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INVESTIGATION OF PARTIAL SHADING INFLUENCE ON PHOTOVOLTAIC PANELS PERFORMANCES

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Abstract: Photovoltaic (PV) systems are usually mounted on the roofs or on building facades, thus partial shading caused by surrounding objects and debris is not rare. Even for ground mounted PV systems, installed in fields, passing clouds or trees can make partial shading issue, indicating that partial shading impact on PV panels performance should get more attention. Partial shading of PV panels can be induced by the presence of dust, leaves (or similar objects), bird droppings etc. on their front surfaces or by the shadows caused by surrounding buildings, objects, chimneys, clouds. When PV panels are partially shaded, they receive lower solar radiation intensity, and their performance decreases. Also, when partial shading occurs, PV panels may not get uniform solar radiation. The locations of partial shading on PV panels are variable and random. In this paper, results of an experimental investigation of the partial shading effects on optimally inclined monocrystalline silicon PV panels performances are shown. Results showed that the power of partially shaded PV panel reduced for 42.47% compared to the referent PV panel.

Keywords: PV panel, partial shading, power, I-V curve.

1. INTRODUCTION

In the era of more pronounced consequences of climate change, renewable energy sources (RES) are considered irreplaceable technology for mitigation of climate change effects. Besides environmental benefits, RES provides energy security and drives economic growth [1]. Also, energy utilization is growing whereupon estimation of annual global energy consumption shows 580 million terajoules [2], indicating the need for new and reliable energy sources.

Due to its benefits, RES trend is popular all over the world. The European Union (EU) has committed to becoming the first climate-neutral continent by 2050 [3].

Energy sector in Western Balkan countries strongly relies on coal and is still dominated by state-owned utility companies, especially in Serbia and Bosnia and Herzegovina [4]. Electricity prices in Western Balkan countries are usually lower compared to Western Europe, thus RES investments and return on investment are more favorable. Also, investments in RES (e.g. solar and wind) lead to long-term cost savings on electricity bills. Companies from Western Balkan region are disposed to obey environmental regulations, but they especially consider if that would be financially viable [5]. In Western Balkan countries, there is great solar and wind potential, and it should be strongly promoted [6]. However, limited infrastructure that supports RES implementation is often a barrier [5].

In 2020, the leaders of six Western Balkan countries also proclaimed commitment to the same EU 2050 target of carbon neutrality. Compared to the energy system in EU, endeavor for achieving EU 2050 target in Western Balkan countries is much greater since energy systems are more outdated, relying mostly on thermal power plants. In such situation, there is a great opportunity for RES utilization in Western Balkans [3].

Photovoltaic (PV) technology, as one of the renewable energy technologies, fulfills environmental requirements and also provides necessary reliability [2].

PV panels transform solar radiation into electricity. Solar cells are organized in an array with series and parallel configuration in order to generate power with required current and voltage. Output current is defined by the number of solar cells arranged in parallel, and output voltage is set by the solar cells' quantity arranged in series [7].

PV panels' performance depends on environmental conditions. PV system's output power depends on incident solar radiation intensity, temperature, partial shading and soiling [8]. Having in mind that PV systems are often mounted on the roofs or on building facades, partial shading caused by surrounding objects and debris is not rare. Even for ground mounted PV systems, installed in fields, passing clouds or trees can make partial shading issues [2].

Partial shading represents a critical factor for electricity generation in PV panels [9] that decreases the output power of the PV array. The output power decrease depends on the shaded area, shading patterns, PV panels positioning within the PV array [7].

Most of PV systems are grid-connected. PV array has nonlinear I-V curve where MPP (maximum power point) represents its single optimal operating point, that shifts with changing environmental circumstances. In partial shading conditions, P-V characteristics show multiple peaks [10].

It is not always easy to meet uniform environmental conditions for PV panels operation. Sometimes in the same group of solar cells exposed to various solar radiation conditions (partial shading) output P-V curve has multiple peaks with different extreme points. In the partial shading case, the cause for the traditional MPPT algorithms failure is the difficulty in locating MPP. Various methods for improving global search ability of the traditional MPPT method were presented [11].

