# UNIVERSITY OF BUEA

**FACULTY OF ENGINEERING AND TECHNOLOGY**

**DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING**

# Performance and Payback Time Assessment of Polycrystalline and Monocrystalline Silicon Solar Panels Operating under Different Climatic Conditions. Case Study of Buea and Garoua.

**By**

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# DEDICATION

This work is dedicated to Mr. and Mrs. Otto Lyonga-Mokenge and Mrs. Drusilla Enanga Hadisson.

# CERTIFICATION

The Thesis submitted by Patience Monjoa Lyonga-Mokenge (FE19P012) entitled "**Performance and Payback Time Assessment of Polycrystalline and Monocrystalline Silicon Solar Panels Operating under Different Climatic Conditions. Case Study of Buea and Garoua"** submitted to the Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology of the University of Buea in partial fulfillment of the requirements for the Degree of Master of Engineering (M.Eng.) in Electrical Power System has been performed by her and has not been submitted to any other institution for academic purposes.

**Date______________________________**

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**Supervisor**
**Ngwashi Divine Khan,Phd**

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To my family, course mates and close friends I thank you for your support during this period of commitment.

# ABSTRACT

The significant increase in the world's population has caused a sharp increase in electrical energy demand, leading to the exhaustive extraction and consumption of fossil energy which is the main contributor to many environmental issues such as climate change. In a bid to combat climate change and its impacts, one of the SDG of the UN recommends that every country should invest towards putting in an effort to switching over to renewable energy technologies. Among such is solar energy from the sun which is free and abundant.

However, solar systems suffer from huge initial cost than conventional energy sources but once the solar technologies are installed, they have very low operating costs and require minimal input. In addition, installed Solar PV modules exhibit significant loss in their expected performance due to variations in weather conditions such as ambient temperature and solar irradiance which result in lesser module power output compared to predictions from Standard Test Conditions (STC) and the Nominal Operating Cell Temperatures (NOCT). The high initial costs, coupled with systems losses tend to discourage consumers from installing PV Module Systems since they are not sure of recovering their profits within their lifetime. The current research in this direction is to investigate which crystalline PV Module technology performs better in cold (Buea) and hot (Garoua). The Monocrystalline PV Module produced a maximum power of 91.19W while the Polycrystalline produced a maximum power of 88.77W in Localized climatic Conditions of Buea. In localized Climatic Conditions of Garoua, the former produced a maximum Power output of 119.0W while the later, 116.10W.

**Keywords: Payback Assessment Time, Crystalline Technology, PV Module, Climatic Conditions**

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# NOMENCLATURE

Boltzmann's constant [K] = 1.380 × 10−23 J/K

Charge of an electron [q] = 1.602 × 10−19 C

Diode Ideality Factor [n] indicates how well the cell is manufactured and how much deformation, impurities within the cell.

Energy band gap, for silicon [$E_g$] is the minimum energy carried by a photon to liberate an electron from the valence band to the conduction band. = 1.1 eV

G =Solar irradiance [W/m$^2$]

Gref =Solar Irradiance at STC [W/m$^2$]

I= Output current from the PV panel [A]

Imp =Maximum power current [A]

$K_i$=Temperature coefficient of cell short circuit Current

$N_s$= Number of cells in series

$P_{Max}$= Maximum Power at STC [W]

P.R=Performance Ratio

SDG=Sustainable Development Goals

STC=Standard Testing Conditions

T=Real-time temperature [$^0$C]

$T_n$= Reference temperature [$^0$C]

UNO=United Nations Organization

V= Output voltage from the PV panel [V]

Vmp =Maximum power voltage [V]

Voc= Open circuit voltage [V]

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# CHAPTER 1: GENERAL INTRODUCTION

## 1.1 Background Knowledge and Context of Study

The world population boom has led to a high energy demand. In order to meet this demand, the excessive combustion of fossil fuel as main energy source has greatly contributed to global warming by increasing the Carbon dioxide emissions resulting from the combustion of fossil fuel which in turn increase the temperature of the atmosphere. As Cameroon moves towards development, the energy requirement will be intensive. Hence the need to incorporate renewable energy sources as a substitute to fossil fuel combustion.

Solar Energy can be harnessed via PV module technologies. These are solid-state devices that simply generate electricity from sunlight, silently and with little to no maintenance, no pollution and no significant depletion of material resource. However, only part of the incident solar spectrum is converted into electricity, while the rest is diffused as heat. This heat causes the increase of the module temperature which leads to the decrease of the module efficiency and output power [1]. This decrease in output efficiency, alongside the huge initial cost of installation, is a discouraging factor to adopting solar energy as an optimum replacement to fossil fuels since the return on investment otherwise known as payback assessment time is slow.

Cameroon lies in the tropical region between $1^0$N and $7^0$N, and $100^0$E and

119 $^0$E and blessed with an array of weather conditions such as availability of sunlight, suitable for photovoltaic implementation. However, 2 case studies with slightly different climatic conditions shall be considered. These are Buea which lies on latitude 04.156799°, 009.231552° and has a tropical highland climate, and Garoua which lies on latitude 09.30707°, 013.393453°with a hot semi-arid climate [2].

### 1.1.1 Research Objective

The objective of this study is aimed at theoretically investigating the effects of climatic temperature on the Power Output of Monocrystalline and Polycrystalline PV Panels each operating under real conditions in tropical climatic conditions of Buea and outdoor

Sub Saharan Climatic Conditions of Garoua, using Mathematical modeling of PV Panels.

### 1.1.2 Research Questions

- Is it possible to generate same quantity of energy from photovoltaic in both cold and hot climate?
- What type of crystalline photovoltaic technology exhibits a better performance ratio in each of cold and hot climate?

### 1.1.3 Research Methodology

The research methodology adapted is based on intensive literature review, comparative studies of various cases studies of photovoltaic modeling and simulations under varying weather conditions to arrive at final outcome.

Various experimental and theoretical procedures on analyzing the Power output of Mono and Polycrystalline PV Panels, at varying ambient temperatures and irradiance will be studied. Subsequently, the payback assessment time shall be calculated, as a function of efficiency based on the MPPT of the varying P-V Curves.

## 1.2 Significance of Study

The performance of field installed PV Modules can be different from parameters obtained from STC due to losses resulting from the influence of specific environmental parameters in the given location such as global solar radiation intensity and spectrum, ambient temperature, relative humidity, wind speed, and dust concentration in the air. All these factors strongly depend on meteorological conditions, characteristic for given climate. Final energy production depends on the overlapping of several effects, which are difficult to analyze individually. In general, the most important factors are solar irradiation and temperature, since they directly influence the energy production, and PV modules temperature, which affects modules efficiency [3]. Therefore, knowledge and understanding of the PV module performance under site of installation operating conditions is of great importance for correct product selection and accurate prediction of their energy performance. Monitoring of the production and performances of energy systems based on photovoltaic panels in the real conditions of operation of the specific implementation site is of great importance to estimate the reliability and the production of these systems

Thus, it is important to predict the power output of PV module at normal weather before installing solar PV systems. Various solar PV models have been proposed by researchers and each model comes with certain advantages of its own [4]. An understanding of how efficiency of PV Modules is affected will lead to a balance between cost and payback.

## 1.3 Scope of Work

Matlab/Simulink Modeling of Poly and Monocrystalline PV Modules to study the efficiency at localized climatic conditions of Buea and Garoua. Hence, establishing the notion that choosing the suitable PV module is a crucial and important step before installing a PV power generation system, since the efficiency will affect the overall cost of the PV system.

## 1.4 Research Outline

The next chapter will present reviewed papers related to this research and will present the various modeling methods with their limitations. these scientific papers are centered on modeling techniques of PV Module systems and effects of localized climatic conditions on output performance

Chapter three (methodology) will present the procedure and methods applied during this research. Chapter four will give a clear depiction of the results which will be discussed related to recommendations on the methods used and outcome. The final chapter will be the conclusion.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction.

Solar PV cell is the basic unit in a PV system. It consists of a junction between two thin layers of dissimilar semi conducting materials. One is the positive type semi-conductor or P-type and the other is the negative type semi-conductor or N-type. These semi-conductors can be made from Silicon, Germanium, Gallium - Arsenide, Indium-Phosphate, Cadmium- Sulphide, Cadmium-Telluride etc. But semi-conductors are usually made from Silicon since Silicon is one of the most available elements on earth. It exists in nature predominantly in a combined form (Silicon-Oxide). For solar PV cell the pure Silicon is needed. N-type semi-conductors are made from crystalline silicon that is doped with tiny quantities of an impurity (usually phosphorus) in such a way that the doped materials possess a surplus of free electrons. P-type semi-conductors are also made from crystalline silicon that is doped with very small amount of a different impurity (usually boron) which causes the material to have deficit of electron [5]. To meet the electron flow capacity as needed, a number of solar cells are combined in a certain area called the solar panel. The transfer of electrons between two layers of photovoltaic cells which are opposite in the solar panel due to exposure to sunlight is called the photovoltaic effect [6] as shown in the figure below :

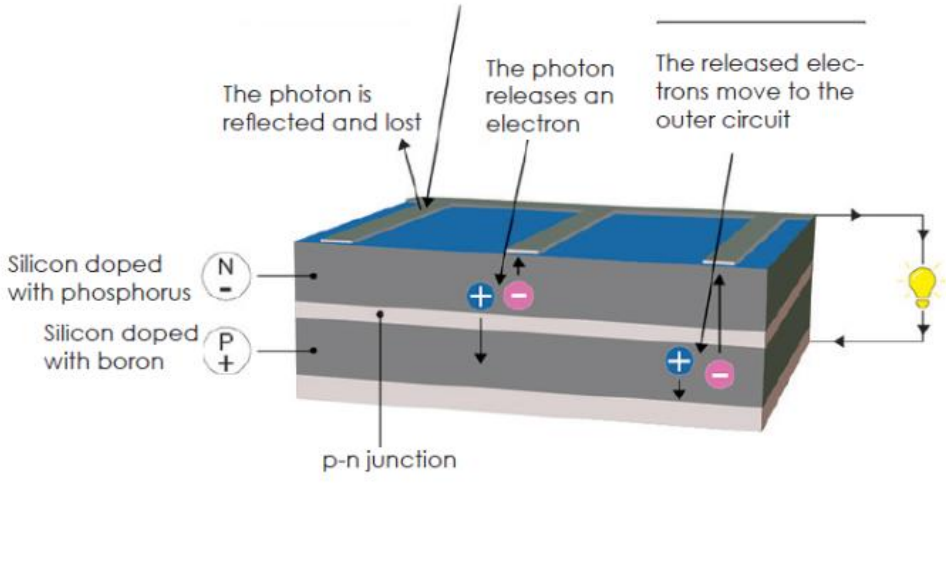



Figure 1: The Photovoltaic Effect [7]

## 2.1.1 PV TECHNOLOGIES

Silicon-based PV technologies can be grouped into three types: Monocrystalline silicon (m-Si or mono-Si), Polycrystalline silicon (poly-Si or multi-Si), and thin-film amorphous silicon (a-Si). Silicon technology now occupies approximately 80% of the PV market. Among the silicon-based PV cells, Monocrystalline ones are usually black or gray in color and have higher efficiencies and higher prices since they are made from pure Monocrystalline silicon. Polycrystalline PV cells are fabricated from ingots of multi-crystalline silicon. They can be easily manufactured with multi-colored shining blue tones. They are cheaper but are less effective. In Thin film silicon PV cells, a thin un-crystallized silicon layer is attached to the substrate, which causes the cell to be relatively thin. The color of the amorphous silicon cells is reddish-brown or black. The power efficiencies of these silicon-based PV cells are very different from each other. For Monocrystalline cells, the efficiency ranges between 14% and 17%. The efficiency of polycrystalline cells varies in the range of 12–14%. [8] [9]

The following figure depicts the types of PV Cells that dominate the PV market:

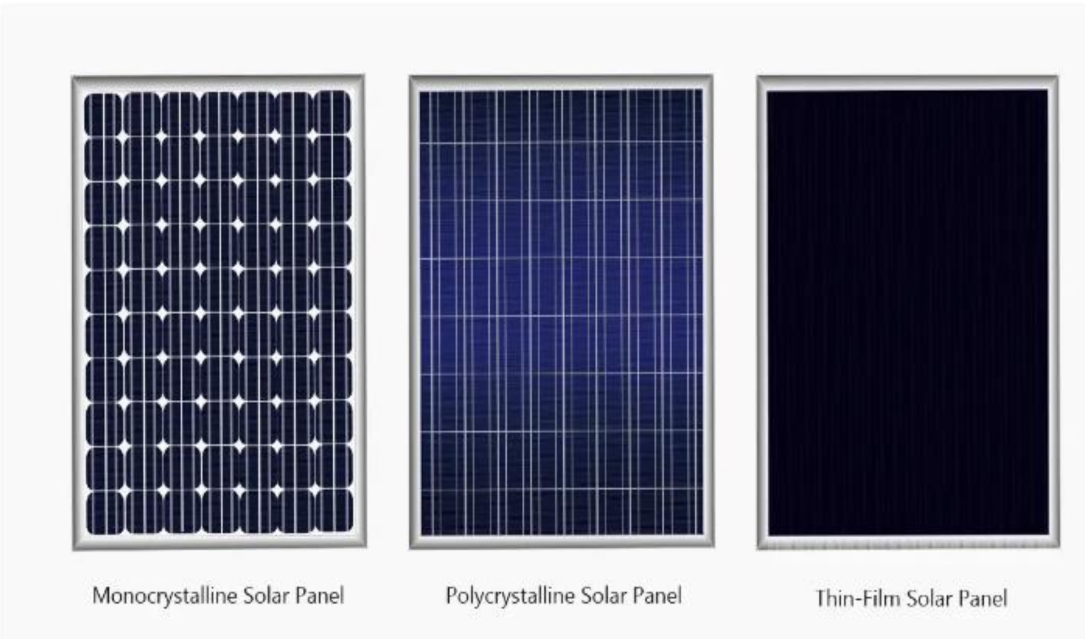



Figure 2: Types of PV Panels [10]

## 2.2 Modeling Techniques of PV Modules

During the last decade, several researchers investigated modeling and simulation of solar PV modules to obtain informative results. There are various methods of modeling and optimization of solar PV modules like analytical methods, linearization methods, artificial intelligence methods, numerical methods, artificial neural networks, fuzzy methods and genetic algorithms etc. [11] .In the next section various modeling and simulation techniques of PV model is discussed alongside their limitations.

