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Evaluation of the Electrical Characteristics of a Photovoltaic Solar Module in the Various Climatic Zones of Chad

YACOUB Nassian Nimir, Idriss Dagal, Djongyang Noël

Abstract*: *The performance of solar photovoltaic modules depends on the availability of solar radiation and the temperature of the solar cells. Knowledge and a good mastery of methods are essential to the design and the choice of the best technology. The chosen method should take into account the nonlinearity effects of the variation of current as a function of irradiation, and the variation of voltage as a function of temperature. In this work, the five-parameter, five-point model is used to evaluate the electrical characteristics of a solar photovoltaic module in the various climatic zones of Chad. Simulations are performed on a 250Wp polycrystalline photovoltaic solar module (SL250CE-36P composed of 72 cells connected in series) with an efficiency of 12.9%. The validation of the models was done by comparing the characteristics of the module in the various climatic zones of Chad. Results showed that most of the parameters depend on both the temperature of the cells and solar irradiance. This study shows that the five-point model is an excellent tool for evaluating the electrical characteristics of solar PV modules in the area. It is an improved method for extracting the five key physical quantities from the solar PV module characteristics. Most of the parameters depend on both the temperature of the cells and the solar irradiance. Accuracy varies depending on operating conditions. The effect of nonlinearity has made it possible to obtain a better match of the characteristics.

Keywords*: *Solar photovoltaic; Temperature; Irradiance; Climatic zones of Chad.

I. INTRODUCTION

Energy production represents a major challenge for the coming years. Indeed, the energy requirements of industrialized societies continue to grow. In addition, developing countries will have to invest more and more energy to achieve their growth. Today, most of the world's energy is produced from fossil fuels. By using these sources, we produce greenhouse gas emissions and therefore increase pollution. The additional risk lies in the excessive consumption of natural resources, which leads to a dangerous reduction in reserves of this type of energy for future generations. On the other hand, energy considered renewable must be renewed naturally and indefinitely over time. Currently, solar energy meets these criteria of both abundance on the Earth's surface and infinite regeneration on our scale. In this way it can be used directly in thermal form and, since the discovery of the photovoltaic effect, it can be converted into electricity. Despite its reputation for many years as a source capable of generating energy ranging from a few milliwatts to megawatts, it remains at an anecdotal stage and is not yet developed in large proportions, due to the excessive cost of sensors used [1]. The photovoltaic effect, which consists of converting light into electricity, was discovered by Becquerel in 1839. This energy conversion can be carried out using a sensor composed of materials that are sensitive to the energy present in photons. On a basic scale, this sensor takes the form of a cell called a photovoltaic (PV) cell. The electrical energy produced can be different depending on the material used, the geometric parameters of the sensor, and its ability to collect electrons before they recombine in the material. The possibility of associating several photovoltaic cells in series/parallel theoretically makes it possible to adjust the production of photovoltaic energy according to demand. The combination of these associations forms a photovoltaic generator (GPV) that has specific, non-linear current-voltage I(V) characteristics and has maximum power points (MPP) that vary according to the illumination level and the cell temperature [2]. Indeed, to develop profitable and economically viable conversion systems, it is essential to have a good understanding of the various elements of the system, in particular the solar panel. It is made up of various solar cells which require study and understanding. The literature has exposed several models to analyze the behavior of a solar cell and identify its characteristics, including the current-voltage characteristic and the power-voltage characteristic. These models can be grouped into two categories: versions with two diodes and versions with a single diode. Furthermore, the specification of the maximum power has attracted additional interest because it is essential to obtain simplified models that model the behavior of the photocell as a function of climatic conditions (temperature, illuminance), particularly during the stage of sizing.

