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Supervisor Control for a Stand-Alone Hybrid Generation System

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Abstract

This paper focuses on a supervisor control for a standalone PV-Wind hybrid energy system for locations where extension of grid in either not feasible or it is expensive. The Hybrid PV-Wind standalone energy system proved to have higher reliability compared to either Wind or PV standalone systems as wind and solar are complementary. A MATLAB/SIMULINK model of an integrated standalone PV-Wind hybrid system using a battery for storage and backup protection is presented. The individual component of the system is modeled and discussed. A novel and unique control strategy is proposed and simulated to control the power flow of the system while maintaining the battery charging and discharging limit. In addition, different converter design and maximum power point tracking control are applied to ensure efficient and reliable power supply under different loading conditions.

Keywords: Photovoltaic system, PMSG, Battery, Maximum power point tracking, wind turbine.

INRODUCTION

Due to the critical exploitation of industrial fuels such as oil, gas and others, the utilization of renewable energy sources is continuously improving. This is the main reason for renewable energy sources becoming extremely important these days. Few other reasons include abundant availability in nature, eco-friendly and recyclable. Among the many available renewable energy sources such as solar, wind, hydro and tidal, solar and wind energy are the world's fastest growing energy resources. Without emission of pollutants, energy conversion is done through wind and PV cells.

In this paper, a wind-photovoltaic hybrid power generation system model is modeled and simulated. A hybrid system has more advantage compared to individual power generation system as they may not be completely reliable. When any one of the system is insufficient / unavailable, the other can system can generate and supply power. A block diagram of entire hybrid system modeled in this paper is shown below.

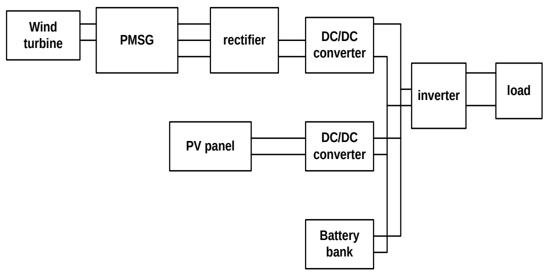


Figure 1: Block diagram of hybrid system

The entire hybrid system comprises of PV and the wind systems. The light incident on the PV cells is converted into electrical energy by solar energy harvest. The maximum power point tracking system with Perturb & absorb algorithm extracts the maximum possible power from the PV modules. The ac-dc converter converts is used to converter ac voltage to dc.

Wind turbine, generator and an AC – DC converter are included in the wind energy system. The wind turbine is used to convert wind energy to rotational mechanical energy and this mechanical energy available at the turbine shaft is converted to electrical energy using a generator.

Both the energy systems are used to charge a battery using bi-directional converter. Bidirectional converter and the battery form the common additional load to the wind and PV energy systems.

Hybrid generation system uses more than one source, so that we can extract energy from different sources at the same time which enhances the efficiency. From [2],[3] the working of PV /Wind hybrid system is understood, different topologies that can be used for the hybridization of more than one system and also about advantages and disadvantages of hybrid system. From [1], [4], [18] and [5] basic details of PV cell, PV module, PV array and their modeling are studied. Also, the behavior of PV modules at varying environmental conditions like solar irradiation and temperature are studied.

Different MPPT techniques, their advantages and disadvantages and why MPPT control is required is explained in [6]-[8].The wind energy system, its working and also techniques to extracts the maximum power from the wind energy system is understood from [9]-[13]. From [14]-[16] study about different type of bi-directional converters, their working and how to use them in battery charging and discharging is carried out. From [17] study about Supervisor Control for a Stand-Alone Hybrid Generation System Using Wind and Photovoltaic Energy. From [19] Design of Three Phase PWM Voltage Source Inverter for Photovoltaic Application is explained. From [20] An LC filter design method for single-phase PWM inverters is studied.

MODELING OF PV CELL

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The fig.2 manifests the equivalent circuit of PV cell [1]. Equivalent circuit has a current source (photo current), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current.