The following modeling techniques are methods reviewed from the research papers which will be cited and presented subsequently.

### 2.2.1 Mathematical Modeling Technique

Krismadinata et al [12] described a method of modeling and simulating photovoltaic (PV) module implemented in Simulink/Matlab in order to define a circuit-based simulation model for a PV cell and allow its interaction with a power converter, to investigate the effect of irradiation and temperature on the performance of the circuit model. A simplified PV equivalent circuit with a diode model is employed and the simulation results are compared with different types of PV module datasheets. Its results indicated that the created simulation blocks in Simulink/matlab are similar to actual PV modules, compatible to different types of PV module and user-friendly

Mohamed El-Ahmar et al [4] presented a Matlab system of equations for investigating the detailed models of PV module of both single and double diode model analysis related to Shockley diode equation. These models consider the solar irradiance and temperature as input parameters of the KC200GT-200W module for a wide range of different parameters. They illustrated the influence of several variables on both single and double diode models of the KC200GT-200W module and compared the simulation results to the module's datasheet used in this study. They discovered that the simulated results are an accurate approximation of the experimental results.

Wafaa ABD EL-BASIT [13] estimated the effect of environmental conditions on the output characteristics of the PV Cell using the one diode mathematical model and implemented using MATLAB script. He established that for any solar cell, the model parameters are function of the irradiance and the temperature values of the site where the panel is placed. The variation of slopes of the (I–V) curves of a cell at short-circuit and open-circuit conditions with intensity of illumination in small span of intensity and different temperature levels have been applied to determine the cell parameters, shunt resistance, series resistance. The results show that the efficiency of solar cells has an inverse relationship with temperature; irradiance levels affect the change of the photo-generation current and the series resistance in the single diode model.

Anurag Rai et al [14] developed a model for studying the 250 watt photovoltaic module manufactured by Tata Solar power to illustrate the effect of change in environmental conditions like irradiance and temperature, alongside variation of physical parameters such as shunt and series resistance on the output performance of photovoltaic module, based on mathematical expression of the conventional single diode model for solar cell. The simulations of proposed model using Matlab/Simulink software are compared with the reference photovoltaic module. It was observed that, the results of the simulated module were similar to those of the data sheet.

Mustapha I et al [15] evaluated the performance of commercially used polycrystalline solar photovoltaic module KD 315 under Maiduguri-Nigeria weather conditions. The model of the PV module was implemented using a Newton-Raphson method to solve systems of nonlinear equations in a MATLAB program and the model parameters are evaluated using daily data of temperature and solar irradiance obtained from Maiduguri for a period of one year (January to December) of the year 2010. They concluded that the photovoltaic module exhibited good performance in the region under study as the manufacturer's maximum power of 315 W was achieved during the sunniest month. Simulation results confirm that the voltage of the module decreases by about 0.5% per degree centigrade temperature increase and that power produced by the panel is dependent on the solar irradiance and ambient temperature.

These papers described the final model but lack detailed modelling of subsystems of the PV Solar Panel.

### 2.2.2 Experimental Set ups

Mabrouk Adouane et al [16] carried out a performance analysis and comparison of eight photovoltaic (PV) technologies under the local harsh climate conditions of Kuwait, with special attention given to the influence of temperature and dust on the performance of the PV modules. The eight technologies employed in this work are, Monocrystalline (m-Si), Polycrystalline (p-Si), Heterojunction (HIT), and thin film; Cadmium Telluride (CdTe), Copper Indium Gallium Diselenide (CIGS), and Amorphous Silicon (a-Si) during a period of 12 months. The results show that m-Si, p-Si and HIT modules performed better in high irradiance levels while decreasing rapidly at lower irradiance levels. The authors also established that cylindrical CIGS module showed good performance in low irradiance level while a-Si and CdTe performed significantly lower than the other technologies mainly due to capture losses. At high irradiance, m-Si, p-Si and HIT modules display better performance while a-Si and CdTe, performed much lower than other technologies mainly due to significant capture loses. Ahmed Bouraiou [17] also presented the modeling and simulation of ISOFOTON 75 panel based on the one and two diode model using the software Matlab/Simulink. The experimental validation of the one and two diode model under STC condition was performed and the simulation results of P-V and I-V characteristics of ISOFOTON 75 panel under different values of temperature and irradiation are presented and compared. The study shows a similar effect trend between the experimental and simulated results on the effect of temperature and solar irradiation on P-V and I-V modules array characteristics. Similarly, Azhar Ghazali M.et al [18] presented a dynamic system designed to support the three types of PV panels(M-Si, P-Si and Amorphous PV Cells) which are allowed to move with single degree of freedom (horizontally) according to the sun's orientation (sunrise to sunset) from east to west. It was found that poly-crystalline solar module has shown better performance ratio and average module efficiency compare to the other tested PV module under Malaysian climate. The performance ratio for each type of PV modules show that poly-crystalline solar module is most suitable type of photovoltaic module to be used under Malaysian climate condition when applying single-axis time/date solar tracker.

Mobark Mohamed Osman [19] investigated the efficiency of photovoltaic integration in building in hot and cold climates, and how it could be optimized for sustainable development, based on comparative case studies of office buildings from hot climate, where Sudan was chosen as case study area, and for cold climates NCC Office building in Finland. It was discovered that thin film PV panel is more appropriate for hot climates and polycrystalline for cold climates. Thin film solar panel could be used both in hot and cold climates since it is relatively cheap compared to the other two, but less efficient than the other two types, therefore, the installed area should be increased. For hot climate Thin film is the most appropriate type because it is more tolerant to heat, cheap and can operates even when the climate is cloudy and dusty, therefore in Sudan Telecommunication tower it is being used, due to the fact that the weather is semi desert, very hot, dusty in summer, therefore, thin film is highly recommended in hot climates. However, poly-crystalline too can be used, since it is less affected by high temperatures, if good ventilation or cooling system is mounted at the back of the cell to boost efficiency. The author then concluded by stating that all the three types can effectively operate in cold climate, but if both efficiency, economical and payback time is considered, Polycrystalline is the best.

Akram Abdulameer Abbood Al-Khazzar [20] experimentally presented the effect of temperature on the behavior and performance of four different photovoltaic PV modules: Monocrystalline Silicon, Poly-crystalline Silicon, amorphous Silicon and Copper Indium Gallium diselenide (CIGS) under Iraq climate conditions of Baghdad city. The results showed that the amorphous silicon and CIGS modules perform better than the crystalline modules in high operating temperature.

The module temperature and the module output parameters (open circuit voltage, short circuit current and maximum power output) were recorded at a constant solar radiation and a range of ambient temperature between 13 to 47°C for a period of 5 months. To analyze the data, a scatter plot was used between each of $V$, $Isc$ and $Pm$ and temperature. It had been seen that there is a linear relationship, so a linear regression was used to find a relation between them and the temperature.

## 2.2.3 Exergy Analysis

Cheikh El Banany ELHADJ SIDI et al [21] highlighted the performance analysis of a 30 Wp Monocrystalline silicon photovoltaic module to study the effect of irradiance and temperature on module performance in a real environment, using the variation of the exergy efficiency as a function of the module temperature. By examining the electrical exergy rate and the thermal exergy losses rate of the module, the findings of this study show that the exergetic efficiency depends on the variation of the irradiance and temperature during the day. Results give an exergetic efficiency of the module varying from 14.87 to 17.93% per day for the PV module. The results also show a variation of exergetic efficiency for the same irradiance and decrease in efficiency with increasing module operating temperature. The thermal exergy losses rate increases with the difference between the module's operating temperature and the ambient temperature. He concluded by saying that the thermal exergy losses rate of the module is a function of ambient climatic temperature on a sunny and cloudless day which leads to a reduction in the yield and greatly affects the total output of the system.

## 2.3 Conclusion

The effect of irradiance and ambient climatic temperatures of localized geographical areas on the performance of PV Modules have been analyzed both theoretically and experimentally by numerous researchers. From the Literature review, the Single Diode Mathematical Modeling of PV Panels is more often implemented in order to predetermine the effects of climatic conditions on the Output performance of PV Modules. Based on this assertion, this research work is based on the mathematical modeling Polycrystalline and Monocrystalline PV Modules using a combination of the methods reviewed above and then for localized climatic conditions of Garoua and Buea, process the power output of both modules. The single diode model will be used instead of the double diode model due to its facilitated analysis [13]. The Performance ratio of both modules in each region will be used as the basis to analyze the payback assessment time and deduce how the climatic conditions affect power output.

# CHAPTER THREE: METHODOLOGY AND ANALYSIS

## 3.1 Introduction

The mathematical model of single diode equivalent photo-generator module is developed using analytical methods under Matlab/Simulink environment using methods developed by [1,4,11,12,13,17,25]. For the development of solar PV module stepwise approach of modeling and simulation is adopted and manufacture data of BLD 200W Series solar PV module is considered during modeling. To validate the model manufacture data sheet results and simulated results are compared.

The single diode model contains a p–n junction called a diode, a photocurrent generator represented a generation of current from light and two resistors, one is arranged in series and another one is in parallel which described the Joule effect and recombination losses.

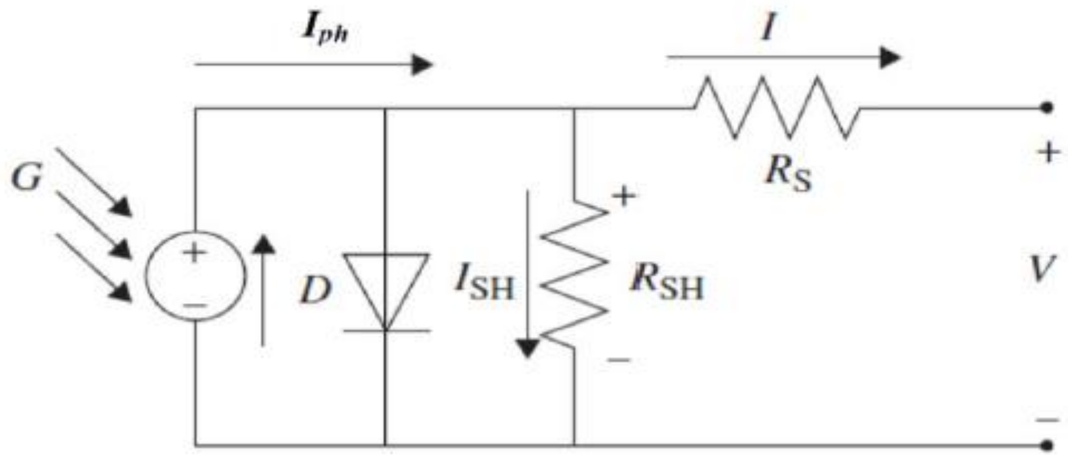



Figure 3: Single Diode Model of a Solar Cell [22]

A practical PV solar cell describes a nonlinear voltage – current characteristic, and can be modeled as a current source (Iph), parallel to the diode and resistances as illustrated in Figure.3. By using the Kirchhoff's current law, the output current of a practical solar cell is described in Eq. (1) [13]

$$I = I_{ph} - I_D - I_{sh} \qquad (1)$$

Where I= Output Current of Solar Cell

$I_{ph}$= Photon Current

$I_D$= Diode Current

$I_{sh}$=Shunt Current

The five fundamental mathematical equations describing the I–V characteristics of the PV solar cell from the theory of semi-conductors will be expressed in the following sections as stated by the methodology flowchart.

The following figure summarizes the methodology adopted towards simulating a reference model of a Polycrystalline and Monocrystalline PV Module operating under localized climatic conditions of Buea and Garoua, using the MATLAB/Simulink software.

