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EFFECT OF TEMPERATURE ON PHOTOVOLTAIC MODULES: A REVIEW

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ABSTRACT

This project aims to review the study on effect of temperature on the performance and efficiency of photovoltaic (PV) modules. Photovoltaic modules are used to convert sunlight to electricity, but their efficiency and power output can vary depending on environmental factors such as temperature. The photovoltaic generation is commonly used renewable power generation in the world but the solar cells performance decreases with increasing of panel temperature. The objective of this research is to review on the temperature effect on the solar photovoltaic (PV) power generation. The photovoltaic cells suffer efficiency drop as their operating temperature increases especially under high insolation level and cooling is beneficial. Characteristics parameters of selected photovoltaic modules are the short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), and maximum power (P_{MAX}). The increase in temperature leads to a decrease in module efficiency and a subsequent reduction in power output. This can be attributed to the negative temperature coefficient of the photovoltaic cells, which causes their voltage and current output to decrease as temperature rises. Some of the values recorded include a temperature of 50°C-120°C with a decrease in efficiency 20%-60%, 25°C-60°C of temperature and efficiency 10%-25%, another temperature of 20°C-80°C and efficiency 5%-25%, it shows that when the temperature increases the efficiency decrease. An intermediate temperature and efficiency was also recorded -20°C-50°C and 20%-50% for the temperature and efficiency respectively. Finally a recorded temperature decreases while the efficiency decreases 25°C-60°C and 40%-55% for the temperature and efficiency respectively.

Keywords: Photovoltaic modules, power efficiency, power temperature.

1.0 Introduction

The photovoltaic (PV) effect can be defined as the generation of a potential when radiation ionizes the region in or near the built-in potential barrier of a semiconductor. It is characterized by a self-generated electromotive force (e.m.f) and the ability to deliver power to a load, the primary power coming from the ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by the use of the PV are called solar cells [1].

The explanation of the photovoltaic effect can relies on ideas from quantum theory. Light can be made up of packets of electricity called photons, whose energy depends upon the frequency, or color of the light. The energy of visible photons is sufficient to excite electrons, bound into solids, up to higher energy levels where they are more free to move. An extreme example of this is the photoelectric effect which was explained by Einstein in 1905, where blue or ultraviolet light provides enough energy for electrons to escape completely from the surface of a metal. When light is absorbed by matter, photons are given up to excite electrons to higher energy states within the material, but the excited electrons quickly relax back to their ground state [1].

In a photovoltaic device, however, there is some built-in asymmetry which pulls the excited electrons away before they can relax, and feeds them to an external circuit. The extra energy of the excited electrons generates a potential difference or e.m.f. This force drives the electrons through a load in the external circuit to do electrical work. The effectiveness of photovoltaic device not only depends on the choice of the light absorbing material but also on the way in which they are connected to the external circuit. The direct conversion of sunlight to electricity is likely to be a prime energy source of the future assuming that practical economic means of direct conversion can be developed. Photovoltaic modules can provide an independent, reliable electrical power source at the point of use making it particularly suited to remote or inaccessible locations [1].

The principal advantages of photovoltaic energy over the other conventional energy sources are:

(i) The photovoltaic systems convert sunlight directly to electricity with no requirement for a thermal or mechanical step in the conversion process.
(ii) Once installed, PV systems require very little maintenance and have expected life of 20 years or more.
(iii) PV systems are modular. A solar array is composed of individual modules so each system can be seized to meet a particular demand .
(iv) PV systems can be used to improve quality of life. For example, the provision of lightening the rural school allows evening educational or community activities. Refrigeration at health center improves effectiveness of immunization programmes
(v) PV systems are highly reliable. The reliability of PV modules is significantly higher than that of diesel generators or wind generators.
(vi) The system provides national economic benefit because reliance on imported fuels such as coal and oil is reduced and many small scale applications can

