

SIMULATION OF RECONFIGURATION SYSTEM USING MATLAB - SIMULINK ENVIRONMENT

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Abstract. Reconfiguration strategy of solar energy has been a challenging task in the energy optimization field, in which the intention is to minimize losses and increase efficiency of the photovoltaic (PV) system under non-homogeneous solar irradiation based on irradiance equalization. The reconfiguration system (RS) proposed includes: irradiance equalization algorithms which is effective in the calculation to find an optimal configuration; dynamic electrical scheme (DES) switching matrix which is controlled to obtain the optimal configuration for PV array. Recently, publications have focused on bringing out the algorithms with the aim to select the optimal connection configuration and control DES switching matrix. However, to our knowledge, there has been no published work using Matlab-simulink to simulate the RS operation. The simulation enables researchers to perform experiments and evaluate reconfiguration algorithms effectively before deploying in reality. In the paper, we present a study on simulation of RS operation using Matlab-simulink environment. The results show that, with RS, the effectiveness of the PV array performance can rise by 10-50%.

Keywords. Optimal, photovoltaic, reconfiguration system, matlab, simulink.

1. INTRODUCTION

Currently, solar energy plays a very important role in the development of global energy. It is the green source with largest potential in renewable energy. The European Union has committed to reduce the emissions of greenhouse gas by at least 20% below the level in 1990 and to produce more than 20% of its energy consumption from renewable sources by 2020. The solar power generates electricity from the solar irradiation without emitting carbon dioxide and greenhouse gas.

The solar power plants (SPPs) can bring power supply closer to the power loads in remote areas where the electricity grid cannot reach. However, the investment cost for the SPPs is very high while the performance of SPPs is low. Therefore, researches on solar power technologies in near future is now promoted strongly to reduce power production costs and compete with other power resources [2, 3].

To the best of our knowledge, most of the recent publications focus on algorithms, architectures and control techniques in applications of the PV system to find out maximum power point tracking (MPPT) [6, 10, 18, 19, 32, 35, 36]. However, during operation, there are many cases in which PV modules in the SPPs can receive non-homogeneous solar irradiation levels. The causes can be several factors such as shadow of clouds, trees, houses and

antenna mast. This results in inefficiency in operation of most of the techniques on MPPT [13] leading the falling of the output power. Moreover, it can cause Hotspot phenomenon at shaded solar cell panels, then damage directly solar cells [12, 34].

Effects due to partial shading of the PV system are given in [12, 34]. When being in shading, not only the systems output is damaged but it also results in a misleading phenomenon (This phenomenon is caused when there are many working points offering the maximum power points). Power losses of the solar power system is divided into two parts including recoverable losses and irrecoverable losses. At present, operative techniques for recovering losses could be grouped into the following three main categories [12]:

- Distributed MPPT.
- Multilevel inverters.
- Photovoltaic array reconfiguration.

One of the main research scopes for power losses recovery is to develop the reconfiguration strategy of the solar power system [4, 7, 20, 23, 25, 26, 31, 33]. In this manner, the reconfiguration is an efficient rearrangement of connections of PV modules in order to increase the output power and protect the equipment when the system operates under non-homogeneous solar irradiation condition. For instance, when one or more PV modules in the connection circuit is shaded, the generated power decrease causing the loss of the system output power [11]. Moreover, when being shaded, temperature of the PV modules highly increases which results in the Hotspot phenomenon [14, 16] and directly damaging the solar modules. Usage of bypass diodes [30] shall help to prevent the Hotspot but cause the potential partial power losses on such connected circuits and the damages of the system output power [15].

2. PHOTOVOLTAIC CHARACTERISTICS

2.1. Irradiance effect

Output power of PV module is affected by incident irradiation. Short circuit current of PV module (I_{SC}) is linearly proportional to the irradiation, while open circuit voltage (V_{OC}) increases exponentially to the maximum value with increasing the incident irradiation, and it varies slightly with the light intensity. Figure 1 describes the relation between photovoltaic voltage and current with the incident irradiation of a PV module with module data-sheet parameter as seen in Figure 9.

2.2. Temperature effect

Module temperature is highly affected by ambient temperature. I_{SC} increases slightly when the PV module temperature increases more than the Standard Test Condition (STC) temperature, which is 25°C. However, V_{OC} is enormously affected when the module temperature exceeds 25°C. In other words, the increasing current is proportionally lower than the decreasing voltage. Therefore, the output power of the PV module is reduced. Figure 2 explains the relation between module temperature with voltage and current.

