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Dust accumulation effects on efficiency of solar PV modules for off grid purpose: A case study of Kathmandu

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ABSTRACT

The future of the world lies with renewable energy resources and solar energy is one such type of clean and sustainable energy resource. Solar PV modules are exposed to outdoor environments where dust accumulation is a prime degrading factor. Soiling and its effect on performance of solar modules are generally of high concern for regions with a high deposition of dust and low frequency and less intensity of rain. But some areas with abundant rainfall may also suffer from high dust deposition in the dry season. Kathmandu, with its peculiar environment conditions, suffers high air pollution and minimum rainfall during the dry winter. In this study, the effect of dust on PV modules is investigated with respect to dust deposition density and meteorological variables for Kathmandu with the objective to calculate a regression equation describing efficiency loss. Outdoor installation of experimental setup showed that during the study period of 5 months, the efficiency of dusty solar module left to natural dust deposition phenomena decreases by 29.76% with respect to the module which was cleaned on daily basis. Dust deposition density on the PV module accounted to 9.6711 g/m^2 over the study period. The research also showed that dust accumulation is highly concentrated at the bottom of the PV modules having a high risk of hot spots which could eventually lead to permanent module damage.

1. Introduction

Nepal, a developing country, lacks on the adequate production and consumption of energy. Due to lack of efficient production of power from conventional energy resources, Nepal has primarily relied on the renewable energy resources to supplement energy requirements. The current energy production by hydropower remains only 787 MW of required energy whereas the demand is in excess of 1200 MW (NEA, 2014) leaving people of the country to long hour of blackouts in dry seasons and power cuts even in rainy season. There is a need to improve reliability of the present power production by adopting the energy mix strategy in the country. For the nation to attain a sustainable development without degrading the environment, renewable energy generation techniques provide promising option. Renewable energy with the annual share of 13.5% globally is more than capable of meeting future energy requirements (Asif and Muneer, 2007). Research on various renewable energy sources is under progress to meet increasing demand for the commercial energy and issues related to the supply security and price volatility of the fossil fuels. These techniques include solar, wind, biomass, tidal, wave and geothermal energy production. Most of these technologies are at intermediate stage, some in research phase only but they have shown promissory results to control greenhouse emissions and meet local energy demand (Islam et al., 2004). Based on the Nepal's geological location and economic conditions, solar power has significant market over other distributed renewable energy techniques.

1.1. Dust

Dust is a general term for any particulate matter less than 500 μm in diameter, which is about the dimension of an optical fiber used for communications or 10 times the diameter of a human hair (Sarver et al., 2013). Dust can comprise various matters like vegetation pollens, animal cells, carpet and textile fibers and generally minerals from geomorphic fallout such as sand, clay or eroded limestone (Bagnold, 1965). Atmospheric dust (aerosols) is attributed to various sources, such as soil elements lifted by wind (Aeolian dust) (Siddiqui and Bajpai, 2012), volcanic eruptions, vehicular movement and pollution. The particle size, constituents of dust and their shape vary according to region throughout the world. Furthermore the deposition characteristics and rates vary dramatically in different localities. These factors are based on the geography, climate and urbanization of a region. Important dust

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characteristics are typically represented by size and distribution, density shape, composition, chemistry and charge. Important ambient conditions that affect these characteristics are humidity/-moisture gradients, variation in wind velocity direction and magnitude and seasonal variations (Sarver et al., 2013). When particles are deposited on PV modules, they interfere with illumination quality by both attenuating and scattering incident light (Qasem et al., 2011). The degree to which the particles interfere depends on their constitution, density, and size distribution. Particles impinge onto a surface due to gravity, electrostatic charge or mechanical effects (wind or water droplets). After deposition, they are held by the variation of electrical potential near the surface (charge double layer), surface energy effects, and capillary effects, in addition to gravity and electrostatic forces (Qasem et al., 2011). The roughness and structure of the surface also play a role in increasing the surface friction between the particles and the surface. It appears obvious that dust has a direct effect by reducing the performance of solar PV modules. A progressive effect of dust has been reported for certain weather parameters such as relative humidity, rain and ambient temperature (Kalogirou et al., 2013). Settled as well as airborne dust reduces the amount of solar radiation incident on the surface of a PV module (Qasem et al., 2011; Kalogirou et al., 2013).

