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# Impact of accumulated dust particles' charge on the photovoltaic module performance

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ABSTRACT

This work is focused on analysing effect of accumulated dust particles' charge on PV module performance. In the Dundee University's laboratory, dust particles have been created through epoxy powder and charged by using corona and tribo-electric charging methods by varying the charge levels of the accumulated dust particles. The PV module output has analysed for finding a relation between charge levels of the accumulated dust particles and its output voltage. Obtained experimental results have shown that charge level of accumulated dust particles on PV module's have significant impact on its output and dust particle accumulations are not associated with panel tilt angle.



## 1. Introduction

The theoretical potential of solar energy is enormous – far beyond what the world could ever require. With today's solar photovoltaic (PV) efficiencies, solar energy from desert regions would be more than enough to meet all the electricity demand in both industrialized and developing countries [1]. The introductions of very large solar PV systems in desert areas are very attractive and would also contribute towards the regional economic development. A detailed analysis of technical, socio-economic and environmental aspects of very large scale solar PV system installations in the desert areas have been given in report [2]. There are many meteorological factors which affect the PV system performance. The solar PV system output mainly depends on the operating solar cell temperature, temperature coefficient, maximum power point tracking, module efficiency, inverter mismatch factor, and incident solar radiation on the PV module. Especially in the desert area, where large scale PV system have been under planning, dust accumulation on the PV modules' surfaces would have substantial impact on the system performance. Dust is defined as small particles in the atmosphere which can settle due to their own weight, but which remain airborne as a dust/air mix for some time. The motion of dust particles during wind erosion causes charging of the particles and it is particle size dependent [3,4]. The electrostatic charge of the dust particles can significantly affect the PV system output especially in the tropical/desert region/industrial area applications.

Many studies have validated effect of dust gathering on the PV module output [5–10]. But they have not analysed the effect of the charge levels of accumulated dust particles on the PV module performance. The effect of charged particles on the performance of PV module under extra-terrestrial satellite in the Mars atmosphere has been reported in Refs. [11,12]. They have not provided any measureable analysis about the charge levels of accumulated dust particles on PV module's output. Dust accumulation on a surface mainly depends on dust particle's size, electrostatic charge, and the presence or absence of an adsorbed moisture layer, the electrical resistivity of the dust, etc. [13]. It has been reported in Ref. [4] that immediately after a dust storm, smaller particles are predominantly charged positive and larger particles are predominantly charged negative. The relation between the charge levels of accumulated dust particles' and the PV module's performance has not been well explored in the existing literature. Clouds of uncharged particles such as sand or volcanic ash become charged by some undetermined mechanism and experiments now show that nearby electric fields could be responsible [13]. The dust depositions on the PV module are considered due to tilt angles of the PV module [9,10] but

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they have not considered the effect of charge level of dust particles on the surface adhesion. The main objective of this work is to study the impact of the charged dust particles on the PV module output and find a relationship between them.

## 2. Methods for charge measurements

This work is focused on analysing the effect of accumulated dust particles' charge on the PV module performance. The experimental setup for this purpose has been developed at the University of Dundee (UK). At present, the scientific understanding of the dust storm is still very limited [14]. In the laboratory, the dust particles have been created through epoxy powder. It has been explained in Ref. [15] that approximately 70% of the powders handled by industry, including dust that may have generated from handling solid epoxy resins. Therefore solid epoxy resin with different sizes has been considered as dust in this work. The epoxy powder has been charged by using corona and tribo-electric charging methods for varying the charge levels of the dust particles.

In this work, the epoxy powder has been used as dust particles on the PV module. One purpose of this investigation has been to establish quantifying the amount of charge deposition from a cloud of charged particles by a method of change of capacitance to earth of each Faraday cup [16–19]. The method of measurement involved the application of a capacitance sensor, whose voltage to earth has been measured. For the purposes of this investigation a PCB of FR4 material has been used with an array of 16 F cups. Each cup was the result of a deposition of Ni on to the FR4 substrate, as shown in Fig. 1a and b.

The amount of charge in each cup has been determined using the following relation for the capacitance of each cup ($C_{cg}$) [16,17,19],

$$C_{cg} = \frac{4\varepsilon_o k_{FR4} L d}{t_1} + \frac{\varepsilon_o k_{nickel} L w}{t_2} \tag{1}$$

where $t_1$is the thickness of the FR4 substrate, $t_2$ is the thickness of the nickel, and $w$ the width of the bottom, $\varepsilon_o$ is the permittivity of space, $k$ is the dielectric constant, $L$ the sidewall length and $d$ the sidewall depth of each cup respectively.