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A model deduced from an equivalent electrical circuit regulates the operation of a solar cell. Different models can be found in the literature, notably single-diode models and double-diode models, whose precision depends on the mathematical modeling of the different intrinsic physical phenomena that intervene in the electricity production process. Kamelia [3] outlined the design of a photovoltaic power generation system by comparing different single and dual diode models to evaluate the I(V) and P(V) characteristics of a solar panel system. Several elements influence this characteristic, including temperature, luminous flux, shunt resistance, and series resistance. Researches on the comparison between the one- and two-diode equations in the literature indicate that the series resistance makes a difference between the various models, while the four-parameter (L4P) model combines simplicity and accuracy, making it the choice that we consider the most interesting. Dounia et al [4] studied the one- and two-diode models by detailing the various techniques discovered in the scientific literature to solve these two equations. The experimental technique used by the ISOPHOTON I-50 card and the Newton-Raphson numerical method was used to evaluate the expected photocurrent. The photovoltaic model is optimized using a genetic algorithm (GA). The findings of the study showed that using the error on the two-diode equation is more accurate than on the one-diode equation. Temon [5] explains how to make and characterize photovoltaic cells. He first analyzed the solar cells in the presence of lighting and the dark and then characterized them using TLM patterns. Analytical calculations of the different resistances were carried out and compared to the series resistance extracted from the I-V curve under illumination. The author concluded that to optimize the cell one must take into account the shading rate calculated previously. Elhaouari [6] precisely extracted the real parameters that influence the electrical behaviors of the series resistance, the parallel resistance, the efficiency, and the form factor of the cell. This exaction made it possible to identify the various phenomena and interactions that are responsible for the degradation of performance. In short, the characterization of a solar photovoltaic cell consists of seeking the information required to act or make appropriate improvements to guarantee optimal performance and use in difficult conditions. The objective of this paper is to characterize a single-diode photovoltaic cell in the various climatic zones of Chad. The five-parameter, five-point model was used to evaluate the electrical characteristics of solar photovoltaic modules in the various climatic zones of Chad. The calculations were performed on a polycrystalline commercial photovoltaic solar module; a SL250CE-36P module with a power of 250Wp composed of 72 crystalline poly cells connected in series[12][13][14][15][16]. The calculations were performed on this commercial solar PV module with an efficiency of 12.9%. The validation of these models was carried out by comparing the characteristics of the module in the different climatic zones of Chad.

II. STUDY AREA

Chad is a completely landlocked country in the central Africa region. It is located in the heart of the continent between the 7th and 24th degrees of North latitude and the 13th and 24th degrees of East longitude. It covers an area of 1,284,000 km² [7] of which 2/3 are located in the arid zone (Saharan zone and Sahelian zone), facing a recurring cycle of food, nutritional and pastoral crises. Since Chad benefits from a considerable amount of solar radiation, the country's annual hours of sunshine vary from 2,850 hours in the south to 3,750 hours in the north. The overall radiation intensity is on average 4.5 to 6.5 kWh/m^2/day. The cultivated land area is vast, with more than 19 million hectares of cultivated land, of which 5.6 million hectares can be irrigated. Only 10% of this potential is currently exploited. Groundwater resources are abundant, estimated at 20 billion cubic meters (m^3), representing 75% of the land area [8]. It is characterized by a semi-arid tropical climate. The country is divided into three climatic zones (figure 1): the Sahara zone in the north, with precipitation between 50 and 200 mm, the Sahelian zone in the center, with precipitation between 300 and 800 mm, which favors the development of vegetation, rainfall in grassland, savannah, and Sudan zone that ranges from 900 mm to 1,200 mm, favoring the development of savannah to rainforest vegetation. In the Sahara, the rainy season does not last more than two months, in the Sahel it lasts three to four months and finally, in Sudan, it lasts five to six months [9]. The maximum intensity of solar radiation generally corresponds to the period of maximum water demand. Potential evapotranspiration (ETP) varies between 120 to 270 mm/month. The months with high ETP are July, August, and September when it rains heavily, and little during dry months like January, February, March, and December [10]. The objective of this work is to evaluate the characteristics of a photovoltaic solar module in the different climatic zones of Chad.

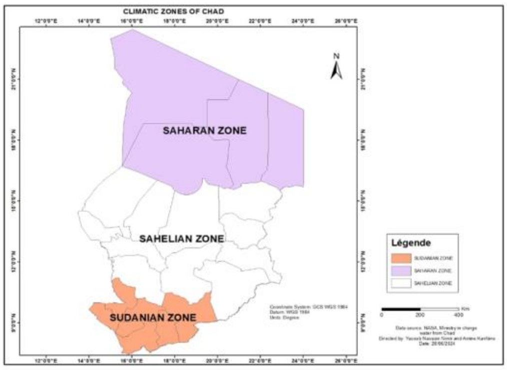

Figure 1: Map of the Various Climatic Zones of Chad

III. MATERIAL ET METHODS

MATLAB Simulink is a visual programming interface designed to make modeling systems intuitive. It offers solutions to solve equations numerically using a graphical user interface, rather than requiring code. Models contain blocks, signals, and annotations on a background [11]:

