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MATLAB Based PV Cell Characterization Under Varying Different Temperature and Irradiance Conditions

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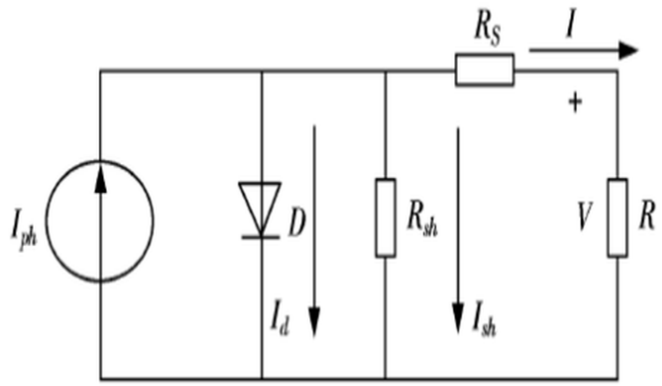
Abstract:
This study presents an analysis of variations in the output characteristics of mono-crystalline silicon PV cell under different temperature and irradiance levels using MATLAB as a simulation tool .The base of study is mathematical modeling of PV cell characteristics using the well- known one-diode equivalent model in MATLAB. The designed tool computes and displays current-voltage (I-V) curves , power- voltage curves (P-V) , maximum power point values (V_m , I_m , P_m) , optimal load resistance (R') for maximum power , open-circuit voltage (V_{oc}) , short-circuit current (I_{sc}) and saturation current (I_o) over a range of cell temperature and irradiation levels . The user provides essential parameters as inputs on the front panel in MATLAB from the datasheet which are given for standard test conditions (STC). The developed design facilitates the prediction of PV cell behavior over a range of temperatures and irradiance levels other than STC. The results obtained from the simulation tool have matched well with the datasheet values by graphically for validating the tool. The design is flexible in the sense that it can be applied to PV cells of any size from any manufacturer. The values of series and shunt resistance are selected so as to have least effect on the output characteristics.

Index terms: MATLAB, output characteristics, single diode PV cell model, and validation.

1. INTRODUCTION

Energy was, is and will remain the basic foundation which determines the stability of the economic development of any nation. Just as the fossil fuel based energy industry relies on exploration and proven reserves for discovery and economic support of energy markets, the renewable energy sector depends upon the assessment of resources for planning and selling their energy production technology. Fossil fuel reserves, which provided the most part of the energy source for the world, are limited and generally decreasing consequently. The increasing energy demand and environmental problems in the world point out that the research and the development activities in the renewable energy sources are essential. Renewable energy resources have enormous potential and can meet the present world energy demand. They can enhance diversity in energy supply markets, secure long – term sustainable energy supplies, and reduce local and global atmospheric emissions. So researchers have developed more efficient way of producing energy from alternatives sources. One of the most promising renewable energy technologies is the solar photovoltaic technology (PV). The solar energy that reaches the earth's surface in less than one hour would be sufficient to satisfy the energy requirements of all human activities for more than one year. For solar-based renewable energy technologies such as solar thermal or photovoltaic conversion systems. The basic resource or fuel available is solar radiation. The increasing use and promotion of renewable energy technologies such as biomass, wind, hydroelectricity, solar thermal and solar electricity, seems to be a viable solution to environmental problems caused by other energy sources. The energy received from the sun on the earth's surface in one hour equals to the amount of approximately one year energy needs of the earth. Sun acts like a blackbody radiator with the surface temperature of 5800 K which leads to a 1367 W/m^2 energy density over the atmosphere [1]. Photovoltaic (PV) refers to the generation of electric power through the use of photovoltaic or solar cells to convert the photons of sunlight directly into electric current. More than 83% of photovoltaic solar modules produced, for terrestrial applications, are made from crystalline silicon solar cells [2]. PV cells can be grouped to form panels or modules. A single silicon PV cell typically generates 0.5 V to 0.8 V which is very low for practical use hence they are grouped in series or parallel to form panels or modules. Nevertheless for all practical purpose the output its basic element [3]. Hence the analysis of the output characteristics of a solar PV cell becomes an essential procedure. The PV cell represents the fundamental power conversion unit of a PV panel. The output characteristics of a PV cell depend largely on the solar insolation or irradiance (G), cell temperature (Tc), series resistance (Rs) and shunt resistance (Rsh). Rs and Rsh remain constant after the cell has been manufactured so their effect is not considered in the model and their values are selected so as to have negligible effect on the output characteristics. The maximum power (Pm) derived from the PV cell or its maximum operating power point depends on the load resistance (R) due to the non-linear output characteristics of the PV cell or its maximum operating power point depends on the load resistance (R) due to non-linear output characteristics of the PV cell, a tool for modeling and simulation is proved to be useful for deriving the maximum power from the PV cell by determining the optimal load resistance (R'). This paper presents the solar PV cell modeling using MATLAB where different models for PV cell based on coding, equation based design in Simulink using single diode model. The developed tool facilitates the prediction of PV cell behavior over a range of temperature and irradiance levels other than STC which proves resourceful during the design of PV panels and serves as a guide for the selection of PV cells for a panel designer. The efficiency for mono-crystalline cells is generally between 15% to 20% and between 9%to 12% for polycrystalline. In case of thin film cells, the efficiency is 10% for a-si. 12% for CuInSe2 and 9% for CdTe. Since mono crystalline silicon based PV cells have the highest efficiency and popularity, this paper focuses on them.

