International Journal of Computer Applications (0975 – 8887)
International Conference on Advances in Emerging Technology (ICAET 2016)

Modelling and Simulation of a Multijunction Photovoltaic-Wind Hybrid Power System

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ABSTRACT
This paper takes into account a hybrid power system consisting of solar and wind units. Both units are connected to the utility grid. The paper concentrates on the use of multi-junction solar cell (MJSC) in order to increase the conversion efficiency. The DC output of solar photovoltaic (PV) system is raised by using boost convertor. MPPT technique is used to maximize the output of solar system. A multilevel invertor is used to convert DC to AC power. In wind system, PMSG is used which is derived by a turbine. The modeling and analysis of the above system is carried out in MATLAB using Simulink toolbox.

Keywords
MPPT; Multi-level inverter; Multi-junction solar cell; PMSG; Boost converter

1. INTRODUCTION
With the sources of energy such as coal and oil depleting, the world and its people must look to a new and renewable source of energy to sustain our way of life. The major advantages of such type of energy sources are that they have no polluting by-products and hence have negligible harmful effects on the environment. Also another positive outcome is their ability to serve people living in rural and remote areas, to whom electric power is still a dream.

Various types of renewable power sources are present such as solar, wind, biogas, tidal energy etc. But solar and wind are most popular. But these resources are dependent upon climate and are not reliable if used in individual mode. So, it's reliable as well as economic to use them in hybrid mode. By this practice, we can always have a certain amount of reserved capacity available which can be utilized later on such as at the time of peak loads etc.

The ministry of new and renewable energy (MNRE) has collected a data about the use of these resources in India. Total Wind potential is 102772 MW, installed capacity is 21136.2 MW. Total Solar potential is 100000 MW, installed capacity is 2647 MW. So much of energy is still un-trapped. In this field of energy, various challenges are low capacity credit, reduced utilization of dispatch able plants and over-produced generation. These challenges cannot be neglected in system analysis and planning [1]. Various hybrid models have been designed by many researchers using different techniques and components in Simulink environment [2-4].

This paper depicts such a hybrid system consisting of a multi-junction solar cell and wind system which is connected to a grid with application of load. Paper is carved into various sections. Section 1 gives the introduction. Section 2 consists of various subsections describing the basic parts of hybrid system. Section 3 depicts the hybrid power system modeling in MATLAB Simulink. Sections 4 and 5 gives simulation results, conclusions and future scope respectively. .

Overall system performance in terms of total harmonic distortion (THD) has been analyzed.

2. SYSTEM DESCRIPTION
Fig.1. represents a basic model of a PV-wind hybrid power system. Various components are represented in the form of interconnected blocks. A multi-junction solar cell (MJSC) is used in this model. Solar output is raised by boost converter and converted to AC by a multilevel inverter. Maximum power point technique (MPPT) is used to track the maximum power continuously. Permanent magnet synchronous generator (PMSG) is used to obtain the electric power from the wind turbine. Both the systems are serving the grid. Induction motor is used as a load.

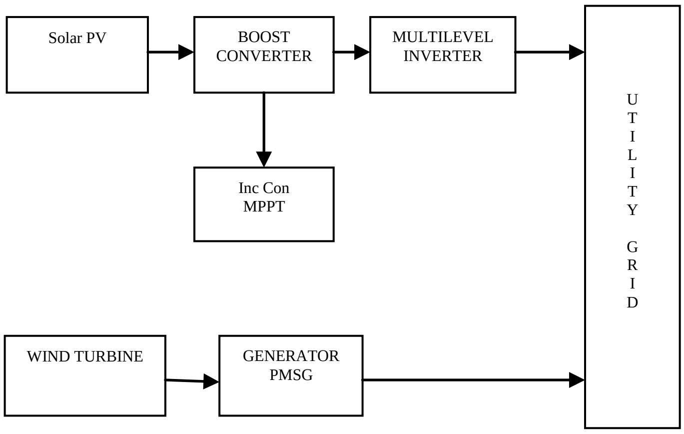

Figure 1. General block diagram of the model

This model will be developed in MATLAB environment using Simulink toolbox for the analysis purpose.

