South Libya High Temperature Impact on the Performance of PV Solar System Plant

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Abstract:

Solar photovoltaic (PV) power represents one of the most promising future sources of energy in the world. Notably, mega projects are being considered for installation in the Middle East and North Africa (MENA) region**.** In this review paper the effect of hot wheaters on the PV solar systems was investigated by many authors, important of solar energy, impact of the ambient temperature as well as mitigation of temperature effect processes and technique was studded in details. The quantity of electricity and power generated by a PV cell is contingent upon a number of parameters that can be intrinsic to the PV system itself, external or environmental. Thus, to improve the PV panel performance and lifetime, it is crucial to recognize the main parameters that directly influence the module during its operational lifetime. Among these parameters the temperature of the solar panel, installed in Sabha South of Libya, and its influence on the produced energy was reviewed. It was shown that the efficiency and the total output produced electricity of the systems hardly influenced by the ambient temperature of the area which exceeds the SCT (25 C^o) and reach up to 45C^o. To increase the system performance and panels lifetime. In this article Sabha city wheater, PV solar cell background, temperature impact on the PV solar cells, and system performance, mitigation of temperature effect processes and technique were reviewed.

Keywords: South Libya climate, PV system; PV performance; PV temperature effect; PV cooling

الملخص

تمثل الطاقة الشمسية الكهروضوئية واحدة من اهم مصادر الطاقة في المستقبل في دول العالم. وقد لوحظ مؤخرا العمل علي انشاء مشاريع ضخمة في مناطق الشرق الأوسط و شمال أفريقيا. في هذه الورقة المرجعية تمت استعراض عدد من دراسات

تأثير المناخ الساخن على الأنظمة الكهروضوئية بواسطة عدد من البحاث، كما تمت دراسة أهمية الطاقة الشمسية وتأثير حرارة الجو المحيط وكذلك الوسائل والطرق التي يمكن اتخاذها لتقليل او التحكم في تأثير درجات الحرارة بدراسات مفصلة.

كمية الطاقة الكهربية المنتجة من الأنظمة الكهروضوئية تعتمد اعتمادا جوهريا على عدد من المتغيرات الخارجية أو البيئية، لذلك ومن أجل تحسين أداء وزيادة عمر الألواح الكهروضوئية من المهم أن ندرك أهمية العوامل الأساسية تأتي تأثر مباشرة على الوحدة خلال عمرها التشغيلي. من بين تلك العوامل، التأثير المباشر لدرجات حرارة الألواح الشمسية المثبتة في منطقة سبها جنوب ليبيا وتأثيرها على الطاقة المنتجة تمت مراجعته بالتفصيل. وجد أن كفاءة الأنظمة الكهروضوئية ومعدلات الطاقة المنتجة تتأثر تأثرا بالغا بدرجة حرارة المنطقة التي تزيد عن درجة الحرارة المثالية (25م0) والتي تصل الى 45م0.

لتحسين معدل أداء المنظومة الشمسية وزيادة عمرها التشغيلي تم في هذه الورقة مراجعة طبيعة او خلفية الخلية الكهروضوئية وتأثير دراجات الحرارة على عملها وبالإضافة الى أداء الأنظمة الكهروضوئية وسبل وتقنيات تخفيف تأثير درجات الحرارة على أداءها .

الكلمات المفتاحية: مناخ جنوب ليبيا، نظام الطاقة الكهروضوئية، أداء الطاقة الكهروضوئية، تأثير درجة حرارة، تبريد الأنظمة الكهروضوئية

1. Introduction

Due to the increased desire for more renewable sources of energy in recent years, solar power has seen increasing popularity. In 2022, the total global energy usage was approximately 595 EJ (exajoules, $x10^{18}$). Meanwhile, the harvestable annual solar energy that falls upon the Earth's landmasses is estimated to be 50,000 EJ. (Ossila, 2019). Libya being a North African Country. The climate is dominated by the hot Saharian weather. The warmest months are July and August, at Sebha (south of Libya), the summers are long, sweltering, arid, and clear and the winters are short, cool, dry, and mostly clear. Over the course of the year, the temperature typically varies from 5°*C* to 39°*C*. South Libya is accounted with large amount of solar resources makes it distinctively perfect for the installation of utility-scale of solar PV systems. However, energy consumption has demonstrated an upsurge with a rapid increase in population and growing demand of modern civilization (Peters et al., 2019). Designing of smart grids which incorporates response from utilization, distribution, generation and demand of resources would pave ways for sustainable utilization of energy. Performance of the PV cell is mostly affected through the solar irradiance and ambient temperature (Njok et al., 2018:2). The electrical power can be extracted from solar energy directly with PV cells; however, the climatic conditions can severely disturb the photovoltaic solar system performance, thus the location has severed influence on the system efficiency and, declining the economic viability of such systems. That's mean continuous and more intense exposure to such temperatures leads to thermal imbalanced and disturb the efficiency and thus energy produced by the PV cells (Pillot et al., 2017). The power parameters of the photovoltaic solar system are highly varying with the temperature, especially the open-circuit voltage (V_{OC}) decreases by 2 mV $°C^{-1}$, short-circuit current (I_{SC}) increases by 0.06% $°C^{-1}$ and the fill factor (FF) by 2.2% $°C^{-1+}$ (Siamak et al., 2017:41-45. Dhassa et al., 2014: 1713-1722).