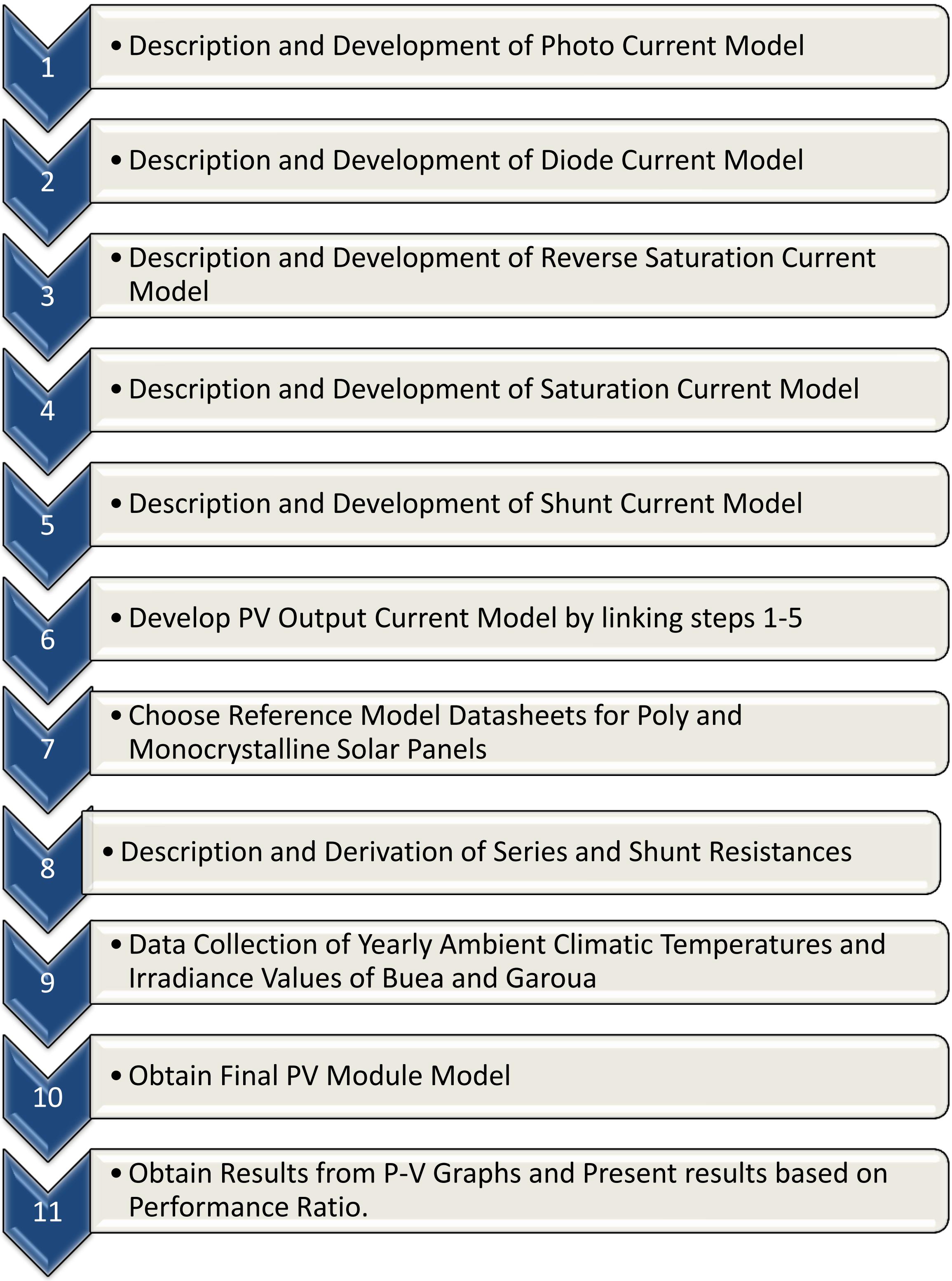



Figure 4: Methodology Adopted

## 3.2 Mathematical Modeling of Subsystems

### 3.2.1 The Photo Current Model

It is mathematically defined as:

- $$I_{ph} = [I_{sc} + K_i * (T - 298)] * \frac{G}{1000} \qquad (2)$$

Where

$I_{ph}$= Photo Current

$I_{sc}$= Short Circuit Current

$K_i$= Temperature coefficient of cell short circuit Current

G=Solar Irradiance Value

T= Real Time Temperature

It is proportional to the incident flux and independent of V. It is linearly dependent on the solar radiation and also influenced by temperature.

The Photo current Subsystem is illustrated in the figure below:

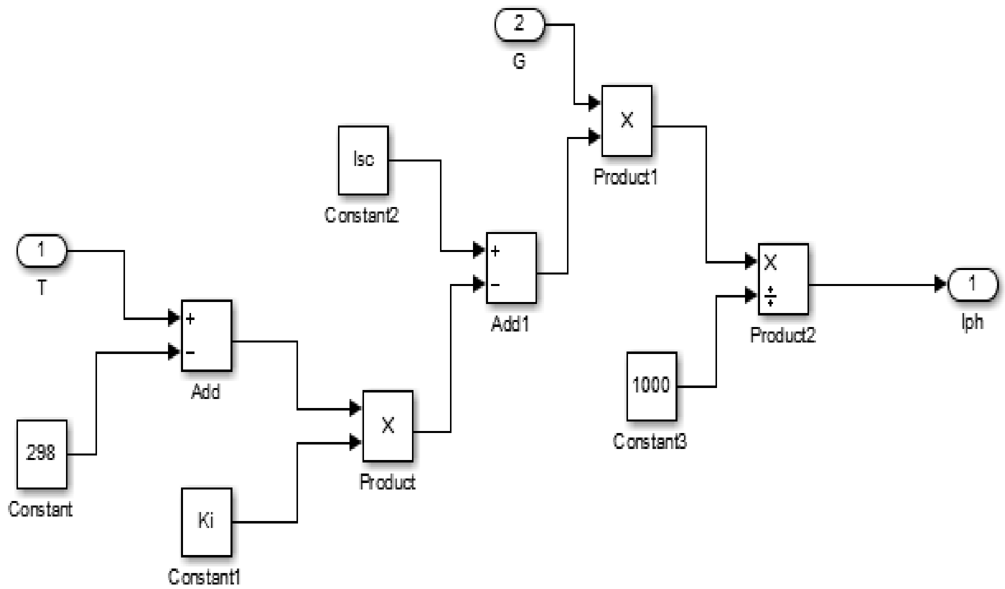



Figure 5: Photocurrent Subsystem

### 3.2.2 The Diode Current Model

Diode Current is determined by the Shockley diode current equation and mathematically defined as:

$$I_D = I_O * \left[\left[\exp\left(\frac{q * (V + I * R_S)}{n * K * N_S * T}\right)\right] - 1\right] \qquad (3)$$

Substituting (3) in (1), we have (4)

$$I = I_{ph} - I_o * [\left[\exp\left(\frac{q * (V + I * Rs)}{n * K * Ns * T}\right] - 1\right] - I_{sh} \qquad (4)$$

Where I= Output Current

$I_{ph}$=Photo Current

$I_O$= Saturation Current

q= Charge of an electron

V= Output Voltage

$R_s$= Series Resistance

K=Boltzmann Constant

$N_S$= Number of Cells in Series

T=Ambient Temperature

$I_{sh}$=Shunt Current

There are some parameters that need to be determined for modeling, which depends on the selected model of PV module [11]. In the following models, we require to compute the Saturation Current, Reverse Saturation Current and the Shunt Current.

### 3.2.3 The Saturation Current Model

The saturation current, $Io$ is an indicator to the amount of recombination rate (or leakage) of charge carriers through the PN junction in reverse bias. $Io$ for a PN junction solar cell is noticeably increased with cell temperature [6]. It is mathematically defined as follows:

- $$I_o = I_{rs} * [\frac{T}{T_n}]^3 * \exp[\frac{q*Eg0}{n*K}] * \left(\frac{1}{T_n} - \frac{1}{T}\right) \qquad (5)$$

and has as input the reverse saturation current($I_{rs}$), energy band gap($Eg_0$), electron charge(q), reference temperature($T_n$) and operating temperature of module(T) .The simulation model is shown in the figure below:

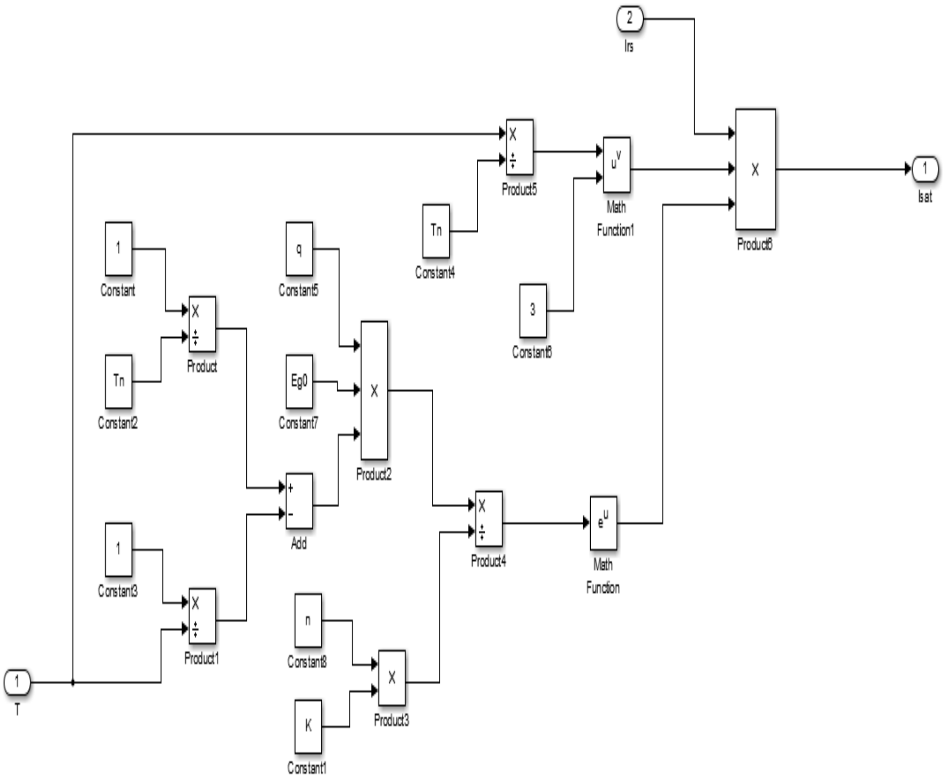



Figure 6: Saturation Current Model

### 3.2.4 The Reverse Saturation Model

It is defined by the following mathematical equation [17]:

- $$I_{rs} = {}^{I_{sc}}\Big/_{[\exp(\frac{qV_{oc}}{N_sKnT)-1})]} \qquad (6)$$

Where:

$V_{oc}$=Open Circuit Voltage

$N_s$= Number of Cells in Series

K= Boltzmann's Constant

n= Diode Ideality Factor

T= Ambient Climatic Temperature

It is developed by using data sheet parameters and is modelled as shown in the figure below

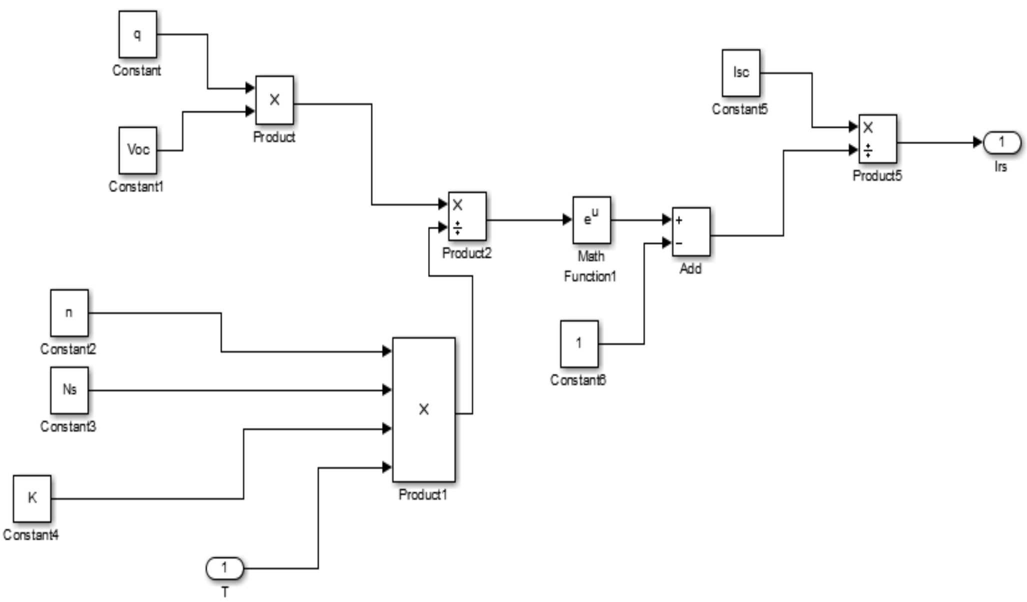



Figure 7: Reverse Saturation Current Subsystem

### 3.2.5 Shunt Current Model

The output current of the module is due to the leakage current through “the parallel branch”. It is described by the following equation [4]:

- $$I_{sh} = \left(\frac{V+I*Rs}{R_{sh}}\right) \tag{7}$$

Where:

$R_s$= Series Resistance

$R_{sh}$= Shunt Resistance

The PV Module is simulated by interlinking the entire sub systems modeled above and represented by equations 1-7 as shown in the figure below:

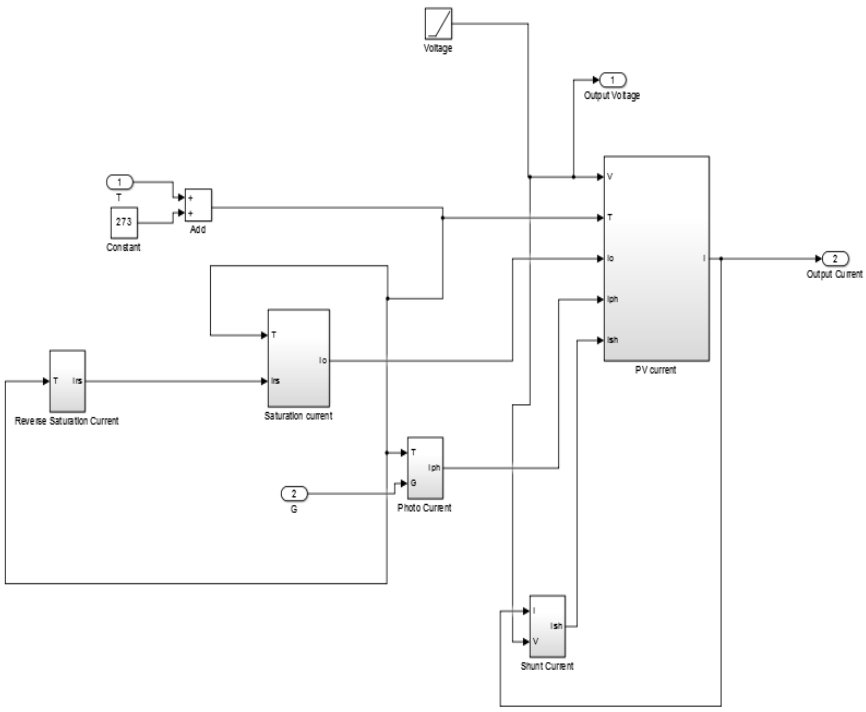



Figure 8: Linked Subsystems

## 3.3 Reference Data Sheet Parameters

The following table states the Module parameters of the BLD 200W Series of the Mono and Polycrystalline PV Module

**Table 1: Reference Data Sheets Parameters**

| Parameter | BLD 200-72M Series | BLD200-60P Series |
|---|---|---|
| Peak Power_$P_{max}$ | 200W | 200W |
| Max Power Voltage_$V_{MP}$ | 37.77V | 28.50V |
| Max Power Current_$I_{MP}$ | 5.29A | 7.02A |
| $V_{OC}$ | 45.25V | 36.24V |
| $I_{SC}$ | 5.92A | 7.94A |
| Module Efficiency | 15.67% | 12.22% |
| Temp Coef of $I_{SC}$ | 0.037%/$^0$C | 0.045%/$^0$C |
| $N_S$ | 72 | 60 |

## 3.4 Series and Shunt Resistances

In the case of a photovoltaic module, its effective series resistance is composed by the junction's internal resistance, metallic contacts and interconnections [23]. Series resistance, $Rs$ reduces the output voltage. It is known that the electrical resistance of a conductive material increases with temperature, this is because the mobility of charge carriers has an inverse relationship with the temperature. As temperature increases, the carrier scattering is increased on lattice vibrations and impurities. This reduction in mobility decreases the conductivity and hence increases the series resistance. [1]

It can be approximated by the following equation [24]:

$$R_S = \frac{\propto_{ref}\ In\left[1 - \frac{I_{MP,ref}}{I_{SC,ref}}\right] + V_{OC,ref} - V_{MP,ref}}{I_{MP,ref}} \qquad (8)$$

Where $\propto_{ref}$=Thermal Voltage Completion Factor at Reference Conditions and calculated as:

$$\propto_{ref}= \frac{2V_{mp,ref} - V_{oc,ref}}{\left(\frac{I_{sc,ref}}{I_{sc,ref} - I_{mp,ref} + In\left[1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right]}\right)} \quad (9)$$

Numerical Substitution from table 1 in equations 8 and 9 yield the series resistances of the reference PV Modules as tabulated below:

**Table 2: Series Resistance Values**

| Parameter | BLD 200-72M Series | BLD200-60P Series |
|---|---|---|
| $\boldsymbol{\propto_{ref}}$ | 4.20 | 3.21 |
| $\boldsymbol{R_S}$ | 0.45Ὠ | 0.54Ὠ |

The series resistance increases with temperature and decreases with insolation according to [25]:

$$R_s = \frac{T}{T_{STC}}\left[1 - \lambda In\frac{G}{G_{STC}}\right]R_{s_{STC}} \quad 10$$

Where

$R_S$= Series Resistance

T= Ambient Climatic Temperature

$T_{STC}$= Temperature at Standard Test Conditions

$\lambda = 0.217$

G= Irradiance

$G_{STC}$= Irradiance at Standard Test Conditions

$R_{S,STC}$= Series Resistance at Standard Test Conditions

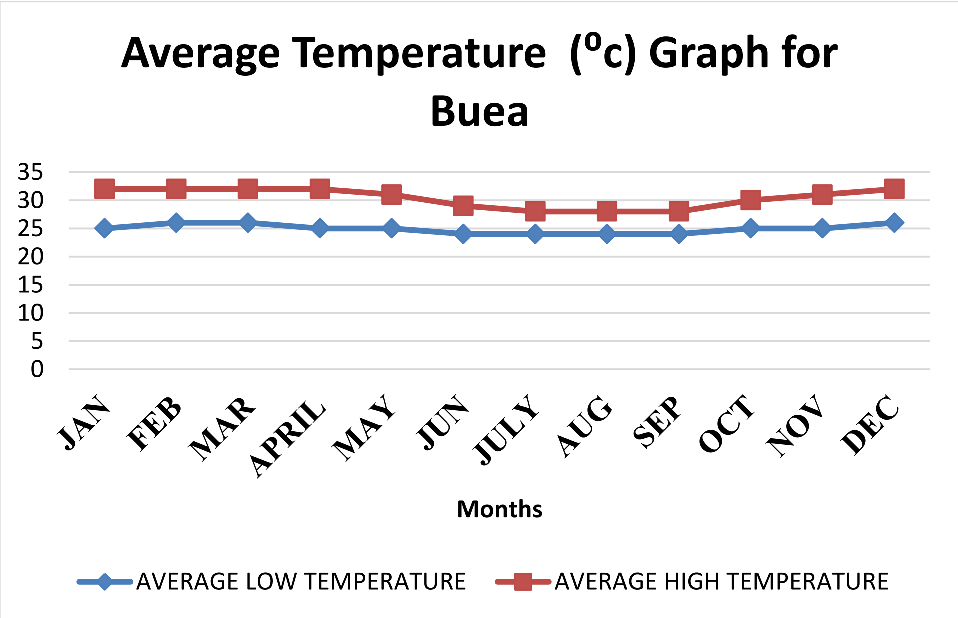
Shunt resistance, $R_{sh}$ reduces the output current of the module because of the leakage current through “the parallel branch”, so ideally it should be infinity. Significant power losses caused by the presence of a shunt resistance, $R_{sh}$, are typically due to manufacturing. Low shunt resistance causes power losses in solar cells by providing an alternate current path for the light-generated current. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell [26].

## 3.5 Weather Data of Buea and Garoua

### 3.5.1: Average Climatic Temperature

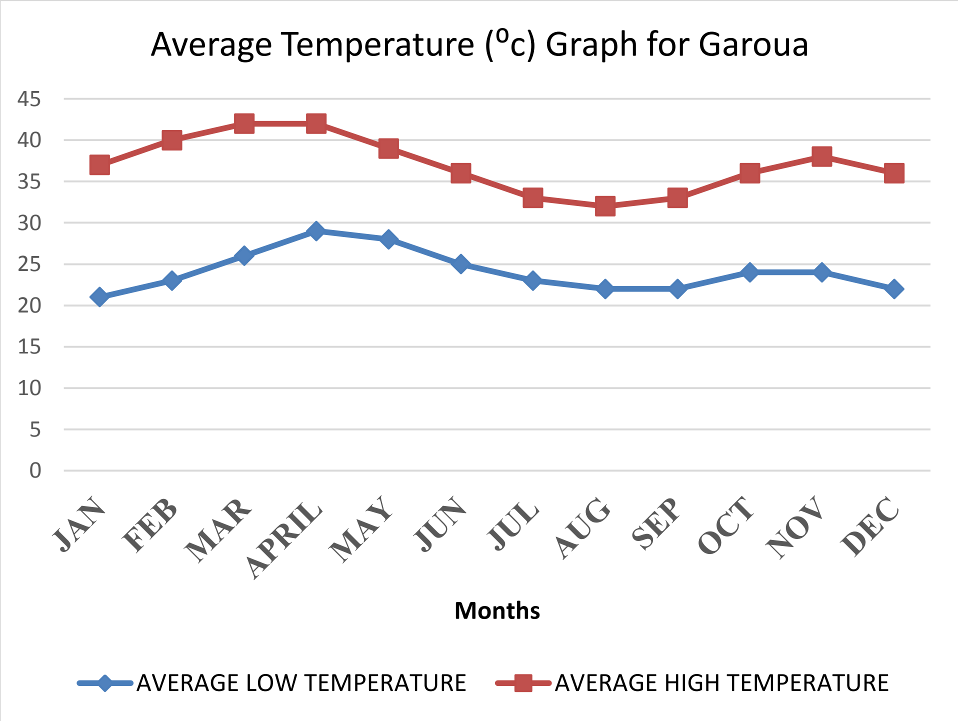
It has already been stated that climatic temperature is a factor which affect PV output. The average low temperatures are observed during the rainy seasons while average high temperatures are observed during the hotter seasons of the year. The difference in climatic temperature can be attributed to the differing amounts of radiation received by different parts of the earth.

The following graphs depict the yearly average temperatures of Buea and Garoua respectively over the last 10 years:




| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average Low Temp** | 25 | 26 | 26 | 25 | 25 | 24 | 24 | 24 | 24 | 25 | 25 | 26 |
| **Average High Temp** | 32 | 32 | 32 | 32 | 31 | 29 | 28 | 28 | 28 | 30 | 31 | 32 |

Figure 9: Average Low and High Yearly Climatic Temperatures of Buea [27]




| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average Low Temp** | 21 | 23 | 26 | 29 | 28 | 25 | 23 | 22 | 22 | 24 | 24 | 22 |
| **Average High Temp** | 37 | 40 | 42 | 42 | 39 | 36 | 33 | 32 | 33 | 36 | 38 | 36 |

Figure 10: Average Low and High Yearly Climatic Temperatures of Garoua [28]

## 3.5.2: Average Solar Irradiance

Solar Irradiance refers to the sun's radiant power, represented in units of $W/m^2$ or $KW/m^2$ while Solar Irradiation is the sun's radiant energy incident on a surface of unit area expressed in units of $KWh/m^2$. [29]

The Average Annual Irradiation in KWh/$m^2$ daily of Cameroon varies as illustrated by the figure below:

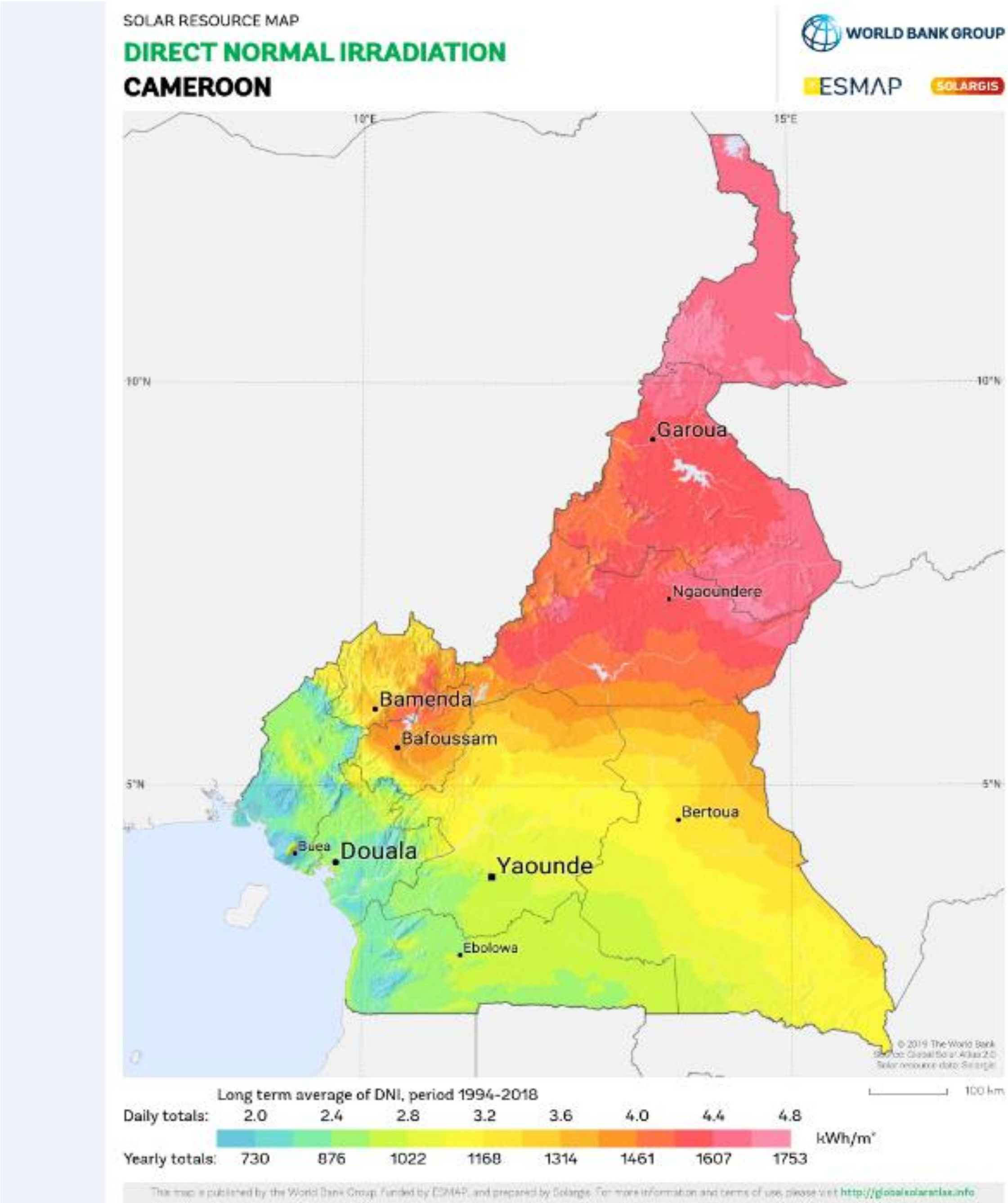
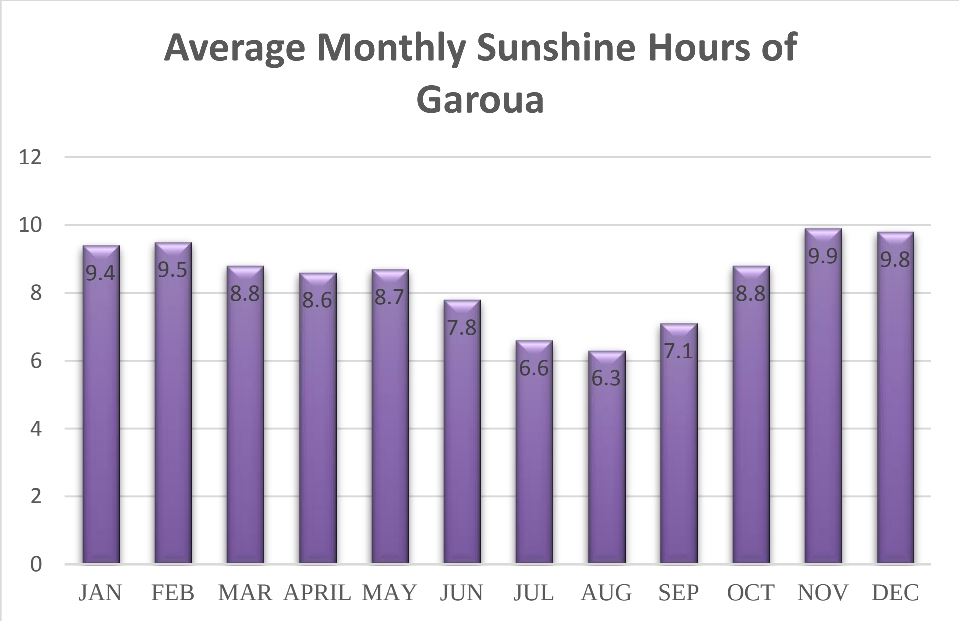


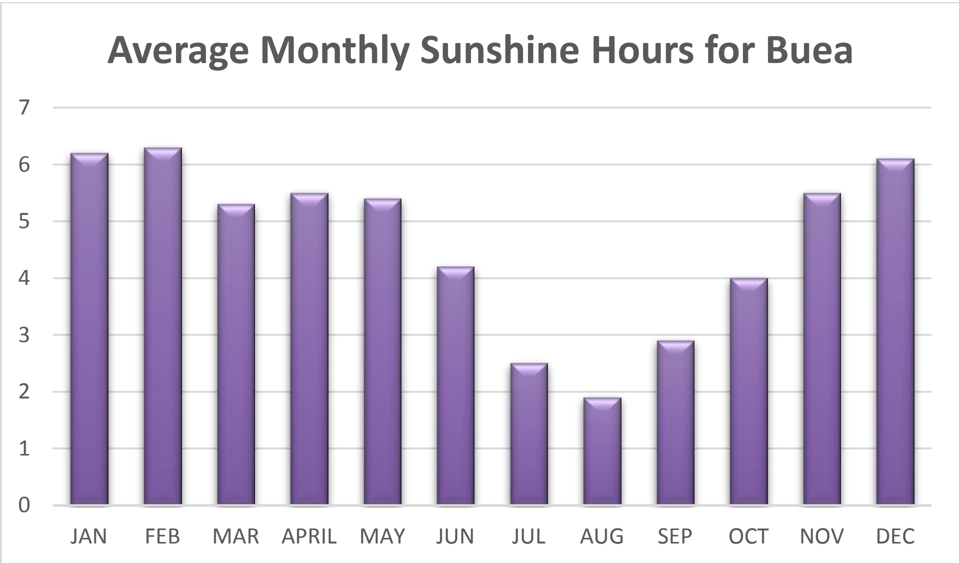

Figure 11: Direct Nominal Irradiation of Cameroon [2]

The Monthly Average numbers of Sunshine hours for Garoua and Buea respectively are shown in figures 12 and 13 below:




| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hrs of Sunshine | 9.4 | 9.5 | 8.8 | 8.6 | 8.7 | 7.8 | 6.6 | 6.3 | 7.1 | 8.8 | 9.9 | 9.8 |

Figure 12: Average Monthly Sunshine Hours of Garoua [30]




| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hrs of Sunshine | 6.2 | 6.3 | 5.3 | 5.5 | 5.4 | 4.2 | 2.5 | 1.9 | 2.9 | 4.0 | 5.5 | 6.1 |

Figure 13: Average Monthly Sunshine Hours of Buea [29]

Therefore, the mean monthly average of sunshine hours for Garoua and Buea are 8.44 hours and 4.65hours respectively.

We can thus calculate average annual irradiance of Garoua and Buea by making P, the subject in the energy equation,

$$P = \frac{Energy(DNI)}{T(N_o\ of\ sunshine\ hrs)} \qquad (10)$$

Where the Direct Normal Irradiance is defined as direct irradiance received on a plane normal to the sun over the total solar spectrum. DNI is an essential component of global irradiance, especially under cloudless conditions, and represents the solar resource that can be used by various forms of concentrating solar technologies [31]

Therefore,

$$Irradiance_{\ Buea} = \frac{2.0 * 1000}{4.65} = \boldsymbol{430.11W/m^2}$$

And

$$Irradiance_{Garoua} = \frac{4.4 * 1000}{8.44} = \boldsymbol{521.33W/m^2}$$

The irradiance values differ as a result of different latitudinal and longitudinal positions of Buea and Garoua from the Equator.

## 3.6 Simulation Results and Analysis

The average Irradiance values and ambient temperatures as seen on figures 14 and 15 are used as input into the final PV module as shown on the figure below:

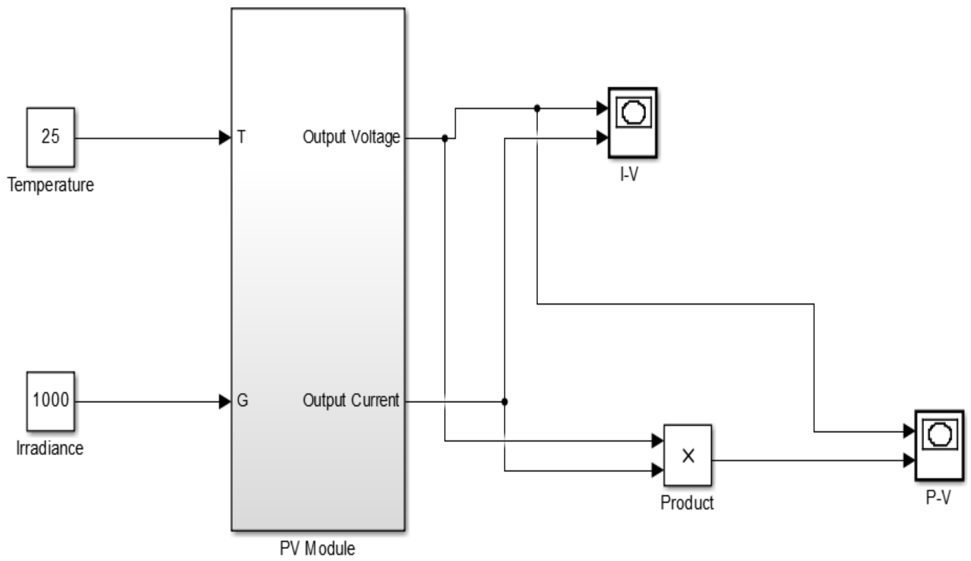



Figure 14: Final PV Module

# CHAPTER FOUR: RESULTS AND DISCUSSION

## 4.1: Simulation Results

As a reference, the Maximum Power output at STC Conditions of 25$^0$C ambient Temperature and irradiance of 1000W/m$^2$ are simulated for both reference PV Modules as shown in figures 15 and 16 below:

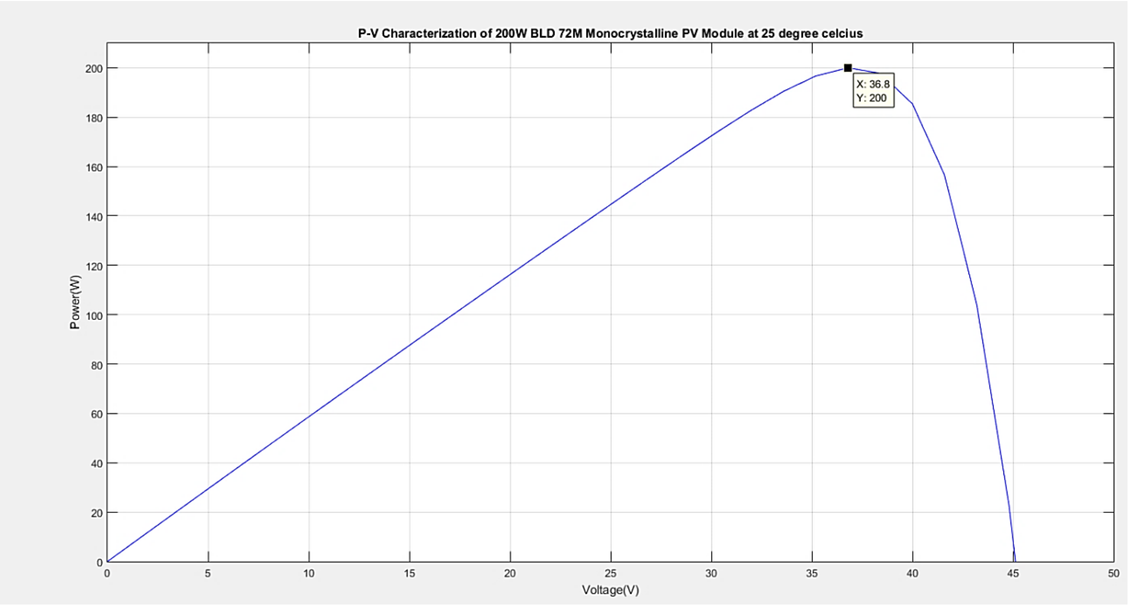



Figure 15: P-V Characterization of 200W BLD 72M at STC

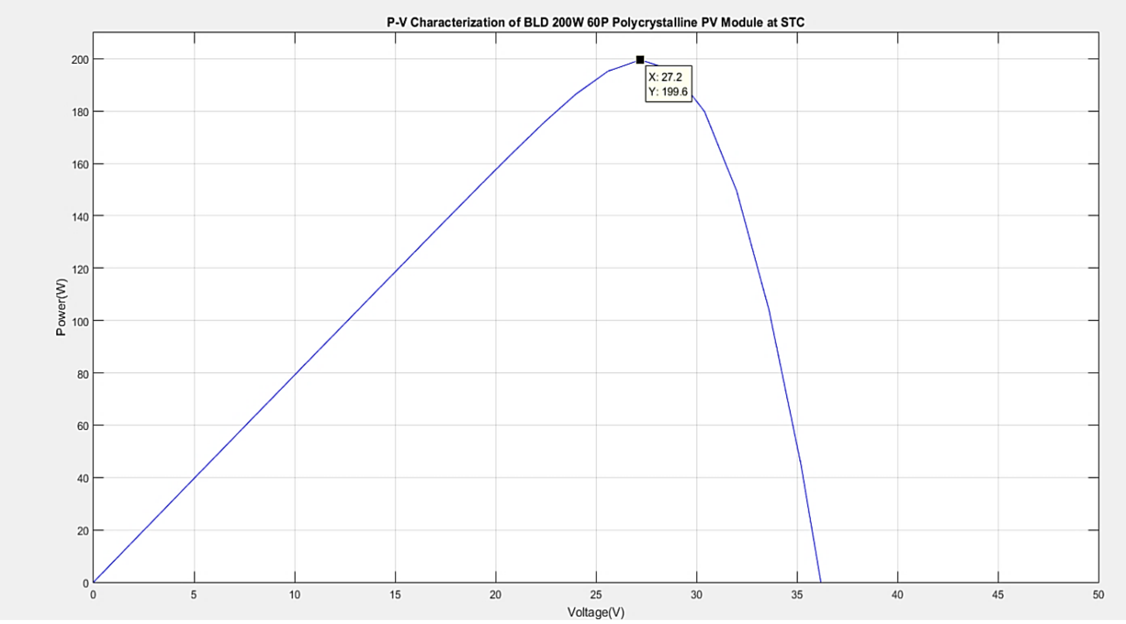



Figure 16: P-V Characterization of 200W BLD 60P at STC

The following table shows the relative accuracy of Vmp and Maximum Power Values to the Data Sheet Reference Values:

**Table 3: Accuracy of Simulated Model**

| **PV Module** | **Parameter** | **Data Sheet Value** | **Simulation Value** | **Accuracy%**$=\frac{\textit{Simulation Value}}{\textit{Data Sheet Value}} * 100$ |
|---|---|---|---|---|
| BLD 200W_72M | Maximum Power | 200W | 200W | 100% |
| | Vmp | 37.77 | 36.8V | 97.43% |
| BLD 200W-_60P | Maximum Power | 200W | 199.6W | 99.95% |
| | Vmp | 28.50V | 27.2V | 95.5% |

The following P-V graphs and their corresponding tables show the results obtained from the Mathematical Modeling technique of PV Modules as explained in chapter 3, detailing their Power Output Efficiency at localized climatic conditions.

