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A review on advanced cooling techniques for photovoltaic panel

Sampurna Panda [a], Manoj Gupta [a], Babita Panda [b,*], Chitralekha Jena [b], Lipika Nanda [b], Arjyadhara Pradhan [b], C.S. Malvi [c]

[a] Poornima University, Jaipur, India
[b] School of Electrical Engg. KIIT University, India
[c] Madhav Institute of Technology& Sciences, India

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ABSTRACT

Despite generally low efficiency, photovoltaic systems are frequently used. When the P.V. module heats up, its output decreases. This bump is directly related to the energy absorbed by the panel and is then transformed into heat and results in lower panel output, energy efficiency, performance, and the life of the panel. To avoid PV panel overheating and to keep panel temperatures low, cooling techniques can be utilized. This paper describes new advanced cooling methods along with the upcoming research trends. In order to meet the needs of experts who are devising to conduct, improve or develop any cooling techniques for modules, several characteristics and capacities associated to cooling are explained and presented.

1. Introduction

In the current era, we live in a high-energy, consumer-oriented society. Because fossil fuels were instrumental in the industry's quick collapse, there has been a deviation from fossil fuels toward clean, renewable power. Sustainable energy sources are crucial for reducing our dependency on fossil fuels. Photovoltaic (PV) energy is one of a variety of non-traditional energy sources available on a global scale. Solar radiation and geothermal energy are the most prevalent renewable energy sources. This energy can be converted to electrical energy through the use of photovoltaic (PV) or thermal collectors. While photovoltaic (PV) technology has an efficiency range of 10% to 20% [1,2].To generate energy, solar cells use wavelengths between 380 and 700 nm that are visible to the human eye. Electron-hole pairs cannot occur at wavelengths longer than 700 nm, in contrast to shorter wavelengths of less than 700 nm (i.e. act as semiconductors)[3,4]. X-rays and other short wavelengths contain high photon energies, despite the fact that higher-energy photons might possibly kill the solar cell through ionization reactions. The temperature of the solar cell rises as a result of the conversion of non-visible radiation into heat.

By decreasing the operating temperature, the electrical power generated by the solar cells is increased [5–7]. A longer PV lifespan is required to boost electricity production even further. Solar radiation wavelength and material band gap are thought to influence PV panel efficiency, according to most industry experts.

Establishing an advance material to raise the performance of solar systems is a good way to increase performance. The solar photovoltaic system's power output decreases dramatically as the temperature of the solar cell rises. A limited percentage of the sunlight which hits the solar cell's surface is turned into power [8,9]. In either case, the remaining radiation is reflected back or is absorbed and heated up within the cell itself. Temperature of the Material will very high when the absorbed heat reaches 70 °C. Numerous researches have been carried out to reduce the working temperature of PV panels, in an effort to raise their efficiency.

2. Module efficacy parameters

Practically, the power output corresponds to the radiance; however, when the cell temperature is rising, the power supply is reduced. [10] The light intensity of the open circuit (VOC) variation is small but not significant. As the temperature of the panel rises above 25 °C, the VOC decreases, whereas the current, Isc, increases only marginally For illustration, for each 10 °C increase in temperature, the maximum power would be reduced by 0.5%[11] (Figs. 1 and 2).

* Corresponding author Tel.: 7205856704.
E-mail address: pandababita18@gmail.com (B. Panda).

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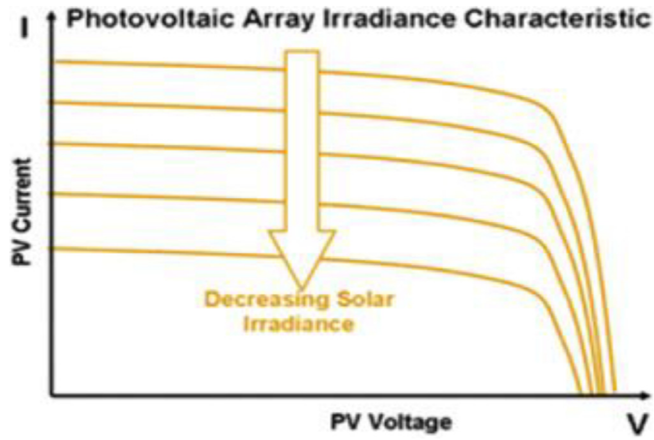

Fig. 1. PV array Irradiance Characteristic [10].

