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On the investigation of photovoltaic output power reduction due to dust accumulation and weather conditions

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ABSTRACT

Certain environmental conditions such as accumulation of dust and change in weather conditions affect the amount of solar radiation received by photovoltaic (PV) panel surfaces and thus have a significant effect on panel efficiency. This study conducted an experimental investigation in Surabaya, Indonesia, on the effect of these factors on output PV power reduction from the surface of a PV module. The module was exposed to outside weather conditions and connected to a measurement system developed using a rule-based model to identify different environmental conditions. The rule-based model, a clear sky solar irradiance model that included solar position, and a PV temperature model were then used to estimate the PV output power, and tests were also conducted using an ARM Cortex-M4 microcontroller STM32F407 as a standalone digital controller equipped with voltage, current, temperature, and humidity sensors to measure real time PV output power. In this system, humidity was monitored to identify dusty, cloudy, and rainy conditions. Validated test results demonstrate that the prediction error of PV power output based on the model is 3.6% compared to field measurements under clean surface conditions. The effects of dust accumulation and weather conditions on PV panel power output were then analyzed after one to four weeks of exposure. Results revealed that two weeks of dust accumulation caused a PV power output reduction of 10.8% in an average relative humidity of 52.24%. Results of the experiment under rainy conditions revealed a decrease in PV output power of more than 40% in average relative humidity of 76.32%, and a decrease in output power during cloudy conditions of more than 45% in an average relative humidity of 60.45% was observed. This study reveals that local environmental conditions, i.e., dust, rain, and partial cloud, significantly reduce PV power output.

1. Introduction

Global developments in the use of solar energy have increased over the last decade. However, although the generation of power using solar PV modules is a major renewable energy source, the amount of power output is greatly influenced by environmental conditions such as solar radiation, wind speed and direction, ambient temperature, humidity, and atmospheric dust. In solar PV applications, the total amount of solar radiation received by the surface of a PV module essentially depends on its orientation and local climate conditions, and although the maximum power point tracking (MPPT) algorithm is applied to determine the maximum power output from a PV module, it is unable to operate adequately if dust is deposited on the surface of the PV module [1,2].

Two studies were conducted to investigate the effects of accumulation and physical properties of dust on the performance of PV cells. In the first study, an experimental investigation of the dust accumulation effect on the fill factor, output power, and short circuit current of PV cells was conducted using known materials that were uniformly spread over the PV cells; results showed that the PV cells deteriorated significantly due to the accumulation of dust. In the second study, experimental investigations were conducted using five different physical properties of dust; results showed that finer particles caused greater deterioration in the performance of PV cells than coarser particles. Both studies were conducted using a solar simulator as the source of light and provide experimental evidence of performance deterioration in relation to the

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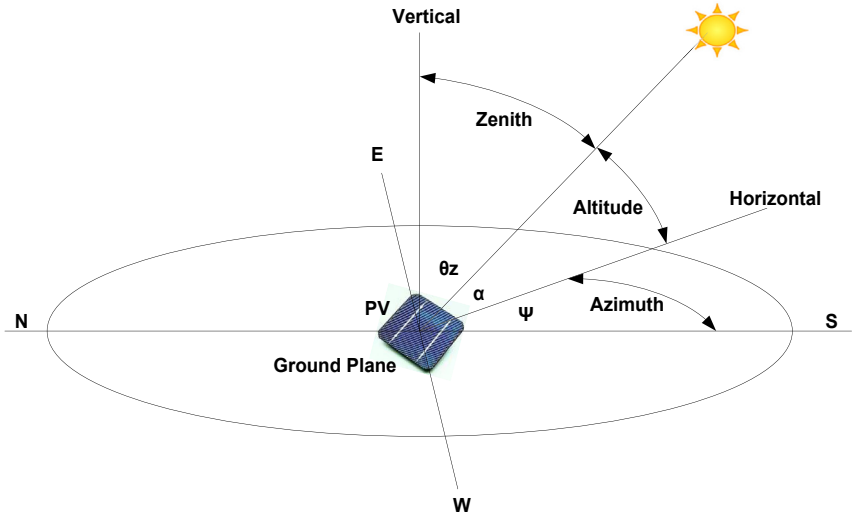

Fig. 1. Coordinate system on Earth's surface.

