ISSN NO. 2320-5407
Journal Homepage: -www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
**Article DOI:**10.21474/IJAR01/21227
**DOI URL:** http://dx.doi.org/10.21474/IJAR01/21227

*RESEARCH ARTICLE*

# CONTRIBUTION TO THE MODELING AND OPTIMIZATION OF A PHOTOVOLTAIC ENERGY SYSTEM INTEGRATED WITH THE POWER GRID OF THE REPUBLIC OF CONGO: A CASE STUDY OF DENIS SASSOU NGUESSO UNIVERSITY

**Kani Mboyo Ursula Vanelie[1], Mankiti Fati Aristide[1,2,3,4] and Nsongo Timothee[1,4]**

1. Laboratory of Mechanics, Energy, and Engineering at the Higher National Polytechnic School Marien NGOUABI university, Brazzaville, Republic of Congo
2. Laboratory of Electronic and Electrical Engineering of the High Polytechnic School of Congo Brazzaville from Marien NGOUABI University, Brazzaville, P.O. Box 1234
3. Department of Engineering in Electronic and Telecommunication, Mastech Advanced Institute of Technology, Accra, GHANA
4. Department of telecommunication, Admitelecom Academy, Accra.

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## *Manuscript Info*

*Manuscript History*
Received: 16 April 2025
Final Accepted: 19 May 2025
Published: June 2025

*Key words:-*
Reflective Mirrors, Gridintegration, Energy Efficiency, Photovoltaic System Optimization, Denisassou Nguesso University

## *Abstract*

This paper presents a contribution to the modeling and optimization of a grid-connected photovoltaic (PV) power generation system. A comparative study was conducted through simulations using PVsyst software, yielding promising results. Additionally, an experimental investigation involved positioning a flat mirror 10 meters from a PV panel to enhance the incident irradiance, thereby increasing the available energy for storage. The experiment demonstrated an irradiance boost of 15.2%, highlighting the potential of this approach for the future photovoltaic plant installation at Denis Sassou Nguesso University. The simulation results enabled optimal sizing of the PV system tailored to the site conditions. PVsyst also facilitated the simulation of current-voltage (I–V) and power-voltage (P–V) characteristics under varying solar irradiance and ambient temperature, which are critical parameters for assessing PV generator performance in different climatic scenarios. Although this work does not claim novelty in PV system modeling and optimization, the integration of reflective surfaces in a grid-connected configuration represents an innovative contribution. This approach offers promising prospects for enhancing the energy yield of PV installations, especially in regions with high solar irradiance variability. The electrical engineering research community is encouraged to further investigate and validate this innovative method to advance its practical application.

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**Corresponding Author:- Kani Mboyo Ursula Vanelie**
Address:- Laboratory of Mechanics, Energy, and Engineering at the Higher National Polytechnic School Marien NGOUABI university, Brazzaville, Republic of Congo.

## Introduction:-

In our effort to contribute to the reduction of instability in the supply of electrical energy in developing countries in general, and in the Republic of Congo in particular, we have focused our research on the modeling and optimization of sustainable energy systems. Indeed, energy production represents a major strategic challenge for the coming decades, especially due to the continuous growth in energy demand within industrialized societies. Moreover, developing nations will require a significant increase in their energy production capacity to support their economic and social development processes (Programme des Nations Unies pour le Développement, n.d.).

Currently, a large portion of the world's energy production is based on fossil fuel sources, whose consumption generates greenhouse gas emissions, thereby contributing to environmental degradation and the gradual depletion of natural resources. This situation necessitates a transition toward renewable and sustainable energy sources (Programme des Nations Unies pour le Développement, n.d.).

In this context, Congo's national energy policy aims to increase access to electricity to 95% in urban areas and 70% in rural areas by 2040, while promoting regional interconnection to achieve a production capacity of approximately 2,500 MW. Although this strategy primarily relies on the country's abundant hydroelectric and natural gas resources, other energy sources such as solar energy should also be further developed. It is worth noting that the Republic of Congo has an average annual solar irradiation estimated at 4.7 kWh/m²/day, which constitutes a substantial solar potential (Programme des Nations Unies pour le Développement, n.d.).

However, access to reliable electricity remains a challenge due to frequent power outages resulting from the limited national production capacity. This issue particularly affects large urban centers and critical infrastructures such as Denis Sassou-Nguesso University (Programme des Nations Unies pour le Développement, n.d.).

This article addresses the issue by proposing a contribution to the modeling and optimization of a photovoltaic system connected to the national electrical grid, using Denis Sassou-Nguesso University as a case study. The main objective is to assess the technical feasibility of such a solution and to optimize its performance.

To achieve this, our methodological approach is structured in several steps:

- ✓ sizing of the study area to determine the parameters required for simulation (available surface, solar irradiation, panel orientation, etc.);
- ✓ simulation of current-voltage (I–V) and power-voltage (P–V) characteristics as a function of solar irradiance and ambient temperature;
- ✓ integration of a flat mirror into the system to increase the irradiance received by the photovoltaic modules.

This work will begin with a literature review to identify previous contributions on similar systems, allowing us to position our research within the current scientific and technological context (Siregar, Hutahuruk, & Suherman, 2021; Zidane et al., 2020; Karunakaran, Karunakaran, & Cassidy, 2022).

## Literature Review:-

From the atomic theory of Democritus of Abdera [Furley, 2022] to the foundational experiments of Edmond Becquerel, who in 1839 observed the generation of electric current under solar radiation [Buisseret and Englebert, n.d.], and culminating in Albert Einstein's groundbreaking 1905 paper on the photoelectric effect which earned him the Nobel Prize in Physics in 1921 [Buisseret and Englebert, n.d.], scientific progress has significantly advanced our understanding of the mechanisms by which light energy is converted into electrical energy.

Prior to Einstein's contribution, light was predominantly considered a wave phenomenon. His work revealed that light also consists of elementary particles, known as photons. When these photons possess sufficient energy, proportional to their frequency, they can dislodge electrons from a metallic surface upon contact, thereby generating an electric current, a phenomenon now known as the photoelectric effect [Buisseret and Englebert, n.d.].

This discovery has enabled a wide range of technological applications, particularly in electronics, through the use of semiconductors whose conductive properties vary under external stimuli. Modern computing systems are largely based on transistors, which form the fundamental building blocks of integrated circuits. Moreover, photovoltaic modules directly exploit the photoelectric effect to convert solar energy into electricity, which is the principal focus of the present study.

Recent research has increasingly focused on the hybridization of photovoltaic systems with hydroelectric sources, as well as their interconnection with national electrical grids. For instance, Siregar, Hutahuruk, and Suherman [2021] conducted an optimization and simulation study of a photovoltaic system deployed at the artificial lake of Universitas Sumatera Utara (USU), covering a surface area of 600 m². Their optimal configuration used mono-crystalline silicon modules rated at 310 Wp and 27 V, installed at a tilt angle of 5°, achieving an annual energy output of 144.21 MWh.

Zidane et al. [2020] proposed a design methodology aimed at maximizing energy performance while minimizing investment and operational costs. Their approach incorporated semi-hourly meteorological data and detailed technical specifications of PV modules and inverters. The study employed a multi-objective optimization strategy based on the Levelized Cost of Energy (LCOE) and annual energy yield. Design variables included the number of series and parallel modules, module arrangement, tilt angle, orientation, and inverter configuration. A hybrid algorithm combining the Grey Wolf Optimizer and the Sine-Cosine Algorithm was used to solve the optimization problem, resulting in a cost reduction of approximately 12% compared to traditional methods.

In another contribution, Rui Li and Fangyuan Shi [2019] investigated the performance optimization of a residential photovoltaic system operating at a 1500 V DC bus voltage. The system architecture integrated photovoltaic panels, a three-phase three-level boost converter, an isolated bidirectional DC-DC converter, energy storage components, and a three-phase five-level DC-AC inverter capable of both grid-connected and islanded operation. Increasing the DC bus voltage significantly reduced line losses and improved system efficiency. An energy management system was also implemented to ensure operational stability and enhance economic performance. In low-voltage battery configurations, LLC and CLLC converter topologies were assessed under DCX transformer mode, with the LLC topology ultimately selected due to superior efficiency and voltage output. An optimized design methodology was also proposed and experimentally validated.

