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Development of a Photovoltaic array in Simulink and its Performance Verification

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Abstract

This paper presents Simulink-based PV module model of various types of Photo-Voltaic(PV) cells which includes a controlled current source and a MATLAB function with the assistance of Simpowersystems Tool box. The PV Cell is the main building block of a PV array for simulating and monitoring the performance. The modeling scheme is done by using some predigested functions in MATLAB. With the proposed model, we can predict the behaviour of a photo voltaic cell under the conditions of both non-uniform and uniform irradiance which is very useful for design engineers to determine the performance of any photovoltaic array in a easier way without performing any tedious iterative numerical calculations. The results are compared with the practical values obtained from the solar panel.

Keywords:

PV cell;
Modelling;

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1. Introduction

Development of alternate energy sources with high efficiency and low emission has become a great importance with the growing concerns about fossil fuel deficit, global warming, damage to environment and ecosystem. Among them, solar energy is widely available and is quiet free of cost. Abundance and sustainability of solar energy are the important factors that characterize the energy through PV (photovoltaic) effect.

1.2 Solar Cell

Solar Cell is used to convert solar energy into electrical energy. They operate on the principle of photo-voltaic effect. It is basically a semi-conductor diode capable of developing a voltage of 0.5V-1V and a current density of 20-40 mA/cm^2 depending upon the material used and the conditions of sunlight.

1.3 Photo-Voltaic effect

Photo-voltaic effect is a process of generating emf by absorption of ionizing radiation. In a piece of pure semiconductor like silicon, there is no free charge carrier at ordinary temperatures, but if the same piece of silicon is doped N-type semiconductor there will be one extra electron per atom. Similarly, if it is doped with P-type semi-conductor there will be deficiency of electron. If both N-type and P-type semiconductors are connected by some means a junction is formed.

When a photon energy ‘hv’ is allowed to fall on the P-region, it is absorbed by an electron in the valence band if ‘hv’ exceeds energy gap Eg, the electron will migrate to the N-region. Similarly, if ‘hv’ is less than Eg in N-region, the photon will be absorbed by a hole which will migrate to P-region.

This charge separation creates an electric field opposite to the electric field created by the diffusion of free electrons of the N-region and in case, the field created by charge separation pre-dominates the electric field created by the diffusion of free electrons from N-region to P-region and holes from P-region to N-region current will start flowing in the circuit.

1.4 Literature Review

PV systems are considered an important type of distributed power generation systems. Also, it can be used as a standalone system. However, PV array operation in this type of power systems suffers from the effect of complete or partial shading, which is usually caused by clouds, trees, and near buildings. If several solar cells in a series PV module are mismatched due to non-uniform irradiance, these cells will limit the output current of normal cells. This leads to decrease of the output power, even generates hot-spot and causes damage to these cells. To avoid the destructive effects of hot spot, a bypass diode is connected in parallel with a PV module or parallel with some series-connected solar cells in a PV module, which creates a replacement path [1]. The output power of mismatched cells is cut off when the bypass diode works. The output characteristics will be more complicated when the PV array is mismatched [2]-[5].

Under partially shaded conditions, the *I-V* characteristic of the PV array become complex with multiple peaks. These different peaks are generated due to the non-uniform insolation levels that are received on a partially-shaded PV array surface. The PV array efficiency is decreased due to these non-uniform characteristics. As a consequence, the conventional MPPT algorithm fails to differentiate between local and global peaks. In order to obtain the maximal PV installation output power, it is very important to reveal PV characteristics under condition of non-uniform irradiance.

To model solar cell, the one-diode model has been proposed [6], and some researchers have studied how to extract parameters for the model [7], [8]. For a higher accuracy, two diode model has been studied for years [9], [10]. In these re-search works, some methods were developed to determine the electrical parameters in these models. The electrical characteristics of a solar cell/PV module derived from those proposed models match the experimental data well when irradiance is uniform. Electrical characteristics of PV module under uniform, non-uniform irradiance have been analysed in [2]. Their results indicate that non-uniform irradiance on PV module leads to more complicated characteristics of PV array, e.g., multiple power peaks in the P-V curves. However, these models cannot be directly used when irradiance is non-uniform.

2. Research Method

The model of PV module was implemented using a MATLAB program. The model parameters are evaluated during execution using equations listed on the previous chapter. The program calculates the current I, using typical electrical parameters on the module (Isc,Voc), and the variables voltage(V), irradiation(S) and temperature(T). The program considers the series resistance in the Module. In this program, Newton-Raphson method was used, because literature indicates much more rapid convergence.