2. PV CELL MATHEMATICS AND CIRCUIT MODEL



The well-known single diode electrical equivalent circuit for a PV cell is shown in fig 1.

Terminology:

T_c = cell temperature in kelvin
I_{sc} ~I_{ph}= short-circuit current at T_c and Irradiance G (W/m^2).
I_d = diode current in amperes
I_{sh} = current through shunt resistance R_{sh} in Amperes
I_o = reverse saturation current at T_C in Amperes
q = electron charge = $1.60*10^{-19}$ coulomb
n = diode ideality factor
K = Boltzmann's constant = $1.38 * 10^{-23}$ joules/kelvin
V = output voltage of cell in volts
I = output current of cell in amperes
T_r = reference temperature, 298.15 kelvin
V_{ocr} = open circuit voltage in volts at T_r
I_{scr} = short-circuit current in Amperes at T_r
The solar cell can be considered as a current source wherein the photo-current I_{ph}, produced by the solar cell is proportional to the solar irradiation intensity falling on it. A single-diode model is adopted in this paper because of sufficient degree of simplicity and precision. The ohmic losses in the cell occur due to the series and shunt resistances denoted by $R_s$andR_{sh} respectively. In ideal case R_s is 0 and R_{sh} is ∞. From the fig.1 it is clear that diode forward bias current and the current through the shunt resistance is supplied by I_{ph}. Only the remaining current flows through the load via series resistance R_s.

Using the Kirchhoff's current law,

$I = I_{ph} – I_d – I_{sh}$ (1)

The current through the diode is given by,

$I_d = I_o [\exp (V_d q/Nkt_C) – 1]$ (2)

And diode voltage is,
$V_d = IR_s + V$ (3)

Leading us finally to the I-V equation of the single – diode equivalent circuit for the PV cell as,

$I = I_{sc} – I_O [\exp \{(V+IR_S) q/Nkt_C\} – 1] – V+IR_S/R_{Sh}$ (4)

When the terminals of the PV cell are open circuited the voltage produced is maximum and is called open circuit voltage V_{oc} given as,

$V_{oc} = \text{In} (I_{SC}/I_O + 1) (nKT_C/q)$ (5)

The reverse saturation current I_{or}at reference temperature is calculated as,

$I_{or} = I_{scr}/ [\exp (qV_{ocr}/nKT_r) – 1]$ (6)

The fill factor of the PV cell is the ratio between the maximum power and the product of open circuit voltage and the short circuit current. It is the square ness of the I-V curve of PV cell and mainly related to the resistive losses. This is a very important factor determining the quality of the PV cell and good PV cells usually have a value more than 0.8 or close to this.

