PHOTOVOLTAIC MODULES SOILING DURING HEATING SEASON IN NIŠ, SERBIA

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Abstract

Wide use of fossil fuels in Serbia causes, beside air pollution, PV modules soiling, especially during heating season. In this paper results of the soiling effects on output power of horizontal and optimal PV modules during the first month of the heating season 2016/2017 in Niš are given. Heating season 2016/2017 in Niš started on 08.10.2016 and lasted until 30.04.2017. This paper shows results of PV modules soiling effects for the period 24.10-25.11.2016. It was noted that power reduction due to fly ash soiling was higher for horizontal PV module. Maximum power reductions of horizontal (32.9%) and optimal PV module (20.8%) were measured after 32 days from the measurement beginning.

Keywords: PV modules, power reduction, heating season (HS), fly ash, soiling.

INTRODUCTION

One of the most important goals in energy sector all over the world is production of safe, reliable, affordable, available, and clean energy [1].

Although the heat represents the largest end-use energy sector [2], the share of electricity in global final energy consumption continues to follow an increasing trend, reaching 20.4% in 2021 [3].

Due to its installation and utilization simplicity, photovoltaic (PV) technology is very convenient option for clean electricity production [4].

Fuel crisis and increase of electricity prices are additional motives for PV modules use because they provide self-production and self-consumption, and lower dependence on the electrical grid, where realizable [5].

After years of declines, PV modules cost increased in 2021 as a consequence of raw materials cost rise. Reasons for PV modules cost augmentation were also polysilicon (raw material for PV wafers production) shortage, shipping delays and rise in shipping container costs from China (dominant PV module manufacturer). Thus, significance of PV modules domestic production came into the focus in some countries [5].

Several research concluded that soiling is one of the most important parameters influencing PV modules efficiency and electricity production [1]. Generally, PV modules soiling represents deposition of particles (particulate matter (PM)) on PV modules surfaces. Worldwide, there are areas with consistent soiling throughout the year, but there are also areas with seasonal differences in PV modules soiling [6].

In Serbia one of the causes for PV modules seasonal soiling appears during heating season (HS), especially in the cases of roof mounted PV modules (close to the chimneys). Although PV modules in Serbia are mainly cleaned by precipitation and wind, they are not enough to achieve efficiency of PV modules given by manufacturers.

Rooftop PV installations and building integrated PV systems are especially affected by soiling during HS. For achieving as low as possible PV modules soiling effects, design innovations of PV integrated surfaces and building products containing PV cells are also important [5].

Serbia has good natural conditions for solar energy use. Energy potential of solar radiation in Serbia is greater for 30% compared to Central Europe. For example, the lowest values of average annual energy from global solar radiation in the northwestern part of Serbia are equal to the highest ones in Germany [7]. Regardless, in 2021 Germany was the first country in Europe and fifth in the world according to cumulative PV capacity [5].

According to [8], Serbia has favorable mid-range PVOUT (photovoltaic power output) average value of 3.52 kWh/kWp. Only 6.5% of evaluated Serbian territory has PVOUT values below 3.4 kWh/kWp, 83.1% of the Serbian territory has PVOUT values between 3.4-3.6 kWh/kWp, and 10.4% has PVOUT values over 3.6 kWh/kWp [8, 9].

Beside possibilities for higher production, in the Republic of Serbia in 2017 only 0.04% of the total produced electricity was generated using solar energy (photovoltaics) [10]. In 2018 and 2019 the percentages were 0.03% and 0.05%, respectively [11, 12].

Due to good Serbian PV potential, it is important to provide best possible conditions for maximum use of PV energy in Serbia and investigate factors influencing PV modules production, such as PV modules soiling. The purpose of this paper is to investigate PV modules soiling at the beginning of the HS (the first month) in Niš, Serbia.

HEATING IN SERBIA

Fossil fuels are still widely used for energy production in Serbia. In the year 2020, 71.2% of electricity and 99.1% of heat was produced using fossil fuels [13].

Mostly used heating source in Serbian households (Figure 1) is wood (37.592%), followed by electricity (21.872%), heat obtained in the district heating system (19.434%), natural gas (10.772%) and coal (10.330%). The primary energy sources for the production of heat in the district heating system in Serbia are natural gas, fuel oil and coal. Fossil fuels burning causes not only emission of harmful gases (NO_x, SO_2, CO_2), but also particles emission. These particles further initiate the binding to other substances in the atmosphere, influencing the formation of smog in the lower layers of the atmosphere. The number of particles emitted into the atmosphere depends, firstly, on the type of burnt fuel, and secondly on the way of use, which is determined by the combustion regime, the existence of filters, etc. [14].

