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Study of the effect of operating condition changes on the performance of photovoltaic cells

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DEDICATION

In this honorable place, with a simple gesture traced in writing, but which springs from the deep feeling of gratitude, allow us to quote the names as a memorandum for those who have a special place:

To our dear fathers To our dear mothers

To our brothers and sisters

To all our cousins without exception To all our family.

To all our friends without exception

To all; we dedicate this theme, which is the meaning of my higher studies, as a Gift from the Heart, praying ALLAH Almighty to put it at the service of our nation and the good of humanity, and that it will be a light on our journey professional

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Introduction general:

Photovoltaic (PV) cells, often referred to as solar cells, play a pivotal role in the global transition towards sustainable energy sources. These devices convert sunlight directly into electricity through the photovoltaic effect, making them a key component of renewable energy systems. With the increasing demand for clean and sustainable energy, the performance of PV cells has gained significant attention, not only due to their potential to reduce reliance on fossil fuels but also for their role in mitigating environmental pollution and addressing climate change.

However, the efficiency and overall performance of photovoltaic cells are highly influenced by various operating conditions. These conditions include factors such as temperature, solar irradiance, angle of incidence, and environmental factors like dust accumulation and humidity. As these variables change, they directly impact the electrical output of PV systems. The sensitivity of PV cells to these factors necessitates a comprehensive understanding of how operating conditions affect their efficiency and power output.

The effect of temperature, for instance, is one of the most critical factors affecting PV performance. Higher temperatures typically lead to a decrease in the voltage output of solar cells, despite an increase in the intensity of solar radiation. Similarly, variations in solar irradiance impact the current generated by the cells. Understanding these relationships is crucial for optimizing the operation of photovoltaic systems, especially in regions with extreme climate conditions.

This study aims to investigate the impact of various operating condition changes, including temperature fluctuations, variations in solar irradiance, and the effects of shading and dirt on the surface of PV cells, on the performance of these devices. Through a detailed analysis of these factors, the study seeks to develop strategies to enhance the performance and reliability of PV cells, thereby improving their efficiency and longevity in diverse environmental conditions. By understanding how these changes influence the output of PV cells, the study will contribute to the development of more effective and sustainable solar energy solutions.

The findings of this study have important implications not only for the performance of individual photovoltaic systems but also for the broader field of solar energy applications, particularly in optimizing energy production, reducing maintenance costs, and extending the lifespan of PV systems. The insights gained could be instrumental in the design of more efficient solar power plants and for informing policies that promote the adoption of solar energy globally.

CHAPTER I

Fundamentals of Photovoltaic Cells and the Impact of Environmental Factors on Their Efficiency

I.1.Introduction :

Solar energy technology is witnessing a remarkable development in light of the increasing need for alternative and sustainable energy sources, and photovoltaics are emerging as one of the most important practical applications to achieve this goal by converting sunlight into electricity. In this chapter, it reviews the principles of operation of photovoltaic cells and classifies them into multiple types characterized by different technical characteristics. In addition, the chapter discusses the factors affecting the efficiency of these cells such as the intensity of solar radiation, environmental conditions, cell design, etc. Besides reviewing its various uses in various fields. The research also addresses the advantages and disadvantages of photovoltaics, providing a comprehensive view that contributes to a deeper understanding of the challenges and opportunities available for the development of this promising technology.

I.2.General overview of photovoltaics

sola r or For photovoltaic cells or photovoltaic cells are a device and a tool in the form of cells paved next to each other that converts sunlight into electricity by exploiting the photovoltaic effect of effort, and solar cells have been used for decades, as they have been working with satellites since 1996, in addition to providing the International Space Station ISS with electricity, and currently there is in Spain the largest solar-powered powe

Figure (1.1): photovoltaïques cell

I.2.1.The cells working principle of solar

A photovoltaic cell is the core module of a solar power generation system where sunlight is instantly converted into electrical energy. A solar cell is a PN junction device. Type n refers to negatively charged electrons donated by donor impurity atoms and type p refers to positively charged holes created by receptor impurity atoms, referring to of the structure of photovoltaics As shown in **Figure (1.2)** [1_3].

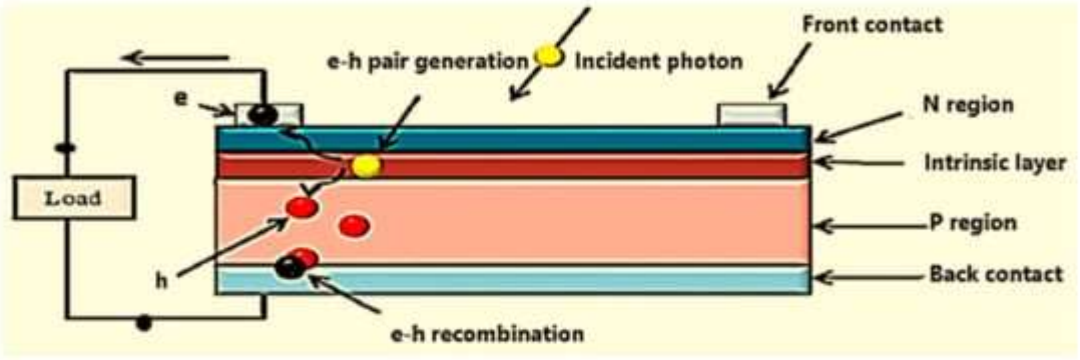


Figure (1.2) . PV cell with pn junction.

The principle of operation of solar cells is based on the photoelectric effect. The photoelectric effect can be divided into three basic actions [4_6].

- Absorption of photons in electronic semiconductors with a pn junction to generate charge carriers (electron-hole pairs). The absorption of an energy photon $(E = h\upsilon)$ higher than the gap $energy\,'E\,g'$ of the formed semiconductor material means that its energy is used to excite an electron from the valence range 'Eυ' To the range of delivery 'E_c' Leaving a void (hole) At the level of Valence. Given energy Additional electron or hole kinetics by excess photon energy $(h\upsilon - h\upsilon\,0).'h\upsilon\,0'$ is the minimum energy or working function of a semiconductor required to generate an electron-hole pair. The working function here represents the energy gap. Excess energy is dissipated in the form of heat in semiconductors [7_8].

- Subsequent separation of carriers of charge generated by light. In the outer solar circuit, holes can flow away from the junction through the p-region, and electrons can flow through the n region and pass through the circuit before combining again with the holes.

- Finally, discrete electrons can be used to power an electrical circuit. After the electrons pass through the circuit, they will combine again with the holes.

Type N should be designed thinner than Type P. Thus, electrons can pass through the circuit in a short time and generate current before being recombined with holes. In addition, an anti-reflective coating is applied to the n-layer to reduce surface reflection and enhance light transmission to the semiconductor material.

I.3.Materials from which solar cells

A photovoltaic solar module consists of photovoltaic cells, an encapsulant, bypass diodes, connectors, a junction box, cables, a protective glass on the front, a glass or polymer film on the back and an aluminum frame As shown in **Figure (1.3)**

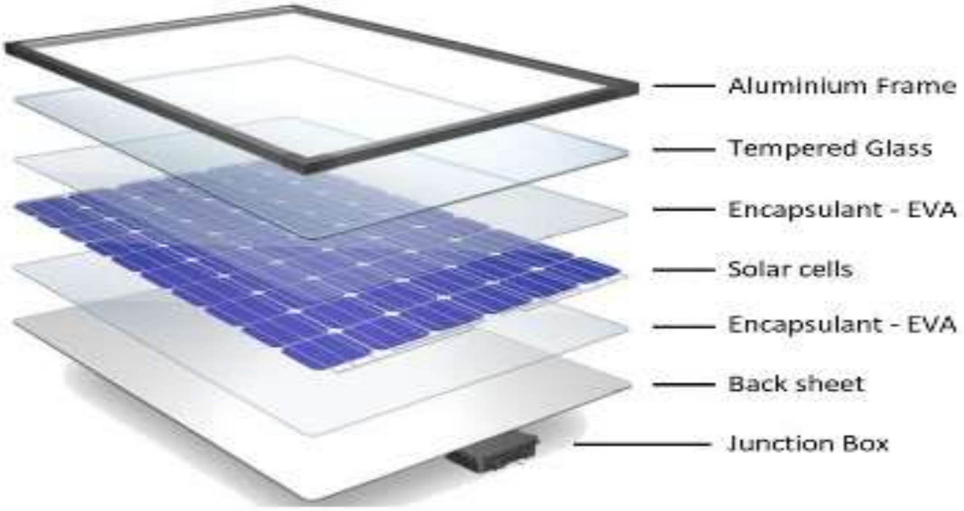


Figure (I.3): Photovoltaic cell components

I.3.1.Verre face avant

The front side of the module contains a tempered solar glass that must have high transparency، high transmittance, low reflectivity and low iron content. The glass forms the front end of the photovoltaic module and protects the components housed inside the laminate from weathering and mechanical stress. At the same time, it serves as a support in the lamination process. High transmittance increases the efficiency of the photovoltaic cells and therefore has a direct influence on the power and performance of the final module. A low iron content in the glass composition and an anti-reflective coating reduce the absorption of radiant energy. They have a hydrophobic anti-reflective layer that increases the absorption of light and reduces the accumulation of dust on the surface. They achieve excellent resistance to mechanical stress and temperature changes thanks to the manufacturer's preload. The thickness of the glass can be selected in the range of 2.5 to 10 mm .[9]

I.3.2.Encapsulating

Protecting photovoltaic cells from moisture, fungus or oxidation is the secret to stable energy production [10]. In the solar panel structure, the encapsulation provides this protection

I.3.3.Photovoltaic cells

A cell is the smallest piece of semiconductor that has a single junction and generates an electrical voltage. In monocrystalline or polycrystalline silicon solar panels, each cell is made up of a single piece of silicon. In thin-film panels, the semiconductor material is deposited over a large area, then divided into electrically isolated regions to form cells []

I.3.4.Back Side (Back Sheet)

The back face of solar panels consists of three main layers, each with a specific function: the inner layer provides strong adhesion to the encapsulation material, the middle layer enhances mechanical and electrical properties, and the outer layer protects against environmental factors. The materials used include PET, PVDF, PVF, EVA, etc., and these layers are usually made by laminating or co-extrusion. The performance of each layer directly affects the performance of the back face, which in turn is reflected in the efficiency of the solar panel as a whole [12]

I.3.5. Frame and junction box

The solar panel frame and junction box are key components that affect the cost and performance of the panels. Emphasis is placed on improving the design and reducing costs while maintaining durability and performance. Diodes play a vital role in protecting the panels from failure, but their design and use requires a delicate balance between cost and performance [14 13].

