GRID INTEGRATION OF WIND AND PHOTOVOLTAIC HYBRID ENERGY SYSTEM

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Abstract: *Hybrid energy system usually consists of two or more renewable/nonrenewable energy sources. Currently hybrid systems involving wind power as one of the constituent along with fuel cell and /or photovoltaic power are more appealing. The main purpose of such hybrid power systems is to overcome the intermittency and uncertainty of wind energy and to make the power supply more reliable. Hybrid wind power with fuel cell can avoid the drawback of wind power intermittency, since fuel cell can act as an energy barrier and adjust the power output effectively. Wind power and solar energy can be combined into a hybrid system, especially for the power supply for remote areas where the cost of transmission line is too high. Another advantage of this kind of hybrid system is that they are both renewable energies, which is compatible to the environment.*
In order to deliver the stable power to the load, a substantial battery bank is needed, which enhances the size of the system, cost and also causes environmental pollution. The deployment of battery can be avoided by directly connecting the hybrid system to the grid. The work presented in this paper consists of modeling and simulation of wind and photovoltaic hybrid energy system inter-connected to electrical grid through power electronic interface. The power conditioning system is implemented to control power electronic circuits and system performance is evaluated for different input power levels and load variation.

Key words: *hybrid energy system, photovoltaic power, grid integration, wind energy system, power conditioning system.*

1. Introduction

In case of thermal power plant, diesel engine plant, gas turbine plant and small hydroelectric generation direct grid connection is viable through synchronous or asynchronous generators. Wind energy system generates power in the form of AC with different voltage and frequency levels in case of variable speed operation. Solar energy system generates power in the form of dc voltage, the level of which varies depending on temperature and irradiation levels. Both of these systems require power electronic interface for inter-connection with the grid. Varying DC output voltage of the photovoltaic system due to change in input parameters like irradiation and temperature can be controlled using a boost converter. AC voltage generated by the wind turbine generator can be converted to DC by using uncontrolled rectifier and then, be regulated using a boost converter. Further, VSI can be used to connect the systems to the grid through LC filter[1-4].

The fig 1 shows power flow between a VSI and grid, where the impedance represents the combined filter, transformer and transmission line inductance and resistance. The active and reactive power flows from the converter can be regulated by controlling magnitude and phase of the converter output voltages relative with grid parameters. The active power flow can be controlled by regulating the phase difference and reactive power flow is by adjusting the magnitude of inverter output voltage with reference of grid voltage. The control of modulation index regulates amplitude of the output voltage, and synchronization and phase angle control of modulating sine wave controls the phase of the output voltage. The real and reactive power delivered to the utility is given by following relations 1-2.

$$P = \frac{V_{inv}V_{grid}}{Z}\cos(\theta_z - \delta) - \frac{{V_{inv}}^2}{Z}\cos(\theta_z) \quad (1)$$

$$Q = \frac{V_{inv}V_{grid}}{Z}\sin(\theta_z - \delta) - \frac{{V_{inv}}^2}{Z}\sin(\theta_z) \quad (2)$$

where,

$$Z = \sqrt{\left(R^2 + X^2\right)}$$

$$\theta_z = \tan^{-1}\left(\frac{X}{R}\right)$$

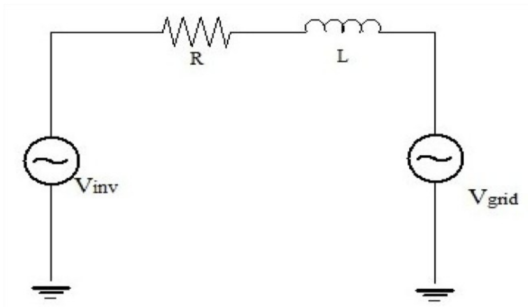

Fig. 1 Power flow between a VSI and grid

and V_{inv} is the inverter voltage, V_{grid} is the grid voltage, R is resistance of filter, transformers and transmission line, L is the inductance of filter, transformers and transmission line and δ is the load angle.