Zidane et al. [n.d.] further contributed a comprehensive review of optimization strategies for photovoltaic systems, addressing sizing of components, module tilt angles, inverter selection, transformer specifications, and cabling configurations. Their work included a comparative analysis of inverter topologies commonly used in such installations.

Karunakaran, Karunakaran, and Cassidy [2022] focused on increasing the efficiency of standalone photovoltaic systems in off-grid rural regions. In equatorial Malaysia, for instance, consistent cloud cover limits solar performance. The authors examined several solutions, including solar tracking technologies, digitization of system monitoring, enhanced maintenance protocols, and the use of artificial intelligence. Maximum Power Point Tracking (MPPT) systems were also recommended to optimize power extraction under varying environmental conditions.

Essakhi and Farhat [2019] developed a mathematical model of photovoltaic modules using nominal manufacturer data such as open-circuit voltage, short-circuit current, and maximum power point values. This model allows simulation of I-V and P-V characteristics as functions of irradiance and temperature, and can be integrated into renewable energy systems for system-level analysis.

In light of these contributions, it is evident that most studies converge on the modeling, optimization, and integration of photovoltaic systems to improve their efficiency and reliability. The present work proposes the deployment of a grid-connected photovoltaic system to ensure continuous electricity supply to Denis Sassou Nguesso University in the Republic of Congo. An innovative feature is introduced: the integration of flat mirrors into the photovoltaic array to enhance solar irradiance, thereby improving the overall energy efficiency of the system.

## Theoretical Background

### Operating Principle of a Photovoltaic System

The primary objective of a photovoltaic system is to convert solar energy into electrical energy. Its operating principle can be summarized in six essential steps (Kalogirou, 2020):

- ✓ Solar Panels: Photovoltaic modules, composed of solar cells, capture solar radiation. These cells are typically made from silicon, a semiconductor material whose properties are favorable for energy conversion.
- ✓ Photovoltaic Effect: When photons from sunlight strike the photovoltaic cells, they excite the electrons within the silicon, thereby generating an electric current. This phenomenon is known as the photovoltaic effect.
- ✓ Direct Current (DC): The electricity produced by the solar cells is in the form of direct current (DC). This current is then directed to an inverter for conversion.

- ✓ Inverter: The inverter converts the direct current (DC) into alternating current (AC), which is the standard form of electricity used by most electrical appliances and power distribution networks.
- ✓ Distribution: The alternating current (AC) is then distributed either for immediate use by electrical loads or injected into the national power grid.
- ✓ Storage: In certain configurations, excess electricity can be stored in batteries for later use, particularly during periods of low solar irradiance (e.g., at night or during overcast conditions).

This process enables the efficient utilization of solar energy, a renewable and environmentally sustainable resource, by converting it into usable electrical power for residential buildings, industrial facilities, and public infrastructure.
Within the scope of the present study, the objective is to provide electricity to the campus of Denis Sassou Nguesso University. To enhance the overall efficiency of the system, an innovative component is integrated: a flat mirror, strategically positioned to increase the solar irradiance received by the photovoltaic panels, as illustrated in Figure 1.

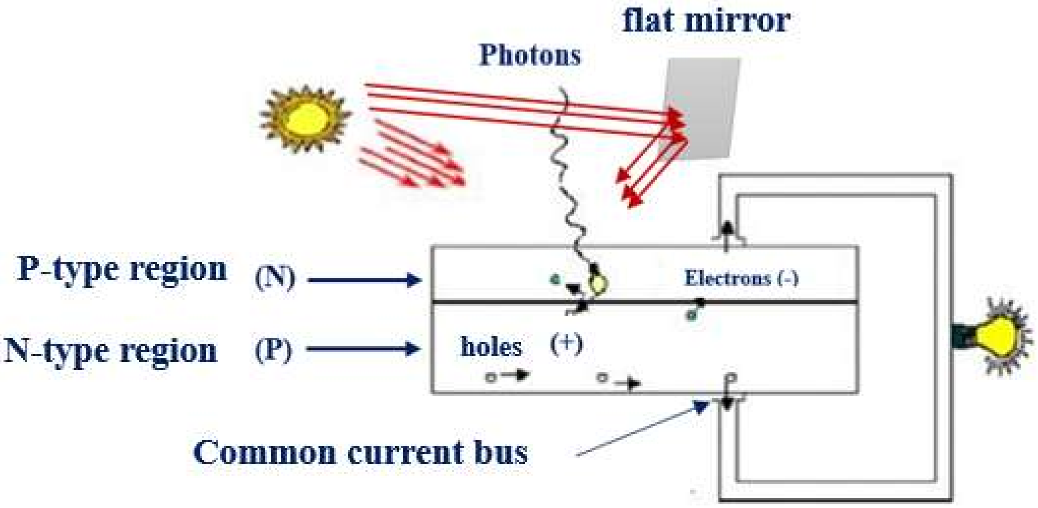

**Figure 1:-**Schematic Representation of a Solar Cell with Integrated Planar Mirror.

### Modeling of a Photovoltaic Cell

### Case of ideal cell

In the ideal case, a photovoltaic cell with a PN junction exposed to light and connected to a load can be modeled as a current source $I_{Ph}$ in parallel with a diode. This configuration is illustrated in Figure 2, which shows the equivalent circuit of an ideal solar cell (Angel & Pastor, 2006):

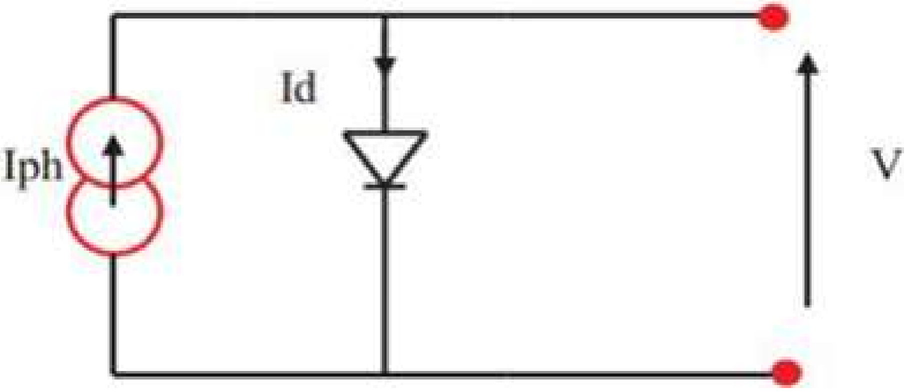

**Figure 2:-** Equivalent circuit diagram of an ideal solar cell (Angel & Pastor, 2006).

The equations adopted for this model are:

$$I_{PV} = I_{Ph} - I_d \qquad (1.1)$$

The photocurrent$I_{Ph}$ is assumed to be equal to the short-circuit current $I_{SC}$ under the condition $V_{PV} = 0$, which corresponds to a short-circuited load.

$$I_{Ph} = I_{SC} = \frac{E}{E_{ref}} \tag{1.2}$$

Where:
$E$: the irradiance absorbed by the cell
$E_{ref}$ : the reference irradiance (1000 W/m²)

$$I_{Ph} = I_0\left[exp\left(\frac{vd}{vt}\right) - 1\right] \tag{1.3}$$

In the formula (1.3), $I_0$ is the reverse saturation current of the diode, expressed in amperes.

$$V_t = \frac{NKT}{q} \tag{1.4}$$

Where:

$V_t$ :Thermal voltage expressed in volts (V)
N : Ideality factor of the photovoltaic cell
K : Boltzmann constant $(1.38.10^{-23} J/K)$
q : Electron charge $(1.6.10^{-19} C)$

**Case of a real solar cell**

AThe performance of a solar cell is limited by the influence of two physical phenomena, which can be modeled as two resistances: the series resistance $R_S$ and the shunt resistance $R_{Sh}$, as illustrated in Figure 3 (Zidane et al., 2020)

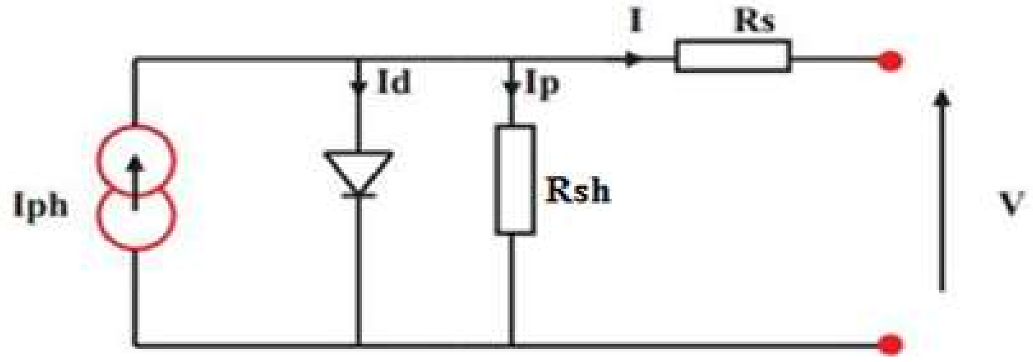

**Figure 3:-** Equivalent circuit of a real solar cell (Angel & Pastor, 2006).

Where:

$R_S$: Series resistance, primarily caused by Joule losses within the current collecting grids, the intrinsic resistance of the semiconductor materials, and poor contact between the semiconductors and the electrodes (Angel & Pastor, 2006).