PV systems in urban environment along with BIPV (building integrated photovoltaics) represent a key component of the transition to a low-carbon society. PV panels have the best performances when solar radiation is homogeneous. In the case of shading, solar radiation is heterogeneous. Shaded parts of PV panel lead to electrical mismatch and decreased output power, and potentially to PV system damage. Results of studies indicated that heterogeneous solar radiation conditions due to partial shading may contribute to system losses ranging 30-70% in string inverter-based systems. However, PV shading is usually not properly considered in PV modeling [12]. Partial shading impact on PV panels performance should get more attention [13].

This paper is organized as follows. After the Introduction, the second chapter describes partial shading issues of PV panels and the third chapter an overview of experimental setup. The main results and their discussion are given in the fourth chapter, while the corresponding conclusion is given at the end.

2. PARTIAL SHADING OF PV PANELS

Partial shading of PV panels can be induced by the presence of dust, leaves (or similar objects) [13], snow [8], bird droppings etc. on their front surfaces or by the shadows caused by buildings, objects, chimneys, clouds [13], trees [8] and it can reduce solar radiation in some parts of PV panels [14]. When PV panels are partially shaded, their performance decreases, and the temperature of their surface is increased. The locations of partial shading on PV panel surface are variable and random [13].

When partial shading occurs, some of the series-connected PV panels may not get uniform solar radiation that can cause mismatch losses between the array rows. As a consequence, mismatch current flow between shaded and unshaded PV panels results in multiple power peaks and leads to output power reduction. In these circumstances, it is not easy to track the global power peak [8].

In the case of uneven solar radiation distribution (acting as load), partial shading of PV panels can induce hot spots formation [2]. Shaded solar cells can still generate reduced power or solar cells can carry current of non-shaded solar cells, causing hot spots effect [14]. For mitigation of hot spot effects, bypass diodes connected anti-parallel across PV panels are often used [2].

Shading influence on the I-V characteristic of a PV panel also depends on the internal structure, actually on the way the solar cells connect and the internal connection of the bypass diodes. Two technologies dominate the market today, full-cell and half-cut, whereby half-cut technology takes more than 80% of the market [15]. Bypass diodes will work if in the cell string they bridge there is complete or partial shading of one or more cells [16].

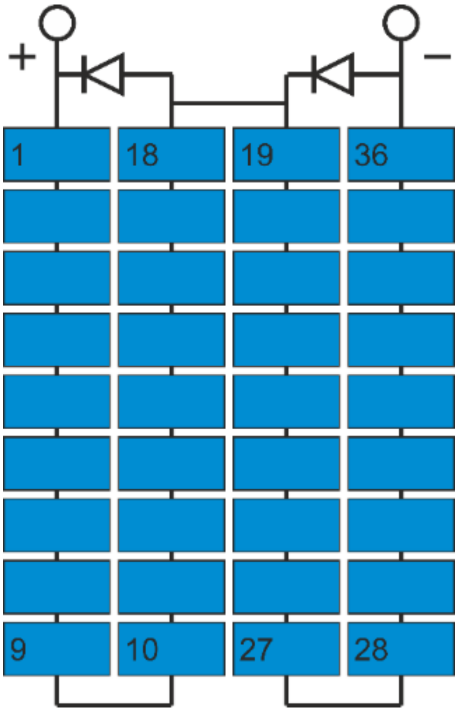

Figure 1. *PV panel layout of conventional full-sized solar cells interconnection [16]*

Figure 1. shows the layout of a PV panel with 36 full-cells and two bypass diodes. A simulation model of the PV panel from Fig. 1 was created using the Simscape library model of solar cell [17]. Partial shading of cell No. 9 was simulated for different solar radiation values: 1000 W/m^2 with no shading, 800 W/m^2, 500 W/m^2 and 0 W/m^2 when the cell is completely shaded. Figure 2. shows the I-V and P-V characteristics of the PV panel for the specified solar radiation values and for the cell temperature of 47^{o}C [16].