I.4.Types of solar cells

Photovoltaic solar panels are made up of photovoltaic cells and vary according to type

I.4.1. Monocrystalline Solar Cells

Monocrystalline panels are composed of high-purity silicon crystals. The monocrystalline silicon ingot has a cylindrical shape, a diameter of 13-20 cm and a length of 200 cm, and is obtained by the growth of a slowly rotating filiform crystal. This cylinder is then cut into 200-500 µm thick wafers and the surface is treated to obtain "micro-grooves" to minimize reflection losses. The main advantage of these cells is their efficiency (14 to 17%), their long lifespan and the retention of characteristics over time. Panels made with this technology are generally characterised by a dark blue colour [15] As shown in **Figure (1.4)**

Figure (I.4): Monocrystalline solar cell

I.4.2.Polycrystalline Solar Cells

The crystals that make up cells aggregate into different shapes and directions. In fact, the typical iridescence of polycrystalline silicon cells is caused by the different senses of the crystals and therefore by the different behavior in relation to light. Polycrystalline silicon ingot is obtained by melting and casting silicon in a parallelepiped-shaped mold. The platelets obtained in this way have a square shape and characteristic striations of 180-300 µm thickness. The efficiency is lower than that of monocrystalline silicon (12 to 14%), but the cost is more advantageous. The crystals that make up cells aggregate into different shapes and directions. In fact, the typical iridescence of polycrystalline silicon cells is caused by the different senses of the crystals and therefore by the different behavior in relation to light. Polycrystalline silicon ingot is obtained by melting and casting silicon in a parallelepiped-shaped mold. The platelets obtained in this way have a square shape and characteristic striations of 180-300 µm thickness. The efficiency is lower than that of monocrystalline silicon (12 to 14%), but the cost is more advantageous. Duration of visible content [16] As shown in **Figure (1.5)**

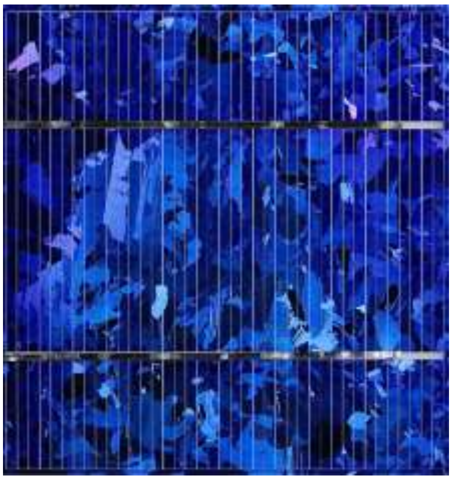


Figure (I.5): multicrystalline solar cell

I.4.3.Thin Film Thin Film Solar Cells

Thin-film cells are composed of semiconductor material deposited, usually in the form of gas mixtures, on supports such as glass, polymers, aluminum, which give physical coherence to the mixture. The semiconductor thin film is a few µm thick compared to crystalline silicon cells, which have hundreds of them. As a result, the material saving is remarkable, and the possibility of having a flexible support increases the scope of application of thin-film cells

[17] As shown in **Figure (1.6)**

Figure (I.6): Thin film solar cell

I.5. Uses of Solar Energy

Solar energy is defined as the energy that can be generated after being absorbed through the rays arriving from the sun to the solar panels, and the uses of renewable solar energy vary To several uses and we will mention the most important of them in this research

Figure (I.7): Image expressing the use of solar energy

I.5.1.1Solar Water Heating

Solar energy is used to heat water through a solar heater, which is a cleaner and less expensive way to operate than the stoves that were used for this purpose, which relied on burning wood or coal. [18] Although the cost of oil and natural gas fell in the early twentieth century, and some countries resorted to replacing solar water heaters with them, other countries, such as Australia and Spain, still require their use in any new construction [19] Nin addition, some 28 developing countries use solar energy to disinfect water to make it drinkable on a daily basis, by filling water in plastic bottles and then exposing it to sunlight for several hours. [20] As shown in **Figure (1.8)**

Figure (I.8): Solar water heating

I.5.2.Electricity Generation

Many factories exploit the sun's heat to generate electricity as an abundant source of renewable energy, and this process is based on the use of sun-following mirrors that reflect its rays to a central point at the top of a tower that contains pipes with a liquid that absorbs heat. [21] When it becomes hot, this liquid is then pumped into a generator that converts it into steam, and the resulting steam drives a turbine responsible for generating electricity. [22]

Figure (I.9): Solar power generation

I.5.3.Heating houses

Solar energy can be relied on to work on heating rooms and homes, and this can be illustrated through the (solar room) model, in this model the glass room allows sunlight to cross into it during the day through the transparent glass feature that combines these rays, to obtain heating for the room. [23] In order to continue to get heating in the period after sunset, it is possible to add plants and rocks in the room as a kind of decoration, as these rocks will be used in that they will store heat and then benefit from it after sunset Figure (10.1) shows the heating method

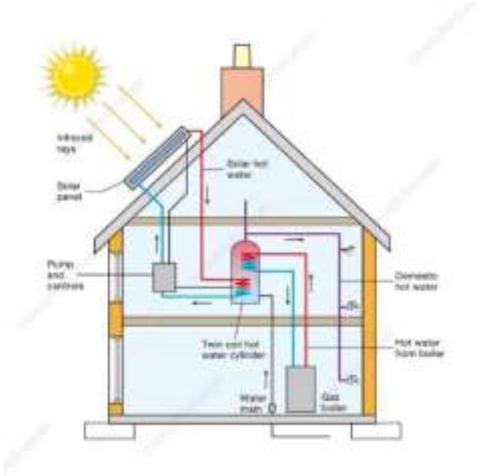


Figure (I.10): Solar home heating

I.5.4.Charging batteries with solar energy

You can take advantage of sunlight during the day by charging some types of batteries, such as video game batteries, for example, in addition to taking advantage of the energy stored in the day and using it at night, or in cases of power outages. [24] Charging batteries based on solar energy is a very fast process on sunny days, but charging

Figure I.10 requires a voltage regulator in anticipation of keeping the battery from damage.

I.5.5.Solar Energy in Industries

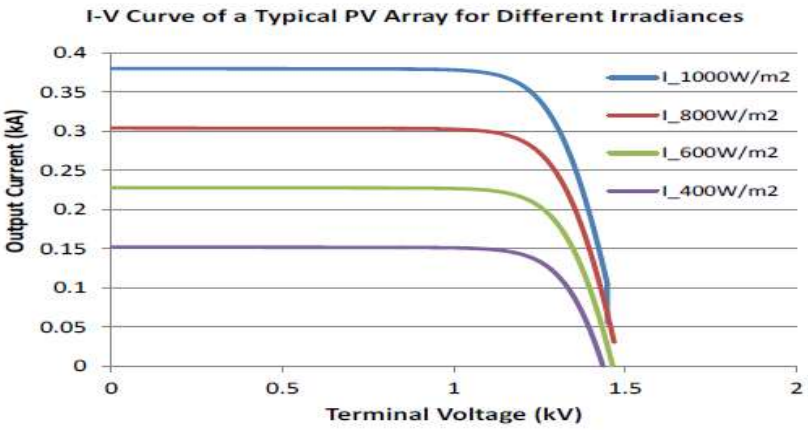
Solar energy enters various industries through the need for factories to generate the heat necessary to carry out their chain of tasks without harmful emissions, including: Metal processing. Chemical products. Food products. Desalination. The methods used to generate thermal energy using solar energy in factories are divided into several types, namely [25] Solar thermal energy technologies. Resistance heaters. PV panels connected to heat pumps.

I.6.Factors affecting the efficiency of solar cells

PV panels are exposed to multiple environmental factors that significantly affect their performance and efficiency. High solar radiation boosts the productivity of solar cells, while high temperature reduces their efficiency. Not only that, but the panels face challenges caused by the distribution of dust and pollution in the atmosphere, which negatively affects the efficiency of these panels. In addition to wind, shading and humidity, their effects are evident on the performance of photovoltaic panels. In this article, we will learn about the most prominent environmental factors affecting the performance of solar panels, includingSolar radiation , temperature, dust, wind and humidity.

I.6.1.Effect of solar radiation

Solar radiation directly affects the efficiency of photovoltaics, as the amount of electricity produced depends on the intensity of the radiation incident on the surface of the cells. When the intensity of radiation increases, the number of photons absorbed increases, resulting in an increase in the flow of electrons inside the cell and a rise in the resulting electric current. However, higher radiation intensity may have indirect effects on efficiency, especially if combined with overheating, as excessive heat reduces the open circuit voltage.) and increased energy loss due to intracellular recombination. The different angle of incidence of radiation also affects the amount of light absorbed, making it necessary to adjust the mounting angles of solar panels to achieve the highest possible efficiency. In addition, dispersion caused by clouds and pollution can reduce the effective radiation intensity, resulting in reduced cell efficiency. Therefore, improving the design of solar cells and the use of solar cooling and tracking technologies help improve their performance and ensure optimal utilization of available solar radiation. The effect of solar radiation is shown in Figure 11



Figure(I.11): The effect of solar radiation on the efficiency of the electrical cell

I.6.2.Temperature effect

A PV cell converts a small portion, approximately less than 20%, of the irradiance into electrical energy while the remaining is converted into heat. Overheating of the module mainly occurs due to excessive solar radiation and high ambient temperatures [26]. Module temperature is a parameter that has great influence on the behavior of a PV system, as it greatly affects the system efficiency and energy output. The main effect of the increase in cell temperature is on the open circuit voltage which decreases linearly with the cell temperature increase. The Cell voltage decreases by approximately 2.2 mV per 1 °C rise in operating temperature and thus the efficiency drops by about 0.5% for crystalline PV cells [27].