The potential of renewable energy sources is enormous as they can meet up with the world's energy demand [1]. Renewable energy sources such as biomass, hydropower, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources. A transition to renewable-based energy systems is looking increasingly high as their costs decline while the price of oil and gas continue to fluctuate [1]. Renewable is a term used for forms of energy which are not exhausted by use overtime. It means that the renewable resources can be regenerated or renewed in a relatively short time. Renewable energy sources currently supply somewhere between 15% and 20% of world's total energy demand [2]. The supply is dominated by traditional biomass, mostly fuel and wood used for cooking and heating, especially in developing countries in Africa, Asia and Latin America [2]. A major contribution is also obtained from the use of large hydropower, with nearly 20% of the global electricity supply being provided by this source. New renewable energy sources (solar energy, wind energy, geothermal energy, and small hydropower) are currently contributing about two percent [2]. A number of scenario studies have investigated the potential contribution of renewable to global energy supplies, indicating that in the second half of the 21st century their contribution might range from the present figure of nearly 20% to more than 50% with the right policies in place [2].

Solar radiation is available at any location on earth [2]. The total world average power at the earth's surface in the form of solar radiation exceeds the total current energy consumption by 15,000times, but its low density and geographical and time variations pose major challenges to its efficient utilization. The solar source is generally assessed on the following criteria[2];

i. Power density
ii. Angular distribution (diffuse or direct components)
iii. Spectral distribution

The maximum power density of sunlight on earth is approximately 1KW/m^2 irrespective of location. Solar radiation per unit of area during a period of time is defined as energy density or insulation [2].
Photovoltaic is the field of technology and research related to the devices which directly convert sunlight into electricity [3]. The solar cell is the elementary building block of the photovoltaic technology [3]. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductor that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice [3]. Several types of PV panels exist, representing three generations of technology and characterized by differentiated material composition [3].

A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Modules are designed to supply electricity at a certain voltage, such as a common 12volt system, The current produced is directly dependent on the density of light reaching the module, Several modules and arrays produce direct-current electricity [3]. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination [3].

2.0 EFFECTS

2.1 TEMPERATURE EFFECTS ON SHORT CIRCUIT CURRENT

When the temperature increases on PV cell, the I_{sc} also increases simultaneously.

2.1.1 TEMPERATURE COEFFICIENT OF CURRENT

Most materials used in electrical conditions have a positive temperature coefficient, meaning that the resistance of the conductor increases with increasing temperature. As the resistance increases, the I_{sc} decreases. The extent of this decrease depends on the material used for the conductor [4].

2.1.2 TEMPERATURE RISE

When a short circuit occurs, a significant amount of current flows through the circuit, causing resistive heating. The heating raises the temperature of the conductors, further increasing their resistance and reducing the $I_{sc.}$ The amount of temperature rise and its effect on the I_{sc} depends on the magnitude of the shirt circuit current, the duration of the short circuit, and the heat dissipation capability of the conductor [4].

In summary, temperature affects the short circuit current by increasing the resistance of the conductors, both due to the temperature coefficient of current, and the resistive heating caused by the short circuit.

2.2 TEMPERATURE EFFECTS ON OPEN CIRCUIT VOLTAGE

As the temperature increases, the V_{oc} value decreases, because PV cell p-n junction voltage affects of changing the operating temperature and correspondingly the FF is decreased [4]. The hotness of the PV cell modify the V_{oc}, is given by

$$V_{oc} = KT/q \ \ln(I_{ph} + 1) \quad (1)$$

2.2.1 TEMPERATURE COEFFICIENT VOLTAGE

Most electronic devices, such as solar cell or batteries, have temperature coefficient of voltage. This coefficient indicate how the open circuit voltage changes with temperature. For example, solar cells typically have a negative temperature coefficient of voltage, meaning that as the temperature increases, the open circuit voltage decreases. This is mainly due to changes in the bandgap energy of the materials used in the solar cell, which affect the voltage output [4].

2.2.2 INTERNAL RESISTANCE

An electrical device or system has some internal resistance, which includes the resistance of the conductors and components. The internal resistance may have some temperature dependence. As the temperature changes, the resistance may increase or decrease, affecting the open circuit voltage. The effect of temperature on internal resistance and consequently, on the open circuit voltage depends on the specific device or system [4].

