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Analysis of the impact of dust, tilt angle and orientation on performance of PV Plants

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ABSTRACT

The objective of this study is to review and compare performance of PV systems under the influence of dust, different tilt angles and orientations. The process was carried out by comparing one-year measured data, simulated data and analytically calculated data. The performances of five different PV installations which amount to 1280 kW_p installed in Cyprus International University, North Cyprus was analyzed as a case study. The PV plant, which was planned and commissioned by Sustainable Energy Research Center of CIU, is installed in five different locations on the campus by deploying three mounting techniques. The influence of dust and cleaning on the PV systems were examined. After implementation of the cleaning procedure, an average of 2.5% variance in specific yield was obtained. The effect of the different inclinations on each system is also reported. Mean specific yield of Arazi (25° tilt) plant is 1732.44 kW/kW_p which is 17.3% and 5.6% higher than Stonite (6° tilt) and Arena (6° tilt), respectively. In addition, simulation results were compared with the measured data from installed PV plants. The energy production at Arazi, Carpark and Arena PV plants were higher than the simulated results by 7%, 3% and 7%, respectively while Stonite and B-Block energy production dropped by 3% at each. The mathematical method of obtaining energy output or extracting the global irradiation on an inclined surface presents average variance of 0.3% between calculated and measured energy. It is found that the mathematical model is more reliable than simulation and it can be used to extract the solar radiation on inclined surfaces with minimal error when the energy output is already measured. It can also be applied to other studies in the future.

1. Introduction

The last five to ten years feature enormous increase in photovoltaic (PV) modules demand around the world as a result of government policy formations, subsidies, and advancement in PV systems reliability, stability and efficiency [1]. Globally, the electric power output by solar PV in early 2014 is 150 GW according to International Energy Agency, the rate at which new solar PV systems capacities were installed was at 100 MW per day in 2013 [2]. Several factors have been found to affect the performance of PV systems; these factors include solar radiation incident on the solar modules, ambient temperature, cell temperature, shading effects, tilt angle and orientation, soiling/dust effect, and mounting techniques etc. Advantages of PV systems include: environmentally friendly technology with no noise or pollution; flexibility and possibility of being adapted to many different applications; no moving parts - this makes PV systems reliable and last long with highly reduced maintenance required; offer energy independence; the energy source for PV systems is sunlight which is free and readily available; costs of PV are generally decreasing as conventionally produced electricity is expected to become more expensive, hence PV systems can be used to hedge against future energy price increases. Despite several and undisputable advantages**,** PV systems also has some demerits such as high initial cost compared to competing power generating technologies; require relatively large array area to produce significant amount of power; availability of solar radiation resource at a particular location determines the feasibility of producing appreciable amount of power; limited or lack of knowledge about the potential of solar PV systems in some regions.

1.1. PV installation in North Cyprus

Several studies have been carried out globally and in Cyprus on performance evaluation of PV systems; a comparison of two 200 W_P PV systems was conducted in CIU; 200 Wp fixed PV inclined at 36° tilt and a dual tracking system [3]. It was found that the tracking system produce about 40% more energy than the fixed system under North Cyprus meteorological conditions. Also, the deployment of solar geometry equations to determine the monthly, seasonal, and yearly tilt angle for

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Table 1
Dust effect on PV modules in various countries.

Ref	Dust Effect on PV modules	Location
[23]	6–13% decrease in power output in spring, winter & summer.	Cyprus
[24]	Average of 4.4% daily energy loss for a year. This could increase to more than 20% in dry conditions.	Spain
[25]	50% reduction power output for panels exposed to approximately six months without cleaning.	Saudi Arabia
[26]	17.4% loss per month in energy yield for south-facing panels at tilt angle of 45°.	Egypt
[16]	16–29% degradation of power output of 7 different PV modules without any cleaning procedure for 18 years.	Australia
[27]	2.78% daily reduction in short circuit current.	Saudi Arabia
[28]	10% power output reduction after 5 weeks of outdoor exposure.	UAE
[29]	10% in PV module efficiency after 100 days of outdoor exposure.	Qatar
[30]	5–6% decrease in module efficiency after one week.	Palestine
[31]	Annual dust reduction factor of 93%.	Greece
[32]	Airborne dust concentration on PV performance leading to decrease in efficiency from 33.5% to 65.8% for an exposure of 1–6 months	–
[33]	11% reduction in transmittance was estimated for a 5 g/m^2 dust deposition over a month.	–
[20,34]	73 g/m^2 deposition of cement dust resulting in an 80% drop in PV short circuit voltage.	–
[35]	20 g/m^2 of dust accumulation on PV panel reduced the short circuit current by 15–21%, and the open circuit voltage by 2–6% and the efficiency by 15–35%.	–