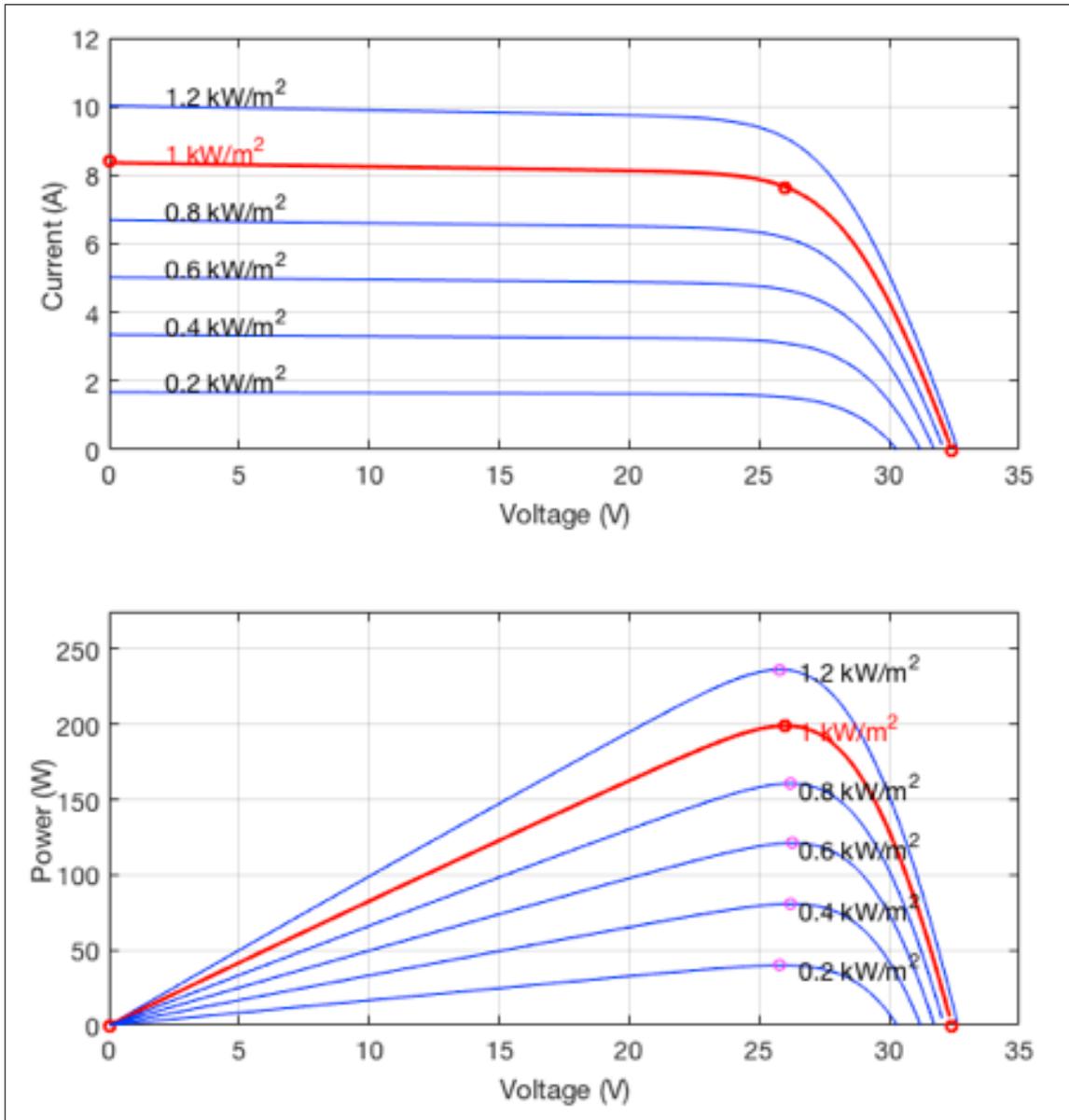


Figure 1. I-V curves at constant temperature (25°C) and different irradiance values

2.3. Maximum power point (MPP)

Maximum output power of the PV module is equal to the current at maximum power point (I_{MPP}) multiplied by the voltage at maximum power point (V_{MPP}), which is the maximum possible power at STC. Referring to Figure 3, the I-V curve represents the maximum power point (P_{MPP}) of the PV module. The usable electrical output power depends on the PV module efficiency which is related to the module technology and manufacture.

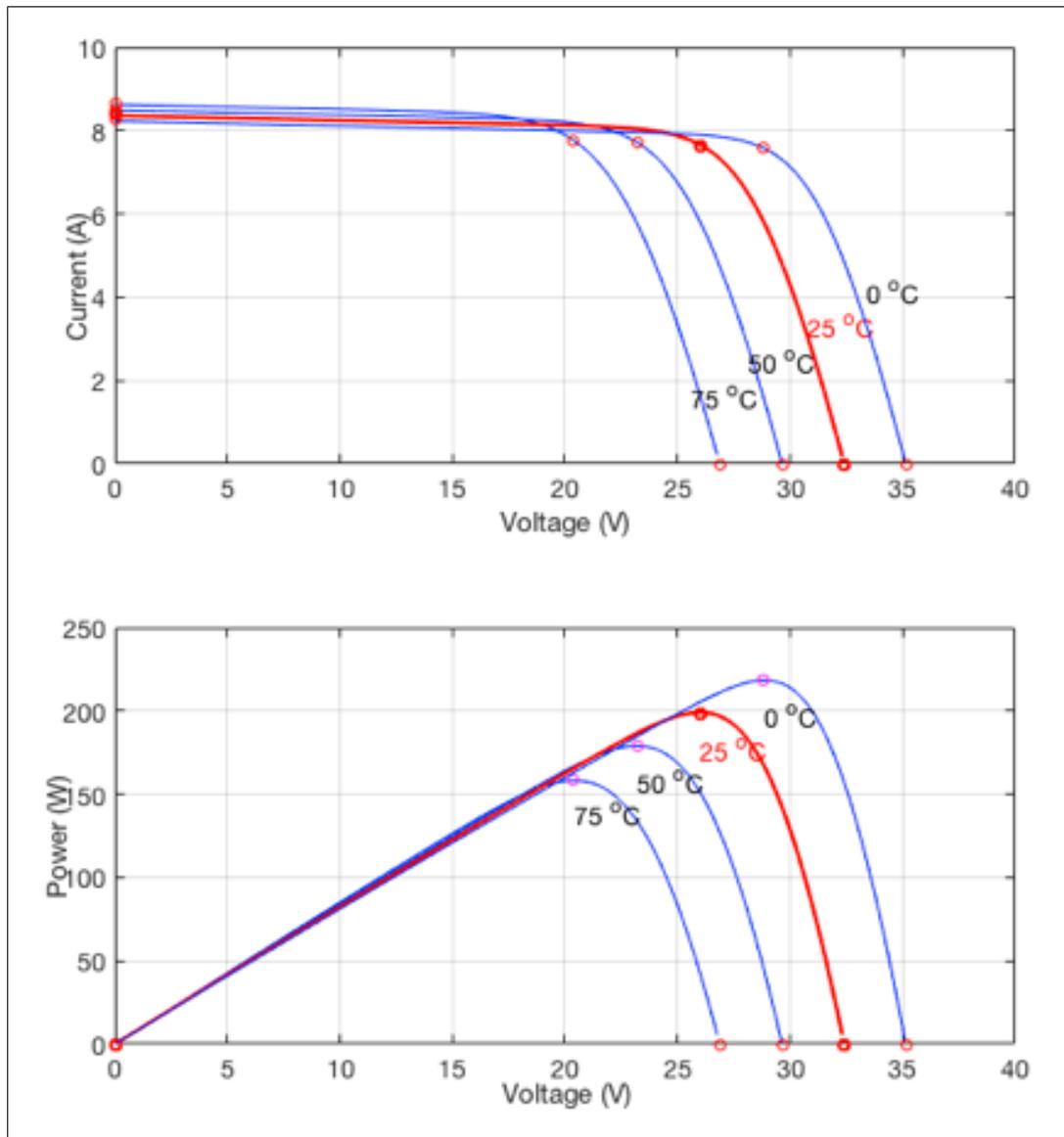


Figure 2. I-V curves at constant irradiation ($1kW/m^2$) and different temperatures

2.4. Connection topologies of PV array

Many alternative array interconnection topologies have been proposed in [20], they include: Series array (Figure 4a), parallel array (Figure 4b), series-parallel array (SP) (Figure 4c), total-cross-tied (Figure 4d), bridge-link (BL) (Figure 4e) and honey-comb (HC) (Figure 4f). Moreover the advantages and disadvantages of each method are explained [20]. Connect solar modules are connected in series in order to increase the total voltage and in parallel to increase the total current.