The partial shading simulation of 60-cell PV panel, with a maximum power of 250 W (Figure 3), was carried out in order to show more complex I-V and P-V curve patterns. Solar cells from 1 to 20 are

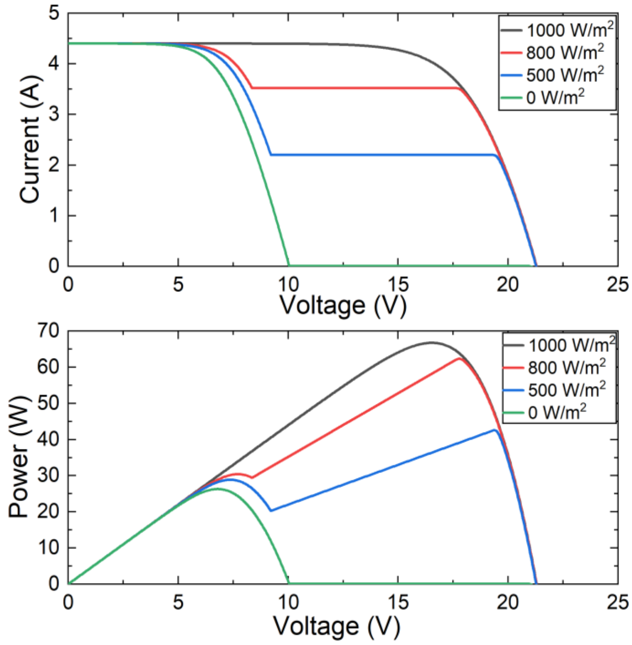

Figure 2. *I-V and P-V characteristics of PV panel with different levels of shading for cell No. 9*

under standard conditions of solar radiation intensity of 1000 W/m^2 and PV panel surface temperature of 25^{o}C. Solar cells from 21 to 40 are shaded and solar radiation intensity has value of 300 W/m^2. Solar cells from 41 to 60 have solar radiation intensity of 600 W/m^2.

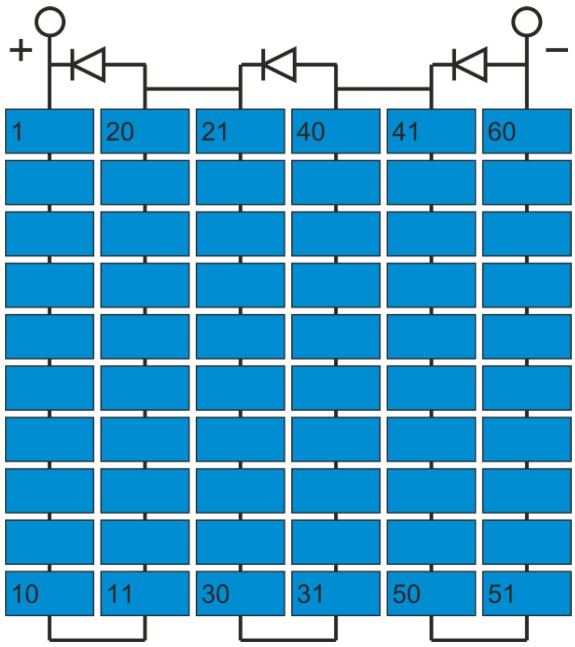

Figure 3. *Layout of a PV panel with a nominal power of 250 W*

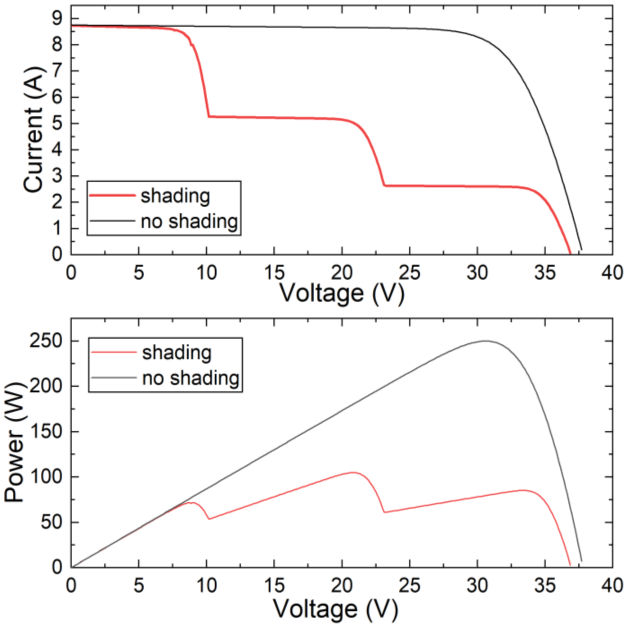

Figure 4. *I-V and P-V characteristics of a simulated 250 W PV panel in no shading and partial shading conditions*

Obtained I-V and P-V characteristics of partially shaded PV panel are shown by the red line in Figure 4. On this figure it can be noted that finding the output power's absolute maximum is not easy in the case of PV panel's partial shading. Due to the optimal utilization of the PV system's installed capacity, finding this maximum is required, which in case of partial shading is not a simple task. It can be seen that the maximum power of the partially shaded panel is 104.8 W, which is significantly lower than the declared value.

