PANEVĖŽIO KOLEGIJA ISSN 2029-1280, eISSN 2669-0071. Taikomieji tyrimai studijose ir praktikoje – Applied Research in Studies and Practice, 2021, 17.

INVESTIGATION OF THE EFFECT OF DUST AND DIRT ACCUMULATION ON THE ELECTRICAL PERFORMANCE OF SOLAR PV PANELS

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Abstract. With the development in the industry, the increasing demand for electrical energy, expensive electricity consumption costs and the rapid decrease in existing fossil fuel reserves have accelerated the search and use of new energy sources. The most important feature of solar energy for the world and future generations is that it is a clean, sustainable, green energy source and plentiful in many places, so solar energy is very popular among renewable energy sources. Solar PV panels are the key element commonly used to generate electrical energy from solar energy. With the development of photovoltaic panels, solar fields have started to be established in order to provide the clean energy needed, and these fields with various capacities and sizes have started to contribute to the energy production of our country. While the contribution of the returns of the systems, which are put into operation after their investments are completed, to the national economy has started to reach visible levels, the efficiency of these products should be accurately measured and monitored. External factors such as dust, dirt, bird droppings and crystalline residues accumulating on the surface of solar PV panels cause a serious decrease in the electrical efficiency of solar PV panels. In this study, silty sand, cement dust, coal dust and bird droppings deposited on the surface of solar PV panels were extensively investigated to show their effects on the electrical performance of solar PV panels. Experimental studies are carried out under conditions of natural dustiness and dirtiness. Solar PV panel output current and voltage, solar radiation, temperature data are recorded instantly. In this study, the dust and dirt effect is investigated with the change in short-circuit current. Electrical performance analyzes of solar PV are investigated with the change in I-V and P-V characteristic curve of the panels.

Keywords: solar energy; solar PV panel; dust; dirt; electrical performance.

INTRODUCTION

Solar photovoltaic (PV) technology, which converts the radiation from the sun directly into electricity, has received great attention in recent years as an important renewable energy source. Due to its advantages such as providing the desired energy with lower cost and high efficiency, solar PV modules have been applied in many places on a large and small scale and it continues to increase day by day. In reality, it has been seen that many environmental factors affect the performance of PV modules. The efficiency of solar panels is affected by factors such as dustiness, dirt, temperature of the panel and the environment (Demirdelen et al. 2019), tilt angle of the panels (Alici et al. 2021), climatic conditions and partial shading (Yavuzdeğer et al. 2021). Dust and dirt, which are common problems in many regions of the world, are at the beginning of these negative effects. The dust accumulated on the PV module surface seriously affects the output power. In general, the dust and dirt accumulated on the PV module surface cause the sun's radiations to be refracted, absorbed by the accumulated dust, and the glass permeability is reduced, and therefore the energy conversion efficiency is greatly reduced.

Many studies have been carried out in the literature to determine how dust and dirt affect PV panel efficiency. Various loss rates have been reported in the literature since the decrease in power generation in PV modules due to dust pollution is dependent on location and weather conditions. Abderrezek et al. (2017), conducted outdoor experiments to see the effect of uniform dust and non-uniform dusts with different densities on the efficiency of the panels. In maximum power generation, a decrease of 50% in uniform dust with a density of 8 g/m^2 and a decrease of 16.74% in non-uniform dust was observed. The results in this study are mostly suitable for desert environment conditions. Sevik et al. (2022), showed that up to 5.66% power reduction occurs for PV modules that have been dirty for about a year. It was determined that the dust removal effect of the rain increased up to 0.94%. The power plant, which had a snow load for three days, produced 50-75% more energy than the other power plant. Said et al. (2014), showed in their study that PV modules exposed to the external environment for 45 days had a 20% reduction in glass transmittance and a dust accumulation of 5 g/m2 on the glass cover. Adinoyi et al. (2013), conducted a study on the effect of dust accumulation on the power output of solar PV modules in the Eastern Province of Saudi Arabia. As a result of the studies, it has been observed that the performance of the PV module decreases gradually unless the

