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RESEARCH ARTICLE

Simulation and Performance Analysis of a Solar Photovoltaic Panel Under Partial Shading Conditions

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ABSTRACT

In recent years, the global demand for energy has been increasing due to the rapid population growth, industrialization, technological development, and economic competition among the developed countries. Energy from renewable sources is now being widely used to meet this demand, especially solar or photovoltaic (PV) energy. Photovoltaic energy systems allow the conversion of solar electromagnetic waves of different wavelengths into DC energy in the visible light spectrum. However, the efficiency of the solar PV panel is adversely affected by partial shading conditions (PSCs) such as the shade of trees, leaves, clouds, buildings, or chimneys. One of the potential solutions is to use a bridge diode to increase the energy efficiency of the solar PV panel under PSCs. Therefore, in this study, the performance analyses of 80 W solar PV panels are carried out under six different conditions of partial shading. To present the superiority of the use of a bridge diode, the solar PV panel with bridge diode is analyzed under different intensities of solar radiation by MATLAB/Simulink. In addition, the effects of PSCs on the solar PV panel without bridge diode are evaluated in detail, as part of the experimental application. The results of the analyses under different PSCs reveal that the use of the bridge diode in the solar PV panels has a significant influence on the power produced from the PV system.

Index Terms—Partial shading condition (PSC), photovoltaic (PV) energy, power losses, renewable energy.

I. INTRODUCTION

Recently, the number of applications based on renewable energy sources has increased significantly in an effort to reduce the dependence on fossil fuels. With the rapidly increasing environmental damage attributed to the use of fossil fuels, scientists emphasize the importance of using energy from renewable sources effectively to meet the global energy demand. Among the renewable energy sources, the global installed power capacity of solar energy is increasing considerably day by day. Critical parameters such as temperature, solar radiation, and shading affect the efficiency of photovoltaic (PV) energy systems. Especially, shading conditions dramatically reduce the electrical energy obtained from PV energy systems. Many studies have been conducted to eliminate or minimize the effect of full shading and partial shading conditions (PSCs) on the produced power, as reported in the literature.

The efficiency of PV cells is a vital parameter for solar energy systems. As partial shading significantly reduces the efficiency of the PV cell, different enhanced techniques have been developed to overcome this problem. In this study, the effects of five different PV array configurations on power generation, such as total-cross-tied (TCT), honeycomb (HC), bridged-linked (BL), series-parallel (SP), and series have been investigated using MATLAB/Simulink, under six different shading conditions. According to the simulation results obtained, it is presented that the TCT configuration performs better than other configurations under all PSCs [1]. New PV array topologies have been proposed to increase the output power produced by the solar energy system under eight different shading patterns. The performances of existing and proposed PV array topologies have been comparatively examined using MATLAB/Simulink. According to the performance analysis results, the modified TCT configuration under PSCs approximately doubled the output power compared to the existing TCT topology [2]. Variable environmental conditions adversely affected the production of solar PV energy. Conventional maximum power point tracking (MPPT) techniques under PSCs may not be able to track the correct MPP. To minimize the negative

