IMPACT OF DUST AND TEMPERATURE ON ENERGY CONVERSION PROCESS IN PHOTOVOLTAIC MODULE

by

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Original scientific paper
https://doi.org/10.2298/TSCI19S4199J

The impact of the photovoltaic module temperature and natural dust deposition on the module front surface on the photovoltaic system performance was investigated. The study was conducted in the city center of Krakow, Poland, characterized by high pollution and low wind speed. The objective of this study was to evaluate the photovoltaic module power output decrease and energy conversion loss as a function of the dust deposition mass and cell operating temperature. The results show a significant decrease in photovoltaic efficiency when the mass deposition or temperature increases. The maximum mass deposition observed for exposure periods of one week on a single module exceeds 480.0 mg and results in an efficiency loss equal to 2.1%. The results that were obtained enable the development of a correlation for the efficiency loss caused by dust deposition which is desired by the system designers.

Key words: *renewable energy, photovoltaic module efficiency, dust accumulation*

Introduction

Solar energy is one of the primary sources of renewable energy, it is free, non-permeable and clean, and has various applications – direct and indirect ones. In recent years, significant progress has been made in the development of photovoltaic (PV) modules, with new concepts of improved performance features, long lifetime period and high reliability that has been introduced to the market [1-3]. Usually, PV module efficiency is defined under standard test conditions (STC) and it varies depending on the cell type. This efficiency for the polycrystalline silicon is in the range of 13-16%, while for the monocrystalline silicon is in the range of 15-20% [4, 5]. However, in addition to that, the cell operating temperature and other environmental factors such as solar radiation intensity, ambient temperature, dust, soiling, wind speed and air humidity may influence nominal efficiency [6].

Most of these variables have to be taken into account when the accurate prediction of PV module power is required. The module temperature directly influences the energy

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conversion process in the PV module, and this is affected by the environmental conditions and PV technical characteristics. In all the PV module types, when the cell temperature increases, the energy conversion efficiency significantly decreases [6]. Additionally, accumulative dust deposition on the module front cover surface reduces the incident solar radiation intensity and further reduces the power output [7]. In recent years a number of research studies were performed, reporting in a separate manner the impact of the dust or temperature on PV efficiency [8-33].

The PV module efficiency loss influenced by dust constitutes a local phenomenon and differs significantly from region to region. The first experimental study reported in this field has been conducted in the United Stated by Hottel and Woertz in 1942 [8]. The results show that the average reduction of the flat-plate solar heat collector energy is 1% every month. However, the number of published papers dealing with the impact of dust and pollution on the PV systems has grown rapidly in the last decade [9]. The factors influencing the operation and efficiency of PV systems are reviewed in [10]. The results show that in addition to the cell technology, climate parameters including dust and temperature have a significant impact. A review conducted in the Middle East and North Africa region related to the effects of dust accumulation and ambient temperature on PV performance was developed by using multivariate linear regression and artificial neural network techniques [11]. In [12] a review associated with the studying of the effects of the environmental variables such as accumulative dust, wind speed, ambient temperature and humidity, as well as the tilt angle, orientation and surface properties of the dust that settles on the PV modules is presented. A review of dust, wind velocity, and humidity on the PV modules were presented in [13]. The main conclusion was that the humidity has a direct effect on the solar radiation intensity and dust deposition. Also, they conclude that the cell temperature and humidity effect decrease when the wind speed increases. An analysis of the available literature from around the world [14-16] which takes into account the module type, geographical region as well as the duration of dust deposition shows that considerable PV module performance variations depend on exposure time. However, most of the studies report energy-yield loss versus exposure time without the detailed information about dust concentration density, and this precludes direct linking of local pollution condition with the PV efficiency loss [17-21].

Separate research studies focused on the effects of operating conditions and the surrounding conditions on the performance of PV systems, however, although without dust effect consideration. A large number of researchers from different regions of the world have devoted their work to studying the temperature variation of PV modules. The PV module temperature has a direct influence on the generating power. As the cell temperature increases, the voltage decreases, which leads to the decreasing in the electrical efficiency [22]. In [23] the authors show the models for the power and efficiency of the PV module, taking into account the PV module temperature. They also noted that the power and efficiency decrease almost linearly with the increasing temperature. In other studies [24, 25], several correlations have been evaluated for the temperature of the PV module based on the module operating temperature, solar radiation, ambient temperature and other environmental parameters. In [26] a linear and nonlinear model for predicting the effect of the PV module temperature on the output power and efficiency have been developed. The results have been compared for five different models and showed that the nonlinear model performed much better. The thermal behaviour of a PV module at different wind speeds was tested in [27], and the authors have shown that there was an adverse difference in convective and radiative heat loss from the module at different wind speeds.

