Original scientific papers UDK 621.311.243:620.9
DOI 10.7251/COMEN1902152R

THE INFLUENCE OF SOLAR MODULES SOILING ON THEIR ENERGY EFFICIENCY

Ivana Radonjić[1], Tomislav Pavlović[1], Dragoljub Mirjanić[2], Darko Divnić[2]*
[1] University of Niš, Faculty of Sciences and Mathematics, Department of Physics, Str. Višegradska 33, 18000 Niš, Serbia
[2] Academy of Sciences and Arts of the Republic of Srpska, Str. Bana Lazarevića 1, 78000 Banja Luka, Republic of Srpska, Bosnia and Herzegovina

Abstract: This paper deals with the influence of solar modules soiling on their energy efficiency. Soiling is the term used to describe the deposition of dust on solar modules. Dust, most often contains organic minerals and particles which result from the burning of fossil fuels, etc. In research studies investigating the influence of dust on the solar modules efficiency in the world, in the Solar Energy Laboratory at the Faculty of Sciences and Mathematics in Nis, and in the Solar Energy Laboratory at the Academy of Sciences and Arts of the Republic of Srpska, it was concluded that all types of dust negatively affect the energy efficiency of solar modules, with ash, limestone (calcium carbonate), red soil and sand (silicon dioxide) having the greatest impact.
Keywords: solar modules, soiling, dust, energy efficiency.

1. INTRODUCTION

Since the major energy crisis in 1973 renewable energy sources (solar, wind, geothermal energy, etc.) are increasingly being used. Solar cells of monocrystalline, polycrystalline and amorphous silicon and other materials are used to convert solar radiation into electricity. Systems for photovoltaic conversion of solar radiation are applied in households, agriculture, industry, etc. Solar modules are often installed on the roofs of the residential and commercial buildings, and sometimes they are integrated as roofing and facade elements.

The performance of solar modules is influenced by various factors such as: material from which the module is made, solar module tilt angle, the intensity of solar radiation falling onto the surface of the module, module surface soiling, its temperature, etc. The lifetime of solar modules is estimated at 30 years. Due to the ageing of solar module materials, their energy efficiency decreases by 0.5-1.0% per year. Metal frames of solar modules can eventually corrode under the atmospheric influences, dirt, bird droppings, etc. [1-3].

[*] Corresponding author: r_ivana_fizika@yahoo.com

2. SOLAR MODULES SOILING

Soiling is the term used to describe the deposition of dust (dirt) on solar modules. Soiling of solar modules is particularly problematic in dry areas where the amount of dust in the air is high and the amount of precipitation is low. Solar radiation is absorbed and scattered on dust that exists in atmospheric air, but it is also absorbed and scattered on the dust deposited on solar modules, resulting in decrease in the intensity of solar radiation that reaches solar cells. This may cause the entire PV system to be difficult to operate and that less electrical energy is generated.

Soiling includes not only the deposition of dust, but also the deposition by plant products, salts, bird droppings, the growth of organic species, etc, which negatively affects the performance of solar modules.

Reducing the efficiency of solar modules due to their soiling depends on the area in which they are located and on the climate characteristics of the area [1–12].

Generally, dust is a mixture of different pollutants characteristic of a particular geographical area. The word dust represents a general term for particles of any matter of diameter less than 500 μm. The important characteristics of dust are the size and distribution of its particles, density, shape, chemical composition, etc. The size and shape of dust particles, as well as the behavior of deposits and the rate of dust accumulation depend on the geographical location, climate conditions and urbanization of a particular site.

Depending on the location, the chemical composition of the dust and its quantity on solar modules can vary significantly. Dust most often contains organic minerals (mostly sand (quartz) and eroded limestone (calcite), and somewhat less dolomite and clay, etc.) and particles that result from the burning of fossil fuels, but dust can also contain small quantities of pollen and fungi, bacteria, vegetation, microfibers, etc.