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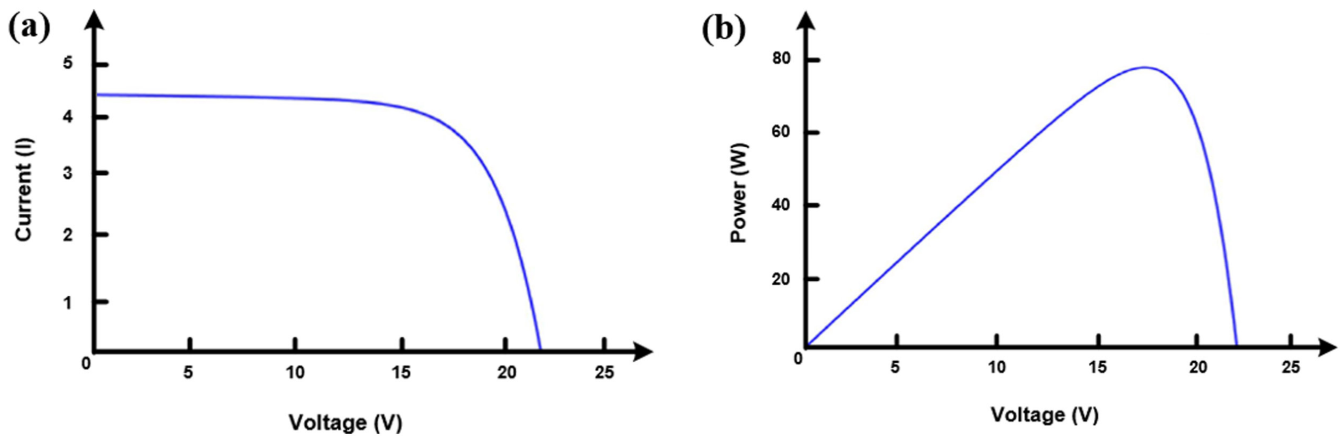

Fig. 1. Solar PV panels used in applied research (a) I–V and (b) P–V characteristics.

impact of partial shading on the generated power, different meta-heuristic techniques have been presented in comparison with the simulation results. The simulation results show the superiority of Gray Wolf Optimization in the speed of convergence and the time to catch global MPP [3]. Various MPPT algorithms which have been widely applied in PV energy systems under PSCs in recent studies are discussed. It has been observed that novel MPPT algorithms as well as hybrid techniques are preferred to increase the efficiency of the PV energy system [4]. A new method has been developed to detect faults such as fire hazards and partial shading using the data of array voltage, array current, and radiation. In addition, experimental studies have been carried out to present the effectiveness of the developed technique [5]. The advantages and disadvantages of MPPT techniques such as Particle Swarm Optimization (PSO), Perturbation and Observation (P&O), Cuckoo Search, Hill-Climbing (HC), Neural Network, Incremental Conductance (IncCond), and Fuzzy-Logic of PV energy systems under uniform radiation and PSCs are discussed in detail [6]. A new method has been developed to obtain P–V and I–V curves of a particular PV energy system under PSCs in different patterns using the standard test condition values of PV modules and the radiation values applied to each module. The simulation results obtained from MATLAB/Simulink show that the electrical properties of PV arrays under partial shading increase the prediction accuracy by including the real effect of bypass and blocking diodes [7]. The MPPT techniques based on bio-inspired algorithms under the changing environmental conditions of PV energy systems have been extensively examined and have contributed to the research in the field of MPPT [8]. PV array configurations are offered to reduce power dissipation under PSCs. Global MPP is readily determined, thanks to the developed method. In addition, it has been compared with the SP and TCT configurations to evaluate the performance of the proposed configurations, and the superiority of the proposed configuration is revealed [9]. A novel hybrid MPPT technique under PSCs is offered. The superiority of the present technique over the standard PSO algorithm and the P&O algorithm has been demonstrated by experimental and simulation results [10]. The behavior of a PV array under PSCs has been examined using MATLAB/Simulink software [11]. Different shading conditions in the PV array have been investigated, and a formula has been developed to determine the critical point from the obtained results [12].

Main Points

- The power obtained from photovoltaic (PV) panels is dramatically reduced due to the decrease in the efficiency of PV cells under different partial shading conditions.
- Shaded modules in the solar PV panels produce many maximum power points in the I–V and P–V curves. The number of those maximum power points has increased because of the increasing number of shaded modules.
- The bridge diode significantly improves the function of the PV panels under different shading conditions. A solar energy system with bridge diodes obtains significant power output compared to a system without these, showing that bridge diodes improve the operating efficiency of solar PV systems.

