18th International Conference on Environmental Science and Technology

Athens, Greece, 30 August to 2 September 2023

Solar attenuation due to particulate matter in arid environments

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Abstract: The depletion of solar irradiation has several causes such as clouds and suspended particulate matters in the atmosphere. Particulate matters play an important role in decreasing solar irradiation by blocking partly the solar energy from reaching the ground. This lost irradiation must be taken into consideration when planning large installations of PV panels' fields along with other environmental factors. The blocking effect of PMs is higher in places where the density of PMs is higher due to geographical location or the lack of precipitation. The main objective of this work is to study experimentally the impact of particulate matters of different sizes (PM2.5, PM10, and TSP), measured at ground-level, on global horizontal irradiation (GHI) in arid climates. The measurements were taken over a six-month period, from May to October 2022. The city of Riyadh, Saudi Arabia, was chosen to represent arid conditions due to its high suspended particulates density and the lack of precipitation. The PM measurements were recorded every minute from dawn to dusk and were processed to obtain a correlation between the measured PM values and the actual GHI. In addition, a comparison between the GHI obtained by the developed model and the one obtained from ASHRAE clear sky model. During the period of the experiment, the measurements showed that the ASHRAE clear sky model overestimated the amount of solar energy reaching the ground by over 10%

Keywords: Solar irradiation, Particulates matter, ASHRAE.

1. Introduction

A long-term study for aerosol over central KSA was carried out using aerosol robotic network AERONET which measures the aerosol concentration properties in atmosphere layer from a ground-based network measurement from 1999 to 2013. It was found that aerosol concentration increased during spring and beginning of summer due to dust storms whereas lower concentrations were observed during fall and winter [1]. During the period between 2016 and 2020 in Southern Riyadh, researchers analyzed data from the general authority of meteorology and environment protection standard and found that the mean PM_{10} was 214 $\mu g/m^3$, exceeding the safe limit of 150 $\mu g/m^3$, according to the National Ambient Air Quality Standards (NAAQS) [2]. PM concentration in Riyadh, measured from 2011 to 2012, was found to be higher than air quality standards by three-fold and was higher during the summer by 84% compared to winter due to sandstorms [3]. In Korea, weather data are taken from Korea meteorological administration and solar panel was tested under cloudless days for two years to see the effect of PM on power generation. The results showed that PM10 and PM2.5 reduce the power generation by 10% under "normal" air quality conditions and 20% under "bad" air quality conditions [4]. In Egypt, where the data of aerosol collected from Moderate resolution Imaging Spectroradiometer MODIS, which is an instrument that operates on both NASA's Terra and Aqua satellites that represent the properties of aerosol in the atmosphere, was studied. The results showed that the PM density diminish the global horizontal irradiation (GHI) by 0.7 to 12.9 % [5]. A logarithmic relationship between PM2.5 and solar irradiation was established as follows: Rs = -118.3*ln (PM2.5) + 1003.6, showing that attenuation of solar radiation due to increase in the amount of PM2.5 was observed in China over 10 years where the data of aerosol was taken from AERONET measurement [6]. Aerosol (CO, NO2, O3, SO2, PM2.5 and PM10) from 2019 to 2020 in Riyadh city was studied to compare with standard Air Quality Index (AQI). The data of aerosol in Riyadh city has been taken from National center for Environmental Compliance where it's eleven air quality monitoring stations are provided in Riyadh city to measure the aerosol. Results reveled that all air quality components are below the AQI standard, PM levels is higher in south of Riyadh due to presence of oil refinery and cement mill. A significant decrease in aerosol during weekend days by 16% compared to working days. Due to COVID 19 lockdown, the AQI in Riyadh city was decreased by 33% which indicates that the urbanization and the mobile movement play a huge role in the quality of air [7]. In this study, the PM levels were measured using air quality monitor that was installed on the roof of a three-story building in the heart of the city of Riyadh in the central region of Saudi Arabia. The device also measures the solar irradiation along with the PMs, simultaneously. The measurements were recorded every minute for six months to study the effect of PMs on the irradiation and to develop a model that predicts the irradiation based on PM density.