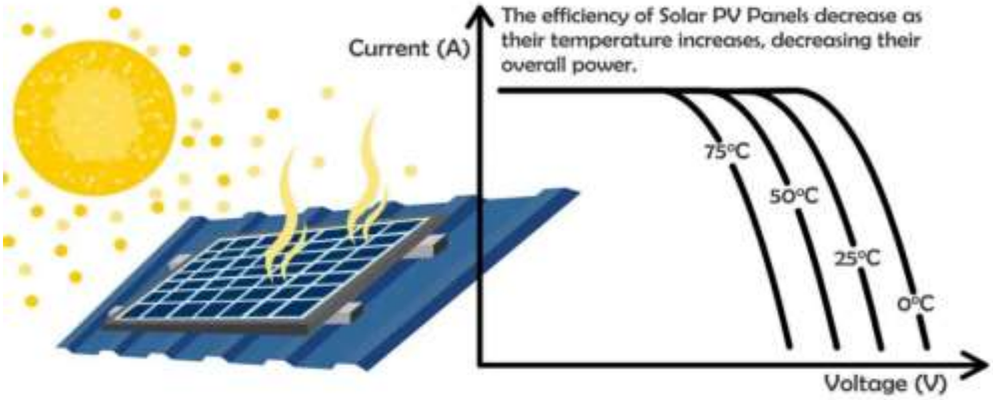


Figure (I.11): . PV efficiency versus module temperature

I.6.3.Dust effect

The efficiency of photovoltaic modules deteriorates when dust, water vapor, air particles and other pollutants in the atmosphere prevent sunlight from falling on the photovoltaic panel. The sun's rays can be scattered by dust particles in the air, which are larger than the wavelength of the incoming sunbeam and lead to a decrease in solar radiation. 53 Dust can also form a thick layer on the surface of the photovoltaic module. The dust layer can change the optical properties to enhance light reflection and absorption and reduce its transmissibility on the surface, thus producing a photovoltaic power module. 27 Dust accumulation depends on environmental factors such as wind speed, humidity, precipitation, dust particle source, particle type, photovoltaic module technology and PV module surface cover Figure 13 shows the effect of dust on the efficiency of the solar panel [28]

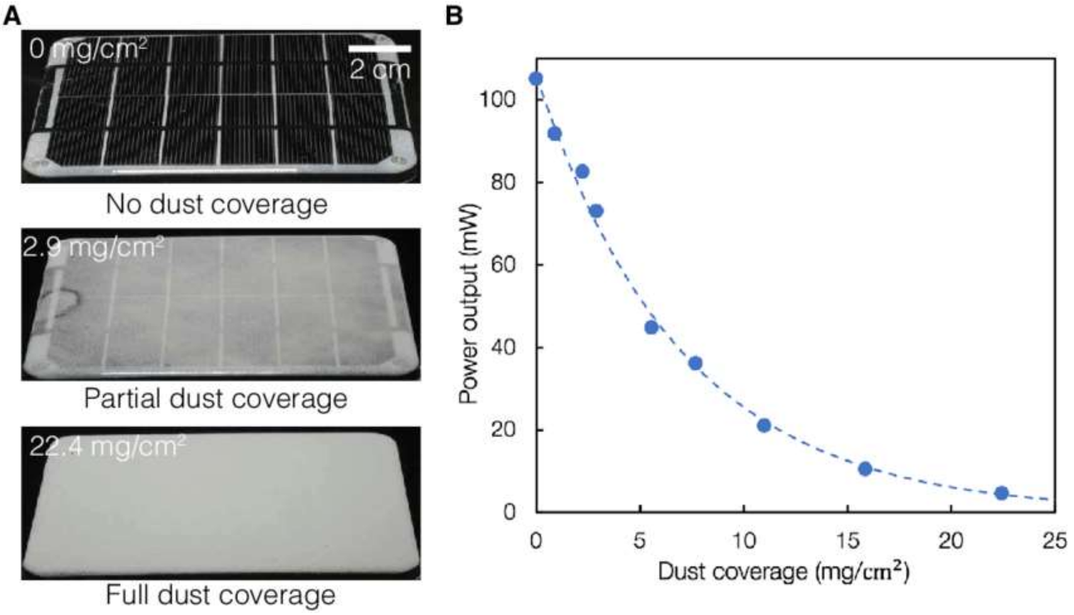


Figure (I.13): Effect of dust on photovoltaic cell performance

I.6.4.Wind effect

Wind conditions, including wind speed and direction, control the energy produced by the PV module. [29] effect of wind on photovoltaic performance is described by factors such as unit temperature, surface structure and dust deposition. [30] Section how to enhance the efficiency of a photovoltaic module by reducing the temperature of the module. The most cost-effective option for cooling is to use convection heat transfer by natural wind flow as far as possible. [30] The overheating of photovoltaic cells is very sensitive to wind speed, not wind direction. [31] shape and structure of the surface clearly affect the cooling of the PV panel's convection. Structured and fluted glass cover surfaces may operate at lower temperatures at higher wind speeds. However, the cooling effect is significantly higher for a flat surface at low wind speeds. [32]

I.6.5.Moisture effect

Relative humidity is an influencing factor responsible for the accumulation of small water droplets and water vapor on solar panels from the atmosphere. Water droplets can break, reflect or neutralize sunlight away from solar cells and reduce the number of direct components of solar radiation they hit to produce electricity. [33] In addition, the radiation intensity changes nonlinearly with humidity due to greater dispersion angles with smaller water vapor molecules. [34] Long-term exposure in a humid atmosphere corrodes PV modules due to moisture ingress into the solar cell. [35] In addition, moisture retention in the unit shell increases the electrical conductivity of the material and leakage currents. [36]

Furthermore, the condensation of water at the interface between the coated material and the solar cell material creates increased corrosion rates putting the coated material at risk of separation. [37] deterioration in unit performance can be overcome by either using a suitable airtight seal or a laminated material loaded with a desiccant with a very low diffusion rate. [38] In addition, high relative humidity (RH) leads to the formation of sticky and cohesive dust layers on the surfaces of photovoltaics [39] which may cause pollution and lead to reduced energy output. [40] The efficiency of solar cells increases from 9.7% to 12.04% when relative humidity drops from 60% to 48%. [41] In terms of power, increasing relative humidity by 20% reduces power generation by 3.16 watts. Another study shows that PV production decreases by 40% at 76.3% relative humidity during the rainy period and decreases by 45% at 60.5% relative humidity in cloudy conditions. [42] Although radiation reduction due to moisture is a natural loss, the loss of dust adhesion to the surface of the unit can be compensated by proper cleaning methods. Figure 14 shows the effect of moisture on the solar cell [43]

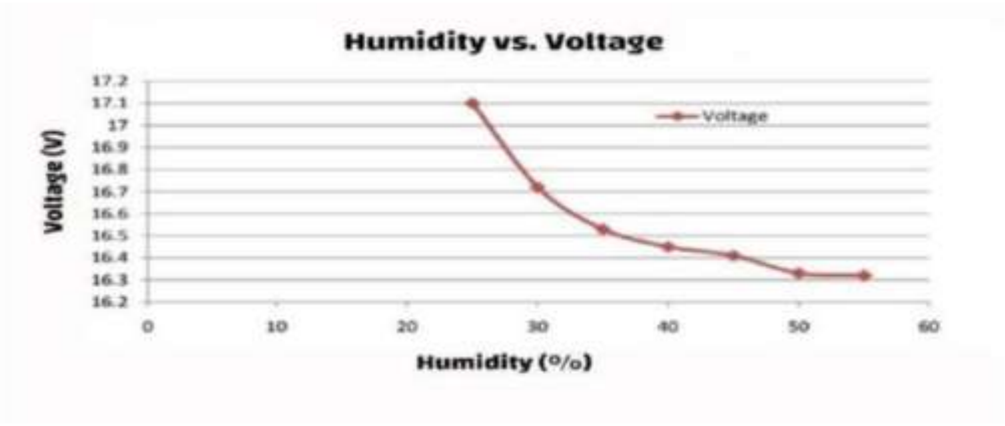


Figure (I.14): Effect of humidity on photovoltaic cell performance

I.7.Advantages and disadvantages of solar energy

I.7.1.Advantages

- Easy to install, operate and inexpensive maintenance.
- Long lifespan compared to traditional sources.
- You do not need an operational cost.
- Can be transported and easy to disassemble.
- Sustainable, clean, environmentally friendly and non-harmful to health

It does not produce noise.

- No moving parts required except trackers

I.7.2.Defects

- Its founding cost is high.
- Requires ample space.
- Limited operation because it only works in the daytime and weakens on cloudy days
- Requires special technical expertise
- Requires commitment and caveats in the operating times of electrical appliances
- Easily breakable and damaged if not fixed with special rules

I.8.Conclusion

At the end of this chapter, it is clear that photovoltaics are the cornerstone of renewable energy, relying on precise physical principles to convert sunlight directly into electricity. We have reviewed their operating principles, different types, and factors affecting their efficiency, highlighting the importance of improving their design and installation to reduce negative impacts such as high temperatures and environmental pollution. We also discussed its multiple uses while highlighting its advantages such as sustainability and long-term cost savings, as well as some disadvantages that require further research and development. Continued research and technology efforts are crucial to making the most of this technology and expanding its future applications in the global energy sector.

CHAPTER II

Analysis of Experimental Results

Introduction

System modeling is essential for understanding and predicting the behavior of complex systems in fields like engineering, economics, and environmental science. It involves creating abstract representations to study system dynamics and interactions, aiding in decision-making and risk mitigation. However, external factors such as environmental changes, economic shifts, or technological advancements can significantly influence system behavior. Incorporating these factors into models is crucial for improving their accuracy and reliability. This introduction emphasizes the importance of system modeling and the role of external factors in enhancing predictive capabilities and managing complex systems effectively

I.2.Architecture of a photovoltaic module

I.2.1.Grouping cells in series

An elementary photovoltaic cell constitutes a low-power electrical generator, insufficient on its own for most domestic or industrial applications. Photovoltaic generators are, therefore, made by connecting a large number of elementary cells in series and/or parallel.

A series connection of (Ns) cells increases the voltage of the photovoltaic generator. The cells are traversed by the same current, and the resulting characteristic of the series connection is obtained by adding the voltages of the individual cells, as represented in Figure II.1.

Equation (1.3) summarizes the electrical characteristics of a series connection of (Ns) cells:

$$V_{oc_{N_s}} = N_s \times V_{oc}; I_{cc_{N_s}} = I_{cc} \qquad \text{II.1}$$

$V_{oc_{N_s}}$: The sum of the open-circuit voltages of the (Ns) cells in series.

$I_{cc_{N_s}}$: The short-circuit current of the (Ns) cells in series.

This connection system is generally the most commonly used for commercial photovoltaic modules.

As the surface area of the cells increases, the current produced by a single cell steadily increases with technological advancements, while its voltage remains very low. The series connection thus allows for an increase in the overall voltage, thereby enhancing the total power output.

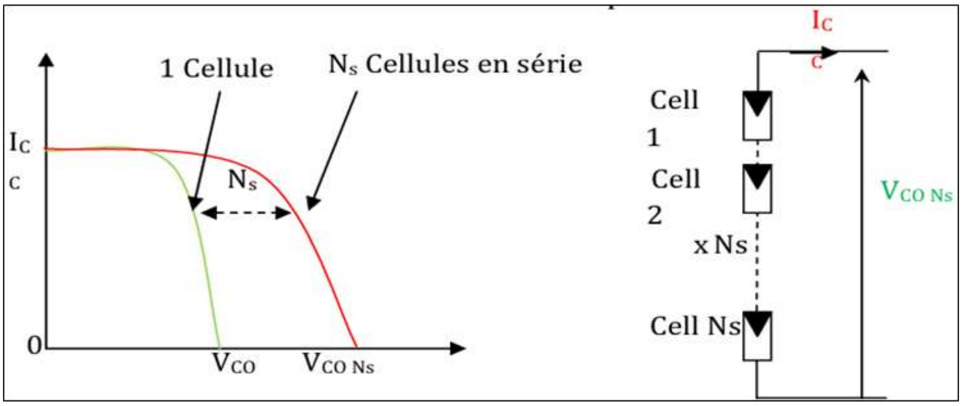


Figure II.1: Resulting characteristic of a series connection of (Ns) cells.