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A. Characteristics of a Photovoltaic Solar Cell

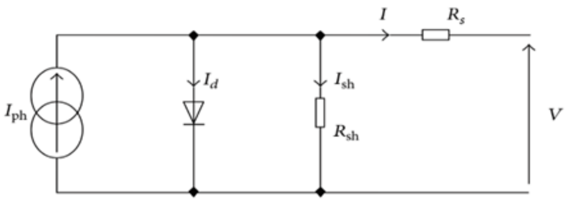

Figure 2: Diagram of a Cell with a Diode [4]

B. Cell Current

The cell current is obtained from figure 2 through Kirchhoff's first law (knot law) [4].

$$I = Iph - \mathrm{Id} - \mathrm{Ish} \quad (1)$$

with

I: Current generated by the photovoltaic cell

Iph: Photocurrent created by the cell (proportional to the incident radiation)

Id: The current flowing through the diode.

C. Diode Current

The diode current is obtained by the relation [4]:

$$\mathrm{Id} = \mathrm{I0}[\ \exp\left(\frac{\mathrm{V+IRs}}{\mathrm{a}}\right) - 1] \quad (2)$$

D. Shunt Current

The shunt current is determined by Kirchhoff's second law (mesh law) [5]:

$$Ish = \frac{V+IRs}{Rsh} \quad (3)$$

By substituting Id and Ish by their expression of the current I, we have [5]:

$$\mathrm{I} = \mathrm{Iph} - \mathrm{I0}[\exp\left(\frac{\mathrm{V+IRs}}{\mathrm{a}}\right) - 1] - \frac{\mathrm{V+IRs}}{\mathrm{Rsh}} \quad (4)$$

with a the ideality factor.

E. Ideality Factor

The ideality factor is given by [6]:

$$a = \frac{Ns.A0.K.Tc}{q} \quad (5)$$

F. The Photocurrent

The photocurrent is determined by the formula [6]:

$$\mathrm{Iph} = [Icc + \mathrm{Ki}(\mathrm{Top} - Tref].\frac{G}{G0} \quad (6)$$

Isc: Short circuit current

Ki: short-circuit temperature coefficient

G0: illumination of the STC

Top: Cell operating temperature.

Tref: cell reference temperature

G. Reverse Bias Current

The reverse polarization current is therefore given by the relation [4]:

$$I_0 = Icc\left(\frac{Top}{Tref}\right)^3 e^{\frac{Eg}{aK}\left(\frac{1}{Tref}-\frac{1}{Top}\right)} \quad (7)$$

Isc: the short-circuit current of the cell at the reference temperature

a: ideality factor of the diode junction 1.6

Eg: Gap energy [ev] 1.11 ev

K: Boltzmann constant (1.3854.10-19C)

Q: the elementary electric charge 1.6.10-19C

H. Characteristics of the Photovoltaic Solar Module Used

The photovoltaic solar module used is type SL250CE-36P, polycrystalline. Standard Test Conditions (STC): air mass AM 1.5, irradiation 1000W/m^2, cell temperature 25°C. The simulation parameters are given in table 1 and the other parameters are reported in detail.

Table 1: Simulation Parameter Values

Parameters of the Module	Value
The number of cells in series Ns	72
The maximum voltage Vmax at PPM (V)	35.42V
Open circuit voltage Voc (V)	43.41V
The maximum current Imax at PPM (A)	7.05A
Short circuit current Isc (A)	7.55
Module efficiency (%)	12.9
Temperature coefficient (%/°C)	0.04
Temperature range	-40 to +85
Power tolerance (%)	+/- 5

To solve this equation, we use the 'Constrained Algebraic' block which is integrated into the library 'Simulink/Math Operation' (figure 3).

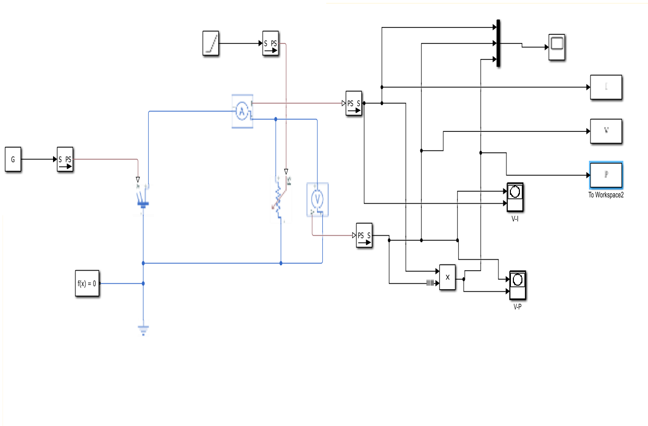

Figure 3: Simulation Diagram of a Photovoltaic Cell

Figure 4 and figure 5 present the I-V and P-V characteristics of a PV cell.