$R_{Sh}$: Parallel resistance, also referred to as shunt resistance, accounts for recombination losses. These losses are mainly attributed to the cell's thickness, surface effects, and non-idealities of the PN junction (Angel & Pastor, 2006).

$$I = I_{Ph} - I_S[exp\left(\frac{q(V+R_S I)}{AkT}\right) - 1] - \frac{V+R_S I}{R_{Sh}} \tag{1.5}$$

Where:

- ✓ $\boldsymbol{I_{Ph}}$: The photocurrentgenerated by the diode, expressed in amperes (A)
- ✓ $\boldsymbol{I_S}$: The diode's reverse saturation current, expressed in amperes (A)
- ✓ $\boldsymbol{q}$: The elementary charge of an electron (1.603 × $10^{-19}$ C)

- ✓ $\boldsymbol{A}$: The diode ideality factor, which depends on the diode's technology (material) and typically ranges between 1 and 2
- ✓ $\boldsymbol{K}$: Boltzmann's constant (1.38 × $10^{-23}$ J/K)

The photocurrent$I_{Ph}$ varies with temperature according to equation (1.6):

$$I_{Ph} = \frac{G}{G_{ref}}\left(I_{SC} + \alpha_i\left(T - T_{ref}\right)\right) \qquad (1.6)$$

Where:

$\boldsymbol{I_{SC}}$: The standard short-circuit current (under standard test conditions)
$\boldsymbol{T_{ref}}$: The reference temperature (298.15 K)
$\boldsymbol{\alpha_i}$: The temperature coefficient of the short-circuit current (A/K)
$\boldsymbol{G_{ref}}$: : The reference irradiance (1000 W/m²)
$\boldsymbol{G}$: The actual irradiance (in watts per square meter, W/m²)

The saturation current$I_S$ varies with temperature according to equation (1.7):

$$I_S = \frac{I_{SC} + a_v(T - T_{ref})}{exp\left(\frac{V_{0C} + a_V(T - T_{ref})}{AkT}\right) - 1} \qquad (1.7)$$

Where:

- ✓ $\boldsymbol{V_{0C}}$: The open-circuit voltage of the cell, expressed in volts (V)
- ✓ $\boldsymbol{a_v}$: The temperature coefficient of the open-circuit voltage (V/K)

The output current (in amperes, A) of a PV panel composed of **N** cells connected in parallel is given by the following equation:

$$\mathrm{I} = \mathrm{I_{Ph}} - \mathrm{I_S}\left(\exp\left(\frac{\mathrm{q(V_m + R_S)I}}{\mathrm{NAkT}}\right) - 1\right) - \frac{\mathrm{V_m + R_S I}}{\mathrm{R_{Sh}}} \qquad (1.8)$$

The output power P delivered by the panel is the product of the maximum power point voltage ($\mathrm{V_m}$) and the current (I), expressed in watts (W).

**Maximum Power Point Tracking System.**

The output power of a photovoltaic (PV) panel is highly dependent on climatic conditions (solar irradiance and temperature) as well as the electrical load. The power–voltage (P–V) characteristic curve of a PV panel (Figure 0.3) exhibits a unique point referred to as the Maximum Power Point (MPP) for each specific irradiance and temperature condition, at which the panel delivers its maximum power output. This point is defined by a current ($I_{MPP}$) and a voltage ($V_{MPP}$) that continuously vary with the panel's operating conditions (Bratt, 2011).

To ensure that the panel operates at this optimal point and consistently delivers its peak power, a Maximum Power Point Tracking (MPPT) system is required. An MPPT system typically includes a real-time tracking algorithm to identify the MPP, coupled with a power electronic converterusually a DC-DC converter (such as a buck, boost, or buck-boost converter)which adjusts the electrical operating point of the PV module accordingly (Bratt, 2011).
The principle of this control strategy is based on the automatic variation of the duty cycle α, driving it towards its optimal value in order to maximize the power output delivered by the PV panel (Bratt, 2011).
Figure 4 illustrates the schematic diagram of a conventional MPPT converter. The MPPT controller adjusts the duty cycle of the static (DC) converter using an appropriate electrical signal to extract the maximum power that the photovoltaic generator can provide.

The MPPT algorithm can vary in complexity depending on the method used to track the Maximum Power Point (MPP). In general, it relies on varying the converter's duty cycle according to the evolution of its input parameters (current and voltage, and consequently the power of the PV generator) until it reaches the MPP (Bratt, 2011).

**Operating Factors of Solar Cells**

Solar cells, also referred to as photovoltaic cells, convert sunlight into electricity through the photovoltaic effect. Various factors influence their operation and efficiency, including but not limited to the following:

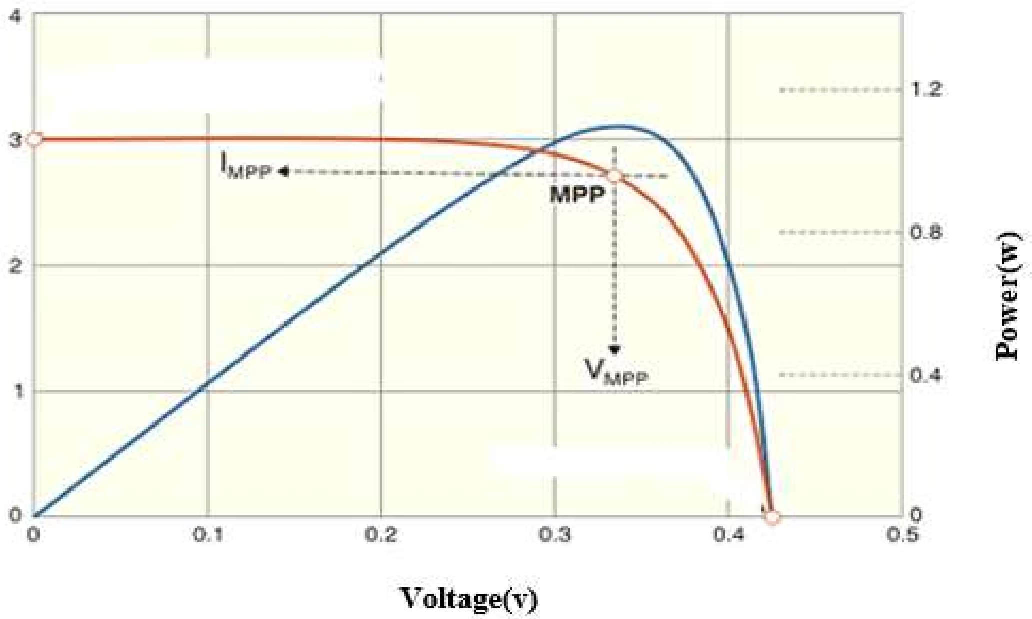

**Figure 4:-** MPPT Power Characteristic Curve (Bratt, 2011).

### Solar irradiance

The amount of sunlight received is critical. The higher the solar irradiance, the greater the energy production. This irradiance on solar panels, also referred to as solar irradiance, is commonly expressed in terms of power per unit area. The mathematical relationship that defines solar irradiance is given by(Bratt, 2011):

E

Where:
**E : represents** the solar irradiance (in watts per square meter, W/m²),
**P :**is the solar power received (in watts, W),
**A :**is the surface area of the solar panels (in square meters, m²).