2.1 PV module model in MATLAB/Simulink

The block diagram of the Simulink-based PV module model is shown in Fig. 2.1 *S*1 is irradiance, *T* is the temperature of the PV module, *V* is the output voltage of the PV module, and I_{out} is the output current of the PV module. I_{out} connecting to a controlled current source is used for simulating the output current of the PV module. A bypass diode is connected in parallel with the controlled current source.

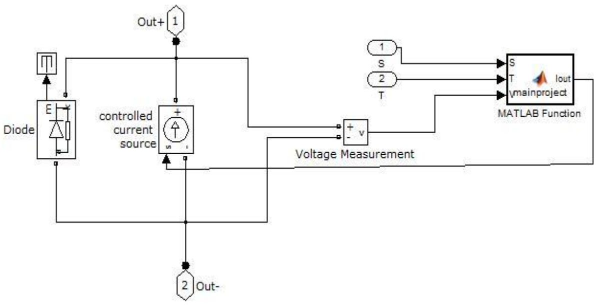

Fig 2.1 Block diagram of PV module model in MATLAB/Simulink

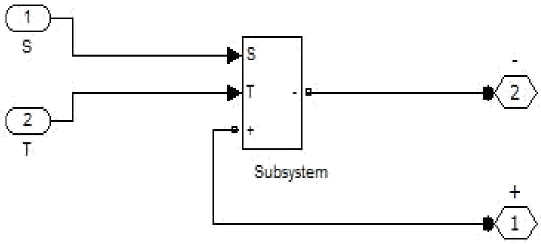

Fig 2.2 Block Diagram of PV module model

The subsystem block in Fig. 2.2 is a basic PV module mode of MATLAB-Simulink. In the subsystem block, port of out + is the positive terminal of the PV module, port of out− is the negative terminal of the PV module, port of S is the in-plane irradiance, and *T* is the temperature of the PV module. The subsystem blocks can be connected in series/parallel according to the actual PV array; then it can be simulated in MATLAB-Simulink.

2.2 PV cell under different conditions

- Maintaining Temperature Constant and Varying Irradiance
- Maintaining Irradiance Constant and Varying Temperature.

2.2.1 Maintaining Temperature Constant and Varying Irradiance

While working under different irradiation and same temperature the short circuit current mostly gets affected and the effect on open circuit voltage is almost negligible. As the irradiation increases the short circuit current increases and the open circuit voltage almost remains same.The simulation results of I-V curves and P-V curves of a single PV module under three different test conditions are shown in Fig.3.1, Fig.3.2. Testing conditions are irradiance at 800 W/m^2 with module temperature at 25^0 C, irradiance at 1000 W/m^2 with module temperature at 25^0 C, and irradiance at 1050 W/m^2 with module temperature at 25^0 C.

2.2.2 Maintaining Irradiance Constant and Varying Temperature

While working under different temperature and same irradiation the open circuit voltage gets mostly effected and the effect on the short circuit current is negligible .As the temperature increases the open circuit voltage decreases and short circuit current almost remains same. The simulation results of I-V curves and P-V curves of a single PV module under three different test conditions are shown in Fig.3.3, Fig.3.4. Testing conditions are irradiance at 1000 W/m^2 with module temperature at 30^0 C, irradiance at 1000 W/m^2 with module temperature at 40^0 C, and irradiance at 1000 W/m^2 with module temperature at 50^0 C.

2.2.3 Study case of a PV array under non-uniform irradiance

To evaluate the performance of the proposed model under non-uniform irradiance conditions, the following experiments and simulations have been carried out. Given three PV modules in one frame of the testing platform are connected in series to obtain the *I–V* and *P-V* characteristics under the conditions of non-uniform irradiance. The corresponding simulation diagram is shown in Fig.2.3. Three PV module models are employed and they have their own inputs of temperature and irradiance.

