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# Fundamentals and Modelling of A Solar PV System

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**ABSTRACT**:Solar energy has been reined by humans since ancient times. Most of the usable renewable energy sources in the world are derived from solar energy. Photovoltaic systems(PV) convert solar energy directly into electricity by the principle of photovoltaic effect. Basic unit of these systems is a solar cell which is a p-n junction diode. These cells can be connected in series and parallel to obtain the required voltage and power output. In this paper, a PV system is modelled and analysed under different conditions of temperature and irradiance.

**KEYWORDS:** Solar Energy, Photovoltaics, Solar cell.

## I.INTRODUCTION

With the outburst of industrial revolution, the demand of electricity has increased tremendously. At present, majority of power generated in the world is from fossil fuelled power plants. Fossil fuels are the largest greenhouse gas emitters in the world, contributing 3/4th of all carbon, methane and other greenhouse gas emissions. Also, world's fossil fuel reserve is being depleted drastically. Within a short span of time, world will have to depend on renewable energy sources to meet most of its energy demand. Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy sources.

Solar energy is one among the promising renewable energy sources for the future. Solar energy is the light and heat radiated from the sun harnessed using a range of evolving technologies including solar architecture, solar photovoltaics, solar thermal energy and solar heating. It is a clean form of energy and emits very small amount of carbon dioxide and sulphur oxides. Other advantages of solar energy are that it is affordable, reliable and flexible.

Solar PV systems convert energy of sun directly into electricity. The solar energy conversion into electricity takes place in a semiconductor device that is called a solar cell. In order to use solar electricity for practical devices, which require a particular voltage or current for their operation, a number of solar cells have to be connected together to form a solar panel, also called a PV module. For large-scale generation of solar electricity the solar panels are connected together into a solar array[1].

## II. LITERATURE REVIEW

Solar cell is the basic unit of a PV system. A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an n type dopant such as phosphorous. On the base of the slab a small amount of a p type dopant, typically boron is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. Dopants are similar in atomic structure to the primary material. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell.

Majority of modules use wafer based cells or thin film cells based on non-magnetic conductive transition metals, tellurium or silicon. Some cells are round or square, while thin film PV modules may have long narrow cells. One silicon solar cell produces 0.5 volt. 36 cells connected together have enough voltage to charge 12volt batteries and run pumps and motors. A typical module has 36 cells connected in series, plus to minus, to increase the voltage. With connected cells and a tough front glass, a protective back surface and a frame, the module can be used for real-world systems [2].

Module is a group of PV cells connected in series and/or parallel and encapsulated in an environmentally protective laminate. The PV module is the smallest package that produces useful power. The process involved in manufacturing these modules requires high precision and quality control in order to produce a reliable product. Encapsulation is the

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method in which PV cells are protected from the environment, typically laminated between a glass superstrate and EVA substrate. Panel is a group of modules that is the basic building block of a PV array. A group of panels that comprises the complete PV generating unit is called PV array. Fig.1 shows a solar cell, panel and an array.

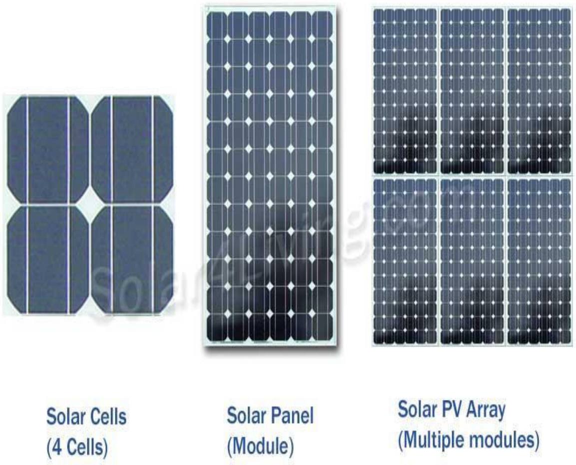


FIG.1. Solar cell, Module and Array

The phosphorous gives the wafer of silicon an excess of free electrons. This is called the n type silicon. The n-type silicon is not charged. It has an equal number of protons and electrons. But some of the electrons are not held tightly to the atoms. They are free to move to different locations within the layer. The boron gives the base of the silicon a positive character, because it has a tendency to attract electrons. The base of the silicon is called p-type silicon. The p-type silicon has an equal number of protons and electrons; it has a positive character but not a positive charge.