In the study which was conducted in [28], a 3-D model was used to predict the thermal and electrical performance of the PV module for varying environmental and operating conditions. The results show that the variation in efficiency from 8.47% to 10.5%. In [29], the impact of the ambient temperature on the PV temperature was analysed. The analysis of wind incident angle on the temperature of the PV module was studied in [30]. The results demonstrated that the PV temperature slightly decreased by increasing the wind incidence angle, particularly at high wind velocities. Similar studies for different ambient temperature and solar irradiation can be found in [31-34].

The non-uniformities in the PV cells temperatures and its effect on the module power output was investigated in [35]. The study executed by 11 isolated PV cells were fabricated and exposed to the constant solar radiation equal to 615 W/m^2 for 18 minutes. The results show the decrease in the maximum output power output for the cells with high temperature than the cells with low temperature and the cells short-circuit increase with cell temperature increasing. Effect of the dew formation on the PV module temperature has been investigated in [36]. The investigation performed on two types PV modules (polycrystalline silicon and monocrystalline silicon) were conducted at three values of 45, 60, and 75% on the modules surface and at the ambient temperature 25 °C. The results show that the module relative efficiency increase linearly by increasing dew amount on the module surface for both module types. The observed an increase was about 2.83, 3.13, and 4.06% for monocrystalline silicon and 1.45, 3.26, and 4.39% for polycrystalline silicon. Effect of the ambient temperature on the electrical performance for two PV systems (monocrystalline silicon and amorphous silicon) connected to the gird has been analysed in [37]. The results reported that both systems are affected by ambient temperature however the monocrystalline modules are affected larger than amorphous silicon one.

One may infer the following conclusions from this survey of literature: the environmental conditions with seasonal variations have a direct influence on the dust deposition mass and module temperature. The effect of air pollution is significant also in urban areas due to the high population density, vehicles and growth in the industrial activities. Dust deposition on the front surface of the PV module can significantly reduce the amount of solar energy as well as influence the module temperature. Moreover, the phenomena have a local effect. The information available in the literature usually applies to the specific location where the experimental work was performed. Due to this fact, it is complicated to create a general model for dust and temperature related to the performance loss of the PV system.

Moreover, a large number of experimental works uses artificial dust particles which are usually not adequate to the natural dust composition. It is only through systematic research of the dust effect at different locations that the dust deposition impact on the PV performance can be better understood. In this work, the impact of the PV module temperature and natural dust deposition on the cover surface of the module on the performance of the PV system was investigated, and the objective was to evaluate the PV module power output decrease and energy conversion loss as a function of the dust deposition mass and cell operating temperature. The results enable the development of a correlation for the efficiency loss caused by dust deposition.

Methodology

The solar radiation, air temperature and wind speed were obtained from the local sensors (Pyranometers, Thermometer), at the AGH University of Science and Technology in the city centre of Krakow, Poland (50.066216N, 19.921511E). The experimental set-up of the

PV system consists of ten module strings connected in series. The string is built using Sharp ND-RJ260-type polycrystalline PV modules (temperature coefficient of power 0.42 %/^{o}C and 1.6 m^2 of surface area) with a nominal power of 260 W equipped with individual optimisers (SolarEdge, P405) which monitor electrical parameters of modules and seek a maximum power point $P_{\max}$ on every single module. The modules were adjusted at a tilt angle β = 15^o and an azimuth γ = 20^o West. In fig. 1 an example of dust deposition on the modules (located next to the analysed modules) is presented.

Figure 1. An example of dust deposition on the module surface

For the present analysis, the data collected for the four modules M_1-M_4 were presented. The dust from modules M_1 and M_3 was collected each week, while the modules M_2 and M_4 were not cleaned and were used for the purposes of reference for calculating the efficiency losses.

Dust deposited on the PV modules surface was removed from the surface using distillate water and specially designed devices equipped with a scratcher and suction pump. The dust-water solution was collected in plastic containers, followed by freeze-drying (an Alpha 1-4 LD Lyophilizator). The mass of dust deposited on the modules M_1 and M_3 after one week of deposition was evaluated gravimetrically using the OHAUS Discovery DV215CD balance. The meteorological data were obtained from the Vaisala WXT520 meteo station provided courtesy of the Faculty of Physics and Applied Computer Science. Total suspended particles were collected at the place where the system was located. The PM10 concentration (at Krasinskiego Avenne) was obtained from the Voivodeship Inspectorate of Environmental Protection in Krakow.

Analysis and modelling

In order to design the PV system properly, the PV module has to take into account the cell temperature and dust deposition on the PV power. The $P_{\rm PV}$ has to be calculated by the module specification and real local measurement. In general, the PV module power depends on the total solar irradiance incident on the PV surface G_T, but it also depends on several additional factors such as dust and soiling, losses, shading, age, temperature. In the literature, a large number of formulae for PV power output, $P_{\rm PV}$, of varying complexity is presented. The most practical formula can be written as follows [38]:

$$P_{\rm PV} = C_{\rm PV}\eta_{\rm der}\left[1-\alpha_P\left(T_c - T_{c,\rm STC}\right)\right]\frac{G_T}{G_{T,\rm STC}} \tag{1}$$

where $C_{\rm PV}$ [kW] is the module rate capacity, η_{der} [%] – the module derating factor, α_P [%/°C] – the thermal power coefficient, T_C [°C] – the module temperature, $T_{C,\rm STC}$, $G_{T,\rm STC}$ [kW/m^2] – the module temperature and solar radiation at STC conditions, and G_T [kW/m^2] – the incident solar radiation.

