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Conference: 13th AICLST, Kolkata, 6–8 March 2026

Paper reference: TC-102/P

Printed pages: 359–366

Source: *Leather 2050: Challenges & Opportunities*, ILTA (2026)

Impact of Environmental Conditions on Energy Generation from

Solar Photovoltaic plant installed in leather sector

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Ref. No. TC-102/P

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Abstract

Solar energy has emerged as a key sustainable alternative to depleting conventional energy resources and combating climate change. Its adoption is accelerating globally due to factors like population growth, increasing energy demand, and market uncertainties. India, a tropical nation, has taken a global leadership role in solar energy, achieving significant milestones in large-scale solar installations. However, addressing efficiency losses in solar plants installed in Common Effluent Treatment Plant (CETP) of leather sector remains crucial for sustained growth. The efficiency of solar modules depends on factors such as cell material, temperature, solar irradiation, wind speed, and temperature coefficient loss being the most significant. This study investigates the impact of module surface temperature and wind speed on the efficiency of a large-scale in situ solar plant installed a CETP over four months. The findings confirm that increased cell temperatures lead to efficiency losses regardless of seasonal conditions. Wind speed provides a cooling effect that lowers module surface temperature, but its impact is limited during periods of low wind. These insights emphasize the need for innovative strategies to mitigate temperature-induced losses and enhance system performance. Addressing these challenges is critical for optimizing solar energy production and supporting the global transition

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toward renewable energy solutions. This study underscores the importance of sustainable design improvements in advancing solar energy.

Keywords: Solar Energy, Temperature Coefficient, Solar Module Efficiency, wind speed

1. Introduction

Renewable energy, especially solar energy, has been the choice of many users as it is easily available in tropical countries. Globally, the investment of solar energy has seen an increasing trend relative to fossil fuels, as per the International Energy Agency (Daniel SA, 2013). Additionally, by 2027, solar photovoltaic (SPV) installation capacity is expected to overtake charcoal as the world’s largest source of electricity. By 2026, cumulative solar PV capacity would be almost tripled, exceeding over 1500 GW, reaching charcoal by 2026 as well as natural gas by 2027. Annual solar PV capacity addition is also likely to growth annually every year for another five years (Babu JSC, 2015).

Developing countries, especially India, are concentrating more on solar energy. India has ranked 4th in solar power deployments in 2022 with 61.97 GW capacity of solar plants commissioned in the country, which includes 52 GW from ground-mounted solar plants, 7.82 GW from rooftop solar plants, and 2.09 GW from off-grid solar plants (P N

2018). India’s solar tariff has become more competitive due to advancements in technology, economies of scale, and the decline in the cost of solar cells and modules.

With such a continuous increase in demand and investment in the market and updating of technology, it is very critical to check the losses occurring in PV systems and study and investigate the effect and influence of

ambient site conditions on solar power generation. There are three different PV modules that are widely used in the market: monocrystalline, polycrystalline, and thin film material (Mohamed CA, 2021).

Based on the material characteristics of the modules used, the conversion efficiency differs in the range of 16–25%. In Standard Test Conditions (STC) of solar irradiation of 1000 W/m2 and temperature at 25oC, the efficiency of SPV panels 25% as provided by the manufacturers is reported. But in real time, conversion efficiency depends on location, plant layout, shading roof orientation, equipment quality, weather conditions, operation and maintenance aspects, etc. Among all losses happening in the solar PV system, temperature coefficient loss is the maximum, and it is one of the main concerns for tropical countries like India (Seker S, 2023). It is observed from previous studies that the monocrystalline showed the highest temperature loss co-efficiency among three other materials (Irwanto M., 2019).

2. Materials and Methods

2.1 Solar PV plant

An existing ground-mounted 4 MW solar PV plant was installed with a polycrystalline solar PV plant in southern India, which is supplying energy to an industrial wastewater treatment plant through the electricity grid. The solar PV module is a polycrystalline cell with 2 m2

of area, and a total of 15000 cells are mounted. This plant has been selected, and data was collected for the overall weather condition in a year, and data was studied and analyzed to examine the energy generated at

various weather conditions. In addition, weather condition data have been collected with a dedicated weather monitoring system installed at the site i.e., an anemometer and a pyranometer to measure wind speed and solar irradiation, respectively. The surface temperatures of modules are also monitored with temperature sensors placed at two locations in the plant to study the impact on solar energy generation.