$FF = I_m * V_m / I_{sc} * V_{oc}$ (7)

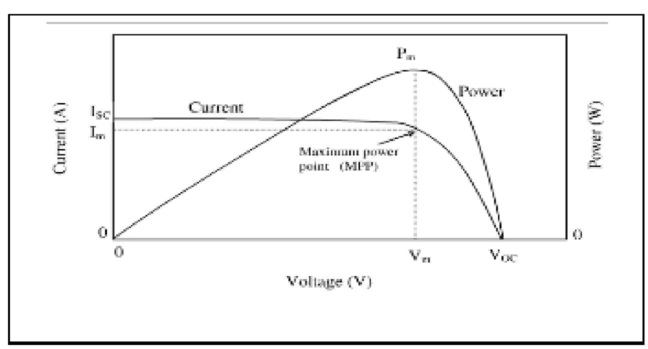
Where 'V_m' and 'I_m' are the voltages and current values at the maximum power point respectively. The optimal load resistance (R') is that resistance at which the operating power point of the PV cell is at its maximum. Hence it can be expressed as follow,

$R' = V_m / I_m$ (8)

The PV cell efficiency is given by the relation,

$\eta = I_{sc} \times V_{oc} \times FF / P_{in}$ (9)

Where P_{in} is the incident irradiance in W/m^2. P_{in} is multiplied by the cell area in m^2 to obtain the total P_{in} for the cell for which the simulation is carried out. All the above equations are implemented in the MATLAB software for the PV cell characterization. Typical I-V and P-V characteristics of a PV cell are shown in fig.2