## 4.2: BLD 200W 72M Monocrystalline PV Module Analyses

### A) Average Climatic Temperatures of Buea

Figure 17 and table 4 below represent the expected Maximum Power Yield for the BLD 200 W Monocrystalline PV Module operating in average climatic temperatures of Buea with a constant average daily irradiance value of 430.11W/m$^2$. Substituted Values in equation (10) yield the estimated values of Series Resistance ($R_S$) at different ambient temperatures.

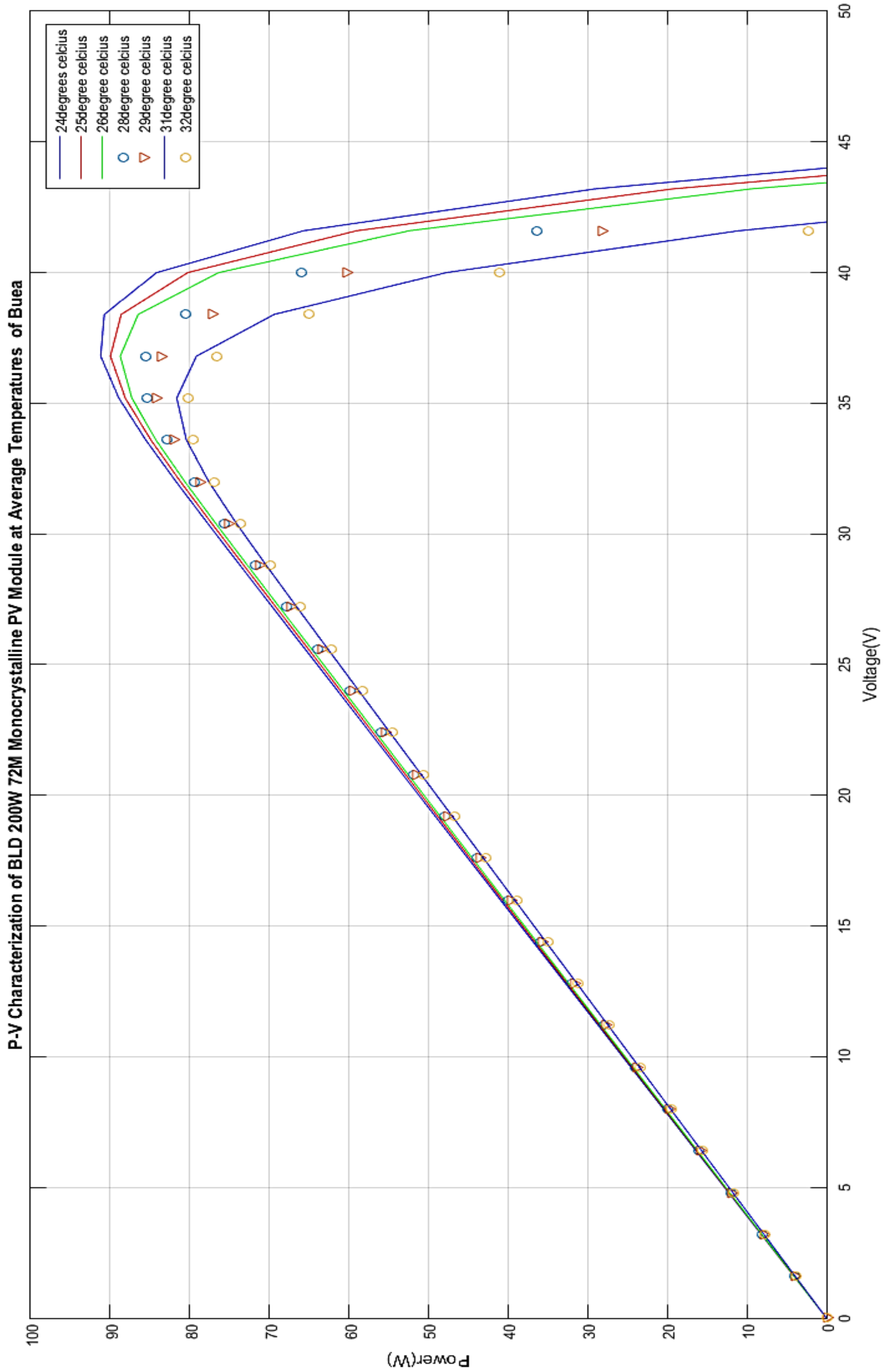



Figure 17: Maximum Power Output at Average Climatic Temperatures of Buea

**Table 4: Maximum Power Output at Average Climatic Temperatures of Buea**

| Temperature/$^0$C | $R_S$/Ω | Pmax/W | $V_{MP}$/V |
|---|---|---|---|
| 24 | 0.51 | 91.19 | 36.8 |
| 25 | 0.53 | 89.97 | 36.8 |
| 26 | 0.55 | 88.73 | 35.8 |
| 28 | 0.59 | 85.50 | 35.2 |
| 29 | 0.61 | 84.20 | 35.2 |
| 31 | 0.66 | 81.63 | 35.2 |
| 32 | 0.68 | 80.17 | 33.2 |

## B) Average Climatic Temperatures of Garoua

In a similar way, the estimated maximum Power of this same PV Module at the average Temperatures of Garoua and daily average irradiance of 521.33W/m$^2$ are simulated and presented in Figure 18 and Table 5 below. Substituted Values in equation (10) yield the estimated values of Series Resistance ($R_S$) at different ambient temperatures.

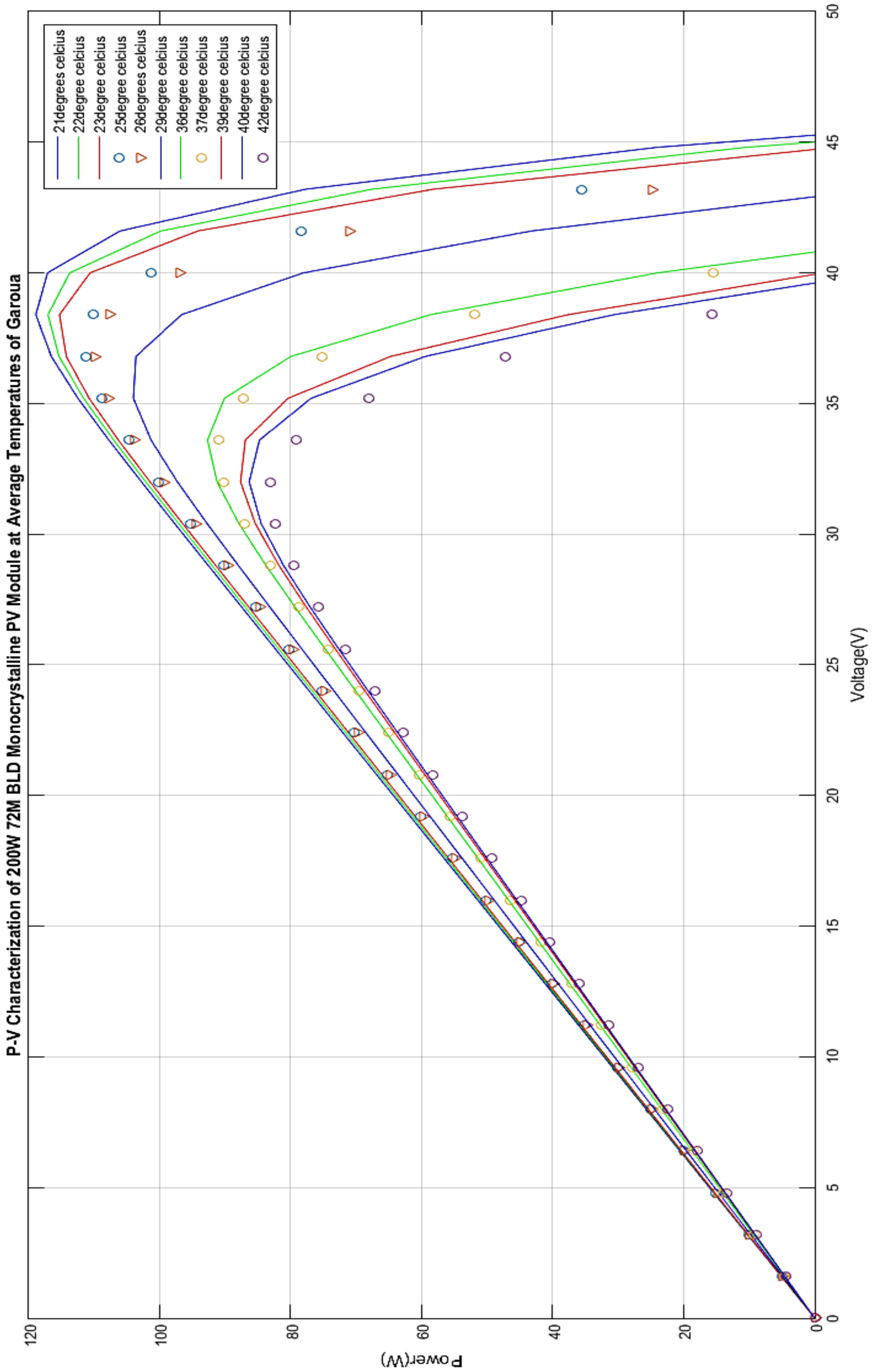



Figure 18: Maximum Power Output at Average Temperatures of Garoua

**Table 5: Maximum Power at Average Temperatures of Garoua**

| Temperature/$^0$C | $R_S$/Ω | Pmax/W | $V_{MP}$/V |
|---|---|---|---|
| 21 | 0.40 | 119.00 | 38.40 |
| 22 | 0.43 | 117.1 | 38.40 |
| 23 | 0.45 | 115.37 | 36.80 |
| 25 | 0.51 | 111.30 | 36.80 |
| 26 | 0.53 | 109.90 | 36.80 |
| 29 | 0.59 | 104.00 | 36.80 |
| 36 | 0.73 | 92.71 | 33.60 |
| 37 | 0.75 | 91.00 | 33.60 |
| 39 | 0.79 | 87.66 | 33.60 |
| 40 | 0.81 | 86.34 | 32.00 |
| 42 | 0.86 | 83.02 | 32.00 |

## 4.3: BLD 200W 60P Polycrystalline PV Module Analysis

## A) Average Climatic Temperatures of Buea

In this section Maximum Power Yield is simulated for the BLD 200W 60P PV Module, using the same data input as the Monocrystalline PV Module. Figure 19 and table 8 below represent the expected Maximum Power Yield for the BLD 200 Polycrystalline PV Module operating in Average Climatic Temperatures of Buea.