modules are cleaned by rain or human action, due to prolonged exposure to outdoor conditions and dust accumulation. They say that if the modules are not cleaned for more than six months, the power output can drop by more than 50%. Also, the composition of the accumulated dust from the EDS analysis shows that oxygen is the largest elemental composition for the dust at the installation site of solar PV modules. Semaouia et al. (2015), presented results on the effect of dust on PV panel electrical parameters. The relative losses of the I_{sc} and P_p parameters are 2.23% and 7.98%, respectively, at 10:00 am. While the power produced was 454.5 on the clean panel, it was determined as 418.22 on the dusty panel. The established experimental setup was experimentally validated in the Algerian deserts for several months. Memiche et al. (2020), investigated the factors affecting the efficiency of PV panels such as dusting, temperature, weather conditions and aging. The decrease due to dustiness was measured as approximately 11% at 730 W/m^2 irradiation and 34°C. Sulaiman et al. (2011), carried out daily, weekly and monthly cleaning of the modules mounted horizontally and at an angle of 30°, and observed the production data. The production of the module that is cleaned daily is 15.32% more than the module that is not cleaned. They found that this module produced 10.7% and 5.52% more energy than the monthly and weekly cleaned modules, respectively. For modules installed with a 30° inclination angle, the daily cleaned module produced much more average power of 16.17%, 11% and 5.33% on average than the non-cleaned, monthly and weekly cleaned PV modules. Ekici et al. (2017), examined the output power of 30 degree inclined PV modules and horizontal PV modules. As a result of their experiments, they observed that the cleanliness of the PV modules has a great effect on the output power. In this way, the efficiency of the modules can be increased up to 15-16%. Rehman et al. (2012), studied the energy output and corresponding efficiencies of PV modules for July and August. The highest energy efficiency was achieved in both July and August with maximum efficiency of 14.7% and 14.3%, respectively. When compared to July and August, they observed a decrease of approximately 5 kWh in energy efficiency. They argued that the reason for this decrease in energy efficiency is dust accumulation. Hanai et al. (2011), observed that dust accumulation on the panels reduces the intensity of solar radiation reaching the panels, reducing the efficiency of the system. Looking at the data before and after the panels were cleaned, a 13% increase in maximum power was observed after dust removal, which corresponds to a 5.79% increase in system efficiency. Some of the panels required wet cleaning due to the amount of accumulated dust, and a 5.37% increase in efficiency was observed after 35 days of showers for several days removing some of the accumulated dust. It compares the effect of manually cleaning the panels with a cloth to the effect of rain on dust removal. Although the performance of the system improved in both cases, rain didn't seem to remove dust as effectively as manually cleaning the panels.

In this paper, silty sand, cement dust, coal dust and bird droppings deposited on the surface of solar PV panels are extensively investigated to demonstrate their effects on the electrical performance of solar PV panels. Although there is a lot of research on dustiness in the literature, given the lack of the effect of silty sand, cement dust and coal dust in the literature, the main contributions of this article can be summarized as follows:

- Observing the change in the I-V and P-V characteristic curves of solar power plants exposed to natural dust, cement dust, coal dust and bird droppings in the outdoor environment,
- Analyzing the electrical performance of solar PV, to draw attention to the decrease in power generation for PV power plants in regions that cause this type of dust and dirt, and to provide information for those to be established.

The electrical properties of the PV panel used in the following sections of the paper, the developed measuring station, the result and discussion are presented in a comprehensive manner.

MATERIAL AND METHODS

There are many environmental factors that affect the electrical performance of solar PV panels. Dust accumulation or various types of dirt on the PV panel surface affect the power produced from photovoltaic PV panels at different rates. In this study, the effects of silty sand, cement dust, coal dust and bird droppings on the electrical performance of solar PV panels are presented by examining experimentally. The experiment setup consists of 4x45 watt solar PV panels, pyranometer, j-type 4-20 mA thermocouple, DC voltage-current sensors, adjustable load and measuring station, as shown in Figure 1.