In the following sections of the paper, solar PV panel characteristics and experimental investigation have been analyzed comprehensively. The performance analysis of the 80 W solar PV panel has been experimentally conducted under six different PSCs. The solar PV panel with bridge diode has been investigated with simulation under the different conditions of solar radiation by using MATLAB/Simulink software, and the results obtained reveal the superiority of the use of bridge diodes.

II. SOLAR PV PANEL CHARACTERISTIC

Photovoltaic solar cells, which have an important place in solar energy systems, convert solar energy directly to DC electrical energy when solar light (in the form of photons) falls on it. The warranty period determined by manufacturers for the smooth operation of solar PV panels is generally 25 years on average. However, it has been stated that the panel power decreases linearly over time. In this study, the performance of the solar PV panel used for the practical study is evaluated with the I–V and P–V curves given in Fig. 1. In addition, Table I presents the parameters of the solar PV panel used for the applied research.

TABLE I
ELECTRICAL PROPERTIES OF THE SOLAR PV PANEL USED IN THE APPLIED RESEARCH

Electrical Characteristics	Value	Electrical Characteristics	Value
Power Rating	80 W	Voltage at maximum power (V_{mp})	17.5 V
Open Circuit Voltage (V_{oc})	21.76 V	Power Tolerances	0% - +5%
Short Circuit Current (I_{sc})	21.76 V	Peak Efficiency	17.6%
Maximum Voltage	1000 V	Current at maximum power (I_{mp})	4.57A

In order to obtain maximum power from the solar PV panels used in PV systems, they are placed at a horizontal angle of inclination and the solar radiation is aimed to fall at a right angle. The level of radiation falling on the panels depends on the latitude and longitude of the location where the panels are placed. The performance of a solar PV panel is affected by many factors. Some of these factors are related to the structure of the panel itself, while others are related to the location and environment in which the panels are installed. The factors are material degradation, solar radiation, panel temperature, parasitic resistances, shade, contamination, and inclination angle.

The shading of solar PV panels is one of the major problems in solar energy systems. Shadow formation significantly reduces the power produced by the solar PV panels, causing huge losses to the customer. Trees, leaves, clouds, buildings, and chimneys can create shadows on the panel, which cause a decrease in the electrical performance of the solar PV panel. The shading effect occurs when the system is not exposed to the same amount of radiation due to some obstacles in the path of light falling on the panel. In this case, solar cells are exposed to lower levels of radiation, and the shading effect reduces system power instead of generating power. Fig. 2 shows the I–V and P–V curves according to the amount of solar radiation reflected on the PV panel, due to shading.