I.2.2.Parallel Connection of Cells

A parallel connection of (Np) cells is possible and allows for an increase in the output current of the generator thus created. In a grouping of identical cells connected in parallel, the cells are subjected to the same voltage, and the resulting characteristic of the grouping is obtained by adding the currents.

Figure II.2 summarize the electrical characteristics of a parallel connection of (Np) cells.

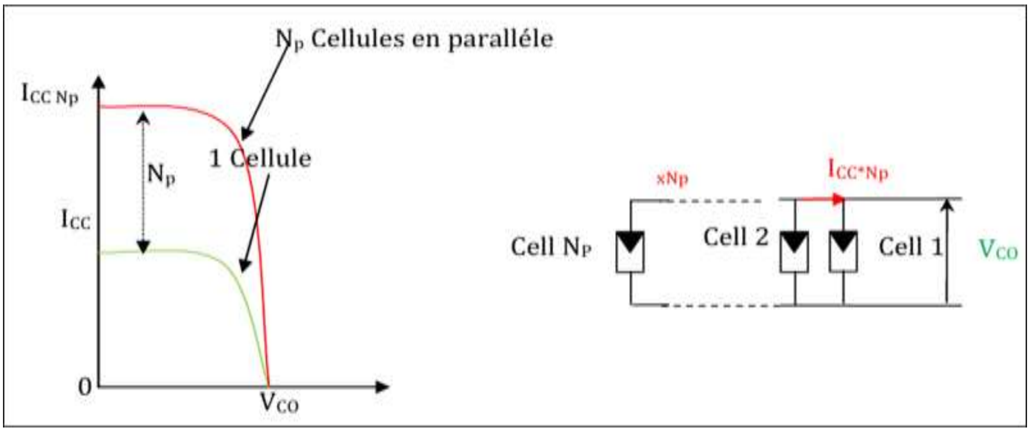


Figure II.2: Resulting characteristic of a parallel connection of (Np) cells [41].

$$I_{cc_{N_p}} = N_p \times I_{cc} \qquad \text{II.2}$$

$$V_{oc_{N_p}} = V_{oc} \qquad \text{II.3}$$

$I_{cc_{N_p}}$: The sum of the short-circuit currents of (Np) cells connected in parallel.

$V_{oc_{N_p}}$: The open-circuit voltage of (Np) cells connected in parallel.

I.2.3.Hybrid Connection of Cells (Series & Parallel)

Depending on the series and/or parallel connection of these cells, the values of the total short-circuit current and the total open-circuit voltages are given by the following relations:

$$I^t{}_{cc} = N_p \times I_{cc} \qquad \text{II.4}$$

$$V^t{}_{oc} = N_c \times V_{oc} \qquad \text{II.5}$$

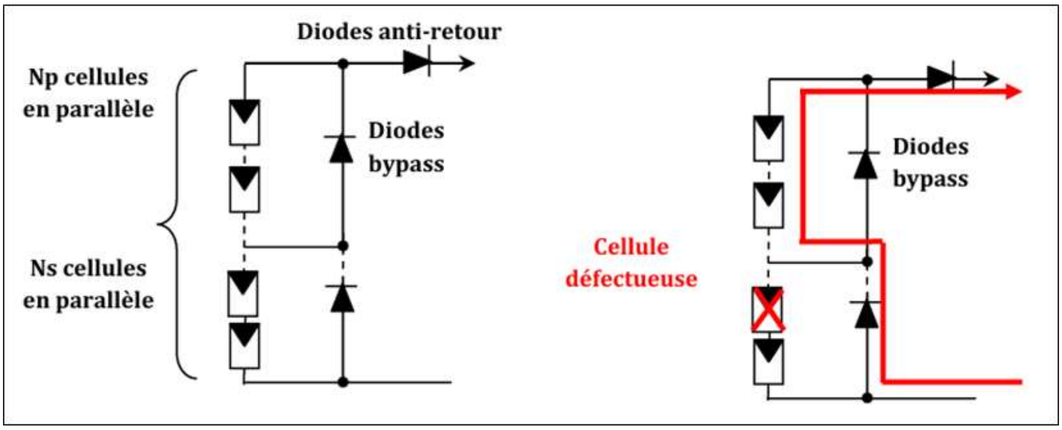


Figure II.3: Resulting characteristics of a hybrid connection of ($Ns\ x\ Np$) cells [41] .

Where:

N_c: Number of cells connected in parallel.

N_p: Number of cells connected in series.

$I^t{}_{cc}$: Total short-circuits current.

$V^t{}_{oc}$: Total open-circuit voltage.

Thus, the characteristic $Ip\ Vp$ of a photovoltaic generator can be considered the result of a network of $Ns\ x\ Np$ cells connected in series/parallel. The overall characteristic can also vary depending on illumination, temperature, cell aging, shading effects, or illumination inhomogeneity. Furthermore, even single shading or degradation of a cell in a series connection can cause a significant reduction in the current produced by the photovoltaic module.

When the current drawn exceeds the current produced by the poorly illuminated cell, the voltage of that cell becomes negative, turning it into a receiving element. The cell then dissipates an excessive amount of electrical power, which could lead to its destruction if the fault persists for too long. This phenomenon is known as the "hot spot effect".

To address this issue, photovoltaic panels are equipped with bypass diodes, which serve to protect cells that become passive. When the bypass diode activates, it short-circuits a part of the module, thereby preventing reverse currents within defective cells. However, this effective solution reduces both the power output and the voltage across the module terminals. The degradation of a cell renders the group of cells associated with the defective cell, and protected by the bypass diode, incapable of producing power.

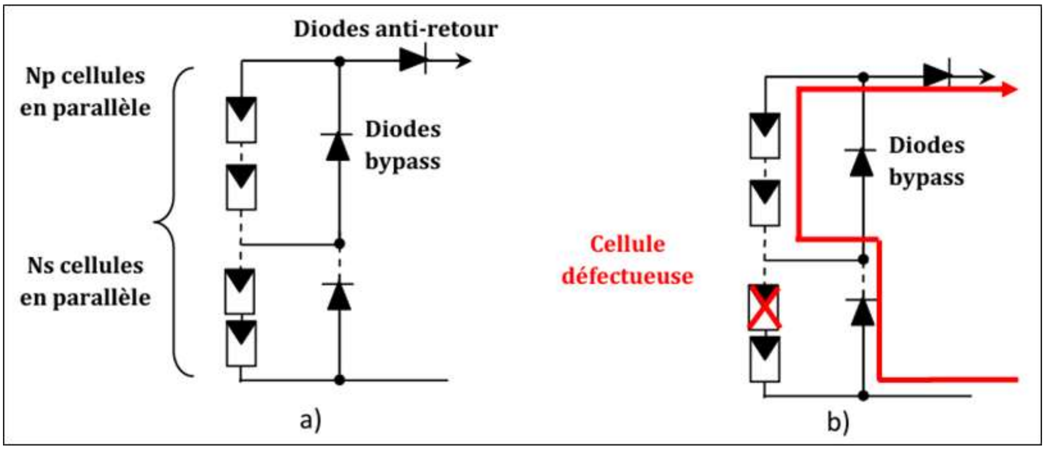


Figure II.4: a) Classical architecture of a photovoltaic module with protective diodes.
b) Failure of one of the PV module cells and activation of the bypass diode, highlighting the circulation current .

This phenomenon of partial power loss should be compared to the total loss of a module in the event of a problem with a single cell in a module operating without protections.

I.3.Modeling of Photovoltaic Installation Elements

I.3.1.Conversion of Light into Electricity

The photovoltaic generator converts light into electrical energy using semiconductor devices, commonly referred to as "photovoltaic cells," which are typically made from semiconductor materials, usually silicon [42].

The photovoltaic generator, or "solar field," consists of photovoltaic panels interconnected in series (Nps) and/or in parallel (Npp) to produce the required power. These panels are mounted on a metallic frame that supports the solar field at a specific tilt angle.

The photovoltaic panel itself is made up of (Ncs) cells in series and (Ncp) cells in parallel, encapsulated under glass. Series connections of multiple cells increase the voltage for a given current, while parallel connections increase the current while maintaining the voltage.

I.3.2.Single-Diode Model

The characteristic (I-V) of an elementary cell is modeled by the equivalent circuit represented in Figure II.5. This circuit includes a current source and a diode in parallel, as well as series resistance (Rs) and parallel (shunt) resistance (Rsh), to account for dissipative phenomena at the cell level [43.44].

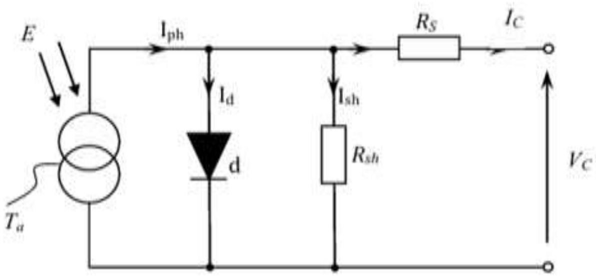


Figure II.5: Equivalent electrical schematic of the PV cell with a single diode.

With:

I_c : Current delivered by the cell.

I_{ph} : Photocurrent generated by the cell (proportional to the incident radiation)

I_d : Current of the diode.

I_{sh} : Shunt current.

$$I_{ph} = P_1 \cdot E_G \cdot \left[1 + P_2 \cdot (E_G - E_{\text{ref}}) + P_3 \cdot \left(T_j - T_{\text{jref}}\right)\right] \qquad \text{II.6}$$

$$T_j = T_a + E_G\left(\frac{N_{oct} - 20}{800}\right) \qquad \text{II.7}$$

$$I_d = I_s\left[\exp\left(\frac{q}{A \cdot K \cdot T_j}\left(V_c R_{s-p} \cdot I_c\right)\right) - 1\right] \qquad \text{II.8}$$

$$I_s = P_4 \cdot T_j^3 \exp\left(\frac{-E_G}{K \cdot T_j}\right) \qquad \text{II.9}$$

$$I_{sh} = \frac{V_c}{R_{sh}} \qquad \text{II.10}$$

$$I_c = I_{ph} - I_d - I_{sh} \qquad \text{II.11}$$

With:

EG: Solar irradiation.

$P1$, $P2$, $P3$, $P4$: Constants dependent on the nature of the cell material, determined experimentally by the manufacturer.

Ta: Ambient temperature.

$Tref$: Reference temperature (298 K).

Tj: Temperature of the cell.

$Noct$: Nominal operating temperature of the solar cell, as provided by the manufacturer (45°C).

Eef: Reference illumination (1000 W/m²).

Is: Saturation current of the diode.

Eg: Energy gap for crystalline silicon (1.12 eV).

A: Ideal factor of the junction ($1 < A < 3$).

R_{sp}: Series resistance of a photovoltaic panel.

$R_{\mathrm{sh-p}}$: Equivalent resistance of a photovoltaic panel.

q: Electron charge (1.6×10^{-19} C).

K: Boltzmann constant (1.38×10^{-23} J/K).

Vc: Voltage across the cell terminals.

