U.P.B. Sci. Bull., Series C, Vol. 80, Iss. 3, 2018 ISSN 2286-3540

THE INFLUENCE OF DUST DEPOSITION ON THE ENERGY PERFORMANCE OF THE PHOTOVOLTAICS

Alexandra DANU[1], Diana Mariana COCÂRȚĂ[2], Vladimir TANASIEV[2], Adrian BADEA[3]

The photovoltaic panel efficiency is strongly influenced by their angle, shading, dust, temperature, solar radiation. Dust dispersion and amount on the surface conduct to impermissible energy losses. The experiments investigate the atmospheric particulate matter influence on the photovoltaic panel and showed that the percentage of the produced energy diminished as a function of dust deposition rate. They demonstrated that the panel starts to lose more than 30% of its efficiency when covered with more than 14g/m2 and showed significant power loses when its surface is covered with more than 84,3g/m2 of dust and the output power drops considerably, under 64,69%.

Keywords: photovoltaic panels, dust deposition, energy losses, particulate matter

1. Introduction

The Sun is an unlimited energy source. Nowadays, the population needs 15TWh of power and the solar radiation that reaches the Earth on a continuous basis amount to 120000TWh. In this case, just a fraction of this power would cover the energy requirements. Photovoltaic technology has been experiencing a rapid growth rate in the recent years, which translates into over 30GW of the global installed peak power [1].

Among other things, the energy production of photovoltaic panels is also strongly influenced by the amount of dust deposited on their surface. Optimists say that this energy loss is up to 10% while pessimists appreciate that it can reach up to 40% [2]. The dust consists of very fine solid particles from natural fragmentation of the Earth's crust, solid bodies or from biological processes of the living beings. Additionally, atmospheric particulate matter pollution which could be released directly from a specific source or could be formed through complex chemical reactions in the atmosphere is a source of dust that can be deposited on

[1] Ph.D., Scientific researcher, INCDE ICEMENERG, Bucharest; Faculty of Power Engineering, University POLITEHNICA of Bucharest, Romania, alexandra.danu@gmail.com, Romania;
[2] Lecturer, Faculty of Power Engineering, University POLITEHNICA of Bucharest, Romania;
[3] Prof., Faculty of Power Engineering, University POLITEHNICA of Bucharest, Romania, Academy of Romanian Scientists.

panels' surface. Dust particles have sizes between 0,1µm and 500µm and may contain pollen, fungi, bacteria, dead cells, microfibers etc.

Although the composition of the dust has been studied for more than seven decades, its influence on the energy transfer from the Sun to solar panels is not fully understood. The effect of the dust deposition on photovoltaic modules leads to impermissible energy losses [3]. This study is focused on the influence of the dust particles with a diameter bigger than 100µm on the photovoltaic (PV) panels. The adhesion forces of the particles on flat surfaces increases with the size of the particle due to a bigger contact area. The deposition of dust on the PV module glass reduces the glass transmittance and hence reduces the modules power output [4]. The factors that are influencing dust deposits on the photovoltaic panels are: the particles characteristics (size, density, shape, composition and electrical charge), the texture of the PV surface, the dust distribution and the angle of the solar panel [5], the outdoor temperature, humidity, vegetation, pollution and wind speed. Considering the factors previously mentioned it can be noticed that dust deposition increases substantially during summer dry periods. Consequently, a solution for this occurrence is cleaning of the panels with specialized equipment [6].

The dust affects the PV module performance by diminishing the diffusivity coefficient of the PV glass cover. Generally, increasing dust deposition leads to decrease PV module performance [7,8,9], due to the decrease in glass cover spectral and overall transmissivity [10,11,12]. Different studies have quantified the amount of PV performance reduction due to dust deposition rates [13,14]. The reduction in PV module conversion efficiency was 10%, 16% and 20% for 12,5g/m^2, 25g/m^2 and 37,5g/m^2 dust density [15]. It has been observed that PV module efficiency reduction range between 0% to 26% when the dust deposition increased from 0g/m^2 to 22g/m^2 [16].

Garg [17] studied in 1974 the effect of dust accumulation on glass and plastic plate's transmittance, exposed to outdoor conditions for two months in India. The results indicated that the plastic showed more transmittance reduction than the glass. A similar conclusion was reached by Nahar and Gupta [18] who noticed that the PVC plate has more transmittance reduction than acrylic and glass. The frequency of PV system cleaning depends on the prevalent climatic and environmental conditions [19]. In Romania, the optimal period to remove the impurities from the PV modules is between March and October, because in this period, the solar radiation represents 80% from the total energy for the entire year. The companies dealing with the cleaning of PV panels recommend two washes per year [20,21].