Under non-homogeneous solar irradiation, each PV module will operate with different

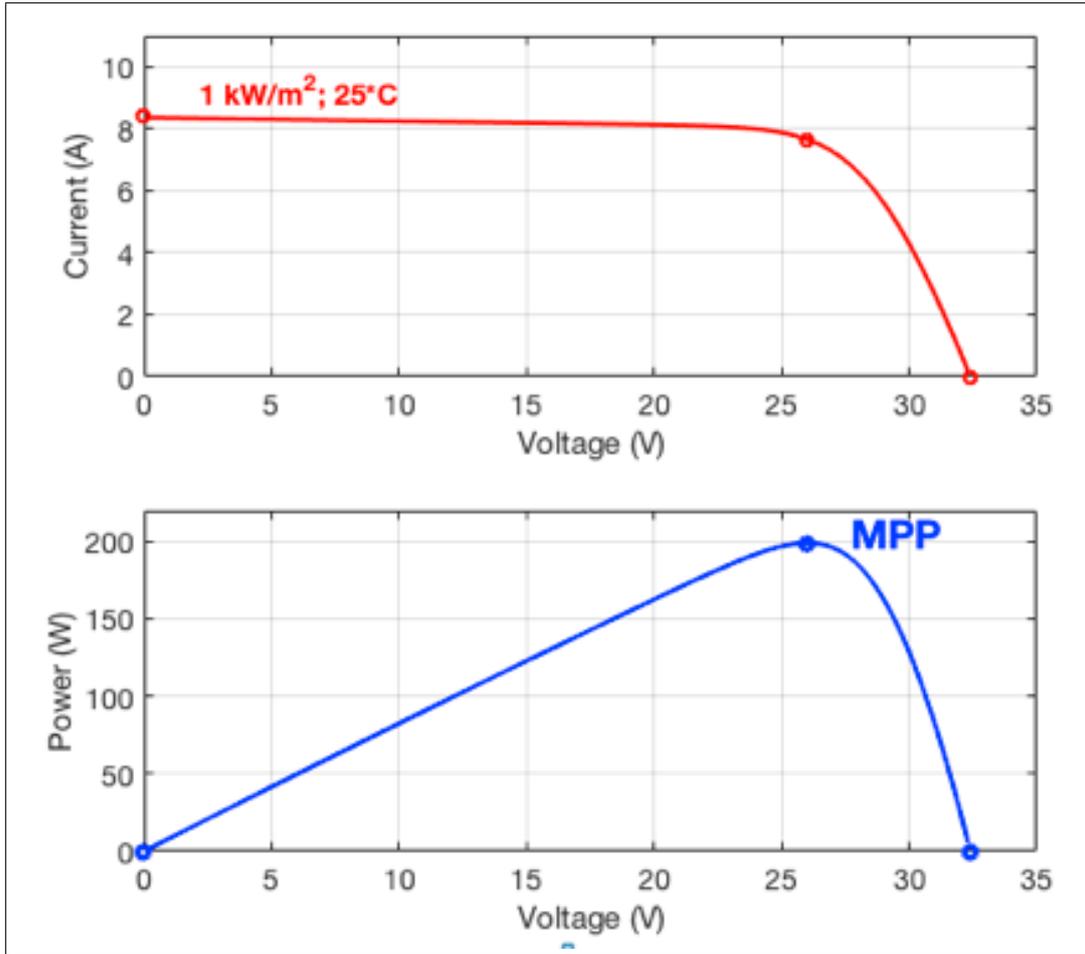


Figure 3. Important points in the characteristic curves of a solar panel

P-V characteristics resulting in output DC current. Based on the physical properties, when the PV modules connected in series, the current will be the smallest current, the voltage is the total voltages; When the PV modules are connected in parallel, the voltage is the smallest voltage, the current is the total currents. This leads to a decrease in the output power of the PV system. In the next part of the paper, the reconfiguration strategy for TCT topology was introduced to increase the efficiency of PV system under non-homogeneous solar irradiation.

3. RECONFIGURATION STRATEGY FOR TCT TOPOLOGY

Reconfiguration strategy for total-cross-tied (TCT) topology is shown in details in [29]. TCT topology (Figure 4d) combining with DES switching matrix [27] (Figure 5a) is allowed from the initial TCT interconnection. As a result, through the switching operations, a new TCT interconnection with any configuration can be established (Figure 5b).

In our configuration, an ampere meter and a voltmeter are installed at each PV panel