In the eq. (1) the PV module derating factor $\eta_{\rm der}$ is introduced, taking into account additional factors affecting the module such as dust and soiling, shading, age, snow cover, *etc*. and it can be broken down into a few key derating components in the following way:

$$\eta_{\rm der} = \eta_{\rm dust}\eta_{\rm shade}\eta_{\rm age} \tag{2}$$

where η_{dust}, η_{shade}, η_{age} are the module derating factors caused by the dust and soil, shading, age.

Results and discussion

The dust samples were collected from two modules every week during five consecutive weeks and were the subject of analysis. They represent one-week dust deposited at the module surface.

The weekly dust deposition from two identical modules is presented in fig. 2(a). One may see that the weekly dust deposition differs by up to 15% between successively cleaned PV modules. During the analysis, considerable variability in the dust particle deposition is observed. The highest weekly dust mass deposition was 480.0 mg while the lowest one was 41.2 mg. Due to the stochastic nature of variations of the environmental condition including pollution, the dust deposition lends this nature, and for the week without rainfall (May 18-23, 2017) the top deposition was observed. In fig. 2(b) PM10, total suspended particles (TSP) concentration and rainfall are presented for reference.

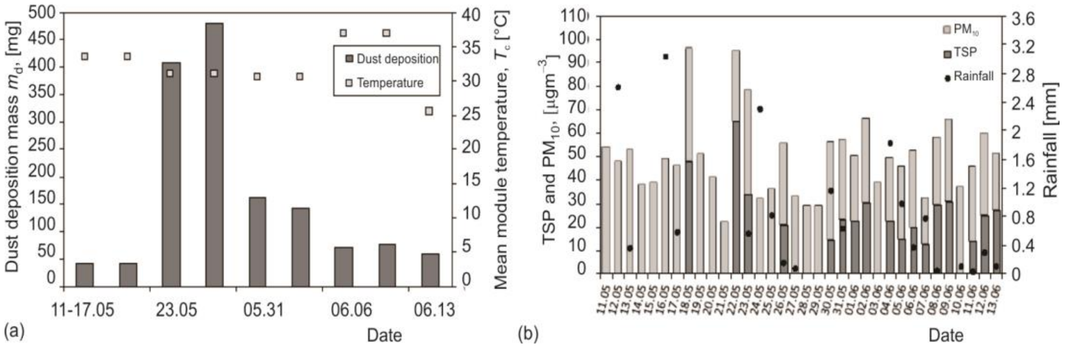

Figure 2. Dust deposited mass and the PV module temperature (a) and TSP, PM10, rainfall (b)

The average power output P_{PV} from the PV modules was recorded every 15 minutes. Because the optimisers required power to work and this power is taken from the modules, the recording time was always from sunrise to sunset. The average power output P_{PV} for the four modules M_1, M_2, M_3, M_4 for the day 05.05.2017 before the procedure of cleaning started is shown in fig. 3.

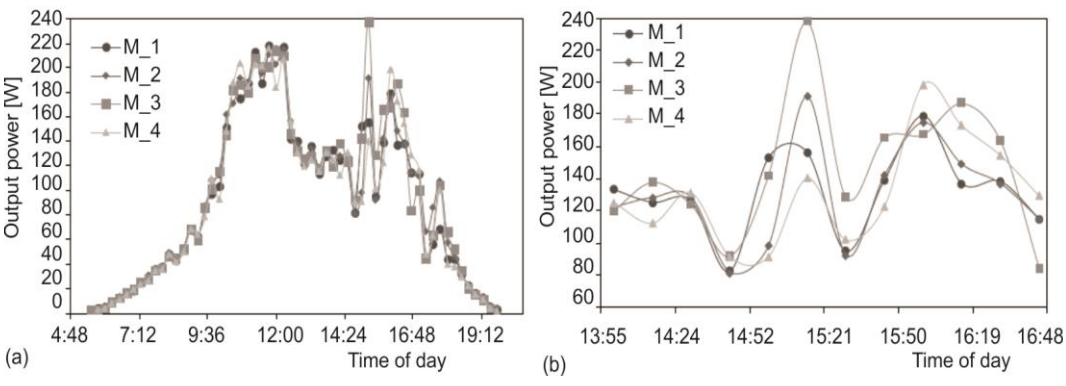

Figure 3. The average PV power output for modules M_1- M_4 from sunrise to sunset (a) and the zoom at midday (b)

The results show that even though the modules are of the same type, they generate different power. Assuming the modules are subject to exposure to the almost identical weather conditions and geometrical conditions, the difference in obtained power output from modules can be attributed to the manufacturing process and the power optimisation process. To account for the effect of different power output of the module, a normalization procedure is applied and the correction factors are evaluated on the basis of average energy production, E_i, (calculated on the basis of 10 days which precedes the cleaning of modules and the days after the cleaning) from subsequent modules i (M_1-M_4):

$$K_i = \frac{E_i}{E_1} \tag{3}$$

The estimated mean correction coefficient for analysed modules is presented in tab. 1.

