Preliminary Study on the Application of Water Spray Cooling on Solar Panel Surfaces: An Electrical Properties Perspective

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Abstract. The present experimental research work aims to investigate how water spray cooling of the surface of solar panels affects the electrical performance, particularly the output voltage. A series of solar panels were tested at various cooling temperatures. Without cooling, the average output voltage of the panel was 85.8 V. When the panel surface temperature was maintained at 34°C by water spray cooling, the average output voltage increased to 89.72 V, which is 4.57% higher than in the case without cooling. Similarly, for surface temperatures of 35°C, 36°C, and 37°C, also maintained by water spray cooling, the average output voltages were 89.35V, 88.04V, and 87.83V, respectively, meaning that the improvements were 4.14%, 2.61%, and 2.36%, respectively. The findings indicate that water spray cooling can significantly improve the output voltage from solar panels. We found the maximum value of the output voltage at a surface temperature of around 34°C, and a gradual degradation appeared at higher temperatures. This preliminary experimental study points out the potential of water spray cooling as an effective way to improve the electrical characteristics and overall efficiency of solar panels, concerning those operating at high ambient temperatures. Additional investigation is necessary to examine the extended resilience, water usage, and financial aspects of incorporating water spray cooling systems into solar panel installations.

Keywords: Electrical Properties, Solar PV, Water Spray

1 Introduction

Solar photovoltaic (PV) technology has emerged as a significant clean, renewable energy source for electricity generation over the past few years. PV systems convert sunlight directly to electricity using semiconductor materials, mainly silicon (Rahmatmand et al., 2019; Sunu et al., 2023). They have an abundance of benefits, including zero emissions during operation and low maintenance demand, and can be scaled from small residential installations to large utility-scale power plants. Yet, despite all the favorable factors, conventional photovoltaic systems are still now

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handicapped against conversion efficiency and cost-effectiveness issues as compared to traditional fossil fuel-based power generation (O'Shaughnessy et al., 2020). The main factor that hampers the performance of PV systems is the mechanical effect of increased operating temperatures on solar cell efficiency (Al-Shahri et al., 2021). Only about 15-20% of the solar radiation is converted to electricity, while the remaining portion is converted into heat since it is absorbed by the photovoltaic panels. This important portion of heat necessarily heats the cell significantly above the ambient conditions of the element—it is more pronounced under high solar irradiation. Indeed, for silicon-based PVs, electrical efficiency degrades at about 0.4-0.5% per 1 °C of cell temperature rise above 25 °C. Temperature-induced losses in efficiency generate huge losses in charge output/power at its mount location in hot climates or during summer months, when panel-surface temperatures may rise well above 60–70 °C.

The cooling techniques remove the heat of the panels passively or actively and aim at maintaining low operating temperatures, consequently increasing the electrical efficiency of the panels. The several developed approaches to cooling down PV modules reduce their thermal losses and enhance their efficiency. The cooling systems methods can broadly be categorized into passive and active. Passive cooling approaches typically involve heat sinks, phase change materials, or natural air circulation to enhance heat dissipation without external energy input. For instance, reviewed the use of phase change materials (PCMs) for thermal regulation of building-integrated photovoltaics, highlighting their potential for temperature control without ongoing energy consumption. Passive air cooling methods have been found to slightly raise performance levels in photovoltaics through the natural cooling process by (Tonui & Tripanagnostopoulos, 2007). Bahaidarah et al. (2013), tested back surface water cooling which revealed drops of around 20% temperature for hot weather conditions and increased efficiency of around 9%. Developed active cooling system using means of forced air circulation by Teo et al. (2012), showed improvements in mean power output of up to 12.5%. Some other researchers doubled with more advanced active cooling concepts using nanofluids or microchannels to get enhanced heat transfer through augmentation of heat transfer and improvement of electrical efficiency. Another alternative for the temperature issue through which energy may not be wasted is hybrid photovoltaic-thermal (PV/T) systems. Such systems combine PV modules with thermal collectors to produce not only electric energy but also useful heat. The review of PV/T technology and various designs of it along with their potential concerning enhanced overall energy efficiency, was done by (Fu et al., 2012). Though PV/T systems allow for dual energy output, most of them usually involve much more complex, expensive installation compared with simple cooling techniques.

