

Simulation of a Novel Approach of Accurate Solar Photovoltaic Array

Ozgur C. Ozerdem¹, Hayder H. Abbas¹

¹Electrical and Electronic Engineering Department Near East University, Lefkosa, N. Cyprus
oozerdem@neu.edu.tr, hayder.hassan@ieeee.org

Abstract

There is a need for an accurate method for modeling the Photovoltaic (PV) cell, because the modeling of PV cell is based on manufacturer datasheet. The manufacturer datasheet is recorded under standard test condition (STC) and under laboratory conditions, especially the PV cell temperature, where the temperature used in modeling is ambient temperature, but in the real operation of a PV cell, there are huge differences between ambient temperature and PV cell temperature. Therefore, in this paper a novel approach is used for modeling a PV array by the use of back of panel temperature and real life recorded data (outdoor data). The developed model gives a real life operation condition according to the simulation results, which is compared with validation data (real life data).

1. Introduction

As a matter of fact no one can deny that electricity is an important part in our everyday life. Furthermore, electricity actually plays an essential role in the development of industry, agriculture, medicine and all fields of human activities. The global primary electric energy demands are met largely from conventional energy source as fossil fuels, which add to environmental degradation problems through gaseous emissions, using renewable and unconventional energy power sources will help to control, replace and avoid adverse environmental impacts [1]. From the 50's of the last century the scientist are trying to find a new technology to generate clean energy. The sun is considered to be the most important alternative because it's clean and renewable source. This field was developed many times. Among a wide variety of solar energy conversion process, a photovoltaic (PV) is the most promising one as a future energy technology [2] and has less operational and maintenance costs [3, 4].

In general, the basic elementary device used in PV systems is the PV cell; a PV cell is consisting of semiconductor material which directly converts sunlight into electricity [5]. A group of cells interconnected in series or parallel to form a new building block so called PV module [6]. The modules are then connected together depending upon required voltage and current and general series and parallel topologies are used in order to increase voltage and current respectively. A PV array is formed by series and parallel combinations of modules and the produced power is direct current (DC) [7].

A PV device is a nonlinear device and the characteristic of generating power depend essentially on solar irradiance and cell temperature [7]. The system can be mathematically modeled based on the theoretical equations that describe the functioning of the PV system using the equivalent circuit [8]. The equivalent circuit of a single solar cell could be modulated by using one current source, one diode or two diodes when more accuracy is

required, and parallel resistor (R_p) with series resistor (R_s) connected in series [9].

PV modeling has been addressed by few research studies. All these recent studies aimed to modeling a PV System by using MATLAB/Simulink package, the mathematical equations were used for modeling a single solar cell. Numerical method is used to find such parameters which are not provided by the manufacturers data sheet, for example series resistor (R_s), Parallel resistor (R_p), diode ideality factor (a), Photovoltaic current (I_{pv}), and saturation current (I_{sat}).

For instance in [10, 5] the authors neglecting the parallel resistor and series resistor of solar cell, but in [3, 6, 7, 11, 12, 13, 14] the authors take into their consideration of (R_s) and (R_p) and they highlighted the effect of these resistors on the output of the PV array specially when there are validation data which compared with simulated results.

Finally, An electric model is presented in [8]. This model consists of photo-current current source, a single diode junction and a series resistance, and also includes temperature dependences, the author neglecting the parallel resistor to achieve easy calculation and simple electronic circuit.

Therefore, in this paper we propose a novel approach, which is replacing the ambient temperature that was used by a pervious researchers with a new temperature (back of panel temperature). The back of panel temperature records for a period of one year to validate the implemented circuit. A Matlab/Simulink package will be used to simulate the PV array and the electronic model is used to investigate the operation of PV cell were presented by [8].

2. Solar Cell Modeling

2.1. Experimental Work

The experimental work is based on real data, which were recorded by the researchers at outdoor conditions. The data of PV system were taken during a one year period (three to four times) per week, and (twelve to thirteen times) per month where the voltage, current, and power were recorded. Also a temperature sensor with Explorer XLT from PASCO equipment used in order to record the cell temperature (back of panel temperature). The solar irradiance, daylight duration was taken from local weather station and NASA database respectively [15].

