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Determining the Effect of Soiling and Dirt Particles at Various Tilt Angles of Photovoltaic Modules

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Abstract— Photovoltaic modules (PV) are the future of renewable energy production market. They provide green energy with no carbon signature. However there exists factors which degrades the performance of PV modules. Over time, sand and dirt particles are accumulated on the surface of modules which effects its performance. Similarly little amount of field data exists about the PV plants to predict its behavior. Generally the photovoltaic modules are mounted at a fixed tilt angle which is near to the latitude of the location in order to get maximum output energy. Soiling loss effects the output power of solar modules to a great degree. It has a relationship with the terrain, and the climate behavior of the location, the tilt angle of the modules and the frequency of rain at the installation site. For un-cleaned modules, adjusting the tilt angle would result in increase in the output energy. In this research we have developed a cheap solution for monitoring the soiling losses at different tilt angles. The selection of 33.5^{o} was done because it is the latitude of the experimental area (Peshawar) where the test results were collected, because a general thumb rule is to install the photovoltaic modules according the latitude of the installation location. Furthermore instead of using huge photovoltaic modules small scale mini-modules were used for this study and their respective power ratings and dimensions are also described in detail. These mini modules were highly accurate and sensitive since a small amount of error would result in in-accurate data. The data was collected on regular basis from the mini-modules which were installed at different tilt angles. For each tilt angle two similar mini-modules were mounted, one was cleaned regularly while the other was left out un-cleaned for the entire period of study. In addition the irradiance data was also collected. In the end of the experiment the horizontal mini-module installed showed larger losses as compared to the other mini-modules.

Keywords— Photovoltaic Modules, Soiling Losses, Dust Particles, Solar Cells, Tilt angle

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I. Introduction

Photovoltaic modules will pave a path for the global energy demands. They generate clean and green energy without any carbon signature. Since their early production, their demand and production have escalated significantly. Commercial PV power plants are being installed globally, with the increase in the residential scale plants as well. However these plants needs proper maintenance in order to generate maximum power up-to its installed capacity. Photovoltaic modules degrade with time due to various factors and neglecting these factors will cause the modules to die out early before the manufacturer warranty. High operating temperature, high humidity and higher voltage levels will cause potential induced degradation in the modules which will decrease their operating life from years to a few months [1]. Below Figure 1 shows the equivalent electrical circuit for solar cell.

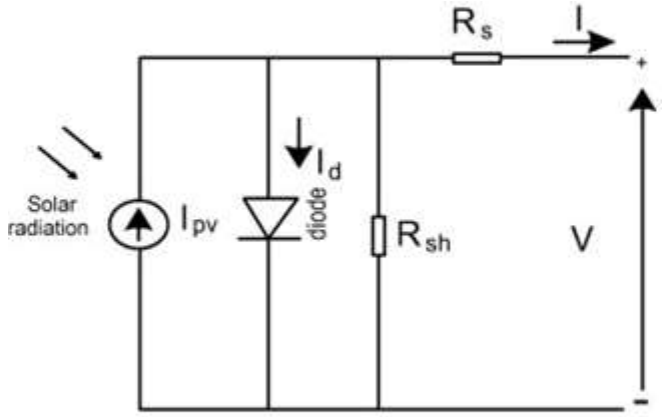

Fig 1. Electrical Circuit equivalent for a Solar Cell

Similarly other reasons effecting the performance of the photovoltaic modules is the accumulation of soil particles and dust elements [2]. The solar cell receives less amount of sun's radiation, than the radiation incident on the cell surface. This is because the dirt particles deposited on the surface of the solar cell known as "soiling", blocks the solar radiation, and also because of reflection and absorption losses of the glass material used on surface of the solar module [3]. When light radiation is incident on a surface of a glass, some of the radiation is transmitted, some is reflected back from the surface, while very little is absorbed by the glass. This property of glass material is dependent upon its refractive index [4].

Modern research on soiling issues presents the following overview. When a dual axis tracker is used to mount the modules, the light rays and the surface of the module will be perpendicular to each other. Hence resulting in maximum power output. However modules are mounted at a fixed tilt, which means the output power is dependent on the angle of incidence of the sun rays, the position of sun, module tilt angle and its orientation. This explained how the soiling losses have a direct relation with the angle of incidence of light rays [5]. This research is based on determining to what extent soiling losses effects the photovoltaic modules performance at various tilt angles, hence the output power. Measuring the short circuit current of the modules which are installed at different tilts, will give a better understanding of the soiling losses. This is because the solar irradiance incident on the PV modules has a direct relation with the short circuit current of the solar modules [6].