2.1 Solar cell model
A solar or a PV cell is used to convert the sunlight to electric power. It is generally made up of semiconductor materials. It is generally represented by a current source in parallel with a diode. Under ideal circumstances like constant irradiance and constant temperature, this current is constant. But practically no cell is ideal so we use series and shunt resistance in addition to ideal circuit. MJSC are the solar cells with multiple p-n junctions made up of different semiconductor materials. Each material will produce electric current in respond to different wavelengths of light. Hence it let the absorbance of a wide range of wavelengths, improving the cells sunlight to electrical energy conversion efficiency [5-8]. Generally single junction solar cells have efficiency in the range of 30-35% but MJSC have achieved efficiency up to 50%. While manufacturing, some essential requirements which are to be followed are lattice matching, band gap

energy matching and current matching. Fig. 2. represents a basic solar cell circuit. It consists of a series and a shunt resistance along with a diode. The direction of current is given by arrows.

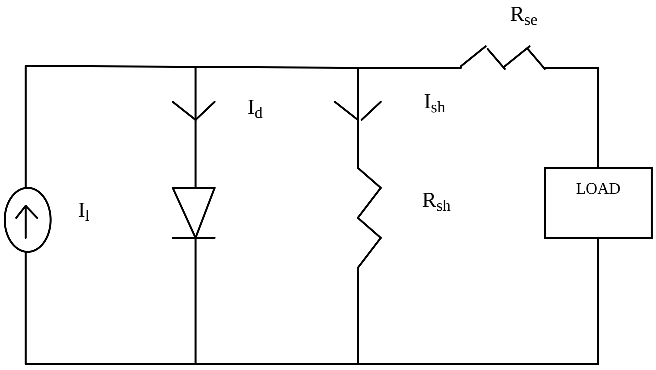

Figure 2. Solar cell basic circuit

The current output by solar PV cell is given as

$$I = I_l - I_d - I_{sh} \quad (1)$$

$$I = I_l - I_o\{\exp[\frac{q(V+IR_S)}{nKT}]-1\}\frac{VIR_S}{Rsh} \quad (2)$$

Where

I =Output current (Amp)

I_l = Photo generated current (Amp)

I_d =Diode current (Amp)

I_{sh} =Shunt current (Amp)

I_o =Reverse saturation current

n =Diode ideality factor (for ideal n=1)

q =Elementary charge

K =Boltzmann constant

T =Absolute temperature

V =cell voltage/voltage across output terminals

The output of the solar cell generally depends upon environment conditions, so it requires a novel MPPT technique in order to maximize its output.

2.2 MPPT techniques

Photovoltaic module results in the output power which keeps on changing with the environmental conditions. Thus, there is a need of control algorithms which can obtain the highest energy from the photovoltaic modules irrespective of the environmental conditions such as temperature and light rays. Numerous control algorithms have been proposed in the recent years. Due to nonlinear relationship between current and voltage, there exists a unique maximum power point that keeps on changing with the atmospheric conditions, ambient temperature and irradiance levels. At the maximum operating point, a PV array operates at its highest efficiency. Fig. 3. represents photovoltaic solar cell I-V curves where a line intersects the knee of the curves where the maximum power transfer point is located.

