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Modeling and Simulation Performance Study of Grid Connected Wind and Photovoltaic Hybrid Distributed Energy System

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Abstract: A large amount of energy is available in the form of renewable energy sources. Among them solar and wind have become popular in recent years. This paper focus wind and PV hybrid inter connection operation with distribution system. The hybrid system has advantage of high reliability to deliver continuous power rather than individual sources. The work presented in this paper consists of wind turbine, PMSG, solar array, boost converter, and grid interface inverter. The power electronic interface transfer power generated from wind turbine and solar array into the grid by keeping capacitor dc voltage constant and power flow to grid is controlled by PQ controller. The power is generated and power flow to gird is evaluated at different wind speed and different solar array and different load conditions .Modeling and simulation of entire system is carried using Matlab.

Keywords: *Hybrid Energy System, Wind Turbine, Solar Array, Grid Interface*

1. Introduction

The degree of development and civilization of a country is measured by the amount of utilization of energy by human beings. Energy demand is increasing day by day due to increase in population, urbanization and industrialization. The depletion of fossil fuels, oil reserves, uncertainly and political issues concern nuclear generation and the environmental associated with coal and natural gas fired generation are encouraging researches, practitioners and policy makers to look for alternative and sustainable sources of energy. One of the solution is distributed generation (DG) .DG has recently gained a lot of momentum in the power industry due to market deregulation and environmental concerns. There are many reasons a customer may choose to install a DG are power savings, standby or emergency generation, reliability etc. Wind and solar are the most abundant renewable energy sources have experienced the greatest development during the last few years. The operation of wind and solar based system highly depends on weather conditions and thus electrical generation is variable in time often the pattern does not actually follow the load demand. In order to full fill the energy requirement during the period of low available resources, energy needs to be stored.

2. System Description

The system consists of a wind system (i.e) wind blades along with the direct driven Permanent magnet synchronous generator (PMSG). Permanent magnet synchronous generator has advantage over another generator like pmsg has property of self-excitation allows pmsg operate at high power factor and high efficiency .the system does not require slip rings and an additional power supply for the excitation of magnetic field system. Energy drawn from this wind system is directly connected to uncontrolled AC/DC rectifier and it is connected to common dc link voltage capacitor through grid interface voltage source inverter (VSI) the controlling of power flow to grid is done by VSI with help of dc link voltage. Another generating system consists of solar array and DC/DC boost converter which boost the voltage level to the common dc link voltage level and connect the solar system to the common dc link [13].

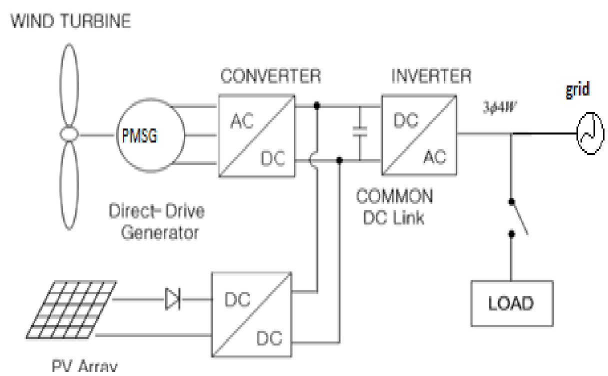


Figure 1 *Block diagram of grid connected wind/pv system.*

Also, Induction generators need reactive power compensation. These problems are overcome by using permanent magnet synchronous generators (PMSG) with power electronic interface between the generator and the grid. With decrease in the price of the power electronic devices, the wind technology solutions employing power electronics equipment has become more attractive. A photovoltaic system transforms sunlight into electrical energy. In order to overcome the disadvantages of the stand-alone system the system is operated in the grid connecting model.