In order to establish the influence of dust deposits on the productiveness of photovoltaic panels a series of experiments were conducted. In this regard, the first experimental setup establishes the influence of impurities deposition on photovoltaic cells' temperature by using pictures of photovoltaic panels taken with a thermal imaging camera followed by an experiment which aimed at determining the concentration of dust particulate matters from the air in correlation with a third experiment whose purpose was to determine the dust from the atmosphere that can be settled on a flat surface. The last experiment concentrates the most important work of the current paper by presenting the electrical measurements of a photovoltaic panel covered with different amounts of dust to establish the influence of dust on photovoltaic panel yield. The main conclusions of the current research are presented in the last chapter.

2. Material and methods

2.1. Location

The experiment on photovoltaic panels dust deposition was conducted on the installation at the Passive House Laboratory, the Faculty of Power Engineering, University POLITEHNICA of Bucharest (Fig. 1). The photovoltaic panel was placed on the Southern façade of the Passive House in order to benefit from direct solar radiation and to perform an accurate experiment.

The installation is composed of a BP Solar SX40U PV panel, a Keithley data logger and a computer, which stored the collected data. The data acquisition system collected the temperature using two sensors, the solar radiation and the voltage of the PV panel.

Fig. 1. BP Solar SX40U connected to Keithley data logger

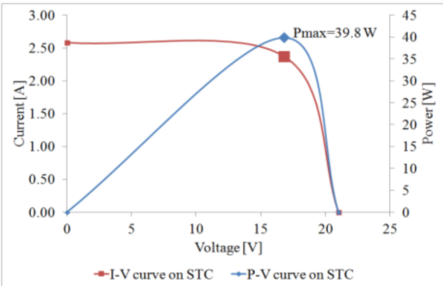

Fig. 2. BP Solar SX40U I-V and P-V operation curves

The PV BP Solar SX40U panel used has 36 series of multicrystalline cells [22]. In standard test conditions (STC) (STC: 1000 W/m^2, T_{cell} = 25ºC, AM air mass = 1, 5) the maximum power guaranteed by the producer is 40W for BP Solar SX40U. The rest of PV panel's parameters are illustrated in Table 1.

Table 1

Photovoltaic panel technical specification for BP Solar SX40U 40W

Parameters	Value	Parameters	Value
Maximum Power (P_{max})	40,00W	Guaranteed minimum power	36,00W
Voltage at maximum power V_{pm}	16,80V	Short-circuit current I_{sc}	2,58A
Current at maximum power I_{pm}	2,37A	Open-circuit voltage V_{oc}	21,00V

In Fig. 2 are presented the I-V and P-V operating curves on STC, in order to have a better understanding of the experiments' results. The Maximum Power Point (MPP) is situated at 39,81W for BP Solar SX40U.

2.2. Hotspots on photovoltaic panels

The deposits left by birds, dust and pollution from traffic or agricultural activities diminish the efficiency of the photovoltaic panels by up to 20% in summer. Some deposits of dust and dirt create shading effect that leads to the overheating of the panels; as a result, the supplied energy decreases. Some effects include partial or total destruction of the encapsulating material. Other factors, such as panel orientation and the nature of collector panel surface influence the dust deposition [23].

Frequent removal is very important because consistent dust deposits lead to permanent losses represented by hotspots [24]. Hotspots occurrence is caused by partial shading and interconnection of the PV modules with various performances. When a PV cell does not receive enough solar radiation it becomes a consumer by getting reverse polarity and dissipating heat. This defect can be easily detected using thermal imager with IR-Fusion Technology [25].

2.3. High Volume Sampler for identification of the ambient air Total Suspended Particulate Matter (TSP)

In order to identify the Total Suspended Particulate Matter (TSP) in the university campus atmosphere was used a high-volume sampler (HVS) (Fig.3). The experiment was conducted at the end of July 2015. The sampling head used for the experimental study is retaining the particles with a diameter less than 100μm.

Fig. 3. High Volume Sampler (HVS) for the ambient air TSP identification

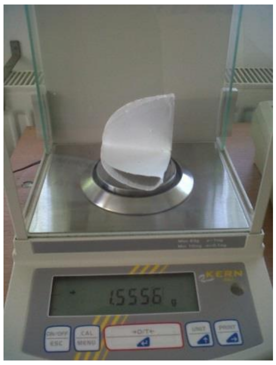

Fig. 4. Weighing the filter after sampling

The experiment was performed twice using different sampling rates: 200l/min and 500l/min. First, the filters were weighed on electronic scales with five decimal places; afterwards, the same operation was performed considering

24-hour sampling (Fig. 4) according to the Romanian Standard STAS 10 813–76, ‘Determination of particulate matter’.