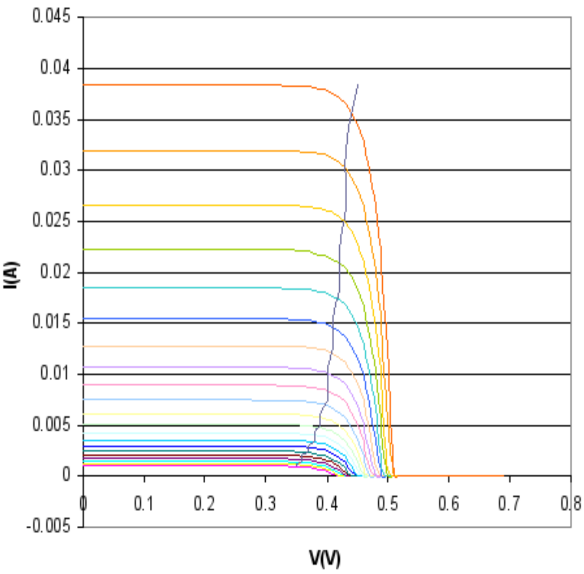

Figure 3. Solar cell I-V curve in varying sunlight

To obtain maximum power point under varying atmospheric conditions, maximum power point tracking (MPPT) control algorithms are generally used [9-11]. Certain algorithm has to be implemented in order to maximize the output of the solar cell. Work has been already been done on various techniques and after comparison it has been concluded that incremental conductance (Inc Con) MPPT algorithm is to be used because of its medium complexity and high accuracy. Another advantage is that it takes into account the rapid change of irradiance level. This method is based on the differentiating the PV output power with respect to PV voltage and setting the result equal to zero. At MPP it is set equal to zero, while value less than or greater than zero shows the deviation of operating point from the MPP.

Main advantage of this method is that it yields good result under rapidly varying environmental conditions.

$$\frac{dP}{dV} = I + V\frac{dI}{dV} \quad (3)$$

So, in this model Inc Con is to be implemented.

2.3 Multilevel inverter

In order to convert the DC output of the solar PV cell the inverter is used. Multilevel Converters are very impressive devices for medium and high voltage operations because of their inherent advantages such as lesser power dissipation on power switches, lesser harmonic contents and low electromagnetic interference outputs. Multilevel inverter (MLI) produce an output signal with low Total Harmonic Distortion (THD), because of this the complexity of the output filter decreases. The existing technique of cascaded H-Bridge MLI is general type of MLI. It consists of a DC source for each of the H-Bridge and semiconductor switches such as MOSFET. This inverter uses a number of H-Bridges joined in series to provide a sinusoidal output voltage. It consists of a number of H-bridges and the output voltage generated by the MLI is finally the addition of the voltages produced by all individual blocks i.e. suppose there are

N H-bridges in a MLI then number of output voltage levels will be 2N+1. The Cascaded H-Bridge (CHB) inverter is generally used as a solution for large-scale PV power plants, because it has many positive outcomes like the number of possible output voltage levels is more than two times the number of DC sources [12-16]. The series of H-bridges makes for modularized layout and packaging which will result into the manufacturing process to be done in a quicker and a cheap way. In this model a 21-level MLI has been implemented consisting of 10 H-bridges. Cascaded H-bridge MLI is considered as best technique among the various options available.

2.4 Boost convertor

The boost convertor is basically a DC to DC voltage converter which is used to get the higher value of DC voltage from the low value DC output of the solar panel. It is a type of switched-mode power supply (SMPS) consisting of minimum two semiconductors (a diode and a transistor) and at least one energy storage component such as a capacitor, inductor, or both in integrated form. Filters consisting of capacitors (sometimes in integration with inductors) are generally used at the output of the converter to reduce the ripples in the output voltage. In this model insulated gate bipolar transistor (IGBT) is used. A boost converter in most of the cases is called as a step-up converter because it "steps up" the voltage of the source. The main working principle of boost converter is that the inductor in the input circuit resists sudden variations in input current. When switch is OFF the inductor stores energy in the form of magnetic energy and discharges it when switch is closed.