3. Modeling of Wind Turbine

The wind turbine (WT) system converts wind energy to mechanical energy. A model of the WT is necessary to evaluate the torque and power production for a given wind speed and to study the effect of wind speed variations on the produced torque. The torque and power produced by the WT within the interval [V_{min}, V_{max}], where V_{min} is minimum wind speed and V_{max} is maximum wind speed, are functions of the blade radius R, air pressure, wind speed and coefficients C_q and C_p [4]. The power available in the wind can be calculated by the equation1.

$$P_m = C_p(\lambda,\beta)\frac{\rho A V_{wind}^3}{2} \tag{1}$$

Where P_m = power in watts, ρ= air density, A= rotor swept area, V_w= wind speed in m/sec Cp known as the power coefficient of rotor the effective area of rotor blade ,wind speed ,and wind flow condition determine the power absorption from wind turbine. Where λ is the tip speed, V_{wind} is the wind speed, R is the radius of turbine blades and β is the blade pitch angle. Torque of the turbine T is given by equation 2.

$$T = \frac{P_m}{\omega_m} \tag{2}$$

$$\lambda = \frac{R*\omega}{V_{wind}} \tag{3}$$

The performance coefficient $C_p(\lambda, \beta)$, which depends on tip speed ratio λ and blade pitch angle β, determines the amount of wind energy that can be captured by the wind turbine system. A nonlinear model describes $C_p(\lambda, \beta)$ as in equation4 [12].

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta + C_4\right)e^{\frac{C_5}{\lambda_i}} + C_6 \tag{4}$$

Where, C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21and C_6=0.0068.λ_i is expressed in terms of λ and β as in equation 4

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{5}$$

4. Modeling of PV Array

The equivalent circuit of a PV cell is shown in Fig. 1. I-V characteristic of the ideal PV cells can be expressed mathematically by equation 7 and 8 [3-6].

$$I = I_{pv} - I_o\left\{\exp\left(\frac{q(V+IR_s)}{AKT}\right) - 1\right\} - \frac{V+IR_s}{R_p} \tag{6}$$

$$Io = \frac{I_{sc} + K_I d_t}{\exp((V_{oc} + K_v d_t)/aV_t) - 1} \tag{7}$$

where $I_{pv,}$ is the photo voltaic current generated by incident light, I_o diode current, I_{sc} is the reverse saturation or leakage current of the diode, q is the electron charge [1.60217646 x 10^{-19} C], k is the Boltzmann constant [1.3806503 x 10^{-23} J/K], T is the temperature of the p-n junction [K], a is the diode ideality constant.

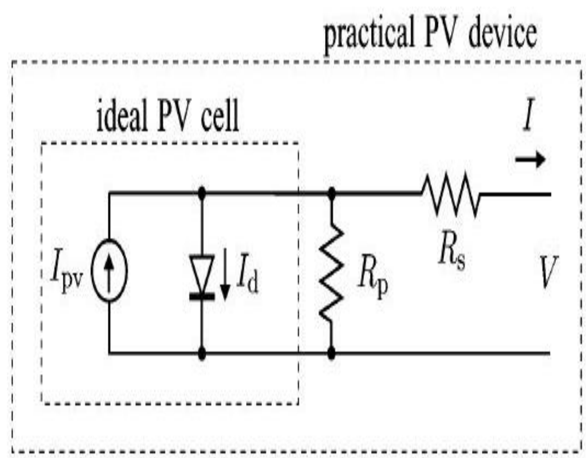


Figure 2 *Equivalent circuit of a PV cell [3]*

Practical photovoltaic arrays consist of several connected photovoltaic cells and the basic equation 6 of the elementary photovoltaic cell is modified to equation 7 in order to make it suitable to practical photovoltaic arrays. Rs is the equivalent series resistance of the array and R_p is the equivalent parallel resistance. The value of R_s and R_p are extracted in an iterative manner. The value of R_s is incremented starting from an initial value .By incrementing the value of R_s corresponding R_p is obtained.