I.3.3.Two-Diode Model

The two-diode model includes an additional diode for better curve fitting. This diode represents the phenomenon of recombination of minority carriers, both on the surface of the material and within its volume.

This model appears more sophisticated and provides greater precision but is somewhat complex and challenging to solve. It requires knowledge of four parameters under standard sunlight and temperature conditions. These parameters are generally provided by the manufacturer or can be obtained through module testing fewer than three conditions: short-circuit current (Icc), open-circuit voltage (Voc), maximum voltage ($Vmax$), and maximum current ($Imax$) at the point of maximum power.

Temperature coefficients are also necessary in this modeling technique to account for the effect of temperature on the critical parameters of the solar cell.

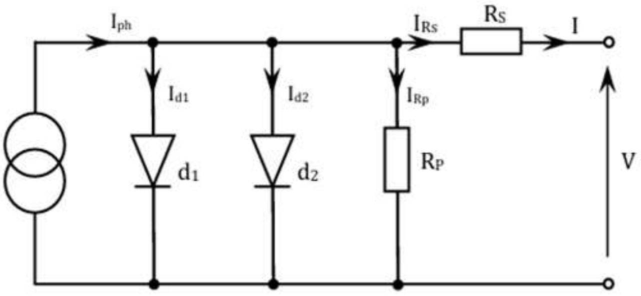


Figure II.6: Electrical two-diode equivalent model of a photovoltaic cell.

$$I_{d1} = I_{s1}\left[e^{\frac{q(V+IR_S)}{n_1 kT}} - 1\right] \qquad \text{II.12}$$

Avec :

$$I_{d2} = I_{s2}\left[e^{\frac{q(V+IR_S)}{n_2 kT}} - 1\right] \qquad \text{II.13}$$

Ainsi :

$$I_{ph} = I + I_{d1} + I_{d2} + I_{Rp}$$
$$I = I_{ph} - I_{d1} - I_{d2} - I_{Rp} \qquad \text{II.14}$$

Alors :

$$I = I_{ph} - I_{s1}\left[e^{\frac{q(V+IR_S)}{n_1kT}} - 1\right] - I_{s2}\left[e^{\frac{q(V+IR_S)}{n_2kT}} - 1\right] - \frac{V+IR_S}{R_p} \qquad \text{II.15}$$

$n1$, $n2$: Ideality factors of diodes $d1$ and $d2$ (ranging between 1 and 2, depending on the technology).

The photocurrent depends on the temperature, and its expression is:

$$I_{ph}(T) = I_{ph}(T = 298K)[1 + (T - 298K) \cdot (5 \cdot 10^{-4})]$$

I_{s1}, I_{s2}: These are the saturation currents of diodes $d1$ and $d2$, respectively, and they depend on the temperature:

$$I_{S1} = K_1T^3e^{\frac{-Eg}{KT}}$$
$$I_{S2} = K_2T^{\frac{5}{2}}e^{\frac{-Eg}{KT}} \qquad \text{II.16}$$

Where:

Eg: Energy, with

K1=1.2A/cm2 T3K1 and K2=2.9×105A/cm2 T5/2.

For a solar panel consisting of z cells connected in series, and considering the model in Figure II.6, the equation describing this panel is:

$$I = I_{ph} - I_{s1}\left[e^{\frac{q(V+IzR_S)}{zn_1kT}} - 1\right] - I_{s2}\left[e^{\frac{q(V+IzR_S)}{nz_2kT}} - 1\right] - \frac{V+IzR_S}{R_p} \qquad \text{II.17}$$

- The Three-Diode Model: The third diode is included in the equivalent schematic to account for effects not considered in the other models (e.g., leakage current related to the diodes).

The current and voltage across the terminals of a photovoltaic panel are given by:

$$I_P = N_{cp}I_c \qquad \text{II.18}$$
$$V_P = N_{cs}V_c$$

Whereas the current and voltage across the terminals of a photovoltaic generator are given by:

$$I_g = I_{Pv} = N_{pp}I_P = N_{pp}N_{cp}I_c \qquad \text{II.19}$$
$$V_g = V_{Pv} = N_{ps}V_P = N_{ps}N_{cs}V_c$$

The current generated by the photovoltaic generator at a given voltage depends solely on the illumination and the temperature of the cell.

I. Simulation results

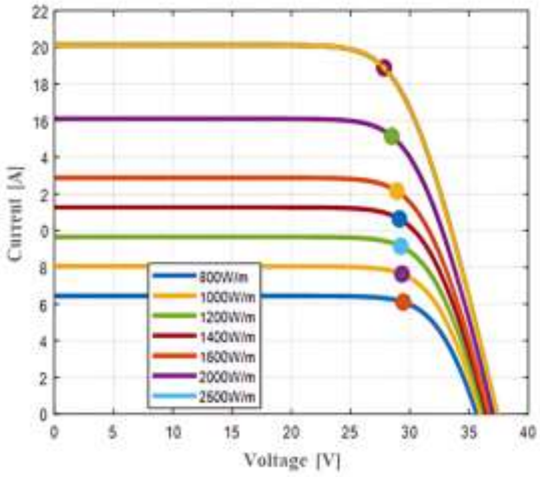


Figure II.7: I-V characteristics, variation of irradiance at constant temperature

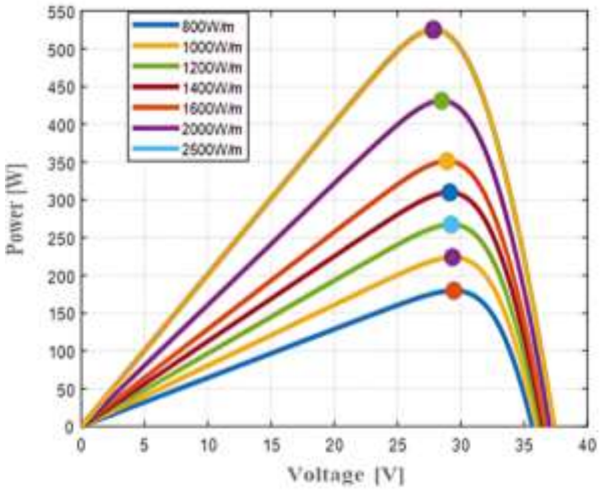


Figure II.8: P-V characteristics, variation of irradiance at constant temperature.

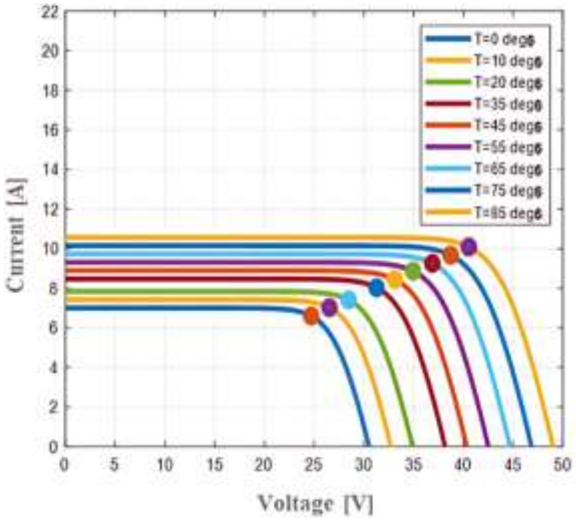


Figure II.9: I-V characteristics, temperature variation at constant solar radiation.

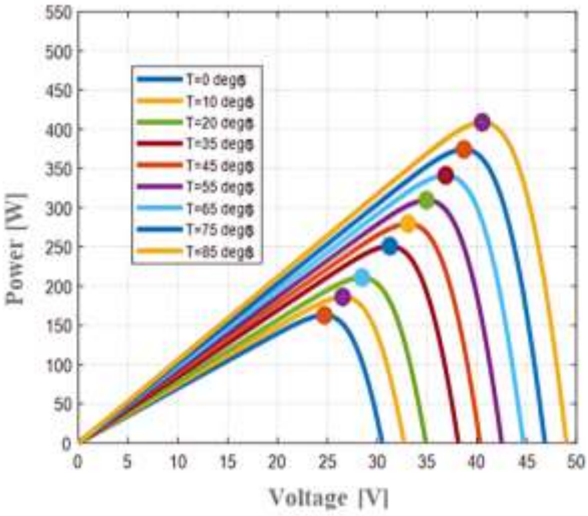


Figure II.10: P-V characteristics, temperature variation at constant solar radiation

The behavior of a photovoltaic (PV) module is highly influenced by variations in irradiance (G) and temperature (T) due to their significant impact on the module's power output. Figure II.7 depicts the variations in current (I_{pv}) and voltage (v_{pv}) with respect to voltage for different illumination levels, while maintaining a constant temperature of 25°C. Multiple P (V) curves are shown, representing the maximum power points (v_{mp},I_{mp}). According to Figure II.8, the open circuit voltage and short circuit current vary proportionally to the illumination. In Figure II.9, with constant illumination ($1000 \mathrm{w/m^2}$) and increasing temperature, the open circuit voltage (v_{oc}) decreases while the short circuit current (I_{sc}) remains relatively stable. Therefore, the operation of a PV module is primarily dependent on the surrounding environmental conditions. It is crucial to consider these factors when sizing a PV system to achieve the desired power output.

The impact of irradiance on a solar PV module is illustrated by the I-V and P-V characteristic curves in Figure II.7 and Figure II.8, where the irradiance intensity ranges from 100 w/m^2 to 1000 w/m^2at a fixed temperature of 25°C. The current remains constant as voltage increases up to 30 V, after which it starts to decrease. Additionally, the current increases with higher irradiance intensity, demonstrating the significant effect of irradiance on the short circuit current. Conversely, the open circuit voltage shows minimal change. The proof of maximum power can be found in the power performance curves.

Observing the figure, when the temperature varies from 0 to 80°C, it is evident that increasing temperature leads to a decrease in power (W) with voltage variations (V).

1.4.factors and phenomena affecting the efficiency of photovoltaic cells

I.4.1.Dust

.The two figures represent curves illustrating the effect of environmental factors on the performance of photovoltaic systems. Figure A shows the relationship between voltage (V) and power under the influence of an environmental factor such as humidity. Power gradually increases with voltage until it peaks at approximately 13 V and 45 W, a point known as the maximum power point (MPP). Power then declines sharply, indicating a decline in system efficiency. This may be attributed to the effect of humidity on the conductive properties or overall performance of components. Figure B shows the relationship between current and voltage for a photovoltaic system under the influence of dust. The current remains nearly constant up to a certain voltage, reflecting the optimal operating area. It then begins to gradually decrease, followed by a sharp drop after reaching the maximum voltage, indicating a clear negative effect of dust. This behavior reflects partial shading or irregular scattering of light resulting from dust accumulation, leading to a decline in electrical energy production and conversion efficiency. In this context, regular maintenance and cleaning are recommended to improve the efficiency of the photovoltaic system.