2.5 Wind system model

Wind energy is generally extracted from air flow using wind turbines to produce mechanical power which is then converted to electrical energy by using generators. In wind system selection of generator is a major concern. There are various types of generators that can be used. The wind turbine generator may operate at a constant speed or variable speed. The use of variable speed wind energy conversion systems (WECS) has become popular these days because it can track maximum power from the wind at different wind speeds and hence yield more power and provide less stress on the generator shaft, as the shaft speed can vary with the variation of wind speed. The variable speed WECS is also cost effective and provide simple pitch control for the turbine [17-20]. Permanent magnet synchronous generator (PMSG) is one of the types of variable speed WECS. It has a number of advantages such as high energy density, simple control methodology, low maintenance cost, self-excitation system and possibility of direct coupling to a wind turbine with elimination of the gearbox, high performance, high efficiency, high precision, high reliability, wide operating range make WECSs based on PMSGs even more attractive [21-22]. The entire wind energy passing through an assumed surface with area A in a time period t is given as:-

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3 \quad (4)$$

Where ρ =Density of air (Kg/m^3)

v =Wind speed (m/s)

$Avt =$ Volume of air flowing through A

$Avt\rho =$ Mass m passing through A

So, the output power of turbine is given by:-

$$P_m = \frac{E}{t} = C_p(\lambda, \beta)\frac{\rho A}{2}v^3 \quad (5)$$

Where C_p =Performance coefficient of turbine

λ =Tip speed ratio (TSR) of rotor blade tip speed to the speed of wind

β = Pitch angle of the blade (degree)

The wind turbine using a PMSG is modeled in Simulink environment. Furthermore various control strategies can be developed for wind energy systems in order to increase their efficiency such as pitch angle control [23].

3. HYBRID SYSTEM SIMULATION

In a hybrid system two or more sources are combined to get the total power. In this paper solar system and wind system are used in a hybrid mode that is connected to the grid. The system designed in MATLAB is shown in fig. 4.

4. SIMULATION RESULTS

Various simulation results have been developed in MATLAB environment. In wind system, the PMSG produces the AC voltage waveform which is as shown in fig. 5.

In solar system, MPPT technique is used to locate the maximum power point and a DC-DC boost convertor is used to raise the DC voltage. This output voltage is shown in fig. 6. The multilevel inverter converts it to AC. The squirrel cage induction motor is used as a load. The sinusoidal stator current waveforms are obtained shown as following in fig. 7, 8 and 9 respectively. The system has also been analyzed for THD and it has been observed that the THD comes out to be just 0.34% as shown in fig.10.

