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REVIEW OF THE IMPACT OF TROPICAL CLIMATE ON SOLAR PHOTOVOLTAIC MODULES PERFORMANCES USING THE COMBINATION OF COOLING SYSTEMS

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Abstract: In tropical areas, not only solar radiation but ambient temperature is also one of the necessary constraints that must be considered when designing and predicting solar Photovoltaic (PV) module performances. Performance monitoring needs to be done on energy efficiency related to the solar PV module's temperature and output power changes. One possible solution to increasing the efficiency of the solar PV module is by using the effects of the cooling strategy on the modules. This paper reviews the impact of tropical climate on solar PV modules' performances using a combination of cooling systems to increase efficiency and power output. Three methods of cooling the solar PV module have been investigated: Heatsink, water, and air media. The review also includes the solar PV module system design's current status with and without cooling systems, the surface monitoring temperature system, and the effect of output power changes. Consequently, a review of the mathematical calculations to obtain the solar PV module's efficiency value and output power is presented. The conclusion of this review is to determine the solar PV module's best combination of cooling systems in tropical climates in achieving the highest possible efficiency with developed a hybrid cooling system concept of Passive Cooling on monocrystalline PV module capacity above 170 W to prove the level of temperature reduction and efficiency in experimental research with and without a cooling system equipped several measuring instruments with a high level of accuracy.

Keywords: Photovoltaic, efficiency, cooling, tropical, climate.

Introduction

Power plants that do not produce pollutants do not require fuel and make them a very profitable energy source are power plants sourced from solar energy. Photovoltaic (PV) modules are one of the most popular renewable energy generation techniques using sunlight to generate electricity (Meral & Dinc, 2011).

Location and season influence the performance of PV modules as a solar power generation system (PLTS). Assessment of PV module performance based on field conditions can provide useful information to improve system efficiency and reliability (Duerr *et al.*, 2016). The amount of solar energy that can be converted into electrical energy by PV modules is only about 31%. In most cases, a greater percentage of the energy is converted into heat energy, which adversely affects efficiency and may even cause material damage to PV modules (Koteswararao *et al.*, 2016). The operating temperature greatly affects the PV module's electrical conversion efficiency. Only 20% of solar radiation can be converted into electricity, while the rest is reflected in the atmosphere or converted into heat, which decreases electrical efficiency (Suresh *et al.*, 2018).

At the peak of sunlight, energy loss in the form of heat occurs, this can reduce the efficiency and output power of the PV module. Concepts involving multiple types of cooling (multi-concept cooling techniques) have the potential to overcome the challenges of reducing efficiency and power output in PV modules. Many experiments have been carried out to create a cooling system. The analysis of the output power with the help of the power equation produces a reduction factor of 80% or an increase in output power of 20.96 watts, and the increase in efficiency achieved is not less than 3% to make the module more efficient and productive (Idoko *et al.*, 2018).

Materials and Methods

The United Nations millennium development goal on green energy is realized by globally adopting and using Photovoltaic modules as the main energy source. In order to reduce global CO_2 emissions by 50%, it is threatened with failure due to poor performance, especially in tropical climates. In tropical climates, the critical value of cell temperature reaching 90°C, wind speed of 0.2 m/s and relative humidity of 85% affect the PV Module's performance. This will harm the PV module performance index, which includes Power Output (PO), Power Conversion Efficiency (PCE) and Energy Return Time (ERT) plus the performance of each component affects the performance of the entire PV module 6. Seasonal climatic parameters such as ambient temperature, relative humidity and solar radiation are problems in hot areas 7. Among the renewable energy technologies available and considered the most promising due to their advantages in energy generation, operation and maintenance of PV Modules 8, three main factors can affect the efficiency of Photovoltaic modules, namely: Cell material, PV system devices and the environment, in detail of these three factors as shown in Table 1.

