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Degradation of electrical performance of a crystalline photovoltaic module due to dust deposition in northern Poland

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ABSTRACT

The reduction in power output caused by the accumulation of dust on the photovoltaic module surface is an important problem and should receive much more attention in the literature. This study was an evaluation of the performance degradation of crystalline photovoltaic modules due to natural and simulated dust deposition. Dust is created from powdered grains of sand and particles of different bodies. Dust originates from different sources, e.g. from the soil and volcanic eruptions. Dust in the air is an aerosol, and in high concentrations can cause climate change. Deposition of airborne dust on photovoltaic modules may decrease the transmittance of solar cell glazing and cause a significant degradation in the solar conversion efficiency of photovoltaic modules. Dust deposition is closely related to the tilt angle of the module, the exposure period, site climate conditions, wind movement and dust properties. In this article, a brief review of the energy yield losses caused by dust deposition on photovoltaic modules and the results of experimental research conducted in Poland are presented. Dust samples were collected after a few years of natural and artificial dust deposition. The reduction in efficiency had a linear relationship with the dust deposition density.

1. Introduction – sources and properties of dust, and the impact of weather conditions on the deposition of pollutants

There are several factors that influence the efficiency of photovoltaic modules:

- the type of front cover material,
- the orientation and angle of inclination,
- the type of installation (tracking or stationary),
- localization,
- solar cell temperature,
- shadowing,
- dust deposition and soiling of the front cover.

Soiling includes not only dust accumulation, but also surface contamination by plant products, soot, salt, bird droppings, and the growth of organic species; these all adversely affect the optical performance. The chemical composition, the dust source, the grain size and the amount of pollutants deposited on the surface of solar modules in various places on the globe differ significantly. The climate, including precipitation, has the greatest influence on the formation of a dust layer.

2. Literature review

2.1. Sources and properties of dust, and the impact of weather conditions on the deposition of pollutants

Many researchers have devoted their work to studying the origin, composition and gradation of dust grains originating from different regions of the world. Fujiwara et al. [1] stated that the composition of dust varies depending on the location of its formation. In big cities, contamination deposited on surfaces is the result of the interaction of liquids, solids and gases derived from different sources. They may also contain heavy metals and organic compounds, derived mainly from road transport. However, in dry climates, i.e. desert or semi-desert, the main source of the dust is soil. Ta at al [2]. described research conducted over 15 years in the region of Gansu, China. They noted that more particles are deposited on the surface of photovoltaic modules in the areas adjacent to the Gobi desert, rather than in areas of loess. Moreover, they found a strong correlation between the quantities of absorbing impurities and the season; this was associated with changes in weather,

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including the wind direction. They demonstrated that over 30% of the total annual quantity of dust is deposited in the spring months, and less than 20% in the winter months.

Fujiwara et al. [1] found the presence of cadmium, sulfur and antimony in samples of dust, which most likely came from the abrasion of automobile brake shoes. In contrast, the origin of lead, zinc and manganese was attributed to mechanical wear and also, to a lesser degree, exhaust gases.

Bi, Liang and Li [3] stated that the concentration of trace metals in different fractions of dust originating both from the soil and from the roads increases with decreasing particle diameter. This is an interesting phenomenon, because as mentioned in their study, trace metals remain in evenly spread the soil, independent of particle size. The tested dust samples showed that approximately 40% of these elements were connected with a particle size not exceeding 100 μm. The authors found an increased content of lead in dust samples taken from the soil, which was matched to the level of this element in the dust coming from industry.

Kazmerski and his group [4] found that the properties of dust vary depending on the location of the photovoltaic system. Dust samples collected from highly urbanized areas in the northern hemisphere contain numerous impurities characteristic of the area. This could be airborne particles from coal-fired power plants, emissions from transport or from urban development. Similarly, in rural areas, pollution is created from fertilizers, land air flow or plant origin.

Cabanillas and Munguia from Mexico [5] identified clay, sand, soot, fungi, spores and plant fibers as the main components of dust deposited in their area. The material bonding the particles floating in the air and anchoring them to the surface of the module were organic pollutants occurring in rural and urban areas.

Research carried out by McTainsh, Nickling and Lynch [6] showed that the grain size of the dust settling on the surface of PV modules is correlated with the distance from which the dust was brought by the wind. There are three ranges of deposited dust, depending on the size of the grains: small particles with a diameter up to 5 μm come from widely spaced areas, while particles in the range of 20–40 μm are dust deposits from regional sources, and larger components of dust, from 50 to 70 μm, indicate a local origin of the dust, which means that these particles were produced by people, vehicles, machines and livestock. The authors found that the pollution coming from the vicinity had a great influence on the deposition of dust on the module cover.

