An Approach Characterizing the Performance Degradation of a 140 kW Solar Panel in WV

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Abstract

The research presents a methodology for evaluating the degradation of a 140-kW photovoltaic (PV) solar panel system's performance in Morgantown, WV. It assumes that panel's productivity depends on the solar energy received and the panel efficiency. To account for daily energy variations, daily electricity production was corrected to the average of the theoretical solar energy received in that month. The maximum of the corrected daily production data was considered the best performance of that month. These monthly best performances were averaged to represent the panel's yearly performance and used to assess the performance degradation. The results show that the yearly average performance of this panel decreased by 2.28% from 2013 to 2016 and then the degradation is 0.17% from 2017 to 2023. This methodology is also based on the assumption that there is at least one sunny day each month, which may not always be correct but is likely to occur.

Keywords: PV module, performance degradation, weather, electricity generation

Introduction

In recent decades, renewable energy sources such as solar, wind, hydropower, and geothermal energy have rapidly been improved and deployed in response to global warming. Solar is largely unintrusive, and unlike the other main renewable sources, it can be feasibly installed at smaller non-industrial scales (Sobri et al., 2018).

Typically, a standard PV module has an optimal efficiency of about 10% to 23%, with the rest of the solar energy being either reflected to the environment or converted into heat (Musthafa, 2014). Environmental parameters responsible for the declining performance of a PV module are solar radiation, dust, soiling, atmospheric temperature, wind velocity, shading, precipitation, and humidity. The presence of dust in the air can decrease PV efficiency by up to 60% (Santhakumari & Sagar, 2019). Natural or artificial shades lower the power output of PV panels. High relative humidity leads to the accumulation of minuscule water droplets and water vapor on solar panels. This reduces the amount of solar radiation reaching the solar panel, lowering electricity production. Additionally, PV construction factors, installation factors, operation, and maintenance also affect the degradation rate of solar panel yearly performance (Hasan et al., 2022). There are numerous failure modes triggered by different environmental factors, including module delamination, hotspot failure, corrosion, glass breakage, anti-reflection coating (ARC) damage, electro-migration in the contact layers and interconnect, discoloration, and others (Kumar & Kumar, 2017).

The degradation rate of solar panels can be examined each year by experimentally measuring the efficiency of solar panels, which is a time-consuming process. A comprehensive 10-year analysis of the degradation rates of PV systems at six different sites, three located within the United Kingdom and three in Australia, was evaluated

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using a year-on-year (YOY) degradation technique by Dhimish et al. (Dhimish & Alrashidi, 2020). The research team found that the PV system in the UK displayed degradation rates ranging from 1.05% to 1.16% per year. On the other hand, their counterparts in Australia found higher degradation rates within the range of 1.35% to 1.46% per year.

The energy loss and performance degradation of a 200-kW roof-integrated crystalline PV system installed at IRB Complex-5, Chandigarh, India was studied by the Kumar research group using the PVsyst simulation tool (Kumar et al., 2019). The estimated degradation rate of the PV system would lie between 0.6 and 5% per year under local weather conditions. The yearly capacity factor, performance ratio, and energy losses are 16.72%, 77.27%, and 26.5%, respectively.

Another study showed that the thin-film PV technology exhibits a significantly lower yearly degradation rate, nearly 0.1% compared to polycrystalline technology within the range of 0.67% to 0.83% after 2.5 years of outdoor exposure (Dag & Buker, 2020).

In a degradation study conducted in the semi-arid climate on a 1-MW PV system for four years, the system efficiency and performance ratio were found to be 11% and 76.46%, respectively (Kumar & Malvoni, 2019).

Sangpongsanont et al. examined the degradation rate of 16 poly-Si PV modules in outdoor conditions for 15 years in Thailand (Sangpongsanont et al., 2020). The average degradation rate was found to be 1.47%/year.

