IMPLEMENTATION OF A REAL TIME MONITORING SYSTEM FOR A PHOTOVOLTAIC GENERATION SYSTEM

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ABSTRACT

Generally PV generators are considered reliable compared to other systems, but like all processes, a PV system can be exposed to several failures causing the PV system to malfunction. Several studies have found that the reliability of PV systems is highly dependent on the equipment used for the construction of PV panels, temperature, humidity and solar radiation. A PV system can have several defects, be it defects of construction types, or material and electrical defects caused by climatic conditions. As such, we can cite the fault most commonly encountered in a PV generator which is the partial shading defect.

This paper is organized as follows. Section II will generally introduce PV systems and their characteristics. Section III will introduce bond-graph models for PV systems. Section IV will discuss the problem of optimal sensor placement. Sections V and VI will validate the method through simulations and experiments. Finally, section VII will discuss the results.

KEYWORDS

Faults detection and location, PV generator, Sensor placement, Bond graph, Output power

1. INTRODUCTION

Recent studies have focused on remote monitoring for fault detection in PV plants [1], [2]. Some authors base their contribution on comparing the theoretical energy yield of the PV plant with real measured data. Errors of about 10 % have been reported using these methods [3]. Other authors have developed new simulation tools for the diagnostic and fault detection of PV systems [4], [5] or using simulation platforms such as SPICE [6], SABER [7], and EMTP [8]. Meta-heuristic models based on Neural Networks [9], Fuzzy logic [10] and Neural-Fuzzy hybrid [11] have also been proposed.

Despite these recent developments, several challenges still remain in this field. Some techniques may require an expensive solar simulator to be validated. Others do not have the flexibility to study more advanced features of PV systems such as interconnection among modules.
Simulated time is also an issue in some software platforms. Even with improvements in the calculation speed of the traditional mathematic models, some electrical characteristics of the PV system still cannot be studied in detail. Other models have a trade-off between complexity and simulation time making scalability of basic models very difficult.

All these problems lead to major difficulties in creating a generic PV model suitable for studying defaults. On one hand, the available models offer limited flexibility for creating defaults. On the other hand, they do not allow an overall study on system observability. This works seeks to contribute on these two issues by presenting a flexible bond-graph based model for a PV plant and using this model to determine the optimal placement of sensors within the plant.

2. MODELLING OF PV SYSTEM

Real-time simulation of the PV system consists of development of the mathematical model of the PV module, boost converter and MPPT algorithm for analog DC input, analogous to temperature and irradiance.

2.1. PV module

Several methods of modelling of PV cells [7]–[11] have been introduced over the years. Ideally, PV cells are represented by a current source in parallel with an ideal diode.

Researchers have modified this ideal model in many ways to account for several factors. The equivalent circuit of the PV model considered in this paper is shown in figure (1).

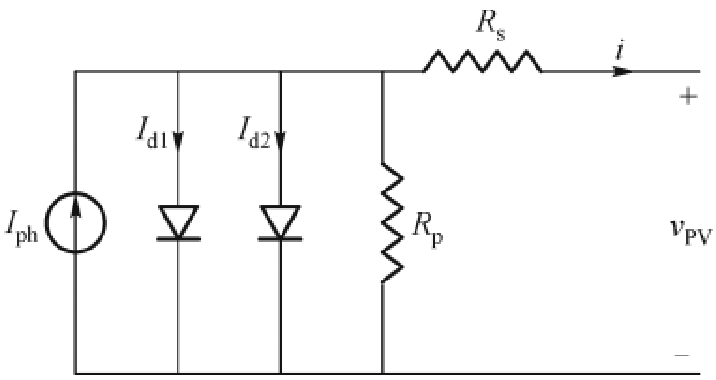


Figure 1. Equivalent circuit of PV model with series and parallel resistance

In this paper, the PV module is designed using equation (1) to (5). The values of Rs and Rp are calculated using the iteration method.