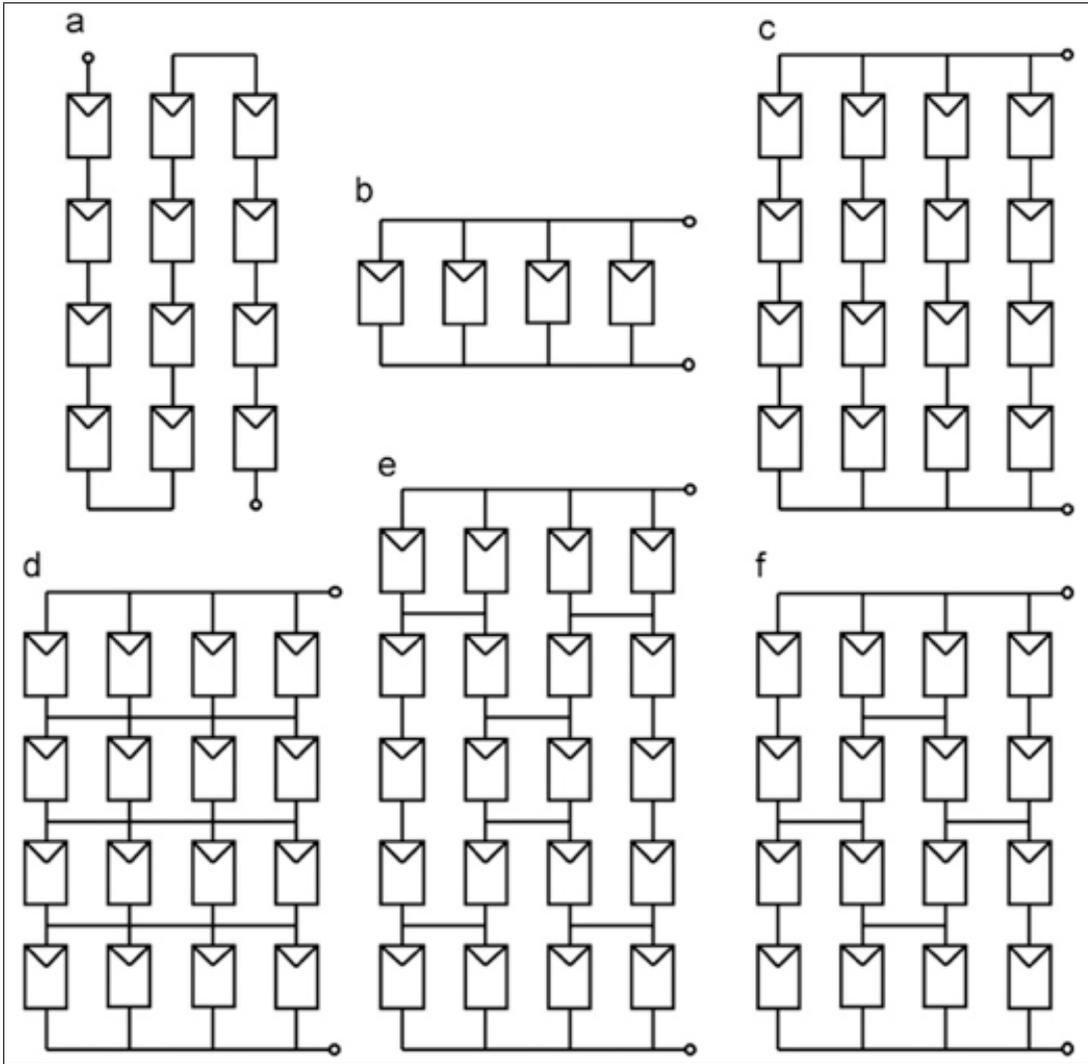


Figure 4. (a) Series array, (b) parallel array, (c) series-parallel array, (d) total-cross tied array, (e) bridge-link array and (f) honey-comb array [20]

to measure current and voltage. Based on the current and the voltage measured from each PV panel, the formula to calculate the irradiation level [33] can be used to estimate the irradiation level obtained from the PV panels: Example of an equation

$$G_{ij} = \alpha \left(I_{ij} + I_0 \left(e^{\frac{V_{ij}}{nV_T}} - 1 \right) \right), \quad (1)$$

where G_{ij} the estimated irradiance, I_{ij} and V_{ij} are the measured current and voltage, respectively, and α , I_0 , and nV_T are a set of parameters which can be evaluated from the values of the I_{SC} , the V_{OC} , and the maximum power operating point of the PV module given in the data sheets of the manufacturer, respectively.

In the generator TCT topology shown in Figure 5b, if we denote G_{ij} as the irradiance values of the PV panel located on row i and column j in TCT circuit, the total irradiation

of row i known as G_i is defined as

$$G_i = \sum_{j=1}^{n_i} G_{ij}. \quad (2)$$

Thus, the total irradiation G can be computed as in the following equation

$$G = \sum_{i=1}^m G_i. \quad (3)$$

The number of modules N can be synthesized as the following

$$N = \sum_{i=1}^m n_i, \quad (4)$$

where n_i is the number of PV panels that were connected in parallel and are located on row i . Note that the number of rows, in which the TCT circuit can be arranged m must be compatible with the inverter input voltage operating range. In order to maximize the output power of the TCT connection, the sum of irradiance on each row after reconfiguration should be equal or close to the average level

$$avg = \frac{G}{n}. \quad (5)$$

After reconfiguration, equalization index (EI) [20] for the new configuration is equal to

$$EI = \max_i(G_i) - \min_i(G_i). \quad (6)$$

To the end, the configuration with the minimum EI index that generates the maximum output power is an optimal configuration.

In Figure 6, the PV system includes 4 PV modules, connected TCT topology with different irradiance on each module in turn is $100\text{W}/\text{m}^2$, $100\text{W}/\text{m}^2$, $800\text{W}/\text{m}^2$, $1000\text{W}/\text{m}^2$. With an initial configuration, the P-V characteristic is green line with peak power at $P_{\max} = 79.60\text{W}$. By using the DES switching matrix and Controller, the PV system reconfiguration to optimal configuration by changing position of module 3 from row 2 to row 1. Then, the P-V characteristic of PV system is red line with peak power increase to $P_{\max} = 368.6\text{W}$.

In order to find out the optimal configuration for PV array, we use a hybrid algorithm which is published in [22, 29]. Dynamic programming (DP) [29] is used for Subset Sum problem in "Knapsack problems". DP technique assesses for each panel the power able to be supplied and inserts it into a dynamic array, which gives rise to the connections between panels. With an intelligent method, DP select panels with total irradiation that are equalization and then arrange them in a separated row. However, DP offers the best result in almost all cases, but in some special situations DP does not bring good results. Smart choice (SC) [22] proposed to overcome the special case of DP. Finally, SC combined with DP in order to create a hybrid algorithm and obtain better results as compared to established methods for irradiance equalization. Diagram of hybrid algorithm is shown in Figure 7.

In the paper, we use Matlab-simulink environment to simulate the operation of RS for optimal PV array configuration. Simulation is executed on PV system including 9 PV modules operating under non-homogeneous solar irradiance. Based on the irradiation received

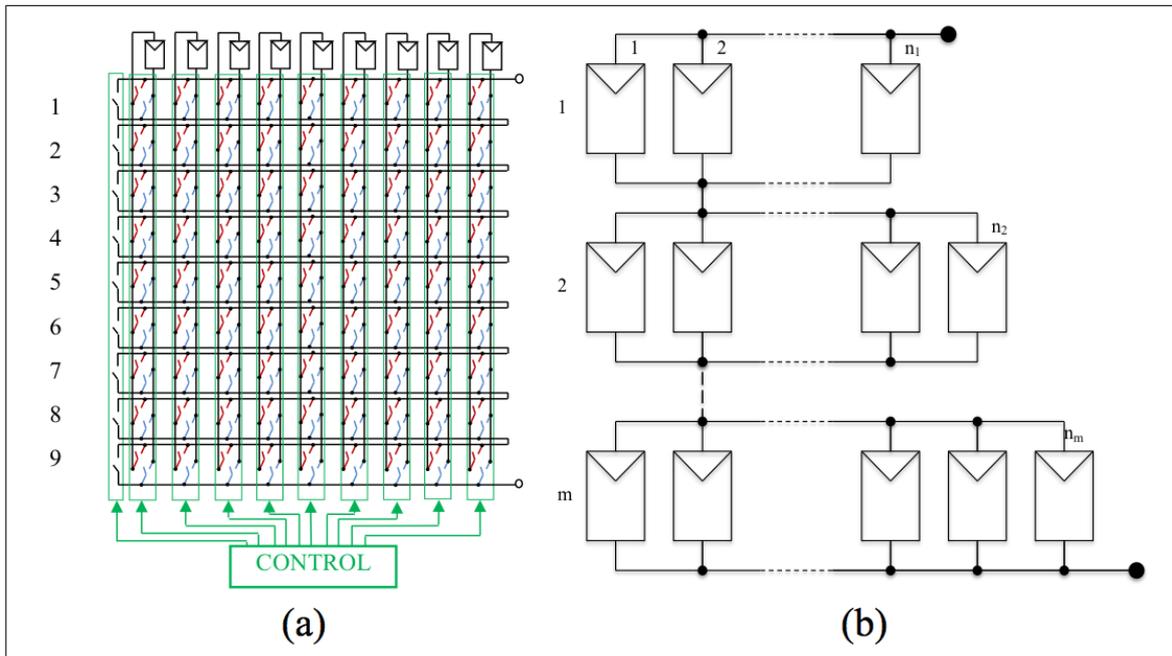


Figure 5. a) Dynamic electrical scheme (DES) switching matrix [27]; b) Generator TCT topology