Table 1: Factors that affect photovoltaic module efficiency

Field	Sub-field
Cell material	1. Corrosion
	2. Degradation
	3. Cracked cells
	4. Contact stability
	5. Selected of semi-conductor
PV system device	1. Size of inverters, batteries and charge controllers
	2. Quality of inverters, batteries and charge controllers
	3. Type of inverters, batteries and charge controllers
	4. Inverter power conversion efficiency
	5. Incorrect size/types of conductor
	6. Extent of voltage drop
	7. Odd wiring technique
	8. Insufficient use of disconnect
	9. Incorrect grounding
	10. Underrated component usage
Environmental factor	1. Dust
	2. Solar radiation
	3. Humidity
	4. Ambient temperature
	5. Shade
	6. Wind direction and speed
	7. Tilt angle

(Idoko *et al.*, 2018)

From the various problems contained in Table 1, the focus of the discussion in this paper is on environmental impacts, especially the effect of temperature on efficiency on the power output of PV modules.

Results and Discussion

Operational flexibility in optimizing combined cooling is an indicator that can show the capacity to withstand the decline in PV performance caused by external variable conditions (Jiangjiang *et al.*, 2020). Exploration of two often overlooked root causes of PV self-heating, namely, band gap absorption and imperfect thermal radiation. Redesigned optical properties of solar modules in the form of selective spectral cooling (to eliminate parasitic absorption) and radiative cooling (to increase thermal emission). Through comprehensive opto-electro-thermal simulation, it is possible to cool a single solar terrestrial solar module to 10°C and increase efficiency absolute by 0.5% to extend the life of up to 80% of solar modules (Sun *et al.*, 2017).

The sol-gel printed ultra-broadband texture with radiation cooling has infrared emissivity > 0.96 at atmosphere 8 -13 mm, solar transmission > 0.94 and fog > 0.95 at wavelength 350-750 mm, representing light management. Applying the printed glass ultra-broadband texture to the silicon PV module has a relatively increased efficiency of the encapsulated enclosure by 5.12%, and short-circuit current by 3.13% (Lu *et al.*, 2017). The research was carried out in the Mirpur area, Pakistan with Experimental research methods and Back Surface Water Cooling methods as well as Solar Irradiation 971 (W/m^2) conditions with two type of cells, namely Monocrystalline, which resulted in a decrease in temperature of 5.44°C and an efficiency of 13%. In contrast, Polycrystalline resulted in a decrease in temperature of 2.8°C and 6.2% efficiency (Bashir *et al.*, 2018).

The effects of passive spectral selective cooling and additive cooling were evaluated under variable conditions with a combined thermal-electric model. In AM1.5 PV module conditions, v = 2 m/s, T = 309.15 K, the efficiency increase was obtained from selective spectral by 0.98%, passive radiation by 2.40%, and combined cooling by 4.55% (Li *et al.*, 2019). The research took place in Split, Croatia. Experimental and the method of cooling Individual Fin-Based Passive Cooling with Air under Solar Irradiation 1014 (W/m^2) conditions using Polycrystalline cell types resulted in a temperature reduction of 5°C and an efficiency of 5% (Čoko *et al.*, 2019). Research that took place in Khon Kaen, Thailand was Experimental and the Passive Cooling method (PCM in a Fnned Container Heat Sink) under Solar Irradiation 1000 (W/m^2) conditions using Polycrystalline cell types resulted in a decrease in temperature of 6.1°C and an efficiency of 5.3% (Wongwuttanasatiana & Sarikarinb, 2020).

The research in Khon Kaen, Thailand is Experimental and the Finned Type PCM Container method under Solar Irradiation 919 (W/m^2) conditions using Polycrystalline cell types resulted in a decrease in temperature of 6.16°C and efficiency of 4.48% (Sarikarin *et al.*, 2019). Research taking place in Tamil Nadu, India is Experimental and Numerically Simulated with the Inorganic PCM Based on the Salt cooling method under Solar Irradiation 1042 (W/m^2) using CIS cell type (SF170-S) resulting in a temperature reduction of 9°C and 10% efficiency (Karthick *et al.*, 2020).