For photovoltaicsystems, solar irradiance is a key factor thatdetermines the amount of electricalenergyproduced. The efficiency of solar panels depends on solar irradiance, the angle of incidence of sunlight, and the quality of the materialsused in the photovoltaiccells (Bratt, 2011).

### Orientation and Tilt

The angle of incidence of sunlight on the solar panels affects their performance. Optimal orientation maximizes solar exposure. The orientation and tilt of solar panels are crucial to maximizing solar irradiance and, consequently, energy output. The following mathematical expressions are commonly used to determine the optimal tilt and orientation angles of solar panels (Bratt, 2011):

The optimal tilt angle ($\boldsymbol{\beta}$) of solar panels depends on the latitude ($\boldsymbol{\phi}$) of the installation site. A general rule is to set the tilt angle as follows (Bratt, 2011):

$$\boldsymbol{\beta} = \boldsymbol{\phi} \qquad (\mathbf{10})$$

For seasonaladjustments:

**In winter:** $\boldsymbol{\beta} = \boldsymbol{\phi} + \mathbf{15°}$
**In summer:** $\boldsymbol{\beta} = \boldsymbol{\phi} - \mathbf{15°}$

The optimal orientation of solar panels isgenerallytoward the south in the NorthernHemisphere and toward the north in the SouthernHemisphere. The azimuth angle ($\boldsymbol{\gamma}$) is measured relative to due south (0°) in the Northern Hemisphere and due north (0°) in the SouthernHemisphere (Bratt, 2011).

**Temperature**

A solar cell can operate at maximum efficiency if its temperature remains within the normal range (2,500 °C). An increase in temperature beyond this normal level in the photovoltaic cell will reduce the open-circuit voltage (OCV). For every 100 °C increase in the temperature of the solar cells (starting from 2,500 °C), the total energy produced decreases by approximately 0.4%, or the output is halved for every 1,000 °C increase in cell temperature (Li & Shi, 2019) . The characteristic curves of solar cells as affected by temperature variations are illustrated in Fig. 5.

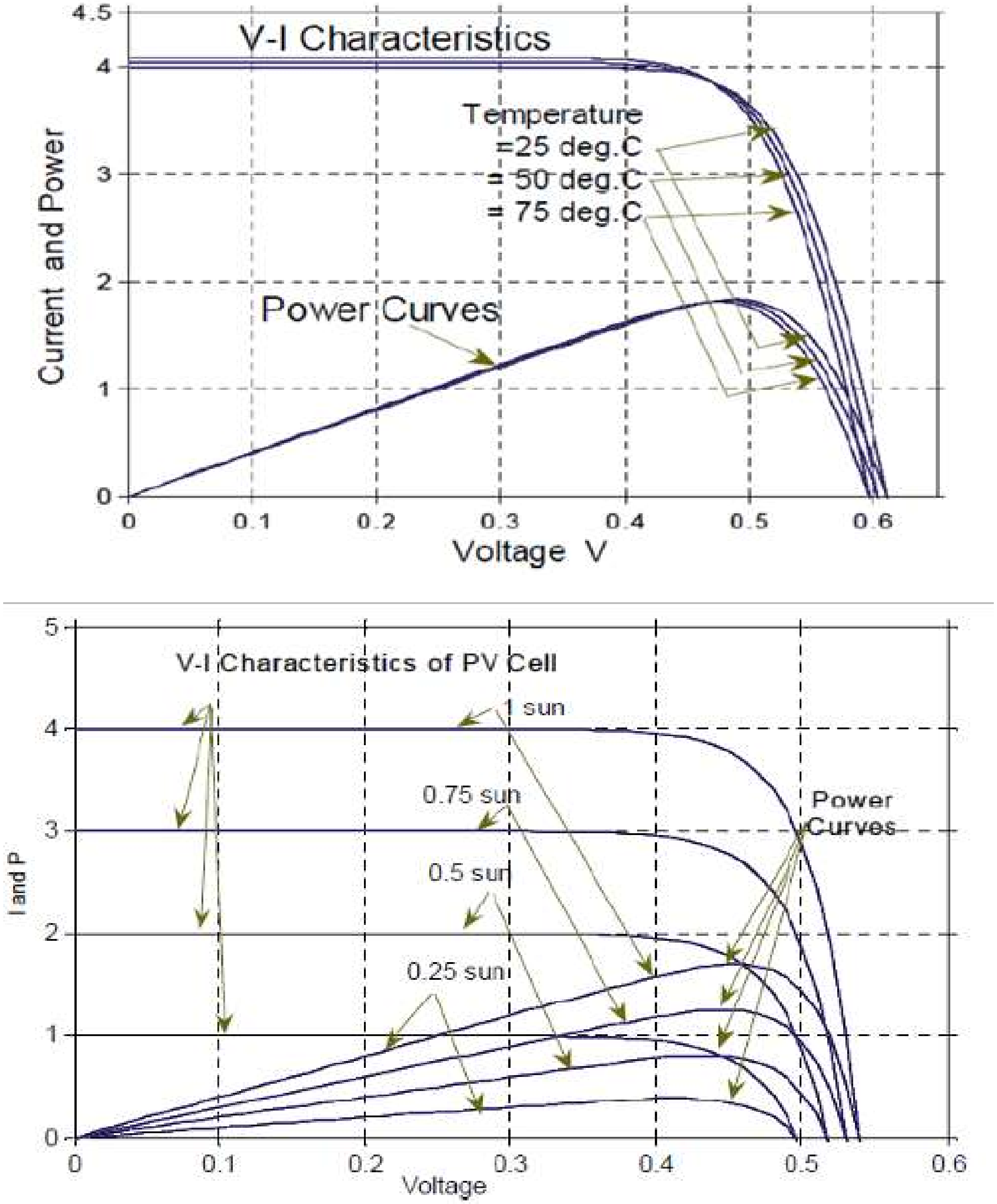

**Figure 5:-** Current–Power Characteristic as a Function of Voltage (Li & Shi, 2019).

**Humidity**

High humidity levels can increase the reflection of sunlight, thereby reducing the amount of light available for conversion into electrical energy (Sara & Jasper, 2020) .

**MaterialQuality**

The materials used in the manufacturing of solar cells, such as silicon, significantly influence their performance. High-quality materials enhance conversion efficiency (Sara & Jasper, 2020)

**Panel Cleanliness**

Dust, dirt, and debris on solar panels can lower their efficiency by obstructing sunlight. These factors demonstrate that in order to maximize the efficiency of solar cells, it is essential to consider sunlight exposure, panel orientation, temperature, humidity, material quality, and panel cleanliness (Sreenath et al., 2020) .

## Methodology:

The methodologyadopted in thisstudyispurelyempirical, utilizingtwo major software tools:**MATLAB** and **PVsyst**. MATLAB isused for data processing, whilePVsystisemployed for acquiringmeteorological data and simulating the grid-connectedphotovoltaic system.

The design of solar power plants depends on several theoretical factors, such as the choice of geographical location, PV modules, inverter quality, and the orientation of the solar panels (Sreenath et al., 2020; Elibol et al., 2022) . In this study, the use of PVsyst offers a major advantage, as it allows for calculations based on these parameters, including climate and geographical resources.

For the purposes of this analysis, we selected a site located at Denis Sassou-Nguesso University in Kintélé (latitude -4.1381° N, longitude 15.3526° E). The solar trajectory conditions at this location are illustrated in Figure 7, along with a simulation flowchart showing the geographic and climatic parameters used through the Meteonorm dataset. PVsyst provides monthly meteorological data with detailed parameters such as wind speed, temperature, global horizontal irradiation (GHI), and diffuse horizontal irradiation (DHI), as shown in Table 1, which presents the monthly meteorological conditions derived from Meteonorm (Elibol et al., 2022).