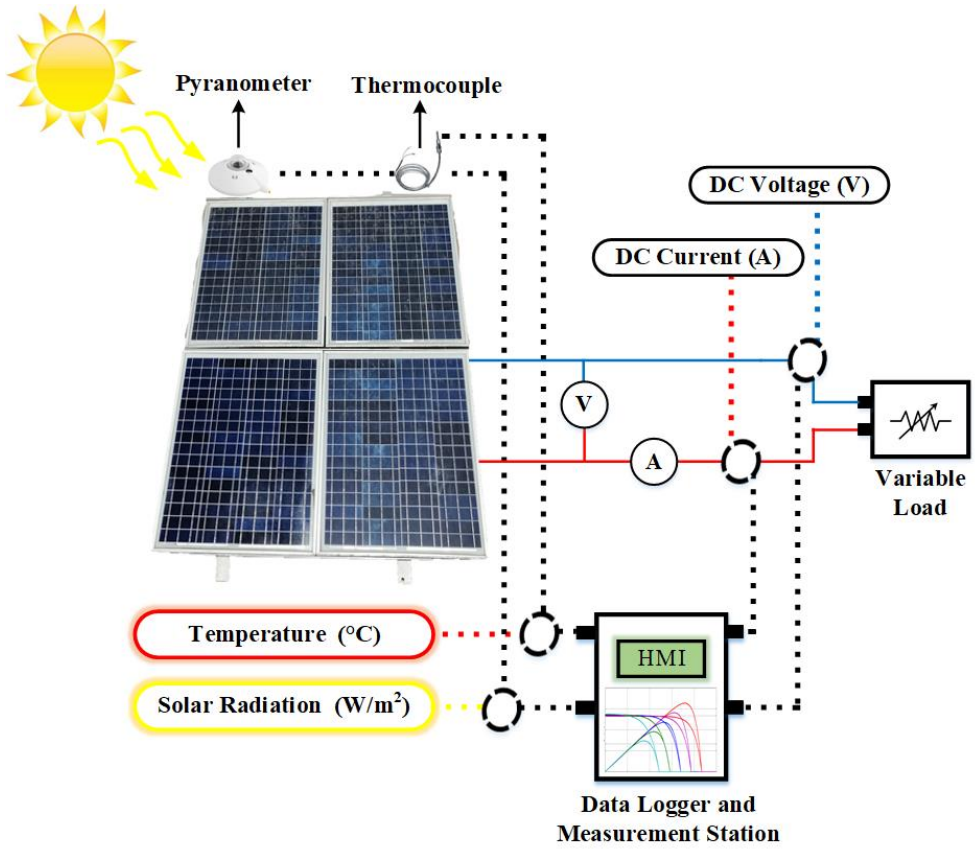


Figure 1. **Experiment setup to examine the electrical performance of solar PV panel**

The measuring station has been designed to record and observe the data to be obtained from experimental studies. Solar radiation, solar PV panel temperature, open-circuit voltage and short-circuit current of solar PV panel data are taken with the help of the relevant sensors and sent to the addresses connected to the analog input modules. The data taken from the sensors are output values as current values between 4mA and 20mA and are scaled according to the minimum-maximum values of the sensors. The output data are given by converting the current ratios that come with the embedded software in the Central Processing Unit (CPU) to the operating ratios of the sensors. The output data at the measuring station are saved in an excel file with one-second time intervals. In addition, the data can be observed instantly thanks to the Human-Machine Interface (HMI) panel thanks to the measurement station. 4x45 Watt solar PV panels are selected to carry out the experimental studies. The electrical and mechanical characteristics of 45 W solar PV panel are given in Table 1.

