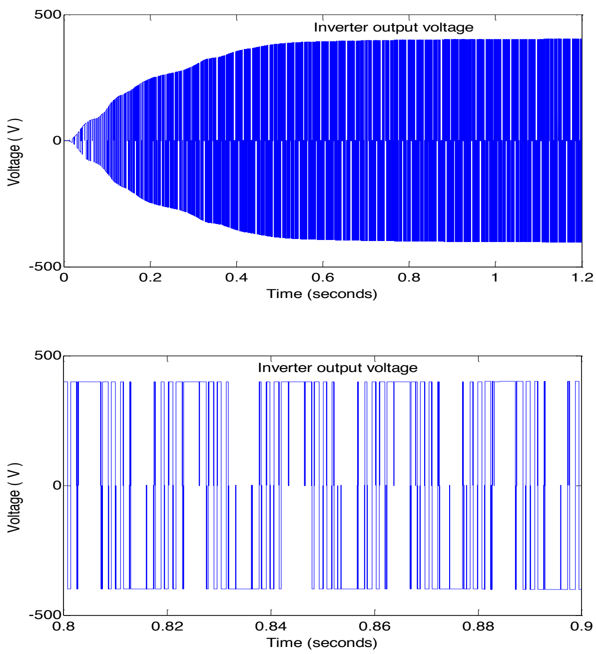


Fig. 30. Inverter output voltage without filter

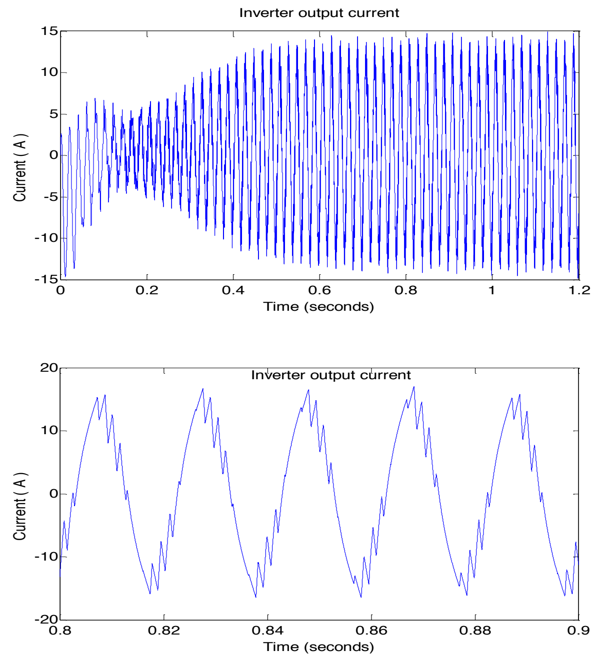


Fig. 31. Inverter output current without filter

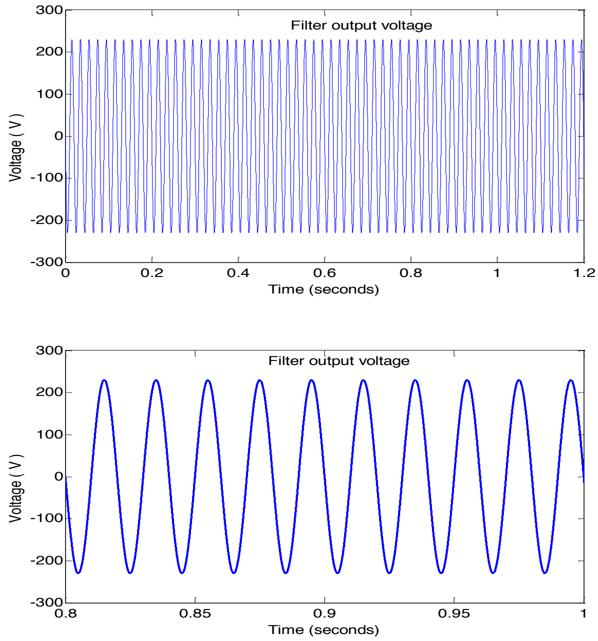
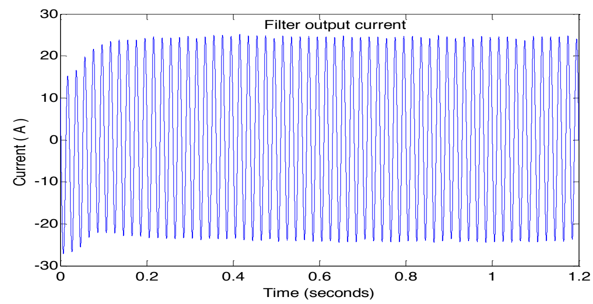