Where the n-type silicon and p-type silicon meet, free electrons from the free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the p-n junction. When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and holes at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type silicon.

If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Most photon electron collisions actually occur in the silicon base.

A conducting wire connects the p-type silicon to an electrical load, such as a light or battery, and then back to the n-type silicon, forming a complete circuit. As the free electrons are pushed into the n-type silicon they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that travels through the circuit from the n-type to the p-type silicon. In addition to the semi-conducting materials, solar cells consist of a metallic grid or other electrical contact to collect electrons from the semi-conductor and transfer them to the external load, and a back contact layer to complete the electrical circuit.

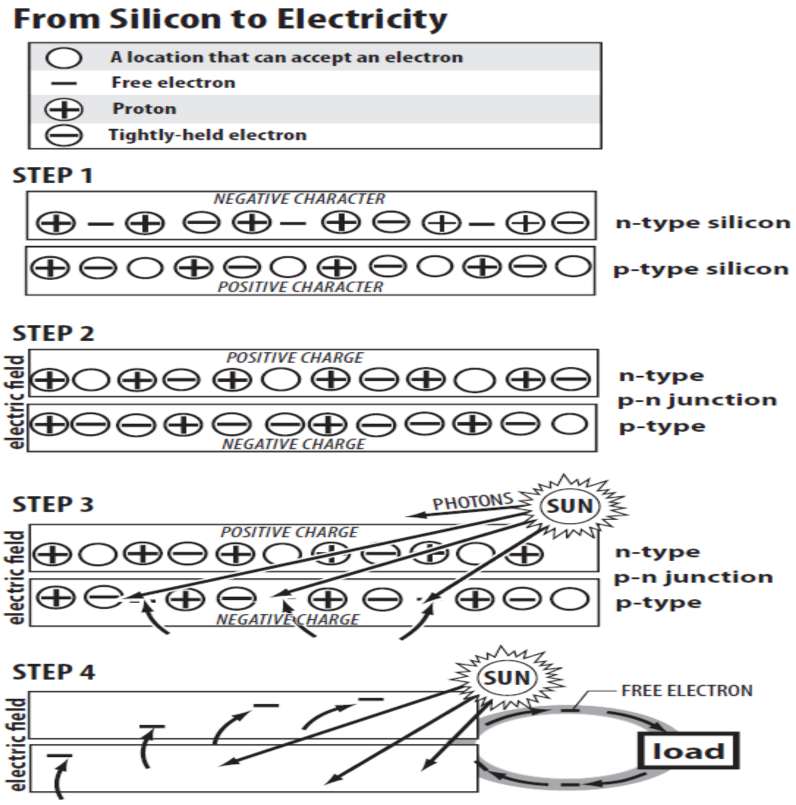


FIG.2 Principle of Operation

## III. PV MODELLING

Solar cell can be typically modeled by a current source and an inverted diode connected anti-parallel to it. It has its own series and parallel resistances. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current. Modelling of PV cell involves the estimation of the I-V and P-V characteristics curves to emulate the real cell under various environmental conditions. An ideal solar cell is modelled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the fig.3.

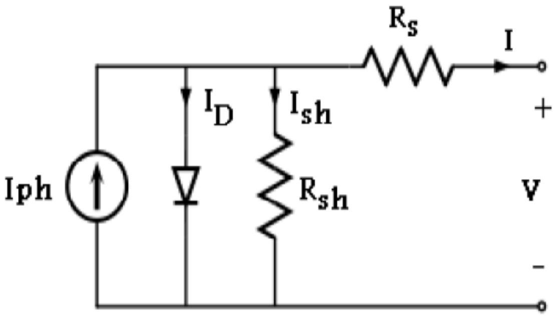


FIG.3 Equivalent Circuit of a Solar Cell

When p-n junction is not illuminated the equation for diode current is given by,

$$I_D = I_o\left(e^{\frac{V}{V_t}} - 1\right) \qquad (1)$$

Where,

$$V_t = \frac{kT}{q} \qquad (2)$$

Here, $V_t$ is the thermal voltage, T is the operating temperature, q is the charge of an electron and $I_o$ is the diode saturation current. When p-n junction is illuminated, the diode characteristics shift as shown in fig.4. By applying KCL to the equivalent circuit, the net current from the PV cell is given by,