In summary, temperature affects the open circuit voltage by changing the bandgap energy of materials, causing a temperature coefficient of voltage, and by potentially altering the internal resistance of the device or system. The exact way in which temperature affects V_{OC} will depends on the specific characteristics and materials used in the device or system.

2.3 EFFECT OF TEMPERATURE ON OUTPUT POWER

The effect of temperature on the efficiency of a PV cell may be varied due to changes in operating parameters, PV cell/module maximum voltage, maximum current, V_{sc}, I_{sc} and FF [4].

$$P=I_M V_M= (FF)\, I_{SC} V_{OC} \tag{2}$$

2.3.1 EFFICIENCY

The efficiency of a device or system typically changes with temperature. For example, in the case of solar cells, higher temperature can reduce their efficiency due to increased electron-hole recombination rates. This can lead to a decrease output power as the temperature increases. On the other hand, in some systems like thermoelectric generators, higher temperature can increase the efficiency, resulting in a higher output power [4].

2.3.2 THERMAL EFFECTS

Higher temperatures can also cause thermal effects that affect the output power. For example, excessive heat can result in thermal losses that reduce the overall output power of a device or system. Additionally, high temperatures can cause components to degrade or malfunction, leading to a decrease in output power [4].

2.3.3 TEMPERATURE COEFFICIENT OF POWER

Similar to the temperature coefficient of voltage, many devices have a temperature coefficient of power. This coefficient indicates how the output power changes with temperature. For example, some solar panels may exhibit a negative temperature coefficient of power, meaning that as the temperature increases, the output power decreases. However, this is not always the case, as some systems may have a positive temperature coefficient of power [5].

2.4 TEMPERATURE EFFECT ON PV CONVERSION EFFICIENCY

The conversion efficiency of photovoltaic PV system is affected in several ways.

2.4.1 TEMPERATURE COEFFICIENT OF THE PV MODULE

Most PV module have negative temperature coefficient, which means as the temperature increases, the efficiency of the module decreases. This is typically a small reduction in efficiency, typically around 0.4% - 0.5% per ^{o}C [5].

2.4.2 INCREASE IN RESISTIVE LOSSES

As the temperature of the PV module rises, the resistance of the electrical contacts and interconnects within the module also increases. This leads to higher resistive loses, reducing the overall system efficiency [5].

2.4.3 REDUCTION IN OPEN-CIRCUIT

The open-circuit voltage of a PV module decreases with increasing temperature. This reduces the maximum power output of the module and this lowers the overall system efficiency [6].

2.4.4 INCREASE IN DARK CURRENT

Dark current refers to the flow of current in a PV cell in the absence of light. At higher temperatures the dark current increases, leading to additional losses and reduced efficiency [7].

Overall, higher temperature reduces the efficiency of a PV system. This is particularly relevant in hot climate or when the system is exposed to direct sunlight with poor cooling. Various thermal management techniques, such as using hot sinks or utilizing active cooling systems, can be employed to mitigate the temperature effect and improve system efficiency [7].

2.5 TEMPERATURE EFFECT ON FILL FACTOR

Temperature has a significant effect on the fill factor of a solar cell. As the temperature increases, the fill factor generally decreases. This is due to several reasons [7].

2.5.1 INCREASES IN SERIES RESISTANCE

As temperature increases, the series resistance of the cell also tends to increase. This leads to a higher voltage drop across the series resistance, reducing the overall voltage output of the cell. The reduced voltage affects the fill factor [7].

2.5.2 DECREASE IN SHUNT RESISTANCE

Shunt resistance refers to the resistance parallel to the solar cell. As temperature increases, the shunt resistance tends to decreases, leading to a higher leakage current.
The increased leakage current affects the fill factor by reducing the overall current output of the cell [7].