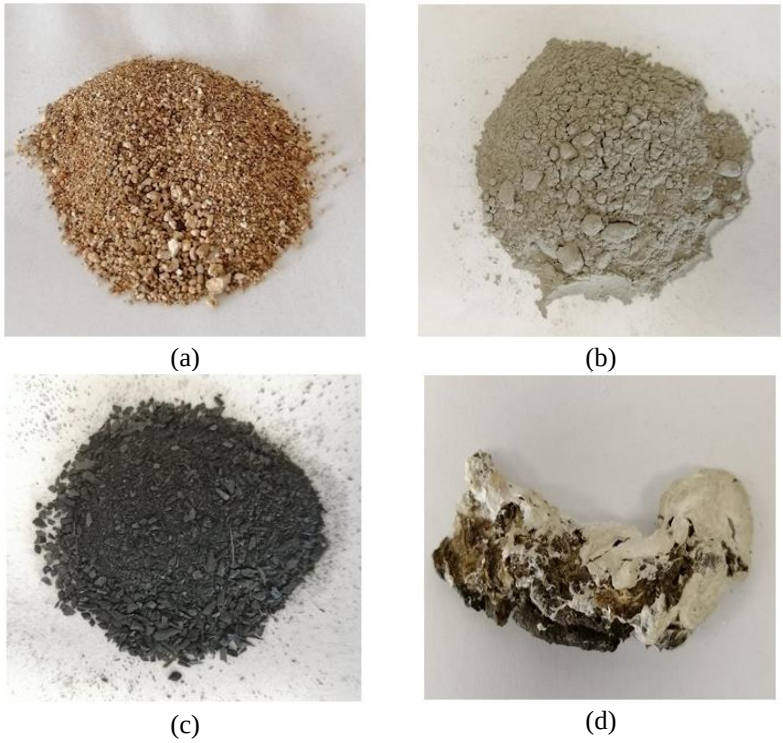
Table 1

The measurements obtained from the experimental setup

	Parameters	Value
Electrical Characteristic	Nominal Power [W]	45
	Open Circuit Voltage (V_{oc}) [V]	21,60
	Short Circuit Current (I_{sc}) [A]	2,59
	Maximum System Voltage [V]	1000
	Series Fuse Maximum Rating [A]	15
Mechanical Characteristic	Solar Cells	64 Polycrystalline Silicon
	Dimensions [mm]	520 x 675 x 28
	Weight [kg]	4,5
	Front Glass Thickness [mm]	3,2
	Junction Box	IP65

The silty sand, cement dust, coal dust and bird droppings used in experimental studies are shown in Figure 2. Different kinds of dust and bird droppings on solar PV panels are homogeneously interspersed and the I-V and P-V curves of the 4x45 watt solar PV panels are investigated comparatively. The maximum

output power values of the PV panels have been determined from the I-V and P-V curves under dusty and dirty conditions.



(a) (b) (c) (d)

Figure 2. **(a) Silty sand, (b) cement dust, (c) coal dust and (d) bird droppings used in experimental studies**

RESULTS AND DISCUSSIONS

The increase in the tendency towards renewable energy sources to meet the energy demand has also increased the need for solar power plants (SPP). Increases are observed in the number of SPPs in order to make the most effective use of solar energy, which is abundant in the world. SPP is widely used in many different areas such as homes, schools, industries, airports, ships. However, dustiness and pollution factors have a negative effect on the efficiency of solar panels. Dust and dirt covering the surface of solar panels reduce the electrical efficiency obtained from the panels with the effect of shading.

Figure 3. **Experiment setup**

In this study, the two significant factors affecting the energy efficiency of solar panels, such as dustiness and pollution, are examined. These are the natural dustiness of the solar panels in the outdoor environment, solar power plants installed close to the cement industry, solar power plants installed close to

the fossil fuel power plants and solar panels exposed to bird droppings. This study presents that silty sand, cement dust, coal dust and bird droppings deposited on the surface of solar PV panels were extensively investigated to show their effects on the electrical performance of solar PV panels. Experimental studies are carried out under conditions of natural dustiness and dirtiness. Figure 3 shows the experiment set up.

In the experiment set, solar panels are the same power and design structure. Simultaneous measurements are taken from solar panels at the same solar radiation intensity and ambient temperature. Firstly, the electrical characteristics of the 45-watt solar panel are measured in its clean state. As seen in Figure 4, the I-V and P-V characteristic curves of the solar panel are obtained under the experimental conditions.

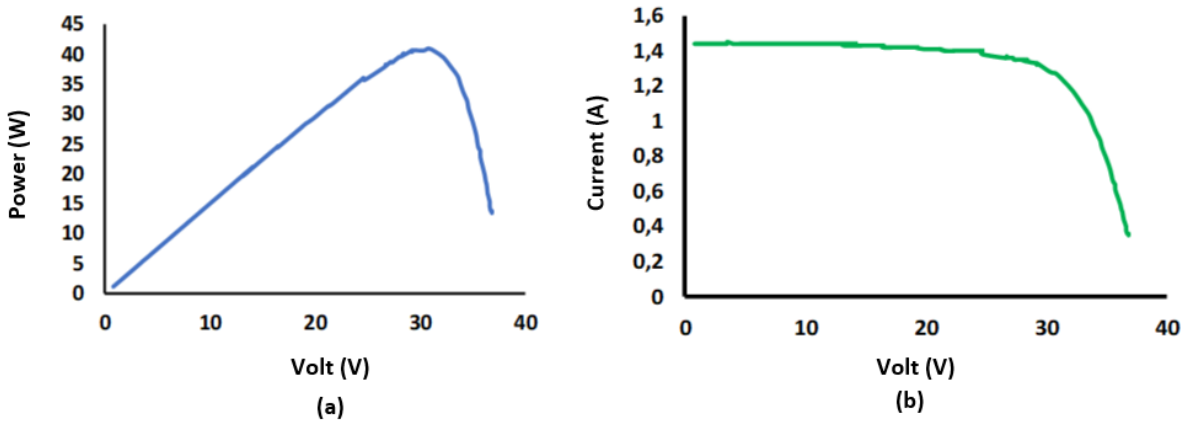


Figure 4. **I-V and PV characteristics of solar PV panel in clean state**

The solar PV panel reaches 40.96 W in clean state. The maximum current flowing from the solar panel to the load is 1.52 A. The performance analysis results of the solar PV panels are given in Figure 5 and Figure 6 under the silty sand, cement dust, coal dust and bird droppings conditions.

