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Energy yield loss caused by dust deposition on photovoltaic panels

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Abstract

Large-scale solar plants are generally located in semi-arid and desert lands where abundant sunlight is available for solar energy conversion. These plants, however, suffer from two major environmental degradation factors: high ambient temperature and high concentration of atmospheric dust. Degradation of solar collectors' performance caused by soiling results in a considerable loss of energy yield in all solar plants of the world. Dust and other particulate accumulation on solar collectors causes transmission loss. This is true with respect to transmission losses in photovoltaic (PV) and concentrated photovoltaic (CPV) systems, and for reflection losses in concentrated solar power (CSP) systems. We present here a brief review of the energy yield losses caused by dust deposition on solar collectors, with particular emphasis on flat-panel photovoltaic (PV) systems. The review includes some of the major studies reported on energy-yield losses on solar plants in operation in several regions of the world. In addition, laboratory-soiling studies are also included. We report on degradation in the performance of solar plants based on the type of solar collectors, geographical location, local climate, and exposure period of the collectors absent any manual cleaning. An analysis of the advantages of cleaning processes that include natural, manual, automatic, and passive methods is presented. Our objective is to provide solar plant designers with a database for predicting anticipated soiling losses in different parts of the world, and for assessing effective cleaning methods for restoring a system's energy yield.

Keywords: Soiling; Dust accumulation; Loss of transmission; Reflectivity loss; Cleaning methods

1. Introduction

Sunlight is an abundant and essentially inexhaustible energy resource but it is not distributed evenly on the earth's surface. Low latitude, arid and semi-arid areas, within 35°N to 35°S, receive the highest direct normal irradiance (DNI). For instance, the Mojave Desert (latitude: 35°N) in southwestern United States, and the Negev Desert (latitude: 30.5°N) in southern Israel receive 1920 kW h/m^2/year and 2007 kW h/m^2/year, respectively (NASA Solar Insolation, 2008). Seven of the worlds deserts, located between these two latitudes, are able to meet the energy needs globally with solar power generation technologies, including photovoltaic (PV), concentrated photovoltaic (CPV), and concentrated solar power (CSP) systems. A recent review (Wu, 2011) reports the mission of an initiative called Desertec to derive electrical energy from solar radiation available in Middle Eastern and North African (MENA) countries to meet major power requirements and to supply up to 15% of the electricity demand of Europe by 2050.

Notwithstanding the fact that deserts and arid zones offer an enormous potential for solar energy harvesting that significantly exceeds current market needs, operation of large-scale PV and CSP plants face substantial challenges. One of the main challenges is the energy yield loss caused by dust accumulation on the optical surfaces

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of solar energy conversion systems such as PV modules and solar mirrors.

The so-called "soiling" effect, referring to particulate contamination of the optical surfaces, has been found to have a significant deteriorating impact on energy yield due to the absorption and scattering losses of the incident light. Fig. 1 shows daily output power losses in different parts of the world caused by dust accumulation on solar collector surfaces. Although these regions receive high solar irradiance (NASA Solar Insolation, 2008), yet dust accumulation has a detrimental effect on the performance of solar collectors.

Soiling includes not only dust accumulation, but also surface contamination by plant products, soot, salt, bird droppings, and growth of organic species, adversely effecting the optical performance. Major performance-limiting factors other than soiling include temperature effects (primarily in monocrystalline silicon and multicrystalline silicon PV modules), high relative humidity (RH), high wind speed, corrosion, and delamination of the energy conversion devices. Dust deposition on solar collector surfaces depends upon two major factors: (1) location of the solar plants and (2) site's local environmental conditions (i.e. climate) (Mani and Pillai, 2010). Relevant dust properties include size and charge distribution, material composition, shape, surface energy, and biological properties. Environmental factors include the surrounding vegetation and soil type as well as climatological characteristics, i.e., frequency of dust storms, precipitation, wind speed/direction, ambient temperature, and relative humidity. Accumulation of dust on the collector surface depends upon the rate of deposition and the rate of removal by wind.