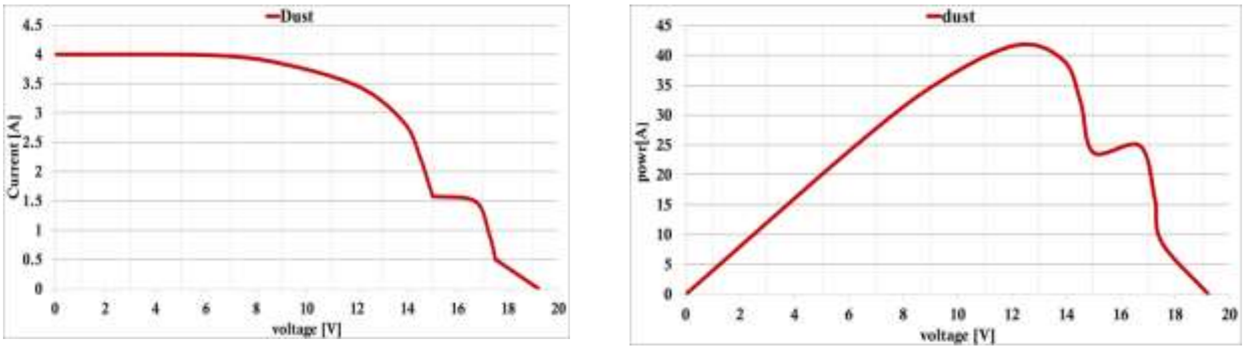


Figure 11: shows the impact of dust accumulation on the PV panels. I-V curves below radiation levels show a reduction in current output and obvious distortion, emphasizing the importance of regular maintenance and repair

I.4.2.Shadow

The two figures represent curves illustrating the effect of partial shading on the performance of photovoltaic systems. Figure A shows the relationship between electrical power and voltage under partial shade. The behavior is nonlinear and exhibits multiple peaks, reflecting the varying efficiency of solar cells due to some being shaded while others remain in optimal operation. These multiple peaks indicate the presence of multiple maximum power operating points (MPPs), making the maximum power point tracking (MPPT) process more complex and increasing the likelihood of the system reaching suboptimal power points. Figure B shows the current-voltage relationship for a solar cell under the same effect. The current starts constant at low voltage and gradually decreases as the voltage increases, with clear breaks in the curve due to the effect of the shade on the cells. Different current levels reveal the presence of multiple operating points, calling for the use of advanced technologies such as multi-point MPPT or bypass diodes to improve performance. Partial shading is an environmental factor that negatively impacts system efficiency, requiring effective engineering solutions to mitigate its impact.

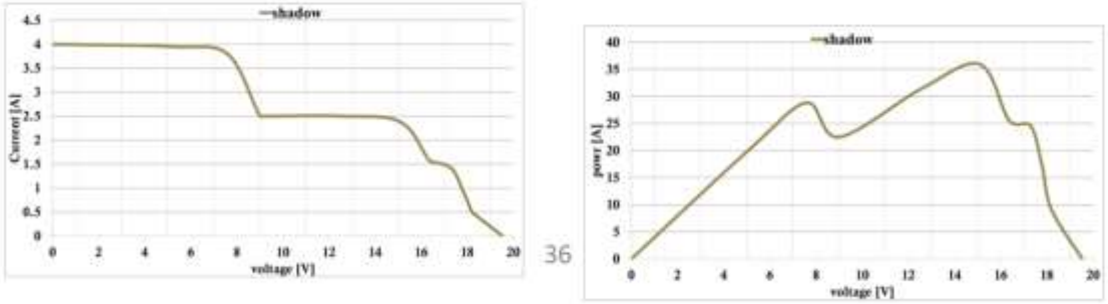


Figure 12: shows the impact of partial shading on the PV panels. The I-V curves show large fluctuations and decreases compared to the healthy condition, which can significantly affect the system performance and power output.

1.4.3.Humidity

The two figures represent curves illustrating the effect of humidity on the performance of a photovoltaic system. Figure A shows the relationship between power (in amperes) and voltage (in volts) under the influence of humidity. The power gradually increases with increasing voltage until it peaks at approximately 13.5 V, representing the system's optimal operating point. Beyond this point, the power declines sharply, indicating a decline in efficiency due to the negative effect of humidity or a physical phenomenon that affects performance at higher voltages. Figure B shows the relationship between voltage and current under the same environmental influence. The current begins at a near-constant value (about 4 A) at low voltages up to 7 V, reflecting the stable conductivity region. Thereafter, the current begins to gradually decrease with increasing voltage, due to a change in the electrical properties of the materials affected by humidity, such as increased resistance. Between 13 and 16 volts, a sharp drop in current occurs, indicating the onset of a breakdown or saturation in the system. The drop continues until the current reaches zero at 20 volts, indicating a complete loss of conductivity due to the cumulative effect of moisture and high voltage.

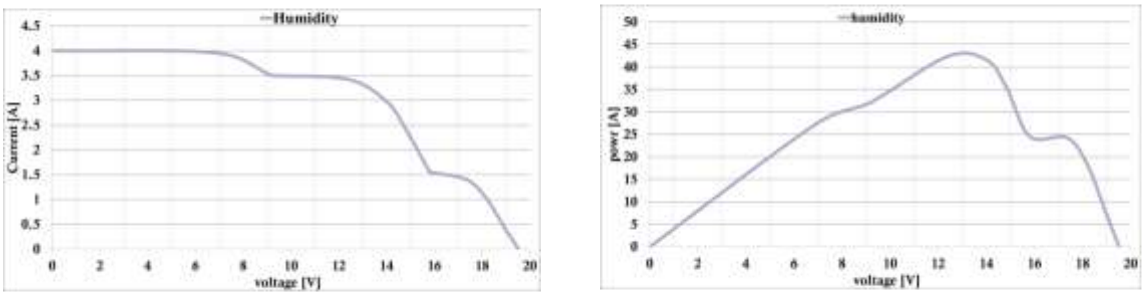


Figure 13: shows the impact of the humidity intensity on the PV system. The I-V curves are irregular and show decreased efficiency, indicating the need for moisture protection measures.

1.4.4.Short circuit

The two figures represent curves that reflect the behavior of a photovoltaic system under short-circuit conditions. In the first figure (A), the curve shows the relationship between voltage and power. The power gradually increases with increasing voltage until it reaches a peak at around 11 V, the maximum power point at which the system operates at its most efficient. After this point, a sharp drop in power occurs, indicating a short circuit. A large current flows without a suitable load, resulting in rapid power loss. This abnormal behavior is an indicator of internal faults or damage to the system components and underscores the importance of protection measures and periodic inspection to avoid serious failures. In the second figure (B), we observe the relationship between current and voltage in a solar cell. The current starts at a high value (around 4.2 A) at zero voltage, known as the short-circuit current. As the voltage increases, the current gradually decreases until it reaches almost zero at around 13 V, the open-circuit voltage. The curve shows the steep decline in current before reaching zero. This represents the maximum power point (MPP), which reflects the optimal efficiency of the system under ideal lighting conditions. This figure reflects the typical performance of a solar module and highlights the importance of tracking the MPP to ensure maximum utilization of solar energy.

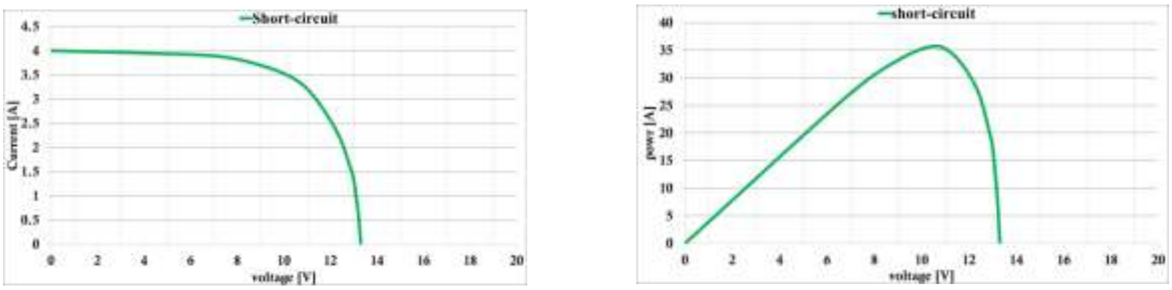


Figure 14: shows the impact of short circuit in PV system. The I-V curves exhibit a significant voltage drop which emphasizes the need for regular maintenance.

1.4.5.PV degradation

Figures (A) and (B) illustrate the effect of natural degradation on photovoltaic system performance through two curves reflecting the relationship between voltage and power, and between voltage and current, respectively. Figure (A) shows a gradual increase in power as the voltage increases until the maximum power point (MPP) is reached at approximately 13 V. Then, as the voltage continues to rise, it begins to gradually decline, indicating a decline in system efficiency over time due to natural degradation. This degradation is attributed to environmental factors such as heat, ultraviolet radiation, and humidity, which negatively impact the overall system performance without causing sharp fluctuations in the curve, confirming that the degradation is endogenous and natural.

Figure (B) shows the relationship between current and voltage. The current starts at a high value and remains nearly constant until a voltage of approximately 11 V is reached, then gradually decreases until it reaches zero at the open-circuit voltage. This behavior reflects a gradual degradation of solar cells due to thermal expansion and climatic factors, without sharp breaks. This also indicates natural degradation not caused by sudden failures. Therefore, periodically monitoring these curves is crucial to determine the annual degradation rate, implementing techniques such as MPPT, and improving maintenance plans to ensure the continued operational efficiency of the photovoltaic system.

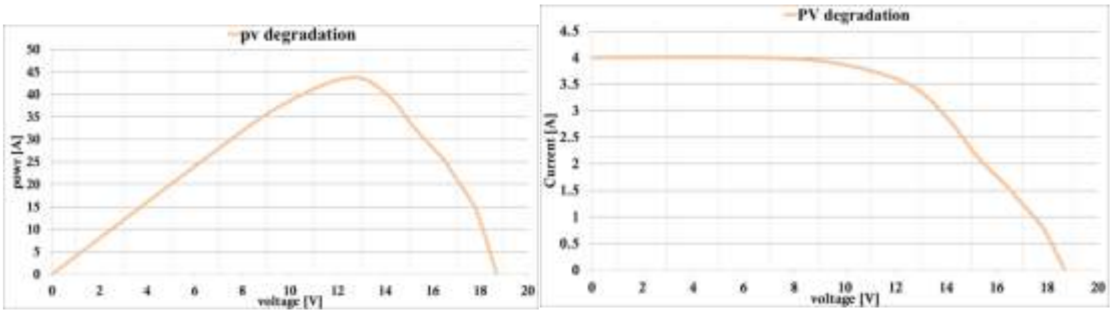


Figure 15: shows the impact of degradation of PV panels with time. The I-V curves show a gradual decrease in performance, indicating the importance of timely repair and replacement of old deteriorating components.