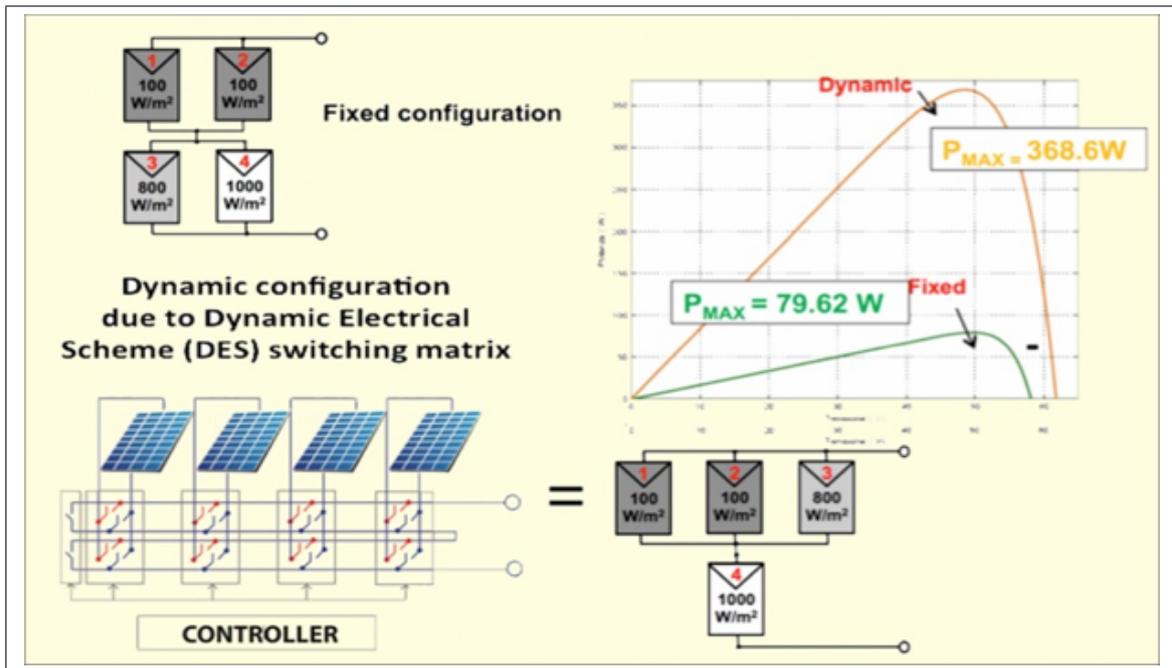


Figure 6. PV system before and after reconfiguration based on irradiance equalization

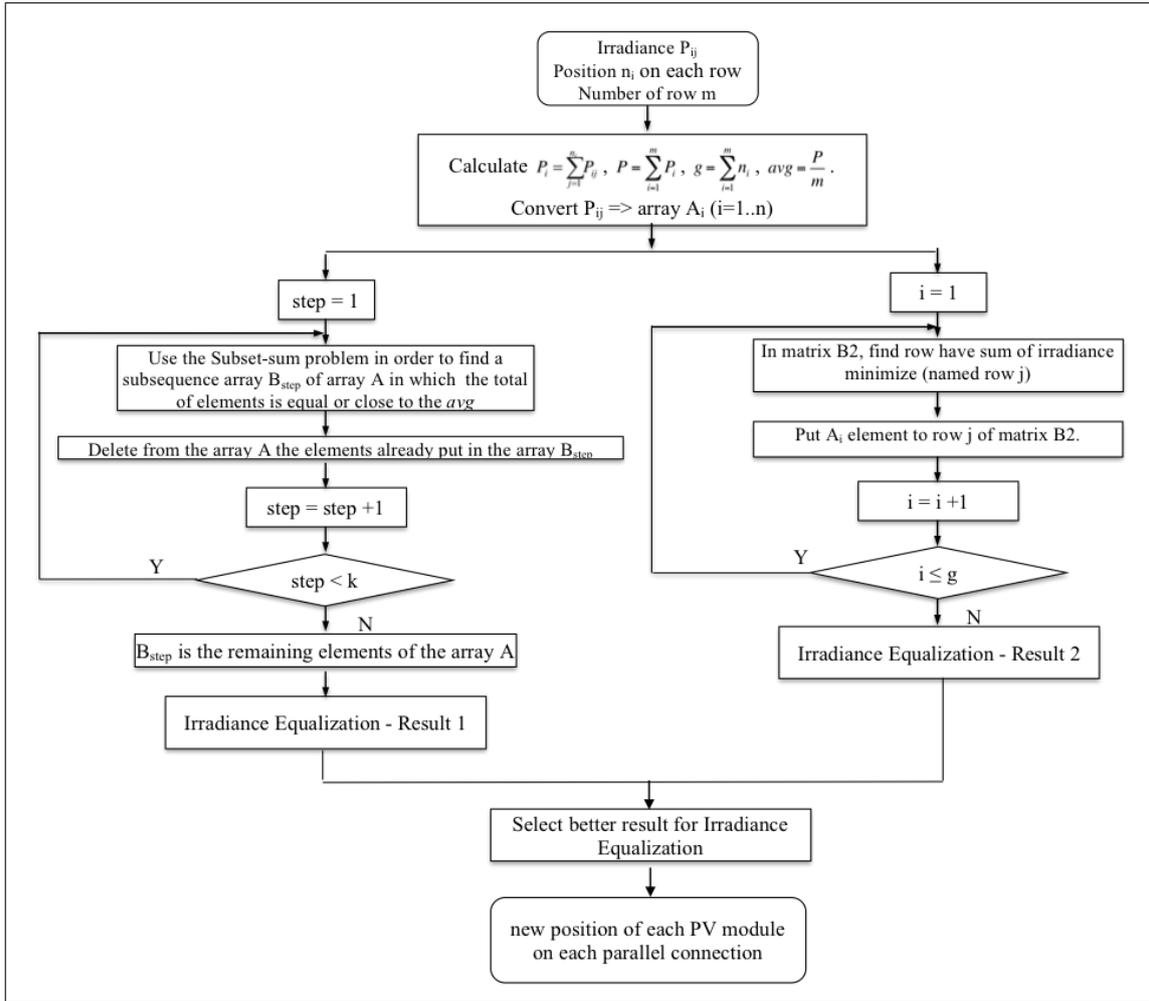


Figure 7. Hybrid algorithm

from the PV modules, irradiance equalization algorithms as proposed can be used to find the optimal configuration. Consequently, the controller controlling DES switching matrix reconfiguration PV system from initial configuration to optimal configuration, PV system will operate at maximum power.