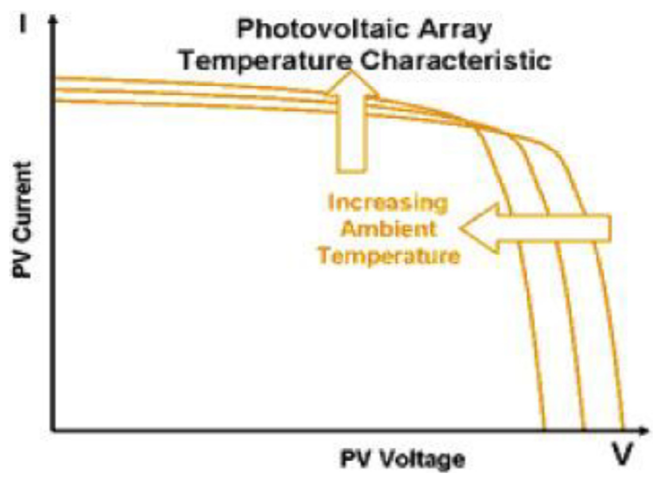

Fig. 2. PV array Temperature Characteristic [12].

3. The methods of solar PV cooling

3.1. The necessity of cooling

As with the rest of the climate, the temperature of the earth's surface varies based on changes in the atmosphere, such as variations in sunlight, wind velocity, moisture, and atmospheric temperature, and additionally on the presence of concentrated dust. Reducing the operating temperature is a good way to improve efficiency. In general, solar radiation on vertical, non-directional surfaces is a primary factor when constructing photovoltaic panels on the building exteriors [12]. In order to increase the efficiency of photovoltaic, a variety of different cooling techniques have been studied and examined in a number of publications.

3.2. Different ways of photovoltaic panel cooling

Reducing P.V. output loss and keeping the PV module's reliability are absolutely necessary to maintaining a constant PV array temperature. Passive and active cooling techniques increase the efficiency of the PV array. Any additional coolant is not required in Passive cooling method and cooling function is typically achieved through the use of a fan or pump. Passive cooling does not need additional power for PV cell cooling [13–15].

In the world of passive cooling, the three main categories are air, water, and conductive cooling. Extra components like heat pipes, sinks, or exchangers may be included in passive cooling schemes. In fact, the heat sinks were made out of conductive thermal equipment. The heat transfer between the solar panel and the local environment is maintained if they are positioned at the bottom of the panel. PVT technology, using a variety of different wavelengths, is used to separate the wavelengths of PV cell emissions and the thermal conversion process of the PVT system [16–18] (Figs. 3 and 4).

Fig. 3. PV Cooling by Air [17].

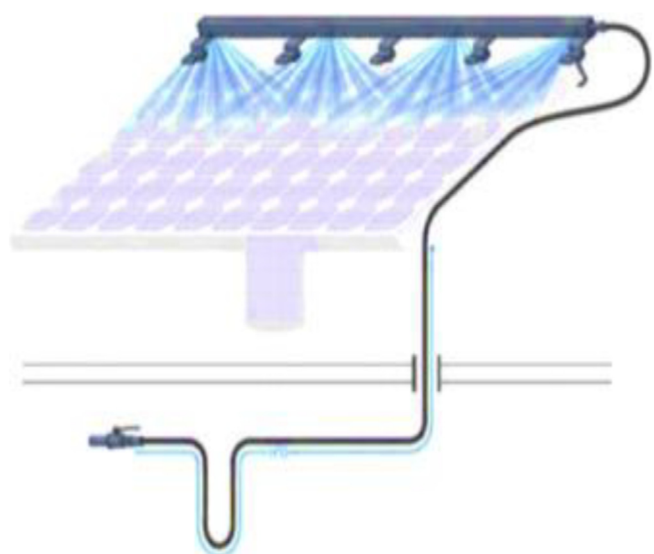

Fig. 4. PV Panel cooling by water.