The samples and the filters were weighted with the same scales, in the same conditions. Identification of dust deposition

2.4. Identification of dust deposition

The method for the determination of the particulate matter from the atmosphere which is settling under the gravity and precipitation is set by the standard STAS 10195-75, “Determination of settable particulates”. The method consists in collecting the dust from the atmosphere in a glass pot with a known surface area in a known time interval in order to determine their mass. For the sampling campaign it was used a device constructed as specified in the above-mentioned standard and illustrated in Fig. 5. The support was two-meters and was made of stainless steel. The support and the vessel were located outside such that it was protected from any interference with other sources of contamination.

During the experiment, the pot was left outside for 34 days between 30th of April and 2nd of June, 2015. Water was poured into the pot up to a level of three centimetres from the bottom of the pot shown in Fig. 5 it was replenished during the experiment as it evaporated due to high temperatures. The impurities, leaves and insects were washed out with distilled water above the pot with the aim of limiting the dust measurement errors.

The content of the pot was brought into a ceramic cup with a spout using a glass rod provided with a rubber sleeve at one end. The water and the dust sample was dried out by heating below water boiling point of 100°C until the dust mass could be set using a hot plate.

In order to determinate the dust mass, the ceramic cup was weighed before the use and after the dust was collected into the cup (Fig. 6). The difference between the two masses represents the amount of collected dust.

Fig. 5. Dust depositing device

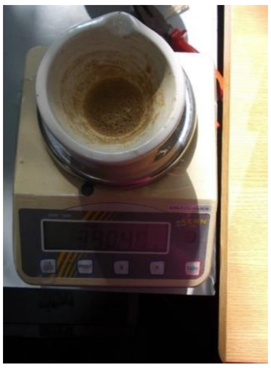

Fig. 6. Ceramic cup with a mass of dust

2.4 Influence of dust deposits on photovoltaic panels parameters

The third experiment included an exposure of the BP SX40 photovoltaic panel to real environmental conditions for two weeks, during summer, with no rainfall. During the experimental exposure 1,72g of dust settled on the 0,36m^2 photovoltaic panel surface (Fig. 7) which means that the dust deposition rate in the campus of University POLITEHNICA of Bucharest is 9,56g/m^2/month, comparable with the amount of 11,70g/m^2/month established previously by means of the national standard "Determination of the setteable particulates".

Fig. 7. Photovoltaic panel covered by 1,72g during 2 weeks in summer

Fig. 8. PV panel covered with 5 grams of dust – 6th of July 2015

In order to analyze the influence of different dust deposition rates on the electrical parameters, the PV panel was coated with different amounts of dust. One of the experiments was conducted on 6th of July 2015, when the average solar radiation was 976W/m^2 and the ambient temperature was 36°C. The photovoltaic panel was covered with 5g (Fig. 8), 10g and 30g of dust. Various dust depositions of 25g, 50g and 70g were subjected to the same weather conditions: an average temperature of 36°C and a mean solar radiation of 1008W/m^2 on 23rd of June 2015. In the spring of 2015 several experiments were conducted using different amounts of dust (100g/PV, 150g/PV, 260g/PV, 340g/PV–Fig. 9). The ambient temperature fluctuated between 19°C and 25°C and the radiation had an average of 943W/m^2. In order to observe the influence of dust on PV temperature a dust covered PV panel was photographed with a thermal image camera (Fig. 10).

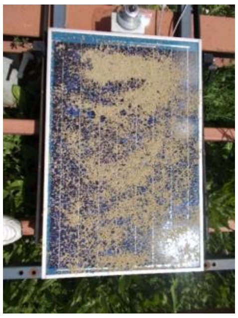

Fig. 9. PV covered with 340g dust

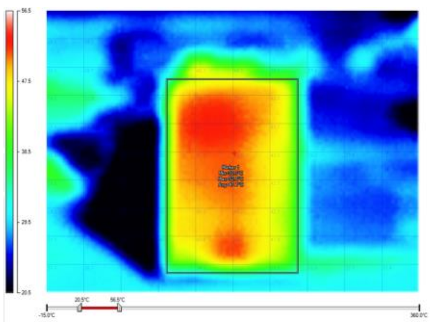

Fig. 10. IR picture of 340g dust covered PV panel

Fig. 10 is the infrared picture of the photovoltaic panel covered with 340g of dust. The picture shows a minimum of 30,3°C, a maximum of 52,8°C and an average temperature of 47,1°C in the temperature distribution of PV panel.

Corresponding graph from Fig. 11 shows the quantitative temperature distribution on the surface of the PV panel. The diagonal diagram shows a temperature variation between 30,3°C and 52,8°C.