Dust in the air is mainly composed of silicone because it is a chemical element that is most represented in the Earth's crust. Dust contains mostly oxygen and calcium, and slightly less aluminum, iron, magnesium, carbon, potassium, sodium, sulfur, chlorine, etc. Calcium in the dust mainly comes from industrial activities (e.g. cement factories), and partly from the permanent construction activities and degradation of building elements. There are many exceptions, bearing in mind that dust composition depends heavily on local conditions [1,2,7,9,11,13–18].

3. AN OVERVIEW OF THE IMPACT OF DUST ON SOLAR MODULES PERFORMANCE IN THE WORLD

In the papers that can be found in the available literature results of the influence of dust on solar modules performance are given. These studies are of a comparative type, i.e. they were comparing the characteristics of clean and soiled solar modules. The impact of dust deposition was tested outside or indoors. Research studies cited in the literature examined the effects of the natural and artificial dust. In this research, various types of dust were used: carbon, cement, calcium carbonate, ash, soil, sand, sandy soil, clay, talc, fine and coarser dust from the air, etc. [1,2,7,9,12,16,17,19,20].

El-Shobokshy and Hussein [21] were among the first to examine the effect of dust on the solar modules energy efficiency. They performed research in laboratory conditions, during which experimental parameters could be maintained, measured and reproduced. The purpose of their experiment was to investigate physical properties of dust particles deposited on solar modules surface, and then study the effect of dust on the degradation of solar modules performance. In this study three types of "laboratory-defined" dust, which are often present in the atmosphere, were used: limestone, cement and carbon. The laboratory experiment was carried out using 1000 W tungsten-halogen lamps with a radiation intensity of about 195 W/m^2 on the monocrystalline silicon module surface. El-Shobokshy and Hussein have concluded that the degradation of solar modules performance depends on the deposition of dust, on the type of dust and on the distribution of the size of its particles. The accumulation of fine dust (dust particles of smaller dimensions) on the solar modules surface has a much greater negative impact on their performance than the accumulation of coarser dust (dust particles of larger dimensions).

This is due to the fact that particles of finer dust are distributed more homogeneously than particles of coarser dust so that the space between particles through which light can pass in finer dust is smaller than in the coarser one. It has also been observed that the type of dust affects solar modules performance. For example, carbon particles absorb solar radiation more than limestone and cement [1,2,16,21].

Meijia and Kleissl [22] examined the effect of dust on solar modules efficiency installed at different angle of inclination on 186 different locations in the United States. Meijia and Kleissl concluded that the decrease in solar modules performance set at small tilt angles (less than 5^o) was higher, whereby the characteristics of the location were not significant [22,23].

Hammond et al. [24] concluded that bird droppings pose a greater problem for the cleaning of solar modules than dust, partly because the rain cannot completely remove it [4,16,24].

All research studies have concluded that all types of dust adversely affect solar modules energy efficiency, but that ash, limestone (calcium carbonate), red soil and sand (silicon dioxide) exert the greatest influence [1,2,12].

Although sometimes in research studies that examine the impact of dust on solar modules energy efficiency contradictory results can be found, these studies are very important because they show that the composition of dust differs at different locations in the world, and that the effect of dust on solar modules efficiency is also different in different parts of the world, which represents a good basis for further, more advanced research, etc. [16].

4. AN OVERVIEW OF THE IMPACT OF SOILING ON SOLAR MODULES PERFORMANCE IN SERBIA AND THE REPUBLIC OF SRPSKA

Bearing in mind the importance that the world assigns to investigating the effects of soiling on solar modules performance, in 2015 the Laboratory for Solar Energy at the Faculty of Science and Mathematics in Nis launched research on the influence of soiling on solar modules performance. In relation to the abovementioned, one doctoral dissertation was defended and 6 scientific papers were published.

Figure 1–4 show photos of some of the examined polutants obtained by scanning electronic microscope at the Medical Faculty of Nis.