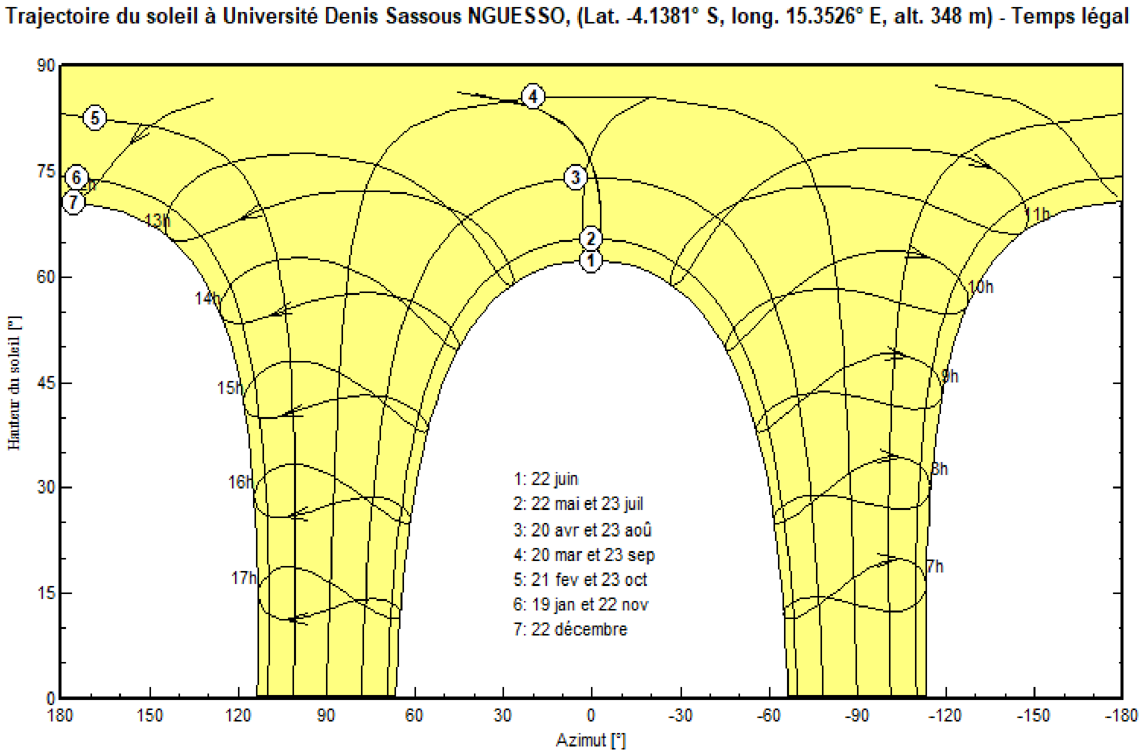

**Figure 6:-**Solar Path Diagram at Denis Sassou-Nguesso University, Kintélé.

Fig. 6 illustrates the apparent solarpath, as well as the trajectory of solar radiation reflected by mirrors, in relation to the placement of photovoltaic panels. The diagramdepicts the position of the Sun in the sky at various times throughout the day and across the year. The horizontal axis represents the solarazimuth, while the vertical axis indicates the solaraltitude (elevation). Plotting the Sun's position at different time intervalsgenerates a curvethatcharacterizesitsdailypath.

Furthermore, the annualmeteorological data for the year 2024 specifically ambient temperature, global horizontal irradiation, diffuse horizontal irradiation, and wind speed are summarized in Table I.1.

**Table1.1:-** Monthly weather from University of Denis Sassou Nguesso.

| Months | Global Horizontal Irradiance (KWh/$m^2$/Mois) | Diffuse Horizontal Irradiance (KWh/$m^2$/Mois) | Temperature(°c) | Wind Speed (m/s) |
|---|---:|---:|---:|---:|
| January | 170,3 | 79,8 | 26,2 | 1,8 |
| February | 147,6 | 82,1 | 26,5 | 2 |
| March | 170,9 | 78 | 26,9 | 1,99 |
| April | 170,5 | 74,8 | 26,4 | 1,9 |
| May | 151,7 | 72,4 | 26,2 | 1,9 |
| June | 137,6 | 73,8 | 23,9 | 2 |
| July | 145,7 | 79 | 23,4 | 2,3 |
| August | 153,1 | 81,3 | 24,3 | 2,59 |
| September | 150,7 | 72,1 | 25,4 | 2,69 |
| October | 159,2 | 78,4 | 26,2 | 2,2 |
| November | 161 | 77,1 | 25,6 | 1,89 |
| December | 154,6 | 77,3 | 25,9 | 1,8 |

Table 1.1 summarizes the monthly meteorological conditions extracted from the Meteonorm database integrated into the PVsyst software, corresponding to the study site without the use of planar mirrors. These data are specific to the geographic location selected for the simulations. The primary climatic parameters considered include global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI), average ambient temperature, and average wind speed. The analysis indicates that global irradiance varies throughout the year, ranging from 137.6 kWh/m²/month in June to 170.9 kWh/m²/month in March, with an annual average of approximately 156 kWh/m²/month. This variation is primarily influenced by solar position, seasonal cloud cover, and atmospheric conditions.

Furthermore, diffuse irradiance accounts for nearly 50% of the total global irradiance on average, reflecting a significant presence of indirect solar radiation typically associated with frequent cloud cover in equatorial regions. Ambient temperatures range from 23.4 °C in July to 26.9 °C in March, values generally favorable for the efficient operation of photovoltaic (PV) modules, although slight performance degradation may occur during periods of elevated thermal stress. Wind speed remains relatively constant throughout the year, fluctuating between 1.8 m/s and 2.69 m/s. This parameter contributes positively to the passive cooling of PV panels, thereby enhancing their thermal performance.

Finally, in Figure 7, histogram-based visualizations were developed to illustrate the seasonal variation of the analyzed climatic parameters.