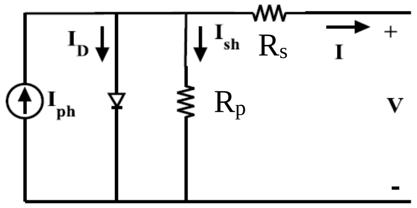


Figure 2: Equivalent circuit of Single diode model of a solar cell

The modeling of PV cell is done by the following equations [18].

Thermal voltage $v_t = \frac{K(T_{op})}{q}$

Diode current $I_d = ((e^{\frac{\frac{V}{N_S}+\frac{IR_s}{N_s}}{nv_t c}})-1)I_S N_P$

Shunt current $I_{sh} = \frac{V+IR_S}{R_P}$

Phase current $I_{ph} = ([(T_{op}-T_{ref})KI]+I_{sc})I_{rr}$

Reversed saturated current at T_{op} $I_{rs} = (e^{\frac{I_{sc}}{\frac{V_{oc}q}{K.C.T_{op}n}}})-1$

Reversed saturation current $I_s = [e^{(\frac{q^2E_g}{kn})(-\frac{1}{T_{ref}}+\frac{1}{T_{op}})}][(\frac{T_{op}}{T_{ref}})^3 I_{rs}]$

Load current $I = I_{ph} * N_p - I_{sh} - I_d$

Where

T_{ref} =Reference temperature

V_{oc}=Open circuit voltage

q=Electron charge

KI=short circuit current temperature coefficient

I_{sc}=Short circuit current

K=Boltzmann constant

C=Cells in module

N_s=Series connected panels

N_p=Parallel connected panels

I_{rr}=Irradiation

T_{op}=Operational temperature

R_s= series resistance

R_p=parallel resistance

n= Ideality factor

A. Maximum power point tracking

There are many algorithms which help in tracing the maximum power point of the PV module. They are listed below

a. Perturb &Observe algorithm

b. IC algorithm

c. Fractional open circuit voltage

d. Fractional short circuit current

e. Fuzzy logic e.t.c

B. Perturb and Observe algorithm

Each and every MPPT algorithm has its own advantages and disadvantages. Perturb and observe (P&O) method is widely used due its simplicity. In this algorithm we introduce a perturbation in the operating voltage of the panel. Perturbation in voltage can be done by altering the value of duty-cycle of dc-dc converter.

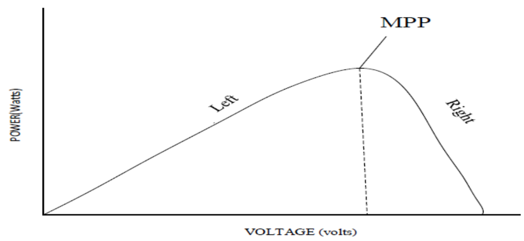


Figure 3: P-V characteristics (basic idea of P&O algorithm)

Fig 3 show the p-v characteristics of a photovoltaic system, by analyzing the p-v characteristics we can see that on right side of MPP as the voltage decreases the power increases but on left side of MPP increasing voltage will increase power. This is the main idea we have used in the P&O algorithm to track the MPP. The flow chart of P&O algorithm is manifested in figure 4.