$$i = I_{ph} - I_{d1} - I_{d2} - \frac{v_{PV} + iR_s}{R_p} \tag{1}$$

Where

$$I_{ph} = \left[I_{sc} + K_i\left(T_c - T_{rf}\right)\right]\left(\frac{G_c}{G_{rf}}\right) \tag{2}$$

$$I_{d1} = I_{01}\left[exp\left(\frac{V_{PV} + IR_s}{nV_t}\right) - 1\right] \tag{3}$$

$$I_{d2} = I_{02}\left[exp\left(\frac{V_{PV} + IR_s}{n_1 V_t}\right) - 1\right] \tag{4}$$

$$I_{01} = I_{02} = \frac{I_{sc} + K_i\left(T_c - T_{rf}\right)}{exp\left(\left[V_{oc} + K_v\left(T_c - T_{rf}\right)/V_t\right]\right) - 1} \tag{5}$$

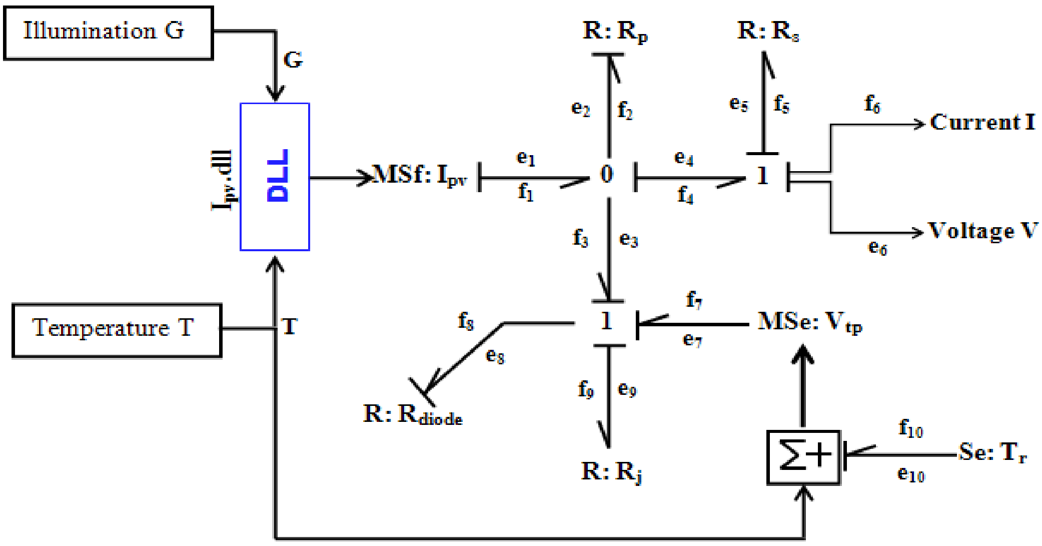


Figure 2. PV Bond graph model with single diode

2.2. Typical Grid-Connedted PV Systems

A typical grid-connected PV system shown in figure (3) is the research target of this paper. It consists of several major components, including solar PV arrays, centralized inverter with MPPT algorithm, electrical connection wirings, and protection devices, such as over-current protection devices (OCPDs) and ground fault protection devices (GFPDs). Note that the PV system in the research is a grounded system, which has a system grounding point Gsys according to National Electric Code (NEC) in the US.

The PV array typically contains $m \times n$ PV modules connected electrically in series and parallel configuration. This array configuration is, nowadays, most common in PV technologies. There are n numbers of PV strings in parallel. Each PV string consists of m number of modules in series.