4. Literature review of PV cooling methods

Babu et-al, 2003 discussed a new uncomplicated model of a PV array. The result of the approach used is that it gives an effective and accurate value for the ideality constant, which the author presented as a fast iterative method that matches when the circuit is open circuit conditions and Voc and MPP conditions. After the proposed work has been validated, by running simulation models for Monocrystaline and multi-crystalline modules, as well as for KC200Gt, MSX-60, and JC 260S, the author has confirmed that the proposed work has merit. These modules were simulated and an algorithm based on the result was proposed. This algorithm was compared with experimentally obtained IV characteristics, which are shown here. 0.1% deviation is shown in the simulation results when compared to the datasheet value, and both IEC and UL-1703 standards were applied in the compiling. The simulation experiment was designed to show the superiority of the proposed two-diode model: Voc, Isc. The model will have a reduced amount of absolute error and RMSD [3].

Meyer et-al, 2011 has presented Low-Cost Evaporative Cooling Method for Improved Power Output of PV System Solar panel performance is highly influenced by temperature, according to the data. The module temperature must be decreased to counteract the heating effect. Despite adopting water-based evaporative cooling, the thermal insulation of solar PV did not alter. When the temperature inside the PV module rises, so does its electrical efficiency and power production decreases. Evaporative coolers are used to lower the temperature of the panels so that more electricity may be generated, therefore lowering the temperature. This procedure has been tested and found to be effective by others. 303 Kelvin appears to be the ideal temperature for silicon solar panels to maximize theoretical and experimental results [13].

Ouyang et-al, 2011 has showed in a stand-alone power supply system, photovoltaic power plants' energy efficiency has been discussed. The study's objective is to locate a single source of independent power supply (dozens of kW). The usual energy usage of this rural town has been the focus of this study. The decision was made to build a PV-diesel power system because of the required energy and the amount of seasonal and daily insolation. The daily energy consumption and solar exposure were plotted based on this statistics. For the most part, electricity is used by small rural villages with populations of a few hundred to a few thousand. In order to attain the highest nighttime peak load of one-point-zero (1p.u.), the filling factor of the graph is 0.36. The average load is 0.36 [14].

Meyer et-al, 2011 discussed that performance analysis of a photovoltaic (PV) array at high temperature. Module efficiency is reduced as a result of the high temperatures. Meanwhile, it is possible for module efficiency to increase due to low temperatures. During the entire day, the temperature of the directly cooled module remained at 34.34 °C. Naturally cooled module topped out at 58.64 °C. In order to meet demand; more than two-thirds of the incident solar energy is used to produce heat, as opposed to generating electricity. This research demonstrates how the two modules respond to daily energy generation. According to the results, the electrical efficiency was reduced, but the total efficiency was raised. On a daily basis, all recordings are analyzed for data and information. Tout can be used to reach a maximum temperature of 45 °C. The final temperature of 55 °C can be reached when the temperature is raised by 10 °C once the temperature reaches 45 °C [16].

Park et-al, 2016 has presented encapsulant delamination may have an impact on the electrical performance of pv modules, according to a study. A solar simulator was used to test the degradation processes and performance of long-term field-exposed crystalline-Si PV modules. PV module defects have been evaluated for their electrical luminance. In this study, researchers compared the line irradiance (measured as electricity transmitted through a copper line) with line sag (the amount of copper loss) and delamination. A five-year-long state of affairs Non-destructive analysis of the 5-year-old, field-aged, South Korean PV module found it to be in excellent condition. An annual electrical performance decrease of 0.6 percent has been found. Delamination is, by far, the most visible of the PV module's problems. It is expected that the EVA has delaminated between the solar cell and the glass interface, since this results in EVA separation between the EVA and the solar cell. Even though the delamination occurred, it is still unclear if the PV module will have a normal lifetime by performing an iv test on PV modules [17].

Kuthanazhil et-al, 2015 has analyzed the Socio-Economic impact of PV Systems Installation in India. Researchers discovered that there is a link between financial models, funding models, and the various ownership models in place. The likelihood of keeping a PV system grows when regular income and cash flows are tied to it. Operational and maintenance tools are found to be more effective when community-owned solar installations are included. In roughly 80% of the PV system owners' cases, the people who performed routine maintenance and repairs on their systems had high maintenance skill levels [11].