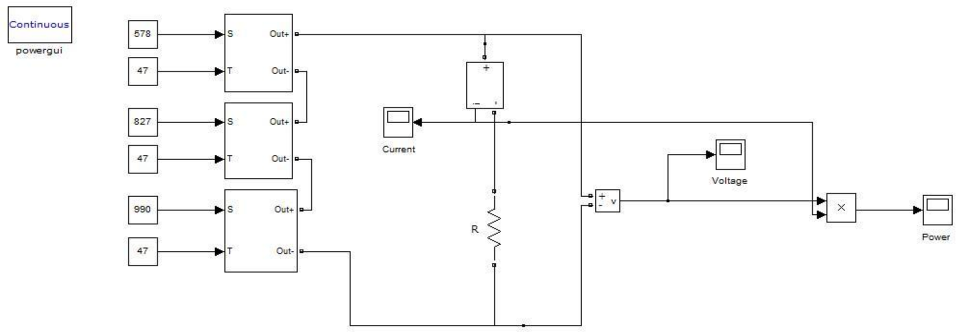

Fig. 2.3 Simulink model of three PV modules connected in series under non-uniform Irradiance

These tests are carried out under the condition of non-uniform irradiance and are done in following steps.

Step 1: Wait for the stable clear sky.
Step 2: The PV module should be covered with translucent plastic.
Step 3: Measure Irradiance and Temperature.
Step 4: Measure I–V curves.

2.4 PV array connected to an inverter

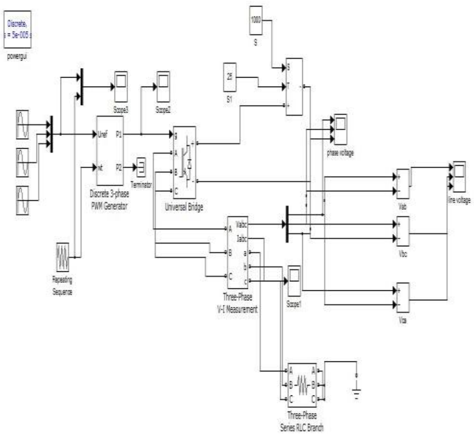

Fig.2.4 PV array connected to a three-phase load through inverter

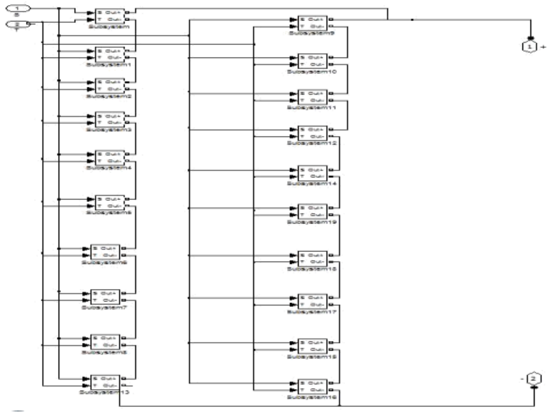

Fig.2.5 Simulink model of PV array subsystem

3. Results and Analysis

The simulation model shown in Fig.2.1 has been used to simulate the PV cell. It is important to understand how the model works under different conditions. The main purpose of this project is to develop a load modeling of a PV module under different conditions of irradiance and temperature and to set parameters of PV module to obtain the best performance characteristics.

The performance characteristics are studied for the PV cell with specifications given in the table.3.1

Table 3.1 Specifications of the PV cell used for simulation

Parameter	Variable	Value
Maximum power	P_{MPP}	50W
Voltage at Pmax	V_{MPP}	17.98V
Current at Pmax	I_{MPP}	2.77A

Short circuit current	Isc	3A
Open circuit voltage	Voc	22V
Temperature coefficient of Isc	A	0.04%/^{0}C
Temperature coefficient of Voc	B	-0.33%/^{0}C

3.1 P-V and I-V curves of single PV cell

Fig.3.1, Fig.3.2 represents the simulation P-V and I-V curves of a single PV cell under standard test condition (STC).