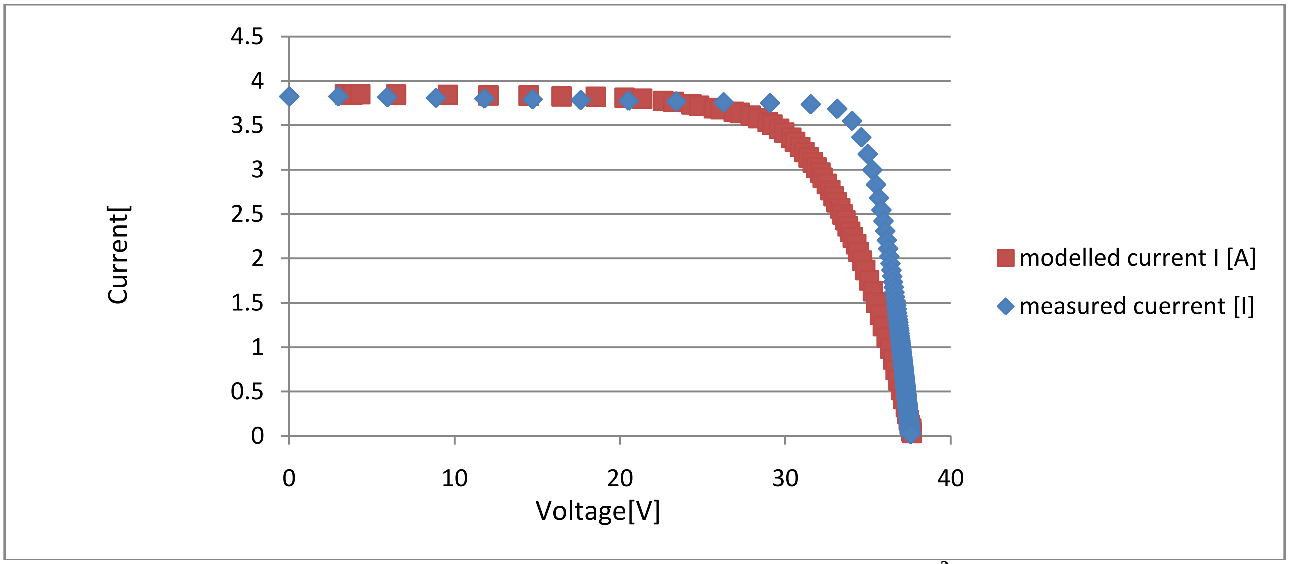


3. MODEL EVALUATION AND VALIDATION

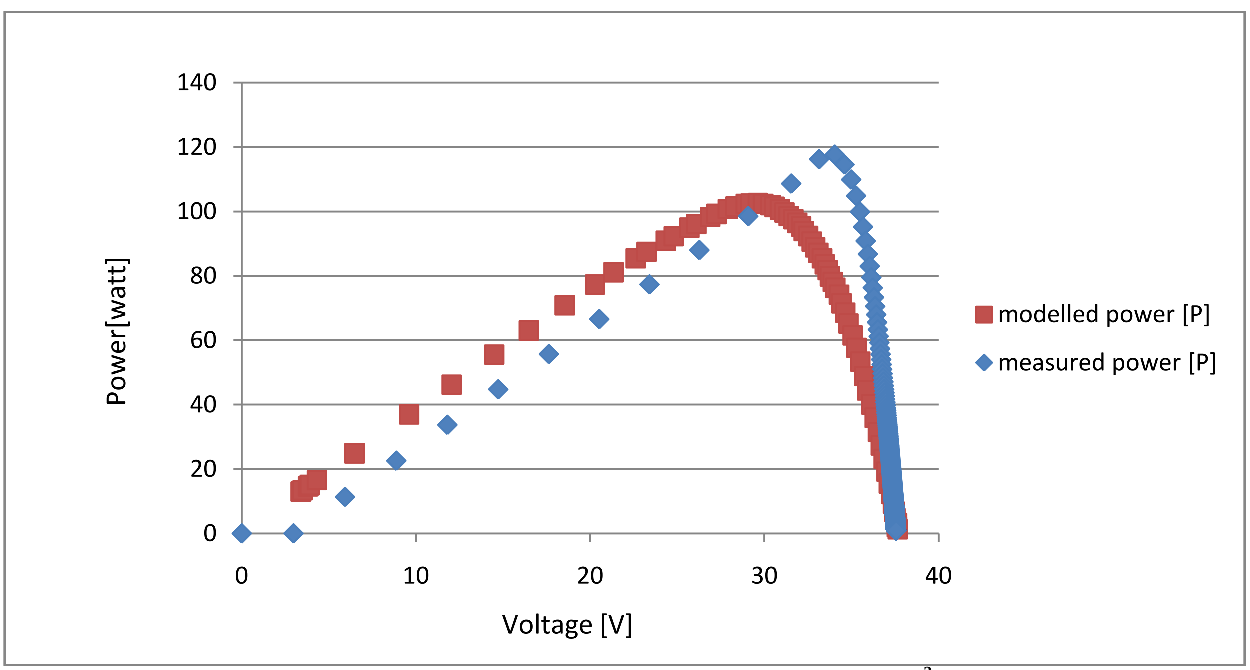
1. COMPARISON BETWEEN MODELLED AND MEASURED PARAMETERS

Table.1. shows the comparison values between modeled parameters I_{max}, V_{max} , P_{max} with measured parameters and deviation for irradiance 866 W/m^2 and STC temperature .

IRRADIANCE (W/m^2)	TEMPERATURE (^{0}C)	PARAMETERS			DEVIATION
			MODELLED	MEASURED	
866	25	I_{max} (A)	3.853	3.8261	0.6985
		V_{max} (V)	37.64	37.55	0.23199
		P_{max} (watt)	102.6	117.6	-14.6368



