A case study of Output Power Improvement of Photovoltaic Modules using Non-woven Fabrics via Back Surface Cooling

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ABSTRACT

The power demand is increasing rapidly day by day. The environmental issues necessitate the effective utilization of solar energy for the generation of electrical power. Solar panel efficiency is comparatively low. Many measures have been taken to improve the efficiency of the solar panel. One of the important methods is cooling of the back surface of solar panel. Non-woven fabrics are used for the cooling of the solar panel. There are two methods of cooling namely evaporative cooling and Phase change material (PCM) based cooling. This case study investigates the impact of non-woven fabrics on the thermal behavior and overall efficiency of bifacial solar photovoltaic (PV) modules in terms of output power. The study focuses on enhancing the back surface cooling of solar panels by introducing high-performance non-woven materials as a thermal management layer beneath the modules. The primary goal is to analyze how thermal insulation using non-woven fabrics on the rear side (facing the Earth) of solar panels can influence temperature regulation and, subsequently, panel efficiency. Various passive cooling techniques are evaluated to reduce rear-surface heating.

I. INTRODUCTION

For the pollution free environment, the countries are taking many measures to reduce the usage of fossil fuels. In countries like India, the electrical power generation is mainly dependent on the fossil fuels. The effective utilization of solar power will reduce the use of fossil fuels. Improving the efficiency of the solar panel is really a challenging task. Many research articles are found in improving the efficiency of the solar panel via the non-woven cooling material.

Chiara Rubino et al., [1] analyzed the use of waste nonwoven material along with PCM for the effective cooling of the building. Ray et al.,[5] analyzed the characteristics of textile woven fabrics with respect to solar radiation and transmittance. Xiang Zhang [7] developed a composite evaporator based on carbon black-modified nonwoven fabric and copper heat sink. This improves the efficiency of cogeneration of solar energy. From the literature it is evident that woven non woven fabrics may be used for the cooling. C.S. Malvi et al., [2] discussed the application of PCM for the cooling and hence improving the efficiency of the solar panel. Miao Qi et al., [3] analyzed the properties of Solar Reflection and Water Repellent of the fabrics coated with cooling material. Mohamad Abou Akrouch et al.,[4] reviewed more than 200 articles in which advanced cooling methodologies were analyzed to improve the efficiency of the solar panel. The authors concluded that the water spray cooling and air cooling methodologies are more effective than PCM based cooling to improve the efficiency of the solar panel particularly. Sardarabadi Mohammad et al., [6] studied the effects of simultaneous use of nanofluids and PCM in PVT systems and experimentally proved that PVT with PCM/Nanofluid increases the thermal energy output by 48%. From the literature study, it is evident that the detailed study of the efficiency improvement of the solar panel by using back coated materials. Hence this paper analyzes the efficiency improvement of solar panel using nonwoven fabric cooling. This nonwoven fabric cooling works on heat and moisture transfer, whereas Phase Change Material (PCM) cooling absorbs a large amount of heat at a specific temperature. Hence non woven cooling, a passive type cooling is analyzed in this paper.

This paper is organized as the detailed background on back radiation followed by the real time study of the proposed work in the solar panel along with the cooling material. The case study is carried out along with the industrial partner Jayashree Spun Bond, a non woven fabric production industry. The fabric produced in the industry is used for the back coating of the solar panel. The study is carried out with various loading and at various irradiation levels. The experimental results are recorded using the FLUKE analyzer to consider the effects of loading on the electrical power and quality of power generated from the solar panel. The experimental results prove that the solar efficiency is improved with the cooling of the solar panel with the coating of non woven fabrics.

II. BACKGROUND ON ATMOSPHERIC BACK RADIATION ON SOLAR PANEL

The long-wave infrared radiation emitted by the atmosphere back to the Earth’s surface commonly referred to as atmospheric back radiation or infrared long-wave radiation plays a critical role in surface heating. After the Earth absorbs solar energy, it re-emits it as long-wave radiation. Part of this radiation is absorbed and re-emitted by greenhouse gases in the atmosphere, which leads to back radiation reaching the solar panels.

This thermal re-radiation raises the temperature of PV modules. For crystalline silicon panels, every 1°C increase in cell temperature leads to an efficiency loss of approximately 0.4–0.5%. Thus, managing heat is essential for maintaining high energy conversion efficiency.