Sandhya et-al, 2015 has proposed a study on the use of water spray cooling to improve the performance of PV cells in Coimbatore, Tamilnadu. A tiny layer of water on top of a solar panel can significantly boost its overall effectiveness. On the 74th day of the year, the sun shines 939.64 W/m2 and on the 74th day of the year, the sun shines 839.62 W/m2. Simulation and comparison with water spray were performed to test the panel's ability to cool. There is a range of 7.5 to 8 percent efficiency for un cooled PV panels, while cooled panels have a range of 10 to 12-percent efficiency. Water spray cooling could boost the annual average of the PV panel's efficiency by 3 percent. In any given day, the front panel will be heated to between 55 and 57°Celsius by sun radiation. The efficiency of PV panels diminishes as the temperature of the panel rises. Within five minutes of activating the cooling process, a mass flow rate of 1 kg/min of water must be maintained to maintain the system's temperature. Water-spray-cooled panels are more efficient than conventional panels by about 2.5 to 3 percent, depending on the panel's efficiency [12].

Ramkumar et-al, 2018 has showed Clay pot evaporative cooling water was used by the authors to improve the performance of a photovoltaic module. Heat is collected from the module's rare-surface using water and air in an experimental hybrid PV Thermal system. There is a heat exchanger in the other system, while the first one has an air duct under the PV array. It was Hussein's goal to see if continually running the PV was more efficient than spraying water on it, and he succeeded. There are three PV solar photovoltaic panels in the experimental setup, however each one is distinct. The idea was tested in Chidambaram, Tamil Nadu, India, during February and March of 2016. The PV/thermal system uses water as a coolant. It is adjusted to 0.3 kg/h of water flow over the panel. As the temperature drops, both the performance of PV and the performance of PV/thermal increase dramatically. This solar and thermal hot water heater was successfully constructed. The water in the pot doesn't boil at a greater temperature because it is cooler than the air around it. When compared to the power generated by a PV/T system, the output of a traditional solar panel is insufficient [10].

Bahaidarah et-al, 2017 has tested the performance evaluation of cooling of a photovoltaic hybrid system on its back surface by means of water. An experimental hybrid water-cooled PV system, which was developed in Dhahran, Saudi Arabia, has been tested in regards to weather in that city. In order to reduce reflections, Krauter tested different thicknesses of water on the panel to find the right balance between complete wetting and no dripping. Decreased cell temperature led to an increase in electrical efficiency because water sprayed on top of the panel improved electrical conductivity. According to Rosa, a water-immersed PV panel increases its electrical efficiency by an average of 11%. The experimental data shows that using a circulating water system reduces system energy consumption. A hybrid PV system that generated hot water through waste heat and generated additional electrical power used that heat to increase power output. With a reduction in operating temperature of about 20%, and an increase in electrical efficiency of about 9% when using the active cooling technique, usage of the module has increased. In comparison to a photovoltaic system by itself, this hybrid system offers nearly four times the energy yield. In the hybrid system, 750 W of energy was stored, while in the PV system, only 190 W was collected. Warming causes a rise in water flow, which increases mass flow rate [7].

Ilaiyaraja et-al, 2013 has studied the performance modeling and assessment of several photovoltaic arrays for Indian climate conditions. Soil loss increases to a total of 11.2% when 13 mm of rainfall is received, and the amount of soil loss decreases to nearly zero when over 150 mm of rainfall occurs in a month. The midday insolation of 1058 W/m2 reaches its peak value, while the power output of crystalline I and crystalline II technologies peaks at 8 kW and 8.63 kW. Also, thin-film technology has an output of 8.93 kW between 12:00p.m. and 12:00 noon. When calculating loss due to temperature effects, the figure for I technology is 7.8 percent, while for II technology it is 8.5 percent. This means that the thin film loses only 3.8% of its temperature due to the environment. The projected PV array output for all three technologies is within 10% of the measured output with an error of less than 10%.Crystalline I technology has a performance ratio of 79.58 percent, thin film technology has a performance ratio of 83.3 percent, and crystalline II technology has a performance ratio of 78.3 percent. With regard to the calculation of power output, the comparisons performed between PVIND, PVSYST, and measured values have found to be in agreement [8].

Cristaldi et-al, 2017 has devised a new approach to tracking photovoltaic panels' maximum power points. Even a tiny inaccuracy in the MPP current can result in a considerable loss of power. In this research, a brand-new algorithm was put forward. A PT100 sensor is installed on the back of the panel and digitized to measure the panel's temperature. Using a nonlinear least squares approach, the parameters B1 through B9 have been determined. This paper proposes a new MPPT algorithm for module integrated converters. An expensive radiometer does not need to be used for the initial estimation of parameters in this method. A modest perturbation step shows that the authors' proposed method offers steady-state accuracy comparable to the P&O and INC procedures [9].