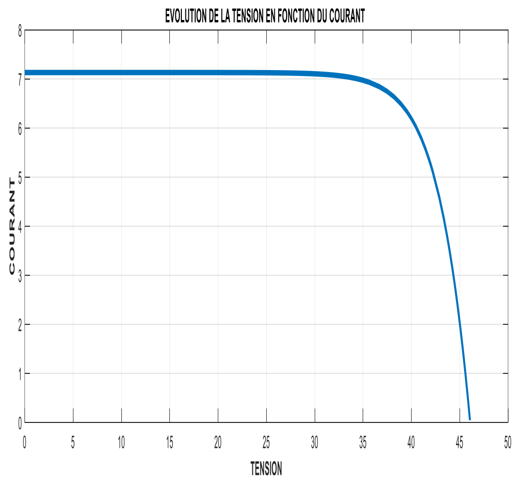

Figure 4: I-V Characteristic of a PV Cell

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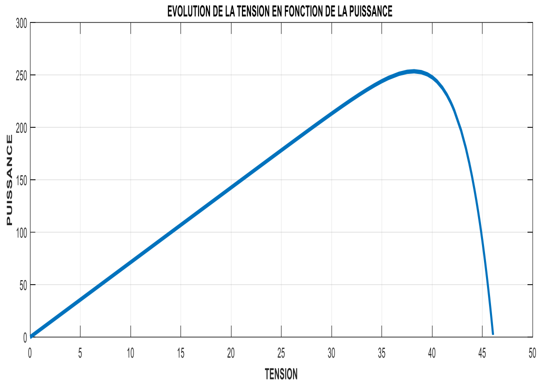

Figure 5: P-V Characteristic of a PV Cell

IV. RESULTS AND DISCUSSION

A. Irradiance

Solar irradiance is the quantity of radiative energy coming from the Sun received by a surface of 1 m² from the top of the Earth's atmosphere when it is located one atmospheric unit from the Sun and the trajectory of the ray is perpendicular to this surface [8].

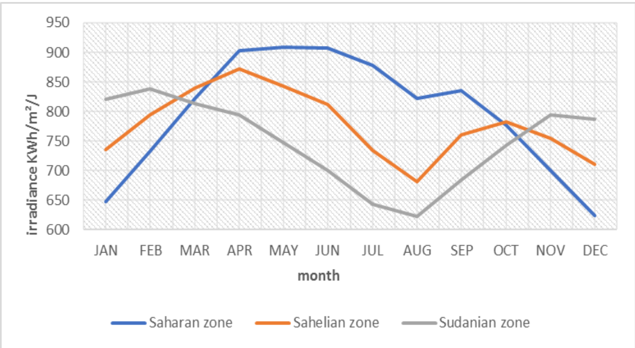

Figure 6: Evolution of Monthly Irradiance

The total solar irradiance varies over time (table 2 and figure 6). Irradiance over the country ranges between 623.76 kWh/m^2/day and 908.10 kWh/m^2/day. We observe low irradiance in the Saharan region between October and March, increasing from 623.76 kWh/m^2/day to 813.15 kWh/m^2/day, and an increase from April to September. In the Sahelian and Sudanian regions, the period from April to October is characterized by a rainy season and low irradiance.

Table 2: Summary Table of Irradiance (in kWh/m2/day)

Month	Saharan Zone	Sahelian Zone	Sudanian Zone
January	647.42	735.69	821.17
February	732.74	794.67	838.75
March	822.01	839.91	813.15
April	903.39	872.17	794.73
May	908.10	842.79	747.12
June	906.79	812.30	700.59
July	877.65	734.47	642.70
August	822.01	680.70	622.48
September	835.59	759.86	683.97
October	776.67	782.03	743.42
November	700.43	754.98	793.54
December	623.76	709.97	786.48

B. The Current

An electric current is the flow of a series of electric charge carriers, usually electrons, in a conductive material. The action of the electromagnetic force, whose interaction with matter is the basis of electricity, causes these movements.