Kazem et al. published a literature on the aging measurements of a grid-tied 1.4-kW solar PV plant located in Oman for a period of seven months (Kazem et al., 2020). They reported that aging decreased the system efficiency by 6.3% and the production rate to 5.9%. In a 1-MWp solar PV power plant in Andhra Pradesh, India, Navothna et al. investigated the performance, degradation rate, and power and energy losses (Navothna & Thotakura, 2022). There are several forecasting methods that can predict the performance degradation rate of PV solar panel performance. Most forecasting techniques use artificial neural network and deep neural network models (Ahmed et al., 2020).

Finally, the references in the existing literature describing degradation analysis in the United States are very limited. In this study, a new methodology is proposed for estimating the performance degradation rate of an existing solar array installed at Mountain Line Transit Authority (MLTA), located in Morgantown, WV. The research team used this solar power plant project to examine the average solar power plant performance degradation rate.

However, as years of data on solar panel performance and radiant solar energy received is required to evaluate degradation in the performance of solar panels, it is

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impossible to calculate the efficiency of a solar panel at a given time unless data on how much solar energy reached the panel at this time is available.

System Description

The 140-kW PV solar panel system was installed and commissioned on June 12, 2012. MLTA was awarded $1.1 million to fund a solar power plant project in 2010. The PV modules are situated in 39°6 N and 79.8° W. A 140-kW solar panel array consisting of 572-piece 245-W polycrystalline PV modules was installed on the roof of MLTA's Morgantown maintenance and administrative facility. One 135-kW inverter is used in the system to convert the DC power input from the PV array to AC power. The datalogger collects the real-time performance information from the inverter and sends this information via internet to the performance monitoring software. The system tilt angle is 12.0 degrees and azimuth angle is 210 degrees.

System Performance

While a general trend over the year can be observed from month to month, the amount of energy generated each day varies substantially due to dramatic variations in local weather conditions. Solar extraterrestrial radiation reaching the top of the atmosphere for each year is calculated using an online calculator provided by Santa Clara University (Calculation of Extraterrestrial Solar Radiation). The online calculator uses Eq. 1 from Duffie and Beckman to calculate the solar extraterrestrial radiation (Duffie & Beckman, 2013). Daily extraterrestrial radiation on a horizontal surface in the absence of the atmosphere, H in a particular location can be calculated by:

$$(1)\ H = \frac{24 \text{ x } 3600\ \mathrm{G}_{sc}}{\pi}\left(1 + 0.033\ \cos\frac{360n}{365}\right) x\ (\cos\emptyset\ \cos\delta\ \sin\omega + \frac{\pi\omega}{180}\ \sin\varphi\sin\delta)$$

G_{sc} is the solar constant, 1,367 W/m^2, ω is the sunset hour angle in degrees, φ is the latitude of the location, δ is the solar declination angle, and n is the nth day of the year. We can also use the following equations for this calculation:

$$\text{Solar declination angle, } \delta\ = 23.45\ \sin(360\,\frac{284+n}{365})$$

$$\text{Sunset hour angle, } \omega = cos^{-1}[-tan(\delta)tan(\phi)]$$

The daily power production and solar irradiation of the study location from January 2023 to December 2023 are presented in Figure 1.