Table 1. Module power correction coefficients

Module No.	M_1	M_2	M_3	M_4
Correction coefficient, K	1.0	0.958	0.978	0.989

In figs. 4(a) and 4(b) the average daily energy production together with normalised average daily energy production for the day next after the cleaning of modules and for modules M_1 and M_3 is presented (the remaining PV modules M_2 and M_4 are left with the dust layer for reference). It has to be noticed that all PV modules do not have a flat glass surface but specialised glass for the front cover is used – with significant surface roughness and a unique texture in order to achieve better light trapping and absorption in solar cells. Moreover, it is possible that the tiny dust surface which virtually increases surface roughness may have a positive effect (see fig.8). When the dust deposition mass on the growth of PV modules – see fig. 2(a), the average normalised daily energy production decreased.

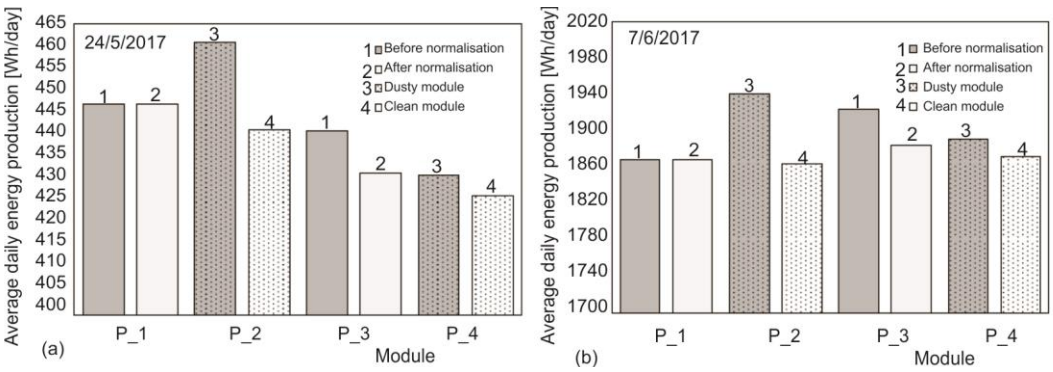

Figure 4. The average daily energy production for analysed modules and for two different days

During the testing period, in the majority of cases, the power output delivery by the modules decreases due to dust accumulation. Since the power rating is different for the PV modules of the same type, in order to calculate module efficiency loss, normalised results are taken into account. The percentage of energy efficiency loss due to dust deposition can be calculated from the following equation:

$$\eta_{\text{loss}} = \frac{E_{\text{clean}} - E_{\text{dusty}}}{E_{\text{clean}}} 100\% \tag{4}$$

where E_{clean} and E_{dusty} are the module average energy production from the clean and dusty module.

In order to take into account, the dust and temperature effect on the PV, a second parameter has been evaluated using three models which are available in the literature [33, 6, 39]. The first model is based on the traditional assumption according to the energy balance equation, while the second model is based on the PV module efficiency and nominal operating cell temperature. The third model also takes into account the wind speed. Model_1 can be described by means of the following expression [39]:

$$T_c = T_a + kG_T \tag{5}$$

where the T_a is the ambient temperature and the PV module temperature T_c depends on the ambient temperature, the incident solar radiation G_T and the Ross coefficient, k. The Ross coefficient is in the range k = 0.02-0.056 [33] and it depends on the configuration of the mounting of the module (cooling conditions). The PV module thermal properties depends also on type of polymer used as well as colour for module lamination. Fur current analysis modules with white back sheet EVA was used

The Model_2 uses $T_{c,NOCT}$ nominal operating cell temperature and the following expression [6]:

$$T_c = T_a + \frac{G_T}{G_{T,NOCT}}\left(T_{c,NOCT} - T_{a,NOCT}\right)\left(1 - \frac{\eta_c}{\alpha\tau}\right) \tag{6}$$

where the nominal operating cell temperature is $T_{c,NOCT}$ of the PV surface where solar radiation is equal to $G_{T,NOCT}$ = 800 W/m^2, under the ambient temperature equal to $T_{a,NOCT}$ = 20 °C, and for a wind speed 1 m/s. The value of $\tau\alpha$ is nearly constant and is about 0.9 and η_c [%] is the PV cell efficiency.