The main objective of this research is to measure and determine the relationship between soiling losses and module tilt angles. For this research study the district of Peshawar was selected with a latitude of 33.5^o and hot and humid climate conditions. The solar cells short circuit current was measured with regular intervals where the cells were installed on a rack structure. During this study the effect of soiling was observed on various modules, half of which were cleaned daily and the rest remained dirty to measure the soiling effect. It also was noticed during the study period that the design and architecture for the soiling station required minimum cost and provided the desirable results. Hence the proposed method for this study proved to be reliable and cheap in terms of cost.

Rest of the research paper is formatted as follows. Section 2 explains the methodology, and clarifies the details about the soiling station where the mini modules were mounted for the entire period of study. Results and discussions are explained in section 3. Finally section 4 concludes the paper.

II. METHODOLOGY

A. Experimental Setup

The experimental soiling station was setup in an open field environmental area. The mini modules which were frameless were mounted on the structure. The modules consisted of two separate groups, installed at three different angles, out of which one group of three modules was cleaned at regular intervals while the rest were left dirty for the entire period of study. The structure was built at four feet from the ground to simulate real time and natural dust conditions, and all the modules were facing south. The mini modules were installed at 0^o, 20^o, which is the common installation angle, and 33.5^o which represents the latitude angle of the experimental setup area. The entire setup was installed in such a place where shading from surrounding trees or buildings was avoided. All the mini modules installed were frameless, polycrystalline silicon cells. It generated 1 watt power and 170mA current at standard test conditions (STC) as shown in Figure 2.

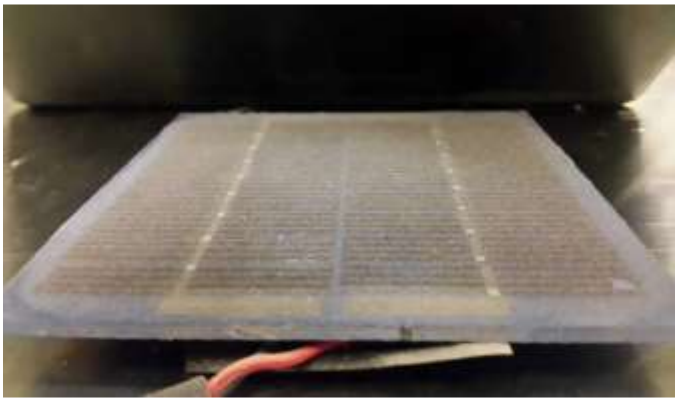

Fig 2. Soil particles accumulated on the Mini-module

These mini modules exactly replicated the design and construction material, equivalent to a commercial full size photovoltaic module. The dimensions for the mini modules were five by five inches. The data of current and voltage was collected using multi-meters for regular intervals as shown in Figure 3. The data was recorded accordingly for the entire period of study. The temperature, wind velocity and rainfall information were obtained from Met office Pakistan.

Fig 3. Mini-module with multi-meter collecting data

B. Bird Droppings

Bird droppings were frequently observed on every modules and were removed from the dirty cells. This was done because bird droppings were not part of soling loss studies and would jeopardize the entire experiment. If they were not removed carefully it would have ended in in-accurate results. A sharp tool was used to remove it from the modules carefully without scratching the surface of the solar cells. Initially bird droppings were creating a lot of problems. In order to keep the birds away from the solar cells metal spikes were placed on top of the solar modules in such a way that it casted no shade on the cell surface. The attachment of metal spikes on the photovoltaic modules declined the bird droppings to a great extent.

III. OUTPUT RESULTS AND DISCUSSIONS

The results collected were compiled using Microsoft excel sheet. In addition to that software's were used to trace out the IV curves for the mini-modules. For this purpose IVPc tracer software setup was utilized to trace the IV curves simultaneously for all the mini-modules in real time, also recording the ambient temperature and the operating temperature of the mini-modules using thermos-couples attached to the back side of the modules.