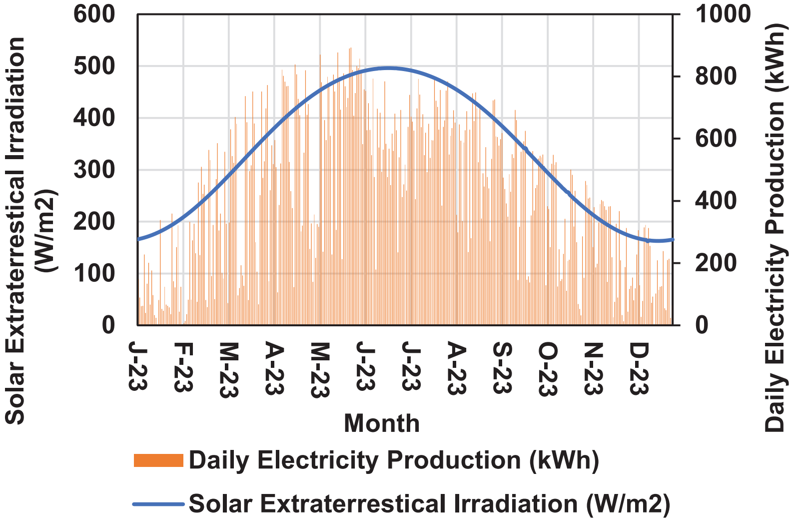

Fig. 1. Daily electricity production and solar extraterrestrial irradiation

Figure 2 shows the yearly production of electricity from 2012 to 2023. This solar power plant was installed in June 2012, so the yearly production data of this system in 2012 was low. As shown in Figure 2, the electricity produced in 2020–2023 was much higher than that in 2018 and 2019. The yearly electricity production cannot be used as a criterion for evaluating the degradation of solar panel performance.

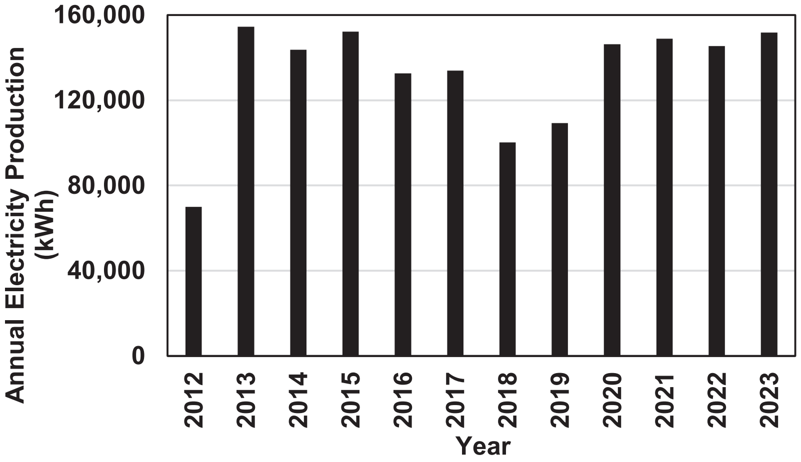

Fig. 2. Annual electricity produced from 2013 to 2023

Figure 3 shows the variation of the maximum daily electricity produced in each month of 2022, 2020, 2018, 2016, 2014, and 2012. The highest maximum electricity production was observed in July 2012 (in the 1st year). However, the maximum daily production data did not always decrease with additional years of service. For example, the maximum daily electricity produced in May 2016 is 4.14% lower in average than in May

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2018, May 2020, and May 2022. The maximum daily electricity production in October 2018 is 5.22% lower in average than October 2020 and 2022.

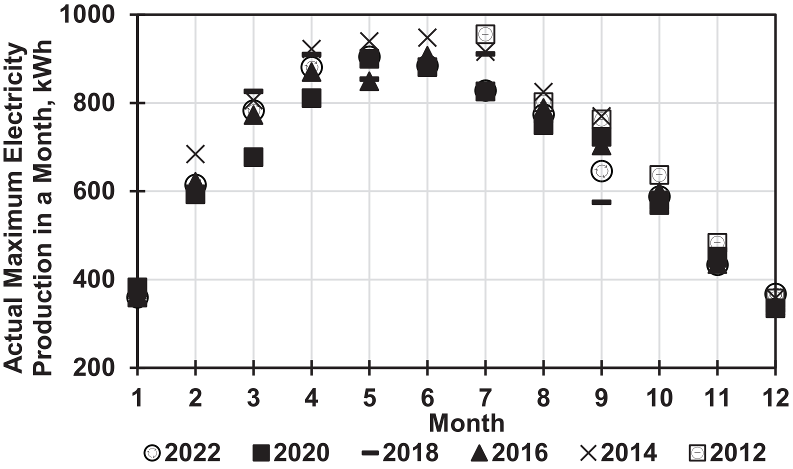

Fig. 3. Actual maximum daily electricity production in each month in 2022, 2020, 2018, 2016, 2014 and 2012

Figure 4 shows the maximum daily solar power production in each month of 2012–2023. This figure shows that there is no firm trend in degradation of power production capacity in each year from 2012–2023.