$$I = I_{ph} - I_D - I_{Rsh} \qquad (3)$$

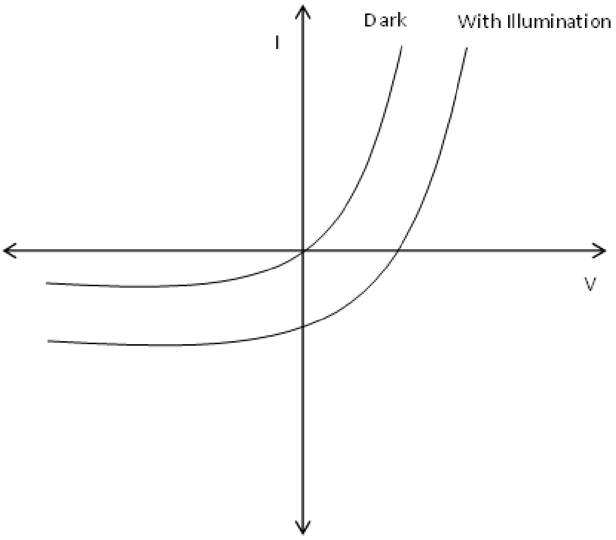


FIG.4 Diode characteristics under dark and illuminated conditions

Considering the intrinsic series and shunt impedances, the net current from the diode is given by,

$$I = I_{ph} - I_o \left[\exp\left(\frac{V + IR_s}{V_t}\right) - 1\right] - \left(\frac{V + IR_s}{Rsh}\right) \qquad (4)$$

The last term in the above equation can be neglected since $R_s >> R_{sh.}$ So it can be written as,

$$I = I_{ph} - I_o \left[\exp\left(\frac{V + IR_s}{V_t}\right) - 1\right] \qquad (5)$$

Equation 5 gives the net current from a PV cell. The module saturation current $I_O$ is given by,

$$I_o = I_{rs} \left[\frac{T}{T_r}\right]^3 \exp\left[\frac{qE_{go}}{BK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \qquad (6)$$

Here, $I_{rs}$ is the reverse saturation current and is given by,

$$I_{rs} = \frac{I_{sc}}{\exp\left[\frac{qV_{oc}}{N_s KAT} - 1\right]} \qquad (7)$$

$I_{sc}$ is the short circuit current and is specific for a particular cell. The equation for photo-generated current $I_{ph}$ is given by,

$$I_{ph} = I_{sc} + K_i(T - T_r)\frac{\lambda}{1000} \qquad (8)$$

Where,

$\lambda$ : PV module illumination
A : P-N Junction ideality Factor
$T_r$ : Reference temperature
$R_s$ : Series impedance
$R_{sh}$ : Shunt impedance
$V_{oc}$ : Open Circuit voltage
$K_i$ : Short Circuit current temperature coefficient

Equation (5) can be used for obtaining the I-V characteristics of the solar cell. Typical I-V and P-V characteristics of the solar cell can be obtained as shown in fig.5.