Model_3 accounts for the wind speed effect on the PV module temperature as follows [36]:

$$T_c = 0.943T_a + 0.028G_T - 1.528V_w + 4.3 \tag{7}$$

where the V_w [ms^{-1}] is the wind speed. In fig. 5 the PV module temperature evaluation is based on the solar radiation in the *in situ* experimental measurement and using three different models are shown. For Model_1 the parameter k = 0.02 was considered. One may infer from this figure that Model_1 predicts the lowest module temperature while the other models during the day predict similar temperature of the module. The prediction difference of the model

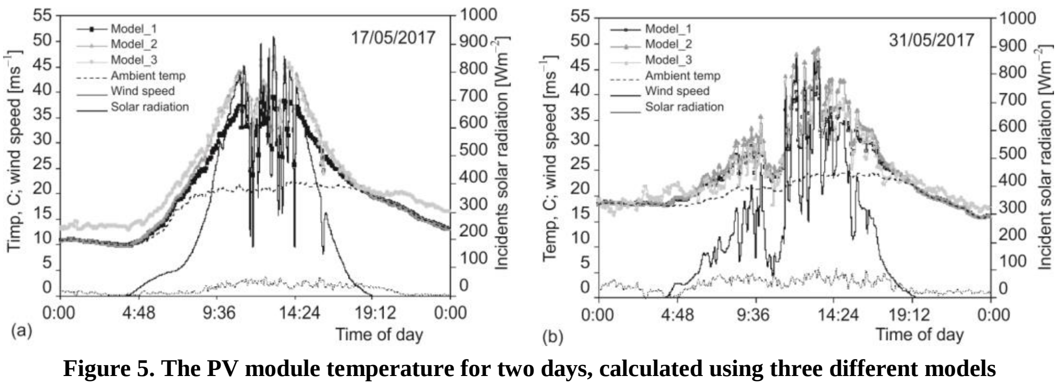

Figure 5. The PV module temperature for two days, calculated using three different models

is mainly due to the taking into account of additional components (wind speed). For the further analysis, Model_3 results will be used.

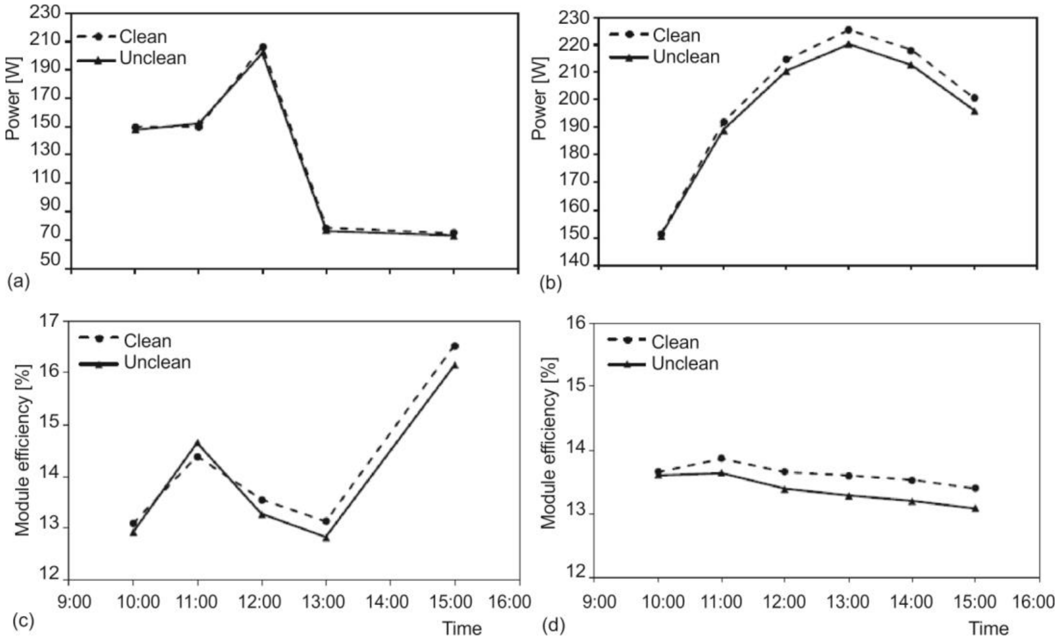

Figure 6. The PV system electrical power (a), (b) and module efficiency (c), (d) for cloudy (a), (c) and sunny (b), (d) days

To calculate the efficiency of the PV module during the day solar radiation and electrical power from the system are required. The PV electrical power is presented in figs. 6(a) and 6(b) for the cloudy and sunny days. The results show that the power generated by the system with a clean module is slightly higher than from an unclean one, and the effect can be easily recognised for a sunny day.

The efficiency of the PV system during the selected two days calculated on the basis of DC power and solar radiation is presented in figs. 6(c) and 6(d). The efficiency of the PV system was calculated from the following equation:

$$\eta_c = \frac{P_c}{G_T A_c} 100\%, \qquad \eta_d = \frac{P_d}{G_T A_c} 100\% \tag{8}$$

where P_c and P_d are the power output of the clean and dusty modules, G_T – the incident solar radiation, A_c – the module surface, while η_c, η_d represents the efficiency of the clean and dusty modules.