4. MATLAB SIMULATION

There have been several publications using Matlab-Simulink to simulate PV module operation under non-homogeneous solar irradiance [1, 5, 8, 9, 17, 24, 28] which mainly focus on the simulation of PV module operation, thereby graphing features I-V and P-V. In this part, we mainly focus on simulation of RS to verify behavior of the system. Hence, we do not focus on how to simulate PV module under non-homogeneous solar radiation, we use the result of “partial shading of a PV module” in [21] for simulating PV module operation.

Matlab simulation (Figure 8) includes four main parts: input data; PV modules, hybrid

algorithm, DES switching matrix. A flowchart of the simulation is shown in Figure 9.

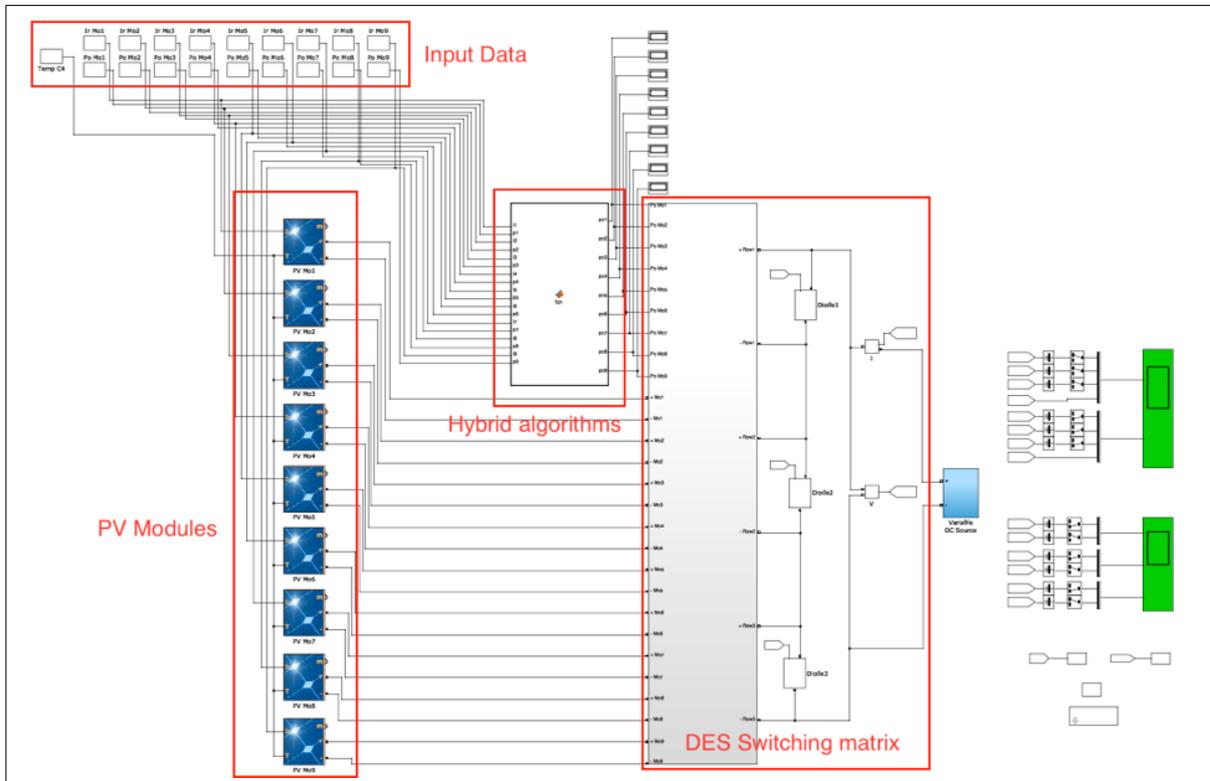


Figure 8. Matlab simulation for PV system

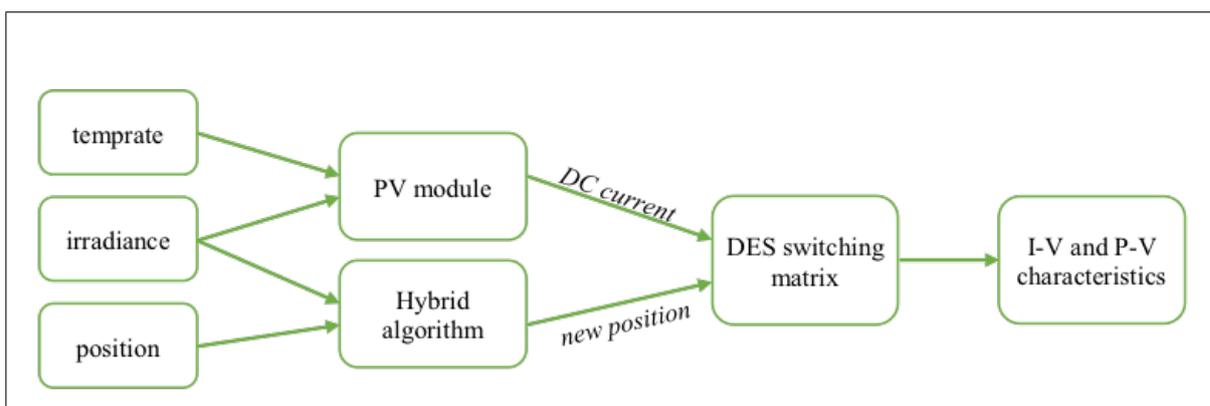


Figure 9. Flowchart of the simulation

4.1. PV module

It is the result of PV module simulation under conditions of non-homogeneous irradiance at [21], the PV module with the input data being irradiance (W/m^2) and temperature ($^{\circ}\text{C}$); and the output data being DC current (+ and -). The model parameter is selected as in the standard PV module data-sheet parameter: I_{SC} , V_{OC} , rated current I_R at MPP and rated voltage V_R at MPP under standard test conditions ($1\text{kW}/\text{m}^2$, 25°C) (Figure 10).