2. AC-shunted grid-connected hybrid PV/wind energy system

The PV system produces dc voltage whereas wind system generates ac voltage. For grid-connection of these two sources, the different power electronic interfaces are required. The AC-shunted grid-connected hybrid PV/wind power system is shown in fig 2 below is used for interfacing the system to the grid [5, 6, 7].

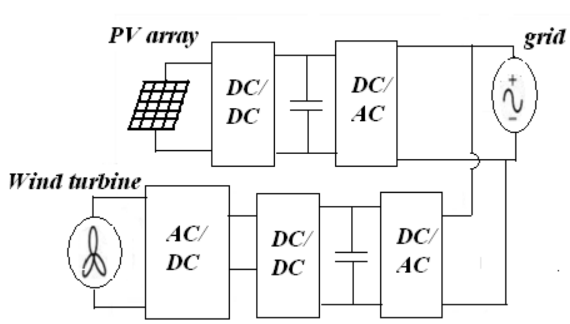

Fig. 2. Block diagram of AC-shunted grid-connected hybrid PV/wind energy system

In AC-shunted grid-connected hybrid PV/wind power system, the output of PV array is connected DC/DC boost converter and controlled to regulate the DC link voltage. Then a VSI with PQ controller is used to integrate the system to grid. AC output voltage of wind power system is first rectified using uncontrolled rectifier and then DC/DC boost converter is used to control DC link voltage. The VSI with PQ controller is used to connect the system to the grid.

3. Power conditioning system for wind and PV hybrid energy system

3.1 The DC/DC boost converter

The DC/DC converter regulates unregulated DC voltage obtained by PV arrays and wind system. The circuit of boost converter [8] is shown in fig 3.

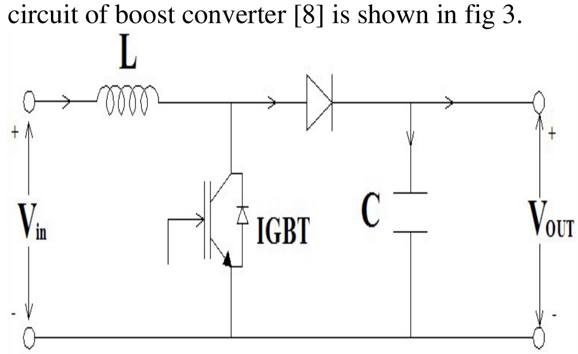

Fig. 3. Block diagram of DC/DC boost converter

The design of DC-DC boost converter is based on the equations 3-6.

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{3}$$

$$R = \frac{V_{out}^2}{P_{in}} \tag{4}$$

$$L = \frac{D(1-D)^2 R}{2 * f_s} \tag{5}$$

$$C \geq = \frac{V_{out} * D}{R * f_s * \Delta V_{out}} \tag{6}$$

where, D is the duty cycle, V_{in} is the input voltage, V_{out} is the output voltage, R is the load resistance and f_s is the switching frequency. PI controller is used to get regulated output voltage from the boost converter [9, 10].

3.2 Control of Inverter

The regulated DC output of boost converter is fed to the VSI which is connected to the grid through LC filter. The inverter is of typical three phase six switch pulse width modulation (PWM) voltage source inverter. Inverter can be controlled typically by two ways. The active and reactive power control scheme (PQ control), when the inverter is operated to meet grid connected operation and active power and voltage scheme (PV control), when the inverter is operated to meet isolated operation [4, 11-14]. Block diagram of AC-shunted grid-connected hybrid wind and PV energy system is shown in fig 4.

