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Simulink of Hybrid low-power Wind Generation and PV grid connected system using MATLAB

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Abstract

The rapid use of distributed energy resources has increased as a supplement and also an alternative to large conventional grid power stations. However, the presence of non-linear loads in the utility grid will ultimately result to generation of the current and voltage harmonics and this in turn will hamper the power quality of the whole power system. Recently, the utility grids are accommodated with mixed energies which results in increase of complexities and various instabilities [1]. The present paper is based on the improvement of power quality with hybrid power generating system comprising of both Wind and PV system. An improved MPPT is implemented for the hybrid system which provides maximum power and helps to attain a stable and reliable power from the generation system both for the loads and the utility grid, thus improving both the steady and dynamic behaviors of the whole generation system. A grid connected control strategy is proposed keeping in view of the problems, which is based on the model of a hybrid system with load parallel in large system. The control strategy can not only make the full use of photovoltaic (PV) power, but can also maintain a synchronous voltage with a fluctuant reactive load.

Keywords: Renewable energy source, Photovoltaic cell, MPPT, an Inverter, a LC filter, a distribution network, Active power, Reactive power, controller, utility grid.

Introduction

Renewable energy sources (RES) such as Solar, Wind, Geothermal, Tidal, Hydro etc. are inexhaustible by nature. The RES have been found promising towards building sustainable and ecofriendly power generation. Due to the limitation of conventional resources of fossil fuels, it has compelled the evolution of hybrid power system. Therefore, new ways to balance the load demand is by integrating RES into the system. Hybrid system enables the incorporation of renewable energy sources and transferals the dependency on fossil fuels, while sustaining the balance between supply and demand. The significant characteristic of hybrid power system includes, system reliability, operational efficiency [4]. The hybrid power system enables to overcome the limitations in wind and photovoltaic resources since their performance characteristics depends upon the unfavorable changes in environmental conditions. It is probable to endorse that hybrid stand-alone electricity generation systems are usually more reliable and less costly than systems that depend on a single source of energy. On other hand one environmental condition can make one type of RES more profitable than other. For example, Photovoltaic (PV) system is ideal for locations having more solar illumination levels and Wind power system is ideal for locations having better wind flow conditions. For RES especially the variable speed wind energy conversion systems, Permanent Magnet Synchronous generator (PMSG) is gaining popularity [3]. PMSG have a loss-free rotor, and the power losses are confined to the stator winding and stator core. A multi-pole PMSG connected to power converter can be used as direct driven PMSG in locations with low wind speed there by eliminating the gearbox which adds weight, losses, cost and maintenance. A gearless construction of wind conversion system represents an efficient and reliable wind power conversion system. In a PV system, a solar cell alone can produce power of 1 to 2 watt. The solar cell is modeled by two diode model. The solar cells are connected in series and parallel to form a PV panel or module. The PV modules are connected in series and parallel to form a PV array in order to generate appropriate amount of power. Thus a PV system consisting of PV array, Maximum Power Point Tracking (MPPT) boost converters, and Wind power system consisting of wind turbine, PMSG, rectifier and MPPT boost converter is integrated into Solar Wind hybrid power system (SWHPS). The efficiency and reliability of the SWHPS mainly depends upon the control strategy of the MPPT boost converter. The solar and wind power generation cannot operate at Maximum power point (MPP) without proper control logic in the MPPT boost converter [8]. If the MPP is not tracked by the controller the power losses will occur in the system and in spite of wind and solar power availability, the output voltage of the hybrid system will not boost up to the required value. The output voltage of the PV and Wind power generation are quite low as compared with the desired operating level. So, this output voltage is brought to desired operating value of 220V using Boost converter.

Hybrid Power System Modelling

Hybrid power system consists of three different stages: the power generation stage, converter / controller stage and the distribution stage.

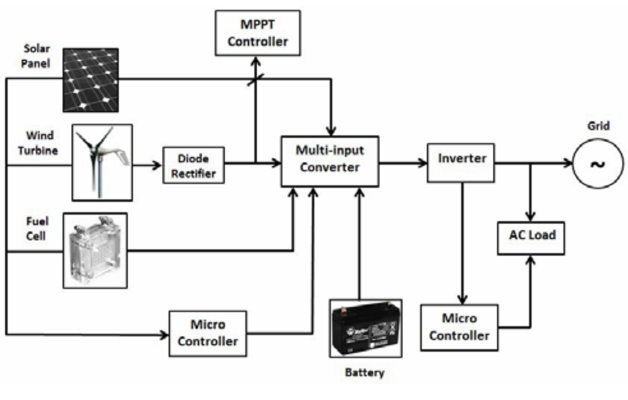


Fig.1. Block Diagram of Hybrid System

In this section, the dynamic simulation model of PV and wind turbine with PMSG is described. The developed model consists of PV array, dc/dc boost converter to achieve the desired output voltage using wind turbine, PMSG, ac/dc diode rectifier, dc/dc boost converter with MPPT. The block diagram of developed model is shown in Figure 1.