$$R_p = \frac{Vmp(V_{mp} + I_{mp}R_s)}{V_{mp}I_{mp} - V_{mp}I_o\exp\left(\frac{q(V_{mp}+I_{mp}R_s)}{AKTN_s}\right) + V_{mp}I_o - p_{max}} \tag{8}$$

The initial value of series resistance is zero and shunt resistance is given by

$$R_{p\min} = \frac{V_{mp}}{I_{sc} - I_{mp}} - \frac{V_{oc} - V_{mp}}{I_{mp}} \tag{9}$$

The value of A that best fits the experimental data specified by the manufacturer is chosen arbitrarily and the value of it varies between 1 and 2.

Once the value of R_s and R_p are determined the equation of I_{ph} is improved.

$$I_{ph} = \frac{R_p + R_s}{R_p} I_{scn} \tag{10}$$

Temperature and irradiance dependence the open circuit voltage and circuit current, and light generated current .The light generated current depend on temperature and irradiance is

$$I_{ph} = \left(I_{phn} + K_I d_t\right)\frac{G}{G_n} \tag{11}$$

I_{phn} is the photovoltaic current at STC, dt is difference between the operating temperature and temperature as STC, G_n is irradiance .The effect of temperature and irradiance on short circuit current and effect of temperature on open circuit voltage is given by

$$I_{sc} = \left(I_{sc} + K_I d_t\right)\frac{G}{G_n} \tag{12}$$

$$V_{oc} = \left(V_{ocn} + K_v d_t\right) \tag{13}$$

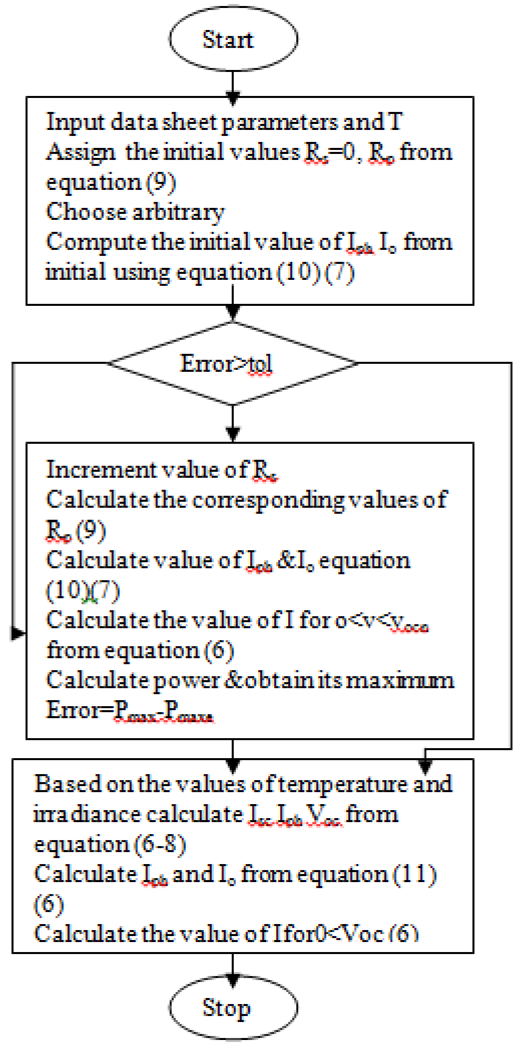
The effect of irradiance on open circuit voltage is obtained by substituting the values of I_{sc}, I_{ph} in equation of OCC and solving open circuit voltage. d_t=T-T_n.

Parameters of the KVT200GT solar array at 25^{0}c, 1000W/m^2 is taken for calculating the initial values.