Thermal Control via Non-Woven Fabrics:

In this study, high-quality non-woven fabrics are applied to the rear surface of solar panels, acting as a thermal insulation layer. These fabrics help mitigate atmospheric back radiation and reduce the heat absorbed from the Earth's surface, thereby lowering the operating temperature of the modules. The expectation is a significant improvement in temperature control, which translates into enhanced electrical output power and efficiency.

T_{cell} – Solar panel cell temperature $$T_{cell} = T_{ambient} + \left(\frac{NOCT - 20}{800} \right) \times G$$

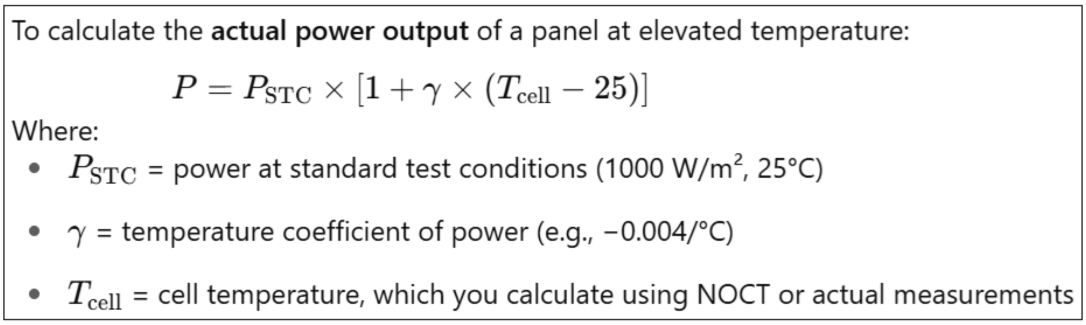
Where,
T_{cell}= Solar panel cell temperature (^{O}C)
$T_{ambient}$ = ambient air temperature (°C)
NOCT = Nominal Operating Cell Temperature
G = Solar irradiance (W/m^2)

Nominal Operating Cell Temperature (NOCT), helps to predict module temperature in real outdoor conditions and it's also helps to estimate performance loss due to heat (since PV efficiency drops with rising temperature). The higher values of NOCT will gives higher cell temperature will leads more efficiency loss. The panel with lower NOCT values are thermally better (e.g., frameless or bifacial modules tend to have lower NOCT).Typical NOCT values range from 40°C to 48°C.

The temperature coefficients are used together with NOCT to calculate power loss in solar panels due to high cell temperatures. The temperature coefficient of power (usually written as γ) expresses how much the panel's output power decreases per degree Celsius increase in cell temperature above 25°C (standard cell temperature at STC).

- It's typically given in **%/°C**.
- For crystalline silicon panels, it's around **−0.4% to −0.5%/°C**.

Power Loss due to Temperature:



To calculate the **actual power output** of a panel at elevated temperature:

$$P = P_{\text{STC}} \times [1 + \gamma \times (T_{\text{cell}} - 25)]$$

Where:

- P_{STC} = power at standard test conditions (1000 W/m^2, 25°C)
- γ = temperature coefficient of power (e.g., −0.004/°C)
- T_{cell} = cell temperature, which you calculate using NOCT or actual measurements

III. STUDY OF CHARACTERISTICS OF PV ARRAY USING POWER QUALITY ANALYZER

The Fluke 1775 Power Quality Analyzer is designed to detect, measure, and analyze power quality issues, including harmonics, voltage anomalies, and current disturbances in three-phase systems. It provides harmonics up to the 50th order. With a high-speed transient capture feature capable of recording voltage spikes up to ±8 kV at a 1 MS/s sampling rate, it is ideal for diagnosing sudden disturbances. The analyzer automatically records a broad range of power parameters, ensuring no critical data is missed.