2.2 Data collection and analysis

2.2.1 Weather Conditions

In this study, the data for four months representing altered seasons of year, i.e., April 2022, August 2022, December 2022, and May 2023, at the peak duration of 10.00 AM–14.00 PM, are collected to study the effect on the efficiency of solar photovoltaic cell. The data collected during April and May, August and December are typically considered for the summer, autumn, and winter seasons, respectively, which are exhibited in local weather conditions.

The technical specifications of the SPV module studied as per the manufacture datasheet are given in Table 1.

Table 1: Specifications of the solar panel

S. No Cell Type Polycrystalline

1 Module Efficiency 16.41%

2 Operating Temperature (C) -40°C ~ +85°C

3 Temperature Coefficients of P max -0.41%/°C

4 NOCT 45±2o C

5 Solar Irradiation 1000W/m2

6 Cell/Module temperature at 25oC

7 Air mass Air Mass of earth’s atmosphere (AM)

1.5

The efficiency of solar photovoltaic cell is given by:

Ŋ = (Pin / Pout) *100 ..... (1) Pin = GT * A ..... (2) A = 15000* 2m2..... (3) Pout = Energy Generated / Time ..... (4)

The following linear equation, which relates “Tc” (module surface temperature) to “Ta” (ambient temperature) and solar radiation, was used to estimate the temperature of the PV cell or module:

Tc = Ta + k GT ..... (5)

Ross Co-Efficient K = (Tc - Ta)/ GT..... (6)

Whereas

A Area of the cells

AM Air Mass of earth’s atmosphere

GT Solar Irradiance

K Ross Co-efficient

NOCT Nominal Operating Cell Temperature

ɳ Efficiency of the solar modules

P max Maximum power output

Pin Power Input

Pout Power Output

STC Standard Test Conditions

Ta Ambient Temperature

Tc Module Surface Temperature

The data pertaining to various parameters, including solar irradiance, wind speed, ambient temperature, module surface temperature, and energy generation, was monitored and systematically collected from the polycrystalline solar photovoltaic (PV) plant. Utilizing this dataset, critical metrics such as input power (Pin), output power (Pout), and the conversion efficiency ( ) were computed. Subsequently, a complete analysis to investigate the impact of local meteorological variables, specifically irradiance, wind speed, and module surface temperature, within the overall efficiency of the photovoltaic system. This study investigates the influence of various environmental elements and energy generation from SPV plants, offering insight into their impact on energy conversion and improving energy efficiency.

ɳ

Additionally, three days’ data was collected and used for analysis to compare observations taken before and after cleaning. Data sets were gathered from 10:00 AM to 14:00 PM for three days, both before and after cleaning. This study aimed to evaluate the effect of cleaning for improving the efficiency on SPV system.

3. Results and Discussion

3.1 Module Surface Temperature versus Efficiency

Various data collected and analyzed from SPV showed that there is a decrease in efficiency with an increase in module surface temperature, as shown in Fig. 1. It is observed that the average highest module surface temperature throughout the year is 58.04°C based on the data collected for 4 seasons. It is reported that the output power of the Solar photovoltaic module reduces by 0.5% per degree Celsius in lab-scale studies with artificial sun (Paslaski J., 1981). In other previous investigations also reported a degree rise in temperature would reduce the efficiency by 0.14-0.47% °C, and however, this value also varies with the material of the module.

Figure 1: Effect of Module Surface Temperature

(MST) on SPV plant Efficiency

It is observed that irrespective of seasonal and daily weather variations, an increase in module surface temperature showed a decrease in efficiency in all four seasons. The gradient of the slope varies due to other factors also, but the uniformity of reduction in all the seasons showed that the loss in efficiency with the rise in Module Surface Temperature (MST) (Yin H, 2011). However, it is to be noted that SPV systems operating in warmer climates often face temperatures exceeding 25 °C, which is a critical factor leading to energy losses (Georghiou George, 2012).