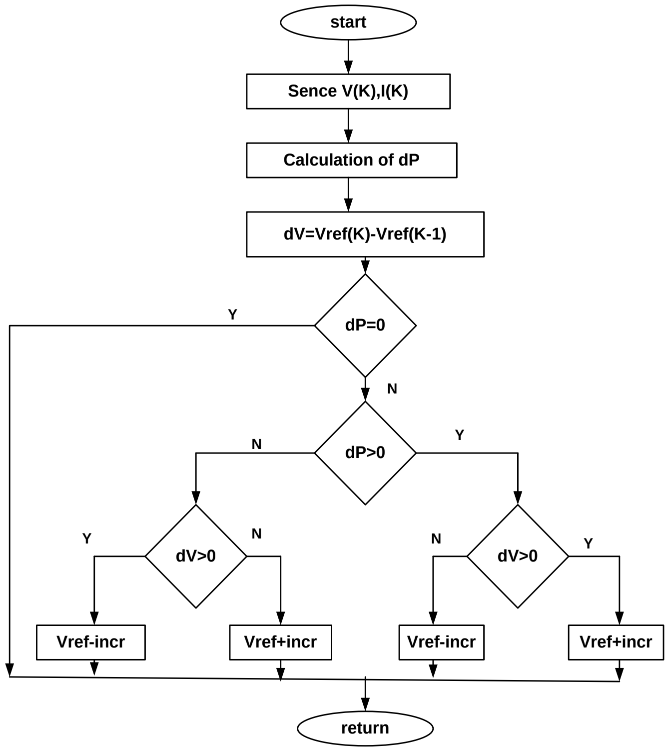


Figure 4: Flowchart of Perturb & Observe MPPT algorithm

As we can see from the flow chart first of all we measure voltage and current, by using these values we calculate power, calculated power is compared with previous one and accordingly we increase or decrease the voltage to locate the Maximum Power Point by altering the duty cycle of converter

MODELING OF WIND TURBINE

The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation.

$$P_{m\_pu} = k_p c_{p\_pu} v^3_{wind\_pu}$$

Where

P_{m_pu} = Power in pu of nominal power for particular values of ρ and *A*

c_{p_pu} = Performance coefficient in pu of the maximum value of c_p

v_{wind_pu} = Wind speed in pu of the base wind speed. The base wind speed is the mean value of the expected wind speed in m/s.

k_p = Power gain for c_{p_pu}=1 pu and v_{wind_pu}=1 pu, k_p is less than or equal to 1

A generic equation is used to model c_p (λ, β). This equation, based on the modeling turbine characteristics of is:

$$c_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right) e^{-\left(\frac{c_5}{\lambda_i}\right)} + c_6\lambda,$$

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$$

The coefficients c_1 to c_6 are: $c_1 = 0.5176$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and $c_6 = 0.0068$.The maximum value of c_p ($c_{pmax} = 0.48$) is achieved for β = 0 degree and for λ = 8.1. This particular value of λ is defined as the nominal value ($\lambda_{\_nom}$).

A. Modeling of PMSG

In the permanent magnet synchronous generator, the magnetic field is obtained by using a permanent magnet, but not an electromagnet. The field flux remains constant in this case and the supply required to excite the field winding is not necessary and slip rings are not required. All the other things remain the same as normal synchronous generator. The modeling equations of PMSG are given below.

$$\frac{d}{dt} i_d = \frac{1}{L_d} v_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} p w_r i_q$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} v_q - \frac{R}{L_q} i_q - \frac{L_d}{L_q} p w_r i_d - \frac{\lambda p w_r}{L_q}$$

$$T_e = 1.5p(\lambda i_q + (L_d - L_q) i_d i_q)$$

L_q,L_d = q and d axis inductances

R = Resistance of the stator windings

i_q, i_d = q and d axis currents

v_q,v_d = q and d axis voltages

ω_r = Angular velocity of the rotor

Λ = Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases

P = Number of pole pairs

T_e = Electromagnetic torque.

From PMSG the AC voltage is converted to DC voltage by using three phase diode bridge rectifier.

BOOST CONVERTER

The functionality of boost converter is to increase the voltage level. The circuit configuration of the boost converter is manifested in figure 5.

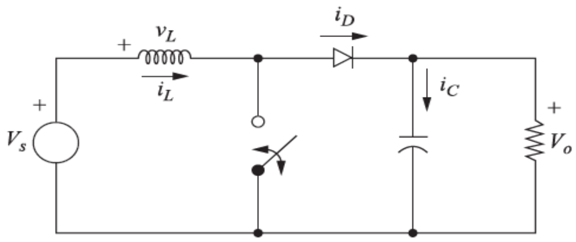


Figure 5: Circuit diagram of boost converter

The current carried by the inductor starts rising and it stores energy during ON time of the switching element. The circuit is said to be in charging state. During OFF condition, the reserve energy of the inductor starts dissipating into the load along with the supply. The output voltage level exceeds that of the input voltage and is dependent on the inductor time constant. The load side voltage is the ratio of source side voltage and the duty ratio of the switching device.