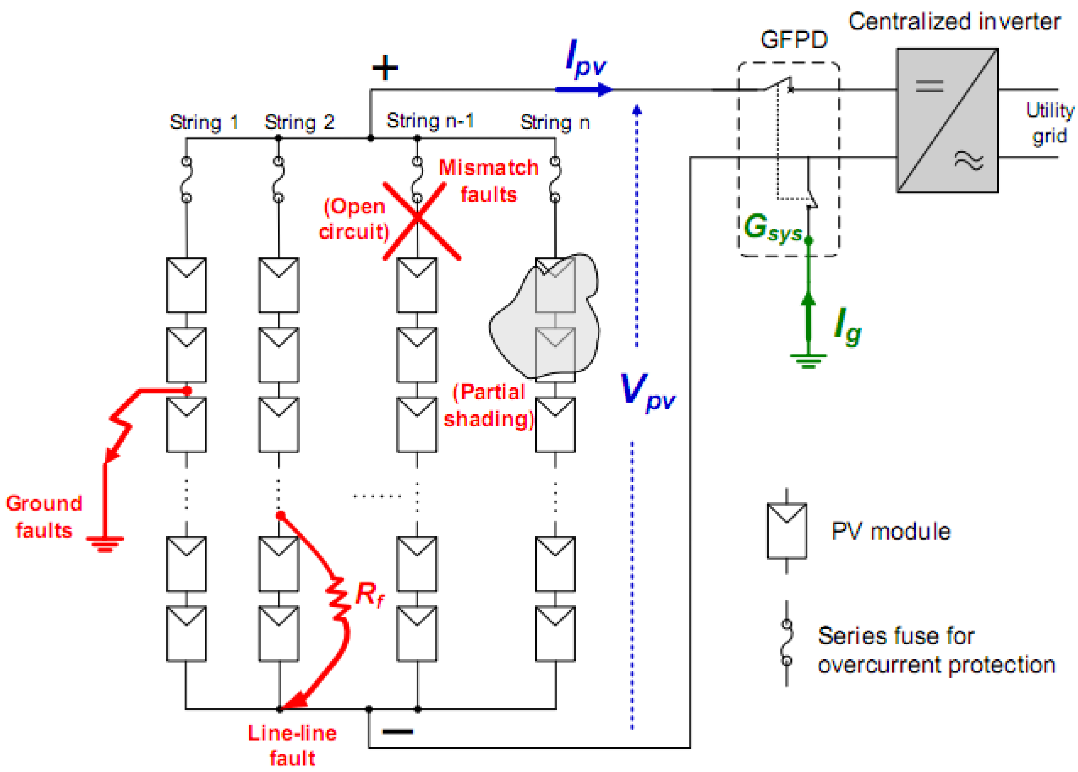


Figure 3. Typical faults in solar PV arrays

2.3. Faults in Solar PV Arrays

Typical faults in PV arrays consist of ground faults, line-line faults, and mismatch faults among PV modules [25-26]. Among these faults, line-line faults and mismatch faults are studied in this paper, since they are more difficult to detect by conventional protection devices than ground faults [27].

- ✓ A ground fault is an accidental electrical short circuit involving ground and one or more normally designated current-carrying conductors.
- ✓ A line-line fault is an accidental short-circuit connection between two points of different potential in PV arrays.
- ✓ Mismatch faults occur when the electrical parameters of module(s) is significantly changed from those of the remaining modules. Mismatch fault could be temporary, such as partial shading on PV modules. Also, it could be permanent, such as open circuit in PV modules/strings, degradation, or defective modules.

3. PROPOSED ALGORITHM

The DT model will be built according to four key steps in the process. The first step is data acquisition, which obtains the training and test set from experiments. The second step is to pre-process the experimental data, including data cleaning, sampling, creating new attributes and attribute selection. The third step is to train the DT model by using 66% of randomly chosen pre-processed data. The last step is using remainder of pre-processed data to test the model.
For example, in figure (4), faults (e.g. line-line faults) in PV arrays usually cause changed current vs. voltage (I-V) curves and reduced maximum power points (MPPs). Fault MPPs may vary from normal MPPs in the I-V curves.