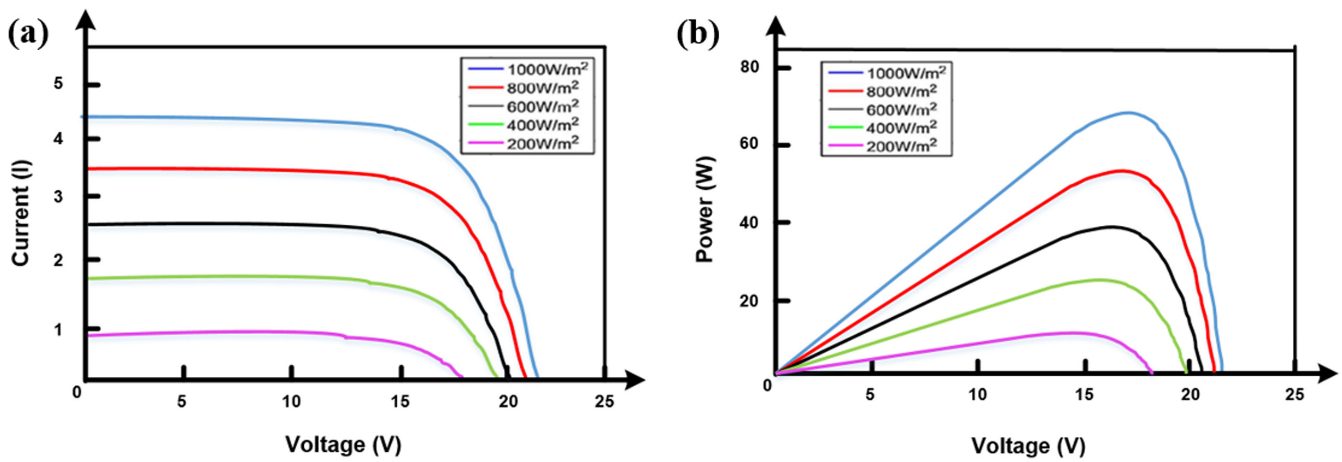

Fig. 2. (a) I–V and (b) P–V characteristics of PV panels at different levels of solar radiation.

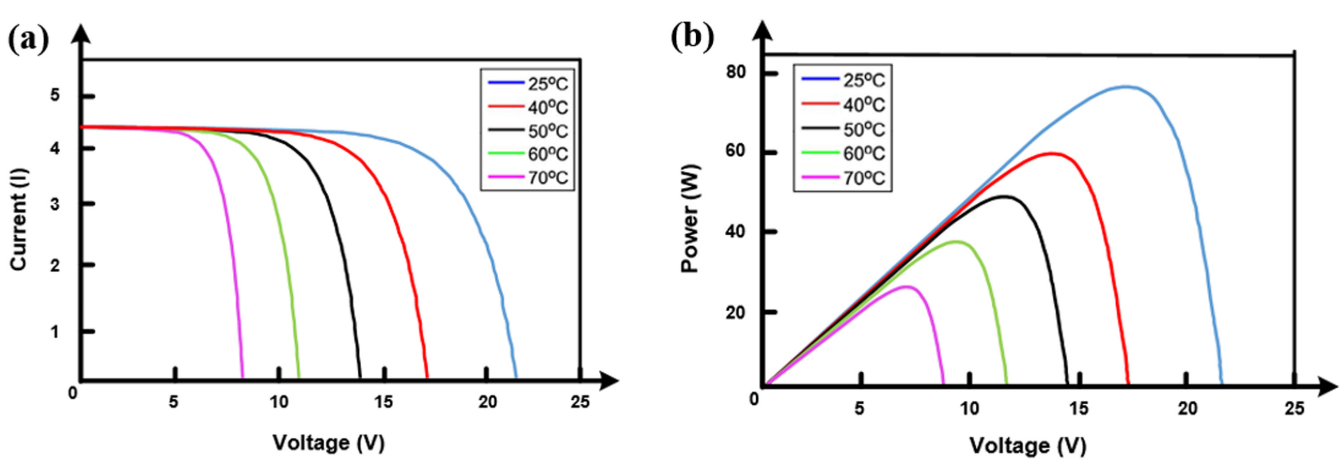

Fig. 3. (a) I–V and (b) P–V characteristics of PV panels at different temperatures.

The output power of a solar PV panel is inversely proportional to the PV panel's temperature. As the temperature of the solar PV panel increases, the power produced by the PV panel decreases. Therefore, the losses caused by temperature are proportional to the solar PV cell temperature. Fig. 3 shows the effect of temperature on the power produced by the solar PV panel.

As the temperature and solar radiation of the solar cell under the shadow change, the produced power decreases. In this case, the shadow results in mismatches of the currents generated from the solar cells of the solar PV panel. Shaded solar cells produce less current than non-shaded chambers. However, since the solar cells in the PV panel are connected in series, the same current must flow through all cells. This situation leads to incompatibilities. Shading the part over one solar cell can significantly reduce the strength of the entire solar PV panel, as if all solar cells are shaded. When a solar cell is under a shadow, the current flow of the shadowed solar cell decreases.