A. Soiling loss percentage mathematical equation

The average soiling loss was determined for various tilt angles for a period of three months varying from December 2015 to March 2016. Since the short circuit current (Isc) has a direct relation to the irradiance of the photovoltaic modules, the Isc was measured for the entire period of study for all clean and dirty mini modules. This data was then normalized to standard testing conditions (STC) using IVPC software. The data collected from the modules for this period provided with soiling loss percentage which is calculated from the below equation:

$$Soiling\ Loss\ Percentage = \left[\frac{DI_{cm} - DI_{sm}}{DI_{cm}}\right] \times 100$$

Where DI_{sm} represents the daily average soiling calculated by the dirty module (kWh/m2) and DI_{cm} is the daily average soiling evaluated by the clean modules (kWh/m2). Using this mathematical equation the daily soiling loss percentage was calculated for this study.

B. Daily measured soiling losses

During this study the soiling losses were measured at various tilt angles using frameless mini modules and calculated for the period of three months. It was observed that the insolation losses were dependent of natural rainfall. During rainfall, the mini modules would get washed up, and then would start performing similar to the clean modules. Light rainfall of about 1mm was insufficient to decrease the soiling loss initially but after some time it would create a dry soil layer formation on the surface of the solar cells. This dry layer formation was responsible for attracting more and more dirt particles that would create a non-uniform layer of soil on the module surface. This layer was not easily removed even by blowing winds, but rainfall greater than 2mm was sufficient to clean the dirty modules so that it would start performing like new ones. The data shown in Figure 4 shows the data recorded for the study duration. From the data points the trend can be traced out which appears to be random depending upon the weather conditions. During the period when it rained the modules would get washed up and hence this would result in the cleaning of the module, and the modules would perform better as compared to other days when it would not rain at all. The modules performance increased a little when they would get washed up due to the rain but overall the soiling loss percentage remained almost the same ranging mostly between 2% to 4% for the entire period of study. The soiling loss percentage would hardly ever go higher than 4% and would hardly ever go below 2% and remained in between these two.

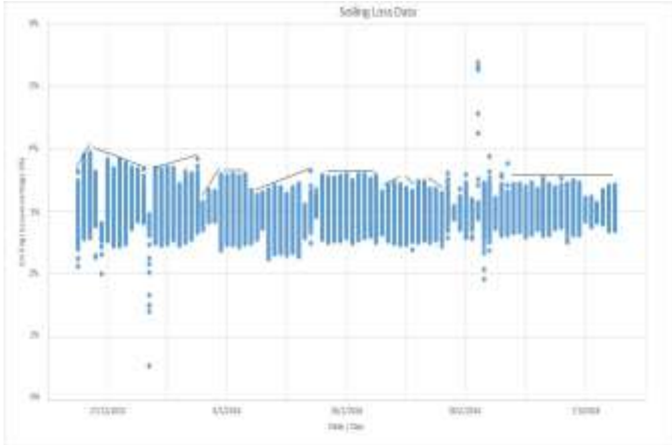

Fig 4. Soling loss data (daily recorded soling loss percentage)

C. Retaining of water at calculated tilt angles

For the horizontal tilt solar cell which was left un-cleaned it was observed that after the rainfall a sticky-muddy layer formation was observed because of the large amount of water being retained on the surface of the module. This result in more dirt particles being accumulated on the module surface hence further decreasing its performance. This effect was observed in all modules but was significantly prominent for the 0^{o} module.

D. Short circuit current (Isc) versus Time

In the figure 5 shown below the data of short circuited current versus time was recorded and the data remained almost the same as shown in figure 5. According to the data collected the Isc for the clean module would reach a maximum peak of 150 milli-Amps during when the irradiance levels were maximum. Similarly the Isc for the dirty modules would also show similar behavior but it would still never catch up to the maximum levels attained by the clean modules and would always show a little loss of power in comparison with the clean modules. In the figure below the clean module data is represented by the gray colored dotted graph while the dirty module data has been shown with the blue colored dotted graph.