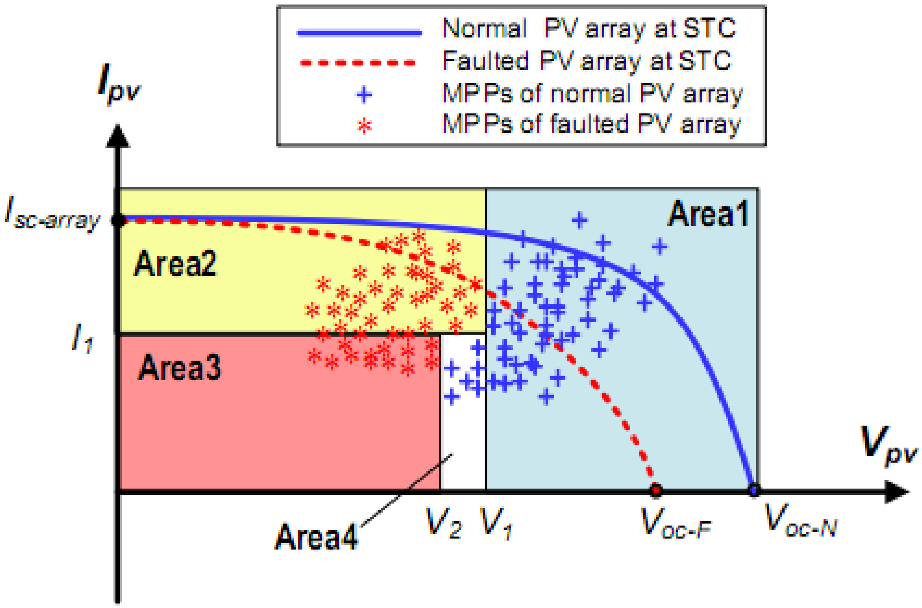


Figure 4. I-V curves of normal and faulted PV arrays

Once the DT model is built and tested, it can operate on-line for fault monitoring, as shown in figure (5). The DT model could be either programmed as "if-then" statements in a separate microcontroller.

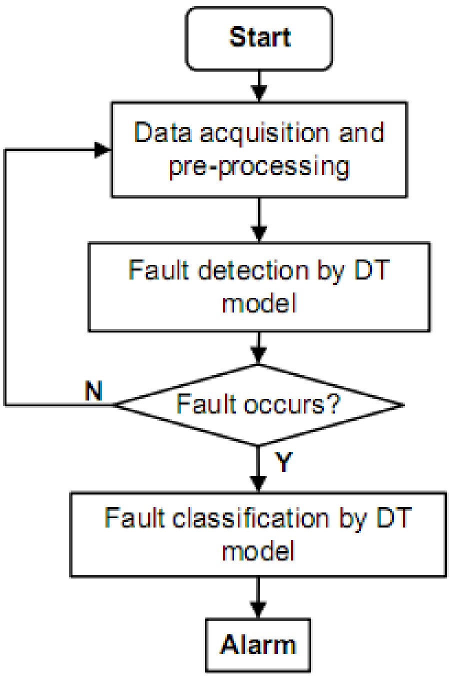


Figure 5. The flowchart of proposed fault detection model

4. MODEL IMPLEMENTATION

The block diagram showing the implementation of the PV array model in RT-LAB simulator is depicted in figure (6). The computation of the I-V characteristic of the array based on the bond graph approach was coded in Embedded Matlab in order to get full compatibility with RT-LAB.

This computation is performed periodically and takes into account at each time the updated parameters from the weather conditions (irradiance G and ambient temperature T) and from the array configuration. The computed I-V characteristic is continuously fed into the look up table which in turn output the control signal according to the measured signal.

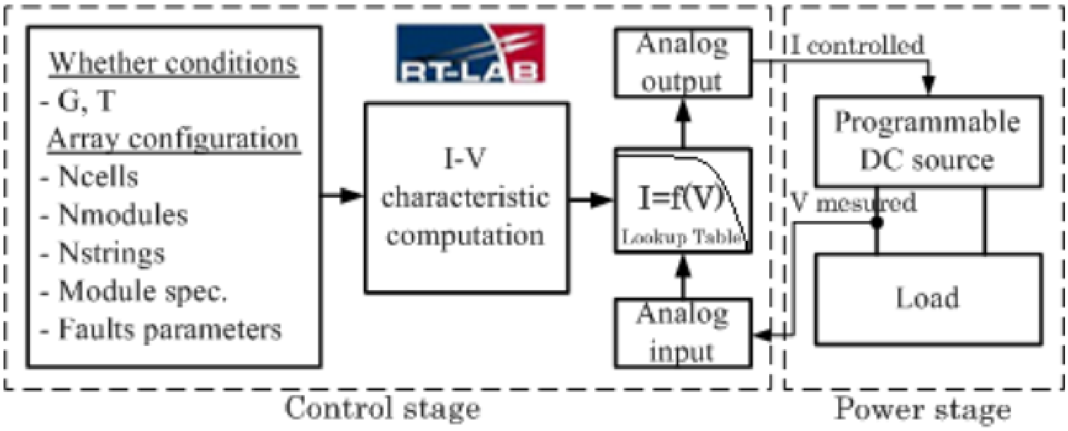


Figure 6. Implementation of PV array model

5. EXPERIMENTAL RESULTS

To validate the proposed PV simulator, the load mentioned in figure (6) was replaced with a commercial PV inverter connected to the power grid. The inverter used in this test is an AXUN 2100.