Among all the methods and formulations studied for water spray cooling, it is quite effective and promising for PV panels because it is simple and effective, with added benefits. Water spray cooling refers to the film or coated water that is put directly on the surface of the PV module and is normally carried on the front. It is claimed to absorb heat from the panel through evaporating water, resulting in a great fall in temperature. This evaporative cooling effect can be very effective in reducing the temperature of panels, especially under high-temperature conditions with dry climates. Several studies have demonstrated the effectiveness of water spray cooling for improving PV panel performance. Nižetić et al. (2016) conducted a comprehensive experimental investigation of water spray cooling applied to both the front and back surfaces of a PV panel. The results were highly encouraging, enhancing electric power output by up to 16.3% and enabling electric efficiency in the PV panel by as much as 14.1% under peak solar irradiation conditions. The authors further point out major temperature reductions from the average 54°C observed in panels that were kept non-cooled, to a mere 24°C when cooled on both sides.

Few researchers have worked on the advancement of a photovoltaic water pumping system such as cooling using water spray. Abdolzadeh & Ameri (2009) found out from studies that water spraying in front of PV cells brought about a reduction of the cell temperature; it reduced losses in reflection, thus ameliorating the system's performance. The researchers reported an average daily cell efficiency increase from 3.26 to 12.5% by employing water spray cooling. The utility of the water spray coolant is found not only with temperature reduction but also most essentially with its self-cleansing properties, very useful in dusty-contacted conditions where soil may decrease light transparency and hence power output. In addition, the water spray technology has been considered very technologically simple, and except some cases, the relatively easy implementation of the installed systems is possible.

Despite encouraging results reported in research works, up to now, there are many issues concerning the water spray cooling technique that need further researched (Hadipour et al., 2021). Such an extensive research gap still exists in the detailed analysis of changes in the electrical parameters caused by cooling of the PV surface. This research paper has focused on a novel approach to cooling solar panels, with a particular emphasis on the water spray's precise temperature control of the PV surface. While most studies talk of cooled versus uncooled panels, this work maintains specific surface temperatures of 34°C, 35°C, 36°C, and 37°C. The fine control allows for a granular test of how such small variations in temperatures impact the performance of solar panels, particularly output voltage. It also examines the average increases in, as well as the variability of voltage output under different cooling conditions. This comprehensive approach allows for considerable insight into the complex variable interactions that affect the performance of photovoltaics in tropical regions. This research offers valuable information for the development of more effective solar panel cooling systems in high-temperature areas with the identification of an ideal temperature range that provides maximum voltage output.

2 Methodology

The experimental setup is made with two identical 72-cell monocrystalline silicon photovoltaic panels rated for peak power output of 220 W. Panels were mounted at 15° to prevent water from running down and to represent the most frequently encountered rooftop installations. One of the panels served as a control not cooled, and another installed with the cooling system using water spray. The cooling system consisted of a 120 L water storage tank, a centrifugal pump, a piping network, and 10 spray nozzles mounted along the upper edge of the PV panel to cover the whole front surface uniformly. A thermostatic controller activated the pump so that water spraying started whenever the temperature of the panel surface was 34°C, 35°C, 36°C, 37°C. The water flow rate adopted for cooling was fixed at 4 L/min. Each panel was fitted with equipment to measure key performance indicators. Many K-type thermocouples were attached to the front surface of both panels for measuring temperature distribution, with data obtained second by second using a data logger. The voltage was measured via a multimeter using Bluetooth communication at intervals of 30 seconds. Solar irradiance was also measured with a solar power meter and continuous recordings of ambient temperature and humidity during the experiments.