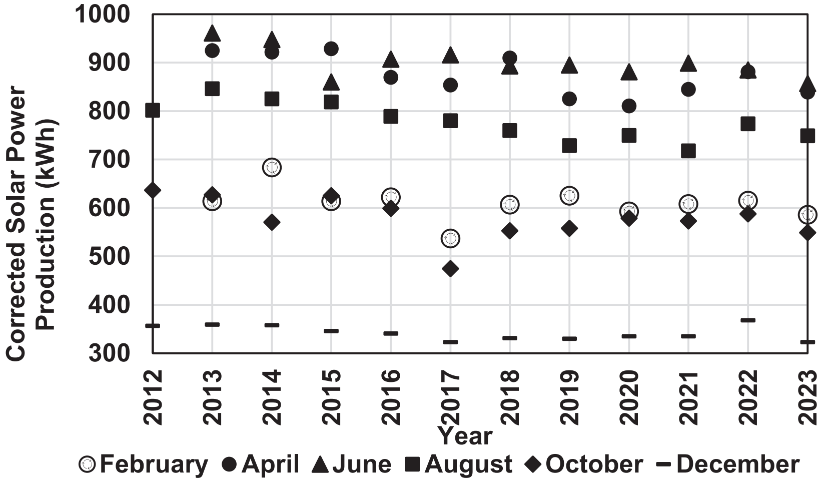

Fig. 4. The maximum actual daily production observed in specific months from 2012–2023

It is concluded that solar panel performance degradation cannot be evaluated using the actual solar panel production data without considering weather contributions. This gives us the opportunity to develop a new methodology to characterize the degradation of solar panel performance using solar panel production data.

Methodology

This research developed a methodology to assess the degradation of solar panel performance with time using the daily solar panel productivity data. This methodology assumes that electricity produced by a solar panel is affected by the solar panel efficiency and the solar energy received.

This method also assumes that there is at least one perfectly sunny day each month on which the daily electricity produced is the maximum possible electricity produced in that day. However, the amount of solar energy received each day in a month is different, so that affects the electricity production. The difference in electricity production can be corrected using a standard reference such as average extraterrestrial irradiance each month. In this research, the power produced each day of a month is corrected using the average irradiance energy received monthly as a reference. This is defined as correction-factor-corrected electricity production $\mathrm{E}_{\mathrm{i,\ corrected}}$, calculated using the following equation:

$$E_{i,\ corrected} = \frac{E_{i,\ actual} \times \mathrm{I}_{Average}}{I_i}$$

Where, $E_{i,\ actual}$, Actual electricity produced in i^{th} day of the month, kWh

$\mathrm{I}_{Average}$, Average daily irradiation in the month, $\frac{W}{m^2}$

I_i, Extraterrestrial irradiation on the i^{th} day, $\frac{W}{m^2}$

Results and Discussion

Figure 5 shows the actual and corrected daily electricity produced using the average irradiation received in October 2022. The maximum actual daily electricity production is 588 kWh, which was observed on October 9th, 2022.

The corrected electricity produced on October 9th was 549 kWh. In comparison, the maximum corrected daily production observed was 571 kWh, which was observed on October 20th, 2022. The actual electricity produced on October 20th was 546 kWh, which was lower than the actual electricity of 588 kWh observed on October 9th. The day with the maximum corrected power production observed may not be the same day on which the maximum actual production was observed.