The PV array used in the model consists of one string of 10 modules. Each module has 72 cells in series protected by 4 bypass diodes. The data sheet values of the module used in the model are given in Table (1)

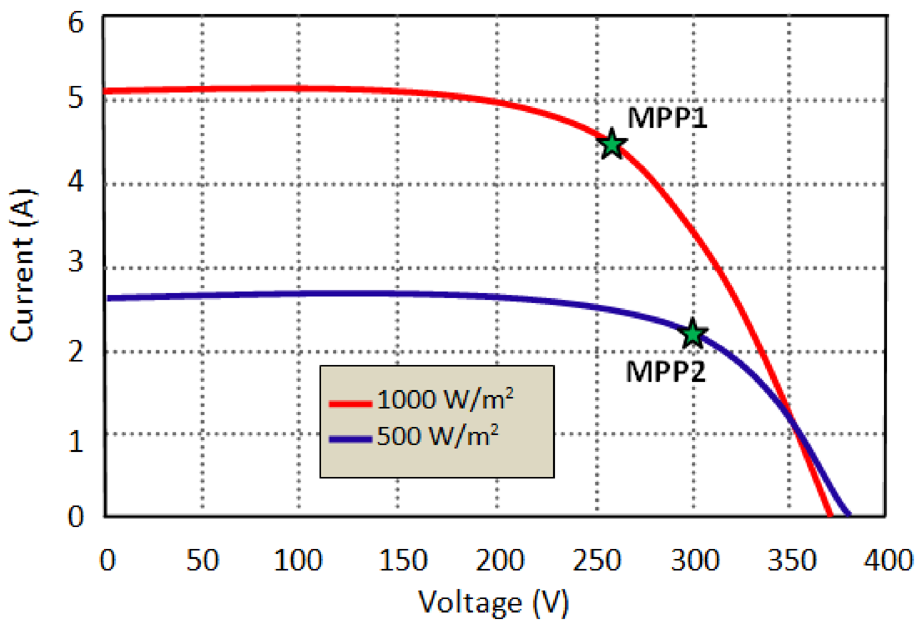
Table 1. PV module data sheet

Maximum power	165 W
Maximum power voltage	34.4 V
Maximum power current	4.8 A
Open circuit voltage	43.2 V
Short circuit current	5.1 A

5.1. Variable weather conditions

In this case, the solar irradiance was set to switch between G =1000W/m^2 and G =500W/m^2 during the simulation.

The temperature was kept constant at 300 °K. The I-V and P-V characteristics of the array obtained from offline simulation at these two irradiance levels and the expected maximum power points (MPP) are shown in figure (7).