1.5.Conclusion

this study emphasizes the importance of system modeling and analyzing external factors to understand and design complex systems. Modeling simplifies reality and predicts system behavior, while analyzing external influences helps identify key impacts on performance. This approach supports informed decision-making and adaptive strategies, ensuring resilient and sustainable systems.

CHAPTER III

Test and Application

III .1.Introduction

Health monitoring and fault detection in photovoltaic (PV) systems are essential for maximizing efficiency and lifespan. Deviations in current-voltage (I-V) curves indicate potential faults, requiring advanced diagnostic methods. This study presents an AI-enhanced approach combining optimization and classification for accurate fault analysis. A DC/DC buck-boost converter is implemented for real-time I-V data extraction. The proposed method improves reliability and reduces maintenance costs in PV power plants. This research contributes to smarter, more sustainable solar energy management

III .1..1Explanation of the applied part

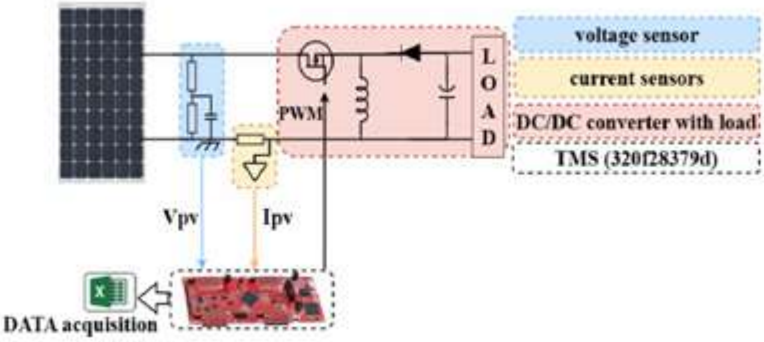


Fig. 1. Proposed Circuit for Extracting Voltage-Current Characteristics Using a DC-DC Buck-Boost Converter.

1. Main Components in the Circuit

Voltage Sensor:

Measures the voltage (Vpv) coming from a power source such as solar panels or batteries.

Current Sensor:

Measures the current (Ipv) coming from the same source.

Buck-Boost DC/DC Converter:

Used to convert voltage and current to appropriate levels (stepping up or down) depending on the load settings.

Load:

Represents the device or circuit that consumes electrical power, such as a resistor or motor.

TMS Control Module (Reference Number: 320128379d):

- power management and control system used to adjust the operation of the Buck-Boost converter, such as changing the duty cycle.

Data Acquisition Module:

Collects readings from sensors and stores them to analyze voltage and current characteristics-.

2. Circuit Operation Steps

- . Measuring Source Voltage and Current (Vpv and Ipv)

Sensors measure voltage and current on the primary (source) side of the circuit.

These readings are sent to a data acquisition unit for recording and analysis.

- . Power Conversion via a Buck-Boost Converter

The converter operates in either Buck or Boost mode, depending on the load and control settings provided by the TMS.

Buck mode: The voltage is reduced if the source voltage is higher than the load voltage.

Boost mode: The voltage is increased if the load voltage is higher than the source voltage.

The conversion ratio is controlled by changing the duty ratio of the PWM signal received from the TMS.

- Connecting the Load

The load is connected to the secondary side of the converter.

The current flowing through the load is determined by the converter's characteristics and control settings.

- Data Collection and Analysis

The data acquisition unit records the voltage and current values on both sides (source and load).

This data is used to plot the voltage-current curve (V-I curve).

3. Steps for Extracting Electrical Characteristics

- Power the circuit and stabilize the power supply (e.g., 24 VDC).
- Gradually change the load (e.g., using a variable resistor).
- Record the Vpv and Ipv values with each load change.
- Use the TMS module to adjust the converter's operation and maintain system stability.
- Plot the curve using the recorded data:
  Horizontal axis: Current (Ipv).
  Vertical axis: Voltage (Vpv).

III .1.2.Experimental Test Bench for Integrating

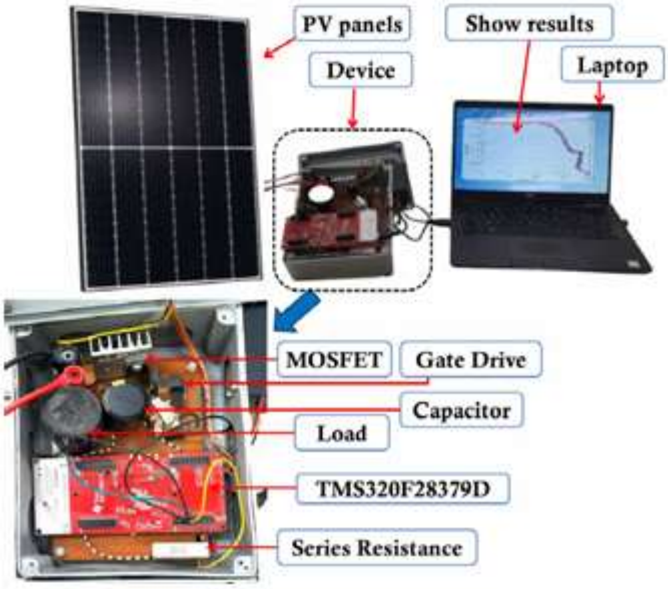


Fig. 5. Experimental Test Bench for Integrating the PV System and Buck-Boost Converter Controlled by the TMS320F28379D LaunchPad.

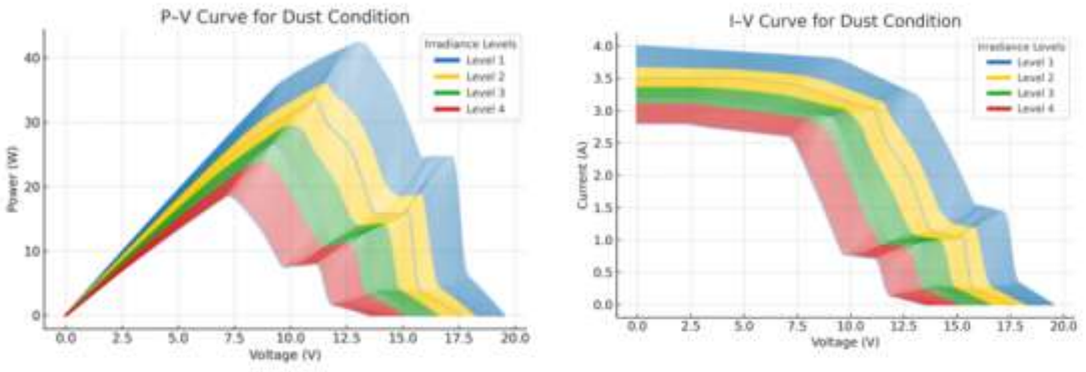
in components such as inductors, capacitors, and semiconductor switches. The Buck-Boost curve starts with the load increasing from zero, and at a duty cycle of around 0.5, the PV panel appears directly connected to the load. Beyond this, the Boost mode maximizes power output, covering all functional points and providing a more accurate VI curve compared to using only Boost or Buck converters.

III .2.Applied results display

After using the previous device, several results were extracted under several variable conditions, including dust, shade, humidity, short circuit, and deterioration. The analytical results for all phenomena were presented. A curve was extracted. (I-V curve) and (P-V curve)

III .2.1Dust

Figure A (I-V curve) and Figure B (P-V curve) clearly and gradually demonstrate the impact of dust accumulation on photovoltaic performance. In Figure A, we observe a significant decrease in the short-circuit current (Isc) as the dust level increases from level 1 (blue) to level 4 (red), while the open-circuit voltage (Voc) remains relatively constant, indicating that the losses are primarily due to the decrease in the amount of light transmitted to the cell surface.In Figure B, the curve shows a decline in the maximum power point (MPP) and a decrease in the output power with increasing dust accumulation, indicating a direct impact on the efficiency of the photovoltaic system. The maximum power decreases significantly, resulting in operational losses that can reach high percentages if neglected.This deterioration is associated with increased surface resistance caused by the dust layer, as well as reduced photon absorption efficiency, which distorts the performance curves. The analysis highlights the importance of regular maintenance and panel cleaning to maintain stable performance and ensure energy production in dusty environments.

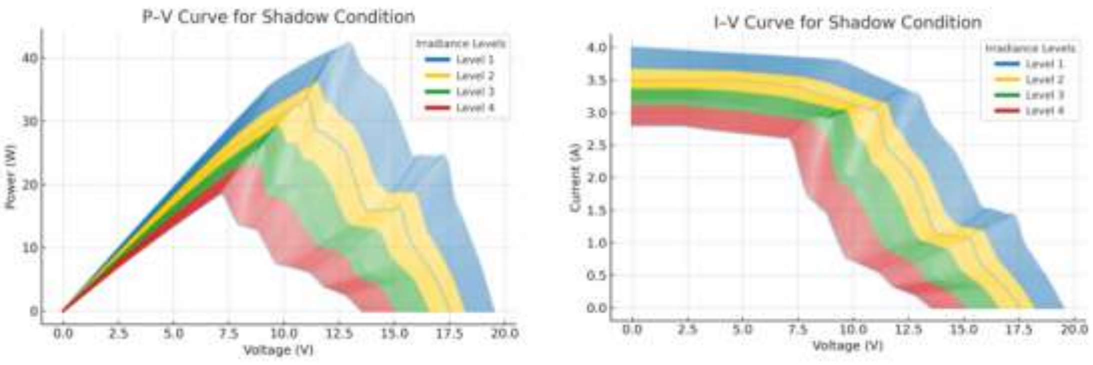


(b) **(a)**

Figure (3.1): The effect of dust on solar panels . (I-V curve) and (P-V curve)

III .2.2.Shadow

In Figure (A), which represents the current-voltage (I-V) curve under shade, we observe that the current gradually decreases as solar radiation levels decrease from Level 1 to Level 4. This indicates that solar radiation intensity directly affects the amount of current generated in the solar cell. The maximum cell voltage also gradually decreases with decreasing radiation, indicating poor electrical performance under shaded conditions.Figure (B), which represents the power-voltage (P-V) curve under the same conditions, clearly shows a decrease in the maximum power point (MPP) with decreasing radiation levels. We observe that the highest power is generated at the first radiation level, while it decreases significantly at other levels, reflecting the direct relationship between solar radiation and power output. The shape of the curve also becomes flatter and more distorted at lower levels, making it difficult to track the maximum power point. These results demonstrate that the effect of shadowing has a significant impact on the performance of photovoltaic systems, leading to power losses and altering the electrical output characteristics of the cell. These findings are essential for designing shadow compensation systems or adopting techno logies such as MPPT to ensure optimal operation