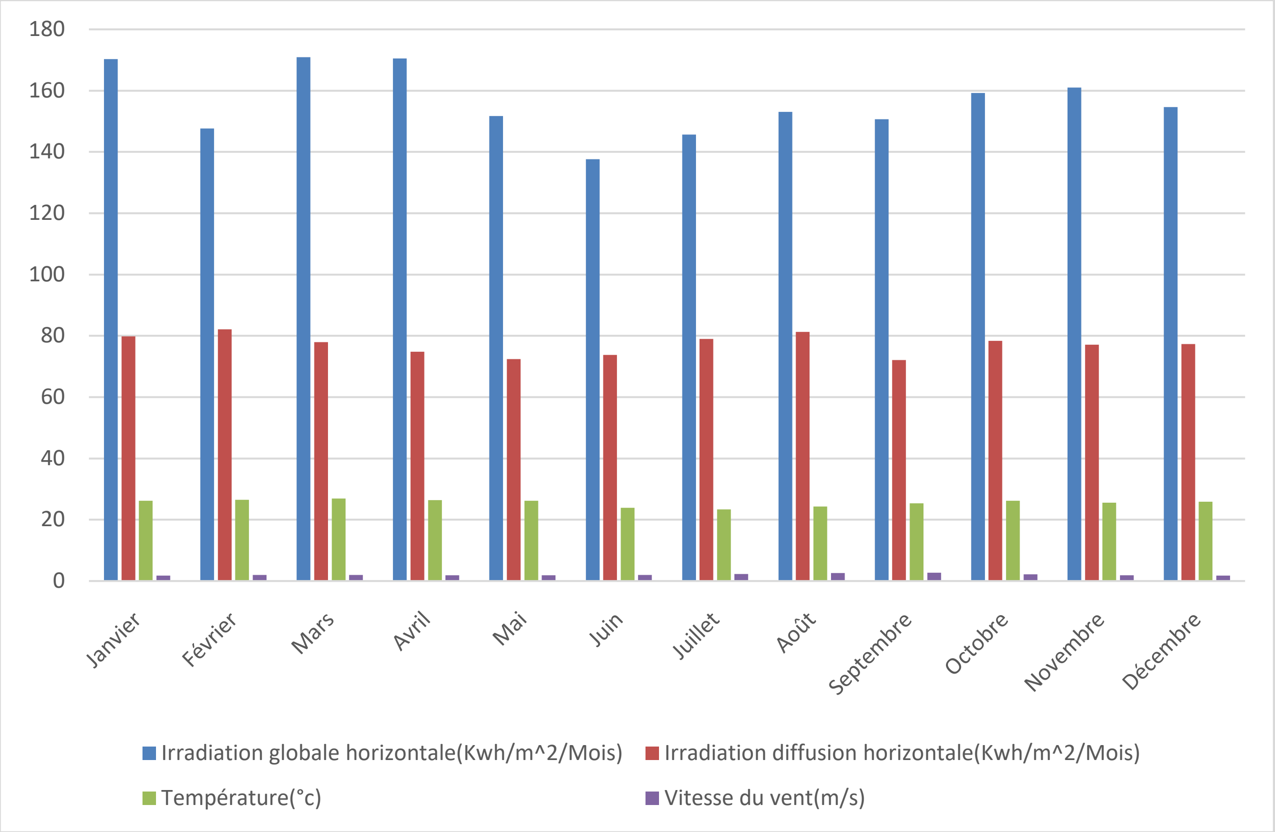

**Figure 7: -** Bar Chart of Monthly Data at Denis Sassou-Nguesso University.

Figure 7 illustrates the monthly variations in global irradiance, diffuse irradiance, ambient temperature, and wind speed, as observed at the Denis Sassou-Nguesso University site in Kintélé. The collected data indicate a strong solar potential throughout the year, with notable peaks in global irradiance occurring in January, March, and April. Ambient temperature remains relatively stable, which is favorable for photovoltaic module performance, although a slight decrease is observed between June and August. A significant portion of the recorded irradiance is attributable to diffuse radiation due to substantial cloud cover, particularly pronounced in February. Wind speed, while moderate overall, reaches a peak in September, thereby contributing to passive cooling of the solar panels, which may enhance their efficiency. Overall, these climatic parameters confirm both the technical feasibility and the relevance of installing a photovoltaic system at this site. While these findings are promising, the potential impact of climate change, which could alter these conditions in the medium to long term, must be considered. As part of this study, we explored the use of flat mirrors placed in front of the photovoltaic panels. This technique aims to increase the incident irradiance on the modules to optimize energy production, especially under low sunlight conditions. Another objective is to enable sufficient energy storage to compensate for periods of low solar irradiation. Figure 8 presents this experimental setup.

This figure illustrates an experiment conducted to enhance the amount of energy available, particularly for storage during periods of low solar irradiance. During this experiment, an increase of 15.2% in incident irradiance was observed. The results are presented in Table 2.

**Tableau2:-** Monthly weather from University of Denis SASSOU NGUESSO after using a mirror in the system.

| Month | Global Horizontal Irradiance (kWh/m²/month) | Diffuse Horizontal Irradiance (+15.2%) | Temperature (°C) | Wind Speed (m/s) |
|---|---|---|---|---|
| **January** | 170.3 | 91.94 | 26.2 | 1.8 |
| **February** | 147.6 | 94.64 | 26.5 | 2.0 |
| **March** | 170.9 | 89.86 | 26.9 | 1.99 |
| **April** | 170.5 | 86.21 | 26.4 | 1.9 |
| **May** | 151.7 | 83.38 | 26.2 | 1.9 |
| **June** | 137.6 | 85.01 | 23.9 | 2.0 |
| **July** | 145.7 | 90.61 | 23.4 | 2.3 |
| **August** | 153.1 | 93.66 | 24.3 | 2.59 |
| **September** | 150.7 | 83.07 | 25.4 | 2.69 |
| **October** | 159.2 | 90.31 | 26.2 | 2.2 |
| **November** | 161.0 | 88.84 | 25.6 | 1.89 |
| **December** | 154.6 | 89.00 | 25.9 | 1.8 |

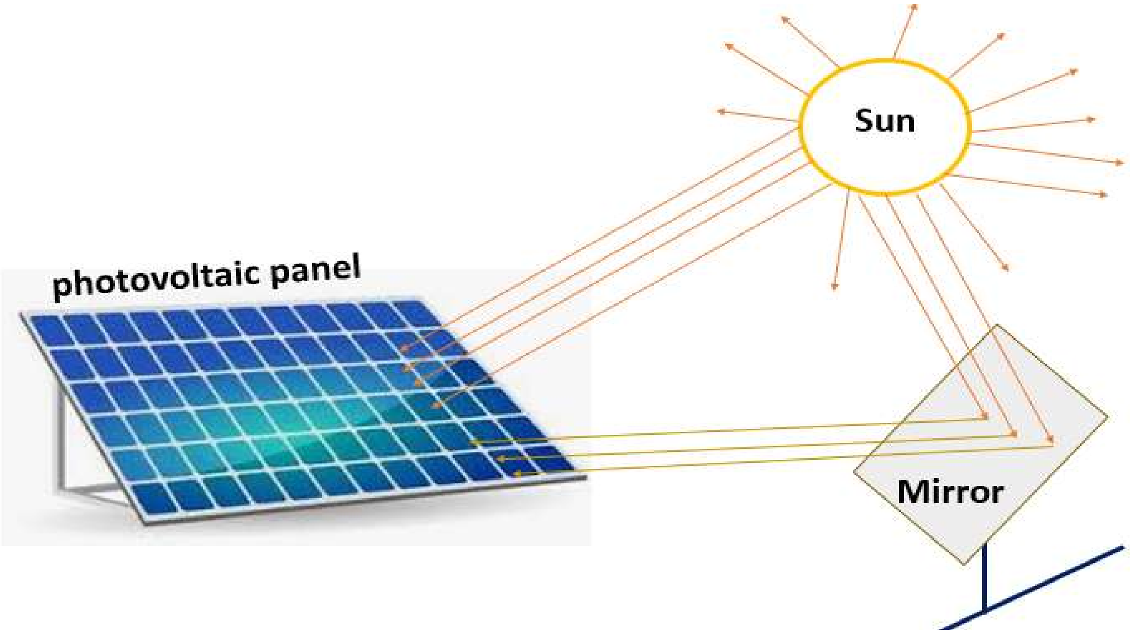

**Figure 8:-** Experimental setup of a photovoltaic panel with a flat mirror positioned 10 meters in front of it..

**Photovoltaic Power Plant Simulation Results**

It shouldbenotedthat, to conduct the simulations, we first defined the sizing of the study area, whichallowed us to collect certain data used for thiswork. Somesizingresults are alreadypresented, including the geographic location with all itscoordinates, the azimuth, tilt, solar insolation, and the system autonomy. The othersizingresults are summarized in Table 3

**Table 3:-** Terrain Sizing Results for Denis Sassou Nguesso University.

| Paramètre | Values | Unit |
|---|---|---|
| Total Power Output | 1768 | KW |
| Operating Time | 12 | Hour |
| Total Energy Consumption | 2040 | KWh |
| Peak Power | 755,555 | Wc |
| System Voltage | 512 | Volt |
| Number of Panels | 1511 | Panels |
| Battery Capacity | 4427 | Ah |
| Number of Battery Banks (//) | 15 | parcs |
| Number of Inverters | 5 | Inverters |

The terrain sizing results enabled the simulations to be conducted using PVsys software, version 7.4. The first simulation focuses on evaluating the current and voltage as a function of the incident irradiance, as shown in Fig. 9.