3. EXPERIMENTAL SETUP

PV panels partial shading experiment was performed on the roof at the Faculty of Sciences and Mathematics in Niš (Figure 5). It means that the experiment was performed outdoors, with variable conditions. In the experiment, monocrystalline silicon PV panels were used, each with the power of 60 Wp, and both of them were placed with optimal tilt angle (32°). Besides the electrical parameters of PV panels, solar radiation intensity was also measured during the experiment.

One PV panel was the referent one, meaning that it was not shaded at all. The other PV panel was partially shaded that was performed by putting a chair in front of it. The chair created a shadow that partially shaded certain parts of that PV panel. Measurements were performed within 20 minutes, thus shadow was more or less at the same position on the PV panel's surface.

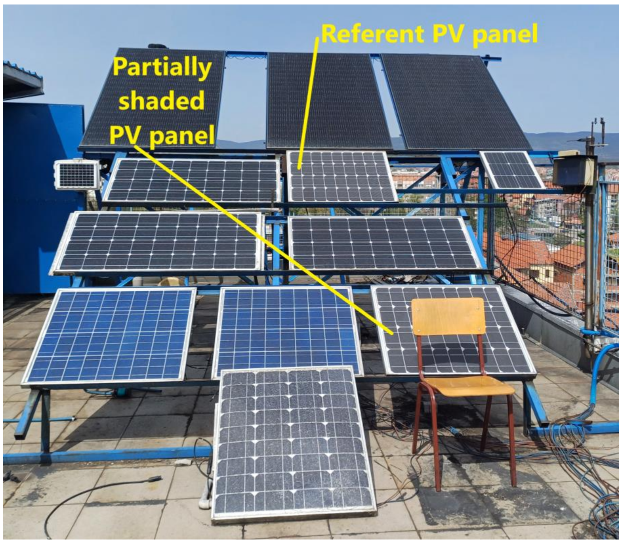

Figure 5. *Experimental setup*

4. RESULTS AND DISCUSSION

The focus of this research was on the examination of PV panels output power that was partially shaded. As a reference, identical PV panel was placed in the same outdoor conditions throughout the experiment, but it was not shaded at all.

Table 1. gives power values of referent and partially shaded PV panels, as well as solar radiation intensity.

Table 1. *Power of referent and partially shaded PV panels*

Time	Power of referent PV panel (W)	Power of partially shaded PV panel (W)
11:35	47.5138	27.3331
11:37	47.6472	27.6922
11:41	48.5264	28.3011
11:45	47.2622	27.7943
11:47	47.8970	28.2111
11:49	48.4057	27.4122

Figure 6. shows irradiance values, as well as power of partially shaded PV panel. It can be seen that power of partially shaded PV panel follows irradiance behavior, proving PV panels' performance dependance on irradiance, as one of the most important factors.

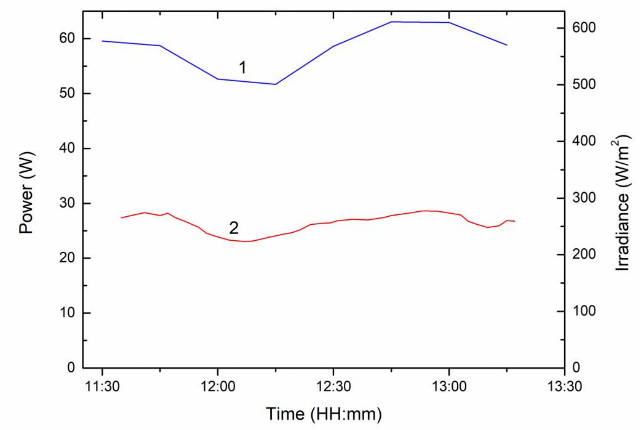

Figure 6. *Irradiance values (1) and power of partially shaded PV panel (2) during the experiment*

Figure 7 shows I-V curves of referent and partially shaded PV panel at 11:35. Partial shading of PV panel led to a reduction of the current, that is manifested by the characteristic step-like shape of the I-V curve. Current flow through the PV panel was interrupted and the output voltage was reduced. Power of partially shaded PV panel reduced by 42.47% compared to the referent PV panel.