***Table 1** Parameters of pv system*

Parameter	Value and units
I_{mp}	7.61 A
V_{mp}	26.3 V
P_{max}	200.143 W
V_{oc}	32.9 V
K_v	-0.1230 V/K
K_I	0.0032 A/K
Ns	54
I_o	9.825×10^{-8} A
I_{pv}	8.214 A
R_p	415.405Ω
R_s	0.221Ω

Flow chart for PV model



5. Integration of Wind and Photovoltaic Hybrid Energy Systems to the Grid

As the system is operating in the interconnection mode to the grid, so for grid-connection of these two sources, separate power electronic interfaces are not required for grid connection. At the grid side because of this converter it is aimed at DC link voltage is kept constant and adjusts the active power and reactive power delivered to the grid. The value of DC link voltage is given by

$$0.612 m_a V_{dc} \geq \sqrt{\left(V_{acc}^2\right) + 3\left(\omega L_f I_{ac}\right)^2} \tag{14}$$

The PI controller is used to regulate dc voltage of the boost converter irrespective of changes in the input conditions. PQ control scheme is used to control the VSI. In PQ control, the real and reactive powers exchanged with the grid are the variables controlled by the inverter. In order to have a faster response it has been chosen to decouple active and reactive power channels the inverter. The dynamic model of this converter in rotating frame is calculated by [11]

$$u_d = e_d - R_{id} - \omega L_{id} - L\frac{d_{id}}{d_t} \quad (15)$$

$$u_q = e_q - R_{iq} - \omega L_{iq} - L\frac{d_{iq}}{d_t} \quad (16)$$

The park transformation of the inverter output currents and voltages from the physical abc reference frame to the stationary d-q reference frame allows to make use of the correlation existing between active power the direct current component (i_d) and reactive power the quadrature current component (i_q). The Phase Locked Loop (PLL) measures the grid voltage phase angle θ_g which is used to implement Park transformation and to synchronize the inverter with grid. To control the active power through the inverter, the DC link voltage is measured and compared to DC link reference voltage. The DC link voltage error is used to generate d axis current reference through a PI controller. This d-axis current reference is compared with actual d-axis current. To control the reactive power flow, reference q-axis current is compared with actual q-axis current. The control voltages for the three phase VSI are generated based on the errors in d axis and q axis currents through PI controllers. The active and reactive synchronous power is calculated by

$$P = \frac{3}{2}\left[V_{gd}I_d + V_{gq}I_q\right] \quad (17)$$

The equation 16 shows the active power of grid side inverter and this is controlled with the pi controllers.

$$Q = \frac{3}{2}\left[VqI_d - V_{gd}I_q\right] \quad (18)$$

The equation 17shows the reactive power of grid side inverter and this is controlled with the pi controller .and the value is zero that we can see from the above equation as the i_q value we are taking as zero in the VSI inverter.

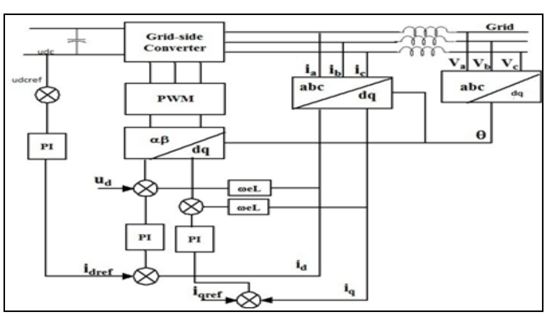


Figure 3 *Block diagram of AC-shunted grid-connected hybrid PV/wind energy system [11].*

6. Results and discussions

Case i:

The 120KW hybrid model simulated is tested for different conditions like change in the wind speed, change in the irradiation, change in temperature and change in the load. It is seen that the dc link voltage is maintained constant by the controllers for changes in the wind speed in wind energy system and changes in irradiation and temperature in case of PV system. Fig. 4 and Fig.5 show dc link voltage of Wind energy system and PV energy system respectively maintained at the reference value, when the inputs like irradiation, temperature, wind speed and the load demand are kept constant with irradiation 1000 W/m^2, temperature 25^0 C, wind speed 12 m/s and load with active power demand of 220 kW and reactive power demand of 41.08 kVAR. It is seen that the dc link voltage is maintained constant at the reference voltage by the controllers.