The PV module, which is used in this study, was amorphous silicon solar cells. The PV module output has been analysed for (i) clean room conditions and (ii) electrostatically charged particles. The experiments were carried out in the laboratory with all environmental effects. For the second set, it was coated by spraying electrostatically charged particles on PV module to simulate the accumulation of the equivalent dust particles on the surface of the same PV array in operation under stormy conditions. For these tests, epoxy powder was used to simulate the expected conditions that may arise in a desert location. Charged particles have been generated in the laboratory by two methods: in one method a corona charging gun has been used and in the second method a tribo-electrification gun has been used. Corona charging produced negative pulses of voltage (negatively charged particles), whereas the tribo-electric gun produced positively charged particles. In ref [3], tribo-electric charging for granular systems has been explained for effect of charging on non-equilibrium dynamics. In which collision-induced electron transfer generates electron accumulation on a particle-size-dependent. The size distributions of charged particles vary at different meteorological conditions. The motion of particles during wind erosion causes tribo-electric charging of the particles and it is particle size dependent [3,4]. Particles with a small threshold for erosion (~100 μm) have been found to preferentially obtain positive charge while larger particles that are too heavy to be lifted preferentially acquire negative charge [4]. Measurements of static electric field are very important in order to develop a coherent picture of electrostatic charging in dust storms.

A new design for Faraday Cup (FC) has been developed using FR4-PCB with a thickness of 115 μm for spraying dust charged dust particles (i.e. epoxy powder). This design has been reported in our work [16,19]. The array consists of sixteen cups. Each cup consists of two enclosed square walls of copper: (i) an inner conductive wall and (ii) an outer grounded wall. Electro-less Nickel plating is used to create the inner conductive cup bottom of thickness 200 nm. A three dimensioned draft for the substrate has been presented in Fig. 1a, while Fig. 1b shows a photo for the cups after the electroless nickel plating. After spraying the array with charged particles the charge measurement has been undertaken for each cup.

## 3. Experimental method

In this work, a measuring instrument has been designed and used to carry out measurements of the effects of charged powder particles on a PV module's output voltage. The instrument has an array of static Faraday Cups on an FR4-PCB, as shown in Fig 1b. The net charge of the accumulated powder particles by individual cups in the array has been measured. For these measurements, a DAQ device in conjunction with the LabVIEW software has been used to collect and display the charge accumulated within each Faraday Cup. A multifunction 6008 USB DAQ device has been used to connect the Faraday Cups outputs to the PC with its LabVIEW software for data acquisition and analysis. It has helped in determining the charge of accumulated particles on the PV module.

## 4. Experimental process

The experiments have been carried out using three amorphous PV modules. The PV modules have different dimensions: (i) PV module (PV1) has of 28 × 70 cm dimensions, (ii) PV module (PV2) has of 15 × 5.5 cm dimensions, (iii) PV module (PV3) has 1.25 × 1.65 cm. Each PV module's open circuit voltage and short circuit current have been measured before coating/accumulating the charged powder on the module surface. These tests have been carried out by measuring the output voltages of each PV module before and after being coated with the charged powder under the same incident solar radiation incident conditions. For this investigation, electrostatically charged epoxy powder has been used as dust accumulation on the PV module.

In the laboratory, the dust particles have been created through epoxy powder and they have been charged by using corona and tribo-electric charging methods for changing the charge levels of the dust particles. In all experiments, the spraying of the epoxy powder has been done using a powder gun through the FCs array on a PV module for a period of 6–7 s of coating time. The electrostatic powder coating adhesion properties for both corona and tribo-electric spraying systems are equal and it needed 6–7 s [17]. The source voltages have been set in the range of 20–70 kV and investigations have been carried out at 10 kV intervals.

Foe these works, four sets of experiments have been carried out at different time. For corona charging, all experiments have been carried out with a constant pressure value (2 bar) and different voltage values varying from 20 kV to 70 kV (10 kV increment each time). Moreover, for the tribo-electric charging, the powder has been charged using different amounts of pressures varying from 1 bar to 2 bar with 0.5 bar increment for each experiment. The distance between the nozzle of the spraying gun and the FCs array and the PV module has been fixed at 27 cm for all experiments. The PV module and the FCs array have been attached vertically to the grounded wall.

After each experiment, the coating system has been switched