The research in Elazig, Turkey is Experimental with PCM, TEM and Aluminum Fins cooling methods at 1015 (W/m^2) Solar Irradiation conditions using Polycrystalline cell types resulting in a decrease in temperature of 2.8°C and efficiency of 7.72% (Bayrak *et al.*, 2020). Research taking place in Kermanshah, Iran is Experimental with the Passive Cooling method (Natural Cooling Water Circulation and Nano-Enhanced PCM) under Solar Irradiation 690 (W/m^2) using Polycrystalline cell type resulting in a decrease in temperature of 25°C and efficiency 48.23% (Abdollahi & Rahimi, 2020).

Research taking place in Saudi Arabia is Experimentally and Theoretically with Passive Cooling (Heat Sink) method at Solar Irradiation

1000 (W/m^2) using Polycrystalline cell type resulting in a decrease in temperature of 12°C and efficiency of 8.7% (AlAmri *et al.*, 2021).

Where the research is not stated is the Numerically Simulated [Discrete Ordinates (DO) Method] with Passive Cooling (Radiation Shield) method under Solar Irradiation 1094 (W/m^2) using Polycrystalline cell type resulting in a decrease in temperature of 12.18°C and efficiency 5.48% (Khorrami *et al.*, 2021). Research taking place in Tamil Nadu, India is Experimental with the CPM and Plant Cooling method under unknown Solar Irradiation conditions using Polycrystalline cell types resulting in a decrease in temperature of 1.8°C and an efficiency of 11.34% (B *et al.*, 2021).

Finally, the research that has been carried out located in Swinoujscie, Poland is Calculation Methods with the Water-Cooling method (from Engine Room Cooling System) under conditions of Solar Irradiation 1020 (W/m^2) using Monocrystalline cell type resulting in a decrease in temperature not mentioned and efficiency 20147% (Zapałowicz & Zeńczak, 2021). Other PV module cooling techniques can be a more comprehensive reference to develop cooling systems and increase PV module efficiency. Table 2 is the result of a review related to PV module cooling techniques from several previous research journals with various types of cooling techniques as the basis for developing cooling systems to increase output

Table 2: Overview of studies on other cooling techniques for PV module

Author	**Method**		**Type of Cells**	**Temperature Reduction (°C)**	**Power Enhancement (%)**
	Research	**Cooling**			
Xingshu Sun *et al.,* 2017	Numeric	Eliminate parasitic absorption and enhance thermal emission	CIGS, Si, CdTe ells	10	0.5
Yuehui Lu *et al.,* 2017	Experiment	Enhance thermal emission	Crystal silicon PV module	-	3.13
Muhammad A. Bashir *et al.,* 2018	Experiment	Back surface water cooling	Mono & poly	5.44 2.80	13.00 6.20
Hao Li *et al.,* 2019	Numeric	Selective spectral and passive radiation	Mono	-	2.24
Filip Grubišić-Čabo *et al.,* 2019	Experiment	Individual fin-based passive cooling with air	Poly	5.00	5.00
T. Wongwuttanasatian *et al.,* 2019	Experiment	Passive Cooling (PCM in a fined container heat sink)	Poly	6.10	5.30
Tachakun Sarikarin *et al.,* 2019	Experiment	The finned type PCM container	Poly	6.16	4.86
Alagar Karthick *et al.,* 2020	Experiment and numeric simulated	Inorganic PCM based on salt	CIS (SF170-S)	9.00	10.00

Fatih Bayrak *et al.,* 2020	Experiment	PCM, TEM and aluminum fins	Poly	2.80	7.72
Nasrin Abdollahi *et al.,* 2020	Experiment	Passive Cooling (natural cooling water circulation and nano-enhanced PCM)	Poly	25.00	48.23
Fahad Al-Amri *et al.,* 2021	Experiment and theoretic	Passive cooling (heat sink)	Poly	12.00	8.70
Navid Khorrami *et al.,* 2021	Numeric simulated	Passive cooling (radiation shield)	Thin-film	12.18	5.48
Ramkiran B *et al.,* 2021	Experiment	CPM and plant cooling	Poly	1.80	11.34
Zbigniew Zapałowicz *et al.,* 2021	Calculate	Water cooling (from engine room cooling system)	Mono	38.80	2.14

power efficiency and reduce temperatures in PV modules.