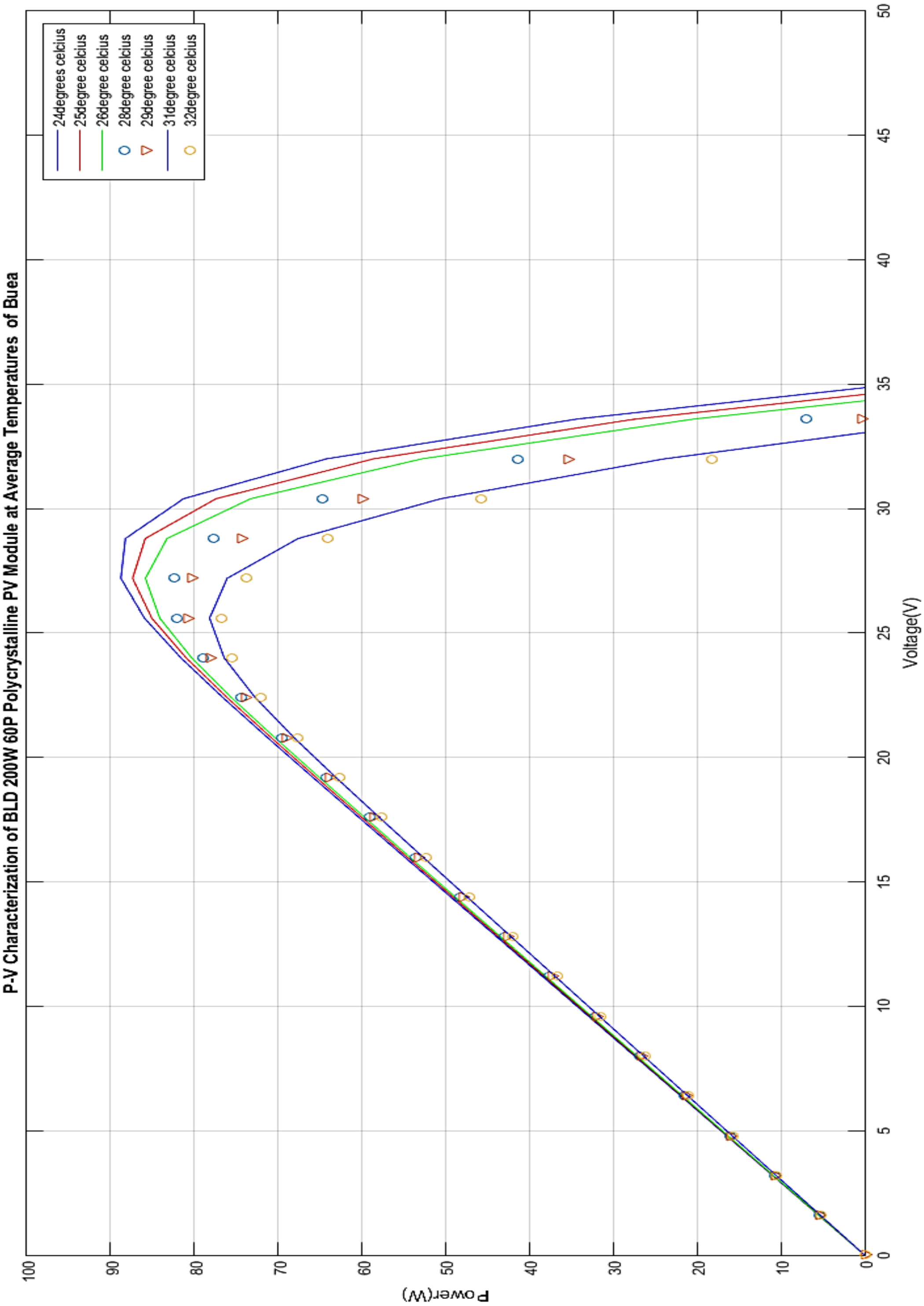



Figure 19: Maximum Power Output at Average Climatic Temperatures of Buea

**Table 6: Maximum Power Output at Average Temperatures of Buea and Daily Average irradiance value of 430.11W/m$^2$**

| Temperature/$^0$C | $R_S$/Ω | Pmax/W | $V_{MP}$/V |
|---|---|---|---|
| 24 | 0.63 | 88.77 | 36.80 |
| 25 | 0.65 | 87.37 | 36.80 |
| 26 | 0.68 | 85.40 | 36.80 |
| 28 | 0.73 | 82.43 | 25.60 |
| 29 | 0.76 | 80.44 | 25.60 |
| 31 | 0.81 | 78.18 | 25.60 |
| 32 | 0.83 | 76.73 | 25.60 |

In a similar way, the estimated Power Output of this same PV Module at the average Climatic Temperatures of Garoua are simulated and presented in Figure 20 and Table 9 below:

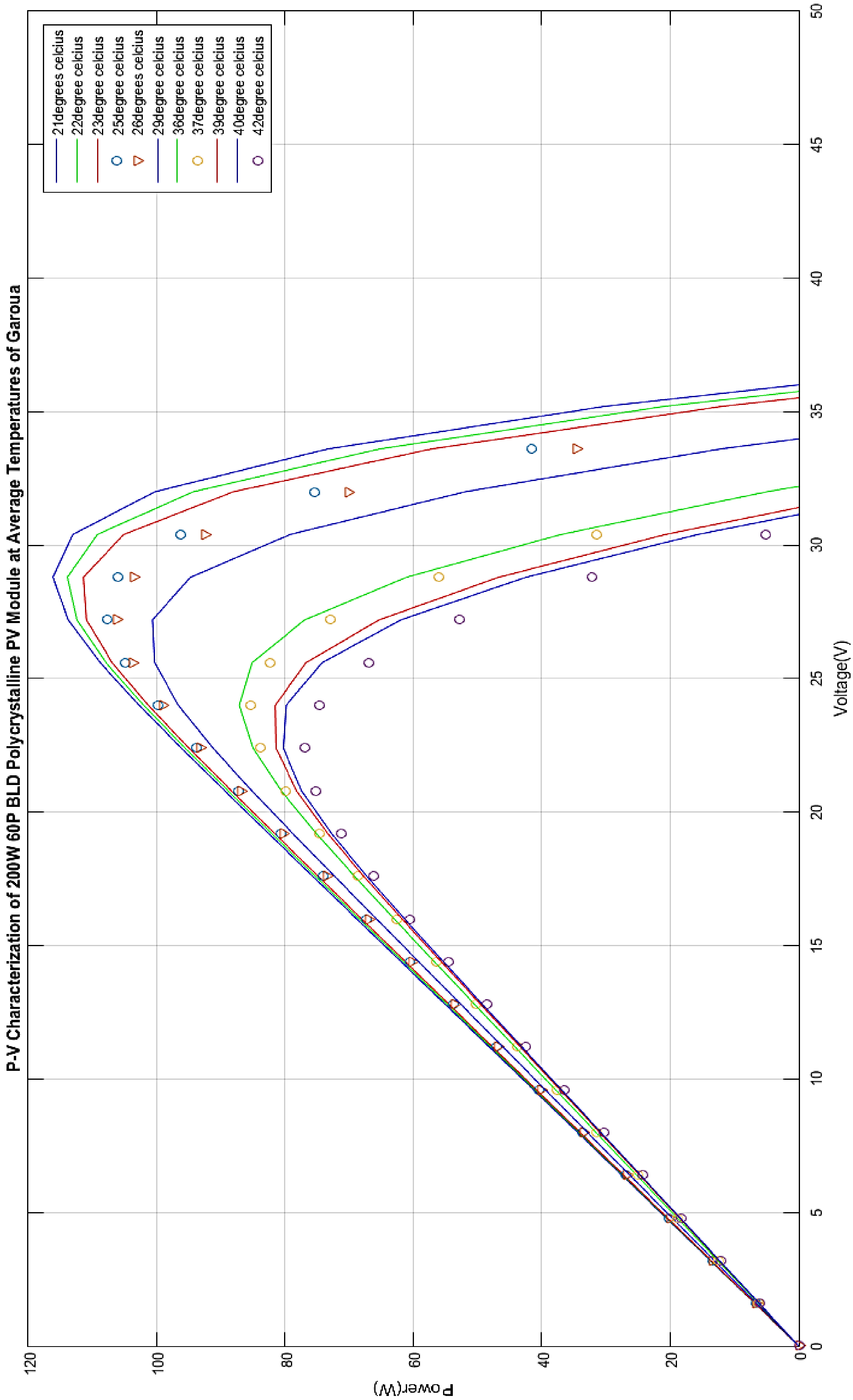



Figure 20: Maximum Power Output at Average Temperatures of Garoua

**Table 7: Maximum Power Output at Average Temperatures of Garoua and average irradiance value of 521.33W/m$^2$**

| Temperature/$^0$C | $R_S$/Ω | Pmax/W | $V_{MP}$/V |
|---|---|---|---|
| 21 | 0.52 | 116.1 | 28.8 |
| 22 | 0.55 | 113.1 | 28.8 |
| 23 | 0.58 | 111.4 | 28.8 |
| 25 | 0.63 | 107.7 | 27.2 |
| 26 | 0.65 | 106.2 | 27.2 |
| 29 | 0.72 | 100.7 | 27.2 |
| 36 | 0.90 | 87.11 | 24.0 |
| 37 | 0.93 | 85.29 | 24.0 |
| 39 | 1.02 | 83.55 | 24.0 |
| 40 | 1.05 | 82.90 | 24.0 |
| 42 | 1.07 | 80.51 | 24.0 |

Based on the Simulation Results there is a clear decline in Power Output of the PV Module as Climatic temperature increases, at constant average irradiation of the localized Climate. Even though an increase in ambient temperature leads to an increase in Short Circuit Current ($I_{sc}$), there exists a simultaneous drop in $V_{oc}$ due to the increase in Voltage drop across the increasing series resistance, consequently leading to an overall drop in output power of the PV Module as temperature increases. Furthermore, it is generally observed that the Monocrystalline PV Module shows better Power Output Performance as compared to the Polycrystalline PV Modules in both High and Low Climatic Conditions.

## 4.4 Result Interpretation

This section analyzes and interprets the results obtained in this research. A cost analysis will further determine which of the Crystalline PV Technologies are recommended in the case studies.

### 4.4.1 Comparison between the Performance of BLD 200W 72M and BLD 200W 60P PV Modules in Buea

The following table compares the Performance Ratios of the reference PV Modules in the localized climatic conditions of Buea. The daily average Irradiance is constant at 430.11W/m$^2$ while the climatic Temperature is varied.

**Table 8: Performance Ratio Analysis of the BLD 200W Series in Buea**

| Temp/$^0$C | BLD 200W-60P | | BLD 200W 72M | |
|---|---|---|---|---|
| | $P_{Max}$/W | Output Power P.R Efficiency/% | $P_{Max}$/W | Output Power P.R Efficiency/% |
| 24 | 88.77 | 44.39 | 91.19 | 45.60 |
| 25 | 87.37 | 43.69 | 89.97 | 44.99 |
| 26 | 85.84 | 42.92 | 88.73 | 44.37 |
| 28 | 82.43 | 41.22 | 85.50 | 42.75 |
| 29 | 80.44 | 40.22 | 84.20 | 42.10 |
| 31 | 78.18 | 39.09 | 81.63 | 40.82 |
| 32 | 76.73 | 38.37 | 80.17 | 40.19 |

It can be noticed that, at average Temperatures of Buea, the Monocrystalline PV Module has a consistent higher output from the Polycrystalline PV Module as shown on the table below:

**Table 9: Difference in Maximum Power Output in Buea**

| Temp/$^{0}$C | $P_{Max-Poly}$/W | $P_{Max-Mono}$/W | $\Delta P_{Max}$/W |
|---|---|---|---|
| 24 | 88.77 | 91.19 | 2.42 |
| 25 | 87.37 | 89.97 | 2.60 |
| 26 | 85.84 | 88.73 | 2.89 |
| 28 | 82.43 | 85.50 | 3.07 |
| 29 | 80.44 | 84.20 | 3.76 |
| 31 | 78.18 | 81.63 | 3.45 |
| 32 | 76.63 | 80.17 | 3.54 |

Furthermore, a vertical analysis of the effect of temperature rise on the Power Output Losses of the PV Modules are shown on the table below:

**Table 10: Power Loss per Temperature Rise in Buea**

| ΔP | $\Delta P_{Poly}$/W | $\Delta P_{Mono}$/W |
|---|---|---|
| $P_{24} - P_{25}$ | 1.40 | 1.22 |
| $P_{25} - P_{26}$ | 1.53 | 1.24 |
| $P_{26} - P_{28}$ | 3.41 | 3.23 |
| $P_{28} - P_{29}$ | 1.99 | 1.30 |
| $P_{29} - P_{31}$ | 2.26 | 2.57 |
| $P_{31} - P_{32}$ | 1.55 | 1.46 |

From the above table it can be observed that for localized climatic conditions of Buea, the Monocrystalline PV Module is less affected by an increase in temperature rise. Hence it can be deduced that in Buea the Monocrystalline PV Module has a lower temperature coefficient compared to the Polycrystalline PV Module.

### 4.4.2 Comparison between the Performance of BLD 200W 72M and BLD 200W 60P PV Modules in Garoua.

Similarly, the following table compares the Performance Ratios of the reference PV Modules in the localized climatic conditions of Garoua. The daily average Irradiance is kept constant at 530W/m$^2$ while the climatic Temperature is varied.