4.1. Common findings of various PV panel cooling technologies:

Stabilizing the panel temperature using this cooling system has allowed the PV panel efficiency to increase by 71.43%, which means an improvement of 720 W/m2 of solar radiation.

- Degradation in the module's power output ranged from 19% to 33%.
- 14.7 percent of maximum efficiency is possible in Polycrystalline solar panel.
- The patch elements are designed through the mathematical modeling and simulation of decimation and interpolation.
- PV electric generation performance is strongly influenced by the PV module operating temperature. Since PV module temperature increases when there is more direct solar irradiance, having a higher wind speed reduces it (Table 1).

4.2. Advantages & disadvantages

4.2.1. Advantages

- When exposed to a total irradiance of 900 W/m2, the hybrid system only gained 7.5 kW while the PV system acquired only 190 kW.
- Because the fan has a relationship to the power it consumes, the flow rate delivered is strongly related to power consumption.
- When the PV systems are implemented in an extreme environment, the PV cooling systems will be powered by the PV generators.
- By running water across the thin film of film of water, we can both reduce the reflection loss and keep the panel cooler. To adjust the temperature of the panel, we can use water cooling.

4.2.2. Disadvantages

- For instance, poly-crystalline panels used for temperature augmentation and low relative humidity saw power efficiency drop by around 10–12 percent.
- Increasing panel temperature has a deleterious effect on PV panel efficiency, but on average, has a positive effect on the overall efficiency.

5. Conclusion

This research was conducted to examine the various PV cooling techniques to explore the many ways they can be utilized and optimized in the future. The following key findings can be derived from our examination of the P.V. cooling system:

- In contrast to passive cooling methods, active cooling method was discovered to be the most simple and efficient method of cooling, and this is a good starting point for further exploration. However, as the later cooling method is uncommon, it should be factored to the develop the system. To achieve this, there

Table 1
Comparison of literature review on the basis of PV panel cooling approach.

Medium used for cooling	Method of Cooling	Technique adopted	Remarks (Data used)
By Using Solar Concentration by Simple Mirrors and by Cooling [3,8-10,14]	Water flow on panel surface	NA	Instead of the two other methods, using mirrors and proper cooling is better as efficiency is 52% in this instance.
By the Use of water [13,11–13]	Water spraying of PV panels	120 water nozzles are being used to cover the panels with water. A centrifugal pump with 1 horsepower (hp) of input power.	The 2C/min cooling rate is applied to the solar cells when their concerned operating conditions are in place.
Application of Floating PV [13–15,11]	Water irrigation reservoirs by means of floating photovoltaic cover system	PV panels are covered by water	To maintain balance of water and energy in arid and semi-arid zones with less water supplies by installing floating solar PV.
By using floating PV [13]	FPCS	PV panels are covered by water	The system is beneficial and reasonable.
By floating panels on water [14,17,18]	Panels installed on a pontoon on water	Hybrid floating gas turbine	Beneficial output can be produced by hybrid floating power plants that utilise renewable energy and natural gas in ocean.

must be a constant supply of cool water, along with an array large enough to handle the total amount of heat being extracted.

- While natural convection was discovered to be the simplest method for passive cooling, it should only be used in the specific scenario above. In contrast to water, which is the more effective coolant, the air is not an effective cooling agent.
- Hot water and energy are used at similar levels in food industries, making water-based cooling systems better for these sectors.
- Additionally, the PV module needs to be cleaned to avoid it accumulating dust. Additionally, this item is also very useful for agricultural sectors.
- It is also worth noting that PCM cooling is best known for its ability to maintain high energy density per unit volume, which makes it the more capable than Active cooling method..
- When it comes to providing additional thermal energy, you can use either air or water cooling methods.

CRediT authorship contribution statement

Sampurna Panda: Conceptualization, Methodology, Software. **Manoj Gupta:** Writing – review & editing. **Babita Panda:** Data curation, Writing – original draft. **Chitralekha Jena:** Software, Validation. **Lipika Nanda:** Supervision. **Arjyadhara Pradhan:** Visualization, Investigation. **C.S. Malvi:** .

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Raj, Ashish, Manoj Gupta, and Sampurna Panda. "Design simulation and performance assessment of yield and loss forecasting for 100 KWp grid connected solar PV system." In *2016 2nd International Conference on Next Generation Computing Technologies (NGCT)*, pp. 528-533. IEEE, 2016.