A. Modeling of PV modules in MATLAB, Simulink:

General mathematical models of PV cell were proposed by various researchers. A two-diode model of PV cell is selected whose equivalent circuit diagram is shown in Fig. 2.

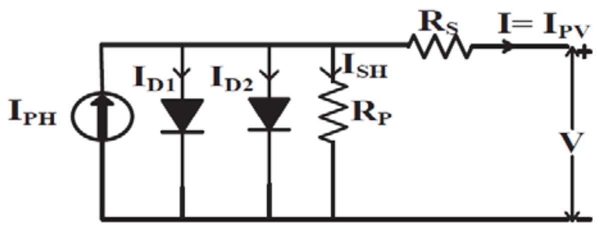


Fig. 2. Equivalent circuit of two-diode model of PV cell

The mathematical model of two-diode PV cell performance is better as compared with the numerous models of single-diode model of PV cell and also under low illumination levels, two diode model of PV cell exhibits better performance.

The two-diode PV cell shown in Fig. 2 consists of Photo-generated current (I_{ph}), two diodes with diode currents (I_{d1}, I_{d2}), Series Resistance (R_s), Shunt Resistance (R_p), output voltage (V) and PV current (I or I_{PV}). The relation between the output current and voltage can be obtained by using Kirchhoff's Current Law (KCL) [7].

$$I_{PV} = I_{PH} - I_{D1} - I_{D2} - I_{SH} \qquad (1)$$

where, I_{D1}, I_{D2} are the diode currents due to diffusion;

$$I_{D1} = I_{S1} [\exp (q * V / N_1 * k * T) - 1] \qquad (2)$$

$$I_{D2} = I_{S2} [\exp (q * V / N_2 * k * T) - 1] \qquad (3)$$

Where, Is_1, Is_2 are the reverse saturation currents of diode D_1, D_2, q is the charge on electron ($1.602*10^{-19}$ C), V is the cell output voltage, N1, N2 are the quality factors of diode D1, D2, k is the Boltzmann constant ($1.38*10^{-23}$), and T is the junction temperature. The practical PV modules have the Rs and Rp as indicted in Fig. 2. These parameters are incorporated to build the mathematical model of PV cell to replicate the practical PV cell.

$$I_{D1} = I_{S1} [e (V + R*I / N_1 * V_t) - 1] \qquad (4)$$

$$I_{D2} = I_{S2} [e (V + R*I / N_2 * V_t) - 1] \qquad (5)$$

where, $V_t = (N * k * T) / q$ is the thermal voltage of the module with Ns being number of cells connected in series, current in the shunt resistance is given by

$$I_{SH} = (V + Rs * I_{PV}) / R_p \quad (6)$$

Substituting (4), (5), (6) in (1) we get the relation between the voltage and current of the two diode equivalent of the PV cell.

A number of approaches for cells and modules parameter determination can be adopted using the datasheet parameters specified by manufacturer or measured. The performance of solar cell is normally evaluated under the standard test condition, where an average solar spectrum at AM 1.5 is used, the irradiance is normalized to 1000W/m^2, and the cell temperature is defined as 25°C [5]. The specifications of the solar panel listed in Table I are used and implemented in the proposed power hybrid system.

TABLE I: SPECIFICATION OF SOLAR PANEL

Specification	**Value**
Peak power output in voltage	1000 V
Maximum power voltage	650 V
Maximum power current	14.75 A
No. and type of cell	44 cells
Working temperature	-40°C ~ 90°C

The perturbation of the output power is achieved by periodically changing (either increasing or decreasing) the controlled output power.

B. Modeling of Wind Turbine in MATLAB, Simulink:

Among various types of wind turbines, the permanent magnet synchronous generator, which has higher reliability and efficiency, is preferred in the proposed scheme. The available power of wind energy system and the mechanical power that is generated by the wind are presented as equation given:

$$P_{wind} = ½ (\rho A V^3)$$

$$P_m = ½ (\rho A V^3 C_p \lambda\beta)$$

Where, *ρ* is the air density (kg/m^3), *A* is the area of the turbine blades (m^2), *V* is the wind velocity (m/s), and *Cp* is the power coefficient. The power coefficient is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It depends on two variables: the tip speed ratio (TSR) and the pitch angle. The TSR (*λ*) refers to a ratio of the turbine angular speed over the wind speed [13]. The pitch angle (*β*) refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis.

The specifications of the wind turbine are listed in Table II.