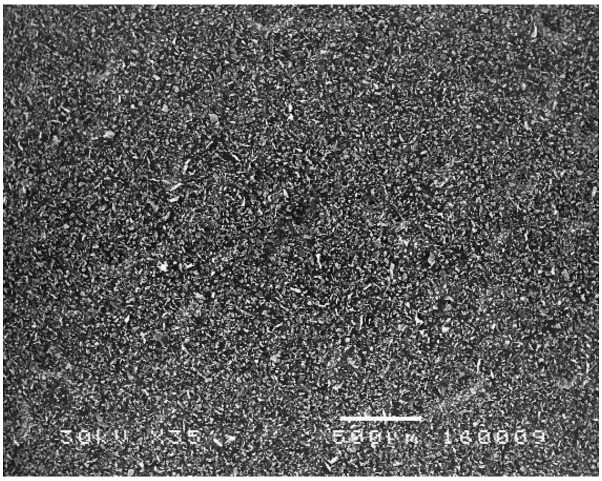

Figure 1. SEM image of carbon particles at 35x magnification [2]

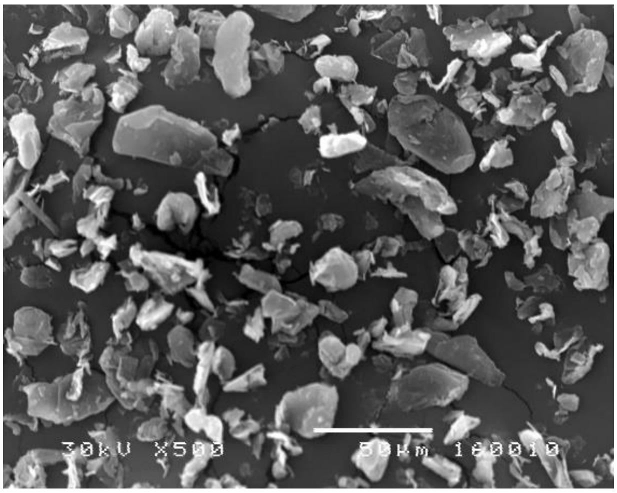

Figure 2. SEM image of carbon particles at 500x magnification [2]

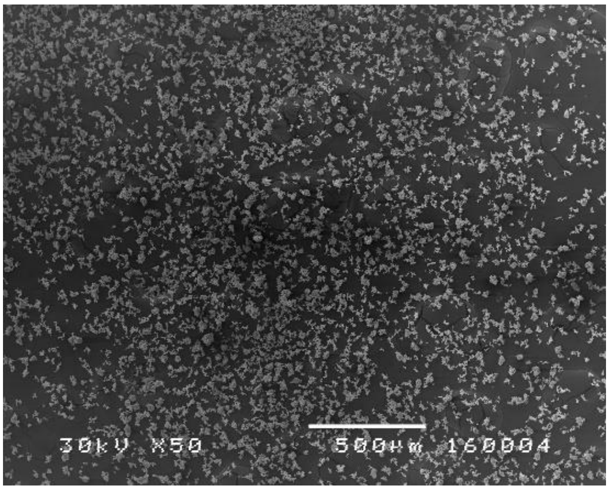

Figure 3. SEM image of $CaCO_3$ particles at 50x magnification [2]

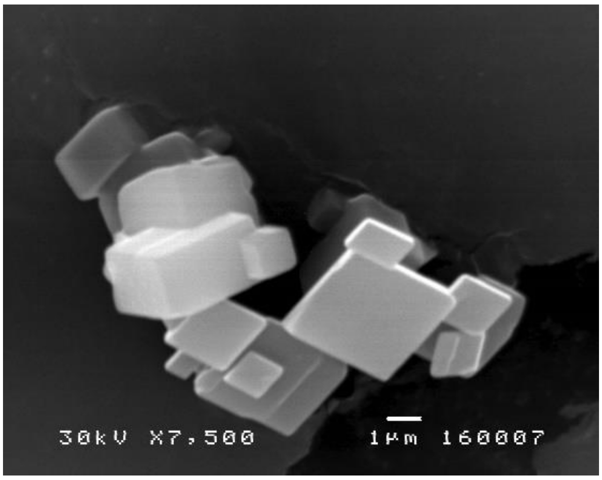

Figure 4. SEM image of $CaCO_3$ particles at 7500x magnification [2]

Figure 1 shows that the carbon particles are distributed homogeneously and densely so that the space between the particles through which the light can pass is very small. Figure 2 shows that the carbon particles have a leaf structure, are of small thickness, with a diameter of about 30 μm. Figure 3 shows that the particles of calcium carbonate are distributed homogeneously, but the space between the particles through which light can pass is larger than that of carbon particles. Figure 4 shows that calcium carbonate particles have a cubic structure, and their diameter is about 30 μm [1,2].