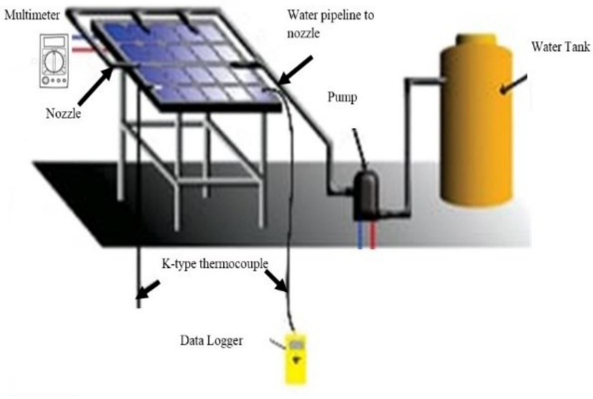

Figure 1. Experiment setup

The research was carried out in Denpasar, Bali, Indonesia, in May 2024. The data was recorded at the highest solar irradiation about 11:00 AM to 1:30 PM. The solar panels were attached to a 50 W load across the experiment. The water spray was regulated to maintain a surface temperature of experiment variables and allowed to vary within ±1°C. On the other hand, the uncooled panel was allowed to reach its natural operating temperature, based on the environmental conditions that existed. The whole experiment was repeated over a series of days to capture the variation in weather conditions and to ascertain the consistency/reliability of the obtained outcomes.

The data were analyzed to evaluate the effectiveness of the water spray cooling system on electrical parameters, especially voltage. First, the temperature of the PV surface was maintain constant, and evaluate the spray cooling performance to maintain the desired surface temperature. The thermal assessment uses 4 thermocouples to calculate average surface temperatures. After that, the electrical performance parameters were analyzed between the voltage of the output of the cooled panels versus the non-cooled panels. Time series data for these parameters were plotted to show performance variation throughout the measurement. Statistical methods were used to provide the mean enhancements in electrical output due to cooling. In addition, the relationship between the panel temperature and electrical voltage was examined to quantify the performance improvements upon temperature. Finally, the overall performance of the cooling system in high-temperature climates was obtained.

3 Result and Discussion

The result of voltage time series data for various PV surface temperature, reveals in Fig. 2.

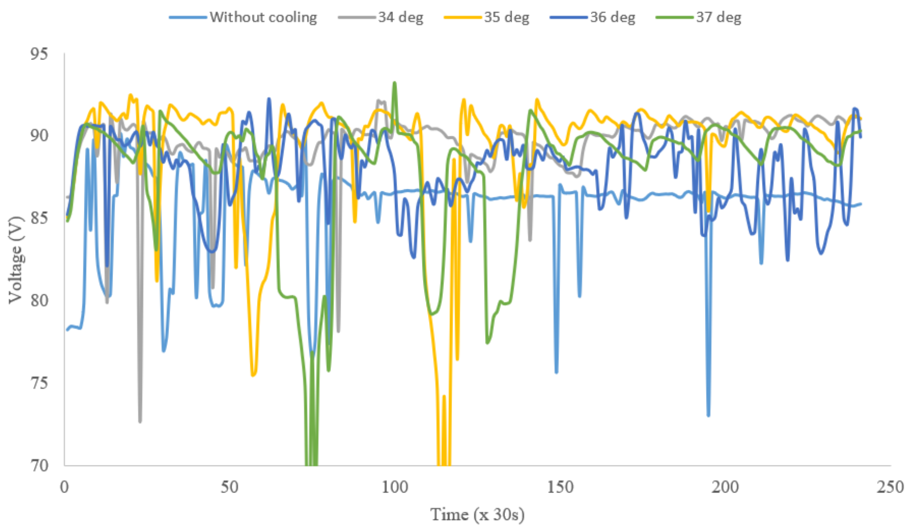

Figure 2. Time series of output voltage of solar PV

The data presents the voltage for a solar PV panel under different cooling conditions, including without cooling and cooling to maintain surface temperatures of 34°C, 35°C, 36°C, and 37°C. For the without-cooled solar PV, the voltage tends to decrease as the surface temperature increases. The average voltage for the without-cooled solar PV is 85.80V, with a maximum of 90.08V and a minimum of 73.07V. This wide range of voltage indicates significant voltage fluctuations, due to ambient conditions throughout the day. Solar PV with a surface temperature of 34°C indicated a notable improvement in output voltage performance. The average voltage increases to 89.72V, with a maximum of 92.42V and a minimum of 51.26V. This higher average voltage suggests improved performance, but the wide range between maximum and minimum values indicates some variability in the cooling system's effectiveness or external factors influencing the solar PV performance. At a surface temperature 35°C, the average voltage is 89.35V, very close to the 34°C condition. The maximum voltage is 92.15V, and the minimum is 72.67V. The narrower range between maximum and minimum values compared to the 34°C condition might indicate more stable performance at this temperature.