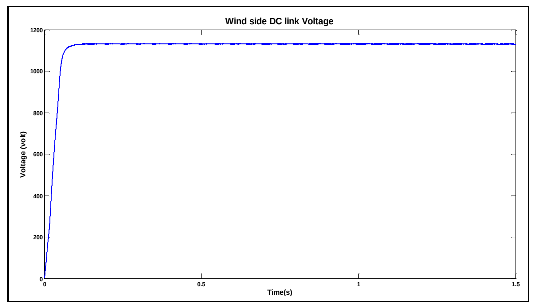


Figure 4 *DC link voltage of wind energy system*

Fig. 5 shows active power supplied by the wind energy system, PV energy system, load power and the power supplied by the grid. With constant wind speed, the wind energy system supplies a constant power. Also with constant temperature and irradiation, PV power system delivers a constant power. Both wind energy system and PV power system contribute to the load demand of 220kw, the deficit being drawn from the grid. It is also observed that the reactive power of wind energy system and PV energy system is constant at zero which is controlled by PQ controllers with zero reactive power reference. The required reactive power of load is supplied by the grid.

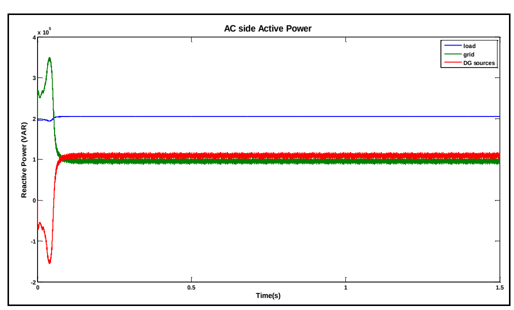


Figure 5 *Active power*

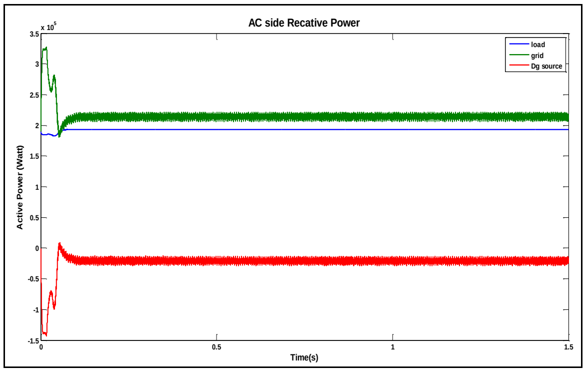


Figure 6 *Reactive power*

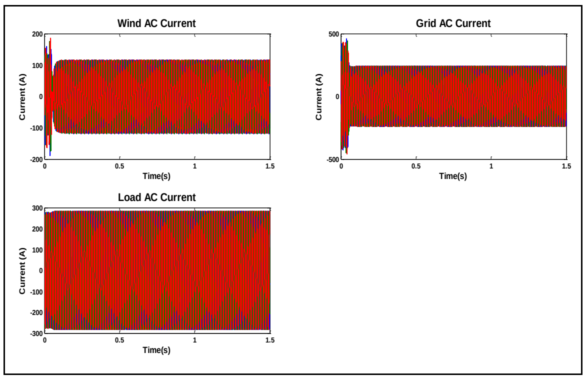


Figure 7 *Ac current of wind, pv system and load*

The current of wind, pv system and load are constant with respect to the input and load parameters.

Case ii:

In this case the input parameters of wind and pv are kept constant and the load parameters are varied at 1sec from 220KW to the 280KW for a period of (1-1.5) sec. AS the input parameters are constant them with irradiation 1000 W/m^2, temperature 25^0 C, wind speed 12 m/s the extra power required for the load is drawn from the grid as shown in the below figures 9, 10.