2.2. Solar Cell Modeling Equations

There are three parameters playing an important role in the study the characteristic of PV system, which are open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum power point (P_{max}). The maximum powers that can be supplied from a PV cell are at the maximum power points. These parameters are

provided by the manufacturer at slandered test condition (STC) where the temperature (T) equal to 25 C, and solar irradiance equal to 1000 W/ m² [16]:

The equivalent circuit of a PV cell is an important issue for simulation purpose. Various models has been developed in order to find accurate, simple, and practical model for PV module, in this regard, the model can be mathematically modeled based on the theoretical equations that describe the functioning of the PV system using the equivalent circuit in the literature. Other models are empirically based models that acquire their versatility and accurate from the fact that individual equations used in the model are derived from individual PV system characteristics [3]. Fig. 1 shows the single-diode model is the common used PV module. This equivalent circuit model used in this paper to describe the behavior of the PV module.

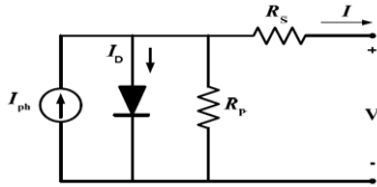


Fig. 1. Single diode model [5].

The mathematical equations describing the equivalent circuit of the single diode PV model are given by:

$$I = I_{pv} - I_{os} [\exp(V + IR_s/V_i, a - 1) - (V + IR_s/R_p)] \quad (1)$$

$$I_{pv} = I_{pv1}(1 + K_o(T - T_1)) \quad (2)$$

$$I_{pv1} = G * I_{sc1} / G_2 \quad (3)$$

$$K_o = (I_{sc2} - I_{sc1}) / (T_2 - T_1) \quad (4)$$

$$I_{os} = I_{os1} * (T/T_1)^{3/2} \exp(-q Vg/a k*(1/T - 1/T_1)) \quad (5)$$

$$I_{os1} = I_{sc1} / (\exp qV_{oc1}/a kT_1 - 1) \quad (6)$$

$$R_s = - dV/dI_{voc} - 1/X_v \quad (7)$$

$$X_v = I_{os1} * q/akT_1 * \exp(qV_{oc1}/a kT_1) \quad (8)$$

- I : The PV module terminal current (A).
- V : The PV module terminal voltage (V).
- I_{pv} : Light-generated Current or Photocurrent: It is generated directly by an incident of sunlight on the PV cell. This current varies linearly with sun irradiation and depends on temperature given by [3]:
- I_{pv1}, I_{pv2} : Photocurrent at T_1 and T_2 .
- I_{os} : Diode Saturation Current: It is a part of the reverse current in a diode caused by diffusion of minority carriers from the neutral regions in the depletion region.
- I_{os1}, I_{os2} : Diode Saturation Current at T_1 and T_2 .
- R_s and R_p : internal resistances of PV cell.
- $V_i = kT/q$: Junction thermal voltage.
- G, G_j : Solar radiance at nominal temperature and at T_2 respectively.

Where,

- K : Boltzmann's constant (1.3806503 e-23 J/K)
- T : Nominal Temperature (298.15 K)
- q : Charge of electron (1.60217646 e-19°C)

All above equations are used for modeling a PV cell [8, 17]. The unknown parameters are determined by the use of numerical method such as a Newton iteration method

2.3. Implemented Model

The implemented circuit is based on the equations (1) - (8) which were used by many researchers in developing the solar cell model. The general circuit of the model is given in Fig. 2.

Also the manufacturers data sheet is used in modeling the circuit. The PV panel used in this paper is NT 111 from SHARP and the given parameters are shown in the table1.