For the 36°C surface temperature, we see a slight decrease in average voltage to 88.04V, with a maximum of 91.98V and a minimum of 27.51V. This condition shows a continuous decrease of average voltage. Finally, at 37°C, the average voltage is 87.83V, showing the highest decrease of all condition variables. The maximum voltage is 92.24V, while the minimum is 82.12V, representing a more stable range compared to some other temperature conditions. Overall, we can observe that cooling the PV panel to maintain specific surface temperatures generally results in higher and more stable voltage outputs compared to the uncooled condition. The data suggests that maintaining surface temperatures 34°C provides the best voltage performance.

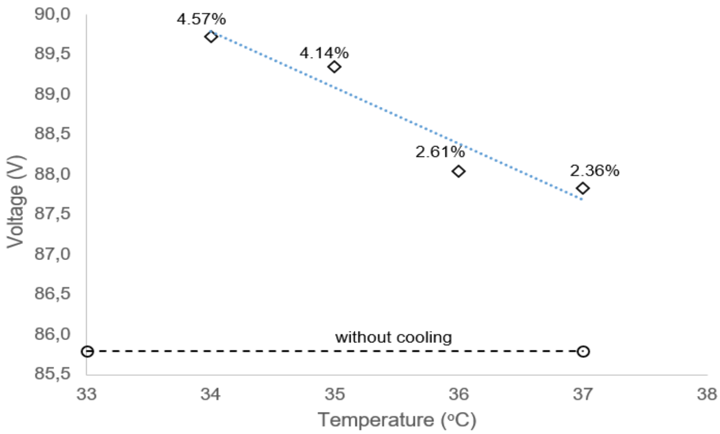

Figure 3. Enhancement of output voltage of solar PV

To analyze the voltage enhancement, we'll compare the average voltages at each controlled temperature to the without-cooled condition. At 34°C, the voltage enhancement is 3.92V (89.72V - 85.80V), or a 4.57% increase. This represents a significant improvement over the without-cooled solar PV and demonstrates the effectiveness of cooling even at a relatively high temperature. For the 35°C surface temperature, the enhancement is 4.14V (89.35V - 85.80V), equating to a 4.14% increase. This is very close to the performance at 34°C, indicating that the panel maintains good voltage output even as the temperature increases slightly. The similarity in performance between 34°C and 35°C suggests that the solar panel efficiency remains stable within this temperature range. At 36°C, we see the voltage enhancement of 2.24V (88.04V - 85.80V), or 2.61%. Finally, for the 37°C surface temperature, the voltage enhancement drops to 2.03V (87.83V - 85.80V), representing a 2.36% increase. While this is the lowest enhancement among the controlled temperatures, it still offers a significant improvement over the without-cooled condition. This suggests that even at higher temperatures, cooling can provide substantial benefits to solar PV performance.

The data reveals a non-linear relationship between surface temperature and voltage enhancement. This non-linearity could be due to the complex interplay of factors affecting PV performance, including temperature distribution on PV surface and interactions between temperature and other environmental factors like humidity or air pressure

4 Conclusion

In conclusion, the data demonstrates the benefits of cooling PV panels to maintain specific surface temperatures. All controlled temperature conditions show significant voltage enhancements over the uncooled panel, with improvements ranging from 2.36% to 4.57%. The optimal temperature appears to be around 34°C, but good performance is maintained across all ranges. These findings underscore the potential for cooling systems to significantly improve solar PV efficiency and electrical output, particularly in hot climates where panel temperatures can rise well above optimal operating conditions. Future research could focus on understanding the factors contributing to peak performance and optimizing cooling strategies to maximize overall system efficiency.

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