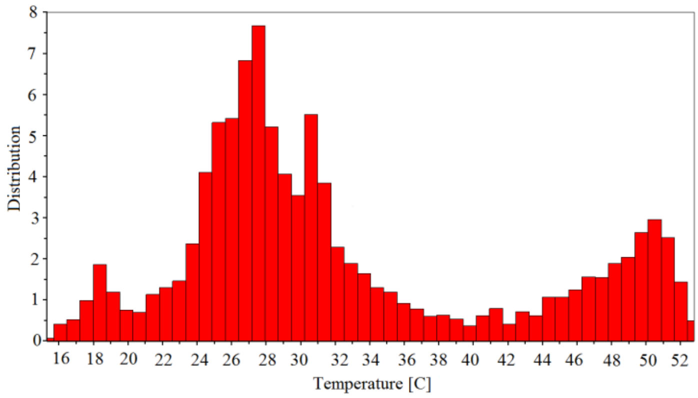

Fig. 11. PV panel covered with 340g dust histogram

The goal of the described experiments was to determine the influence of dust deposition on photovoltaic panels in Romanian climate conditions. The results are discussed in the next section.

3. Results and discussion

3.1. Hot-spots on photovoltaic panels

The first step in studying the dust impact on PV panels was to compare two PV systems, one connected and one not, in terms of the long-time impact of dust on PV cells using thermal imaging**.** In this regard, measurements were made using Fluke thermal imager TI 200 [26]. In the figures below are presented two Schott Solar 225 polycrystalline PV panels, one in open circuit mode (Fig. 13) and one connected to a consumer (Fig. 12). The images suggest that losses caused by the increased temperature of the PV cell are easily perceptible to the thermal imager proving that coating the PV panels inevitably leads to a lower energy production. Any dust deposition or cell defects influence the current intensity circulation in the neighborhood of the affected cell [27].

Pictures taken to inoperative PV panels (Fig. 13) with no hot-spots were analyzed for comparison. The photos were taken on 29th of September 2014; the ambient temperature was 22°C and the average temperature of the panel area was 35,49°C.

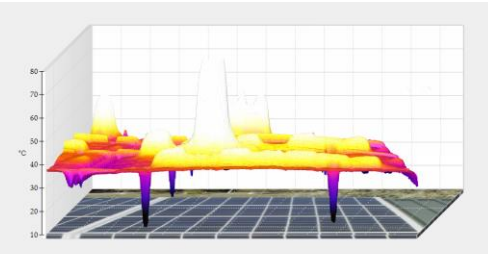

Fig. 12. Histogram of the PV panel connected to a consumer

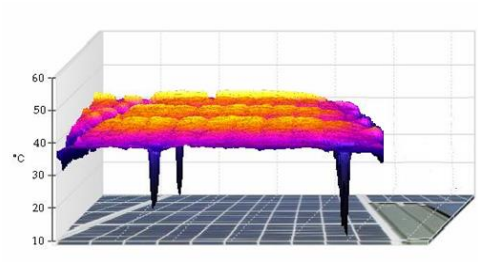

Fig. 13. Histogram of the PV panel in open-circuit function mode

In the next image, which was taken of a connected and used PV panel, it can be noticed the temperature differences between PV cells properly and badly functioning. Looking at the second and third circled area was found large differences in terms of temperatures up to 22°C (Fig. 14).

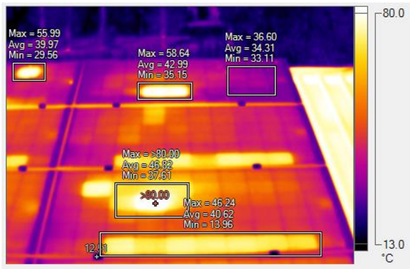

Fig. 14. Hot spots on PVs

So, it can be noticed that dust and dirt deposits irremediably affect photovoltaic cells, and create a domino effect on neighbouring cells conducting to inoperative large areas of the photovoltaic panel.

3.2. High Volume Sampler for identification of the ambient air Total Suspended Particulate Matter (TSP)

The next step in this research was to establish the Total Suspended Particulate Matter in the university campus atmosphere and the dust deposition rate in order to determine the air pollution that helped the experiments take place. Results are summarized in Table 2:

Table 2

Total Suspended Particulate Matter in ambient air and sampling parameters:

Sampling / date	E_1: 23-24 June 2015	E_2: 24-25 June2015
Inlet air volume [m^3]	286,77	716,64
Concentration [µg/m^3]	29,99	34,05

The concentration of the TSPM in ambient air from the Passive House UPB area is 29,99µg/m^3 for the first experiment and 34,05mg/m^3 in the case of the second experiment. With an average of 32,02mg/m^3 of dust deposition, the rate is well situated below the permissible amount of pollution of 150µg/m^3 according to the threshold from Decree 592/2002 [28].