The internal circuit of simulated PV cell is composed of MATLAB function used to calculate the photocurrent of PV cell connected in parallel with the diode, the implemented circuit is connected with resistance (R_s) and it represents the internal series resistor. The final circuit which is used to simulate the solar panel model is shown in the Fig. 4. Which were composed of a PV panel, voltage and current measurements and a load resistor. The temperature used in modeling the PV cell was the back of panel temperature, this temperature is different from the ambient temperature.

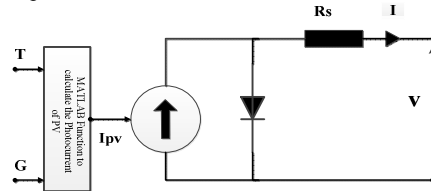


Fig. 2. Implemented circuit diagram of PV module.

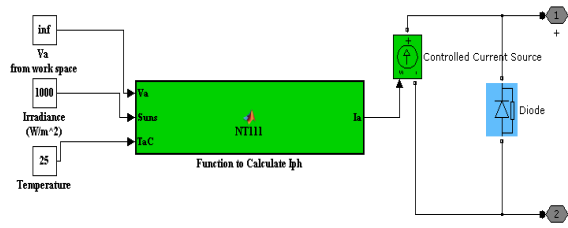


Fig. 3. The internal circuit diagram of a PV array.

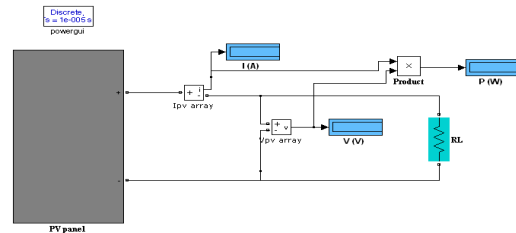


Fig. 4. The complete circuit diagram of a PV array.

Table 1. The manufacturer datasheet for NT-111 Solar panel.

Parameters	Values
N_s	36
N_p	1
P_m	43 W
V_m	17.5 V
I_m	2.46 A
I_{sc}	2.7 A
V_{oc}	21.6 V
K_v	-0.0037 V/K
K_i	0.0005 A/K

3. Simulation Result

The simulation results of PV panel are given in the Fig. 5 and 6 which represent the I-V and P-V curves respectively, table 2. shows the simulation result of unknown parameters which were obtained by the use of the Newton Raphson method. Table 3. shows the ambient temperature, back of panel temperature, and solar Irradance used in simulation circuit. Table 4. Show the differences between experimntal power (P1), simulation power at ambient temperature (P2), and simulation power at back of panel temperture (P3). From the simulation results it is clear that the developed model has better accuracy and operation demeanor according to simulation results which were compared with validation data as shown in the Table 4. Fig.7 and Fig.8 shows the scattering graphs of experimental power with back of panel temperature and ambient temperature respectively. The correlation value of the back of the panel is equal to 94.82% and for ambient temperature is 78.5%, from these results its clear that by use of new method the simulation accuracy are increased by 7.32%, which is considered as a good percentage for development of a new solar cell for real life application.

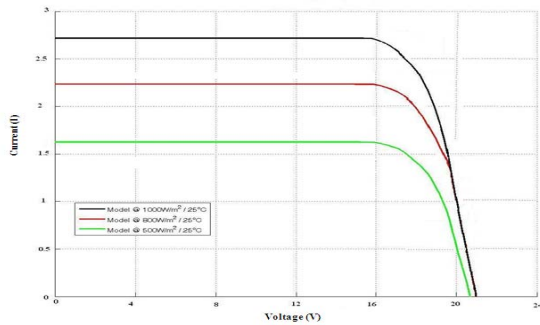


Fig. 5. The I-V curve of implemented circuit.