TABLE II: SPECIFICATION OF WIND TURBINE

Specification	**Value**
Rated power	2500 W
Maximum power	2250 W
Nominal voltage	650 V
Start-up wind speed	2.0 m/s
Rated wind speed	10 m/s

System Control Strategy

A. The PV Side Control: The control strategy of grid connected PV inverter consists of three parts.

i. Direct and quadrature axis current reference generator

ii. PLL and d-q frame generation of grid voltage and current

iii. Conversion voltage generation and PWM reference generation.

The dc-link voltage feedback and the reference dc voltage are introduced to the I_d -I_q reference generator. After making that the per unit error signal is being given to PI controller d axis reference is produced. The q axis component is being set to zero. The grid voltage and the grid current are then given to the discrete three phase PLL reference is produced and using Park's transformation current and voltage, abc are being converted to d-q-o components [7]. From the generated d_q current reference and the measured grid voltage and current d_q reference, the conversion voltage is calculated. Simulation diagram of grid connected PV side controller is shown in fig.3.

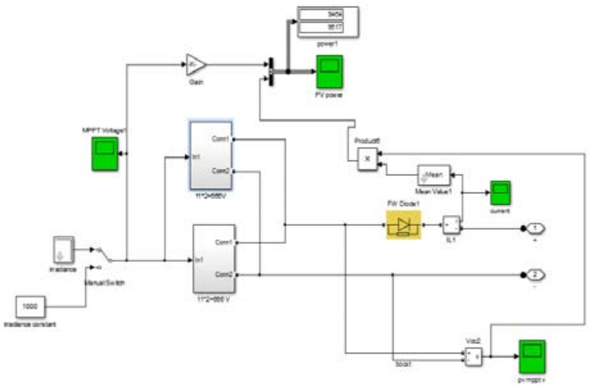


Fig. 3. Simulation diagram of grid connected PV side controller

B. The Wind Turbine Power Control: To control the grid side converter we draw two inputs. One of them is the reference dc-link voltage and the other is the actual dc-link voltage. The error between the two is controlled by a PI controller .It generates the reference direct axis current of the grid side which is compared with the actual grid side direct axis current to obtain the direct axis voltage of grid side. To minimize the cross-coupling effect additional rotating compensating terms are added which finally generates the reference direct axis voltage. Similarly actual and reference quadrature axis current from the grid side are compared and controlled with the help of a PI controller which yields the quadrature axis voltage [11]. This is added with the rotational emf compensating terms to generate the reference voltage vector of quadrature axis. Now the above mentioned references are used to generate the reference voltage vector for space vector pulse width modulation to generate the final switching signals for this converter.

•An outer dc voltage control loop is used to set the d-axis current reference for active power control. This assures that all the power coming from the rectifier is instantaneously transferred to the grid by the inverter.

•The second channel controls the reactive power by setting a q-axis current reference to a current control loop. A voltage reference is generated for the inverter that is compensated by adding rotational EMF compensation terms. Matlab/Simulink setup of Controller is as shown in Fig. 4.

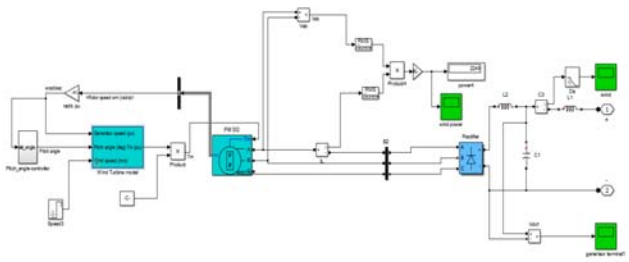


Fig. 4. Matlab/Simulink setup of Controller:

Simulation, Result And Discussion

The overall simulation model with the novel control strategies both for PV and wind combined generation is shown below in fig.5. The main parameters are as follow: the line voltage and frequency of the grid power source are 220V and 50 Hz.

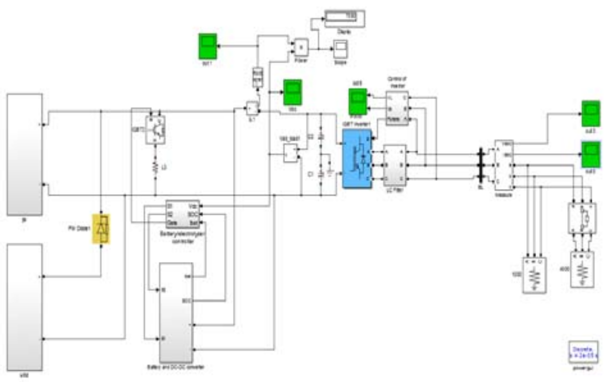
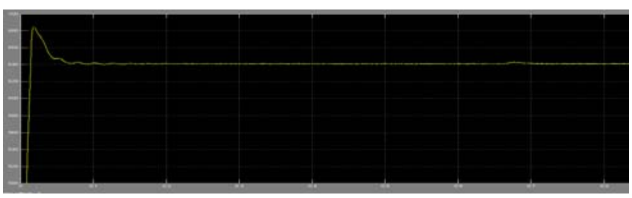


Fig. 5. Simulation diagram of proposed grid connected PV/wind system

The temperature is assumed to be 25 ^{0}C. Output waveform of the PV voltage and PV current along with the maximum tracked power and inverter voltage is shown in fig.6.