Module data		Model parameters	
Module:	User-defined	Light-generated current I_L (A)	8.3924
Maximum Power (W)	198.7164	Diode saturation current I_0 (A)	$1.35\text{e-}10$
Cells per module (Ncell)	60/3	Diode ideality factor	2.5417
Open circuit voltage V_{oc} (V)	$97.2^{\circ}20/60$	Shunt resistance R_{sh} (ohms)	87.4168
Short-circuit current I_{sc} (A)	8.4	Series resistance R_s (ohms)	0.32784
Voltage at maximum power point V_{mp} (V)	$78.03^{\circ}20/60$		
Current at maximum power point I_{mp} (A)	7.64		
Temperature coefficient of V_{oc} (%/deg.C)	-0.33969		
Temperature coefficient of I_{sc} (%/deg.C)	0.063701		

Figure 10. Parameters of PV module

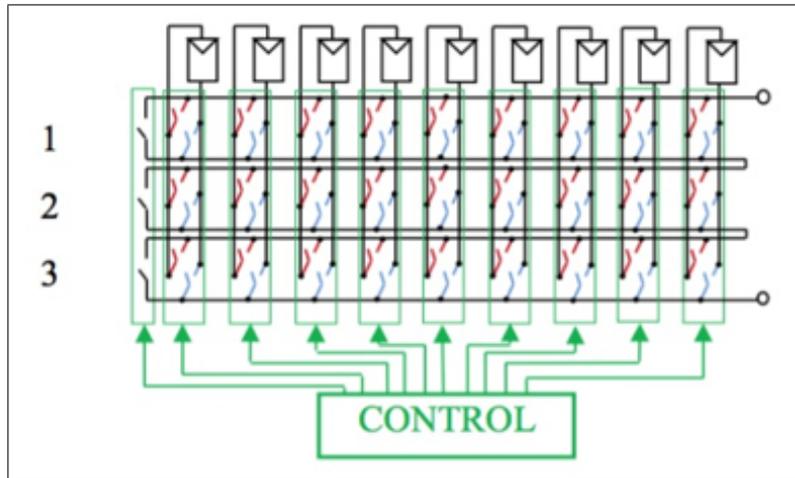


Figure 11. Schematic design of DES switching matrix

When the PV system operates under conditions of non-homogeneous solar irradiance, depending on the irradiance level received, each PV module brings forward a different DC current. In this simulation, we focus on the PV system working at non-homogeneous irradiance, hence we chose the ideal condition for PV modules is 25°C .

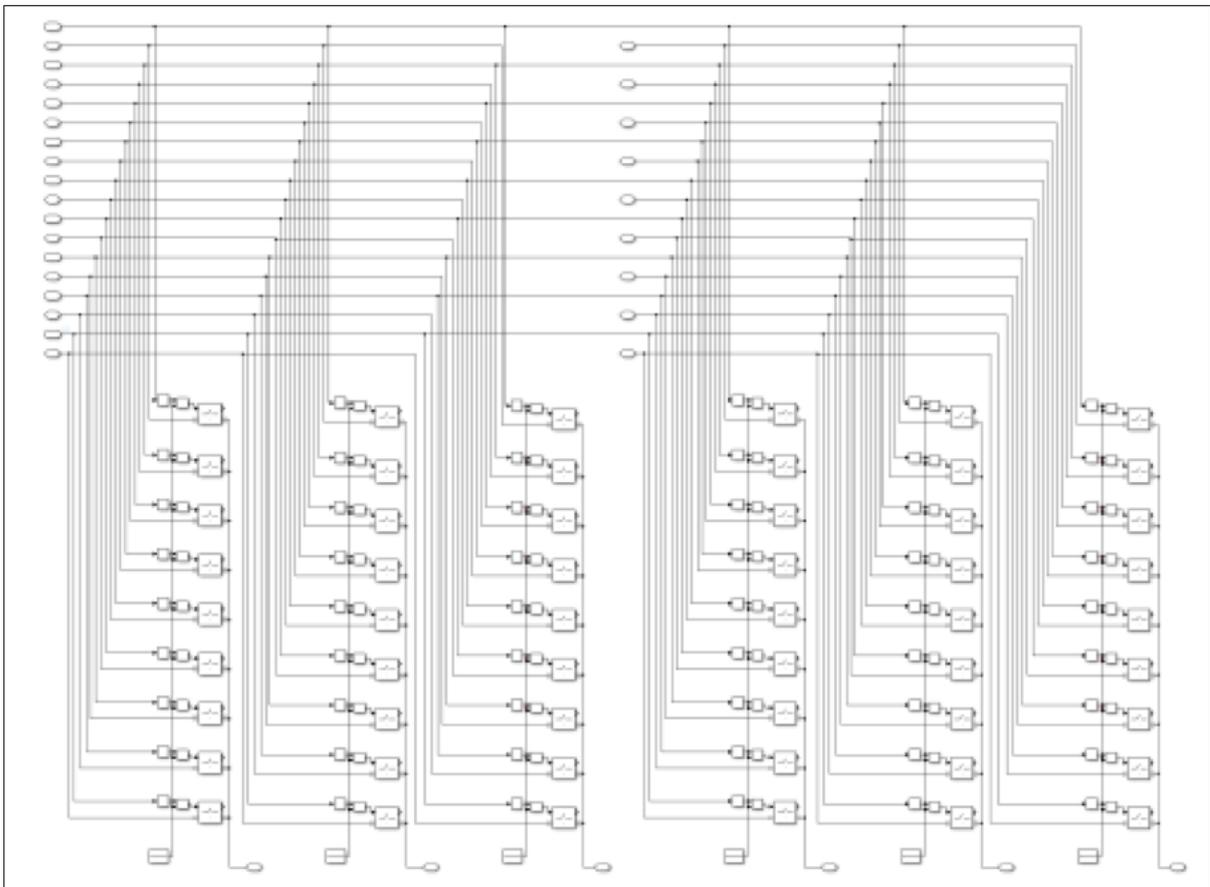


Figure 12. DES switching matrix

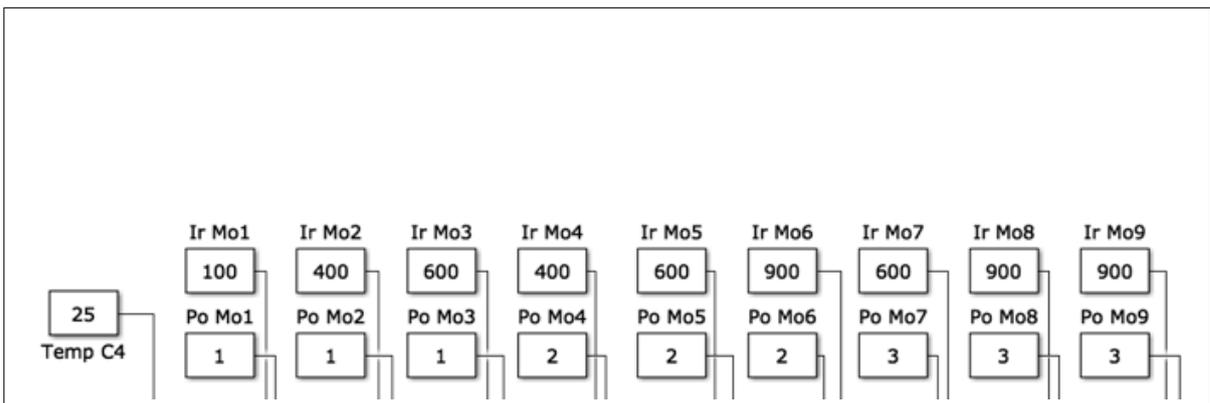


Figure 13. Input data for simulation

4.2. Hybrid algorithm

In this section, we modelize hybrid algorithm in a Matlab function block. The main aim of the hybrid algorithm is to seek the optimal connection configuration of the system to archive the best performance. The hybrid algorithm is shown in Figure 7. The input data of the hybrid algorithm are irradiances and positions of each PV module. The result is the optimal configuration: new position of each PV module on each parallel connection in TCT topology.