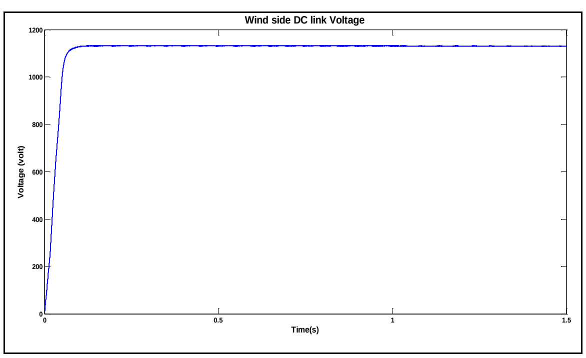


Figure 8 *DC link voltage of wind energy system*

As there is no change is in the input parameters there is no change in the dc link voltage it is maintain constant without any alteration.

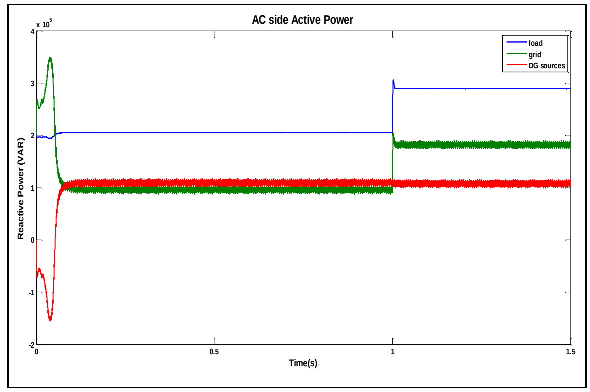


Figure 9 *Active powers when change in load is simulated*

Fig. 9 shows the active power of wind pv system along with load when there is change is load parameter from 220KW to280KW.the active power of DG sources is constant and active power of grid is changed according to load.

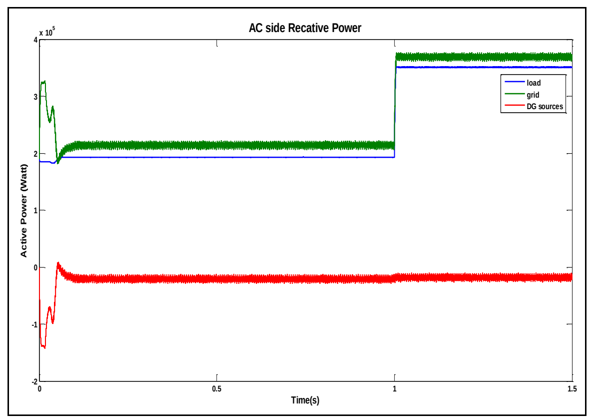


Figure10 *Reactive power when change in load is simulated*

Fig.10 shows the reactive power of wind pv system along with load, when there is change is load parameter from 220KW to280KW.the active power of DG sources is constant as zero controlled by VSI inverter and reactive power of grid is changed according to load.

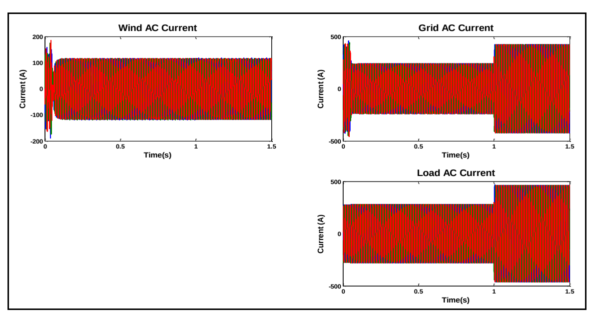


Figure 11 *Current supplied by the wind, pv energy system and load*

Figure shows that there is a change in grid current in according to the requirement of load current.