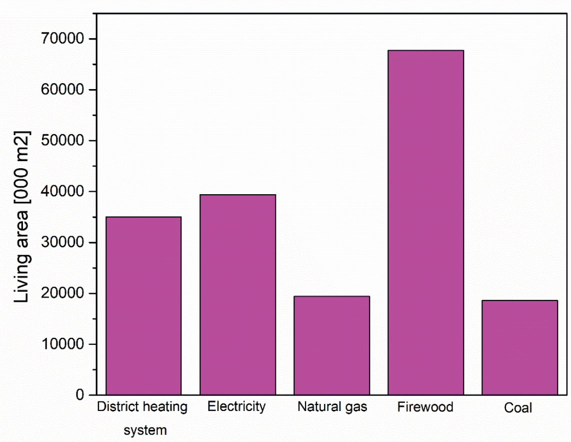

Fig 1. *Households living area and heating sources in Serbia*

The dominant pollutants in Serbian air are PM10 and PM2.5 particles. In the year 2020, the air was over-polluted in 7 (including Niš) out of 8 agglomerations in Serbia [15].

HEATING SEASON IN NIŠ

District heating has been very important in Niš and in whole Serbia, especially because it lasts around six months every year. Municipality of Niš introduced consumption-based billing for district heating. Before that, households haven't been paying for heating services based on the level of consumption, thus some of them started disconnecting from the district heating system. In that way, district heating system becomes less efficient because it usually supplies whole buildings and not just individual apartments [16].

During HS 2016/2017 boiler rooms in district heating system of Niš were using natural gas and fuel oil. HS 2016/2017 in Niš started on 08.10.2016 and lasted until 30.04.2017 (Table 1). It lasted a total of 205 days (more than half of the year), out of which 6 days there was no heating due to high morning and daily temperatures (22-25.03.2017 and 28-29.04.2017). The average daily temperature of the heating days was 5.61°C (Table 2) [17].

Tab. 1. *A-average ambient temperature (°C), B-natural gas consumption (m^3), and C-fuel oil consumption (kg) for each month of the heating season 2016/2017 [17]*

	Oct (from 08.10.)	Nov	Dec	Jan	Feb	Mar	Apr
A	10.91	7.31	-0.01	-3.74	5.16	10.17	11.89
B	1731948	3572024	6320311	7734236	3945197	2233068	1756487
C	184186	284338	435685	578959	333903	223051	192164

Tab. 2. *Average ambient temperature and fuel consumption for the whole heating season 2016/2017 [17]*

	Whole heating season
Average ambient temperature (°C)	5.61
Natural gas consumption (m^3)	27293271
Fuel oil consumption (kg)	2232286

In the cellar of the Faculty of Sciences and Mathematics building in Niš, there is one of the 14 boiler rooms of the city's heating plant. This boiler room uses fuel oil for heat production and in the HS of 2016/2017 it spent 267814 kg of fuel oil and produced 2496 MWh of heat energy [17].

PV MODULES SOILING

In order to investigate the fly ash influence on PV modules soiling, the system of identical PV modules (Isofoton ISF-60/12, each PV module power of 60 Wp) facing south was created on the roof of the Faculty of Sciences and Mathematics in Niš. Two PV modules were placed horizontally side by side, and two more at an optimal angle (32° for Niš area) also side by side. PV modules system was placed at a 12 m distance from a chimney of a boiler room located in the cellar of the Faculty of Sciences and Mathematics building. Due to fuel oil combustion during HS, fly ash was emitted through the chimney into the atmosphere and caused PV modules soiling [18].

In this paper, the results of investigation of PV modules soiling at the beginning of the HS 2016/2017, when the average daily temperature was not below 0°C, are given. Beginning of the HS with average daily temperatures over 0°C was chosen because in that period heating intensity was not on the highest level. The measurements started on 24.10.2016 and the results for the period up to 25.11.2016 (one month, more precisely 32 days) are shown. At the beginning of the measurement, on 24.10.2016, all PV modules were cleaned. On each measurement day one horizontal and one optimally inclined (optimal) PV module were cleaned (referent PV modules), and the other two PV modules (the other horizontal and the other optimally inclined) contained fly ash accumulated from the beginning of the measurement. Measurements were performed at the same time of the day and only on clear days with no precipitation.

Figure 2 shows that at the beginning of the measurement both horizontal PV modules had power of 31.7 W (both were clean). At the end of the measurement period (32nd measurement day), clean horizontal module had power of 23.4 W and fly ash soiled PV module had power of 15.7 W. It means that after 32 measurement days power of horizontal PV module reduced for 32.9% due to fly ash soiling.