Figure 7 and table 3 present the monthly variation of the current in the three climatic regions.

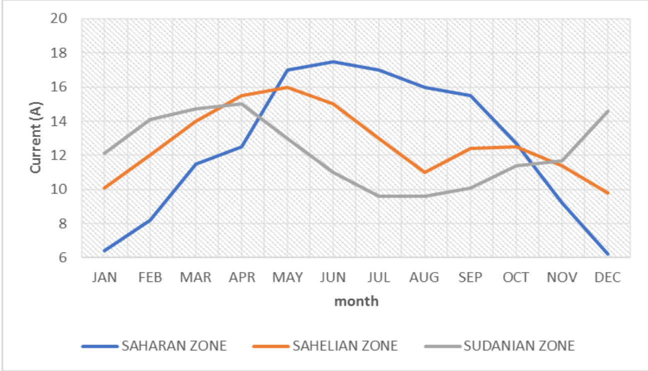

Figure 7: Variation of the Monthly Current

From April to October, there is a period of rain where the current is low, while in the Saharan region, the irradiance is high due to the lack of precipitation. It is cold from November to March, which causes a drop in power.

Table 3: Summary Table of the Current (in A)

Month	Saharan Zone	Sahelian Zone	Sudanian Zone
January	6.4	10.1	12.1
February	8.2	12	14.1
March	11.5	14	14.7
April	12.5	15.5	15
May	17	16	13
June	17.5	15	11
July	17	13	9.6
August	16	11	9.6
September	15.5	12.4	10.1
October	12.7	12.5	11.4
November	9.2	11.4	11.7
December	6.2	9.8	14.6

C. Electrical Power

Electrical power refers to the amount of electrical energy that is transmitted in a circuit during a unit of time. Figure 8 and table 4 present the monthly variation of the current in the three climatic regions.

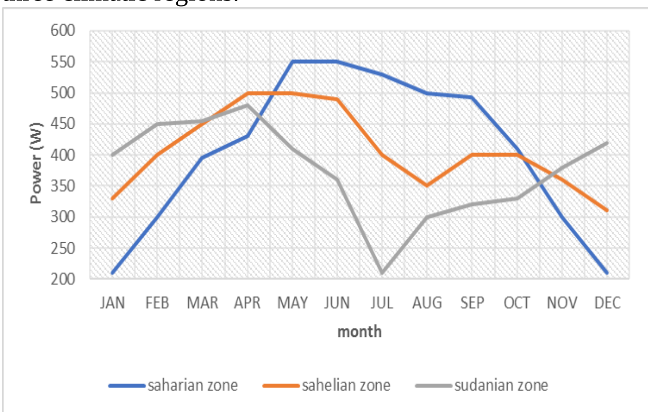

Figure 8: Variation of the Monthly Power

From the period from April to October, the rainy season is observed, with low power in the Sahelian and Sudanian zones, while in the Saharan region, the power increases due to the lack of precipitation. From November to March, the weather is cold, which leads to a decrease in power.

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Table 4: Summary Table of the Power (in W)

Month	Saharan zone	Sahelian zone	Sudanian zone
January	210	330	400
February	300	400	450
March	395	450	455
April	430	500	480
May	550	500	410
June	550	490	360
July	530	400	210
August	500	350	300
September	493	400	320
October	410	400	330
November	300	360	380
December	210	310	420

V. CONCLUSION

In this study, the characteristics of a photovoltaic solar module are studied as a function of temperature and irradiance. It was found that the irradiance intensity varies from 623.76 kWh/m^2/day to 908.10 kWh/m^2/day. In the Saharan region, irradiance is low between October and March, increasing from 623.76 kWh/m^2/day to 813.15 kWh/m^2/day, and increases from April to September. In the Sahelian and Sudanian zones, the period from April to October is marked by a rainy season and low irradiance. As a result, from April to October, the current remains low, while in the Saharan region, the current is high due to the absence of rain. From November to March, it is cold, which reduces the current. The rainy season lasts from April to October, with low rainfall in the Sahel and Saharan regions, while in the Saharan region, the power increases due to the lack of precipitation. Between November and March, the temperature is low, which causes a drop in power. Tensions remain constant in various climatic regions.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	YACOUB Nassian Nimir: Design; writing review & editing; funding. IDRISS Dagal: Writing, review & editing, Methodology, Formal analysis. DJONGYANG Noël: Review & editing, Supervision.

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