The DC voltage is converted to AC voltage by using three phase PWM voltage source converter.

A. LC filter design

The load side PWM-based inverter will generate unwanted high frequency harmonics (based on the switching frequency) in the output ac voltage, which is ultimately supplied to the customer, creating a power quality problem. In this case, the switching frequency (f_s) of the PWM inverter is considered as 3 kHz. PWM switching at 3 kHz produces high-frequency harmonics that can be eliminated using simple passive LC filter.

The LC filter design is based on following equations:

$$L_f = \frac{V_0}{I_0 f_s}\{K\frac{V_{dc}}{V_{0,av}}[1+4\pi^2\left(\frac{f_r\text{^}2}{f_s\text{^}2}\right)K\frac{V_{dc}}{V_{0,av}}]\}\text{^}1/2$$

$$C_f = K\frac{V_{dc}}{L_f f_s^2 V_{0,av}}$$

Where

K=modulation index

V_0= load voltage

I_0=nominal current

f_r=fundamental frequency

f_s=switching frequency

$V_{0,av}$= Total harmonic load voltage =5% of V_0

L_f= inductance of filter

C_f=capacitance of filter

BATTERY CHARGING

Battery is a storage device which stores the excess power generated and uses it to supply the load in addition to the generators when power is required. Both PV and wind energy systems are integrated i.e. connected to a common DC bus of constant voltage and the battery bank is also connected to the DC bus. Any power transfer whether from generator to battery bank or generator to load or from the battery bank to the load takes place via this constant voltage DC bus. As the power flow associated with the battery is not unidirectional, a bidirectional converter is needed to charge and/or discharge the battery in case of excess and/or deficit of power respectively. Here a buck boost Bi-directional DC-DC converter is used due to their ability of allowing the power flowing in both the directions, depending upon the requirement.