2.5.3 CHANGE IN BANDGAP

The bandgap of the semiconductor material used in solar cells can be affected by temperature. Generally, the bandgap narrows with increasing temperature. This can result in increased recombination of change carriers, reducing the cells efficiency and fill factor [7].
Overall, the decrease in fill factor with increasing temperature is primary attributed to increase. Series resistance, decrease shunt resistance, and changes in the bandgap of the semiconductor material. It is important for solar cell manufacturers and researchers to consider temperature effects in order to optimize the performance of the cells under different operating conditions [7].

2.6 PERFORMANCE OF THE CELL AS THE FUNCTION OF TEMPERATURE

The performance of a cell, such as a battery or a fuel cell, typically varies significantly with temperature. Below are some key aspects that describe the relationship between cell performance and temperature [8].

2.6.1 VOLTAGE

The voltage or cell potential typically decreases with increasing temperature. This is due to various factors, including changes in the electrochemical reactions occurring within the cell and the electrical resistance of the cell components [8].

2.6.2 CAPACITY

The capacity of a cell, which is the amount of it can store or deliver, is also affected by temperature. In general, most cells have lower capacity at higher temperatures. This is often due to increase in internal resistance and taster chemical reactions, resulting in increased self-discharge or loss of charge [8].

2.6.3 EFFICIENCY

The efficiency of a cell, which is the ratio of the output energy or power to the input energy or power, can be influenced by temperature. Different types of cells have different temperature dependences; some cell exhibit higher efficiency at elevated temperatures, while others show lower efficiency [8].

2.6.4 RATE OF REACTION

The rate of electrochemical reactions within the cell generally increases with rising temperature. This can lead to taster cell discharge or discharge or charging rates. However, extremely high temperatures can also accelerates unwanted side reactions or internal degradation process, reducing overall performance [9].

2.6.5 LIFESPAN

The overall lifespan or durability of a cell may be affected by temperature. Extreme temperatures especially high temperatures can cause accelerated degradation and reduced cycle life [9].

3.0 RESULTS

Table 1: Recorded temperatures and efficiencies of PV solar cells

S/N	Sources	Recorded Temperature	Recorded Efficiency
1.	A	50°C - 120°C	20% - 60%
2.	B	25°C - 60°C	10% - 25%
3.	C	-20°C - 50°C	20% - 50%
4.	D	20°C - 80°C	5% - 25%
5.	E	25°C - 60°C	40% - 55%
6.	F	20°C	9% - 12%
7.	G	30°C - 70°C	12%
8.	H	Max. 0.050(V/K) Min. 0.010(V/K)	59.35%
9.	I	32.7°C – 35.5°C	14.6% - 10.1%
10.	J	15°C - 75°C	10% - 30%

The table 1 shows the recorded temperature and efficiency of photovoltaic solar cells, the temperatures were recorded at high and low temperature. The efficiencies were also recorded at high and low percentage.