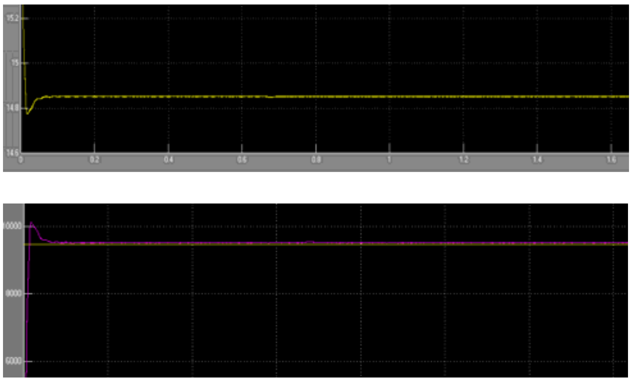


Fig. 6. Waveform of i) PV voltage, ii) PV current, iii) maximum power output,

Fig. 7 shows the different waveform of the wind turbine characteristics. They are:

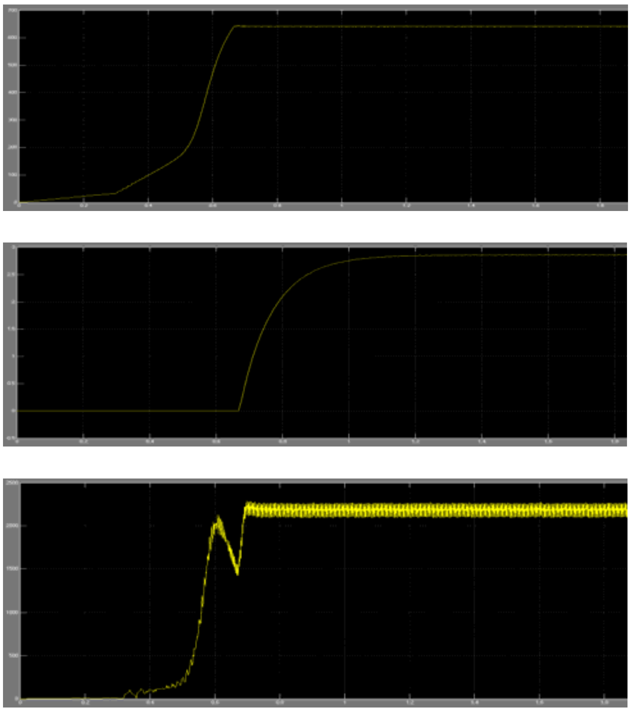


Fig.7. waveform of i) wind voltage ii) wind current iii) wind power

Fig. 8 shows the different waveform of the grid characteristics.

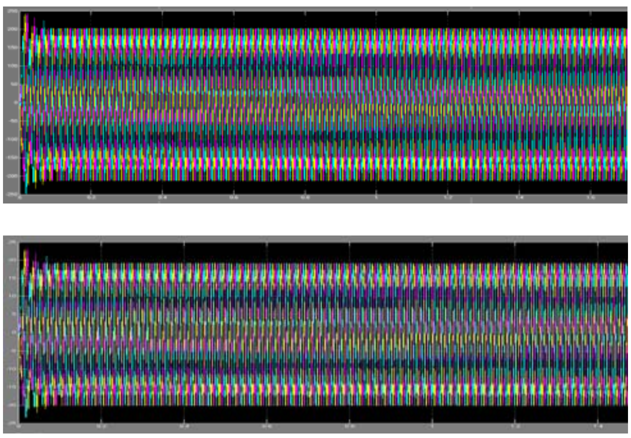


Fig. 8 waveform of i.) Grid Voltage ii.) Grid Current

From the graph we see that turbine voltage and current i.e. transformer output voltage are nearly sinusoidal and in phase with grid voltage and current.

Conclusion

The study on power quality of grid-connected wind/PV hybrid generation system was conducted at the designing stages of the mixed renewable sources hybrid control system. The power electronic interface and its control strategies were proposed for maximum power generation of the hybrid system with grid interface. Here, the dynamic analysis models of the system components and power control strategies were addressed. The modeling, along with the simulation study was carried out based on Matlab2013. The simulation results showed the excellent performance of the hybrid control in response to severe changes in wind speed and solar intensity conditions. Control and analysis of hybrid systems with fuel cell generation or battery storage will be followed in the future work.

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