One may infer that the system efficiency with the clean panel is higher than with the uncleaned one and the highest difference is about 2.34% at 3 p. m. It is also worthwhile to notice that it was observed that for the sunny day efficiency decreases during the day.

Figures 7(a) and 7(b) shows the PV system losses (absolute value in percentage points) due to dust deposition for cloudy and sunny days, respectively calculated from the following equation:

$$\Delta \eta_{\text{loss}} = \eta_c - \eta_d \tag{9}$$

In fig. 7(b) at 11 a. m. negative efficiency is observed. The effect is due to the very high fluctuation observed for incident solar radiation which creates difficulties for accurate measurement for the maximum power point in the modules which were analysed. Increasing incident solar radiation during the day (and temperature) the module efficiency losses increasing also.

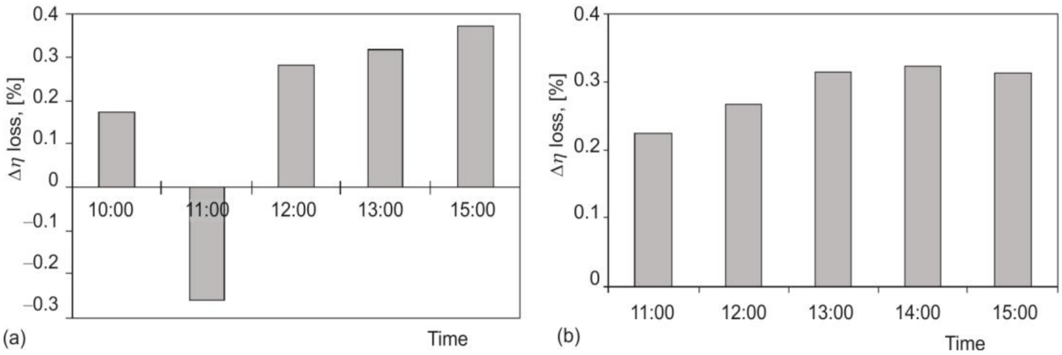

Figure 7. The PV system efficiency loss for cloudy (a) and sunny (b) days

On the basis of the evaluated mean PV module temperature for selected days, the module efficiency loss due to temperature effect can be calculated by means of the following formula:

$$\eta_{\text{loss}\_T} = \alpha p \left(T_c - T_{c,\text{STC}}\right) \tag{10}$$

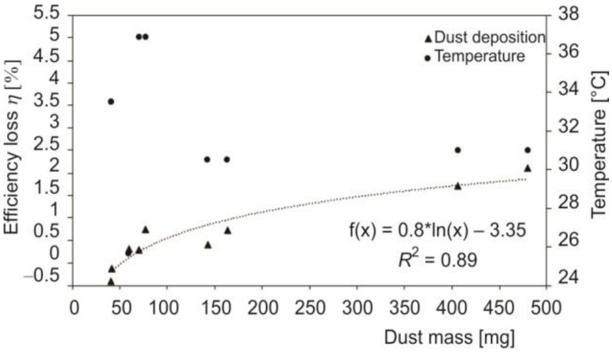

Figure 8. The average energy loss due to the natural dust deposition and module temperature

Figure 8 presents efficiency loss η_{loss} due to module temperature and the mass of the deposited dust deposited. When the mass deposition increases, efficiency loss raises. The highest decline in the PV performance equal to 2.1% was observed for the dust deposition mass m_d = 480.0 mg, which is a significant decrement, considering the fact that this mass was deposited during one week. The efficiency loss gradually increased with the mass and it follows a non-linear trend. The obtained results enable the development of a relationship for the efficiency loss of the PV module caused by dust deposition:

$$\eta_{\text{dust}} = 1 - \eta_{\text{loss}} = 1 - 0.8\ln\left(m_d\right) - 3.35 \tag{11}$$

One may also infer from this figure that efficiency loss is not only mass-dependent. For similar or even larger masses, the effect on efficiency varies from day to day. The preceding remark suggests that the properties of deposited dust are also important. On the other hand, an analysis performed on the same day but for two different panels confirms that efficiency loss increases when the dust mass increases. When the natural dust deposition mass on module surface is very low – m_d = 41.2 mg – the efficiency loss becomes negative, which suggests the positive effect of a thin dust layer. Figure 8, also presents efficiency loss due to a temperature effect for the same days as the dust collections. One may also observe that the thermal effect for selected days is more pronounced than the dust effect, and the combined effects are even more significant.

In reference to the largest mass of dust deposited dust on single module m_d = 480.0 mg which was analysed here and for the relatively low average PV module operating temperature (30.9 ^{o}C see fig. 2 for reference) the coupled efficiency loss is about 4.6%, which is a significant decrement, considering the fact that this mass was deposited during a short period (one week) and PV module average temperature was relatively low.