Bifacial solar panel:

Trina Solar Vertex N TSM-695NEG21C.20 is a high-performance bifacial dual-glass solar panel designed for utility-scale installations.Utilizing advanced N-type i-TOPCon mono crystalline technology, this module offers superior efficiency and durability

Specification:

- Maximum Power Output (P_{max}): 695 W
- Module Efficiency: 22.4%
- Voltage at Maximum Power (V_{mpp}): 40.3 V
- Current at Maximum Power (I_{mpp}): 17.25 A
- Open Circuit Voltage (V_{oc}): 48.3 V
- Short Circuit Current (I_{sc}): 18.28 A
- Power Tolerance: 0 to +5 W
- Operating Temperature Range: -40°C to +85°C
- Temperature Coefficient of P_{max}: -0.29% / °C
- Module Dimensions: 2384 mm x 1303 mm x 33 mm
- Weight: 38.3 kg
- Cell Configuration: 132 half-cut cells
- Glass: 2.0 mm dual-glass with anti-reflective coating
- Frame: Anodized aluminum alloy
- Junction Box: IP68 rated
- Connector Type: MC4 compatible
- Maximum System Voltage: 1500 V DC
- Series Fuse Rating: 35 A

Fig.1 Snapshot of Solar panel and the recording of the data at the panel board using Power Quality Analyzer

IV. RESULTS AND DISCUSSIONS

The electrical parameters such as voltage, real power generated and power quality in terms of harmonics are recorded simultaneously in the solar panel end i.e at the field and the panel board. The power is calculated with and without non woven fabric. The calculations are described below:

Power Calculation (Without Non-Woven Fabric):

Solar Panel

- Maximum Power Output (P_{max}): 695 W
- Nominal Operating Cell Temperature (NOCT): 45 ^{O}C
- Ambient Temperature($T_{ambient}$): 39 ^{O}C
- Irradiance (G): 790 W/m^2
- Temperature Coefficient of Power - P_{max}(γ): -0.29% / °C

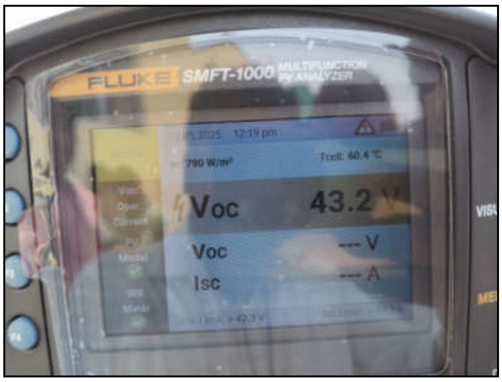


Fig.2: Measurement of Irradiation & Solar Cell Temperature (T_{cell}) without Non-woven fabrics

Step 1: Estimation of Cell Temperature (T_{cell})

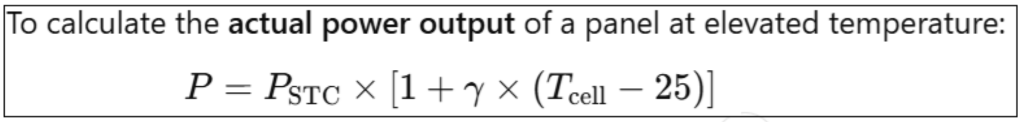
T_{cell} – Solar panel cell temperature $$T_{cell} = T_{ambient} + \left(\frac{NOCT - 20}{800}\right) \times G$$

T_{cell} = 39 + [45-20 / 800] X 790 = 63.68 °C

T_{cell}= 63.68 °C (Calculated)

Tcell = 60.4°C (Measured by using FLUKE SMFT 1000)

Step 2 Output Power calculation:



To calculate the **actual power output** of a panel at elevated temperature:

$$P = P_{\mathrm{STC}} \times [1 + \gamma \times (T_{\mathrm{cell}} - 25)]$$

P = 695 X [1 + (-0.0029) x (63.68 - 25)] = 617.04 watts (by using Calculated T_{cell})

P = 695 X [1 + (-0.0029) x (60.4 - 25)] = 623.65 watts (by using Measured T_{cell})

<u>Power Calculation (With Non-Woven Fabric):</u>

Solar Panel

- Maximum Power Output (P_{max}): 695 W
- Nominal Operating Cell Temperature (NOCT): $45^{O}C$
- Ambient Temperature($T_{ambiant}$): 39 ^{O}C
- Irradiance (G): 728 W/m^2
- Temperature Coefficient of Power -P_{max}(γ): -0.29% / °C

Fig 3: Measurement of Irradiation & Solar Cell Temperature (T_{cell}) with Non-woven fabrics

Step 1: Estimation of Cell Temperature (T_{cell})

T_{cell} – Solar panel cell temperature $T_{cell} = T_{ambient} + \left(\frac{NOCT - 20}{800}\right) \times G$