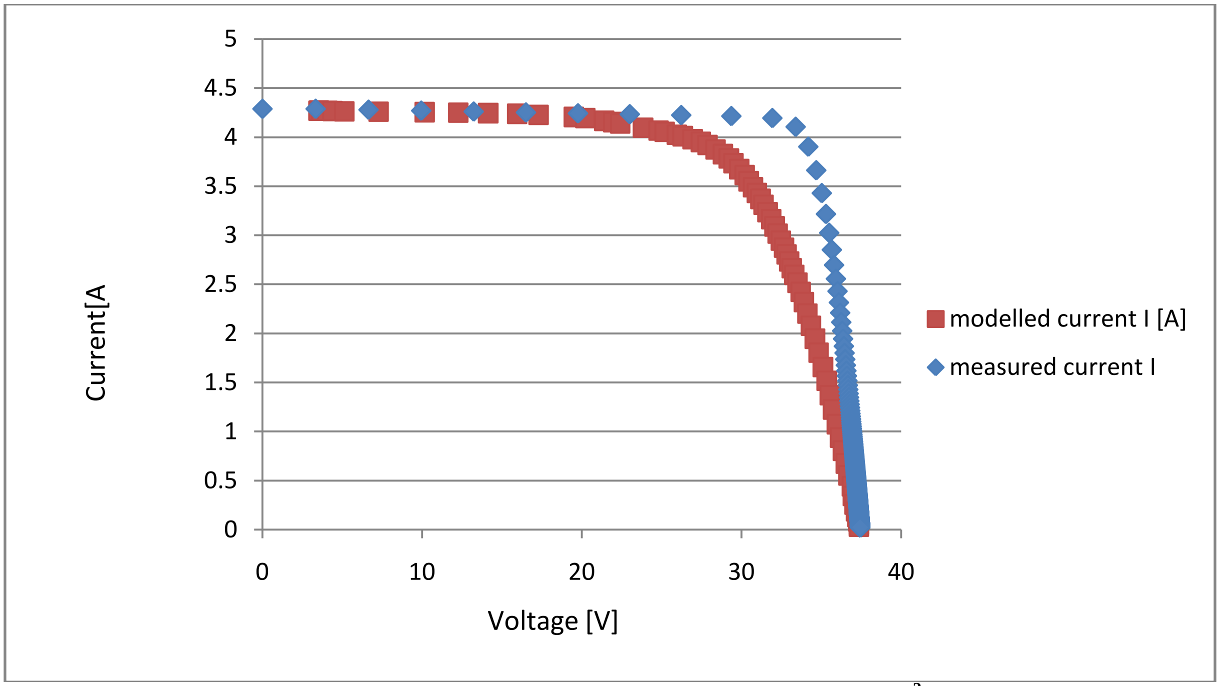
Graph 1 (I-V) characteristics for irradiance 866W/m^2



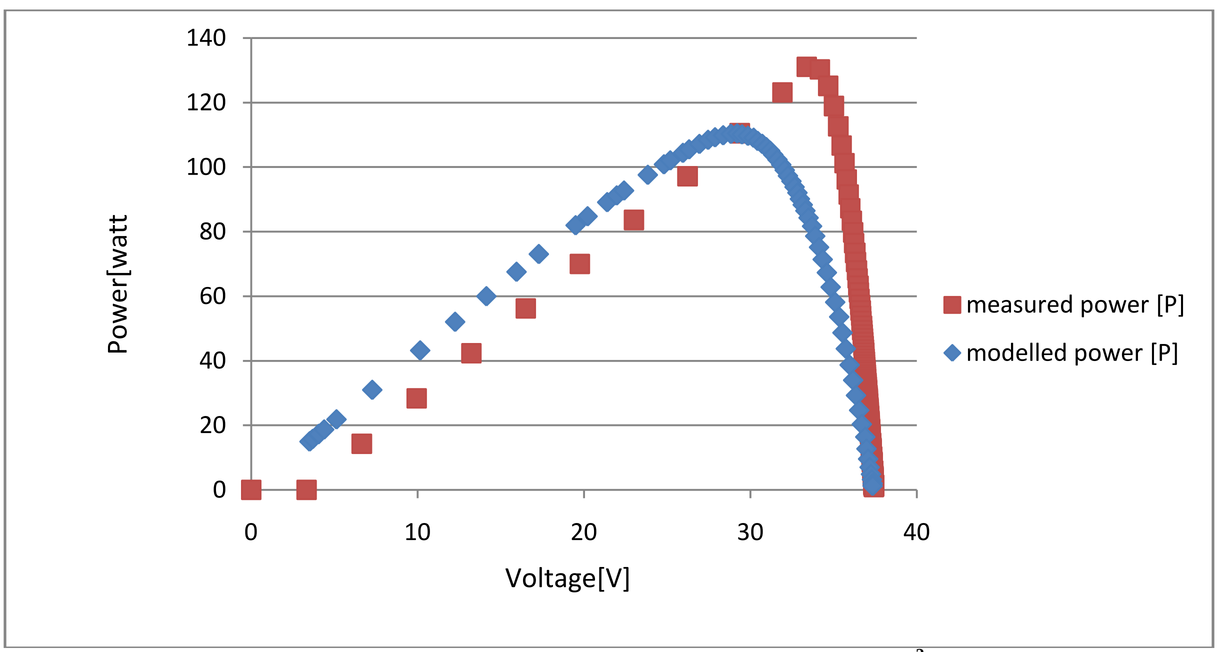
Graph 2 (P-V) characteristics for irradiance 866W/m^2