Case iii:

In this case the input parameters of wind and PV are changed at 1 sec to and the load parameters are constant. As the input parameters are changed from irradiation 1000 W/m^2, temperature 25^0 C, wind speed 12 m/s so power produced is decrease from the DG sources .The extra power required for the load is drawn from the grid as shown in the below figures 13,14

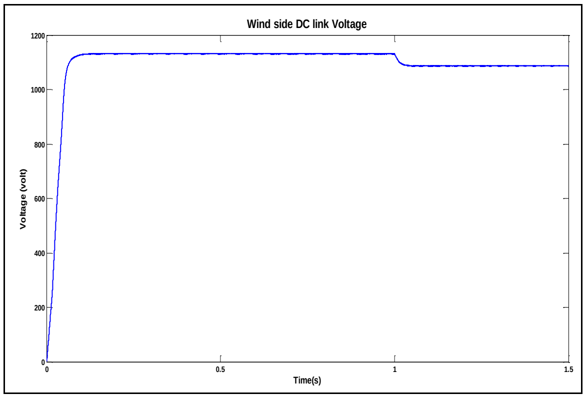


Figure12 *DC link voltage of wind energy system*

As the input parameters are changed there is slight variation in dc link voltage at 1sec and it maintain constant with the help of PI controller shown in fig 12.

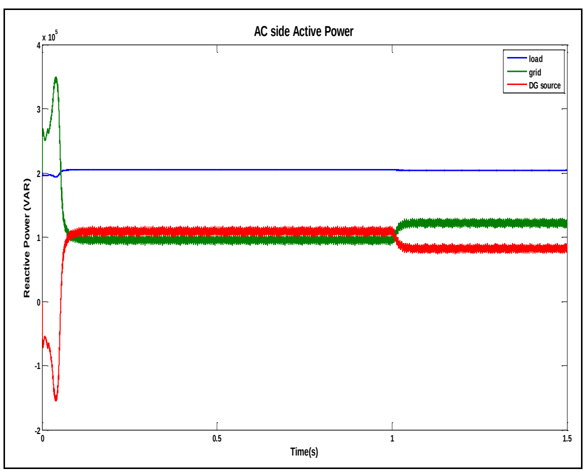


Figure 13 *Active power with change in input parameters is simulated*

Fig. 13 shows active power supplied by the wind energy system, PV energy system, grid and the load power when a change in DG sources is simulated. In this case the inputs like temperature, irradiation, wind speed is changed and load parameters are kept constant. The deficit power due to decreased active power of wind energy system, pv system is drawn from the grid.

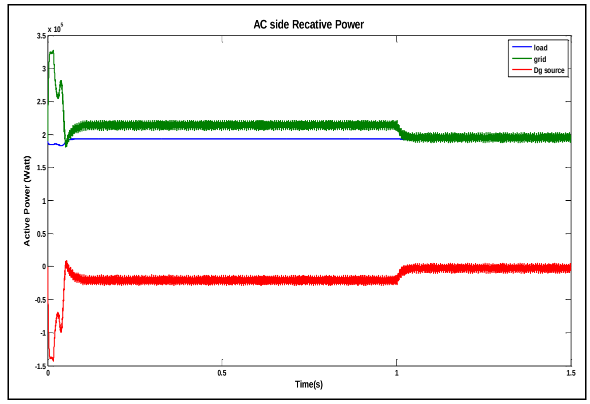


Figure 14 *Reactive power when change in input parameters is simulated*

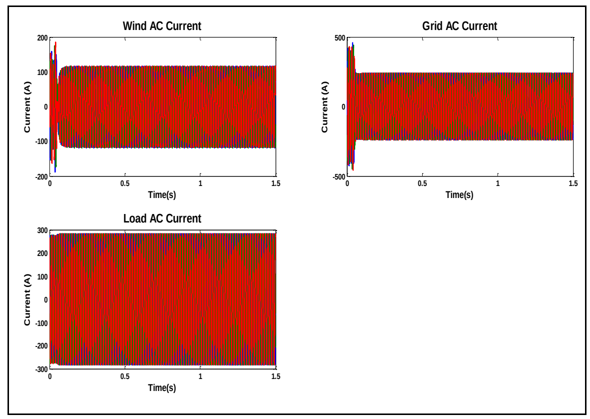


Figure 15 *Current supplied by the wind, pv energy system and load*

Figure shows that there is a change in DG sources current in according to the change in grid current.