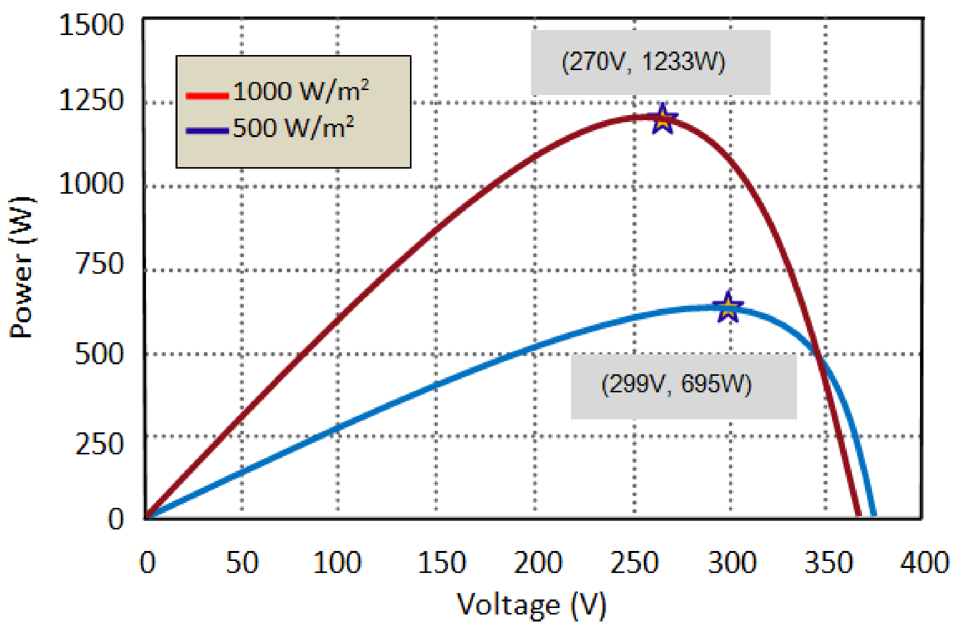


Figure 7. I-V and P-V characteristics from offline simulation (case1)

Figure (8) shows the current and voltage measured at the output of the simulator. The solar irradiance was initially set to G =1000W/m^2 and then changed to G =500W/m^2 at t =110s and backward at t =190s. During start up, the inverter requires approximately 40s to synchronize with the power system. During this period, the DC power supply operates at the voltage equals to the open circuit voltage of the array since there is no demand in current from the inverter. After the connection with the power system is established, the inverter starts to seek the MPP of the corresponding irradiance and oscillates around that point once found. The power at the simulator output can be obtained by multiplying the measured current and voltage. It oscillates around 1230W when G=1000W/m^2 and around 690W when G =500W/m^2.