According to Table 1, the results of the reviews of journals can be concluded that the research that has been done (Lu *et al.*, 2017) showed the highest efficiency level at 13.3% with the experimental method. Still, other literature argues that if there is a significant decrease in PCM material prices, then PCM-based passive cooling techniques can be an option in the future for PV modules. Furthermore, passive cooling techniques focus on developing hybrid cooling (Nizetic *et al.*, 2017). Further review of the studies that have been carried out related to temperature reduction and increased efficiency of PV modules with various cooling methods can be explained as follows. The highest increase in efficiency is 48.23% with a decrease in temperature of up to 25°C with a polycrystalline cell type and a maximum capacity of 10 W (Abdollahi & Rahimi, 2020). This research is quite interesting to develop considering the high level of efficiency and temperature reduction, it just needs to be proven by conducting further research with the concept of a cooling system that is the same, but the types of cells and the capacity of the PV modules are different, such as the concept of Passive Cooling (Natural Cooling Water Circulation and Nano-Enhanced PCM) only using a monocrystalline PV module with a maximum capacity of 400 W. Several important parameters to reduce the temperature of the PV module and increase the efficiency of the output power are the specification of the solar PV module, this can show an increase in the efficiency of the power output and a decrease in the temperature of the PV module in a larger capacity.

Research that has been carried out related to PV module specifications includes two type of cells, namely Monocrystalline (GE-m-40) and Polycrystalline (ASL 40-12) with a maximum capacity of 40 W (Bashir *et al.*, 2018), a Polycrystalline cell type with a maximum capacity of 50 W (Salem *et al.*, 2019; B *et al.*, 2021), a Polycrystalline cell type with a maximum capacity of 20 W (Sarikarin *et al.*, 2019; Wongwuttanasatiana & T. Sarikarinb, 2020), CIS cell type (SF170-S) with the highest capacity of 170 W (Karthick *et al.*, 2020), a Polycrystalline cell type with the second highest capacity, which is a maximum of 75 W (Bayrak *et al.*, 2020), a Polycrystalline cell type (ZT10-18-P) with the lowest capacity, which is a maximum of 10 W (Abdollahi & Rahimi, 2020), the last is the research that has been done by using a different cell type, namely Thin-Film (RT30M) with a maximum capacity of 30 W (Khorrami *et al.*, 2021). The review results related to the Specification of the solar PV module are shown in Table 3.

Table 3 shows many studies of polycrystalline cell types when viewed in terms of cell types while seen from the maximum power the average capacity below 100 W. So, it is necessary to do experimental evidence using types that have not been carried out in this journal review, namely research using this type. Monocrystalline cells with a capacity of more than 170 W. Thus, a study related to the effect of temperature on the efficiency of PV modules can be planned using a monocrystalline cell type with a capacity of 400 W.

Besides the specification of the solar PV module, some components can determine the results of an experimental study, namely measuring instruments. This device can assist in retrieving real data in the field as a basis for data processing and analysis. Because if the measurement instrument does not have a specified standard parameter, then the data obtained still has an inadequate level of accuracy. Based on the results of reviews from several journals related to this instrument, it can be shown in Table 4.