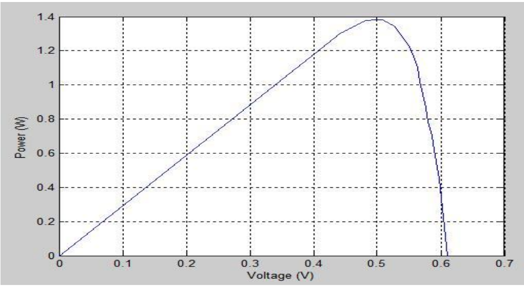

Fig. 3.1 Simulation P-V curve of a PV cell

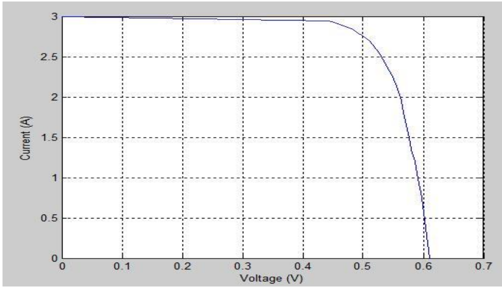

Fig. 3.2 Simulation I-V curve of a PV cell

3.2 P-V and I-V curves of PV cell under different conditions

3.2.1 Maintaining Temperature constant and varying Irradiance

The simulation results of P-V curves and I-V curves of a single PV cell under three different irradiation conditions are shown in Fig.3.3, Fig.3.4.

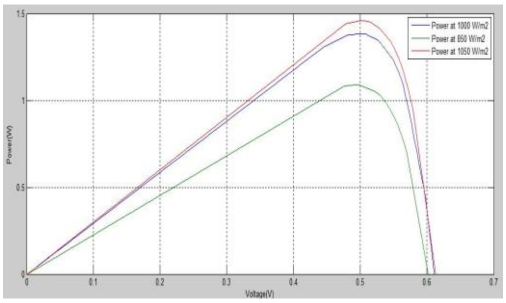

Fig. 3.3 P-V curve of a PV cell with different irradiance

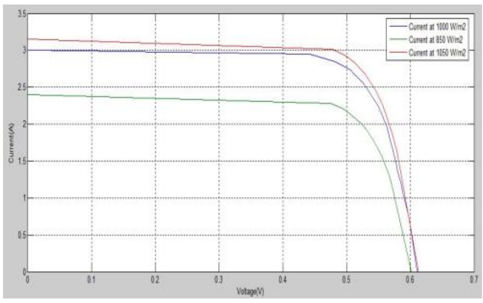

Fig. 3.4 I-V curveof a PV cell with different irradiance

3.2.2 Maintaining Irradiance constant and varying Temperature

The simulation results of P-V curves and I-V curves of a single PV cell under three different temperature conditions are shown in Fig.3.5, Fig.3.6.

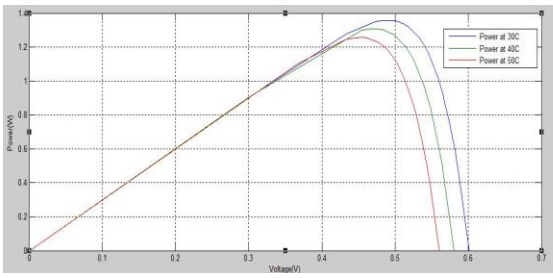

Fig. 3.5 P-V curve of a PV cell with different temperature

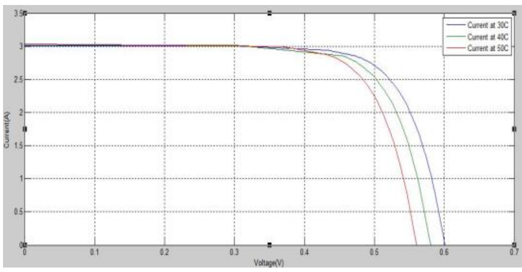

Fig. 3.6 I-V curve of a PV cell with different temperature

3.3 P-V and I-V curves of PV array under non-uniform irradiance

Fig.3.7, Fig.3.8 represent the simulation I-V and P-V curves of a PV array of three PV modules which are connected in series for a variable load under non uniform irradiance.The test conditions are S1=578 w/m^2, S2=847 w/m^2, S3=990 w/m^2 at a temperature of 47^0 C.

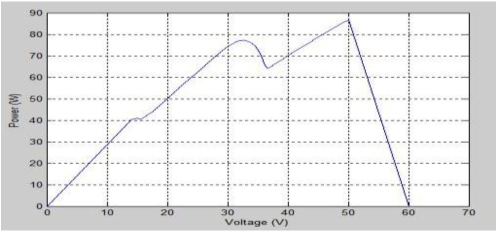

Fig. 3.7 P-V curve of a PV array under non-uniform irradiance

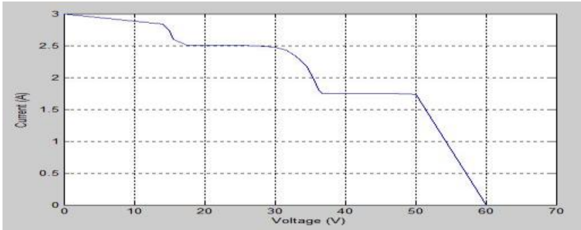

Fig. 3.8 I-V curve of a PV array under non-uniform irradiance

3.4 Experimental validation of PV array

The experiment is carried out on a PV array having 3 PV modules of model 12120, which are connected in series at different temperature and irradiation throughout the day 0n 1st may 2013.
Solar module: 12120