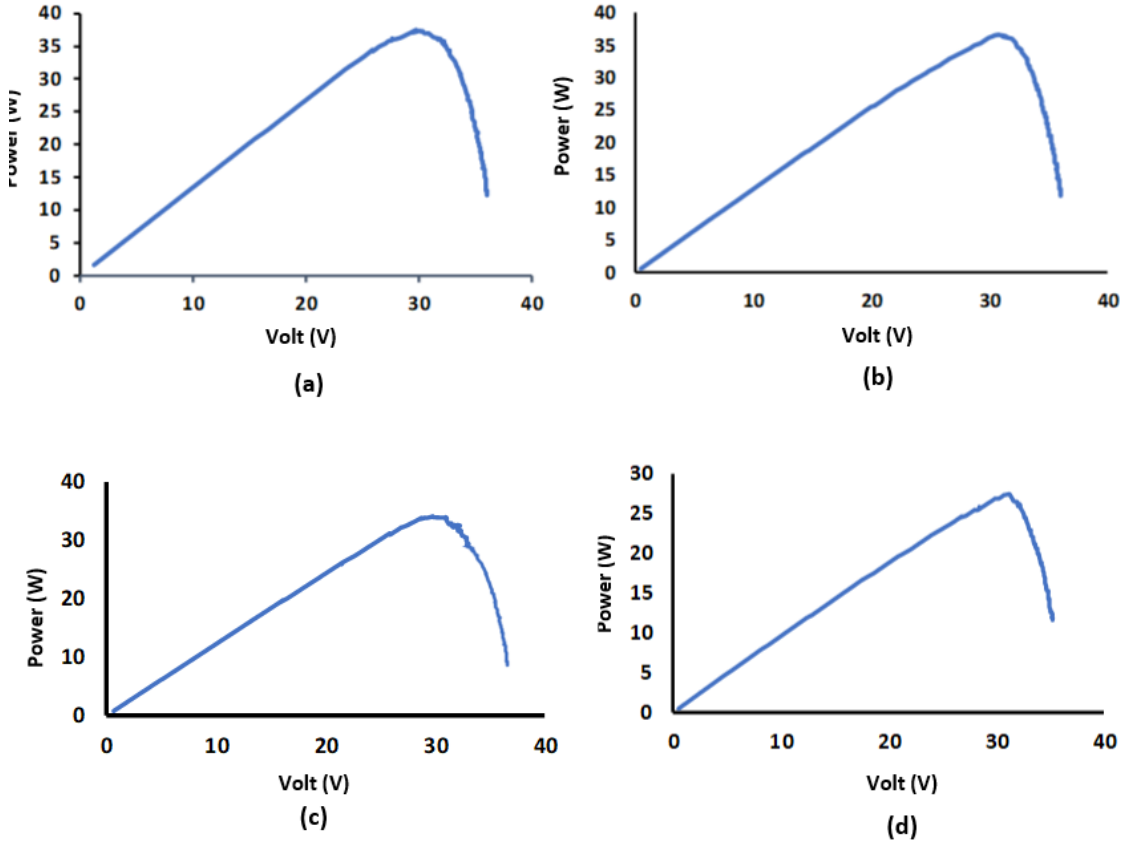


Figure 5. **P-V characteristics of solar PV panels under the conditions a) silt sand b) bird droppings c) cement dust d) coal dust**