Beattie et al. [7] proposed a classification of grain sizes which allows for the identification of their origin: a particle size from 60 to 2000 μm is mainly sand brought by the wind, while dust with a particle size from 4 to 60 μm originated from alluvial soil, and particles less than 4 μm were from clays.

The particle size of contaminants can vary considerably, as was shown by Biryukov [8], who performed an analysis using a computerized optical microscope and a scanning electron microscope (SEM). The author examined a natural dust sample collected in the Negev, Israel. The largest particle size identified, from 20 to 40 μm, covered about 55% of the surface of the module, and the larger or smaller particle sizes in the test sample constituted a tiny minority. In contrast, the fouling factor, expressed as the number of particles that was deposited per cm^2 per hour, indicated that most of the particles had sizes from 5 to 35 μm.

Bouaouadja and co-authors [9] investigated and described the dust obtained in a desert area. They showed that the particle size distribution can be uniform or bimodal, which means that the particle size of the impurities in the test sample may be similar or completely different. Similarly, the morphology of the particles can be different, from rounded grains with smooth edges, to very rough particles with sharp edges.

Zhang, Cui, Fang, Fan and Zhang [10] described 76 dust samples deriving from Wuhu in the Anhui region of China in order to qualify the size of dust grains. It was found that 34% of the particles were in the range of 120–370 μm, and 25% were in the range of 20–55 μm.

Igathinathane et al. [11] studied the properties of the dust coming from the production of pellets made of wood and bark. The volatile air pollutants emitted from sawmills had relatively large dimensions, and therefore were deposited in the vicinity of the plant. As stated in the article, the average size of the particles from the production of wood pellets was 113.8 ± 12.3 μm in length and 73.6 ± 7.6 μm in width, whereas in the production of cortical pellets, the dimensions were 118.1 ± 14.9 μm in length and 60 7 ± 7.1 μm in width.

In semi-arid desert areas, the amount of naturally deposited dust is very high. As has been shown by Ta and co-authors [2], in the area of the Gobi desert, a layer formed with a dust deposition density of about 365.48 g/m^2, while in areas of loess, the layer was thinner, i.e. approximately 251.75 g/m^2.

2.2. The impact of dust on PV performance

The influence of the thickness of a dust layer on the performance of photovoltaic modules is significant, as concluded by Jiang, Lu and Sun [12]. The authors conducted experiments with the use of artificially produced impurities with a grain size of 1–100 μm, wherein about 20% by volume had a particle diameter of 20 μm and 74% were smaller grains. The main components of the dust were SiO_2 and Al_2O_3. As a result, the study came to several important conclusions:

- dust caused a significant decrease in the short circuit current I_{sc}, but did not affect the value of the open-circuit voltage V_{oc},
- with increasing thickness of the dust layer, i.e. with a dust deposition density from 0 to 22 g/m^2, the efficiency decreased by 0–26%; this dependency was linear,
- the surface material may considerably influence dust deposition and accumulation (the polycrystalline silicon module packaged with epoxy degraded faster than other modules with a glass surface),
- larger dust grains had a more significant impact on reducing efficiency, which was also confirmed by Biryukov [8].

Based on these results, the authors stated that in order to maintain the high efficiency of solar energy conversion, it is necessary to clean the surface of photovoltaic modules regularly and quite often, particularly if they are located in regions with high urbanization and its associated air pollution or in dry areas.

Module performance is also affected by humidity and wind speed, as a result of creating additional shading and coagulation of dust on the front cover of the module; combinations of these factors are also important, as shown by Mekhilef et al. [13]. They concluded that an increase in the level of moisture in the atmosphere deteriorates the working conditions of photovoltaic installations, whereas higher wind speeds cool the surface and relatively reduce the ambient humidity; additionally, this increases the number of particles floating in the air, which may lead to their deposition on the modules, This also entrains contaminants on the surface of the installation. However, the clear identification of this impact is difficult.

Depending on the location, the composition of dust may be significantly different, and these differences affect the degree of reduction in the efficiency of photovoltaic modules [14]. Three representative samples of air pollution in Athens, Greece were studied, including red earth, limestone and coal ash as well as dust samples. These pollutants are commonly found in urban areas and