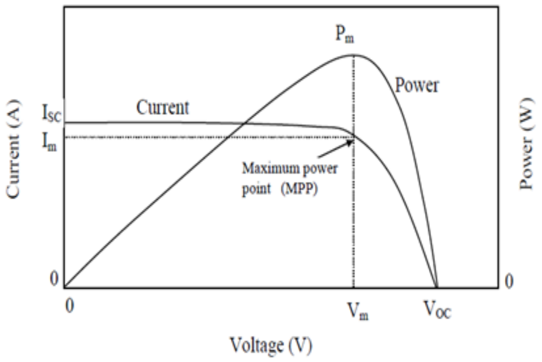


Fig.5. Typical I-V and P-V Characteristics of a Solar Cell

It is clear from the equations that the I-V and P-V characteristics change with insolation and temperature. Matlab based simulations can be done inorder to validate the theoretical concept. Since a reasonable power output can only be obtained by the series and parallel combination of cells, the actual current from the PV module is given by [4],

$$I = N_p I_{ph} - N_p I_o \left[\exp\left\{q\left(\frac{V + IR_s}{N_s KAT}\right)\right\} - 1\right] \quad (9)$$

Where $N_s$ is the number of cells connected in series and $N_P$ is the number of cells connected in parallel. The validation of these concepts using simulation is described in the following sections.

## IV.SIMULATION STUDIES

The Simulink model of the system was made to validate the theory. Equations (1)-(9) can be used for Simulink based modelling. For this purpose, each equation was modelled separately and then combined to form the complete system. The parameters used for simulation are that of an EMVEE DIAMOND PV module. The specifications of this module are given in table I.

TABLE I. SPECIFICATIONS OF MODULE

| | |
|---|---|
| Rated Power | 240 W |
| Module Efficiency | 14.6% |
| Cell Efficiency | 17.4% |
| Open Circuit Voltage | 36.72 V |
| Short Circuit Current | 8.74 A |
| Rated Voltage | 28.29 V |
| Rated Current | 8.31 A |

The Simulink block diagram for the complete system is shown in fig.6.