T_{cell} = 39 + [45-20 / 800] X 728 = 61.75 °C
T_{cell}= 61.75 °C (Calculated)

T_{cell}= 58.7°C (Measured by using FLUKE SMFT 1000)

Step 2 Output Power calculation:

To calculate the **actual power output** of a panel at elevated temperature:

$$P = P_{\text{STC}} \times [1 + \gamma \times (T_{\text{cell}} - 25)]$$

P = 695 X [1 + (-0.0029) x (61.75 - 25)] = 620.93 watts (by using Calculated T_{cell})

P = 695 X [1 + (-0.0029) x (58.7 - 25)] = 627.077 watts (by using Measured T_{cell})

The table 1 shows the comparative analysis of the output power from the solar panel with and without non woven fabric. It is evident that the output power of the solar panel is more when fabric coated based cooling is provided to the solar panel. Hence the efficiency of the panel has also been improved with the non woven fabric coated solar panel.

Table 1: Comparison of Solar Panel Cell Temperature and Output Power by using with and without Non-Woven fabrics

Case Study	Maximum Power Output (P_{max}) Watts	Irradiance (G) W/m^2	Cell Temperature (T_{cell}) (°C)		Output Power (P) Watts	
			Calculated	Measured	Calculated	Measured
Without Non-woven Fabrics	695	790	63.8	60.4	617.04	623.65
With Non-Woven Fabrics	695	728	61.75	58.7	620.93	627.077
Increased Solar output power per panel (Watts)					**3.89**	**3.427**

V. CONCLUSION

A detailed study is carried out to analyze the performance of the solar panel with effective cooling. The solar panel is back coated with the non woven fabric and the output power, voltage and power quality were recorded at various irradiance levels using Power Quality Analyzer. The study has also been carried out with and without coating. The results proved that the non woven fabric coated solar panel provides higher efficiency than the un-coated solar panel. Hence the cooling provided by the coated non woven fabric improves the efficiency of the solar panel.

REFERENCES

1. Chiara Rubino, Stefania Liuzzi, Francesco Martellotta, Pietro Stefanizzi, "Nonwoven Textile Waste Added with PCM for Building Applications", *Appl. Sci.* **2021**, *11*(3), 1262; https://doi.org/10.3390/app11031262
2. C.S. Malvi, D.W. Dixon-Hardy, R. Crook, "Energy balance model of combined photovoltaic solar-thermal system incorporating phase change material, 2011, 85(7), 1440–1446. https://doi.org/10.1016/j.solener.2011.03.027
3. Miao Qi, Ying Wang, Guangtao Chang, and Ruoxin Li, "Energy-saving Cooling Coated Fabric with Robust Solar Reflection and Water Repellent Properties", Fibers Polym **23**, 1881–1887 (2022). https://doi.org/10.1007/s12221-022-4984-4
4. Mohamad Abou Akrouch, Khaled Chahine, Jalal Faraj, Farouk Hachem, Cathy Castelain, Mahmoud Khaled, "Advancements in cooling techniques for enhanced efficiency of solar

photovoltaic panels: A detailed comprehensive review and innovative classification", Energy and Built Environment, Volume 6, Issue 2, 2025, Pages 248-276, https://doi.org/10.1016/j.enbenv.2023.11.002

5. Ray, A., Ghosh, S. & Bhowmick, N., "Solar Radiation Transmittance Characteristics of Textile Woven Fabrics suitable for Greenhouse covering Materials", J. Inst. Eng. India Ser. E **103**, 293–303 (2022). https://doi.org/10.1007/s40034-021-00223-3
6. Sardarabadi Mohammad, Passandideh-Fard Mohammad, Maghrebi MohammadJavad, Ghazikhani Mohsen, "Experimental study of using both ZnO/water nanofluid and phase change material (PCM) in photovoltaic thermal systems", Sol. Energy Mater. Sol. Cells 161 (2017) 62–69, https://doi:10.1016/j.solmat.2016.11.032
7. Xiang Zhang, Lei Sun, Wenyu Jia, Bo Xiong, Lijing Wang, Jianhua Hou, Zhuo Liu, Changyu Lu, Weilong Shi, "Architecturally-engineered scalable nonwoven evaporator with square groove morphology for solar desalination and thermoelectricity generation", Chemical Engineering Journal, Volume 519, 2025, 165005. https://doi.org/10.1016/j.cej.2025.165005.