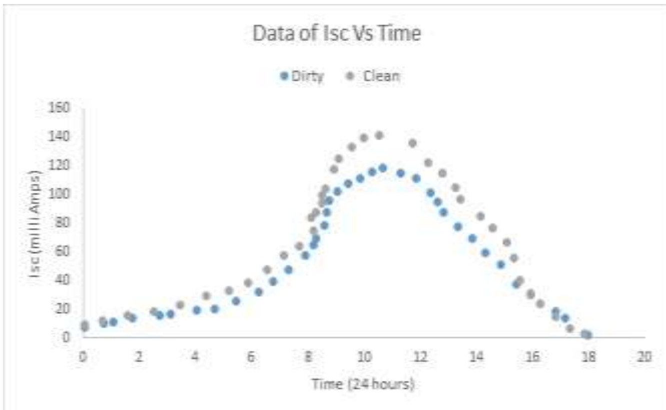

Fig 5. Plot for (%) decrease of Isc vs Time

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E. IV curves traced for mini-modules

The Figure 6 shows the IV curves traced for all the mini-modules used for this experimental study. These IV curves were traced out by the daystar IV curve tracer and the important data was collected and saved by the IVPc software. From the IV curves the maximum power tracking can be accomplished which could help maximize the output performance ratio of the solar photovoltaic systems which are installed commercially and residentially.

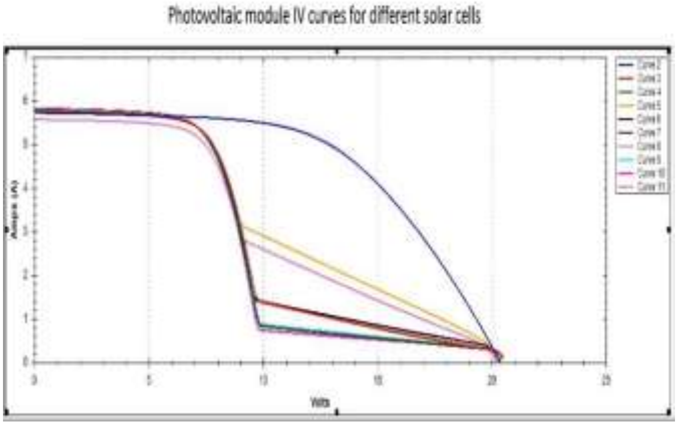

Fig 6. IV curves of the mini-modules

F. Irradiation data versus time

During this study the data for the daily irradiation from the sun versus time was recorded. From the figure 7 shown below it is clearly evident that the irradiation levels would rise up to maximum levels during the afternoon time of the day. The daily irradiation levels revealed the important factor that the photovoltaic modules would generate a maximum output power during the noon time since the natural sunlight irradiance levels are very high during that time. Figure 7 reveals the important reason, why the Isc in figure 5 would go high during the midday? The reason being that the Isc is directly dependent upon the irradiance from the sun, therefore during maximum irradiance the Isc would also results to a maximum value during the entire day.

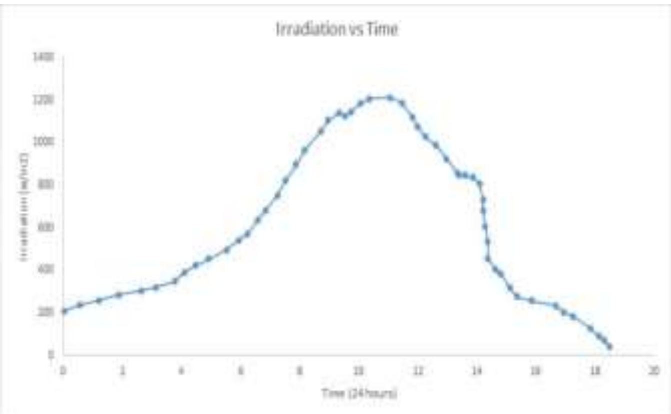

Fig 7. Irradiation versus time (hours)

CONCLUSIONS

This research explains that during the entire period for the experiment, the mini module mounted at horizontal tilt angle had the significant soiling loss equivalent to 2.015% approximately. While the modules mounted at tilt angle 20^o and 33.5^o showed an insolation loss of 0.981% and 0.889% respectively. This shows that there was almost 50% decline in the soiling losses when compared with the absolute horizontal tilt. This research revealed that both the wind speed and the rain frequency and amount played significant roles in cleaning the modules depending on their tilts. Since the rain would combine with the dirt particles and resulted in a mud formation, therefore horizontal tilt module faced the most of the soiling losses. This work enabled us to study the soiling losses at different tilt angles in any desired place.

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