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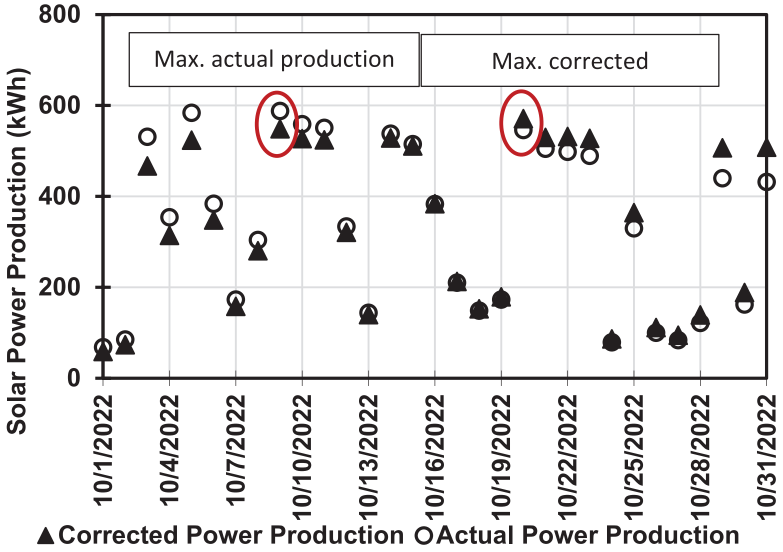

Fig. 5. The actual and corrected daily electricity produced in October 2022

Figure 6 shows the average of the maximum corrected daily production in each month from 2013 to 2023. The solar panel performance represented by the average of the maximum corrected daily production in each month was found to decrease rapidly from 2013 to 2016. The averages of the maximum corrected daily production observed in 2013 and 2016 were 706 kWh and 659 kWh respectively. The average yearly degradation from 2013 to 2016 was 2.28%. In comparison, the degradation of the averaged maximum corrected daily production in each year observed from 2016 to 2023 was very mild (0.17%). The average of the averaged maximum corrected daily production observed in each month from 2017 to 2023 was 658.8 kWh, which was comparable to the 659 kWh observed in 2016.

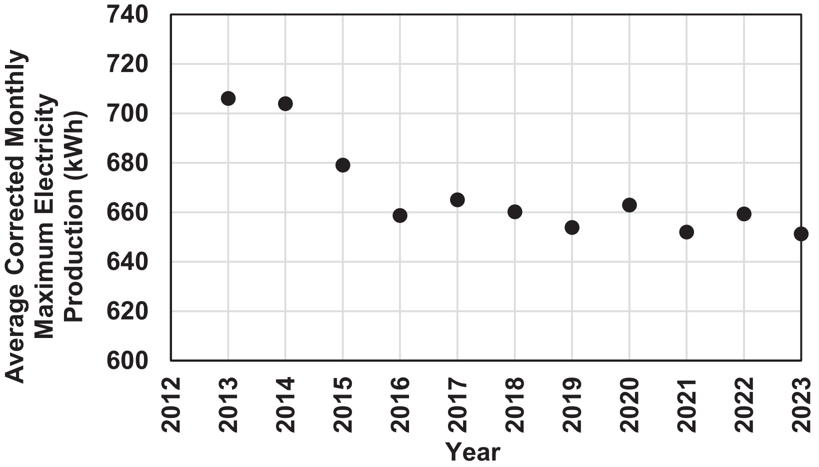

Fig. 6. The average of the maximum corrected daily production in each month from 2013 to 2023

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Conclusion

This research developed a methodology assessing the degradation of solar panel performance using daily electricity production data. The performance of the solar panel was evaluated by examining the maximum corrected daily electricity production data using the average of the irradiation of that month as a reference. The average of the maximum corrected daily production data found in each month of a year was used to represent the best performance of the solar panel in that year and used to assess the degradation rate of this solar panel array. This method was applied to assess the performance degradation of a 140-kW solar panel array installed in Morgantown, WV. The key findings are the following:

- Neither the actual yearly production nor the monthly electricity production of this solar panel array can be used to assess its degradation due to the significant variation in weather from year to year.
- From 2013 to 2016, the average yearly degradation of this solar panel system is 2.28%. In comparison, the average yearly degradation of this panel from 2017 to 2023 was comparatively mild (0.17%).

It should be noted that this methodology can only be applied to solar panels installed in areas where air quality is relatively stable. In the future, the effect of ambient temperature on solar panel performance should also be evaluated. The research team will continue to work on this methodology and further improve it to make it more accurate and viable.

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