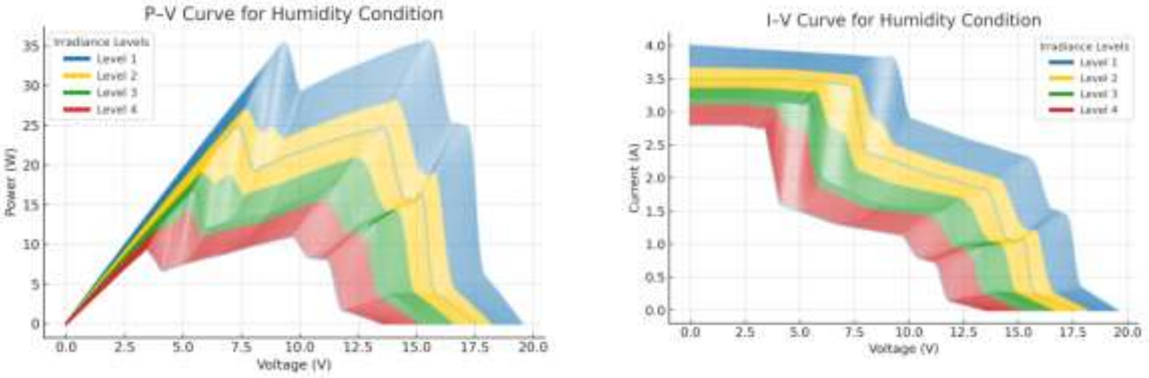


(b) **(a)**

Figure (3.4): The effect of shade on solar panels . (I-V curve) and (P-V curve)

III .2.3.Humidity

Figure (A) shows the current-voltage (I-V) curves under different humidity conditions at four solar radiation levels, while Figure (B) shows the power-voltage (P-V) curves for the same conditions. The results demonstrate that high humidity negatively affects solar cell performance. A clear decrease in current at the same voltage is observed as we move from Level 1 to Level 4, indicating a decrease in photovoltaic efficiency. In Figure (A), the blue curve (Level 1) shows the highest current, indicating the lowest humidity effect, while the red curve (Level 4) shows the lowest current. In Figure (B), the maximum power (Pmax) gradually decreases with increasing humidity, indicating a clear effect on the output power. This decrease in power is associated with a decrease in both voltage and current at the maximum power point. We also note that the shape of the curve becomes less steep and more distorted at high humidity, reflecting the presence of additional losses in the system. These results demonstrate that humidity reduces the efficiency of solar cells due to water vapor absorption of light, reducing the effective radiation incident on the cell, and potentially causing changes in the cell's surface properties. Therefore, humidity control is recommended to improve the performance of photovoltaic systems, especially in regions with humid climates.



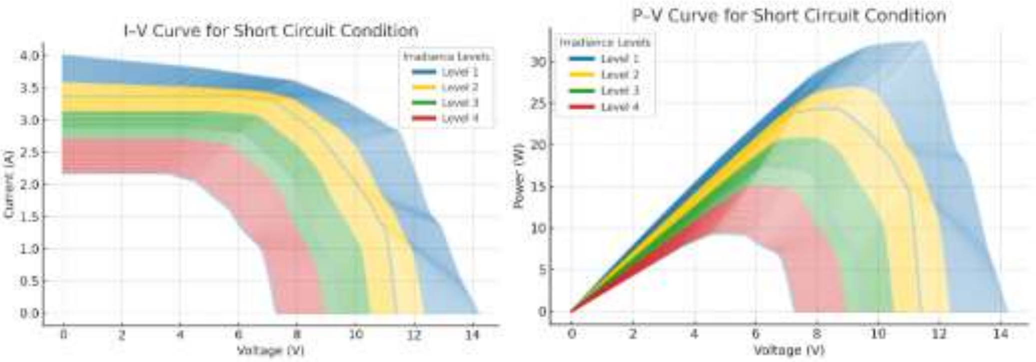
(b) **(a)**

Figure **(3.5): The effect of humidity on solar panels . (I-V curve) and (P-V curve)**

III .2.4.Short circuit

The electrical curves of a solar cell in a short circuit are an important diagnostic tool for understanding the performance of a photovoltaic system. Figure (A) shows the current-voltage (I-V) curve under varying irradiance levels. The short-circuit current (Isc) increases directly with the intensity of light radiation, reaching its highest value at the maximum irradiance level (Level 4) and its lowest value at the minimum level (Level 1). The curve has a constant linear slope, reflecting the nature of the cell's internal resistance, with a clear intersection with the voltage axis at the theoretical open-circuit voltage.Figure (B) shows the power-voltage (P-V) curve, revealing a nonlinear relationship where the power reaches near-zero values in this case. The curve exhibits an inverted hyperbolic shape with a weak peak representing the transition point between the two modes of cell operation. It is worth noting that the area under the curve is almost zero, indicating a near-total loss of useful electrical power.

These results confirm that short circuits are a practically undesirable situation, as the absence of an effective potential difference prevents the exploitation of the generated photovoltaic energy. They also highlight the importance of short circuit protection systems in practical solar system designs. These curves provide valuable data for energy engineers to understand the internal properties of cells and develop more efficient and safer systems.

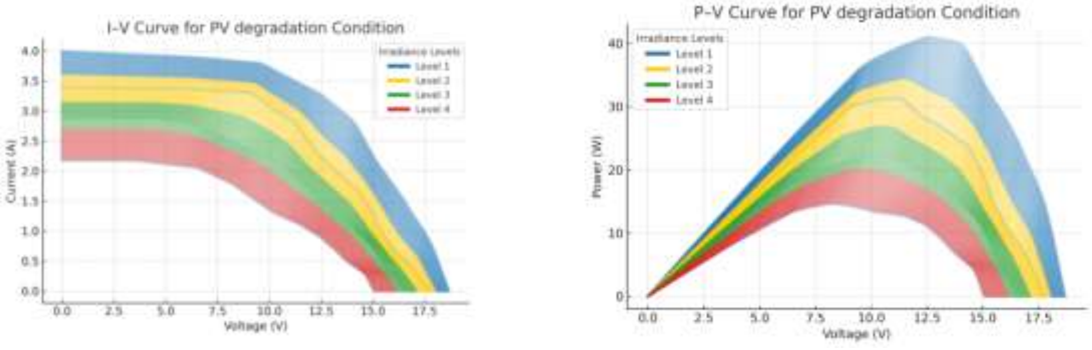


(a) **(b)**

Figure (3.7): The effect of short circuit on solar panels (I-V curve) and (P-V curve)

III .2.5.Degradation

Figure A shows the relationship between current (A) and voltage (V) for four irradiance levels (Level 1 to Level 4) under photovoltaic cell degradation conditions. We observe that the current decreases with increasing voltage, a typical behavior for solar cells due to increased internal resistance. Higher irradiance levels (such as Level 1) exhibit higher current at lower voltages, reflecting higher energy conversion efficiency. Degradation is demonstrated by a decrease in current at the same voltage levels compared to ideal conditions, indicating a loss in performance due to factors such as corrosion or cracking. Figure B (P-V Curve) :Figure B shows the relationship between power (W) and voltage (V) for the same irradiance levels. We observe a peak power point (MPP) for each level, whose value decreases as the irradiance level decreases. Degradation is evident by a decrease in the maximum power and its shift toward lower voltages, indicating a loss in efficiency. The curve also shows a variation in the peak shape, becoming flatter with degradation, reflecting increased heat loss or junction resistance. The results confirm that degradation negatively impacts cell performance, as the peak current and power decrease as the curve characteristics change. These analyses are the basis for assessing cell life and improving their maintenance.



(a) **(b)**

Figure (3.9): Effect of photovoltaic cell degradation . (I-V curve) and (P-V curve)

III .3.Conclusion:

This study highlights the importance of advanced diagnostic techniques in enhancing the performance and reliability of photovoltaic systems. By leveraging artificial intelligence alongside real-time I-V data extraction using a DC/DC buck-boost converter, the proposed approach enables accurate fault detection and efficient system optimization. Ultimately, this contributes to reducing maintenance costs and promoting smarter, more sustainable management of solar energy resources

General Conclusion

General Conclusion:

In conclusion, this study has thoroughly examined the impact of various operating condition changes on the performance of photovoltaic cells. Through the analysis of factors such as temperature fluctuations, irradiance levels, and environmental conditions, it is clear that these variables play a crucial role in determining the efficiency and overall effectiveness of photovoltaic systems. By understanding how these conditions affect the conversion of solar energy into electrical power, this research provides valuable insights into optimizing the operation and longevity of photovoltaic cells.

The findings highlight the complex relationship between the operating conditions and the performance of solar cells, emphasizing the importance of careful monitoring and adjustment of these factors to achieve maximum energy production. This study also suggests that further advancements in materials and technology could mitigate some of the negative effects of operating condition variations, leading to more robust and efficient solar energy systems.

Moreover, this research underscores the significance of considering local environmental conditions when designing and deploying photovoltaic systems, especially in regions with fluctuating weather patterns. By integrating this knowledge, we can improve the reliability and performance of solar power generation, contributing to the global shift towards more sustainable energy solutions.

Ultimately, the study serves as a stepping stone for future research aimed at enhancing the efficiency of photovoltaic cells under varying operational conditions, paving the way for more sustainable and economically viable solar energy systems. The insights gained from this study are expected to be valuable for both the academic community and industry professionals working to improve solar technology and its widespread adoption.

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ملخص

تهدف هذه المذكرة إلى دراسة تأثير تغيرات ظروف التشغيل على أداء الخلايا الكهروضوئية. حيث تم تحليل عدة عوامل بيئية مثل درجة الحرارة، الإشعاع الشمسي، الغبار، الظل، الرطوبة، والتدهور الطبيعي. وتوصلت الدراسة إلى أن هذه العوامل تؤثر بشكل كبير على كفاءة الخلايا الشمسية وقدرتها على إنتاج الكهرباء. تم استخدام نموذج تجريبي يعتمد على تحويل تيار-جهد (I-V) في الزمن الحقيقي باستخدام محول "Buck-Boost" وتحليل النتائج اعتماداً على تقنيات الذكاء الاصطناعي. النتائج تؤكد أن تحسين أداء الخلايا يتطلب صيانة دورية، مراقبة دقيقة، واعتماد نماذج ذكية لتتبع الأعطال وتحسين الكفاءة، مما يعزز من موثوقية واستدامة أنظمة الطاقة الشمسية.

الكلمات المفتاحية|

الخلايا الكهروضوئية، الإشعاع الشمسي، درجة الحرارة، الغبار، الظل، الرطوبة، التدهور، الكفاءة، محول Buck-Boost، تتبع نقطة القدرة القصوى.

Summary:

This thesis investigates the impact of operational condition changes on the performance of photovoltaic (PV) cells. It analyzes several environmental factors such as temperature, solar irradiance, dust, shadow, humidity, and natural degradation. The study shows that these conditions significantly influence the efficiency and electrical output of solar cells. An experimental setup using a real-time I-V data extraction system with a Buck-Boost converter and AI-based diagnostics was applied. The findings highlight the importance of regular maintenance, precise monitoring, and advanced fault-detection strategies to ensure better reliability and energy yield from PV systems under diverse conditions.

Keywords :Photovoltaic cells, solar irradiance, temperature, dust, shading, humidity, degradation, efficiency, Buck-Boost converter, maximum power point tracking