1.1. Background of PV Solar System plants

Since the mid-1970s, photovoltaics has been used as energy generators. Initially, the PV modules are used only for powering the electrical devices and equipment in order to save energy at the customer's house (Zaghba et al., 2024). The PV power plants convert solar energy into electricity by creating a flow of electrons, which is converted into a direct current due to the absorption of sunlight electromagnetic waves. The continuous growth of energy demand, a depletion of natural resources, and significant changes in climate, lead to the development and implementation of a strategy aimed at the diversification of energy sources in the production of electricity (Villegas-Mier et al.,2021). The background of solar system plants, explains the operating principle and Challenges of the solar PV plant, and provides an overview of the power profile. Projects in the field of communication was started 1980 where a PV system was used to supply energy to a microwave repeater station near Zella. The use of domestic solar heater started in 1980 by installing a pilot project of 35 systems, follows by some other projects. There are all together about 6000 solar heaters in Libya. The use of evacuated tubes for solar haters has been started for some hotels and homes and expected to grow up soon. (Hewedy 2022). During a webinar organized by the Department for International Trade (DIT) held in *London, 28 July 2021,* for British businesses, (Zaptia 2021) Mr. Hamid Sherwali, head of the Renewable Energy Authority of Libya (REAoL) said that, there is no renewable energy production currently inputting into the national electricity grid. There are, however, 350 off-grid small generating units in some rural areas, He said Libya's 2018-2030 Renewable Energy Strategic Plan is ready for implementation and studies were completed and tenders have been put out.

1.2. Importance of studying the temperature impact on the performance PV solar cells

The photovoltaic effect is a process that occurs in some semiconducting materials, such as silicon. At the most basic level, the semiconductor absorbs a photon, exciting an electron which can then be extracted into an electrical circuit by built-in and applied electric fields. Semiconductors can carry out this conversion due to the structure of their electron energy levels. Like all other semiconductor devices, solar cells are sensitive to temperature. It was found that the increases in temperature reduce the bandgap of a semiconductor (Siamak et al., 2017:41-45) thereby affecting most of the semiconductor material parameters. The impact of increasing temperature is shown in Fig. (1) Below.

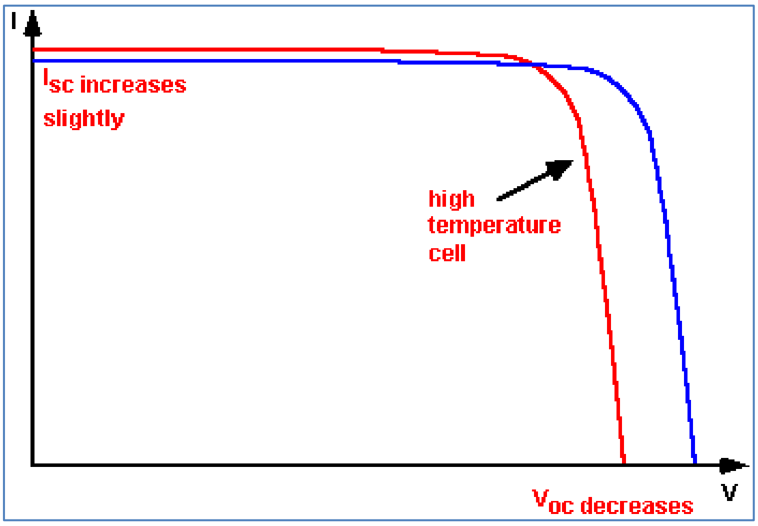


Fig (1) The effect of temperature on the IV characteristics of a solar cell. (Honsberg C. et al., 2024)

The short-circuit current, Isc, increases slightly with temperature since the bandgap energy decreases and more photons have enough energy to create e-h pairs. The change of I_{SC} with temperature is more dependent upon the design of the cell than the semiconductor material properties. A lower performance cell with little light trapping and a poor performance in long wavelengths near the band edge will have very little change in I_{SC} with temperature. Conversely, a cell with a high response near the band edge will see a much larger change in I_{SC} with temperature. In either case, the change of I_{SC} with temperature is smaller than the change of V_{OC}.

The performance curves can be used to verify the state of the PV systems by comparing the Power versus (V-Voc) among a few dates whenever the other conditions such as irradiation spectrum and the angle of incidence are alike. The IV curve of a PV module Fig. (2a & b) (Meng-Hui W.

et al., 201) is a graphical representation of the relationship between its current and voltage output under given sunlight (irradiance) and temperature conditions

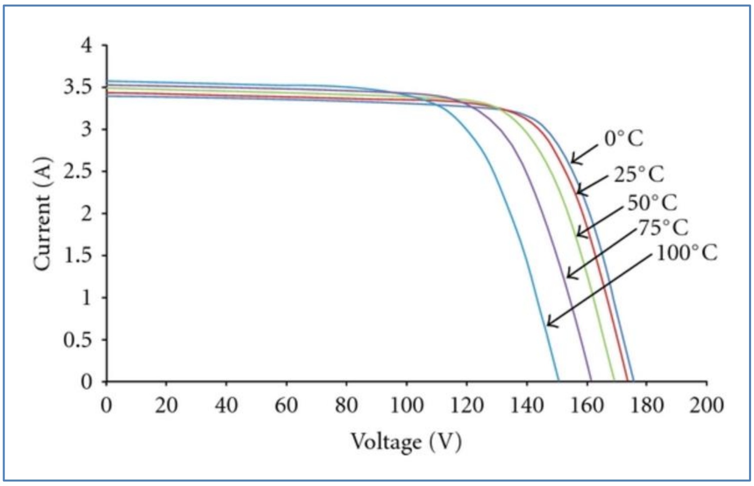


Fig. (2a) The I-V characteristic curve of solar cells under different temperature. (Meng-Hui W. et al., 2012)

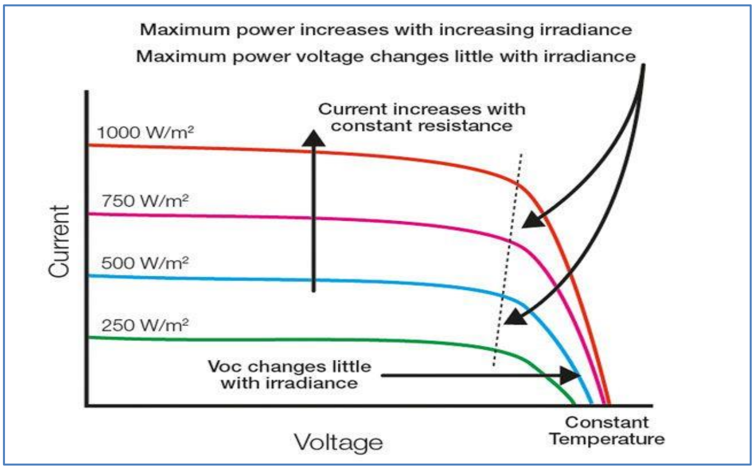


Fig (2b) Factors That Affect Photovoltaic Performance (Akshay., Jan, 2022)