Thus, the total current of the system passes over the shaded solar cell, causing a decrease in the produced power. By operating the bridge diode used for the solar cell under the shadow, the current is provided to pass around the shadowed solar cell. An examination of the bridge diode's effect under partial shading reveals that the presence of a bridge diode in the solar PV panel causes changes in the I–V and P–V curves. If there is a bridge diode in the panel, there is more than one maximum point in the P–V curve of PSCs, while the power value decreases significantly compared to the situation in which there is no shade and no bridge diode. Under partial shading, mismatches owing to the location of the shaded panels and the shape of the shade reduce the power. The dynamic model has been created by MATLAB/Simulink, as shown in Fig. 4.

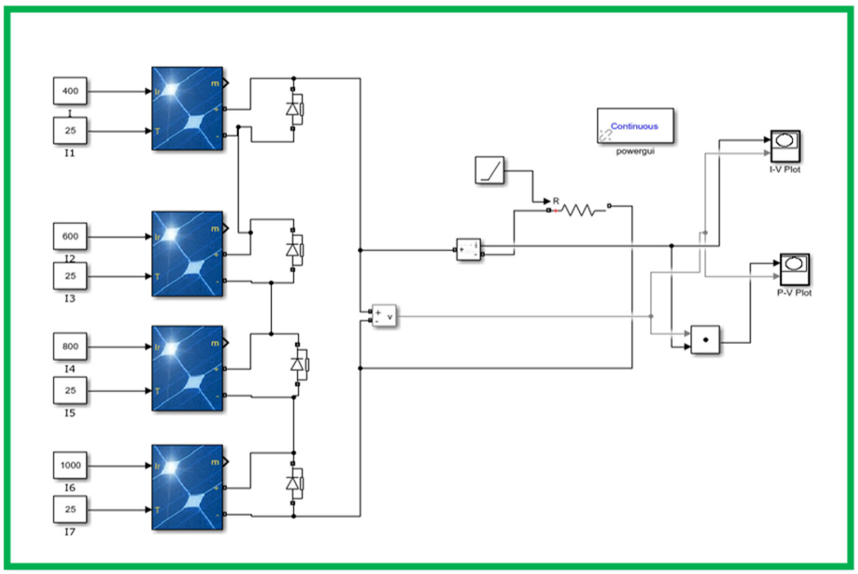

Fig. 4. The dynamic model of the solar PV panel at different levels of solar radiation and temperature.

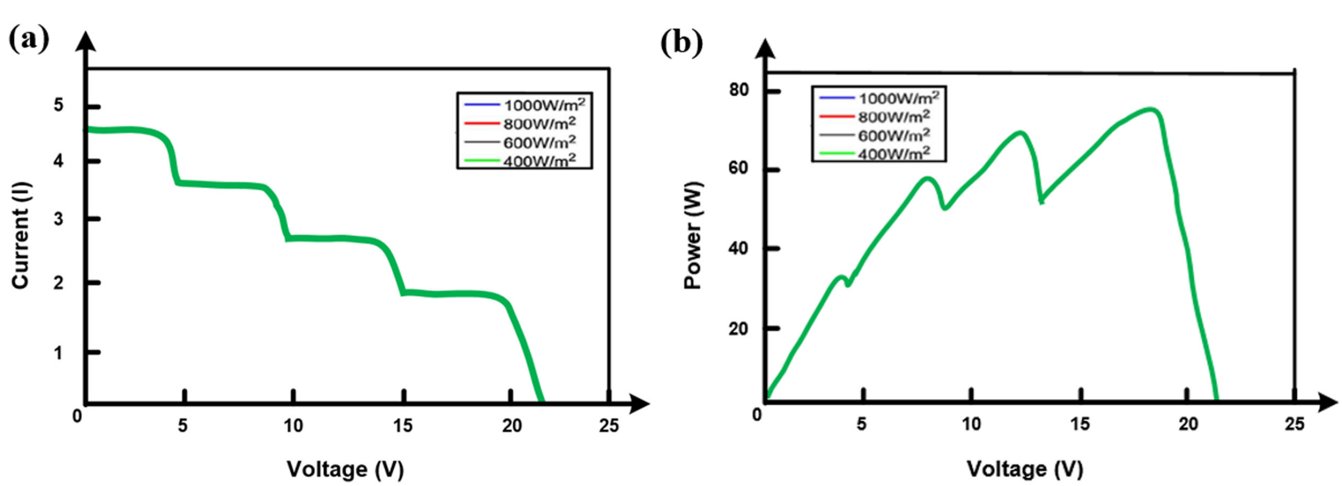

Fig. 5. (a) I–V and (b) P–V characteristics of the bridge diode-connected solar PV panel under the different solar radiation conditions.