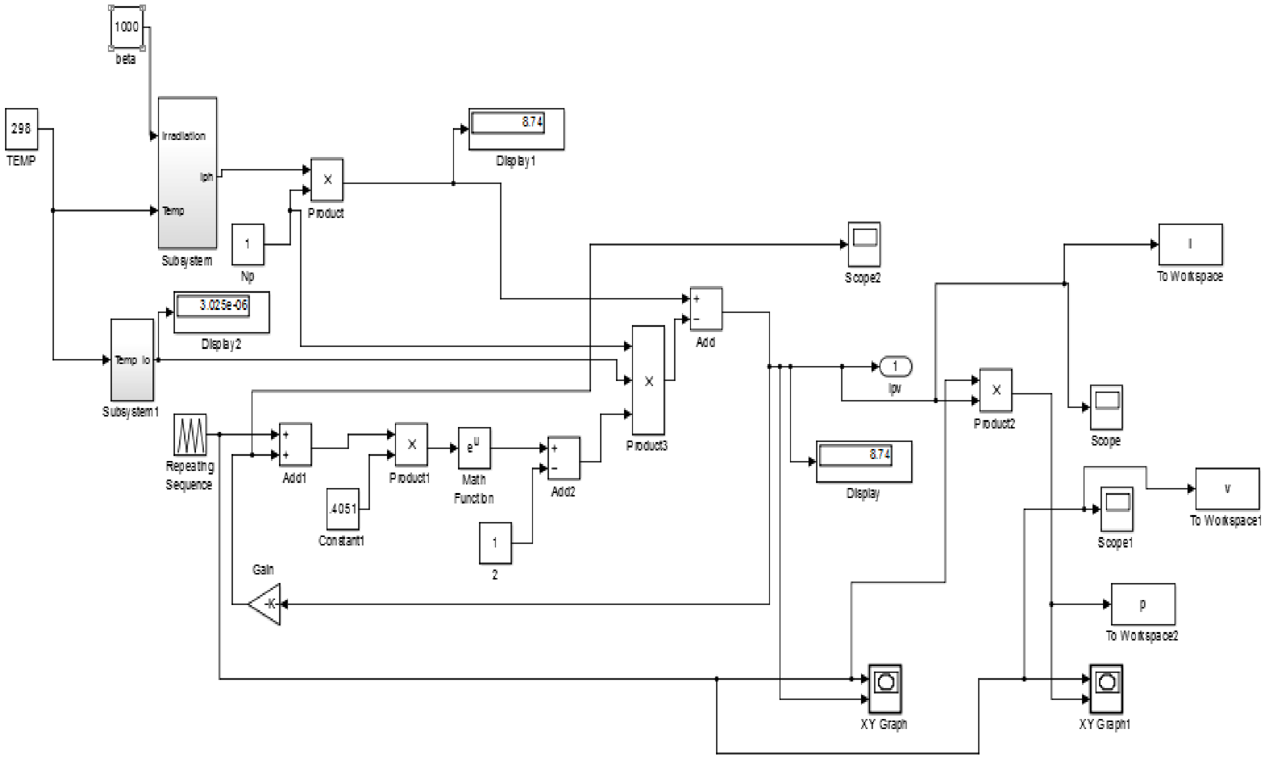


FIG.6 Simulink Block Diagram for the Complete System

The subsystem used for obtaining $I_{ph}$is asown in fig.7.

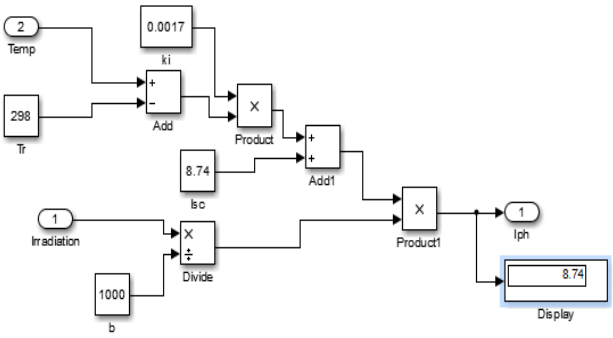


FIG.7 Simulink Block Diagram for $I_{ph}$

The subsystem used for obtaining $I_{ph}$is asown in fig.8.

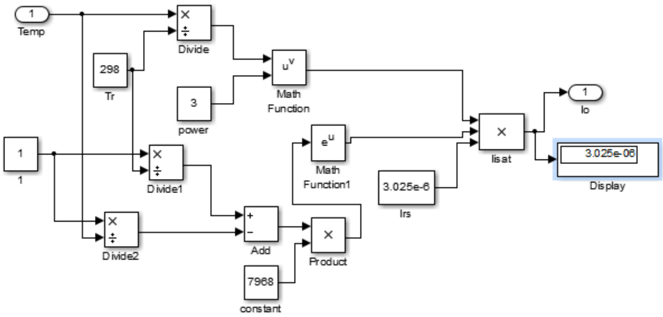
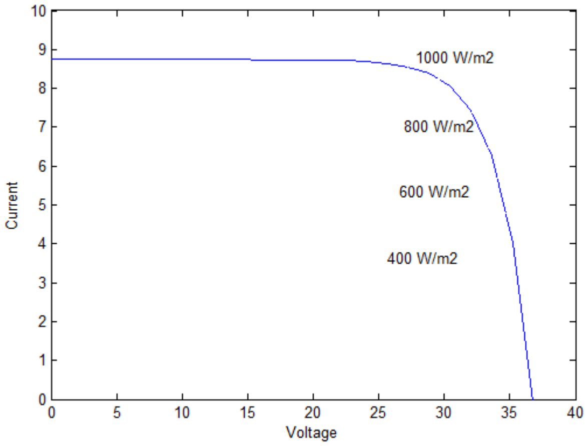


FIG.8 Simulink Block Diagram for $I_o$

These subsystems are combined together to form the complete system. The results obtained from simulations under standard conditions of 1000 W/m2 and 298 K are as shown in fig. 9(a) and 9(b).