[2] S. Panda, C.S. Malvi, Modified MPPT algorithms for various step size and switching frequency using MATLAB/SIMULINK, Solid State Technol. 63 (5) (2020) 8863–8872.

[3] Jianping, Sun. An optimum layout scheme for photovoltaic cell arrays using PVSYST. In 2011 International Conference on Mechatronic Science, Electric Engineering and Computer (MEC). 2011.

[4] S.A. Sannasiraj, V. Sundar, Assessment of wave energy potential and its harvesting approach along the Indian coast, Renewable Energy 99 (2016) 398–409.

[5] ISSN 0960-1481 Suresh, V., S. Naviynkumar, and V. Kirubakaran. "Improved power output of PV system by low cost vaporative cooling technology." In Green Computing, Communication and Conservation of Energy (ICGCE), 2013 International Conference on, pp. 640-643. IEEE, 2013.

[6] R. Arshad, S. Tariq, M.U. Niaz, M. Jamil, Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling, in: Robotics and Emerging Allied Technologies in Engineering (iCREATE), 2014 International Conference on, 2014, pp. 292–295.

[7] S. Sandhya, Study on performance enhancement of PV cells by water spray cooling for the climatic conditions of Coimbatore, Tamilnadu, in: Innovations in Information, Embedded and Communication Systems (ICIIECS), 2015 International Conference on, 2015, pp. 1–5.

[8] B.C. Babu, S. Gurjar, A Novel Simplified Two-Diode Model of Photovoltaic (PV) Module, IEEE J. Photovoltaics 4 (4) (July 2014) 1156–1161, https://doi.org/10.1109/JPHOTOV.2014.2316371.

[9] O. Breitenstein, An alternative one-diode model for illuminated solar cells, IEEE J. Photovoltaics 4 (3) (May 2014) 899–905, https://doi.org/10.1109/JPHOTOV.2014.2309796.

[10] Y.V. Sridhar, Case study of grid connected PV plant feeding power to electrical submersible pumps, in: Power and Renewable Energy (ICPRE), IEEE International Conference on Power and, 2016, pp. 547–552.

[11] M. Irwanto, Y.M. Irwan, I. Safwati, W.Z. Leow, N. Gomesh, Analysis simulation of the photovoltaic output performance, in: 2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014), 2014, pp. 477–481.

[12] R. Ilaiyaraja, P. Gopi, Performance modeling and assessment of different photo voltaic arrays for Indian climatic conditions, in: Renewable Energy and Sustainable Energy (ICRESE), 2013 International Conference on, 2013, pp. 175–182.

[13] P. Yadav, N. Kumar, S.S. Chandel, Simulation and performance analysis of a 1kWp photovoltaic system using PVsyst, in: Computation of Power, Energy Information and Commuincation (ICCPEIC), 2015 International Conference on, 2015, pp. 0358–0363.

[14] K. Passow, L. Ngan, B. Littmann, M. Lee, A.F. Panchula, Accuracy of energy assessments in utility scale PV power plant using PlantPredict, in: Photovoltaic Specialist Conference (PVSC), 2015 IEEE 42nd, 2015, pp. 1–6.

[15] Pagrut, Umesh P., A. S. Sindekar, Sagar S. Lachure, and Jaykumar S. Lachure. "Performance of 125 watt PV module using MATLAB-simulink." In Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), 2017 Third International Conference on, pp. 45-49. IEEE, 2017.

[16] Satish, Y. Sri Sai, B. Manvitha, N. Chandra Sekhar, S. Mahathi Vatsal, and T. Suresh Reddy. "Modeling and simulation of PV panel with implementation of dual-axis sun tracker." In Electrical, Electronics, Signals, Communication and Optimization (EESCO), 2015 International Conference on, pp. 1-5. IEEE, 2015.

[17] N.M. Swarnkar, L. Gidwani, Analysis of hybrid energy system for supply residential electrical load by HOMER and RETScreen: A case in Rajasthan, India, in: Recent Advances and Innovations in Engineering (ICRAIE), 2016 International Conference on, 2016, pp. 1–6.

[18] S. Mukherjee, M.A. Razzak, Design, analysis and optimization of grid-connected solar photovoltaic system using RETScreen in eight divisions of Bangladesh, in: 2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), 2016, pp. 1–6, https://doi.org/10.1109/CEEICT.2016.7873120.