In previous research studies on the impact of soiling on solar modules energy efficiency in the Republic of Srpska, the analysis of the previous research in this field in the world and the installation of the system for experimental measurements in the Laboratory for Solar Energy in the Academy of Sciences and Arts of the Republic of Srpska were conducted. Regarding this, in 2019 construction of an experimental set of six same solar modules and measuring equipment for the investigation of solar module energy efficiency versus soiling with natural and artificial pollutants were started.

5. CLEANING AND MAINTENANCE OF SOLAR MODULES

Due to the soiling of solar modules, their occasional cleaning must be done.

Cleaning solar modules is performed in different ways and using different means. The most efficient cleaning agent for solar modules is water. Pressure or brush water is used to remove adhesive or muddy dirt. In rainy seasons, rain removes all dust from solar modules. However, in periods without rain (for example, in summer) accumulation of dust on the surfaces of solar modules in some areas of the world can cause daily losses of over 20%.

Solar module cleaning can also be done using an air compressor. The air compressor draws dust from solar modules, with some of the dust particles lifted in the air and hovering above the solar modules, so this cleaning method is suitable for small systems.

Figure 5. Manuel cleaning of solar modules [25]

Figure 6. Cleaning solar modules with water under pressure and brush [26]

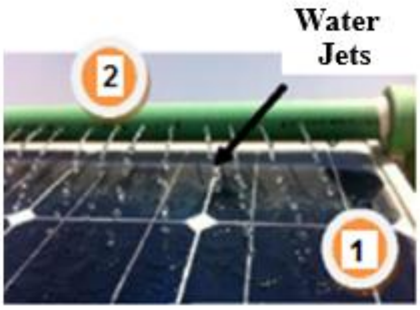

Figure 7. Nozzle system: 1) solar module, 2) pipeline with nozzles [27]

Figure 8. Cleaning solar modules with a mechanical brush system [25]

Solar modules can also be cleaned by a mechanical brush system similar to windshield wipers on vehicles. In this way, the bird droppings cannot be cleaned, nor the adhesive dust that is cemented to the surface glass of the solar module due to high humidity.

Some glass manufacturers offer special anti-soiling coatings for cover glasses of solar modules. Coatings can be hydrophobic and hydrophilic.

One of the most effective methods for cleaning solar modules is the use of self-cleaning nano-films from super-hydrophilic substances such as TiO_2.

In order to maximize the energy efficiency of solar modules, it is necessary to periodically clean them to remove the dirt deposited on their surfaces. There are general recommendations for proper cleaning and maintenance of solar modules depending on the climate conditions in which they are located.

Solar modules should not be cleaned too often to prevent damage to their protective glass [1,2,4,7,25–27].

6. CONCLUSION

The performance of solar modules is influenced by various factors such as: material from which the module is made, solar module tilt angle, the intensity of solar radiation falling onto the surface of the module, module surface soiling, its temperature, etc. Reducing solar modules' efficiency due to their soiling depends on the characteristics of the area. Dust represents a mixture of different pollutants characteristic of a particular geographical area. The size and shape of dust particles depend on the geographical location, climate conditions and urbanization of a particular site. The chemical composition of the dust and its quantity on solar modules can vary significantly, depending on the location. Dust most often contains organic minerals (mostly sand and calcite) and particles that result from the burning of fossil fuels, but dust can also contain small quantities of pollen and fungi, bacteria, vegetation, microfibers, etc.