1.2. Dust effect on PV modules

Studies have shown large performance variations from location to location as a function of exposure time (Siddiqui and Bajpai, 2012; Aassem et al., 2012). Wakim (1981) in Kuwait found a reduction of 17% in power output of PV modules due to sand accumulation over six days. Said (1990) evaluated the effects of dust accumulation over a year on a flat-plate solar thermal collector and a co-located PV panel. Over this period, a 7% per month power reduction rate was reported for the PV modules. Goossens et al. (1993) conducted experiments and wind tunnel simulations to investigate the deposition mechanism of suspended atmospheric dust on PV collectors and concluded that wind direction and collector orientation have a significant impact on dust deposition and distribution. Wind velocities greater than 2 m/s have only a small effect on the distribution of dust deposition. El-Shobokshy and Hussein (1993) covered PV module surfaces with different dust types (i.e. limestone, cement, carbon). The short circuit current was reduced to 20% of its initial value for the carbon accumulation with only 28 g/m^2, whereas same reduction was accounted with 73 g/m^2 deposition for cement, 125 g/m^2 for 50 μm, 168 g/m^2 for 60 μm and 250 g/m^2 for 80 μm limestone dust. It was specifically noted that the material composition of dust also affects PV performance. From the results, carbon particles are seen to absorb solar radiation more readily than the other dust types. This contributes to temperature rise of the converter as well as the amount of light reaching the solar converter (Sarver et al., 2013). Mailuha et al. (1994) expanded on the El-Shobokshy and Hussein (1993) investigations and focused the study on the effects of dust-deposited layer density and included tilt angle and solar intensity. It was found that with the increment of solar intensity, the PV performance degraded due to decrement in dust accumulation. At 700 W/m^2, the reduction in power output was almost negligible; however, when the intensity dropped to 400 W/m^2, the reduction was nearly 25% of the initial power output. Observations from studies of Rao et al. (2014) and Jiang et al. (2011) point that dust deposition is not the significant factor in alteration of open circuit voltage of photovoltaic systems whereas, the short circuit current is affected by dust deposition, up to 30–40% in the outdoor environment and 4–5% in the indoor environment. Jiang et al. (2011) observed the corresponding reduction of output efficiency varied from 0% to 26% when dust deposition density increased from 0 to 22 g/m^2. Mekhilef et al. (2012) mentions continuous humid environment causes degradation in solar cell efficiency. Increased wind velocities are attributed to more heat removal from the PV cell surface. Also, higher air velocity lowers the relative humidity of the atmospheric air in the surroundings which in turn leads to better efficiency. But, wind also lifts the loose dust and suspends it in the environment resulting in dust deposition in modules, shading and poor performance of PV cells. Soiling losses can be modeled as a linear degradation (Kimber et al., 2006). According to Mejia and Kleissl (2013) over an average of 145 day summer drought, dust deposition results in a 7.4% loss in efficiency. For a 15% efficient PV panel soiling losses over a 145 day drought would decrease the efficiency to 13.9%.

1.3. Kathmandu valley and Air Pollution Status

The Kathmandu valley, which has the capital city Kathmandu, is the most densely populated urban area of Nepal. The valley is located between the Himalayan in the north and the Mahabharat mountain range in the south. The Kathmandu city is located at a plain about 1325 m above sea level and is surrounded by hills and mountains. The climate condition of Kathmandu valley depends on the prevailing wind regime from central Asia and the northern hemisphere's cold pole. In the summer and early autumn, the prevailing wind regime in Kathmandu valley is the southwest monsoon. In the winter, the prevailing winds are more westerly. The high mountains in the north present the outbreak of cold Siberian winds from the northeast. The wind pattern is dominated by weak winds. Because of the high occurrence of calm and low winds speeds, the dispersion conditions in Kathmandu are poor. The mean annual air temperature in Kathmandu is 19 °C. The coldest month is January, with a mean temperature of 11 °C while July is the warmest month with a mean temperature of 25 °C. The annual average daily global solar radiation for Kathmandu is 3.83 kW/m^2/day (Poudyal et al., 2012). The driest months are November/December when the average rainfall is less than 1 mm (Shrestha, 2001). The unique topographic features coupled with high emissions of pollutants make the valley particularly vulnerable to air pollution. The valley is surrounded by hills forming bowl-shaped topography, which restricts wind movement and retains the pollutants in the atmosphere. This is especially bad during the winter season (November–February) when thermal inversion occurs in the valley late night and early morning. Cold air flowing down from the mountains is trapped under a layer of warmer air and acts as a lid. As a result, the pollutants are trapped close to the ground for extended periods of time (CANN, 2014). Rapid urbanization, industrialization, poorly maintained roads and vehicles are to be held responsible for deteriorating ambient air quality in Kathmandu valley. Vehicular exhaust and re-suspended road dust from unpaved and poorly maintained roads are the major sources of air pollution in Kathmandu Valley (Shrestha, 2001). The polluting agents generated inside Kathmandu, cannot be transported during the winter time and hence settle on the surface of solar modules installed in Kathmandu.

2. Experimental setup

Experiment has been conducted on the roof of a building attached to a busy roadside, in the premises of Institute of Engineering, Tribhuvan University, Lalitpur, Nepal, from the 13th of August 2015 to 10th of January 2016. Two polycrystalline solar modules manufactured by Rahimafrooz Solar, of specifications listed on Table 1 were installed on the roof of entrance to Central Campus, Pulchowk at location (27°40′51″ NL, 85°14′29″EL) with tilt angle of 27 degrees as shown in Fig. 1.