3.3. Identification of dust deposition

The sediment particles mass is expressed in g/m^2/month and is calculated using the following mathematical relations from STAS 10195-75:

$$PS = \frac{\Delta m}{S} \cdot \frac{30}{n} \left[\frac{g}{m^2 \cdot month}\right]$$

$$PS = \frac{\Delta m}{\pi r^2} \cdot \frac{30}{n} \left[\frac{g}{m^2 \cdot month}\right]$$

$d = 0.242\ [m]$

$r = 0.121\ [m]$

$n = 34$

$\Delta m = 390.47 - 389.86\ [g]$

$\Delta m = 0.61\ [g]$

$$PS = \frac{0{,}61}{0{,}121^2 \pi} \cdot \frac{30}{34} \left[\frac{g}{m^2 \cdot month}\right]$$

$$PS = 11.7017 \left[\frac{g}{m^2 \cdot month}\right]$$

where: PS[g/m^2/month] are the sediment particles, m[g] is the mass of settled particles; S[m^2] is the area of the vessel sedimentation, d[m] is the diameter of the sedimentation surface, r[m] is the radius of the sediment surface and n is the number of days of exposure.

At the end of the experiment, it was found that in the area of University POLITEHNICA of Bucharest 11,70g/m^2/month are deposited in a month of the summer season while the deposition surface was not influenced by wind or washed by rain.

3.4. Influence of dust deposits on photovoltaic panels parameters

The estimation obtained was validated by another experiment made in the framework of the present study. This consisted of a two-week exposure of a PV panel when it was found that the dust deposition rate in the campus is 9,56g/m^2/month, comparable with the amount of 11,0g/m^2/month established previously. Following the analysis of the experimental data, the photovoltaic panel parameters showed a reduction of the peak power down to 85,26% from the STC (Table 3). Open-circuit voltage had an average of 18,06V under a solar radiation of 920,12W/m^2 and a mean environment temperature of 24°C close to 21V established in STC.

Considering the low level of particulate matter air pollution in the investigated area and in order to be able to study the influence of dust deposits on photovoltaic panels' parameters it was decided to use manually and controlled deposition of different quantities of dust on the photovoltaic panels. The electrical parameters were measured, and operating curves were obtained for each case.

In Fig. 15 and Fig. 16 can be observed that the maximum power point does not drop very much when the PV panel is covered with 5g, 10g and 30g of dust reaching values of 31,08W, 28,13W and 25,23W, respectively.

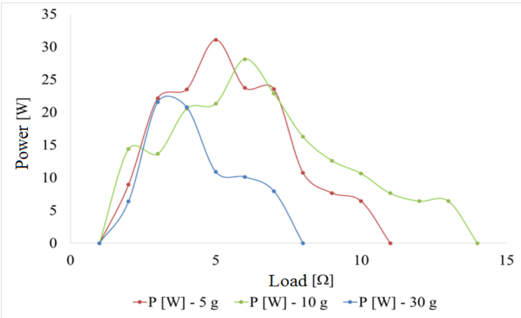

Fig. 15. Power and PV panel dust coverage – 6th of July 2015

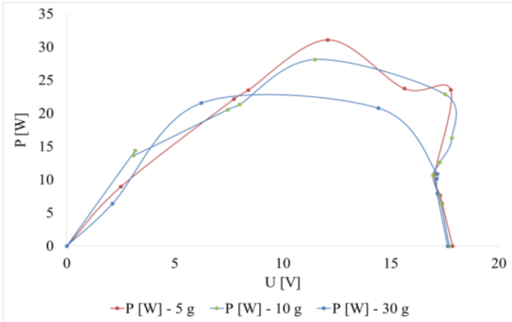

Fig. 16. Power -Voltage operating curves – 6th of July 2015

Studies have showed that the temperature plays an important role in photovoltaic panels' energy efficiency [29]. Open-circuit voltage is strongly influenced by the PV panel temperature of 63°C and varies slightly with the solar radiation captured by the photovoltaic panel, as can be seen in Fig. 17.