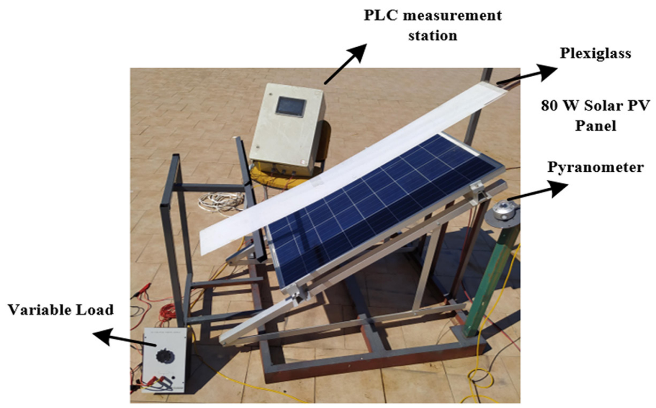

Fig. 6. Experimental setup unit for partial shading conditions of 80 W solar PV panel.

The model shows the shading conditions of the solar PV panel with a bridge diode. The power characteristic of the solar PV panel under the different levels of solar radiation is presented in Fig. 5.

III. EXPERIMENTAL ANALYSIS AND RESULTS

This section details the effect of partial shading on the output power of PV panels, studied by experimental investigation. An experimental test setup was installed on the roof of Alparslan Turkes Science and Technology University in Adana. Experimental studies were performed to investigate the performance of 80 W PV panels under six different partial shading cases. The effect of PSCs on short circuit current and short circuit voltage of PV panels has also been examined. The open circuit voltage and short circuit current values of the 80 W PV panel were recorded by the PLC measurement station. The relationship between the solar radiation level and the produced power was observed by measuring the solar radiation using the pyranometer. The experimental setup unit is shown in Fig. 6.

The solar cells used in the experiment were connected in series, each solar cell having a power of 2.2 W. In order to observe the maximum power point of the 80 W PV panel, experimental studies were carried out at 1000 W/m^2 at 33 °C in the unshaded condition. According to the experimental results in the unshaded condition, the maximum power was 78.8 W at 16.8 V and 4.69 A. The PSCs of the solar PV panels are shown in Fig. 7.

Table II shows the detailed evaluation of the six different conditions. The short circuit current and open circuit voltage, maximum power, and panel temperature under each PSC for the 80 W PV panel are shown comparatively. Significant decrease in output power of PV panel is observed when the performance of the PV panel under