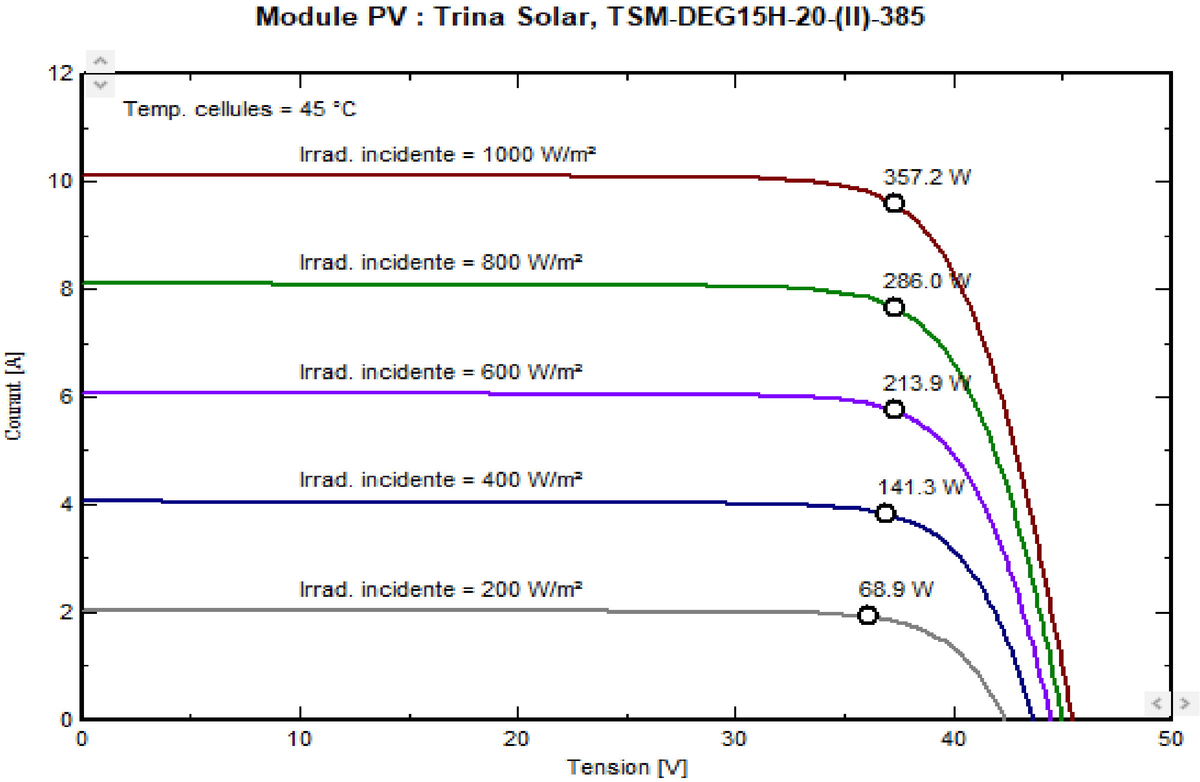

**Figure 9:-** I–V Characteristic of the PV Cell Array at the Kintele Site.

Figure 8 illustrates the current–voltage (I–V) characteristics of the photovoltaic (PV) cell. It can be observed that the voltage reaches its maximum value, referred to as the open-circuit voltage (Voc), when the current is zero. Conversely, when the voltage is zero, the current attains its maximum value, known as the short-circuit current (Isc). The point at which the product of current and voltage is maximized corresponds to the Maximum Power Point (MPP), representing the optimal operating condition of the PV module.

A key feature of the proposed system is the integration of a planar mirror array, which reflects solar radiation onto the surface of the PV panels, thereby increasing the incident irradiance. This enhancement is proportional to the incoming light intensity, as the photocurrent generated by the cell is directly related to the photon flux.

In addition to the I–V response under varying irradiance, Figure 10 presents the influence of temperature on both current and voltage, highlighting the thermal sensitivity of the PV system.

Figure 10 illustrates the influence of temperature on the current–voltage (I–V) characteristics of the photovoltaic system. As indicated in Table 1, the average temperature recorded during the study was 25.575 °C. The integration of mirror-based enhancement technology contributes to maintaining the cell temperature within an optimal operating range, thereby promoting system efficiency.

It can be observed that for voltage values ranging from 0 to 35 V, the temperature remains relatively stable. However, between 40 and 50 V, a gradual decrease in temperature is noted. It is well established that photovoltaic cells operate more efficiently at lower temperatures, as higher voltage levels can be sustained, leading to greater power output. Consequently, the thermal conditions observed during this study are considered favorable for efficient energy conversion.

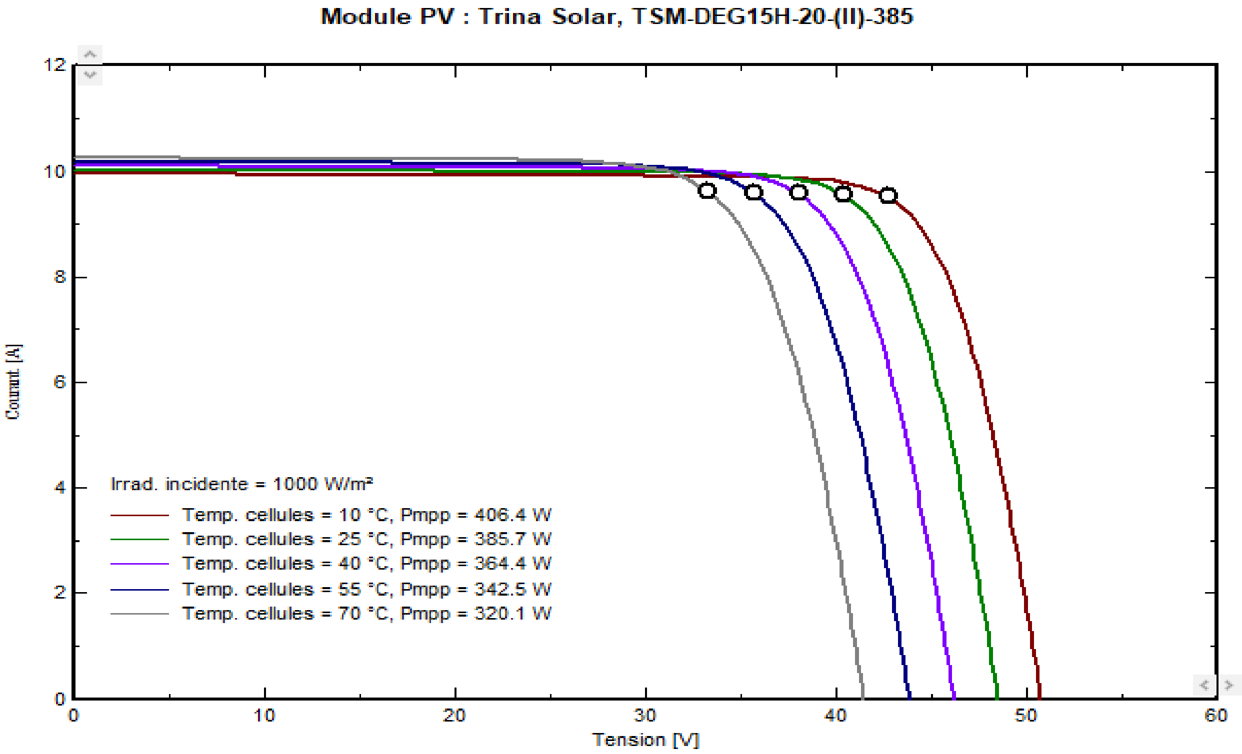

**Figure 10:-** Current–Voltage Characteristics as a Function of Temperature.

To complementthese observations, Figure 11 presents the effect of incident irradiance on the electrical power generated by the photovoltaic system.