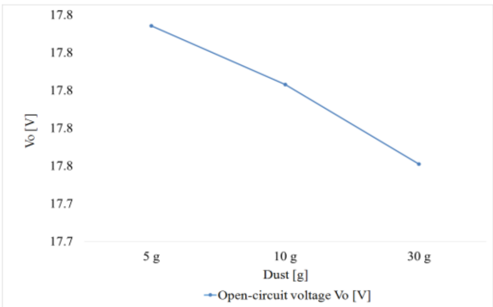

Fig. 17. Open-circuit voltage – 6th of July 2015

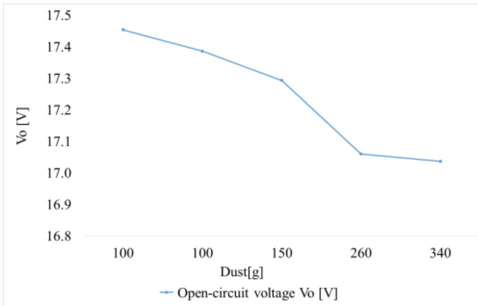

Fig. 18. Open-circuit voltage on 23rd of June 2015

Open-circuit voltage presented in Fig. 18 is another important parameter that shows how photovoltaic panel efficiency diminishes as a function of dust deposition. Open-circuit voltage has a slow decrease in comparison with other electrical parameters such as power and current intensity.

Fig. 19, Fig. 20, and Fig. 21 are representations of the measurements made on the photovoltaic panel. Fig. 19 shows how power curve decreases depending on the dust deposition on the PV surface to a maximum of 26,02W for 25g/PV, a maximum of 14,69 W for 50g/PV and respectively 11,87W maximum output power for 70g/PV. These values are compared to the maximum STC peak power of 39W.

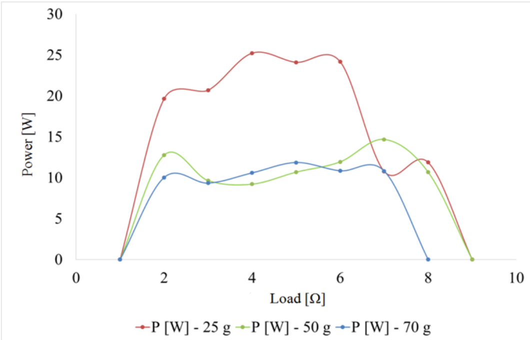

Fig. 19. P-V operating curves - 23rd of June 2015

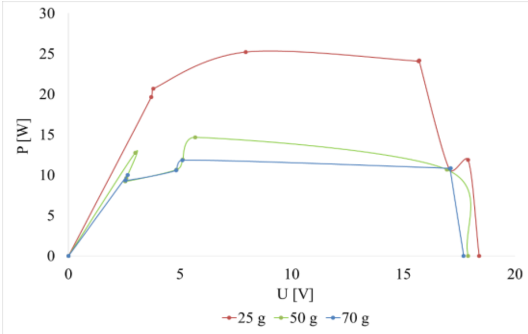

Fig. 20. Power -Voltage operating curve - 23rd of June 2015

The operating curve represented in Fig. 20 shows a 50% decrease of the photovoltaic panel efficiency when PV surface is covered with 25g and 50g of dust.

Fig. 21 shows a sharp decrease in maximum power point when the PV panel is covered with considerable amounts of dust. The power output drops down to 3W.

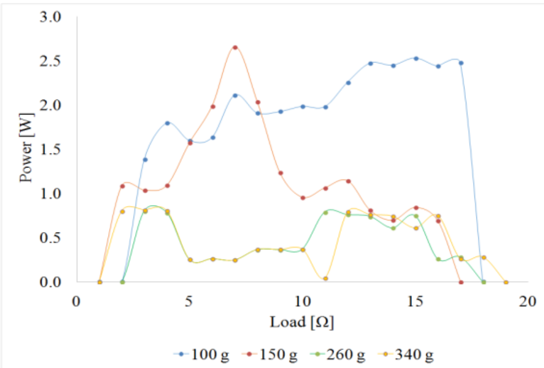

Fig. 21. Operating curves for different dust coverages of the PV panel

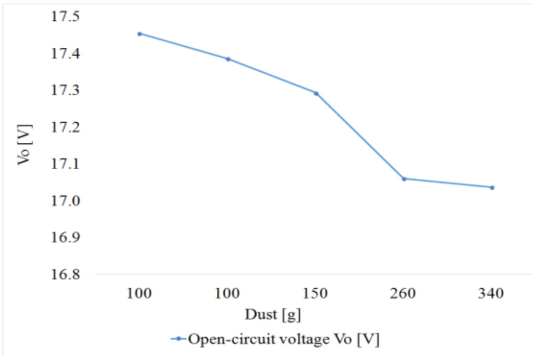

Fig. 22. Open-circuit voltage and dust coverage

Open-circuit voltage acts in the same way as in very poor lighting conditions (sunrise and sunset – Fig 22).