2. Experimental Result

The main objective of this research is to study experimentally the impact of particulate matter of different sizes, namely PM2.5, PM10, and TSP, measured at ground-level on global horizontal irradiation (GHI) in arid climates (Riyadh). Regression analysis was adopted to

develop a correlation between particulate matters (PM) and global solar irradiations (GHI). Model equation for entire experimental study can be expressed as, Model irradiation = [0.903278158 - 0.000685223×(PM2.5) - 0.000346566×(PM10-PM2.5)+0.001122868×(TSP-PM10)] × ASHRAE irradiation. The effect of PM's is clear on MODEL irradiation in figure 1 when compared with ASHRAE irradiation. The sum of ASHRAE, model, and actual solar irradiation for whole months respectively are 1227700.254 Wh/m², 1105121.122 Wh/m², and 1094949.68 Wh/m², respectively. The loss among model and ASHRAE solar irradiation represent the effect of PMs on solar irradiation where the loss percentage for the whole period of the study is 10% with the maximum monthly loss in August at 13%.

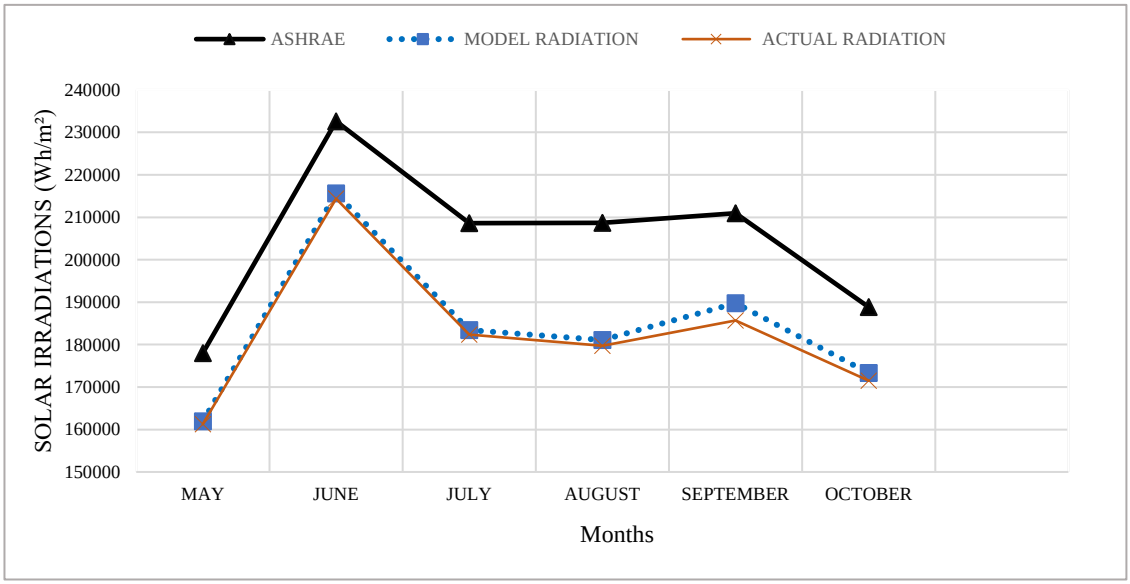

Figure 1. Comparison between solar irradiations.

3. Conclusion

In this study a model was developed to estimate the effect of PM density on irradiation levels. This model provides a more realistic estimate of the revenue expected from a PV field in arid climates. The good agreement between the actual and modeled irradiation levels indicates that the PM ground-level measurements is adequate to estimate the PM effect on irradiation in the atmosphere. With an average irradiation reduction of 10%, the PM effect in arid climates cannot be ignored, especially so for large installations of PVs.

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