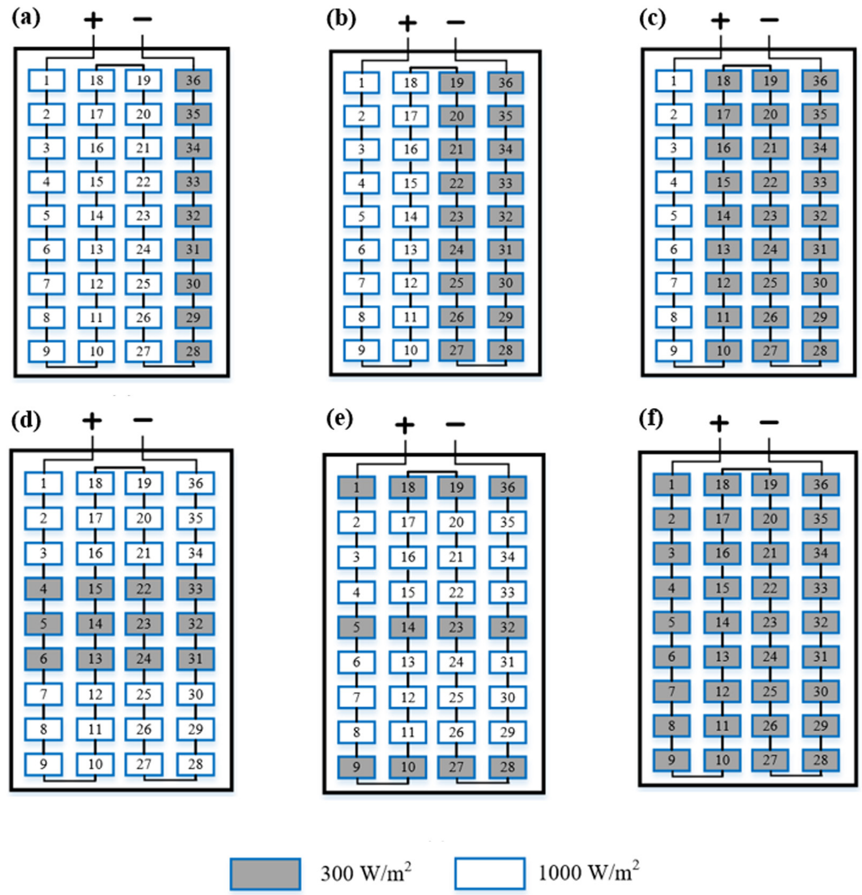

Fig. 7. Partial shading (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4, (e) Case 5, (f) Case 6.

TABLE II
EXPERIMENTAL ANALYSIS OF THE SOLAR PV PANEL UNDER THE PSCS OF (A) I–V AND (B) P–V CHARACTERISTICS

PSCs	P_{max} (W)	V_{max} (V)	I_{max} (A)	Temperature of the PV panel (°C)
Case 1	19.29	21.3	1.51	31.6–33.2
Case 2	16.38	21.1	1.21	33.5–35
Case 3	19.9	19.9	0.76	36.6–38
Case 4	19.6	21.2	1.09	37.8–38.6
Case 5	18.13	21.0	1.11	38.5–40.2
Case 6	9.20	19.8	0.74	36.2–38.3

PSCs, partial shading conditions; PV, photovoltaic.

shaded and unshaded conditions is compared. An 8.5-fold difference in output power between unshaded and fully shaded conditions was observed experimentally. In the studies in the literature, different photovoltaic array configurations such as TCT, HC, BL, and SP have been proposed to eliminate partial shading problems. In this study, in order to minimize the effect of partial shading on PV performance, the method using the bridge diode has been shown to obtain maximum power from the PV panel. As a result, it has been proven by experimental and simulation results that the panel efficiency of the PV panel without bridge diode is much lower than the PV panel with bridge diode under PSCs.

IV. CONCLUSION

The rapid depletion of fossil fuels makes it necessary to develop and use of alternative energy sources. Among the renewable energy sources, solar energy has come into prominence owing to its many advantages such as being emission-free, eco-friendly, infinite, reliable, preventing global warming, having low maintenance costs, etc. Many critical parameters negatively affect the power produced by PV energy systems. Partial shading is one of the most significant problems that diminish the power obtained from PV energy systems. There are many different approaches such as PV array arrangements and bridge diodes that can be applied in PV energy system designs to minimize partial shading losses. This study has examined the improvement in output power of solar PV panel under PSCs. The performance of 80 W solar PV panels under different shading conditions has been analyzed experimentally and under simulation. It is presented that using a bridge diode increases the performance of the solar PV panel under different PSCs, based on the simulation results obtained from the MATLAB/Simulink software. Hence, the efficiency of the solar PV array strongly depends on the usage of a bridge diode. Moreover, solar radiation levels and different shading conditions affect the efficiency of the solar PV energy system.

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