Table.2. shows the comparison and deviation values between modeled parameters I_{max} ,V_{max} , P_{max} with measured parameters for irradiance 941W/m^2 and STC temperature .

IRRADIANCE (W/m^2)	TEMPERAURE (^{0}C)	PARAMETRS			DEVIATION
			MODELLED	MEASURED	
941	25	I_{max} (A)	4.271	4.289	-0.4180657
		V_{max}(V)	37.34	37.43	-0.2344093
		P_{max} (watt)	110.44	131.08	-18.702184



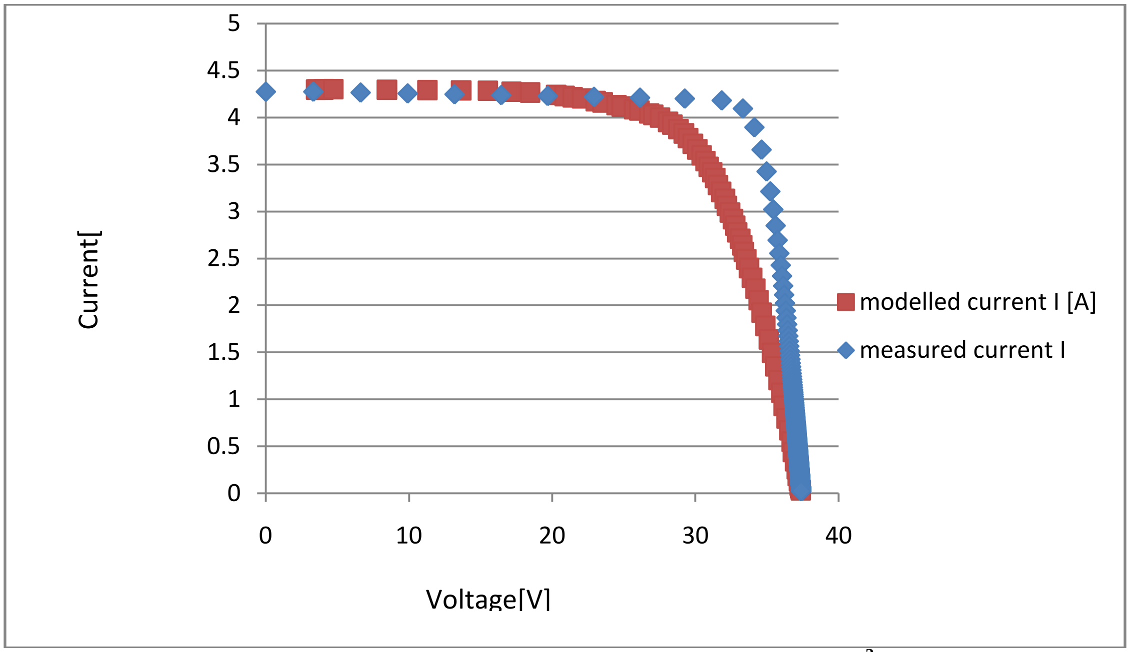
Graph .3. (I-V) characteristics for Irradiance 941W/m^2