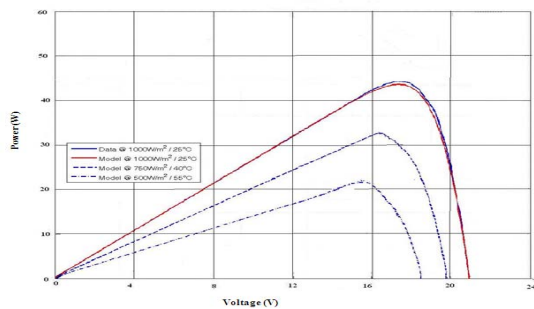


Fig. 6. The P-V curve of implemented circuit.

Table 2. The unknown parameters obtained from the simulation.

Parameters	Values
a	1.2
V_g	1.12 V
R_s	0.162 Ω
R_p	∞ open circuit
I_{sa}	9.6e-9 A
I_{ph}	2.69 [A]

Table 3. The temperatures and irradiance used in the simulation.

Months	Ambient Temp. (C)	Back-of-Panel Temp. (C)	Irradiance (W/m ²)
Jan	13.7	18.1	490
Feb	15.3	20.1	520
Mar	18.6	27.4	610
Apr	22.6	30.1	710
may	29.8	37.2	792
Jun	39	48	826
Jul	42.5	67	810
Aug	42	58	736
Sept	36.5	45	650
Oct	28	35.4	565
Nov	18.5	26.4	510
Dec	13.5	17.5	480

Table 3. The results of experimental power and simulations powers.

Months	Experimental and Simulation Power		
	P1 ¹	P2 ²	P3 ³
Jan	18.46	18.07	17.84
Feb	19.575	20.23	19.91
Mar	26.35	27	25.97
Apr	29.7	32.56	31.02
May	29.6	33.88	32.1
Jun	29.75	32.47	30.29
Jul	24.025	31.26	25.64
Aug	25.44	29.43	26.02
Sep	27.06	27.05	25.63
Oct	22.05	22.7	22.04
Nov	16.8	19.28	18.8
Dec	18.34	17.36	17.6

¹ is the experimental power.

² is the simulation power with ambient temperature.

³ is the simulation power with back of panel temperature

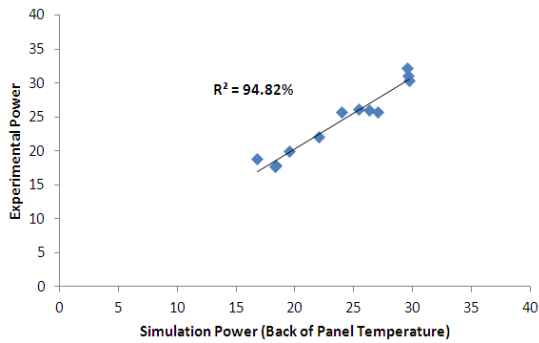


Fig. 7. The Scattering and correlation (R^2) of back of Panel temperature with validation data (experimental power).

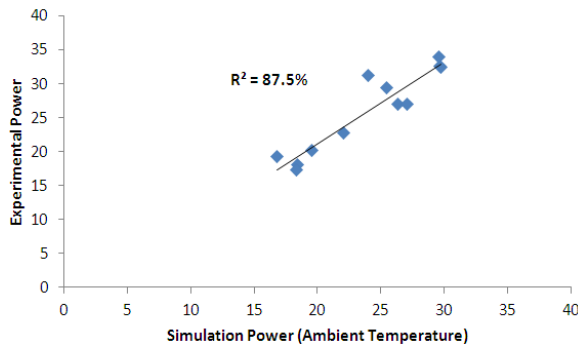


Fig. 8. Scattering and correlation (R^2) of back of ambient temperature with validation data (experimental power).

6. Conclusions

A novel approach to solar cell was developed. The novelty of this work is using real life data, which recorded under different weather conditions, also a new approach to measure the solar cell parameters with the use of back to panel temperature as a modeling temperature.

Obviously, a real life application has been addressed in this work; the proposed model could be successfully used to simulate a real life application, according to achieved accuracy, which is equal to 94.82% and there is improvement by 7.32% in modeling accuracy, this accuracy and improvement are considered as driven force for the researcher to use a new method in the simulation of solar PV cell.

7. References

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