4.3. DES switching matrix

Figure 11 demonstrates a schematic design of the DES switching matrix designed for 9 PV modules. Each PV module is connected into three rows via switches. It can change the

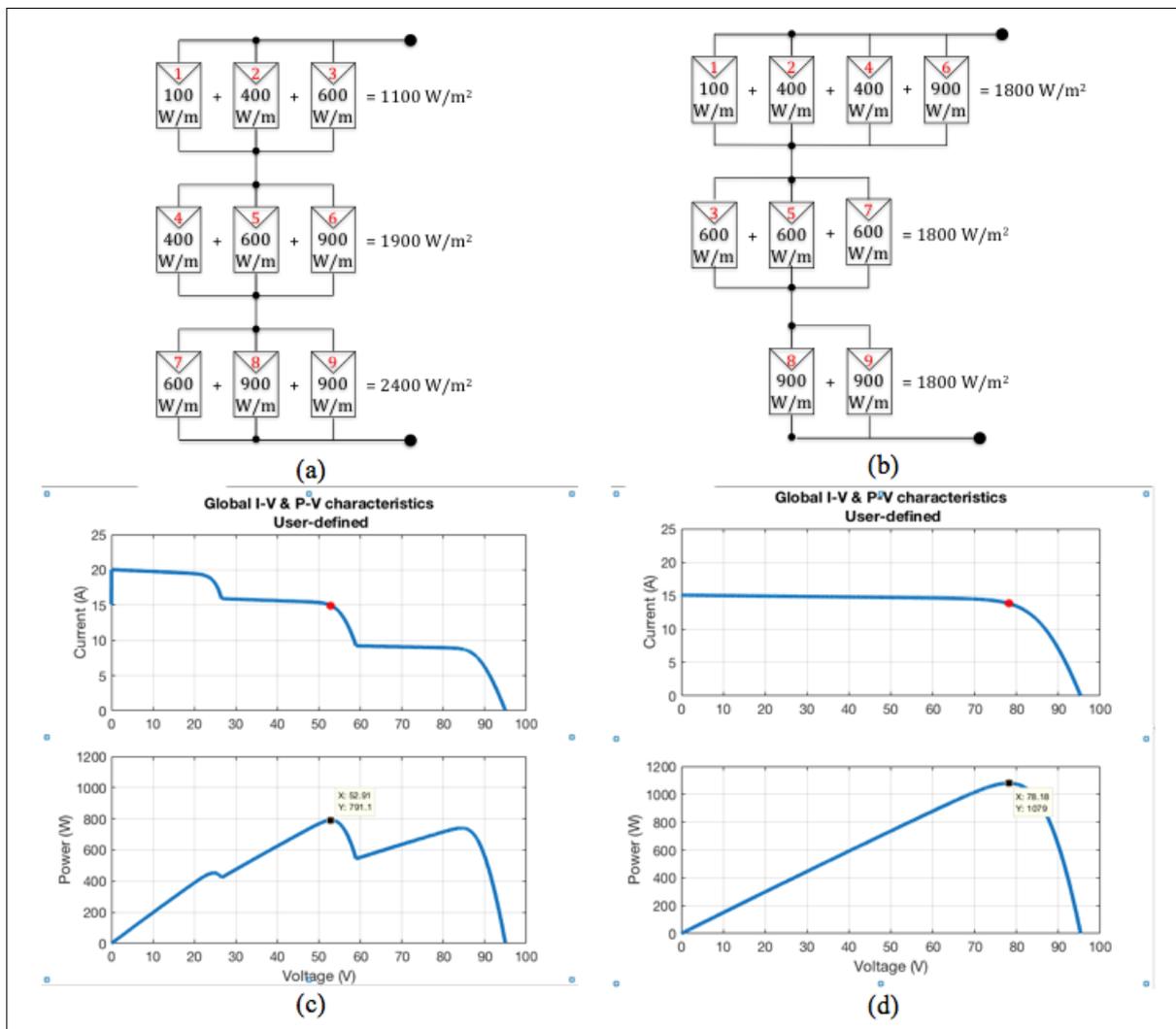


Figure 14. PV system before reconfiguration (a-c) and after reconfiguration with RS (b-d)

position of the connection between the rows. Switching from row x to row y can be done by opening switch at row x and closing switch at row y . For example, PV module want to connect to row 1: switches in row 2 and 3 are open, switch in row 1 is close.

Through opening/closing the switches in DES, PV system can change the configuration from the initial TCT topology to any TCT topology with up to three rows.

Figure 12 is an illustration of the basis of schematic design in Matlab-simulink environment with the input data for each PV module as: DC current and the new position after the reconfiguration. DES switching matrix is restructured within three circuits connected in parallel to ensure the input assumptions for the inverters. Based on the new position of each PV module, the controller is able to control ideal switches for the corresponding connection configuration. The result of the DES switching matrix is DC currents of the PV system.

4.4. Result of simulation

Simulation with 9 PV modules is connected as shown in Figure 14a. At the initial configuration, the PV modules received different irradiance. Hence, total irradiation in the parallel circuit is different. The I-V and P-V characteristics of the system before the reconfiguration with $P_{\max} = 791.1W$ is demonstrated in Figure 14c.

With PV system as seen in Figure 14a (input data of Matlab simulation show in Figure 13), the hybrid algorithm provides an optimal PV configuration. Then, DES switching matrix used the result of hybrid algorithm to change the connection of PV system from initial configuration to the optimal configuration (Figure 14b with irradiance equalization on each row of PV system). The position of PV modules 7, 4, 6, 3 has changed. After using the reconfiguration system, P-V characteristics (Figure 14d) have been improved markedly with $P_{\max} = 1079W$ (performance increases by 29%).

5. CONCLUSIONS

A Matlab/Simulink software has been developed to simulate the behavior of PV modules with different configurations under non-homogeneous of solar irradiance. The effect of the reconfiguration system on PV characteristics under partially shaded conditions has been modeled in the study. Additionally, an experimental measurement has been performed and validity of the simulation software has been verified. The results show that the software is a promising tool for further research on the effectiveness of reconfiguration algorithms in solar power plant.

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