However, the determination of the mismatch losses is more accurately when it is used to compare the PV module performance at an alike operating condition or best with an alike module temperature. The module temperature has also a non-linear impact on the string performance due to the diode effect and since a slight temperature decrease can lead to an increase of the current that leads a large impact on the electrical system power delivered. Therefore, the operating temperature and the total operating resistance within the URI (ultra-reliable inverters) are the similar parameters which are used to calculate the working state of PV inverters and PV systems. The photovoltaic solar (PV) system generation depends on the sunlight falling on the solar panels at the solar radiation falling on the panels which produce directly from the light and which can be calculated using the sunshine hour and extraterrestrial solar irradiance (Zaghba et al., 2024). Since the solar module gets heated up due to its exposure to sunshine, the increase in the module temperature affects the efficiency of the solar cells (Villegas-Mier et al.,2021). The reduced efficiency of the module at high temperature is also a large concern to the manufacturers and the designer of the PV systems. It is also an important to study and develop a scientific research work to foresee the performance of the PV systems based on the ambient temperature (Peters et al., 2019).

2. Weather of Sabha city the capital of west south of Libya

The weather parameter under this study which has significant effect on the performance of PV solar cell efficiency is the increase in ambient temperature above the standard condition. The study of temperature variation in the south of Libya is significant, as it will help to understand and assess the real climate of the area and its potential for successful adaptation policies. As shown from the weather investigation in the area in summer months the temperature is allows above 25C^{o} which means that will have negative effect on the power produced by PV system. Sabha is becoming the largest settlement in the Libyan Sahara, The city is an oasis city in south western Libya, It was historically the capital of the Fezzan region with a hot desert climate (Temehu, 2024, Köppen 2024). Summers are very hot, with temperatures reaching 40 -47°C regularly (July & August); Winters are mild with a high diurnal temperature variation. There is hardly any precipitation in the year with low (32%) humidity, and sunshine is abundant throughout the year. Average monthly temperatures recorded during a year is shown in Fig (3).

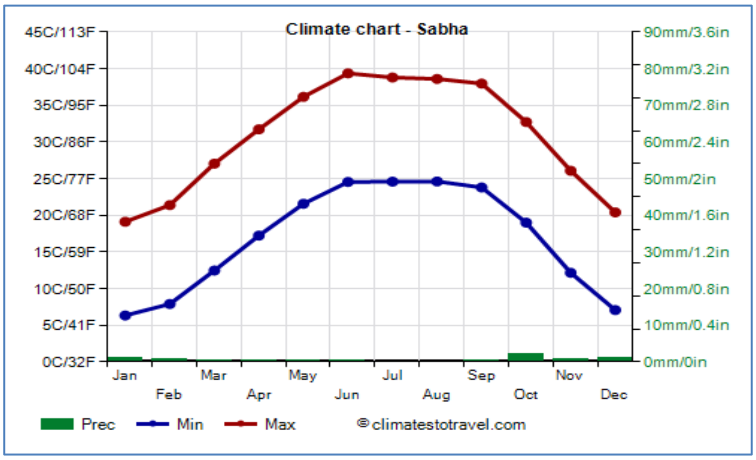


Fig (3) Temperature variation during the year in Sabha city (Climates 2024)

The average temperatures which were recorded during 23 years summarized in table (1) indicated that Sabha area is a hot climate during have of the year (summer months), at the same time the observation shows a relatively high average sunshine hours per year table (2). The 9 hours sunshine is relatively high and good for solar radiation captures (Climates 2024). For the PV solar energy investigation, the day temperature and the sunshine hours are a valuable data, even-though the recorded summer day temperatures in Sabha are relatively high and has pad influence on the performance of the PV systems, the long sunshine hours can compensate for the losses resulting from the high temperatures.

Table (1) Sabha - Average temperatures (1991-2014) (Climates 2024)

Mean (°C)	lax (°C)	Min (°C)
12.7	19.1	6.3
14.6	21.4	7.9
19.8	27	12.5
24.5	31.7	17.2
28.9	36.2	21.6
31.9	39.4	24.5
31.7	38.8	24.6
31.6	38.6	24.6
30.9	38	23.8
25.8	32.7	19
19.1	26.1	12.2
13.7	20.4	7.1
23.75	30.8	16.8

Table (2) average hours of sunshine per day in Sabha city. (Climates 2024)

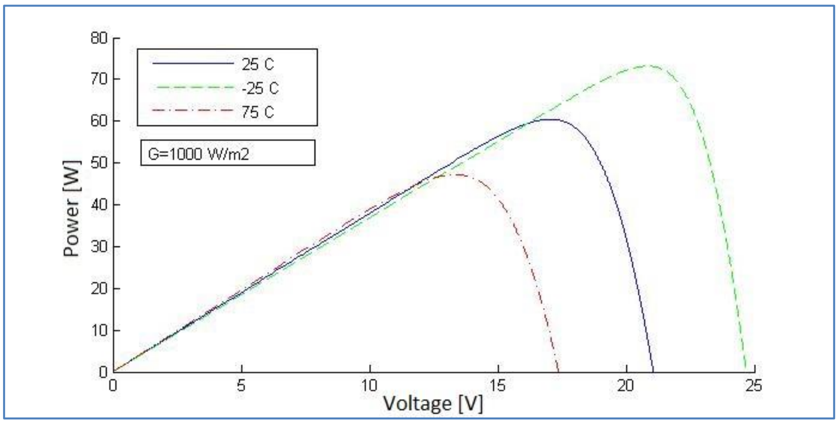
Month	Total	rage per day
January	260	8.5
February	250	9
March	270	8.5
April	275	9
May	305	10
June	340	11.5
July	375	12
August	360	11.5
September	295	10
October	285	9
November	260	8.5
December	250	8
Year	3525	9.7

