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The effect of wind direction on the performance of solar PV plants

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ABSTRACT

The impact of wind direction on the overall performance of a utility-scale PV plant was studied by analyzing field data from Hadley solar farm in the UK. The solar PV plant utilizes a fixed-tilt system with the PV panels facing south at a 20 degree angle. The hypothesis is that when wind blows from the south the total power production of the solar PV plant increases in comparison with non-southerly wind events, provided that all other determining factors, such as solar irradiance, ambient temperature, and wind speed are the same. During the case study of January 1 to July 1, 2017, 42 pairs were identified, each of which includes two cases with equal solar irradiance, equal ambient temperature, and equal wind speeds but different wind directions; in one case wind is from the north and in the other one wind blows from the south. The hypothesis was found to be true across all 42 pairs, i.e., the power production of the solar PV plant was always greater in the event of southerly winds. One take-away from this finding is that wind direction and wind speed frequencies need to be taken into account along with other climatic factors to have an optimal site selection for establishing a solar PV plant. The more frequent the southerly wind occurs, the more power can be extracted from the PV panels. The other practical conclusion of this study is that it is more efficient to build fixed-tilt solar PV plants on areas oriented along the west-east direction.

1. Introduction

Considering the negative environmental, economic and security consequences of depending on fossil fuels, it is in the interest of future generations to smartly invest in carbon-free alternatives. One of the most promising alternatives for fossil fuels is solar energy, and hence, extensive amount of effort has gone into solar market research and analysis [1–5], solar grid and systems integration [6–12], concentrating solar power [13–16], and Photovoltaics (PV) [17–21] during the last decades. Site selection is one of the most critical tasks for developing a photovoltaic power plant. A wide range of environmental, orographic, spatial, and climatic factors need to be taken into account to select a site for developing a solar PV plant with a high average annual power performance and low balance of system costs (see Fig. 1) [22]. Among all, climatic factors including solar irradiance, ambient temperature, equivalent sun hours, and wind speed have the most significant impact on the power production efficiency of any solar PV plant.

According to the literature, the efficiency of PV panels reduces as the panel temperature increases. A measurement study conducted by Deb Mondol et al. [23] indicated that the efficiency of a 13 kW roof mounted photovoltaic system in Northern Ireland was reduced by approximately 10% due to the high temperature of the PV panels in summer months. At low insolation, the PV efficiency was reduced by approximately 4–8%. A field study on a 5.28 kW PV system installed on the east coast of Saudi Arabia indicated 35% reduction in the performance ratio when the PV panel surface temperature was increased from 35 °C to 60 °C [24]. Park et al. [25] studied performance of semi-transparent PV panels and found that the PV panel output power decreases by approximately 0.52% per each 1 °C increase in the surface temperature of the panels under outdoor conditions. Several other studies concerned with the effects of increased temperature on the efficiency of PV panels have demonstrated that increased cell temperature can lower the efficiency of the typical crystalline silicon modules by approximately 0.3–0.65% per each 1 °C increase in the surface temperature of the PV panels [26–28]. More on the inverse relation between the efficiency of PV panels and their temperature can be found on [29–39].

Accordingly, any change helping with cooling of PV panels will cause the efficiency of solar PV plants to increase [44–47]. The most cost-effective option to enhance cooling of PV panels is taking advantage of natural wind to the highest possible extent. This can be achieved by developing solar PV plants in sites with strong and frequent wind from the south, as in PV plants which are developed in the northern hemisphere and are not equipped with a solar tracker system -

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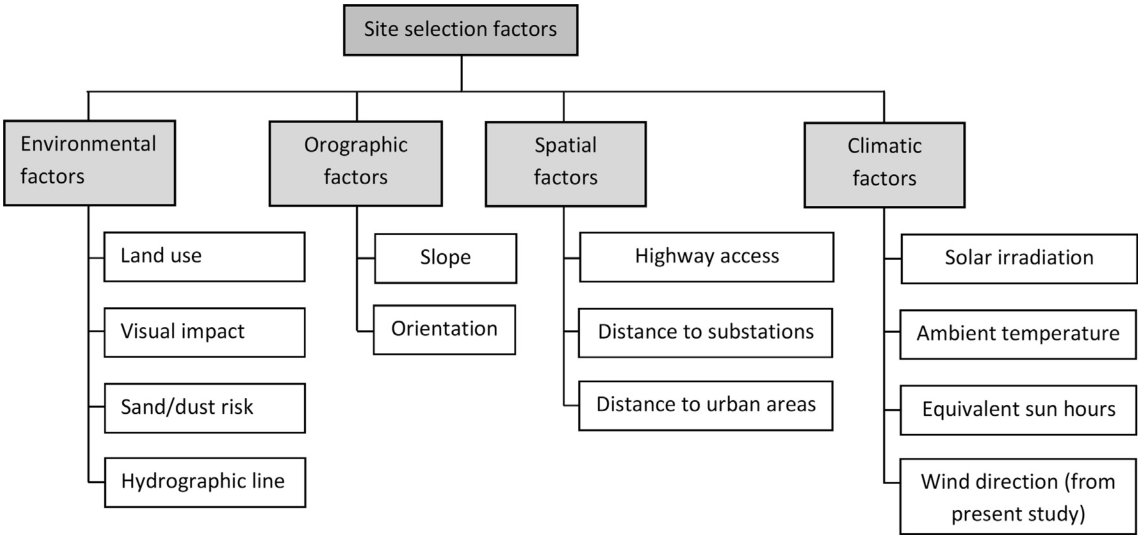