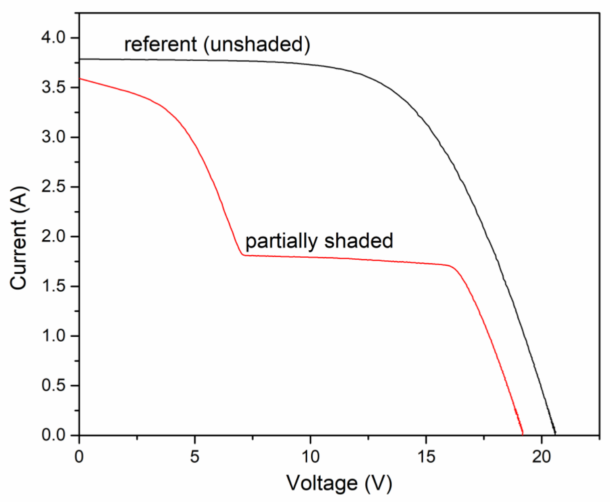

Figure 7. *I-V curves of referent and partially shaded PV panel*

According to the results, it can be said that partial shading issue is not negligible. In some cases, it can cause considerable decrease of PV panels output power. When designing PV system, all possible sources of shading should be considered in order to forecast PV production as precisely as possible.

5. CONCLUSION

Due to increased energy demand and fossil fuels prices, renewable energy sources have become more and more popular and utilized all over the world. Among them, PV technology has achieved necessary maturity and reliability, besides the fact that it fulfills environmental requirements. However, throughout their utilization in outdoor environment, PV panels experience certain circumstances that can decrease their performance, such as partial shading of PV panels. Partial shading caused by surrounding objects, debris, passing clouds etc. is not rare.

Partially shaded PV panels receive solar radiation of lower intensity, and their performance decreases. The locations of partial shading on PV panel's front surface are random and variable. In the case of partial shading, some of the series-connected PV panels may not get uniform solar radiation that can cause mismatch losses between the array rows. Consequently, mismatch current flow between shaded and unshaded PV panels results in multiple power peaks that leads to output power decrease. In such cases, it is not easy to track the global power peak.

After partial shading experiment conducted at the Faculty of Sciences and Mathematics in Niš, it can be concluded that PV panels partial shading induced current reduction, that is manifested by the characteristic step-like shape of the I-V curve, and the reduction of output voltage. Partial shading of PV panel led to power reduction of 42.47% compared to the referent PV panel.

This result shows the significance of the partial shading issues that should not be neglected. Partial shading of PV panels should get more attention when designing PV systems.

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ИСПИТИВАЊЕ УТИЦАЈА ДЕЛИМИЧНОГ СЕНЧЕЊА НА ПЕРФОРМАНСЕ ФОТОНАПОНСКИХ ПАНЕЛА

Сажетак: Фотонапонски (PV) системи се обично монтирају на кровове или на фасаде зграда, тако да делимично сенчење изазвано околним објектима и остацима природних материјала није реткост. Чак и код PV система монтираних на тлу, инсталираних на пољима, облаци који пролазе или дрвеће могу створити проблем делимичног сенчења, што указује на то да би утицају делимичног сенчења на перформансе PV панела требало посветити више пажње. Делимично сенчење PV панела може бити изазвано присуством прашине, лишћа (или сличних предмета), птичјег измета итд. на њиховим предњим површинама или сенкама изазваним околним зградама, објектима, димњацима, облацима. Када су PV панели делимично осенчени, они примају мањи интензитет сунчевог зрачења, и њихове перформансе се смањују. Такође, када дође до делимичног сенчења, PV панели можда неће равномерно добити сунчево зрачење. Локације делимичног сенчења на PV панелима су променљиве и случајне. У овом раду приказани су резултати експерименталног истраживања ефеката делимичног сенчења на перформансе оптимално нагнутих PV панела од монокристалног силицијума. Резултати су показали да се снага делимично осенченог PV панела смањила за 42,47% у поређењу са референтним PV панелом.

Кључне ријечи: PV панел, делимично сенчење, снага, I-V крива.

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