Table 3.2 Specifications of PV module on which experiment is carried out

Parameter	Variable	Value
Maximum power	P_{MPP}	120W
Voltage at Pmax	V_{MPP}	16.4V
Current at Pmax	I_{MPP}	7.5A
Short circuit current	I_{sc}	9.37A
Open circuit voltage	V_{oc}	21.6V
Tolerance	------	±3%

Table 3.2.1 open circuit voltage of PV array at different timings on 1st may 2013

Open circuit voltage	Time	Temperature
19	10:30am	31^oC
17	11:30am	32^0C
18	12:30pm	36^0C
14	2:30pm	37^0C
18	3:30pm	34^0C
18	4:30pm	33^0C
13	5:30pm	32^0C

3.5 Functional Verification of PV Array Module connected to three-phase inverter

An equivalent PV array having two PV arrays connected in parallel and each PV array having 10 PV modules connected in series is taken and connected to a 40 ohms three phase resistive load through an inverter which is operated through PWM controller operated using sinusoidal pulse width modulation is taken and the modulation index is 0.5 and the carrier wave frequency is 500HZ. The output phase voltage is 138V and current is 3.4A with a frequency of 50Hz is obtained. The output voltage and current waveforms are shown in Fig.3.9, Fig.3.10 respectively.

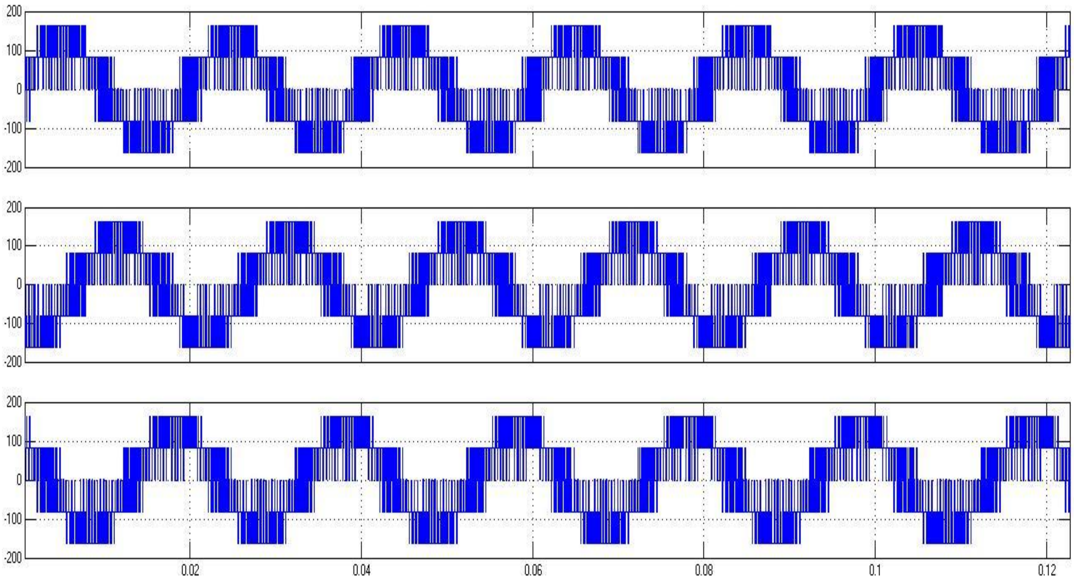

Fig.3.9 Phase voltage waveforms of a PV array connected to a three phase resistive load through inverter