Fig. 1. Factors considered by solar developers to select the most suitable site for developing a solar PV plant [22,40–43].

which is mostly the case particularly in countries at higher latitudes - all PV panels are facing the south, and hence, convection heat transfer from the surface of PV panels is maximized in the event of southerly winds. This is vice versa for solar PV plants developed in the southern hemisphere. In this article, we present results obtained from data measured at a 5 MW solar PV plant located in the northern hemisphere (UK) to evaluate the enhancement in power production of utility-scale solar PV plants in the event of southerly winds. The purpose of this article is, first, to answer whether the wind direction needs to be included within climatic parameters that are currently being taken into calculations in site selection by solar developers, second, to determine the best orientation for the area of solar PV plants, and finally, to propose some research opportunities for future studies.

2. Field study

2.1. Hadley solar PV plant

The Hadley solar PV plant, illustrated in Fig. 2, with a nominal capacity of approximately 5 MW was chosen as the test case for this study. This solar PV plant, which is built over an area of approximately 30 acres, includes approximately 19,500 PV panels, each of which has a capacity of 255 W. In the following sections, specifications of the major instruments that were used to measure data presented in this study are introduced.

2.2. Measuring instruments

2.2.1. Wind

The anemometer consists of four ultrasound sensors taking cyclical measurements in all directions with a resolution of 0.1° and with a sampling rate of 10 s. The wind speed and wind direction are calculated from the measured run-time sound differential with an uncertainty of ±0.3 m/s and ±3°. Wind directions measured by the anemometer are then corrected via data measured by an integrated electronic compass which has a resolution of 1° and sampling rate of 5 min.

The anemometer is placed in a weather station mounted on top of a mast with height of approximately 4.5 m, and the mast is installed on top of a building with height of approximately 3 m, leading to a total height of approximately 7.5 m from the ground. The anemometer station is located approximately in the middle of the solar PV plant (see Fig. 2).

2.2.2. Temperature

The weather station described in Section 2.2.1 also measures the ambient temperature using a precision NTC resistor with an accuracy of ±0.2 °C (for temperatures between −20 °C and +50 °C). In order to minimize the effects of external influences, such as solar radiation, these sensors are located in a ventilated housing with radiation protection. In contrast to conventional non-ventilated sensors, this significantly increases the accuracy of measurements during high radiation conditions.

2.2.3. Irradiance

Irradiance for the PV plant is measured using a Hukseflux SR20-D1 pyranometer which is mounted on a bracket and attached to the panel frame in a horizontal position. The PV plant has 2 pyranometers installed, one for each block of the site (see Fig. 2). The accuracy of the solar irradiance sensors is ±5%.

3. Case study of "January 1 to July 1, 2017"

Wind measurements during the case study of January 1 to July 1, 2017, indicates that the eastsoutherly and southerly directions were the prevailing wind directions with respectively 17.12% and 16.16% of the time at the Hadley PV plant (see Fig. 3). The westsoutherly direction with average wind speed of approximately 3.26 m/s was identified to have the highest wind speed, while the total average wind speed over all directions was measured to be approximately 2.60 m/s. In this study, winds were categorized into two southerly and non-southerly groups. Southerly winds were defined to include all directions between 95° and 265° (a 170°-window around the south), and non-southerly winds were defined from 270° to 360°, and then, from 0° to 85° (a 170°-window around the north), all with respect to the North using the meteorological convention. The time interval between each two consecutive measurements of farm-averaged power production was 15 min, hence, approximately 17,376 measurements were conducted during this case study, for 12,642 of which wind was blowing from the south (i.e., wind direction was between 95° and 265° with respect to the north using meteorological convention). Every single measurement with a southerly wind was compared to all other measurements with non-southerly winds in order to find a pair of two measurements with southerly and non-southerly wind directions which are matched for solar irradiance, ambient temperature, and wind speed. Solar irradiance, ambient temperature, or wind speed of any two measurements were assumed to be equal if the difference between the two values was less than the uncertainty associated with the measuring instrument. Among all 12,642