Conclusions

In the present work, the focus is on the evaluation of the energy conversion loss of PV modules due to the module operating temperature and natural dust deposition. The experimental measurement was conducted under variable environmental conditions. It was observed that the dust deposition and temperature significantly influence the power output and the highest separated efficiency decrement observed in the current experiment due to the temperature or the dust deposition was 5.0% and 2.1%, respectively. On the basis of the results which were obtained, one may state that the particles which exist in the air of polluted urban areas negatively affect the performance of the PV module and the level of degradation is non-negligible. The efficiency loss gradually increased with the dust deposited mass and it follows the non-linear trend. It was observed that this loss is not only mass-dependent but that it also depends on the dust properties.

The coupled thermal and dust deposition effects are even more significant. For the largest deposited mass which was analysed here – m_d = 480.0 mg – and for the PV average module operating temperature on that day, 30.9 ^{o}C, the efficiency loss is about 4.6%, while for the highest observed temperature, 37.1 ^{o}C, efficiency loss is even higher: 5.8%. Further dust deposition and the temperature increase adversely affects on the energy production but also due to the effect of the overheating of the system on the lifetime of the said system.

The obtained results enable the development of a correlation for the efficiency loss of the PV module caused by dust deposition. The proposed relationship eq. (11) for deposited dust can be used to evaluate the dust deposition-related efficiency loss which pursued by the system designers.

Acknowledgement

The PV system was funded by National Fund for Env. Protection and Water Management, 139/2015/Wn06/OA-is-ku/D. This research was partially financed by AGH Grant 16.16.210.476.

References

[1] Goss, R. G., 1984, Technology Developments Toward 30 Year Life of Photovoltaic Modules and Systems, *Proceedings*, 17th Photovoltaic Specialists Conference, Kissimmer, Fla., USA, (1984), pp. 464-472
[2] Vaidya, B. S., Photovoltaics: The Power of Choice, *Electr Conserv Q, 18* (1998), pp.18-23
[3] Benda, V., Photovoltaics Towards Terawatts–Progress in Photovoltaic Cells and Modules, *IET Power Electronics, 8* (2015), 12, pp. 2343-2351
[4] ***, National Renewable Energy Laboratory (NREL), https://www.nrel.gov/pv/silicon_materials
[5] Elibol, E., *et al*., Outdoor Performance Analysis of Different PV Panel Types, *Renewable and Sustainable Energy Reviews, 67* (2017), C, pp. 651-661

[6] Jaszczur, M., *et al*., Fluid Flow and Heat Transfer Analysis of a Photovoltaic Module under Varying Environmental Conditions. *Journal of Physics: Conference Series*, *1101* (2018), Oct., pp. 012009

[7] Styszko, K., *et al*., An Analysis of the Dust Deposition on Solar Photovoltaic Modules, *Environmental Science and Pollution Research*, *26* (2018), 9, pp. 8393-8401

[8] Ward, G. T., Performance of a Flat-Plate Solar Heat Collector, *Proceedings of the Institution of Mechanical Engineers*, *169* (1955), 1, pp.1091-1112

[9] Costa, C., *et al*., Dust and Soiling Issues and Impacts Relating to Solar Energy Systems, *Renewable Energy*, *63* (2016), Sept., pp. 33-61

[10] Meral, E., Dincer, F., A Review of the Factors Affecting Operation and Efficiency of Photovoltaic Based Electricity Generation Systems, *Renewable and Sustainable E. Reviews*, *15* (2011), 5, pp. 2176-2184

[11] Hammad, B., *et al.*, Modeling and Analysis of Dust and Temperature Effects on Photovoltaic Systems' Performance and Optimal Cleaning Frequency, *Renewable and Sustainable Energy Reviews*, *82* (2017), 3, pp. 2218-2234

[12] Jamil J., Performance Degradation of Photovoltaic Power System: Review on Mitigation Methods, *Renewable and Sustainable Energy*, *67* (2017), Jan., pp. 876-891

[13] Mekhilef, S., *et al*., Effect of Dust, Humidity and Air Velocity on Efficiency of Photovoltaic Cells, *Renewable and Sustainable Energy Reviews*, *16* (2012), 5, pp. 2920-2925

[14] Sarver, T, *et al*., A Comprehensive Review of the Impact of Dust on the Use of Solar Energy: History, Investigations, Results, Literature, and Mitigation Approaches, *Renewable and Sustainable Energy Reviews*, *22* (2013), june, pp. 698-733

[15] Sayyah A, *et al*., Energy Yield Loss Caused by Dust Deposition on Photovoltaic Panels, *Solar Energy*, *107* (2014), Sept., pp. 576-604

[16] Jaszczur, M., *et al*., An Analysis of Temperature Distribution in Solar Photovoltaic Module Under Various Environmental Conditions. *International MATEC Web of Conferences, 240* (2018), 04004