**Table 11: Performance Ratio Analysis of the BLD 200 Series in Garoua.**

| Temp/$^0$C | BLD 200W-60P | | BLD 200W 72M | |
|---|---|---|---|---|
| | $P_{Max}$/W | Output Power P.R Efficiency/% | $P_{Max}$/W | Output Power P.R Efficiency/% |
| 21 | 116.10 | 58.05 | 119.00 | 59.50 |
| 22 | 113.10 | 56.55 | 117.10 | 58.55 |
| 23 | 111.40 | 55.70 | 115.30 | 57.65 |
| 25 | 107.70 | 53.85 | 111.30 | 55.65 |
| 26 | 106.20 | 53.10 | 109.90 | 54.95 |
| 29 | 100.70 | 50.35 | 104.00 | 52.00 |
| 36 | 87.11 | 43.56 | 92.71 | 46.36 |
| 37 | 85.29 | 42.65 | 91.00 | 45.50 |
| 39 | 83.55 | 41.78 | 87.66 | 43.83 |
| 40 | 82.90 | 41.46 | 85.34 | 43.17 |
| 42 | 80.51 | 39.26 | 83.02 | 41.51 |

Generally, for a region to be termed a semi-arid region, it implies that climatic temperatures are on the high side for the most part of the year. At Average Temperatures of Garoua, the Monocrystalline PV Module has a higher output than Polycrystalline PV Module as shown on the table below:

**Table 12: Difference in Maximum Power Output in Garoua**

| Temp/$^0$C | $P_{Max-Poly}$/W | $P_{Max-Mono}$/W | $\Delta P_{Max}$/W |
|---|---|---|---|
| 21 | 116.10 | 119.00 | 2.90 |
| 22 | 113.10 | 117.10 | 4.00 |
| 23 | 111.40 | 115.30 | 3.90 |
| 25 | 107.70 | 111.30 | 3.60 |
| 26 | 106.20 | 109.90 | 3.70 |
| 29 | 100.70 | 104.00 | 3.30 |
| 36 | 87.11 | 92.71 | 5.60 |
| 37 | 85.29 | 91.00 | 5.71 |
| 39 | 83.55 | 87.66 | 4.11 |
| 40 | 82.90 | 85.34 | 2.42 |
| 42 | 80.51 | 83.02 | 3.51 |

For Higher Temperatures however (39$^0$C to 40$^0$C), there is a drop in the Output Power of the Monocrystalline PV Module. A vertical analysis on the effect of temperature rise on the Power Output Losses of both PV Modules is tabulated below:

**Table 13: Power Loss per Temperature Rise in Garoua**

| ΔP | $\Delta P_{Poly}/W$ | $\Delta P_{Mono}/W$ |
|---|---|---|
| $P_{21} - P_{22}$ | 3.00 | 1.90 |
| $P_{22} - P_{23}$ | 1.70 | 1.80 |
| $P_{23} - P_{25}$ | 3.70 | 4.00 |
| $P_{25} - P_{26}$ | 1.50 | 1.40 |
| $P_{26} - P_{29}$ | 5.50 | 5.90 |
| $P_{29} - P_{36}$ | 13.59 | 11.29 |
| $P_{36} - P_{37}$ | 1.82 | 1.71 |
| $P_{37} - P_{39}$ | 1.74 | 3.34 |
| $P_{39} - P_{40}$ | 0.65 | 2.32 |
| $P_{40} - P_{42}$ | 2.39 | 2.32 |

From the table above, it can be seen that at extremely high climatic temperatures, the Monocrystalline PV Panel is more affected than its counterpart. This is in line with research work published by [8, 32].

### 4.4.3: Energy Analysis

The average yearly estimated energy produced is calculated.

A: **Yearly Energy Outputs of BLD 200W 72M and BLD 200W 60P PV Modules in Buea.**

**1 Polycrystalline PV Module**

| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Av. Temp** | 28.5 | 29 | 29 | 28.5 | 28 | 26.5 | 26 | 26 | 26 | 27.5 | 28 | 29 |
| **Av. Power** | 80.5 | 80.4 | 80.4 | 80.5 | 82.4 | 84.0 | 85.8 | 85.8 | 85.8 | 83.3 | 82.4 | 80.4 |
| **Sunshine hrs** | 6.2 | 6.3 | 5.3 | 5.5 | 5.4 | 4.2 | 2.5 | 1.9 | 2.9 | 4.0 | 5.5 | 6.1 |
| **Monthly Energy** | 490.11 | 506.77 | 426.33 | 434.77 | 445.12 | 353.01 | 214.60 | 163.09 | 248.93 | 333.28 | 453.36 | 490.68 |
| **TOTAL Average Energy** | **4560.052Wh/year** | | | | | | | | | | | |

2) Monocrystalline PV Module

| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Av. Temp** | 28.5 | 29 | 29 | 28.5 | 28 | 26.5 | 26 | 26 | 26 | 27.5 | 28 | 29 |
| **Av. Power** | 81.2 | 84.2 | 84.2 | 83.9 | 85.5 | 87.5 | 88.7 | 88.7 | 88.7 | 86.0 | 85.5 | 84.2 |
| **Sunshine hrs** | 6.2 | 6.3 | 5.3 | 5.5 | 5.4 | 4.2 | 2.5 | 1.9 | 2.9 | 4.0 | 5.5 | 6.1 |
| **Monthly Energy** | 503.68 | 530.46 | 446.26 | 461.94 | 461.70 | 367.58 | 221.83 | 168.58 | 257.32 | 344.0 | 470.25 | 513.62 |
| **TOTAL Average Energy** | **4285.287Wh/year** | | | | | | | | | | | |

## Yearly Energy Outputs of BLD 200W 72M and BLD 200W 60P PV Modules in Garoua.

1 monocrystalline

| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Av. Temp** | 29 | 31.5 | 34 | 35.5 | 33.5 | 30.5 | 28 | 27 | 27.5 | 30 | 31 | 29 |
| **Av. Power** | 102.30 | 99.3 | 94.5 | 91.9 | 94.7 | 100.10 | 104.00 | 106.00 | 104.90 | 100.80 | 99.3 | 102.33 |
| **Sunshine hrs** | 9.4 | 9.5 | 8.8 | 8.6 | 8.7 | 7.8 | 6.6 | 6.3 | 7.1 | 8.8 | 9.9 | 9.8 |
| **Monthly Energy** | 961.62 | 942.97 | 832.39 | 790.51 | 824.06 | 780.78 | 684.40 | 667.80 | 744.79 | 887.04 | 982.67 | 1002.54 |
| **TOTAL Average Energy** | **Wh/year** | | | | | | | | | | | |

2 POLYCRYSTALLINE

| Month | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Av. Temp** | 29 | 31.5 | 34 | 35.5 | 33.5 | 30.5 | 28 | 27 | 27.5 | 30 | 31 | 29 |
| **Av. Power** | 100.70 | 97.4 | 89.0 | 86.5 | 89.0 | 94.7 | 99.7 | 101.0 | 101.0 | 96.4 | 94.7 | 100.7 |
| **Sunshine hrs** | 9.4 | 9.5 | 8.8 | 8.6 | 8.7 | 7.8 | 6.6 | 6.3 | 7.1 | 8.8 | 9.9 | 9.8 |
| **Monthly Energy** | 946.58 | 925.49 | 783.28 | 744.07 | 774.38 | 739.05 | 658.61 | 636.30 | 717.10 | 848.32 | 938.02 | 986.86 |
| **TOTAL Average Energy** | **9648.04 Wh/year** | | | | | | | | | | | |

**4.5 Cost Analysis**

The Payback Time refers to the amount of time it takes to recover the cost of an investment. The desirability of an investment is related to payback time as shorter payback attracts more investment.

From Table 13 above, the Monocrystalline Solar PV Module is more affected by an extreme increase in temperature rise than the Polycrystalline PV Module. This is more pronounced in Garoua where temperatures are on the extreme high side. This analysis is backed up by research work proposed by [32]. Looking at the overall picture however, the Monocrystalline is more efficient and also more expensive[33,34]. Hence, to balance up cost and efficiency when installing PV Modules in hotter climates (Garoua), the change in the degree of Performance Ratio alongside the effect of temperature rise on the output Power of the modules must also be considered. The following Table gives an estimated cost of installing Monocrystalline and Polycrystalline PV Modules per peak power produced [32]

**Table 14: Installation Costs of PV Panels**

| Type of Solar Panel | Price per Watt Peak/$ |
|---|---|
| Monocrystalline | 1.1 |
| Polycrystalline | 1.06 |

The cost of attaining the Maximum Peak Performance Ratio from the case studies in localized climatic conditions of Buea is presented on the following table:

**Table 15: Cost Analysis of the BLD200W Series in Buea**

| Temp/$^0$C | BLD 200W-60P | | BLD 200W 72M | | Cost Analysis | |
|---|---|---|---|---|---|---|
| | $P_{Max}$/W | Output Power P.R Efficiency/% | $P_{Max}$/W | Output Power P.R Efficiency/% | BLD 200W-60P($) | BLD200W-72M($) |
| 24 | 88.77 | 44.39 | 91.19 | 45.60 | 94.09 | 100.31 |
| 25 | 87.37 | 43.69 | 89.97 | 44.99 | 92.61 | 96.16 |
| 26 | 85.84 | 42.92 | 88.73 | 44.37 | 90.99 | 94.16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | 82.43 | 41.22 | 85.50 | 42.75 | 87.37 | 92.05 |
| 29 | 80.44 | 40.22 | 84.20 | 42.10 | 85.26 | 90.20 |
| 31 | 78.18 | 39.09 | 81.63 | 40.82 | 82.87 | 87.20 |
| 32 | 76.73 | 38.37 | 80.17 | 40.19 | 81.33 | 85.65 |

From the above table, it can be seen that the Monocrystalline PV Panel is more expensive but its cost is covered up for by a better performance ratio and lesser temperature coefficient losses as shown on tables 9 and 10 respectively, compared to the Polycrystalline Module. Hence in the long run, The Monocrystalline PV Panel will have a shorter Payback Assessment Time compared to the Polycrystalline PV Module. From the analysis above it can be concluded that the BLD 200W 72M will be a better choice for PV installations in Buea.

For localized climatic conditions of Garoua, the following table estimates the cost of obtaining Maximum Performance Ratio of the BLD200W Series.

**Table 16: Cost Analysis of the BLD 200W Series in Garoua**

| **Temp/$^0$C** | **BLD 200W-60P** | | **BLD 200W 72M** | | **Cost Analysis** | |
|---|---|---|---|---|---|---|
| | **$P_{Max}$/W** | **Output Power P.R Efficiency/%** | **$P_{Max}$/W** | **Output Power P.R Efficiency/%** | **BLD 200W-60P($)** | **BLD200W-72M($)** |
| 21 | 116.10 | 58.05 | 119.0 | 59.50 | 123.06 | 130.90 |
| 22 | 113.10 | 56.55 | 117.10 | 58.55 | 119.88 | 128.81 |
| 23 | 111.40 | 55.55 | 115.30 | 57.65 | 118.08 | 126.83 |
| 25 | 107.70 | 53.85 | 111.30 | 55.65 | 114.16 | 122.43 |
| 26 | 106.20 | 53.10 | 109.90 | 54.95 | 112.57 | 120.89 |
| 29 | 100.70 | 50.35 | 104.00 | 52.00 | 106.74 | 114.40 |
| 36 | 87.11 | 43.55 | 92.71 | 46.36 | 92.34 | 101.98 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 37 | 85.29 | 42.64 | 91.00 | 45.50 | 90.40 | 100.10 |
| 39 | 83.55 | 42.05 | 87.66 | 43.83 | 88.56 | 96.42 |
| 40 | 82.92 | 41.46 | 86.34 | 43.17 | 87.89 | 94.97 |
| 42 | 78.51 | 39.25 | 83.02 | 41.51 | 83.22 | 91.32 |

The highlighted cost portion of the table illustrates that at extreme high climatic temperatures, the Monocrystalline PV Module is more efficient but considering the effect of extreme temperatures on it, which can lead to a reduction in lifespan of the panel, the Polycrystalline PV Module is the better option for PV System installations in Garoua. It can therefore be concluded that that at extreme high temperatures, the cost of installation is the determining factor since both modules have almost the same efficiency.

## 4.6 Conclusion

Using the simulated model, the performance of Monocrystalline and Polycrystalline PV Modules under localized climatic conditions of Buea and Garoua can be studied by the user. Even though the Monocrystalline technology is more efficient due to the degree of purity in its crystal lattice, it is more expensive to install in hotter climatic temperature conditions since its performance is more affected by an increase in temperature rise as compared to the lower costing Polycrystalline PV Module, giving an advantage to the Polycrystalline Technology.

On the other hand, in colder Climatic Temperatures such as Buea, where average temperatures are generally low for the most part of the year, the Monocrystalline PV Module is recommended since its Performance Ratio Efficiency is quite greater than its counterpart case study of this research and is less affected by temperature rise. This assertion can further be backed by the higher Monocrystalline outputs at average low temperatures of Garoua.

# CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

## 5.1 Introduction

Transiting to Renewable Energy has been identified as one of the major steps toward curbing Global Warming. Amongst the Renewable Energy options is Solar Energy which is fast gaining grounds and harnessed via PV Modules. However, the initial costs of these systems are expensive and might take a long while to recover initial investment. This work affirms that installing the appropriate PV Technology in the climatic condition better suited for its operation will lead to a balance between cost and efficiency.

## 5.2. Future Scope of Study.

For more apprehensive results, an experimental setup in Buea and Garoua can be used alongside the simulated models for optimized results with the sole purpose of striking a balance between cost and efficiency when installing Solar PV Systems.

## 5.3 General Conclusion

The modelling of the Monocrystalline and Polycrystalline PV Modules in Climatic regions of Buea and Garoua was performed to study the effects of localised Climatic Conditions on the efficiencies of PV Modules. The Matlab/Simulink interface was used. Given that, initial installation cost of PV Systems is high, a balance between cost and efficiency must be studied. Reason for the Cost Analysis in Chapter 4. It can be concluded that, in hotter climates of Garoua, The Polycrystalline is better suited since it is less affected by an increase in temperature rise than that of the Monocrystalline PV Module. Whereas in the colder climatic regions of Buea, the Monocrystalline PV Module is recommended since its efficiency slightly outweighs that of the Polycrystalline PV Module.

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