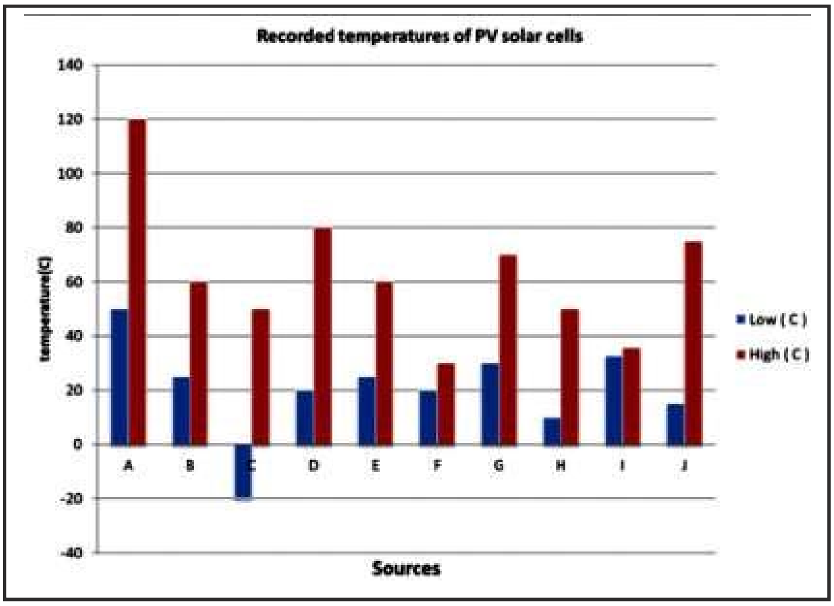

Figure 1: Recorded temperature of PV solar cells

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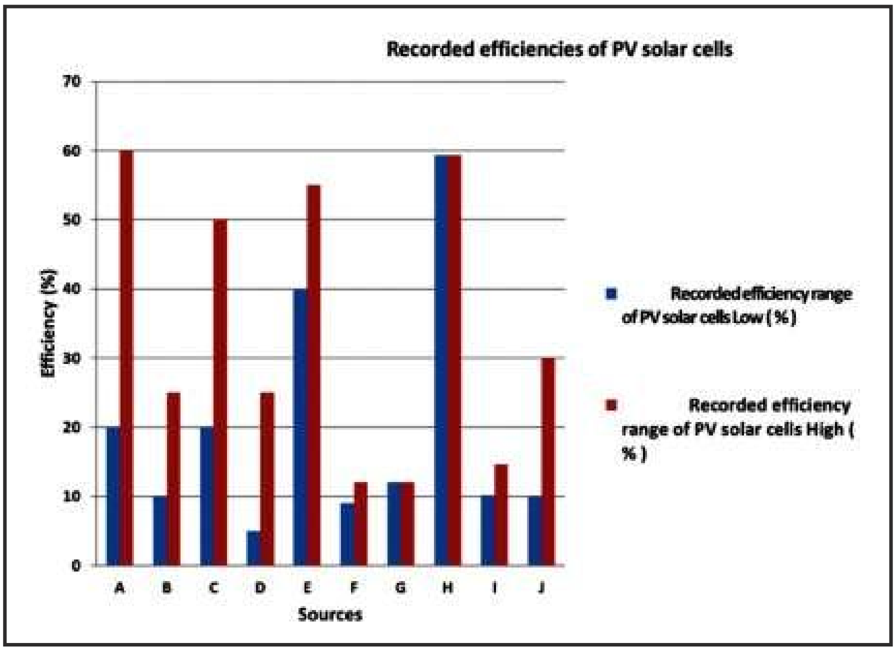

Figure 2: Recorded efficiencies of PV solar cells

The figure 2 shows the recorded efficiency of photovoltaic solar cells, efficiencies were recorded at high and low percentage.

4.0 DISCUSSION

The focus is exploring the effects of temperature on photovoltaic (PV) modules. It is well known that temperature plays a crucial role in the efficiency and performance of PV modules. When the temperature of PV modules increases, it generally decrease in their efficiency. The increase in temperature leads to a decrease in module efficiency and a subsequent reduction in power output. This can be attributed to the negative temperature coefficient of the photovoltaic cells, which causes their voltage and current output to decrease as temperature rises.

Some of the values recorded include a temperature of 50°C-120°C with a decrease in efficiency 20%-60%, 25°C-60°C of temperature and efficiency 10%-25%, another temperature of 20°C-80°C and efficiency 5%-25%, it shows that when the temperature increases the efficiency decrease. An intermediate temperature and efficiency was also recorded -20°C-50°C and 20%-50% for the temperature and efficiency respectively. Finally a recorded temperature decreases while the efficiency decreases 25°C-60°C and 40%-55% for the temperature and efficiency respectively.

5.0 CONCLUSION

In conclusion, it is evident that temperature has significant impact on the performance and efficiency of photovoltaic modules. The increase in temperature leads to a decrease in module efficiency and a subsequent reduction in power output. This can be attributed to the negative temperature coefficient of the photovoltaic cells, which causes their voltage and current output to decrease as temperature rises.

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