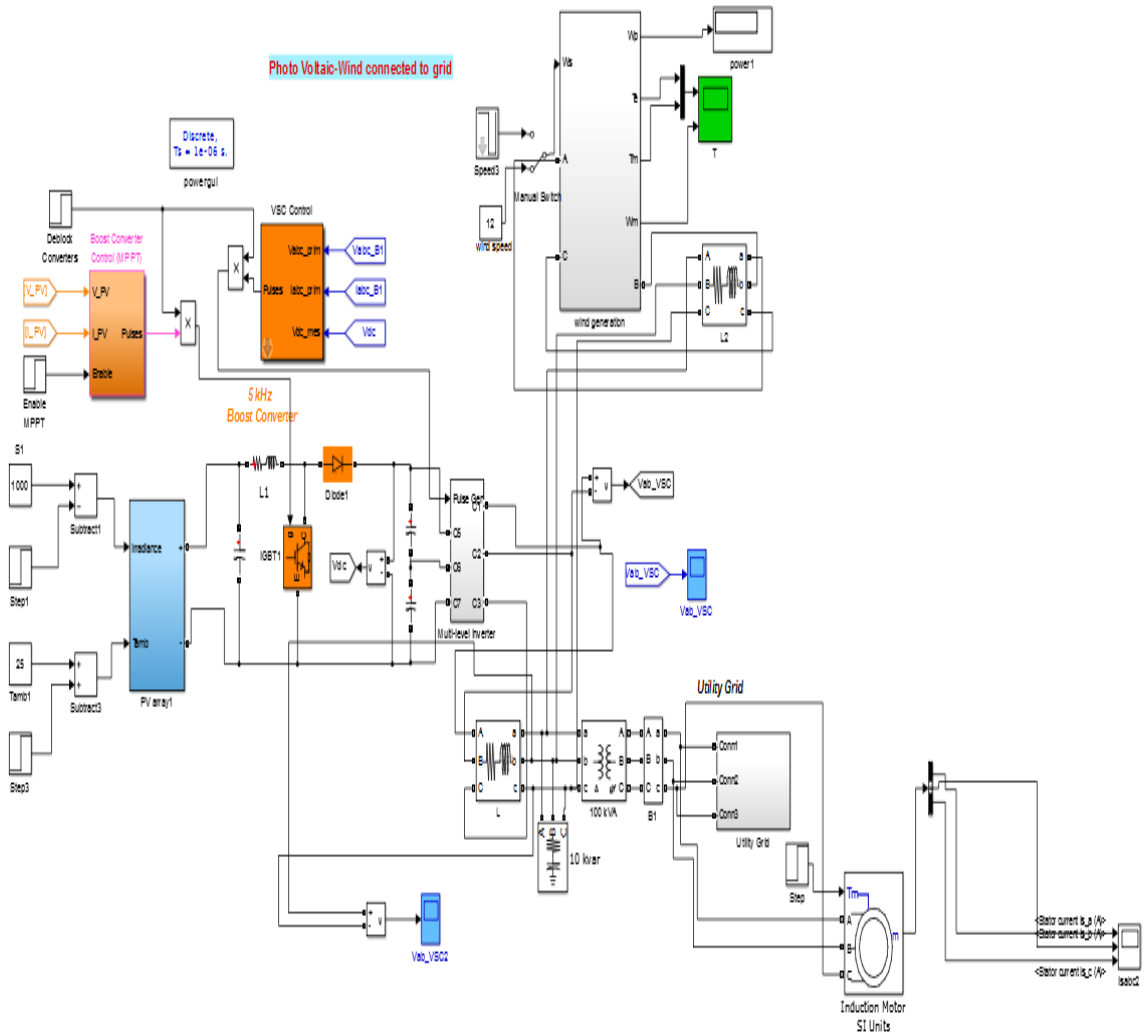

Figure 4. Simulink model of solar-wind hybrid system

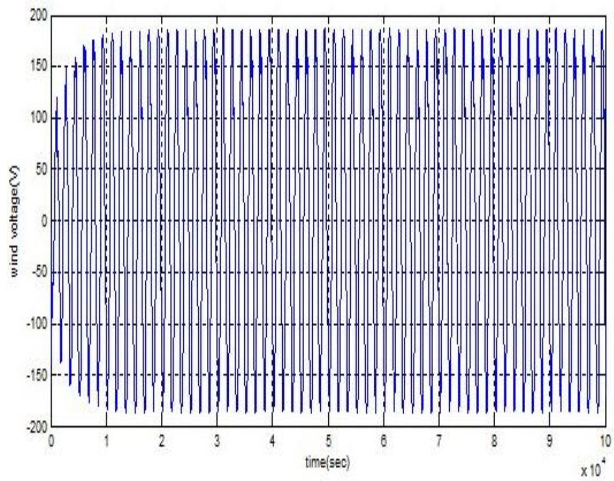

Figure 5. Wind generator output voltage

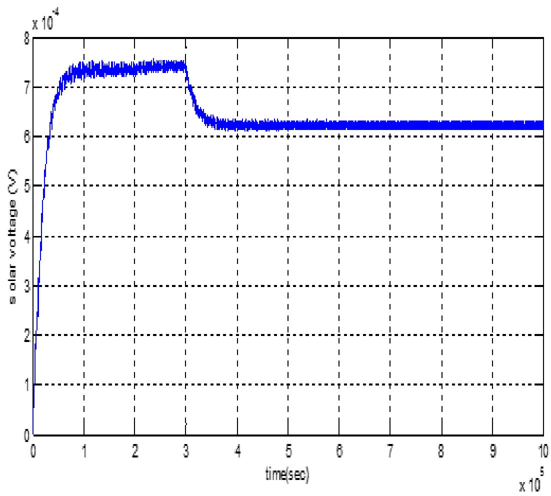

Figure 6. Solar cell output voltage

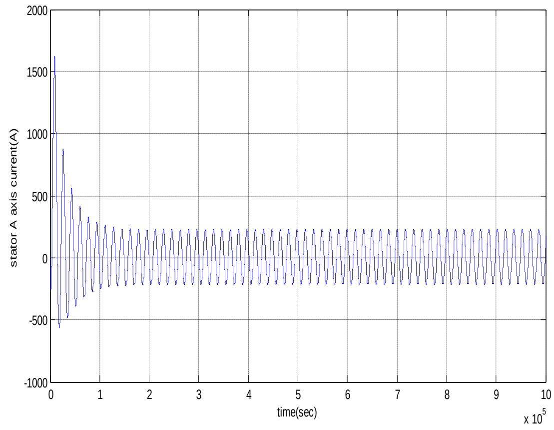

Figure 7. Stator A phase current

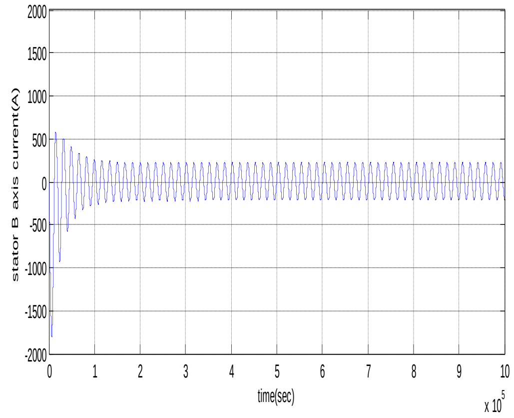

Figure 8. Stator B phase current

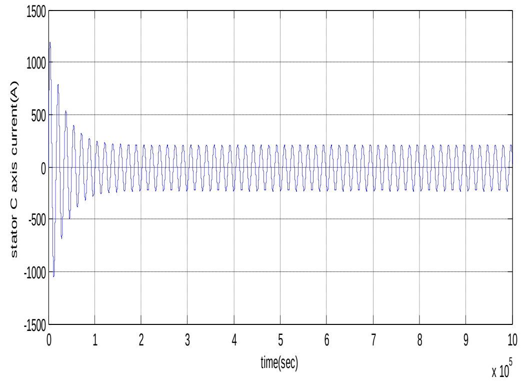

Figure 9. Stator C phase current

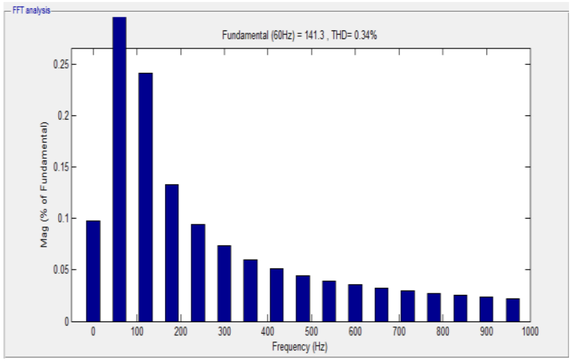

Figure 10. THD analysis of the designed system

5. CONCLUSION AND FUTURE SCOPE

So, from this paper it can be found that renewable energy sources can fulfill the energy demands of the future. These can work more economically and reliably if used in hybrid mode. The application of multi-junction solar cell, multi-level inverter (MLI) and MPPT (Inc Con) has been introduced in hybrid system mode.

As a future scope, this hybrid system's efficiency can be increased by implementation of various types of controllers such as fuzzy logic control, model predictive control for the wind system. Furthermore battery storage option can be considered.

The whole system is very useful for rural applications.

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