3. Performance of The PV solar Systems

Photovoltaic system performance is a function of the climatic conditions, the equipment used and the system configuration. PV performance can be measured as the ratio of actual solar PV system output vs expected values, the measurement being essential for proper solar PV facility's operation and maintenance. Only 10–22% of the sun radiation received by PV can be transformed into electricity, a part of it is reflected and the main share is absorbed as heat by the module (Wang F. et al. 2023:423). As the temperature of a PV panel increases above 25°C (77°F), its performance (efficiency) tends to decrease due to the temperature coefficient. The coefficient measures how much the output power decreases for every degree Celsius above a reference temperature (usually 25°C) (Dubey S. et al. 2013:311-321).

3.1 Temperature Effects on PV Solar System Performance

Understanding how temperature affects photovoltaic systems is crucial not only in efficient energy production but also in the financial modeling of the systems. The performance of photovoltaic systems is influenced by the instantaneous power-voltage and current-voltage characteristics of the solar cell, the relationship between the PV module voltage and power at different solar irradiance levels is shown in Fig. (4). We can see that the power decreases as temperature increases, as illustrated by lower power peaks on the curves.



Fig(4): The effect of Temperature on I-V curve (Mohamed A. 2023)

Effects of temperature on the output characteristics of the solar cells have been studied by many researchers (21-25 Wysocki, J.J. et al. 1960:571-588, Luft, W., 1965:21-40, Bhaumik B. et al.1976:257-268, Burgess, E.L.et al.1977:433-438, Agarwal S.K. et al. 1980:1021-1028). However, the results of these early investigations and those of the later authors (26-35 Agarwal S.K. et al. 1980:1021, Karazhanov, S.Z., 2000:149, Green, M.A.,2003:333, Radziemska, E., 2003:127, Radziemska, E., 2003:1-12, Sabry, M. et al. 2007:331, Singh, P., et al. 2008:1611, Singh, P., et al.2010:36, Dubey, S. et al. 2013:311, Chander, S. et al. 2015:104, Karki, I.B. 2015:35) have not always been consistent with each other. For example, temperature dependency of full-spectrum photovoltaic parameters for polycrystalline PV module was studied experimentally by Karki (Karki, I.B. 2015:35). In this study, the measurements were performed under outdoor environment conditions. This study shows that unlike the situation for conventional PV devices, these cells actually exhibit decrease in efficiency with increasing temperature (reaching a value of 0.05 % at 60°C). Whereas Siamak Azimi et al. (Azimi S. et al.2017:41) shows different variations in the open circuit voltage with temperature change as represented in Fig. (5). These variations are found to be linear with temperature: in this case, about 3 mV/˚C reduction in the open circuit voltage can be observed with the temperature rise. An increase of about 0.6 mA in the short circuit current density for 27 to 80˚C temperature increase can be observed in Fig. (6). These changes in the Isc are found to be linear with temperature. (Azimi S. et al.2017:41).

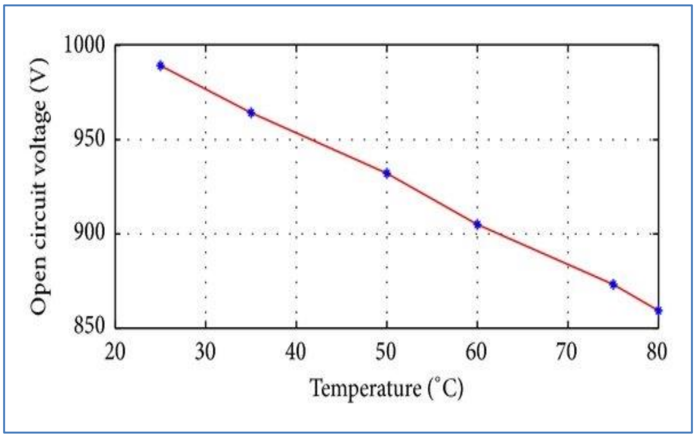


Fig. (5) Variations of the open circuit voltage at different temperatures [Karki, I.B. 2015:35]

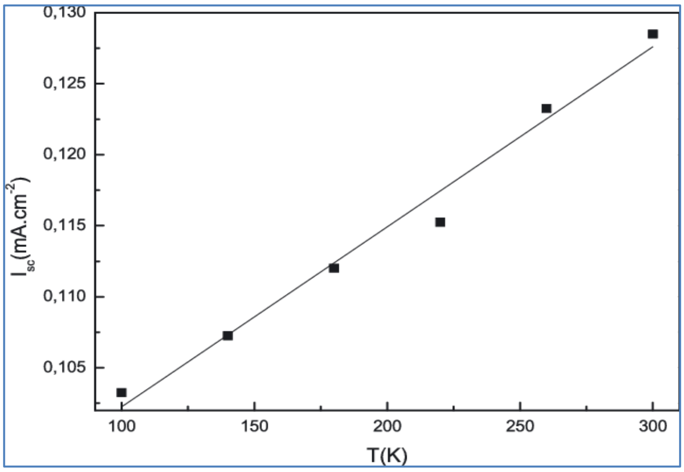


Fig. (6) The short circuit current density variations at different temperatures [Karki, I.B. 2015:35]

The temperature performance of crystalline silicon solar cells was studied because c-Si solar cells most promising substance in the field of photovoltaic application, specially used for the solar cell among low cost and a large area (Carlson D. E.2003:627, Fthenakis V. 2012:202). In photovoltaic industry different materials are used in which silicon most popular candidate due to its easily availability. All the reviewed articles shows that the most important parameter of silicon solar cell efficiency is the open circuit voltage (Voc). For Temperature range 20 to 80 thickness =100µm, the Voc decreases as temperature increased as shown in table (3) (Javed A.2018).