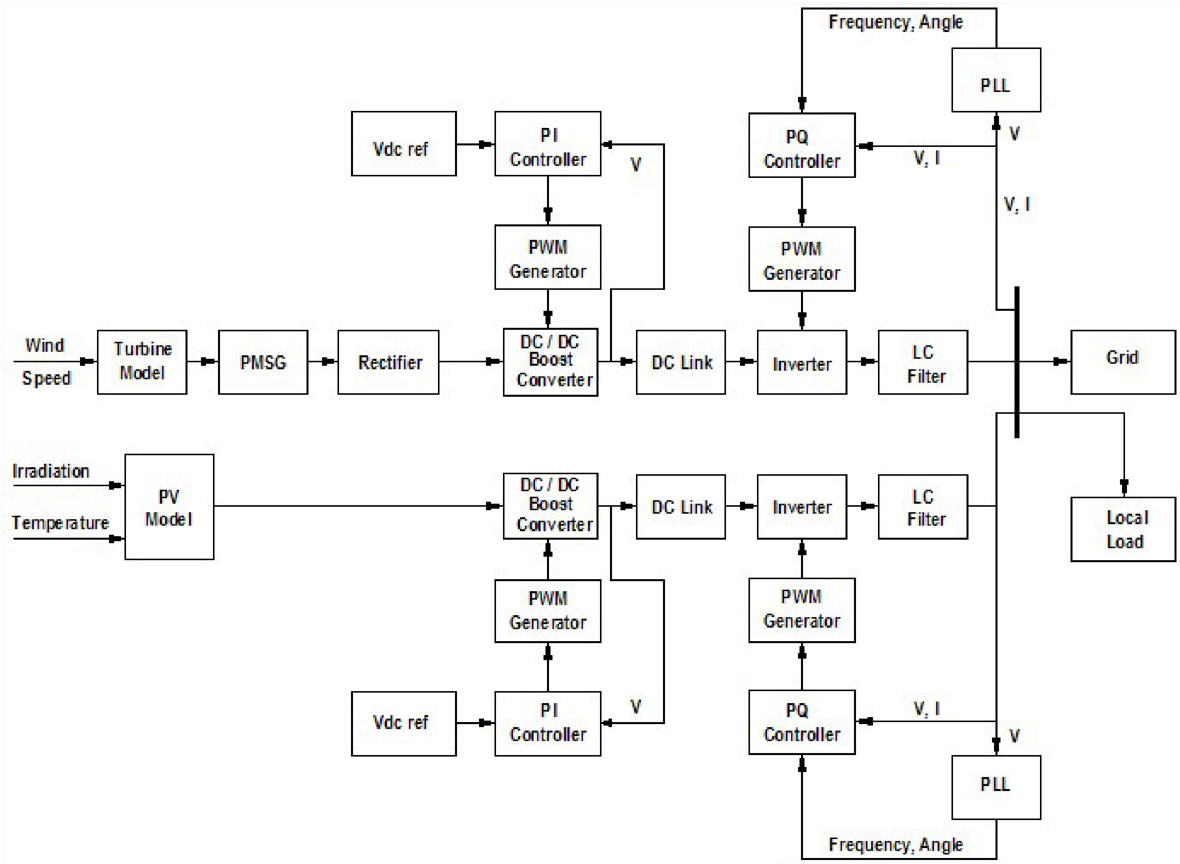

Fig. 4. Block diagram of simulated AC-shunted grid-connected hybrid wind and PV energy system

The DC link voltage is determined by the output voltage of VSI and the voltage drop across the filter. A lower bound on the DC link voltage at a unity power factor can be determined using the equation 7.

$$\frac{\sqrt{3}}{2\sqrt{2}} m_a V_{dc} \geq \sqrt{\left(V_{ac,LL}{}^2 + 3\left(\omega L_f I_{ac}\right)^2\right)} \quad (7)$$

where, $V_{ac,LL}$ is Line- Line r.m.s voltage on inverter side, L_f is filter inductance, I_{ac} is maximum possible r.m.s value of the load current and m_a is Modulation Index of the inverter.