PROPOSED TOPOLOGY OF POWER MANAGEMENT

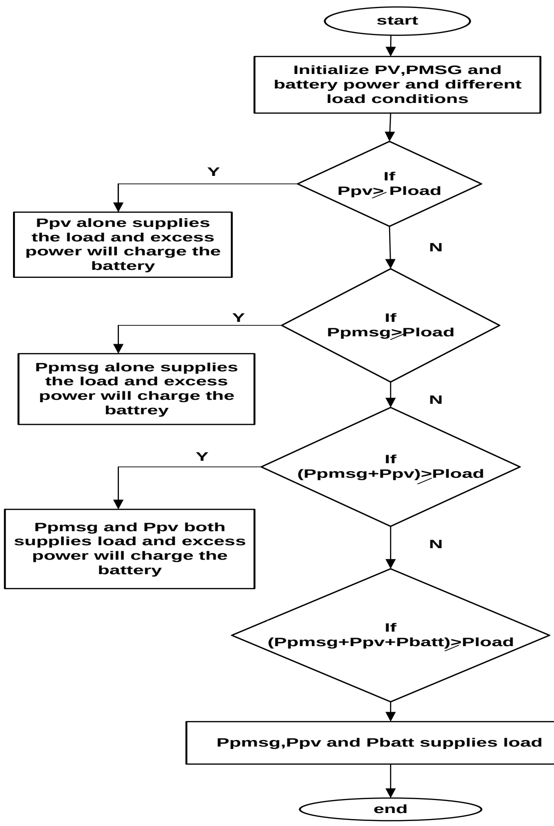


Figure 6: Flow chart for power management system

The parameters used for the modeling of are shown in Table 1

Model	Parameters	Value
PV module	T_{ref}	25+273.15 K
	V_{oc}	21.1V
	Q	1.6e-19 C
	KI	2.2e-3 A/K
	I_{sc}	3.8 A
	K	1.38e-23 J/K
	C	36
	N_s	7
	N_p	4
	I_{rr}	1 KW/m^2
	T_{op}	40+273.15 K
	R_s	0.18 Ω
	R_p	360.002 Ω
	N	1.36
Boost converter (PV side)	Inductor	1e-3 H
	Capacitor	50e-4 F
	Duty cycle	0.8
	Switching frequency	4860 Hz
wind turbine and PMSG	Wind speed	12 m/s
	Number of poles	10
	Rated speed	153 Rad/s
	Rated current	12A
	Armature resistance	0.425 Ω
	Magnetic flux linkage	0.433 Wb
	Stator inductance	4 mH
	Rated torque	40 Nm
	Rated power	6 KW
Boost converter (PMSG side)	Inductor	2e-3 H
	Capacitor	50e-4 F
	Duty cycle	0.36
	Switching frequency	4860 Hz
Battery	Nominal voltage	700 V
	Rated capacity	8.6 Ah
	Initial state-of-charge	20 %
Bidirectional converter (battery side)	Inductor	5e-1 H
	Capacitor	1200e-6 F