Table (3) Open circuit voltage verse Temperature (Javed A.2018)

T(°C)	Vsc(mv)
20	663.9
25	654.9
30	645.4
35	635.7
40	625.9
45	615.9
50	606.0
55	595.9
60	585.8
65	575.7
70	565.6
75	555.4
80	545.2

As well as the performance of a solar cell can be represented using non-dimensional electrical parameters such as the fill factor (FF), the rated power, the short-circuit current at standard test conditions (Honsberg C. et al.2024). The fill factor decreases with the increase of temperature; this means that the performance of a solar cell decreases as temperature increases. Essentially, the performance of a PV device can be expressed as the product of two variables: the maximum power point (with its corresponding voltage and current) and the fill factor. Therefore, deteriorations of one of these variables may affect the performance of the whole system.

3.2. Temperature-related degradation of PV solar panels

Understanding the modes and methodologies of degradation is critical to certifying PV module lifetimes of 25 years. Both technological and environmental conditions affect the PV module degradation rate. As shown by the study done by Doaa M. Atia, et al. (Atia D. M. et al. 2023:13066), the results demonstrate that the modules' maximum power (Pmax) has decreased in an average manner by 23.3% over time. The degradation rates of short-circuit current (Isc) and maximum current (Im) are 12.16% and 7.2%, respectively. The open-circuit voltage (Voc), maximum voltage (Vm), and fill factor (FF) degradation rates are 28%, 12.16%, and 15.3%, respectively. The overall performance ratio obtained for the PV system is 85.9%. High temperature is a major cause of PV degradation. When a solar panel is exposed to high temperatures, it can cause several forms of damage that reduce the panel's efficiency and overall performance (Kyranaki N. et al.2022:1061).

4. Mitigation Strategies for Temperature Effects

To mitigate the impact of temperature on PV cell efficiency, various cooling techniques can be employed, such as active cooling systems, passive heat sinks. Proper system design and installation considerations are crucial to ensure that PV cells operate within their optimal temperature range as much as possible. Implementing effective cooling techniques is crucial for mitigating temperature effects and enhancing the efficiency of photovoltaic (PV) systems. The mitigation strategies for temperature effects on PV solar systems have been searched theoretically, analytically, and experimentally over the previous years. These strategies can be strongly categorized into active and passive cooling techniques (Santamouris M.et al. 2017:14, Díaz-Lopez et al. 2022:221).

The well-known chart of best research-cell efficiencies regularly issued by the National Renewable Energy Laboratory illustrates decades of research and engineering for designing solar cells with ever growing performances (Martínez, J. F.et al.2022) In that chart, efficiencies are rated in the so-called Standard Test Conditions (STC), i.e. for the one Sun (AM1.5) illumination and a cell at a temperature of 25 °C. Unfortunately, STC are rarely met in the field and most solar photovoltaic installations are operating at temperatures greater than 25 °C. More importantly, the efficiency of the vast majority of photovoltaic converters drops when temperature increases, with a rate commonly comprised between −0.1 and −0.5% K^{-1}(Dupré, O. et al. 2017:84). Because of the substantial effect of these thermal losses on the energy yield (Hegedus S.2013:218). and production potential in the world (Kawajiri K. et al. 2011:9030), there is an imperative need for mitigating them. Three strategies are available (Olivier D. et al. 2018:2). (Fig. 7). The first option (S1) is to maximize cooling, by conduction/convection with a colder medium, and by radiation towards the surroundings and the cold outer space under clear sky conditions. The second option (S2) is to minimize the thermal load (internal heat source, Q) in the panel. The aim of these first two strategies is to prevent the panel temperature (T) from rising too far above the outdoor temperature (T∞). The last option (S3) is to minimize the thermal sensitivity (temperature coefficient βP) of the electrical power output (P). Efficiency of these three strategies depends primarily on environmental conditions (Figs 7 and 8) and design. (Olivier D. et al. 2018:2)

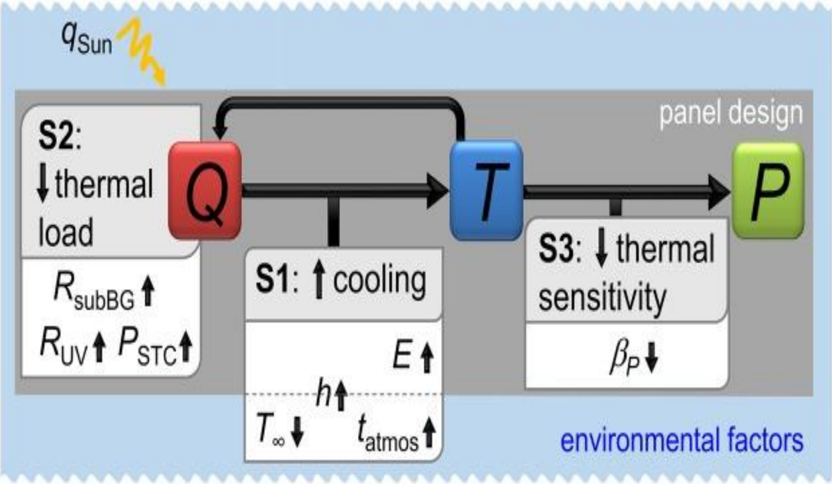


Fig.(7) The three strategies for mitigating the thermal losses: (S1) maximizing cooling, (S2) minimizing thermal load, (S3) minimizing thermal sensitivity.(Dupré, O. et al. 2017 Olivier D. et al. 2018:2).