In the PQ control, control variables are the real and reactive powers transferred to the grid. The PQ control will fail for an isolated operation due to the absence of a voltage reference and the practical impossibility of balancing the load demand. In this work it has been chosen to decouple active and reactive power channels the inverter so as to get a faster response. The correlation existing between active power and the direct current component (i_d), and reactive power and the quadrature current component (i_q) is utilized by converting the inverter output voltages and currents in abc reference frame to d-q reference frame using park transformation.

The inverter controller furnishes the amplitude and frequency modulating index m_a and m_f respectively for the PWM control. The Phase Locked Loop (PLL) measures the grid voltage phase angle θ_g necessary 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 error in the dc voltage is fed to a PI controller which provides d axis current reference. The d-axis current reference is then compared with sensed value of d-axis current and the error is fed to PI controller. In similar way q-axis reference current is compared with q-axis actual current and the error is fed to another PI controller. The control voltages for the three phases of VSI are generated based on the errors in d axis and q axis currents through PI controllers. PQ control scheme is shown in figure 4 and by proper tuning of PI controllers, dc link voltage, active power, and reactive power control is achieved. LC filter is used at the inverter output to improve the quality of waveform. According to thumb rule the frequencies of LC filter configuration must have at least multiples of 10 between fundamental, resonance and switching frequencies to decouple the effects. Then, for 50 Hz fundamental frequency, resonance frequency has to be at least 500 Hz, switching frequency of the inverter has to be at least 5000 Hz. The resonance frequency is given by equation 8.

$$\omega_r = \frac{1}{\sqrt{\left(L_f * C_f\right)}} \quad (8)$$

where, ω_r = Resonance frequency, L_f = Filter inductance, C_f = Filter capacitance.

4. Results & Discussions

The hybrid model simulated is tested for different conditions like change in the wind speed, change in the irradiation 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 5 shows active power supplied by the wind energy system, PV energy system, grid and the active power demand of the load. In this case the inputs like irradiation, temperature and wind speed are kept constant and a step change in load is applied at 1.7 s with irradiation 1000 W/m^2, temperature 25 ^{0}C, wind speed 12 m/s. Active load power changed from75 kW to 125 kW, reactive power changed from 24.65 kVAr to 41.08 kVAr. It is seen that increased active power of load is supplied by the grid.