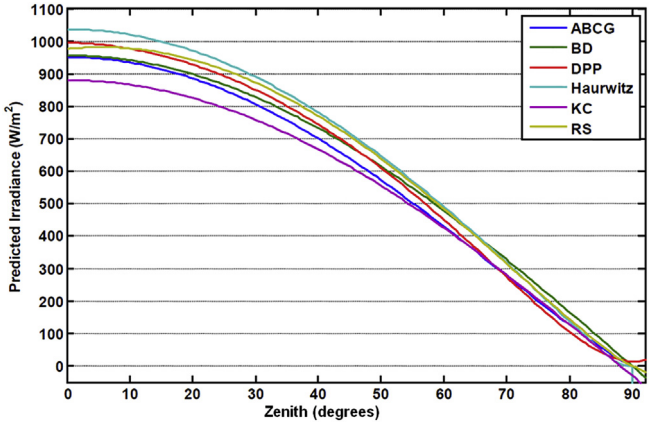

Fig. 2. Comparison of irradiance predictions from several models according to zenith values [26].

accumulation and physical properties of dust [3,4].

Various technical studies using experimental investigations have also been conducted on the impact of dust accumulation and climatic parameters on PV module performance [5–9], and results have indicated that dust concentration, wind direction, wind velocity, air mass, and temperature cause a significant deterioration of PV performance. The researchers in Ref. [10] analyzed PV modules performance based on climatic conditions in desert environment in southern Algeria. In this research, the experimental study was conducted using outdoor measurements of PV modules over an exposure period of 10 years, without specifically identifying particular weather conditions. It is of note that semi-arid and desert regions of the world have high solar intensity but also a large quantity of airborne dust, and large-scale PV plants are commonly located in such regions [11,12].

Furthermore, previous research has also investigated the effects of dust deposition and regional weather conditions on the efficiency of PV modules in various environments. Studies comparing wet and dry seasons have shown that during a long dry season dust deposition can cause a reduction in power output of as much as 20% [13], while in Malaysia it can reach 50% [14], and in Senegal losses range from 18% to 78% [15]. It has also been determined that dust accumulation on PV panels due to a coating of sand in dry regions may decrease PV power by up to 25%, and that if the PV surface is not being cleaned for more than six months losses can reach 50% [16–21].

Ghazi and Ip (2014) investigated the deterioration in PV panel efficiency due to weather conditions in Brighton, UK, in relation to the deposition of solid particles. Results of laboratory experimental simulations using outdoor glass units showed that a small amount of fine particles caused a reduction in light transmittance of 11%. Outdoor field measurement results revealed that the largest negative impacts on the performance of PV panels were related to weather conditions, particularly snow and rain, and the small impact of dust deposits caused by the regional weather [22].

Recent studies conducted experimental investigations on the effect of dust deposition on PV panels in a desert environment. The authors investigated variations in PV module performance during normal days and during dust storm conditions in Iraq. In their experiments, a solar simulator was used to expose dusty and clean modules to a constant level of radiation and temperature with the aim of analyzing the output power and short circuit current. The dust density and particles on the module were also investigated using an aerosol measuring system on a daily, weekly, and monthly basis. Experimental results showed that the accumulation of dust has a significant effect on the expected PV power output [23,24]. In addition, an earlier study evaluated degradation of the electrical performance of PV modules due to the accumulation of dust in southern Poland, where experimental investigations were performed using crystalline PV modules after a few years of exposure to both natural and artificial dust deposition. Experimental results indicated a linear relationship between reduction in efficiency and the dust deposition density [25].

The problem of reduced PV generated power due to dust and weather conditions necessitates an accurate identification of dust accumulation and regional weather conditions. Therefore, this paper aims to investigate the reduction in PV power output due to dust accumulation and weather conditions in the city of Surabaya, Indonesia. Experimental research is conducted to identify weather conditions and the accumulation of dust on the surface of a PV module using a measurement system that was developed based on a simple rule-based model, and solar irradiance and temperature models. Validation results show that field measurement data are in good agreement with prediction results of PV output power. It is considered that the results of this research can be used in the