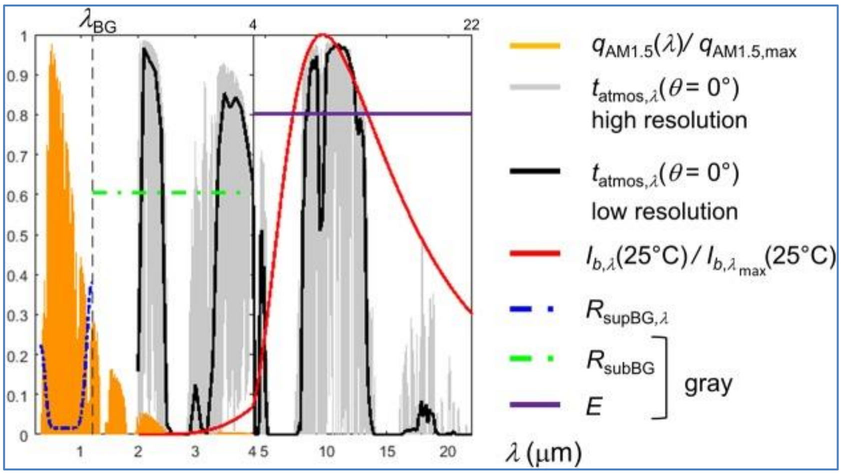


Fig.(8) Normalized AM1.5 solar spectrum, high and low resolution clear sky normal (θ = 0) atmospheric transmissivity, normalized blackbody intensity at 25 °C, solar panel sup-bandgap reflectance (RsupBG, λ ≤ λBG), model gray sub-bandgap reflectance (RsubBG, λBG < λ ≤ 4µm) and emittance (E, 4 µm < λ ≤ 22 µm).(Olivier D. et al. 2018:2)

Environmental conditions are solar irradiation flux (q_{Sun}), outdoor temperature, wind velocity, and clear sky atmospheric transmissivity (t_{atmos}), which depend on where the solar photovoltaic panels are installed. Unfortunately, these conditions can rarely be manipulated to improve the efficiency of the solar PV systems. However, in terms of design, several opportunities for mitigating the thermal losses exist. The use of passive cooling system based on heat sinks with fins could provide a potential solution to increase performance and prevent overheating of photovoltaic (PV) panel systems. The decrease in temperature and the increase in efficiency were 10.2 °C and 2.74%, respectively (Zainal Arifin et al.2020)

4.1. Cooling techniques for PV modules

Cooling of PV panels is used to reduce the negative impact of the decrease in power output of PV panels as their operating temperature increases. Developing a suitable cooling system compensates for the decrease in power output and increases operational reliability. Different divisions of PV panel heat removal techniques can be found in the literature. Depending on the working medium, one can distinguish cooling through water, air or hybrid cooling consisting of, e.g. phase change material, heat pipes, microchannels, nanofluids or thermoelectric elements, which in various combinations yield higher efficiency (Grubišić-Čabo et al. 2017). In the literature, many cooling techniques are demonstrated with their different methods, the first technique is using passive and active cooling methods of water, the second cooling technique is the use of free and forced convection of air, the third cooling technique is the use of phase-change materials (PCM) to absorb the excess of heat produced by the PV panel (Tarek Ibrahim et al. 2024:713). Water is the most coolant used for PV panels excess heat removal. Regardless of the cooling system size or the water temperature, this method of cooling always improves the electrical efficiency of PV modules. The operating principle of this cooling type is based on water use, the water cooling includes free convection, water spray, heat pipes or immersion techniques. A schematic water-cooling system is shown in Figure 9. Collected heat from PV panels can be used in many ways.

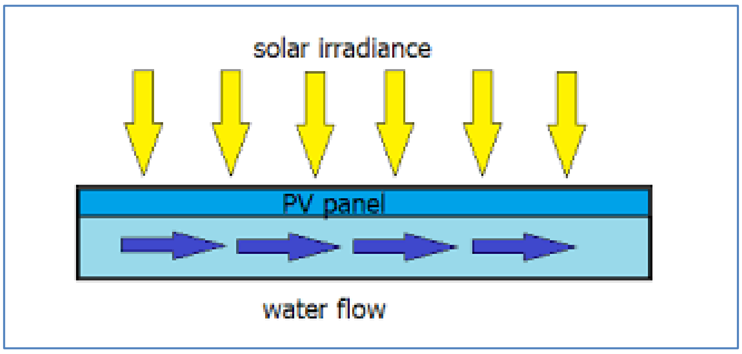


Fig. (9) schematic of water – flow cooling method. (Kozak-J. E. et al. 2023:52)

A proposed a solution where water is sprayed on the surface of the panels was discussed by Kozak et al. This system provides cooling by spraying water onto the PV panel's reverse and returning the water to the tank. The recycled water is collected in a U-shaped borehole heat exchanger (UBHE), installed in an existing well to enhance the cooling capacity. The water exchanges heat with shallow-geothermal energy. Finally, the panel is again sprayed with water to cool it. The water in this cooling system first cooled the PV panel, then the shallow geothermal energy through, the UBHE, was used to cool the cooling water and maintain the cooling system's cooling capacity. Experimental results showed that the proposed solution allows a 14.3% improvement in efficiency (Kozak-J. E. et al. 2023:52).

Irwan et al., carried an indoor experiment in order to investigate the effect of water flowing at the surface in cooling the PV panel. Results showed that a decrease in PV temperature by 5–23 ◦C increases the output power of the PV panel by 9–22%. (Irwan, Y. et al.2015:604). On the other hand, Moradgholi et al. experimentally investigated the effect of heat pipes in cooling PV panels, and the module used in his experimental study is represented in Figure 10. Results showed an increase of 5.67% in power when using methanol as a working fluid in spring and an increase of 7.7% in power when using acetone as a working fluid in summer (Moradgholi, M et al. 2014:82).