Fig. 32. Inverter output voltage With filter



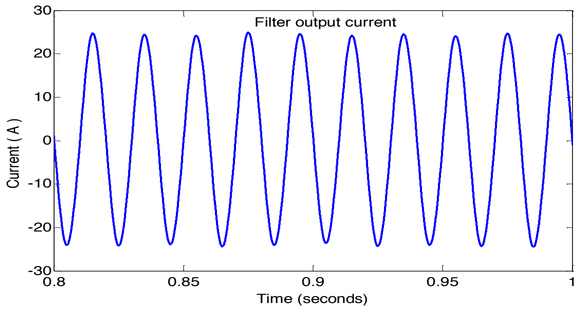


Fig. 33. Filter output current

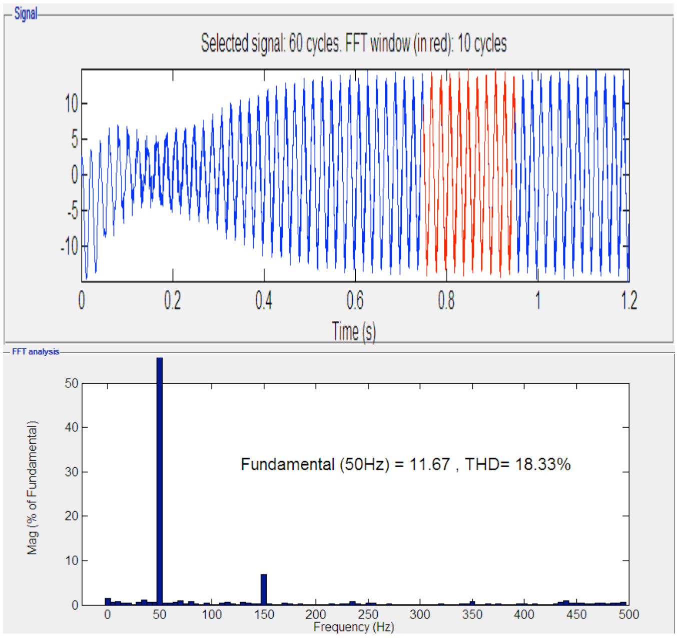


Fig. 34. THD Analysis of Inverter output current without filter

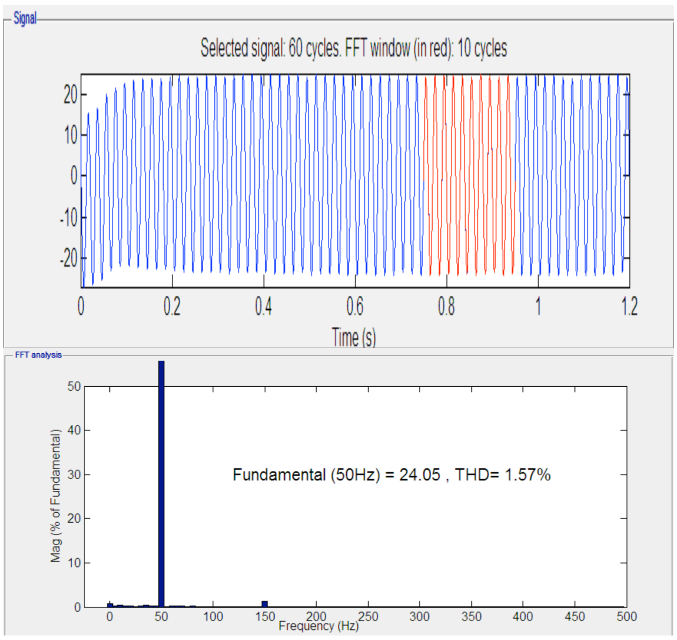


Fig. 35. THD analysis of Inverter output current with filter

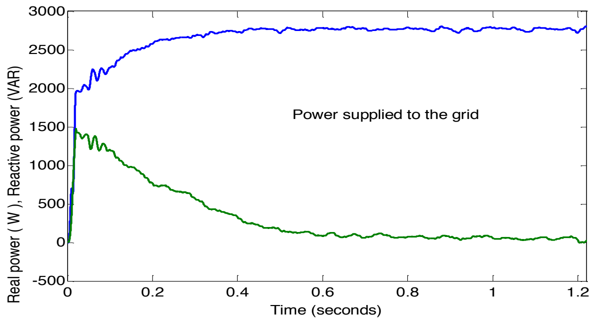


Fig. 36. Real & Reactive power supplied to grid

10. Conclusion

The paper presents a hybrid PV/WEC system connected to grid with maximum power point tracking. The proposed system can supply power continuously with higher reliability and efficiency compared to single source. The characteristic of PV module shows that the maximum power produced by the solar module is 3kW. On the other hand, the characteristics of WECS, indicate a maximum power of 3.2kW at a wind speed of 12m/s and at a tip speed ratio of 8.1, that attains the maximum power coefficient of 0.48 with zero blade pitch angle. This model worked well under sudden change of environmental conditions. The maximum power of PV and WECS are transferred to DC link by two separate boost converters based on P & O MPPT algorithm and operating at 50% duty cycle.The single phase DC/AC inverter based on PQ (reactive power zero) control strategy supplied total power to the grid and maintained DC link voltage constant at 400V. The THD of grid current is 1.57% after LCL filter, without filter grid current THD is 18.33%.

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