solar systems in North Cyprus was examined; the optimum tilt angle for specific sites of installation was determined [4]. Furthermore, the conformity of the output of three PV simulation tools with performance of real life PV applications was presented by [5]; North Cyprus was selected as case study and the variance in the system performance parameters such as energy, specific yield, performance ratio, and capacity utilization factor of a 5.76 kW_p real life PV and that of simulation tools were analyzed. Recently, a new methodology, with core emphasis on self-consumption policy, and optimization of the design of large and medium scale PV power plant was proposed and implemented by Sustainable Energy Research Center of CIU (SERC) [6]. The implementation of this method featured the installation of 1280 kW_p with ground, rooftop, and carpark installations. In addition to this plant, there are few other large scale PV systems installed in North Cyprus in last 3 years which amount to nearly 6 MW_p. It can be seen that North Cyprus, located in the Northern Hemisphere, has enormous potential for solar radiation and it is fast becoming a seat of large scale PV installations for the purpose of ingenious research and harvesting solar energy within the region.

1.2. PV installations impacts and grid integration

PV is one of the fastest growing energy sources worldwide and in order to maintain this growth rate, there is need for new developments with respect to material use and consumption, device design, reliability and production technologies as well as new concepts to increase the overall efficiency [7,8]. Large PV plants are dynamic systems, hence the occurrence of intermittency in operations. Sources of such intermittency include variability is temperature, solar radiation, and shading effects caused by moving clouds. When an entire array or part of an array is covered by moving cloud, it can result in sudden change in generator output [9]. Large PV are variable renewable energy sources; integration of such into the grid present a number of power system operational issues [10]. An important method of ensuring smooth integration of large-scale PV systems into the grid is to deploy the use of grid codes. The grid codes are developed to encapsulate rules covering the use of technologies, operational practices and regulations that enable effective integration of variable renewable energy sources in the grid [10,11]. The important areas of such grid connection codes development are: the size of the power system; the interconnection level; voltage levels; distribution and flexibility of load and generation; characteristics of conventional generators; energy policy; energy planning; market size for energy source and operational practices [11]. Other vital areas of concern in the deployment of large scale PV systems are the influence of dust in windy and tropical climate, economic impacts [9], connection with existing power system protection, stability and reliability [12]. This work did not focus on grid integration, however it is recommended as future work in Section 4.

1.3. Dust and cleaning

Dust or soiling effect refers to particulate grainy contamination of optical surfaces of PV modules. In addition to dust accumulation, soiling includes surface contamination by plant products, soot/smoke, salt, bird droppings, and growth of biological breeds [13]. Outdoor solar PV energy output is highly dependent on solar radiation and PV materials. A major environmental factor that incomparably but temporarily decreases the output energy generated by PV modules is dust [14]. Dust can be removed by cleaning thereby restoring the PV performance to its full capacity. Such cleaning exercise can be carried out naturally, manually, and automatically [13]. Accumulation of dust on PV module glass erodes the glass transmittance thus decreasing the module power output [15]. Deterioration of PV performance induced by dust is not homogenous for every place around the world. This is because dust accumulation on the surface of PV module depends on the environmental conditions such as air temperature, wind velocity, rainfall and humidity [16,17]. A typical annual dust reduction factor is 93% or 0.93; this means that if 200 W panel is considered, it will typically operate at about 186 W (200 × 0.93 = 186 W) due to dirt accumulation [18–20]. Atmospheric dust with mean diameter 80 μm at 250 g/m^2 was tested and found to reduce PV short circuit current by 82% [20]. Dust deposition is site climate-specific and thus its quantity depends on the place, type of dust, and several other factors.

In some regions, high rate of power losses due to dust is as a result of lack of rainfall [15]. It is important to note that dust accumulation rate also affect PV module performance. Increase in dust accumulation rate leads to decrease in PV performance as a result of drop in glass cover spectral and transmittivity [21]. In a research recently conducted, reduction in PV module conversion efficiency are 10%, 16%, and 20% for 12.5 g/m^2, 25 g/m^2 and 37.5 g/m^2 of dust density respectively [22]. Periodic cleaning can help reduce the effect of dust on PV modules. The frequency of cleaning will also depend on the local climatic/environmental condition of the region where the PV systems are installed [14]. As mentioned earlier, environmental influence include soil type, neighboring vegetation, and climatological characteristics. Table 1 details the consequences of dust on installed PV systems around the world.

1.4. Tilt and orientation

Tilt angle of PV is the angle of inclination of PV panel with its horizontal. Mounting techniques, land topography, and climatic conditions are important factors to consider in order to determine the optimum tilt angle of PV plants. When the tilt angle and orientation are made to experience continuous changes by following the movement or