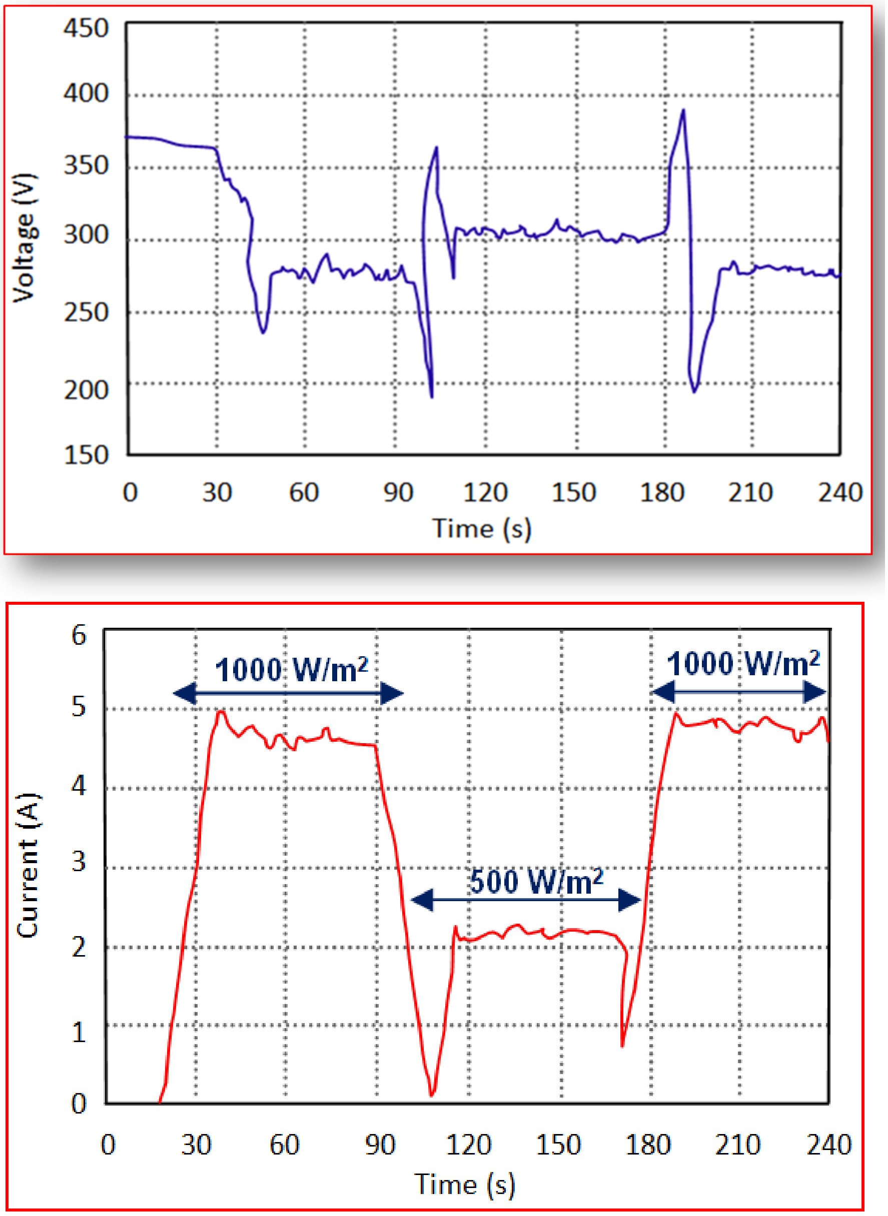


Figure 8. Current and voltage measured at the input of inverter (case1)

5.2. Abnormal operation of the array

In this case, a fault is introduced in the array during the simulation. This fault is due to partial shading on the modules which results in many local maximum power points. The irradiance and temperature were kept constant and equal to 1000W/m^2 and 300 ^{o}K respectively. Figure (9) shows the P-V characteristic of the array obtained from offline simulation. The inverter is expected to operate at MPP1 during normal operation and at MPP3 when there is shading.

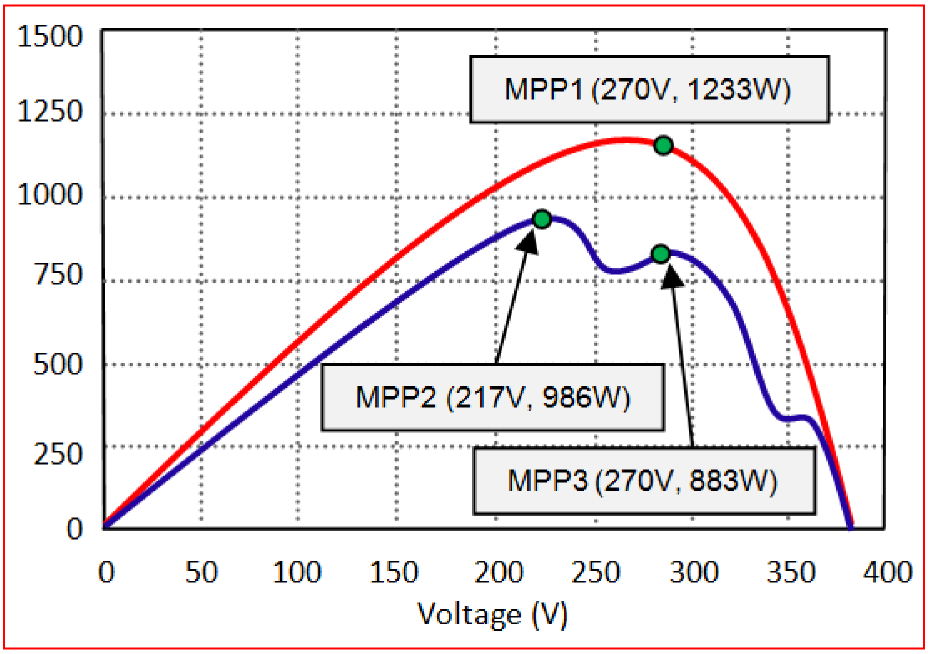


Figure 9. P-V characteristic from offline simulation (case2)

6. CONCLUSION

This paper presented a method for developing a real time simulator of a PV array based on Power Hardware In the Loop (PHIL) simulation. Variable weather conditions and major electrical faults were taken into consideration in the proposed simulator. The steady state performance of the proposed simulator is well established. Though, depending on the dynamic of the applications with which this simulator will be used, their dynamic performances need to be thoroughly examined.

The future research plans to address some of the previously discussed limitations, which include model optimization, cost reduction of fault data acquisition, and integration with PV inverters.

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