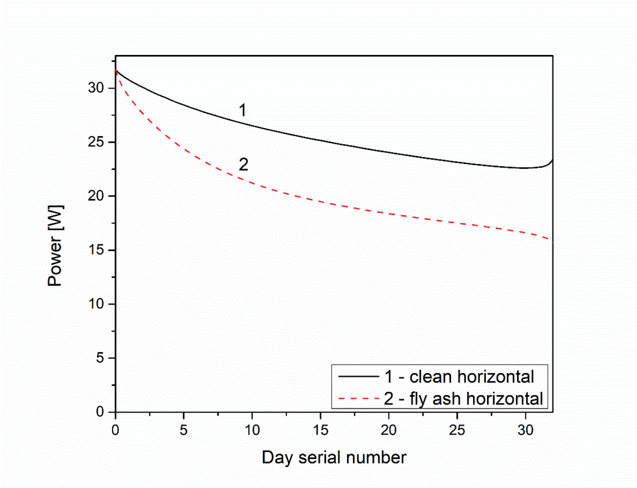

Fig. 2. *Power comparison for horizontal clean PV module (1) and horizontal fly ash soiled PV module (2) depending on the day serial number*

At the beginning of the measurement, both optimally inclined PV modules had power of 45.4 W (both were clean). At the end of the measurement period (32nd measurement day), clean optimally inclined PV module had power of 42.4 W and fly ash soiled PV module had power of 33.6 W (Figure 3). It means that after

32 measurement days power of optimally inclined PV module decreased for 20.8% due to fly ash soiling.

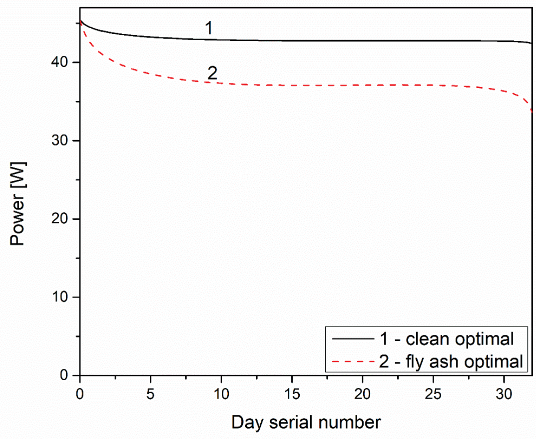

Fig. 3. *Power comparison for optimal clean PV module (1) and optimal fly ash soiled PV module (2) depending on the day serial number*

Figure 4 shows that power reduction due to fly ash soiling was always higher for horizontal PV module, as expected. Maximum power reductions of horizontal PV module (32.9%) and optimally inclined PV module (20.8%) were measured at the end of the period, i.e., after 32 days from the measurement beginning. It was experimentally confirmed that power reduction due to fly ash soiling decreases with the increase in PV modules tilt angle.

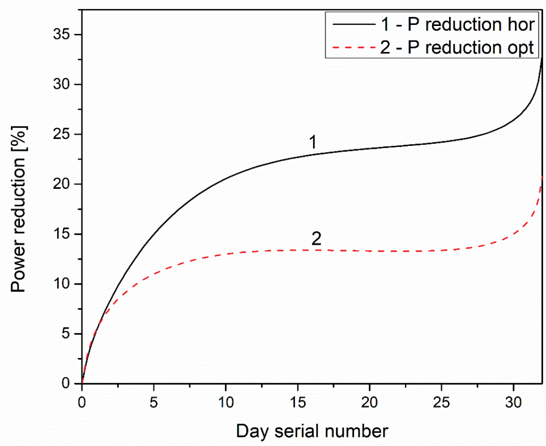

Fig. 4. *Power reduction of the horizontal and optimal PV modules due to fly ash soiling*

It can be also concluded that although measurements were performed at the beginning of the HS, power reduction of both horizontal and optimally inclined PV modules was not negligible.

Power reduction of horizontally and optimally inclined PV modules due to fly ash soiling is affected not only by heating frequency and intensity, but also by meteorological conditions (precipitation, wind direction, wind speed, relative humidity, ambient temperature, etc.) of the PV modules location. Correlation of these parameters affecting PV modules soiling can be subject of future experiments.

CONCLUSION

Serbia has favorable conditions for solar energy use. Electricity production in PV systems can be expanded in several ways, and one of them is increased installation of PV modules on the roofs.

In Serbia heat is produced almost absolutely using only fossil fuels. Like a consequence, during HS, PV systems installed near chimneys (emission sources) are affected by additional soiling caused by fossil fuels combustion. Although PV modules in Serbia are naturally cleaned by precipitation and wind, in cases of fly ash soiling they are not sufficient for reaching estimated PV modules efficiency.

This paper presents experimental results of PV modules power reduction due to fly ash soiling from a chimney of a boiler room located at the Faculty of Sciences and Mathematics in Niš, during HS 2016/2017.

It was experimentally confirmed that power reduction due to fly ash soiling was always higher for horizontal PV module. Maximum power reductions were measured after 32 days from the measurement beginning, and for horizontal PV module maximum power reduction was 32.9%, and for optimally inclined PV module 20.8%. It can be concluded that power reduction of fly ash soiled PV modules decreases with the increase in PV modules tilt angle.

Also, it can be concluded that power reduction of horizontal and optimally inclined PV modules was considerable although measurements were performed at the beginning of the HS.

In parts of the world where fossil fuels are largely used, like in Serbia, renewable energy sources should be used more frequently in order to reduce particles emission and to provide adequate conditions for maximum PV modules electricity production at the same time.

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