SIMULATION RESULTS

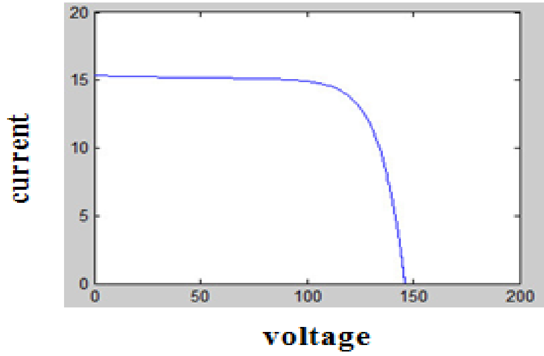


Figure 7: I-V characteristics of PV cell

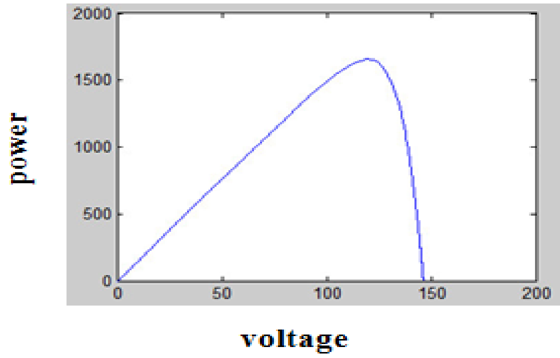


Figure 8: P-V characteristics of PV cell

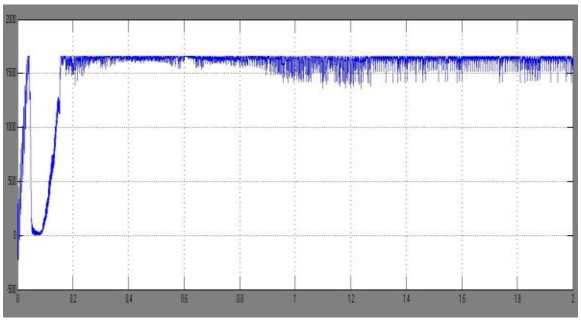


Figure 9: max. Power of PV cell

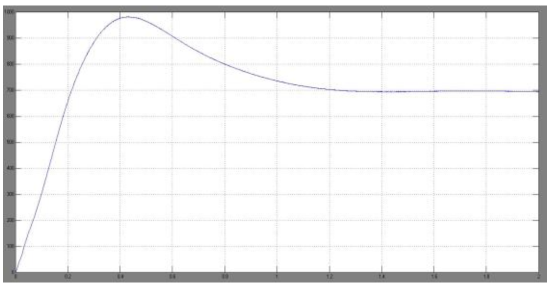


Figure 10: output voltage of boost converter

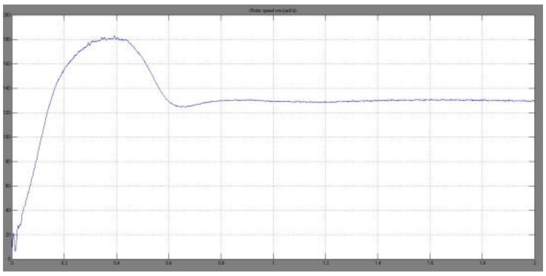


Figure 11: rotor speed of PMSG

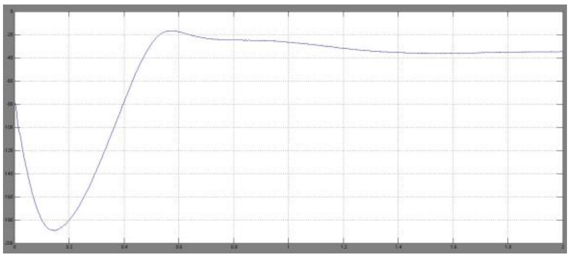


Figure 12: torque of PMSG

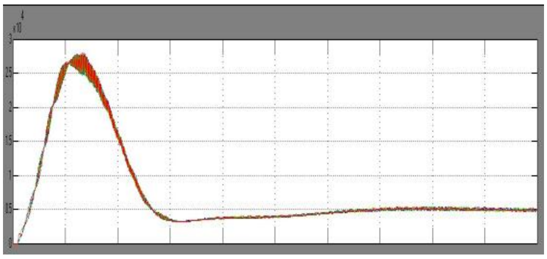


Figure 13: power of PMSG

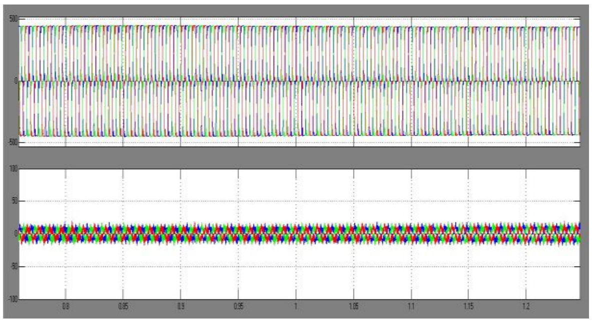


Figure 15: PMSG voltage and current

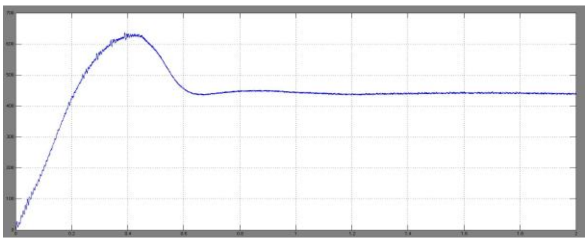


Figure 15: output of rectifier

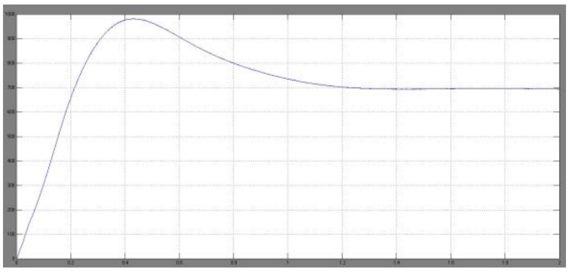


Figure 16: DC bus voltage

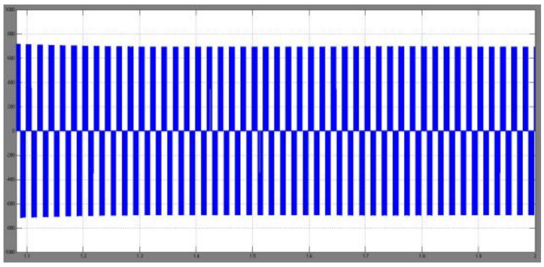