[17] Javed, W., Wubulikasimu, Y., Characterization of Dust Accumulated on Photovoltaic Panels in Doha, *Qatar, Solar Energy*, *142* (2017), Jan., pp.123-135

[18] Saidan, M., *et al*., Experimental Study on the Effect of Dust Deposition on Solar Photovoltaic Panels in Desert Environment, *Renewable Energy*, *92* (2016), July, pp. 499-505

[19] Jaszczur, M., *et al.*, Study of Dust Deposition and Temperature Impact on Solar Photovoltaic Module. *International MATEC Web of Conferences*, *240* (2018), 04005

[20] Weber, B, *et al*., Performance Reduction of PV Systems by Dust Deposition, *Energy Procedia*, *57* (2014), Dec., pp. 99-108

[21] Jaszczur, M., *et al*., The Field Experiments and Model of the Natural Dust Deposition Effects on Photovoltaic Module Efficiency, *Environmental Science and Pollution Research*, *26* (2018), 9, pp.1-16

[22] Baltus, A, *et al*., Analytical Monitoring of Losses in PV Systems, *Proceedings*, 14^{th} European Photovoltaic Solar Energy Conference, Barcelona, Spain, 1997

[23] Skoplaki, E., Palyvos, A.,On the Temperature Dependence of Photovoltaic Module Electrical Performance: A Review, *Solar energy*, *83* (2009), 5, pp. 614-624

[24] García, M. A., Balenzategui, J. L., Estimation of Photovoltaic Module Yearly Temperature and Performance Based on Nominal Operation Cell Temperature Calculations, *Renewable Energy*, *29* (2004), 12, pp. 1997-2010

[25] Ju, X, *et al*., An Improved Temperature Estimation Method for Solar Cells Operating at High Concentrations, *Solar Energy*, *93* (2013), July, pp. 80-89

[26] Pantic, S, *et al*., The Assessment of Different Models to Predict Solar Module Temperature, Output Power and Efficiency for Nis, Serbia, *Energy*, *109* (2016), Aug., pp. 38-48

[27] Armstrong, S., Hurley, G., A Thermal Model for Photovoltaic Panels Under Varying Atmospheric Conditions, *Applied Thermal Engineering*, *30* (2010), 11-12, pp.1488-1495

[28] Siddiqui, U., *et al*., Three-Dimensional Thermal Modeling of a Photovoltaic Module Under Varying Conditions, *Solar energy*, *86* (2012), 9, pp. 2620-2631

[29] Ceylan, I., *et al*., The Prediction of Photovoltaic Module Temperature with Artificial Neural Networks, *Case Studies in Thermal Engineering*, *3* (2014), July, pp. 11-20

[30] Kaplani, E., Kaplanis, S., Thermal Modelling and Experimental Assessment of the Dependence of PV Module Temperature on Wind Velocity and Direction, Module Orientation and Inclination, *Solar Energy*, *107* (2014), Sept., pp. 443-460

[31] Nordmann, T., Clavadetscher, L., Understanding Temperature Effects on PV System Performance, Photovoltaic Energy Conversion, *Proceedings*,3rd World Conference, Osaka, Japan, (2003), Vol. 3, pp. 2243-2246
[32] Hassan, Q., *et al*., Off-Grid Photovoltaic Systems as a Solution for the Ambient Pollution Avoidance and Iraq's Rural Areas Electrification, *E3S Web of Conferences*, *10* (2016), 00093
[33] Ross G., Interface Design Considerations for Terrestrial Solar Cell Modules, *Proceedings*, 12th Photovoltaic Specialists Conference, Baton Rouge, La., USA, 1976, pp. 801-806
[34] Mattei, M., *et al*., Calculation of the Polycrystalline PV Module Temperature Using a Simple Method of Energy Balance, *Renewable energy*, *31* (2006), 4, pp. 553-567
[35] Paul, D. I., *et al*., The Effect of Non-Uniformities in Temperature on the Performance Parameters of an Isolated Cell Photovoltaic Module with a Compound Parabolic Concentrator, *International Journal of Renewable Energy Technology*, *10* (2019), 1/2, pp. 3-25
[36] Hosseini, S. A., *et al*., Experimental Study of the Dew Formation Effect on the Performance of Photovoltaic Modules, *Renewable Energy*, *130* (2019), Jan., pp. 352-359
[37] Maftah, A., Maaroufi, M., Experimental Evaluation of Temperature Effect of two Different PV Systems Performances Under Arid Climate, *Energy Procedia*, *157* (2019), Jan., pp. 701-708
[38] Hassan, Q., *et al*., Mathematical Model for the Power Generation from Arbitrarily Oriented Photovoltaic Panel, *E3S Web of Conferences*, *14* (2017), 01028
[39] Chenni, R., *et al*., A Detailed Modeling Method for Photovoltaic Cells, *Energy*, 32 (2007), 9, pp. 1724-1730

Paper submitted: January 15, 2019
Paper revised: February 28, 2019
Paper accepted: March 21, 2019