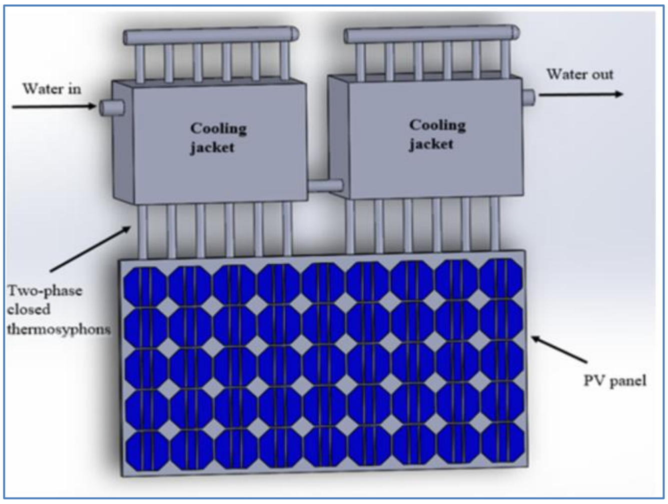


Fig.(10) Heat pipes module (Tarek Ibrahim et al. 2024:10)

Moreover, Sandeep Koundinya et al. investigated experimentally and by simulation the effect of a finned heat pipe with water as the working fluid in cooling photovoltaic panels. Results showed a total decrease of 13.8 K in PV panel temperature (Koundinya S. et al. 2017:2693) and good agreement was found between experimental and computational studies.

The air-cooling method for PV refers to the technique of dissipating heat from PV modules by circulating air around them. It can be implemented in free or forced convection, using heat sinks, fans, or blowers to increase airflow. As shown in Fig. (11), natural convection occurs by the means of circulation and heat exchange between hot and cold fluids, this circulation is caused by the buoyancy effect. When the PV panel becomes hot, it warms up the layer of air surrounding it, thus the temperature of air increases, and the density decreases accordingly. Consequently, hot air rises, causing a movement called a natural convection current. The most common design includes fins, thin aluminum sheets or similar at the bottom of the module, which is responsible for increasing the air ducts radiative and convective heat transfer surface, causing turbulence, and acting as a heat sink. Cuce et al. conducted a study on the effect of passive cooling on the performance of photovoltaic cells, where an aluminum heat sink was used to dissipate excess heat, the results have shown that the proposed cooling technique increases energy conversion efficiency, exergy and cell power at the level of 20% at irradiance equal to 800 W/m^2
(Cuce, E. et al. 2011;299)

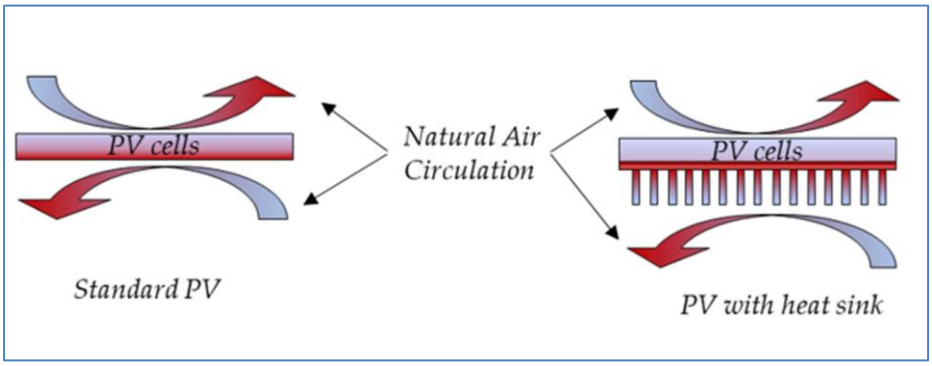


Fig. (11) PV panel under free convection with or without a heat sink. (Tarek Ibrahim et al. 2024:7)

Phase-change materials (PCMs) are substances used in cooling systems for photovoltaic modules to absorb and store heat from the panels during peak sunlight hours. PCMs have a high latent heat of fusion, which means they can absorb large amounts of heat without a significant increase in temperature. Phase change materials (PCMs) are chemical compounds with a high latent heat value, ranging from 100 - 280 kJ/kg, depending on the nature of the material (Musiał, M. et al. 2017:15). PCMs are characterized by their ability to retain thermal energy and allow for temperature stabilization. These substances are readily used to remove excess heat from PV installations due to their ability to absorb and store large amounts of energy. PCMs can be integrated into PV panels, or used in a separate thermal management system to enhance the overall efficiency and lifetime of the PV system Fig. (12).

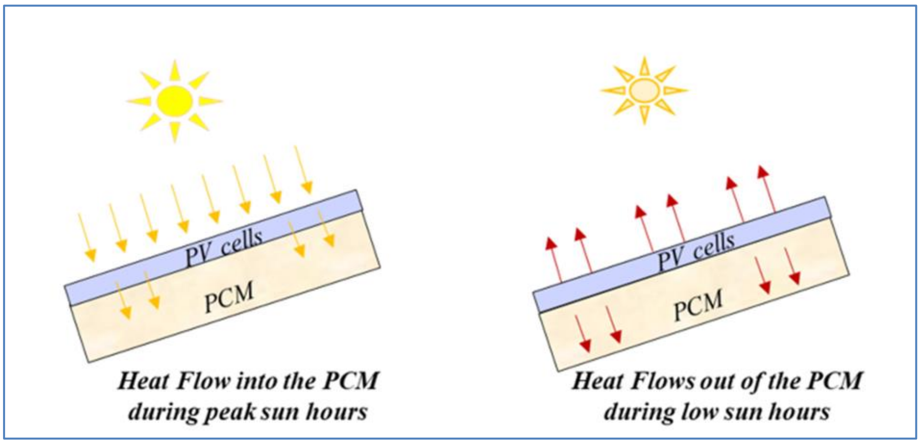


Fig. (12) typical PV–PCM system (Tarek Ibrahim et al. 2024:13)