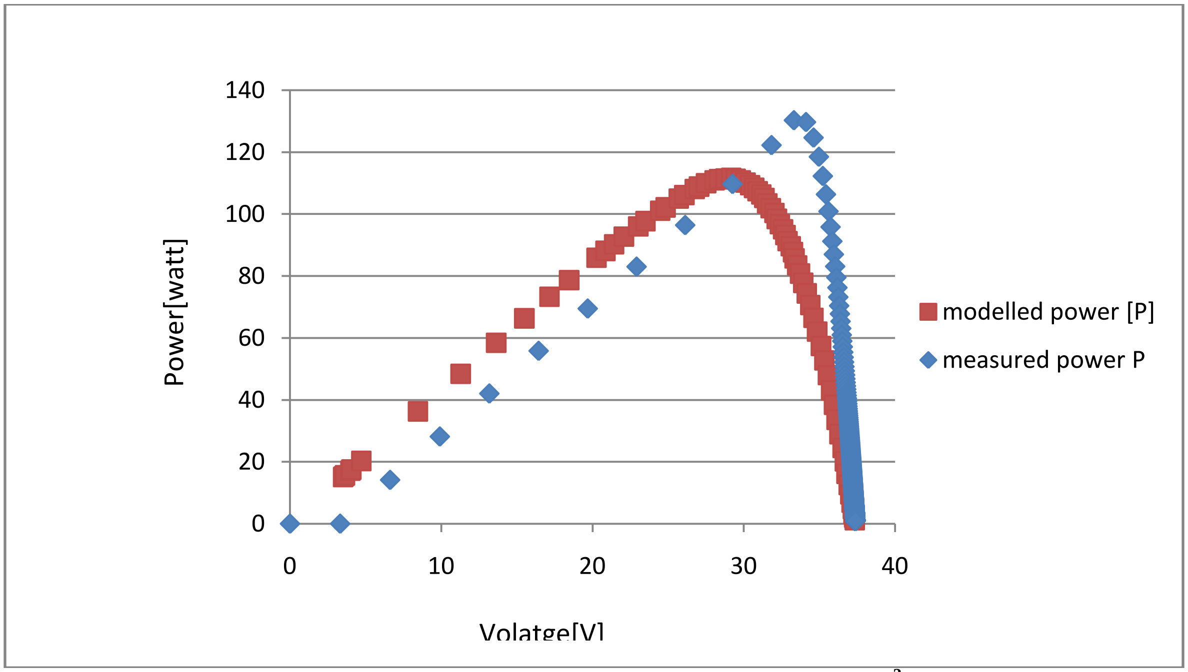
Graph .4. (P-V) characteristics for Irradiance 941W/m^2

Table.3. shows the comparison and deviation between modeled parameters I_{max}, V_{max}, P_{max} with measured parameters for irradiance 955W/m^2 and at STC temperature 25^{0}C.

IRRADIANCE (W/m^2)	TEMPERATURE (^{0}C)	PARAMETERS			DEVIATION
		MODELLED		MEASURED	
955	25	I_{max} (A)	4.299	4.271864	0.63121471
		V_{max} (V)	37.34	34.36744	-0.073497
		P_{max} (watt)	111.7302	130.2536	-16.578696



Graph.5. (I-V) characteristics for Irradiance 955W/m^2



Graph 6 (P-V) characteristics for Irradiance 955W/m^2

4. CONCLUSION

The present work is a detailed modeling and simulation of PV cell and module. It is implemented under MATLAB/Simulink environment; the most used software by researchers and engineer .This model is first drafted in accordance with the fundamentals of semiconductors and the PV cell technology. In other words, the PV module parameters have been selected according to their variation and illumination and temperature. It means that for any type of PV module, one can use this model and determine all the necessary parameters under any new conditions of irradiance and temperature and then, obtain the I (V) and P (V) characteristics. This model can be considered as a tool which can be used to study all the types of PV modules available in markets, especially, their behavior under different weather data of standard test conditions (STC).

5. FUTURESCOPE

Following are the possibilities of future modification of the model presented here,

1. Modeling of the solar cell can be done by considering the effect of partial shade condition to obtain more realistic result.
2. Modeling and analysis of PV plant connected to grid.
3. Modeling of single-diode PV cell can be modified to double-diode for increasing the output efficiency.

6. REFERENCES

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