The results of the reviews of the three journals according to Table 4, it can be seen that the research conducted three measuring instruments and only displayed their level of accuracy (Čoko *et al.*, 2019), while the research conducted quite a lot in the use of measuring instruments up to six types of measuring instruments, it just does not provide the level of accuracy of the tools or other specifications even though it is a reference for a measurement (Khorrami *et al.*, 2021). It differs from the research that provides fairly accurate information regarding the sensitivity of the measuring instrument. However, more authentic evidence is needed for standard

Table 3: Specification of the solar PV module

Author	Cell Type	Maximum Power (W)	Voltage at Maximum Power (Vmp)	Current at Maximum Power (Imp)	Dimension
Muhammad A. Bashir *et al.,* 2018	Mono (GE-m-40)	40 W	15.5 V	2.57 A	690 mm * 495 mm
	Poly (ASL 40-12)	40 W	18.5 V	2.16 A	690 mm * 455 mm
M.R. Salem *et al.,* 2019	Poly	50 W	18 V	2.78 A	670 mm * 550 mm
T. Wongwuttanasatian *et al.,* 2019	Poly	20 W	21.4 V	1.57 A	485 mm * 350 mm
Tachakun Sarikarin *et al.,* 2019	Poly	20 W	21.4 V	1.57 A	485 mm * 350 mm
Alagar Karthick *et al.,* 2020	CIS (SF170-S)	170 W	87.5 V	1.95 A	-
Fatih Bayrak *et al.,* 2020	Poly	75 W	18.36 V	4.11 A	-
Nasrin Abdollahi *et al.,* 2020	Poly (ZT10-18-P)	10 W	-	-	320 mm * 215 mm
Navid Khorrami *et al.,* 2021	Thin-film (RT30M)	30 W	19.8 V	2.06 A	680 mm * 350 mm
Ramkiran B *et al.,* 2021	Poly	50 W	17.8 V	2.81 A	640 mm * 600 mm

Table 4: Sensitivity of the instrument

Author	Filip Grubišić-Čabo *et al.,* 2019	Navid Khorrami *et al.,* 2021	Ramkiran B *et al.,* 2021
Instrument	Pyrometer, wattmeter and thermocouple	Ammeter, voltmeter rheostat, hot-wire solameter and IR camera	Multimeter and infra-red thermometer
Parameter	-	-	Current, voltage and temperature
Accuracy	<1.0 ±1.5 ±0.2	-	DC current = 1.8% DC voltage = ± 0.5% Temperature = ± 0.2°C
Resolution	-	-	Current = 10 mA Voltage = 10 mV Temperature = 0.1°C
Range	-	-	Current = 0-10 A Voltage = 0-200 V Temperature = -30°C - 500°C

measuring instruments suitable for a study such as a document calibration results of measuring instruments. In addition, the variable measuring instruments are limited to multi-meters and infrared temperature, while photovoltaic analysis still requires several other measuring instruments so that the resulting data provides a more accountable level of accuracy (B *et al.*, 2021). Thus, the results of the research are certainly more comprehensive.

Conclusion

If there is a significant decrease in the price of PCM materials, then PCM-based passive cooling techniques can be a future choice for PV modules. Furthermore, the development of passive cooling techniques focused on developing hybrid cooling. The highest increase in efficiency is the research conducted which is 48.23% with a decrease in temperature of up to 25°C with a polycrystalline cell type and a maximum capacity of 10 W. Further research is needed with the concept of Passive Cooling (Natural Cooling Water Circulation and Nano-Enhanced PCM) only using a monocrystalline PV module with a maximum capacity 400 W. In terms of cell types, all studies tend to polycrystalline PV module types, CIS (SF170-S) type photovoltaic and Thin-Film photovoltaic (RT30M) so it can be concluded that monocrystalline cell types still need further development of evidence related to cooling techniques to increase efficiency and reduce PV module temperatures.

Meanwhile, when viewed from the side of Maximum Power (W), the research that has been carried out by Karthick *et al.* (2020) has the largest capacity, which is a maximum of 170 W. No one has conducted experimental research with capacities between 170 W to 400 W. It is necessary to prove the degree of temperature reduction and efficiency by experimental research with and without of cooling system. The measurement instrument variables impact the scope of the analysis carried out. The accuracy of the measurement instrument can also support the retrieval of valid and accountable data by measuring standards in supporting data processing and analysis to obtain a comprehensive conclusion. So, additional measuring instrument variables by describing the standardized level of accuracy are needed.

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