In papers that can be found in literature, as well as in published papers based on the research conducted in the Laboratory for Solar Energy at the Faculty of Natural Sciences and Mathematics in Niš, and in the Laboratory for Solar Energy in the Academy of Sciences and Arts of the Republic of Srpska, the results of the investigation of the influence of dust on solar modules efficiency were given. In these studies, a comparison of the characteristics of clean and soiled solar modules was made, and it was concluded that all types of dust adversely affect solar modules energy efficiency, but that ash, limestone (calcium carbonate), red soil and sand (silicon dioxide) exert the greatest influence.

In the Laboratory for Solar Energy at the Faculty of Science and Mathematics in Nis one doctoral dissertation was defended and 6 scientific papers were published relating to the influence of soiling on solar modules efficiency.

In previous research studies on the impact of soiling on solar modules energy efficiency in the Republic of Srpska, the analysis of the previous research in this field in the world and the installation of the system for experimental measurements in the Laboratory for Solar Energy in the Academy of Sciences and Arts of the Republic of Srpska were performed. The formation of experimental setup for energy efficiency of soiled solar modules measuring is in progress.

Due to the solar modules soiling, their occasional cleaning must be done and the most efficient cleaning agent is water. In order to maximize solar modules energy efficiency, it is necessary to periodically clean them to remove the dirt deposited on their surfaces.

7. ACKNOWLEDGEMENT

This paper was done with the financial support of the project TR 33009 approved by the Ministry of Education and Science of the Republic of Serbia and the projects 19/6-020/961-31/18 and 19/6-020/961-30/18 approved by the Ministry of Science and Technology of the Republic of Srpska.

8. REFERENCES

[1] I. S. Radonjić Mitić, *Investigation of energy efficiency of PV solar modules depending on their soiling in real climate conditions in Nis*, Doctoral dissertation, University of Nis, Faculty of Sciences and Mathematics, Department of Physics, Nis, 2018.

[2] I. S. Radonjić et al., *Investigation of the impact of atmospheric pollutants on solar module energy efficiency*, Thermal Science, Vol. 21–5 (2017) 2021–2030.

[3] I. S. Radonjić, T. M. Pavlović, *Investigation of the energy efficiency of horizontally mounted solar module soiled with $CaCO_3$*, Facta Universitatis: Series Physics, Chemistry and Technology, Vol. 15–2 (2017) 57–69.

[4] J. Cano, *Photovoltaic Modules: Effect of Tilt Angle on Soiling*, A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in Technology, Arizona State University, 2011.

[5] H. M. Ali et al., *Effect of Dust Deposition on the Performance of Photovoltaic Modules in Taxila, Pakistan*, Thermal Science, Vol. 21–2 (2017) 915–923.

[6] M. A. Bashir, et al., *An Experimental Investigation of Performance of Photovoltaic Modules in Pakistan*, Thermal Science, Vol. 19–2 (2015) S525–S534.

[7] G. Picotti et al., *Soiling of solar collectors - Modelling approaches for airborne dust and its interactions with surfaces*, Renewable and Sustainable Energy Reviews, Vol. 81–2 (2018) 2343–2357.

[8] F. M. Zaihidee et al., *Dust as an unalterable deteriorative factor affecting PV panel's*

efficiency: Why and how, Renewable and Sustainable Energy Reviews, Vol. 65 (2016) 1267–1278.

[9] A. Sayyah, M. N. Horenstein, M. K. Mazumder, *Energy yield loss caused by dust deposition on photovoltaic panels*, Solar Energy, Vol. 107 (2014) 576–604.

[10] J. Tanesab et al., *The contribution of dust to performance degradation of PV modules in a temperate climate zone*, Solar Energy, Vol. 120 (2015) 147–157.

[11] E. Klugmann-Radziemska, *Degradation of electrical performance of a crystalline photovoltaic module due to dust deposition in northern Poland*, Renewable Energy, Vol. 78 (2015) 418–426.

[12] W. Javed et al., *Characterization of dust accumulated on photovoltaic panels in Doha, Qatar*, Solar Energy, Vol. 142 (2017) 123–135.