The use of phase change materials placed in the back of PV panels is described, among others, in the paper Hamdan et al. A PCM with a melting point close to the panels standard test condition (STC) temperature was chosen as the cooling material. A PV system consisting of two identical PV panels was studied. The PCM was integrated on the back side of one panel, while the other was kept as standard for comparison purposes. Tests carried out for 28 days showed an increase in power yield of 2.6% compared to non-cooled panels (Hamdan, M. et al. 2018:167). As well as the use of PCM was studded by many auteurs, The literature review has shown that both active and passive cooling methods contribute to reducing the rate of panel temperature rise over time and maintaining panel temperatures within the nominal operating range specified by the manufacturer (Arici, M. et al. 2018:738). In order to achieve the best energy output ratio, during the high-temperatures of the year in South Libya, a detailed investigation of a PV solar system design and parameters is essential (Almaktar M. et al. 2021:279).

5. Impact of temperature on system economics

The efficiency of a PV cell, which is the ratio of electrical energy output to the energy input from sunlight, depends on various factors, including the semiconductor material, cell design, and operating conditions such as temperature. Consequently, the overall efficiency of the PV cell decreases as the temperature rises. This temperature-induced efficiency loss is a fundamental characteristic of PV cells and is a crucial consideration in the design and operation of photovoltaic systems. For every degree Celsius above the optimal temperature, the efficiency of a typical crystalline silicon PV cell can decrease by approximately 0.4% to 0.5% (Radziemska, E., 2003:127). This means that at 25°C above the ideal operating temperature, the cell's efficiency could drop by 10-12.5%. It's important to note that the specific temperature coefficients and efficiency losses can vary depending on the type of PV cell technology and the materials used. From an environmental perspective, reduced efficiency means that more PV panels are required to generate the same amount of electricity, leading to increased resource consumption, energy use, and greenhouse gas emissions during the manufacturing and installation processes. Additionally, inefficient PV systems may have a longer energy payback time, which is the time it takes for the system to generate the same amount of energy that was used in its production and installation. This can negate some of the environmental benefits of solar energy.

Economically, efficiency losses due to temperature translate into lower energy yields and reduced financial returns for PV system owners and operators. This can impact the cost-effectiveness and profitability of solar energy projects, particularly in regions with high ambient temperatures or inadequate cooling systems. Furthermore, the need for active cooling or temperature management strategies to maintain optimal efficiency can increase the operational costs of PV systems (Sharaf M. et al. 2022:26131). These additional costs must be weighed against the potential energy yield gains to ensure the overall economic viability of the project.

To address these environmental and economic concerns, ongoing research and development efforts are focused on improving the temperature tolerance of PV cells and modules, as well as developing more efficient and cost-effective cooling technologies. Additionally, careful site selection and system design considerations, taking into account local temperature conditions, can help mitigate the impact of temperature-related efficiency losses. Understanding the economics of PV systems is one of the most significant considerations when deciding on solar energy. The term that is commonly used when discussing renewable energy sources is called "grid parity". Grid parity is achieved when the cost of energy generated per kWh (kilowatt-hour) is less or equal to grid tariff (Temitope M. et al. 2023:9) Levelized cost of energy (LCOE) is a metric used to evaluate and compare the cost-effectiveness of various sources of energy (CFI team 2024) LCOE can be determined by dividing the lifetime generation cost with lifetime energy generation. The lifetime generation cost is calculated, taking into account the project's capital cost and its annual operation and maintenance cost. The project's capital cost comprises the module cost, inverter cost, and balance of the system, such as cables, meters, etc.

6. Conclusion

It was shown that as the ambient temperature increases, characteristic changes occur, resulting in a reduction of the current/voltage output and performance of the photovoltaic system. On the contrary, next to the negative effects of temperature, they can also have a positive impact on the performance of the photovoltaic systems due to high temperature coefficients of the photovoltaic cells or the semiconductor material used.

With the growing number of installed photovoltaic systems, the research in this field is continually being expanded to ensure best performance and to compensate for existing deficiencies. Most breakthroughs in this field are focused on the design and implementation of new photovoltaic materials with optimal absorption coefficients, in collecting electrical charges, in configuring modules or determining energy performance, and in extending potential applications.

From a system aspect, higher temperatures not only reduce power efficiency but also decrease the lifetime of the system, which needs special concern. An in-depth study of temperature effects on photovoltaic/thermal systems is thus needed in order to achieve better energy efficiency. The investigation of temperature effects on performance efficiency of photovoltaic systems must continue in order to significantly decrease the negative effects of the increased temperature on the performances of the photovoltaic systems. it can be said that photovoltaic cell temperature does greatly affect the performance of photovoltaic systems. Since integrated cooling and photovoltaics are still in their infancy, a lot of further work needs to be done in order to minimize the effect of temperature. Furthermore, further investigation on the effect of other parameters like wind speed, relative humidity, solar radiation, and dust on the PV solar systems should be studied in depth.

Since the southern regions of Libya are characterized by temperatures higher than STC of the PV cells, the establishment of photovoltaic stations requires the use of temperature reduction techniques to maintain the highest production rates. Noting the availability of groundwater, cooling using water may be an effective means of cooling and removing dust accumulation, as well as with the selection of panels suitable for the weather in the region, we can increase the efficiency and maintain the highest production rates and extend the life time of the systems by minimize degradation of the panels. Even-though the recorded summer day temperatures in Sabha are relatively high and has pad influence on the performance of the PV systems, the long sunshine hours can compensate for the losses resulting from the high temperatures. Despite the high level of the sun shine hours and the high solar irradiance, and despite the availability of land areas (at low costs) to construct a large PV solar stations, a group of environmental factors such as high temperature, dust and dry winds must be taken into consideration and migrates its effect by means of reducing the high temperature, dust cleaning and wind controlling to minimize Its negative impact on the efficiency of solar panels and thus on the system's production yield in general.

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