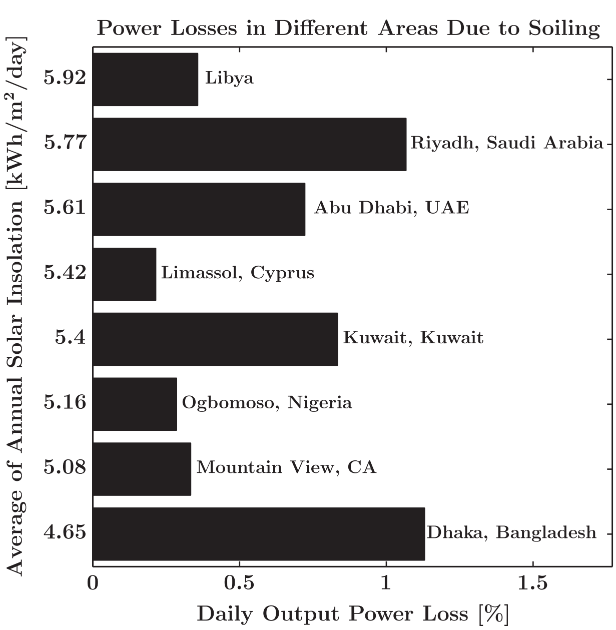

Fig. 1. Daily power loss of solar plants in different parts of the world: Dhaka, Bangladesh (latitude: 23.7°N) (Rahman et al., 2012), Mountain View, CA (latitude: 37.4°N) (Lam et al., 2009), Ogbomoso, Nigeria (latitude: 8.1°N) (Sanusi, 2012), Kuwait, Kuwait (latitude: 29°N) (AlBusairi and Möller, 2010), Limassol, Cyprus (latitude: 34.6°N) (Kalogirou et al., 2013), Abu Dhabi, UAE (latitude: 24.5°N) (Hanai et al., 2011), Riyadth, Saudi Arabia (latitude: 24.6°N) (Salim et al., 1988), and Libya (latitude: 27°N) (Mohamed and Hasan, 2012). (*Note:* The data on power loss, taken from different reports, do not represent annual average loss.)

Atmospheric dust concentration decreases exponentially as a function of altitude except under the dust storm conditions. Thus both orientation, such as tilt and height of the solar collectors make a significant difference in energy yield loss. Degradation is reduced if PV panels are installed at a high elevation to minimize dust deposition. Elevation of the solar collectors is often limited by the structural support needed against high-speed wind and the need of convenient cleaning and other maintenance requirements (Thornton, 1992).

Soiling studies have been conducted to determine dust accumulation rate as a function of soiling parameters such as location, wind speed, atmospheric dust concentration, exposure time between cleanings, and the rate of precipitation. These studies are conducted with collectors being cleaned on a regular basis, performing a comparative study while other(s) are left un-cleaned. The results provide the relative soiling loss as a function of exposure period; the longer the exposure period, the more the energy-yield loss without cleaning. In the laboratory soiling studies, dust deposition density has been correlated with soiling losses, with a definitive correlation between power output losses vs. accumulated dust concentration density on the surface (in g/m^2). Most of the field-studies report energy-yield loss vs. exposure time without the dust concentration density and the particle size distribution.

We also report here on the effectiveness of natural precipitation and manual cleaning techniques in removing deposited dust from collector surfaces. As depicted in Fig. 2, these processes include manual, automatic, and passive methods for maintaining a clean optical surface. Passive methods include modification of collector surfaces to aid cleaning or to minimize surface adhesion of the dust layer. Different methods of manual cleaning with water are reviewed along with newly developing automatic cleaning methods, which are still in the development stage. The advantages and drawbacks of these methods are compared.

Apart from soiling losses associated with terrestrial systems, similar problems related to dust accumulation on solar panels used for powering devices in lunar and Mars missions are also identified. The effect of dust accumulation on the performance loss of solar cells installed on the Mars Pathfinder, was simulated for 30-day and two-year mission periods (Landis, 1996). For the baseline and worst case scenarios assumed in this study, power losses of about 6% and 30%, respectively, were predicted for the 30-day mission period, and 75% and 85% for a two-year mission period.

The major emphasis of this review is to study the loss of energy-yield of PV plants as a function of (1) angle of inclination, (2) particle size distribution, (3) radiation wavelength, (4) environmental parameters such as relative humidity, wind velocity, and frequency of dust episodes,