[13] G. B. Hoidale et al., *A study of atmospheric dust, Atmospheric science laboratory*, White Sands Missile Range, New Mexico, 1967.

[14] C. L. C. Tan et al., *Adhesion of Dust Particles to Common Indoor Surfaces in an Air-Conditioned Environment*, Aerosol Science and Technology, Vol. 48 (2014) 541–551.

[15] S. A. M. Said, H. M. Walwil, *Fundamental studies on dust fouling effects on PV module performance*, Solar Energy, Vol. 107 (2014) 328–337.

[16] T. Sarver, A. Al-Qaraghuli, L. L. Kazmerski, *A comprehensive review of the impact of the dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches*, Renewable and Sustainable Energy Reviews, Vol. 22 (2013) 698–733.

[17] Z. A. Darwish et al., *Effect of dust pollutant type on photovoltaic performance*, Renewable and Sustainable Energy Reviews, Vol. 41 (2015) 735–744.

[18] H. K. Elminir et al., *Effect of dust on the transparent cover of solar collectors*, Energy Conversion and Management, Vol. 47 (2006) 3192–3203.

[19] M. Mani, R. Pillai, *Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations*, Renewable and Sustainable Energy Reviews, Vol. 14 (2010) 3124–3131.

[20] S. Mekhilef, R. Saidur, M. Kamalisarvestani, *Effect of dust, humidity and air velocity on efficiency of photovoltaic cells*, Renewable and Sustainable Energy Reviews, Vol. 16 (2012) 2920–2925.

[21] M. S. El-Shobokshy, F. M. Hussein, *Effect of dust with different physical properties on the performance of photovoltaic cells*, Solar Energy, Vol. 51 (1993) 505–511.

[22] F. A. Mejia, J. Kleissl, *Soiling losses for solar photovoltaic systems in California*, Solar Energy, Vol. 95 (2013) 357–363.

[23] S. C. S. Costa, A. S. A. C. Diniz, L. L. Kazmerski, *Dust and soiling issues and impacts relating to solar energy systems: Literature review update for 2012-2015*, Renewable and Sustainable Energy Reviews, Vol. 63 (2016) 33–61.

[24] R. Hammond et al., *Effects of soiling on PV module and radiometer performance*, In: Proceedings of the 26th IEEE PVSC, Anaheim, New York, 1997, 1121–1124.

[25] M. Köntges et al., *Assessment of Photovoltaic Module Failures in the Field*, Report IEA-PVPS T13-09:2017, 2017.

[26] S. Ghazi, A. Sayigh, K. Ip, *Dust effect on flat surfaces-A review paper*, Renewable and Sustainable Energy Reviews, Vol. 33 (2014) 742–751.

[27] K. A. Moharram et al., *Influence of cleaning using water and surfactants on the performance of photovoltaic panels*, Energy Conversion and Management, Vol. 68 (2013) 266–272.

ନ୧

УТИЦАЈ ПРЉАЊА СОЛАРНИХ МОДУЛА НА ЊИХОВУ ЕНЕРГЕТСКУ ЕФИКАСНОСТ

Апстракт: Овај рад се бави утицајем прљања соларних модула на њихову енергетску ефикасност. Прљање је израз који се користи како би се описало падање прашине на соларне модуле. Прашина, најчешће садржи органске минерале и честице које су посљедица сагоријевања фосилних горива, итд. У истраживањима у којима се анализира утицај прашине на ефикасност соларних модула у свијету, у Лабораторији за соларну енергију на Природно-математичком факултету у Нишу и у Лабораторији за соларну енергију на Академији наука и умјетности Републике

Српске, закључено је да све врсте прашине негативно утичу на енергетску ефикасност соларних модула, с тим што пепео, кречњак (калцијум-карбонат), црвена земља и пијесак (силицијум-диоксид) имају највећи утицај.

Кључне ријечи: соларни модули, прљање, прашина, енергетска ефикасност.

Paper received: 1 August 2019
Paper accepted: 10 October 2019