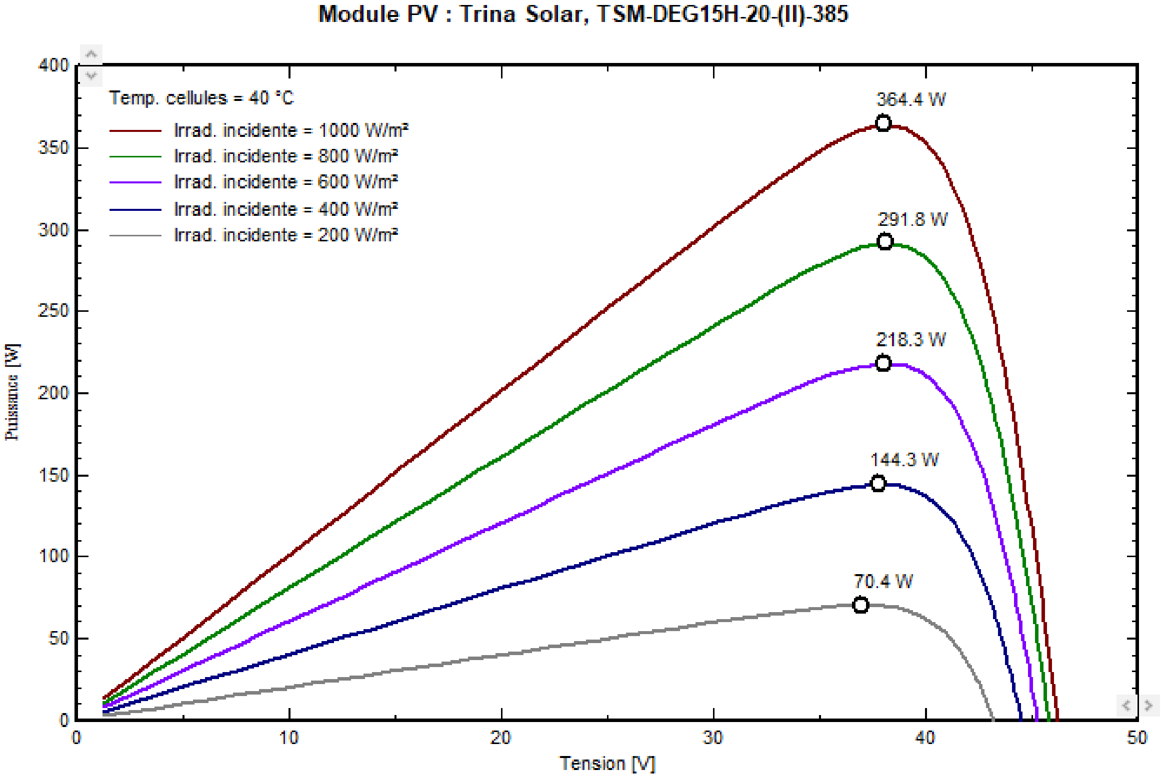

**Figure 11:-** Power–Voltage Variation as a Function of Incident Irradiance.

**Figure 11** illustrates the variation of output power as a function of voltage under different levels of incident irradiance. This curve is derived by point-wise multiplication of current and voltage values from the corresponding I–V characteristics, aiming to assess the influence of solar irradiance on the performance of the photovoltaic cell. It is observed that the power curve exhibits a distinct maximum at point M ($x_{MPP}$ , $y_{MPP}$ ), known as the Maximum Power Point (MPP). Furthermore, the implementation of the mirror technique led to an increase in irradiance, thereby significantly enhancing energy production. To deepen the analysis, the variation of power with respect to voltage under different temperature conditions (P–V curve) is also examined, as presented in **Figure 12**.

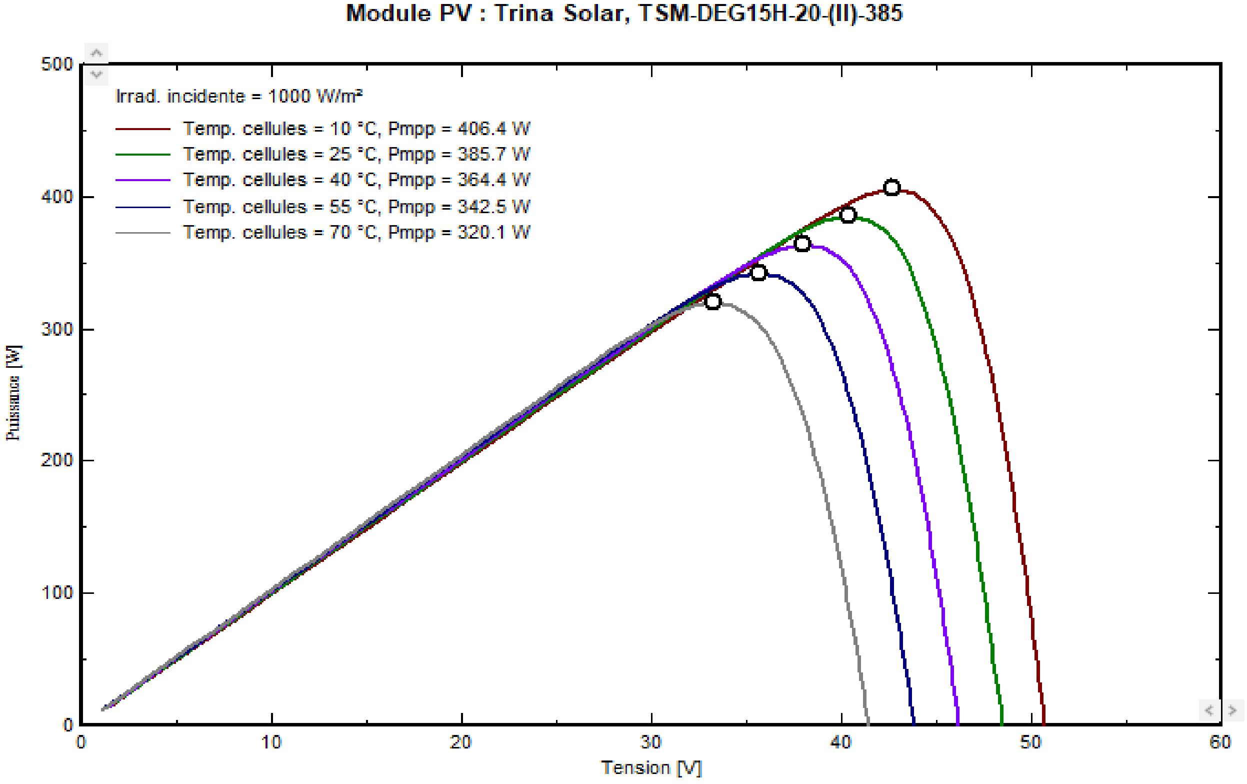

**Figure 12:-**Variation of Power-Voltage (P-V) as a function of Temperature.

Figure 12 presents the power–voltage (P–V) characteristics of the photovoltaic cell under varying temperature conditions, thereby enabling an evaluation of the thermal effects on cell performance. The graph displays multiple P–V curves, differentiated by color, each corresponding to a specific temperature level, while maintaining a constant irradiance of 1000 W/m². Each curve includes a marked Maximum Power Point (MPP), highlighting the optimal operating condition for maximum energy output.

The curves exhibit two distinct phases: an initial ascending region, where both power and voltage increase, followed by a descending phase characterized by a drop in power output. It is evident that temperature exerts a significant influence on photovoltaic performance higher cell temperatures lead to a noticeable decline in power output.

In this study, the thermal conditions are considered favorable, with an average ambient temperature of 25.5 °C, as indicated in the accompanying table. Moreover, solar insolation is especially advantageous during the month of April, with an average daily sunlight exposure of approximately 7 hours [15].

## Discussion of Results:-

A comparison with results reported in the literature, particularly those presented in [4] and [5], highlights the originality of our work, which involves the integration of planar mirrors into the photovoltaic system. Although the study is still at the experimental stage, the initial results are promising, with an observed increase in incident irradiance of 15.2%. This innovative approach enhances system performance, both in terms of available energy production and battery storage capacity.

It is important to note that this experiment was conducted on a single photovoltaic panel. In the future, we plan to extend this technique to the entire panel network as part of the solar power plant implementation at Denis Sassou Nguesso University. Furthermore, we encourage the scientific community to pursue further research in this area to consolidate and expand upon these findings.

## Conclusions:-

In light of the foregoing, it is evident that the Republic of Congo enjoys a geographically favorable position for the exploitation of solar energy, characterized by abundant and consistent sunlight throughout the year. In this context, the development of a photovoltaic power plant at Denis Sassou Nguesso University emerges as a relevant solution to address the instability of the national power grid and to reduce certain operational costs.

To assess the techno-economic feasibility of the project, a simulation of a 1768 kW grid-connected photovoltaic system was carried out using PVsyst and MATLAB software tools. The initial phase of the study involved on-site investigations at the proposed location to validate the project's relevance and perform the electrical load sizing.
An additional experiment was conducted by placing a planar mirror at a distance of ten (10) meters from the photovoltaic modules, with the aim of increasing the incident irradiance. This approach demonstrated promising potential in terms of enhancing the captured solar energy and improving storage capacity.
The simulation results obtained through PVsyst and MATLAB confirmed the effectiveness of this configuration. The current–voltage (I–V), power–voltage (P–V), and power–temperature characteristic curves, incorporating the contribution of the mirror, indicate that the targeted energy performance was achieved. This system thus represents a sustainable alternative capable of reducing fuel consumption in generator sets, minimizing maintenance requirements, and mitigating the effects of electrical grid fluctuations in the Republic of Congo.

It should be noted that this experimental study was conducted on a single photovoltaic panel and that the proposed innovation is still in its early stages. We therefore encourage the electrical engineering research community to further explore and refine this approach in order to consolidate the promising results obtained.

## Acknowledgment:-

I would like to express my gratitude to Professor Ange Antoine Abena, President of Denis Sassou Nguesso University, whose support and encouragement were instrumental in the completion of this research

### Funding:

This study was supported by Denis Sassou Nguesso University to strengthen its electrical infrastructure and guarantee a continuous 24-hour power supply

### Research involving human:

This article does not involve any studies conducted on human participants by any of the authors.

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