The cooling effect due to wind speed could also be observed from Fig 1. There is a decrease in MST-AT value with a rise in wind speed. The wind speed helps to reduce through convection (Kumar B. et al., 2023). This natural convection process is low in April because of low wind speed; this is seen by the gradient difference. Thus, apart

from the location and installation tilt angle, weather factors like wind show a significant contribution in sustaining the efficiency of the photovoltaic (Chandel SS, 2013).

3.2 Effect of Wind Speed on Temperature variation between Module Surface Temperature versus Ambient Temperature (Tc - Ta)

A study using situ data demonstrated that incorporating wind cooling effects was critical in improving the estimation of photovoltaic module temperature. Wind's role is particularly relevant when assessing PV module

temperature (Tetzlaff A, 2013). The temperature variation between the module's surface and the ambient temperatures clearly decreases with rise in wind speed. Furthermore, this variation can be adequately described by the linear square fit graph we have presented. A similar finding was shown in the study of rooftop and ground-mounted PV systems in low and high wind speed regions, respectively (Kavadias K, 2014).

Figure 2: Impact of Wind speed on Temperature different

between Module Surface Temperature and Ambient

Temperature (Tc - Ta) in different seasons

In the present study, it’s evident that wind speed, being a weather variable, varies even within the same season. The figure for April illustrates a narrow range of wind speeds, resulting in a more condensed temperature difference between 10°C and 22°C. However, in May 2023, the wider range of wind speeds leads to a notable reduction in temperature differences, despite it still being the summer season. Analytically, PV panels experience higher temperatures during peak sun hours when there is no wind or lesser wind speed, but the presence of wind can assist in reducing the extent of temperature increase, contributing to improved PV panel performance and generation of more energy (W.Z. Leow1, 2013).

3.3 Effects of soiling

In terms of the SPV plant, the data analysis of the three days before and after cleaning revealed a significant

enhancement in average efficiency. Before the cleaning operation, the PV plant’s average efficiency was measured at 12.20%. Subsequent to the cleaning process, the average efficiency increased to 13.17%, indicating a substantial 7% boost in the SPV plant’s overall efficiency.

Figure 3: Effect of Cleaning in improvement of

Solar PV plant efficiency

This increase in efficiency is particularly noteworthy for a SPV plant, as it directly impacts the ability to transform renewable sources of energy into electrical energy. Cleaning photovoltaic panels or components has evidently resulted in a more effective utilization of available sunlight, contributing to the improved efficiency of the photovoltaic plant and an increase in its energy output.

4. Conclusion

This analysis results showed that wind speed and module surface temperature have a major effect on a groundmounted polycrystalline photovoltaic (PV) plant’s efficiency. The data reveals a decrease in efficiency as module surface temperature rises, aligning with findings of other researchers that reports 0.5% decrease in power output per degree Celsius increase of surface temperature. Furthermore, the research highlights the crucial role of wind speed as a mitigating factor. Wind cooling effects play a pivotal role in reducing the temperature variation between the module surface and ambient temperatures, resulting in improved PV panel

performance. This effect is particularly evident during peak sun hours when wind speed can counteract temperature increase, ultimately contributing to enhanced efficiency. The Ross Coefficient “K” emerges as a valuable parameter, not only for assessing module temperature but also for evaluating plant ventilation. Lower “K” values signify better ventilation and are associated with higher wind speeds. This emphasizes the multifaceted interplay of meteorological factors in PV plant efficiency and underscores the importance of considering both module surface temperature and wind speed in optimizing PV system performance. The study also suggests that proper cleaning and maintenance of the PV plant, undertaken between the two data collection periods, has a substantial positive impact on its performance. The increase in efficiency signifies more effective utilization of solar energy, resulting in a higher energy output. This underscores the importance of regular cleaning and maintenance practices in ensuring optimal PV plant operation and energy generation. It is concluded that solar and power generation can be improved by identifying the proper location and cleaning process, resulting in reductions of carbon footprint meeting SDGs (SDG 7-13).

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