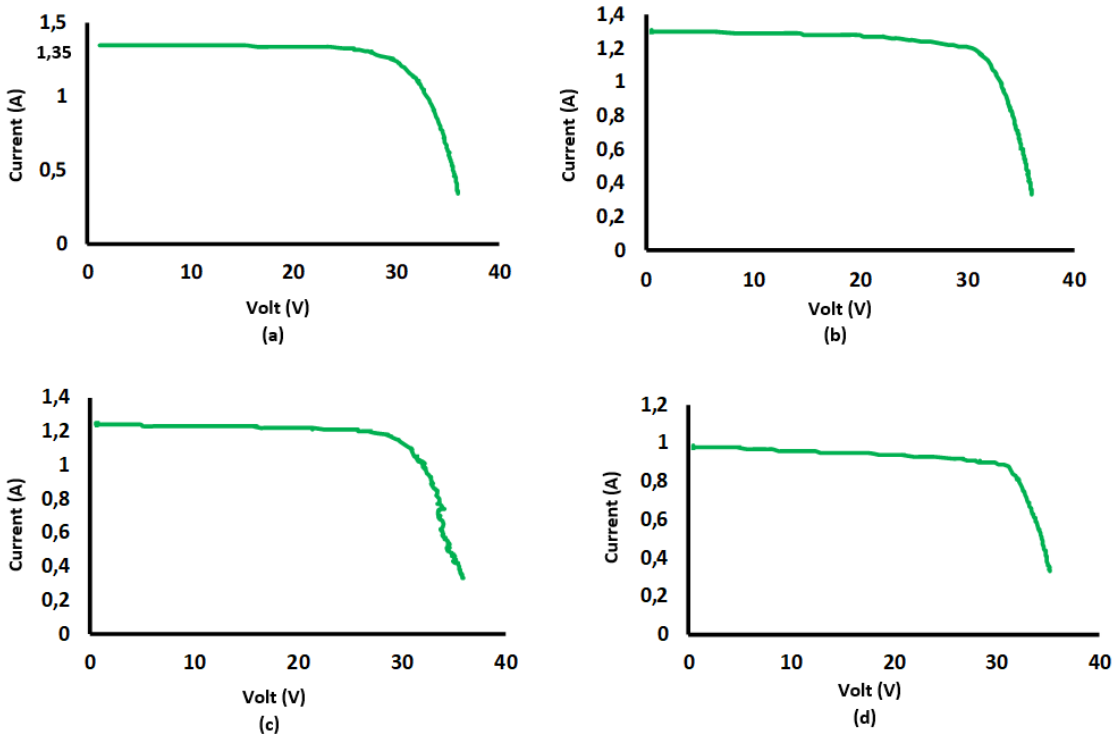


Figure 6. **I-V characteristics of solar PV panels under the conditions a) silt sand b) bird droppings c) cement dust d) coal dust**

Considering the electrical characteristics of solar panels, the electrical efficiency of the solar PV panel is better in case of natural dusting than in other cases. Bird droppings state creates partial shading on the solar panel so the partial shading results in better power than cement dust and coal dust situations. While a certain part of the solar panel is exposed to shading, the other part benefits from full of solar radiation. Also, the experimental results show that coal dust significantly prevents solar radiation from reaching the solar panel. The electrical measurements of the solar PV panels are given in Table 2.

Table 2

The measurements obtained from the experimental setup

States	Short Circuit Current (Isc)	Open Circuit Voltage (Voc)	Maximum Power (Pmax)	Solar Radiation (W/m^2)	Solar PV Panel Temperature (°C)
Clean	1.52	36.8	40.96	1000	44.8
Bird Droppings	1.31	36	36.65	1000	40.4
Silty Sands	1.35	36	37.42	1000	40.6
Cement Dust	1.25	35.9	34.155	1000	40.2
Coal Dust	0.99	35.2	27.46	1000	39.7

CONCLUSIONS

The efficiency of the solar power plants is determined by the losses in the energy produced. SPP power losses are caused by many factors such as environmental conditions to design, materials used to workmanship, dust and dirt on the solar PV panel. Solar panels can produce their nominal power if the ambient conditions are favorable and the surface is clean. The production capability of solar panels is reduced by the accumulation of dust, dirt, pollen, bird droppings and various particles on the solar PV panels. In this study, the two significant factors affecting the energy efficiency of solar panels, such as dustiness and pollution, are examined. Thus, dustiness and dirt conditions, where solar panels are most exposed to pollution, are examined. These pollutions are determined as silty sand, cement dust, coal dust and bird droppings. The efficiency of solar PV panels is observed with electrical performance analysis results by using experimental setup. It is revealed that the efficiency of solar PV panels is mostly affected by coal dust.

In natural dust condition, the efficiency obtained from solar PV panels is higher than in other conditions. Since bird droppings create partial shading on the panel, better results are obtained in bird droppings condition compared to coal and cement dustiness. Cement dust and coal dust significantly prevent solar radiation transmittance. This is also reflected in the temperature values measured from the solar panels.

In future study, it is aimed to prepare the chemical solvents in order to eliminate the dirt and dust conditions in solar PV panels. Thus, studies will be carried out to increase the system efficiency of solar panels by eliminating dust and dirt.

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