Photovoltaic panel parameters analyzed in different stages of dust coverage are summarized in table 3. It can be easily observed that for more than 84,3g/m^2 the output PV power starts to drop considerably, under 64,69%. Covering the PV panel with more than 280g/m^2, it becomes obviously that the output power is insignificant. Table 3 summarizes open-circuit voltage variation and maximum power panel provided under various dust PV panel coating.

Table 3

PV panel electrical parameter measurements

Dust amount [g]	PV temperature [°C]	Environment temperature [°C]	Solar radiation [W/m²]	Open-circuit voltage V_o [V]	Maximum power [W]	Percentage of power in STC conditions [%]	Dust mass [g/m²]
0	25	25	1000	21	39	100	0
1,72	63,45	36,25	1000,02	18,06	33,25	85,26	9,56
5	63,59	36,36	990,91	17,79	31,08	79,69	14,05
10	63,35	35,99	979,33	17,77	28,13	72,13	28,1
30	60,64	35,93	933,01	17,75	25,23	64,69	84,3
50	58,16	37,79	1070,92	17,73	14,69	37,67	140,51
70	56,05	36,23	940,64	17,62	11,87	30,44	196,71
100	16,27	4,33	947,29	17,45	6,18	15,85	281,01
100	25,46	20,63	920,19	17,39	2,66	6,82	281,01
150	29,92	24,51	951,02	17,29	2,58	6,62	421,52
260	20,08	19,73	913,15	17,08	2,53	6,49	730,64
340	20,11	19,8	985,39	17,06	0,81	2,08	955,45

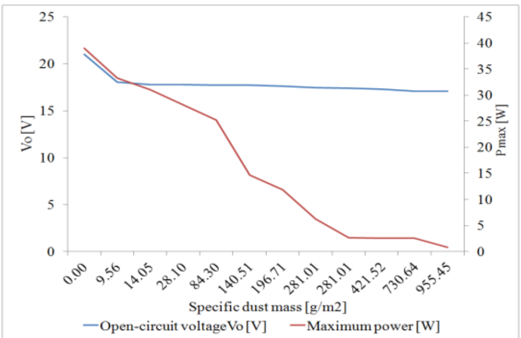

Fig. 23. Open-circuit voltage and peak power depending on dust PV panel coating (1,72g – 340g)

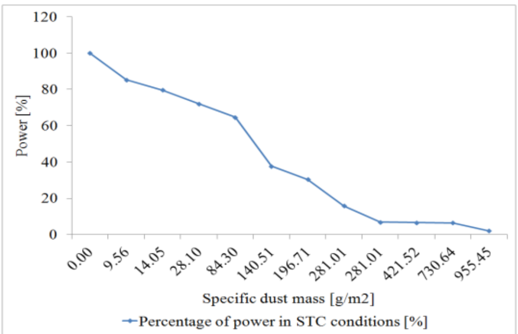

Fig. 24. Influence of dust deposition on maximum power point

Fig. 23 and Fig 24 show significant reductions of the maximum power point with the increase of dust deposition on the PV panel. A 9,56g/m^2 dust deposition brings a decline up to 15% of the STC peak power under STC and 14g/m^2 reduce the maximum power point within 20%.

4. Conclusions

This paper is a targeted study of the impact of dust deposition on photovoltaic panels' efficiency. In order to determine the influence of the ambient air particle deposition on the energy performance of photovoltaic cells both by obstructing the solar radiation and by increasing the photovoltaic cells temperature four different experiments were performed. Analyzing the measurements, it was concluded that in the campus University POLITEHNICA of Bucharest the influence of dust deposition on the operation of photovoltaic panels is insignificant thanks to the small amount of dust deposited in natural conditions of $11 g/m^2$.

The maximum power point decrease of a polycrystalline photovoltaic panel south ward oriented depends on dust amount coverage. Through repeated experiments of covering a photovoltaic panel with different amounts of dust both in winter and in summer it was concluded that more than 14 g/m^2 make a polycrystalline photovoltaic panel lose more than 30 % of its efficiency in comparison with the power supplied in normal operating conditions.

Regarding future research related to the influence of particle deposition from ambient air on the PV's energy performance, the following issues could be considered: • evaluation of the influence of different particle types of particles with different diameters (PM10, PM50, PM100 and PM500) on photovoltaic panels' energy performance; and • identification of a maximum level of dust concentration in the air that does not have a negative influence on the photovoltaic panels.

Acknowledgment

This paper has been funded by the Sectorial Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398, by the Program "Parteneriate" in priority areas – PN II carried out by MEN-UEFISCDI, project No. 47/2014 and Erasmus+ through financial agreement 2014-1-RO01-KA203-002986. The paper was also partially supported under the SOP IEC POSCCE-A2-O2.3.1.-2008-1, ECORISK ID1262, SMIS-CSNR: 38629, ctr. 393/01.08.2012 and PNII-RU-TE2014-4-2348/REMPET project, ctr. no 354/01.10.2015.