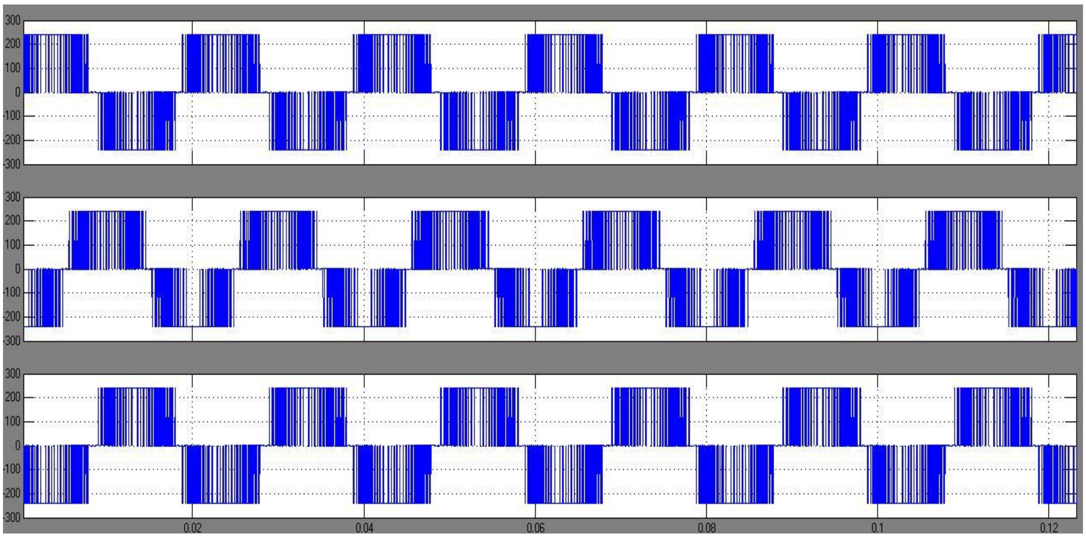

Fig.3.10 Line voltage waveforms of PV array connected to a three phase resistive load through inverter

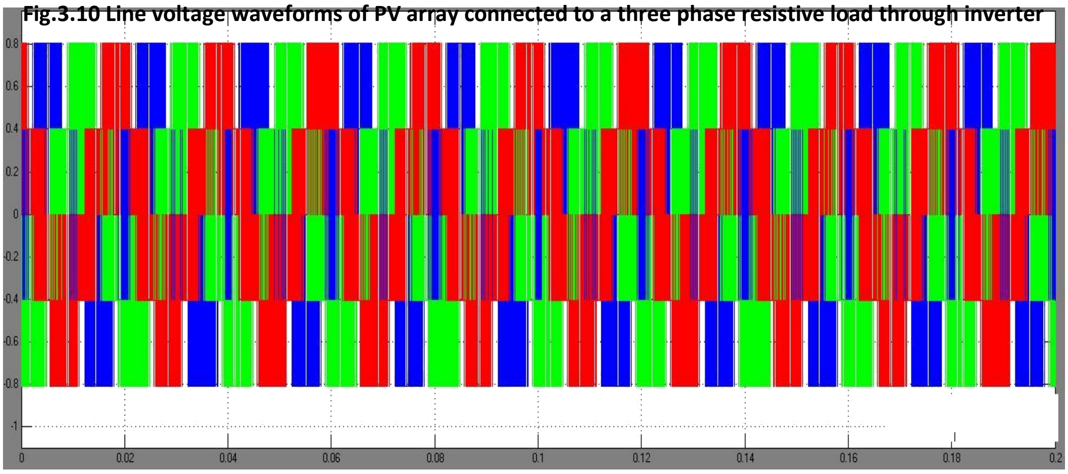

Fig.3.11 Phase current waveforms of PV array connected to a three phase resistive load through inverter

4. Conclusion

A Simulink based PV module model is presented in this paper, which includes a controlled current source and a MATLAB function which allows us to investigate the characteristics of a PV array under various conditions of different irradiances and temperatures especially under condition of non-uniform irradiance. The values of irradiance and temperature can be set independently. The simulation results demonstrate the feasibility of the proposed method. The performance of the proposed model is validated by comparing the outdoor experimental results. Since the comparison between real data and the expected ones allows one to continuously verify the short-time performances of the plant. The simulation results are much validated with that of the outdoor experimental results. The proposed model has good predictability in the general behaviour of MPPT under the conditions of both non-uniform and uniform irradiance. It is proposed not only to study the behaviour of PV array, but also to validate new electronic circuit and MPPT strategies.

5. Future Scope

This model can be extended to grid connected system through inverter and can be used as a stand-alone system. This can also be extended to off grid applications such as solar inverters for home appliances, hybrid PV systems such as PV-wind hybrid system, PV-diesel hybrid system and PV-fuel cell hybrid system dependent on the way the other source is connected to the PV.

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