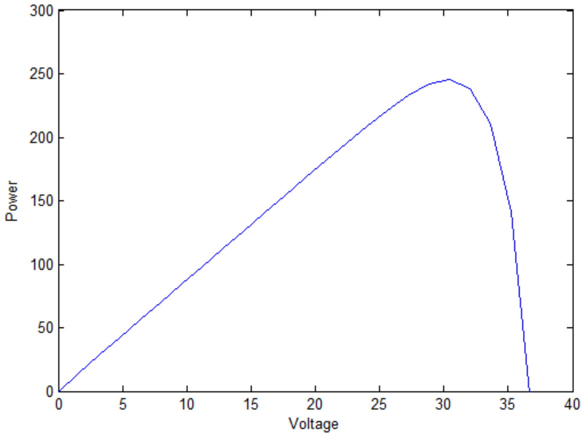
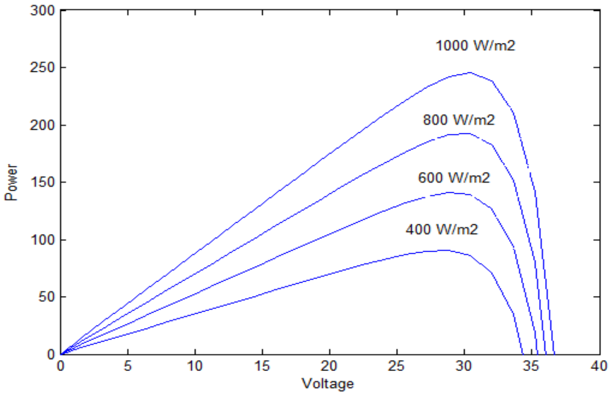


FIG.9(a) I-V CharacteristicsFIG.9(b) P-V Characteristics

I-V and P-V characteristics vary with insolation and temperature. These are shown in the following figures.



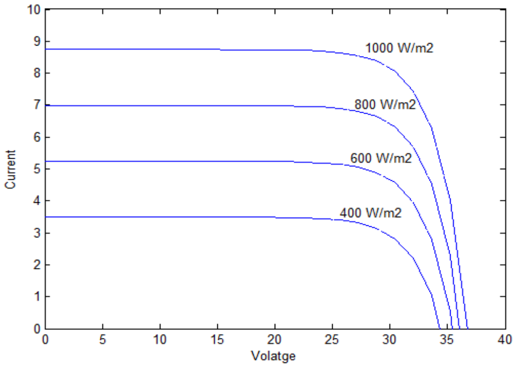


FIG.10 Variation of P-V Characteristics with InsolationFIG.11. Variation of I-V Characteristics withInsolation

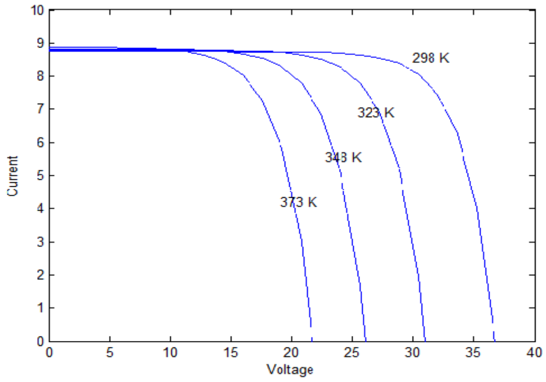


FIG.12. Variation of I-V Characteristics with Temperature

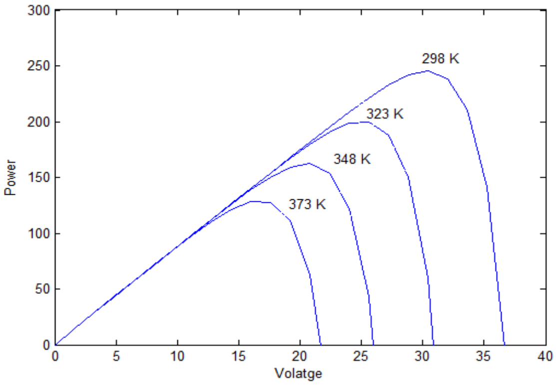


FIG.13. Variation of I-V Characteristics with Temperature

## VI. CONCLUSION

A Matlab based modelling of solar PV system along with the principle of operation of the PV system is discussed in detail in this paper. Since the PV characteristics is non-linear, this system alone will be unable to deliver all its potential power Thus this system should be incorporated with a maximum power tracking system for useful power transfer which is the subject of future studies as many novel algorithms for MPPT is gaining interest nowadays. .

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