R E F E R E N C E S

[1]. Research: Energy, Alliance of Scientific Organisation;
[2]. *Ing. Stefan Oniga*, Privitor la instalatii de energie regenerabila, Efectul depunerilor de praf asupra panourilor solare fotovoltaice, Cluj Napoca
[3] Bagnold RA, The physics of blown sand and desert dust. London: Methuen and Co. Ltd; 1965
[4] *Syed A.M. Said, Husam M. Walwil*, Fundamental studies on dust fouling effects on PV module performance
[5] *E. Suresh*, Dust impact on efficiency in photovoltaic modules, Kalkata University-700-032
[6] http://spalarepanourifotovoltaice.ro
[7] *Mohammad S. El-Shobokshy, Fahmy M. Hussein*, Degradation of photovoltaic cell performance due to dust deposition on to its surface
[8] *Kaldellis, J., Fragos, P.*, et al., 2011. Systematic experimental study of the pollution deposition impact on the energy yield of photovoltaic installations. Renew. Energy 36 (10), Pp. 2717–2724

[9] *Otsuka et al.*, 1988. Measurement of the adhesive force between particles of powdered materials and a glass substrate by means of the impact separation method III: effect of particle shape and surface asperity, Chem. Pharm. Bull. 36 (2), Pp. 741–749
[10] *Adel A Hegazy et all*, Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors, Renewable Energy, Volume 22, Issue 4, Pp. 525–540, 2001
[11] *H. Elminir, A. Ghitas, R.H. Hamid, F. El-Hussainy, M.M. Beheary, K. Abdel-Moneim*, Effect of dust on the transparent cover of solar collectors, Energy Conversion and Management 47, Pp. 3192–3203, (2006)
[12] *H. Qasem, T. Betts, H. Müllejans, H. AlBusairi, R. Gottschalg*, Dust-induced shading on photovoltaic modules, Publication Progress in Photovoltaics, publisher John Wiley and Sons, 2012
[13] Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment,
[14] *E. Klugmann-Radziemska*, Degradation of electrical performance of a crystalline photovoltaic module due to dust deposition in northern Poland, Renewable Energy, Volume 78, Pp. 418-426, 2015
[15] *E. Suresh Kumar, Dr. Bijan Sarkar, D.K. Behera*, Soiling and dust impact on the efficiency and the maximum power point in the photovoltaic modules, International journal of engineering research and technology, vol. 2, issue 2, Pp. 2278-0181, 2013
[16] *Hai Jiang, Lin Lu, Ke Sun*, Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules, Atmospheric Environment, Volume 45, Issue 25, August 2011, Pp. 4299–4304
[17] *Garg. H*., Effect of Dirt on Transparent Covers in Flat-plate Solar Energy Collectors. Solar Energy, *1974*; 15: Pp. 299-302
[18] *Nahar N, Gupta J*., Effect of dust on transmittance of glazing materials for solar collectors under arid zone conditions of India. Solar Wind Technol 7: Pp. 237–243, 1990
[19] *Abhishek Rao, Rohit Pillai, Monto Mani, Praveen Ramamurthy*, Influence of dust deposition on Photovoltaic Panel Performance, Energy Procedia, Volume 54, 2014, Pp. 690–700, 4th International Conference on Advances in Energy Research, ICAER 2013
[20] Coveserv, http://spalarepanourifotovoltaice.ro
[21] *Toro*, http://www.curatarepanourifotovoltaice.ro
[22] Home of alternative energy tutorials, www.alternative-energy-tutorials.com/solar-power/pv-panel.html
[23] http://www.auditorcertificatenergetic.ro
[24] *R.A. Messenger, J.Ventre*, Photovoltaic Systems Engineering, CRC Press, Florida 2004
[25] *L. Dorobantu, M.O. Popescu, Cl. Popescu, A. Crăciunescu*, The effect of surface impurities on photovoltaic panels, International Conference on Renewable Energies and Power Quality (ICREPQ'11), Research: Energy, Alliance of Scientific Organisation;
[26] http://www.fluke.com/fluke/inen/thermal-imagers/fluke-ti200.htm?pid=77087
[27] *M.-I. Mihai, V. Tanasiev, A. Badea, R. Vidu*, The influence of climatic factors on the performance of photovoltaic panels, The 39 t h ARA Proceedings, Rome, 2015
[28] http://documents.tips/documents/normativ-2002-valori-limita.html
[29] *J. Duffie, W. Beckman*, Solar engineering of thermal processes, John Wiley & Sons Inc., 2006