Figures 16,17,18 shows the system frequency in all the three cases.

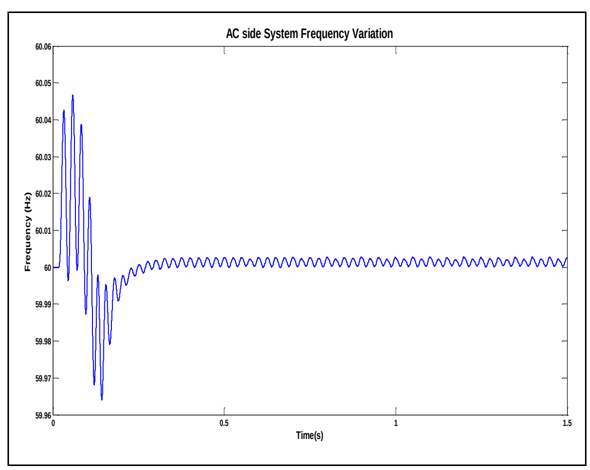


Figure 16 *System frequency when there is no change in input parameters and load parameters*

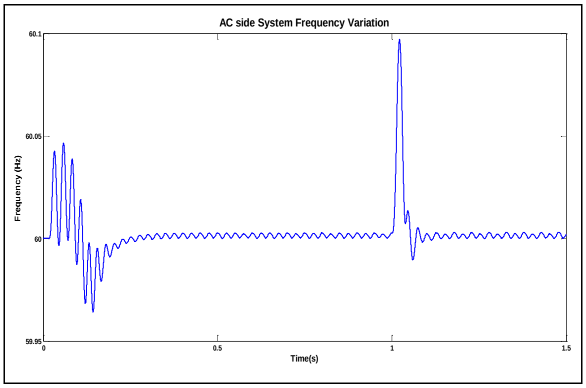


Figure 17 *System frequency when there is no change in input parameters and change load parameters*

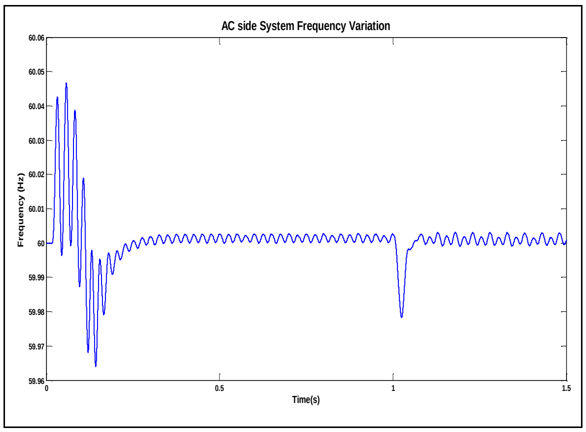


Figure 18 *System frequency when there is change in input parameters and no change load parameters*

7. Conclusions

Modeling of wind turbine coupled with PMSG and photovoltaic energy system is developed using MATLAB. The models of wind and photovoltaic energy systems are integrated with the grid through VSI using AC-shunted grid-connection scheme. PQ control strategy is used to control VSI. The dynamic performance of wind and photovoltaic power systems are studied for different system disturbances like load variation, wind speed variation and different irradiation and temperature inputs. It is seen that the dc link voltage is maintained constant by the controllers for changes in the wind speed in WECS and changes in irradiation and temperature in case of PV system. The simulation results shows that, using a VSI and PQ control strategies, it is possible to have a good response of grid-connected hybrid energy system.

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