Figure 17: inverter one line output voltage

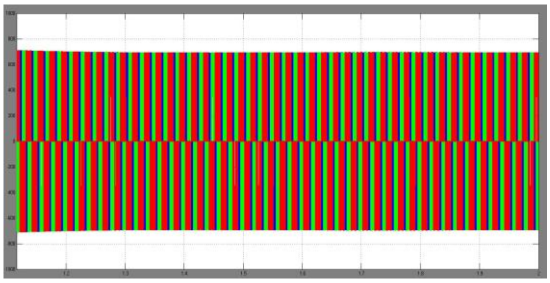


Figure 18: output voltage of inverter

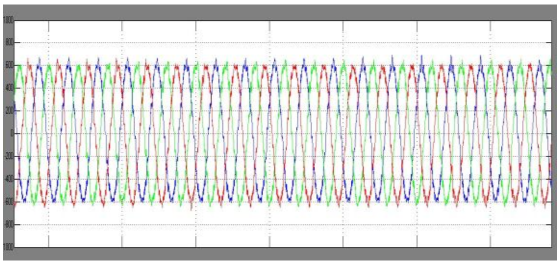


Figure 19: load voltage

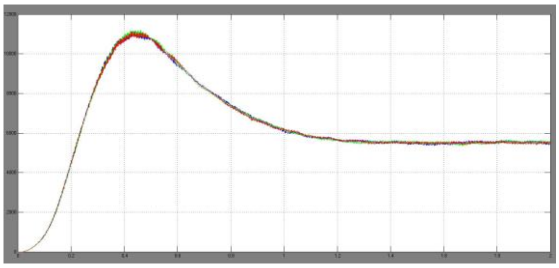


Figure 20: I load power

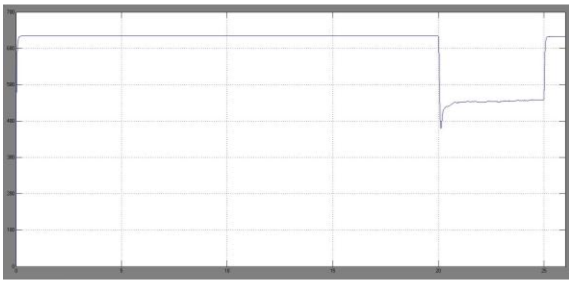
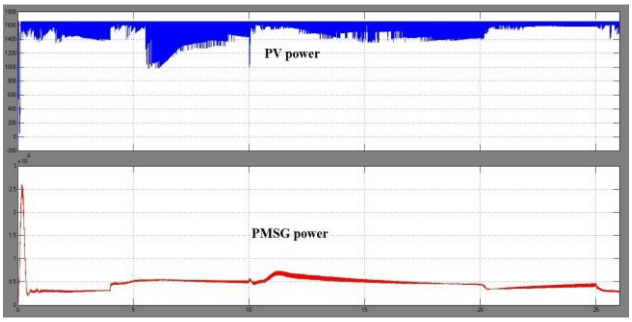


Figure 21: battery voltage



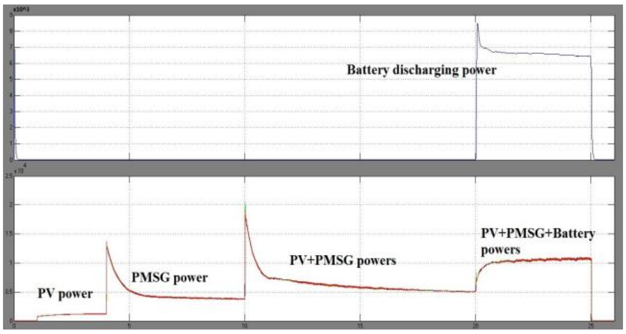


Figure 22: power management waveforms

CONCLUSION

Wind energy system has been studied and simulated. Maximum power point of operation is tracked for PV system using P&O algorithm. Both the systems are integrated and the hybrid system is used for battery charging and discharging. The hybrid system is modeled to satisfy the different load demand.

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