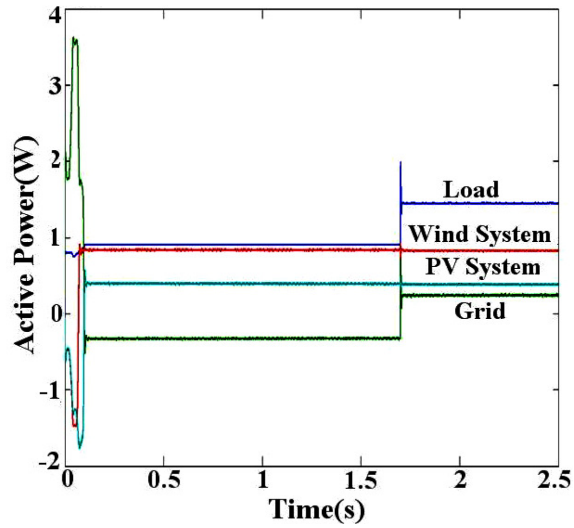

Fig. 5. Active power

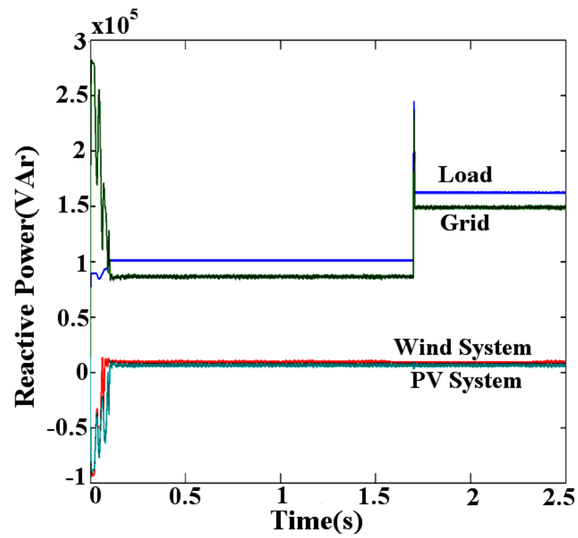

Fig. 1. Reactive power

In fig 6 reactive power of wind energy system and reactive power of PV energy system are constant at zero as controlled by PQ controllers with zero reactive power reference. Required reactive power demand of the load is supplied by the grid. Fig 7 and fig 8 shows the corresponding grid and load currents. Fig 9 indicates that the variation of system frequency is within the limit of synchronization system frequency for operation of inter-connected system as mentioned in (IEEE 1547 2008) i.e; (49.3 - 50.5) Hz for more than 30 kW rated energy systems.

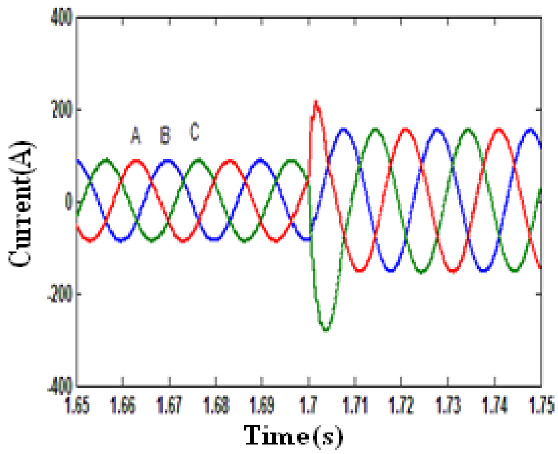

Fig. 7. Grid current

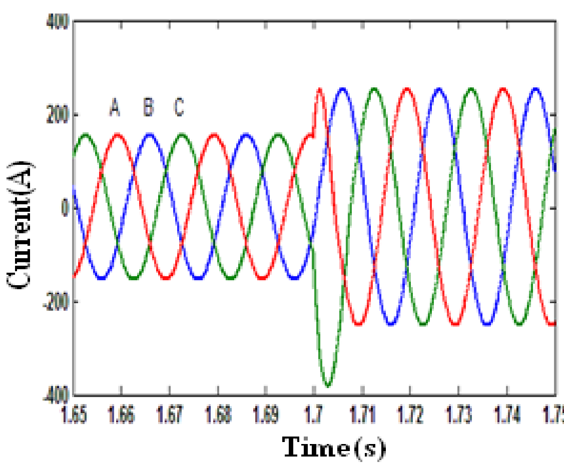

Fig. 8. Load current

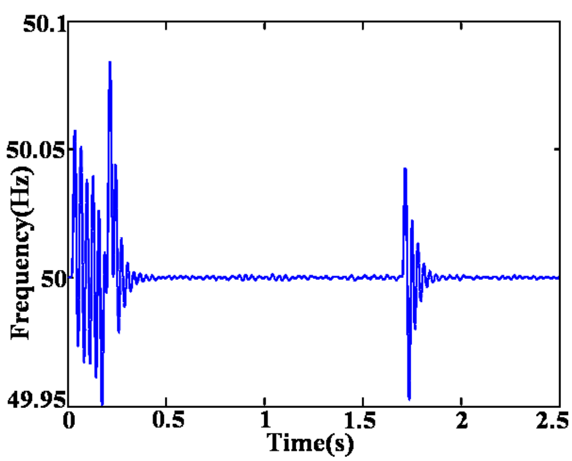

Fig.9. Variation of frequency

From the above results it is observed that the active power of hybrid energy system is constant and reactive power is at zero as controlled by PQ controllers. The increased active and reactive power demand of the load are supplied by grid.

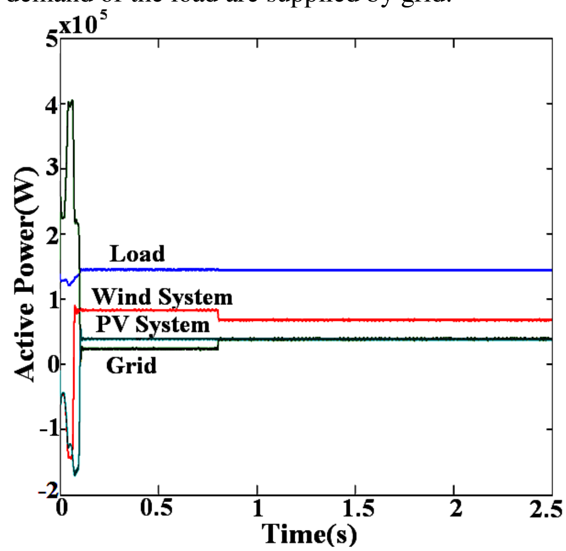

Fig. 10. Active power

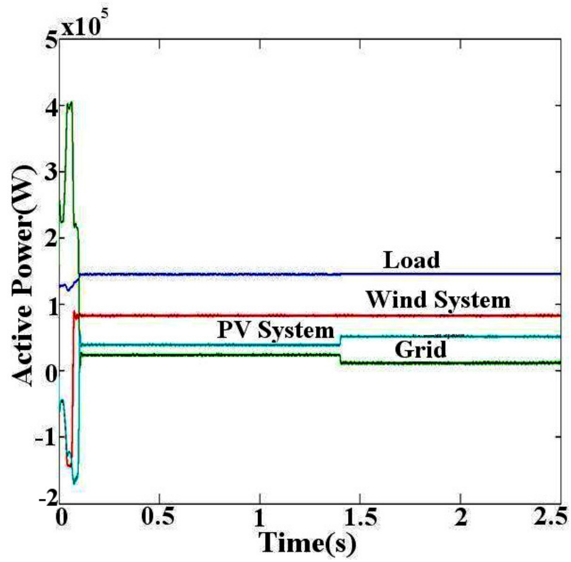

Fig. 11. Active power

Fig 10 shows active power supplied by the wind energy system, PV energy system, grid and the active power demand of the load when a change in the wind speed is simulated. In this case the inputs like irradiation, temperature and load parameters are kept constant and wind speed is changed. Irradiation 1000 W/m^2, temperature 25 ^{0}C and load parameter as 125 kW active power, 41.08 kVAr reactive power are applied. Wind speed is changed from 12 m/s to 10 m/s at 0.8 s. From the figure it is seen that the active power of PV energy system and the active load demand being constants, active power of wind energy system decreased due to the decrease in wind speed at 0.8 s, the deficit load demand is supplied by grid.

Fig 11 shows active power supplied by the wind energy system, PV energy system, grid and the active power demand of the load when a change in the irradiation is simulated. In this case the inputs like wind speed, temperature and load parameters are kept constant and irradiation is changed. Wind speed 12 m/s, temperature 25 ^{0} C and Load parameter as 125 kW active power, 41.08 kVAr reactive power are given. Irradiation is increased from 1000 W/m^2 to 1400 W/m^2 at 1.4 s. From the figure it is clear that the active power of wind energy system and active power of load being constants, active power of PV energy system is increased due to increase in irradiation at 1.4 s. As a result active power supplied by the grid is decreased at 1.4 s.

6. Conclusions

Model the hybrid system consisting of wind turbine coupled with PMSG and photovoltaic energy system connected to the grid is developed using MATLAB. The AC-shunted grid-connection is used as interface with PQ control strategy for the 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. 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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