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The Linear Model of a PV moduel

Mohamed Abd-El-Hakeem Mohamed
Faculty of Engineering, Electric Eng.,Al-Azhar University, Qena, Egypt

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ABSTRACT

This paper proposes a new approach to determine a linear mathematical model of a PV moduel based on an accurate nonlinear model. In this study, electrical parameters at only one operating condition are calculated based on an accurate model. Then, first-order Taylor series approximations apply on the nonlinear model to estimate the proposed model at any operating conditionts. The proposed method determines the number of iteration times. This decreases calculation time and the speed of numerical convergence will be increased. And, it is observed that owing to this method, the system converged and the problem of failing to solve the system because of inappropriate initial values is eliminated. The proposed model is requested in order to allow photovoltaic plants simulations using low-cost computer platforms. The effectiveness of the proposed model is demonstrated for different temperature and irradiance values through conducting a comparison between result of the proposed model and experimental results obtained from the module data-sheet information.

Corresponding Author:

Mohamed Abd-El-Hakeem Mohamed,
Department of Electrical Engineering,
Al-Azhar University,
Faculty of Engineering, Electric Eng., Qena, Egypt.
Email: moh731411@yahoo.com

1. INTRODUCTION

The current-voltage characteristics of photovoltaic is an important role in solar industry because it exactly reflects the module performance [1]. The one-diode model parameters of PV panels from a single I-V curve is identified in [2] by converting nonlinear fitting to a linear system identification. Paper [3] presents analytical solutions for the parameters of a five-parameter double-diode model of PV cells and modules which only require the coordinates of three key points of the I–V curves, i.e., the open-circuit (0, Voc), the short circuit (Isc, 0) and the maximum power point (MPP) (Im, Vm). These analytical solutions are successfully used in Newton–Raphson numerical iterations to achieve convergence and obtain more accurate solutions. Paper [4] presents a novel approach using the shuffled frog leaping algorithm (SFLA) to determine the unknown parameters of the single diode PV model. The validity of the proposed PV model is verified by the simulation results which are performed under different environmental conditions. However, some disadvantages are also existed in the original algorithm, such as nonuniform initial population, slow convergent rate, limitations in local searching ability and adaptive ability and premature convergence. Paper [5] use particle swarm optimization (PSO) with inverse barrier constraint is proposed to determine the unknown PV model parameter. Disadvantages of the basic particle swarm optimization algorithm that,the method easily suffers from the partial optimism, which causes the less exact at the regulation of its speed and the direction .Moreover, many evolutionary and swarm intelligence optimization techniqueshave been used to solve this problem such as genetic algorithms (GA) [6]-[7], differential evolution (DE) [8], particle swarm optimization (PSO) [9], simulated annealing (SA) algorithm [10], bacterial foraging (BF) algorithm [11], harmony search algorithm (HSA) [12], and artificial bee colony (ABC)algorithm [13]. A LABVIEW simulator for photovoltaic (PV) systems is presented in [15]-[16]. The

All of the previously mentioned models suffer from high computational time due to their dependency on complex transcendental implicit equations.

In this paper a five parameters extraction mainly based on a linearization method is presented. The proposed method estimate the parameter of a pv without any the conversion problem. And also ,the number of iteration times is determined . so the calculation time is decresed The predicted I-V and P-V curves are compared with experimental data to conclude on the validity of the model and the followed procedure.

2. NON LINEAR MODEL OF PHOTOVOLTAIC MODULE

Figure 1.shows the equivalent circuit for a PV cell. The output current of the equivalent circuit,I_{pv}, can be expressed as a function of the PV cell's voltage, V_{pv} [1]:

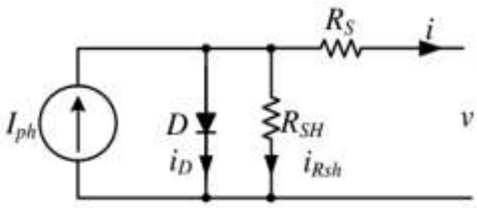

Figure 1. Equivalent circuit of a photovoltaic cell using

The single exponential module

$$F1 = I_{pv} - I_{ph} + I_o\left(e^{\frac{V_{pv} + IR_S}{n_s V_t}} - 1\right) + \frac{V_{pv} + I_{pv}R_S}{R_{sh}} = 0 \quad (1)$$

In the above equation, Vt is the junction thermal voltage:

$$V_t = \frac{AKT}{q} \quad (2)$$

Where k is the Boltzmann constant (1.38 x 10-23 J K-1), q is the electronic charge (1.602 x 10-19 C), T is the cell temperature (K); A is the diode ideality factor, R_s the series resistance (Ω) and R_s is the shunt resistance (Ω). ns is the number of cells connected in series. Equation (1) can be written for the three key-points of the V-I characteristic:

$$I_{sc} = I_{ph} - I_o\, e^{\frac{I_{sc}R_S}{n_S V_t}} - \frac{I_{sc}R_S}{R_{sh}} \quad (3)$$

$$I_{mpp} = I_{ph} - I_o e^{\frac{V_{mpp} + I_{mpp}R_S}{n_S V_t}} - \frac{V_{mpp} + I_{mpp}R_S}{R_{sh}} \quad (4)$$

$$I_{oc} = 0 = I_{ph} - I_o\, e^{\frac{V_{oc}}{n_S V_t}} - \frac{V_{oc}}{R_{sh}} \quad (5)$$

An additional equation can be derived using the fact that is on the P-V characteristic of the panel, at the MPP, the derivative of power with voltage is zero.

$$F2 = \frac{dP}{dV}\Big|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = I_{mpp} - V_{mpp}\,\frac{-\frac{(I_{sc}\,R_S + V_{oc} - I_{sc}R_{sh})e^{\frac{V_{mpp} + I_{mpp}R_S - V_{oc}}{n_S V_t}}}{n_S V_t R_{sh}} + \frac{1}{R_{sh}}}{1 - \frac{(I_{sc}R_S + V_{oc} - I_{sc}R_{sh})R_S e^{\frac{V_{mpp} + I_{mpp}R_S - V_{oc}}{n_S V_t}}}{n_S V_t R_{sh}} + \frac{R_S}{R_{sh}}} = 0 \quad (6)$$

The fifth equation can be derived using the fact that is on the P-I characteristics of a PV system at the maximum power point, the derivative of power with respect to current is zero.

$$F3 = \frac{dP}{dI}\bigg|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = V_{mpp} - I_{mpp}\,\frac{1-\frac{(I_{sc}R_S + V_{oc} - I_{sc}R_{sh})R_S e^{\frac{V_{mpp}+I_{mpp}R_S - V_{oc}}{n_S V_t}}}{n_S V_t R_{sh}} + \frac{R_S}{R_{sh}}}{-\frac{(I_{sc}\;R_S + V_{oc} - I_{sc}R_{sh})e^{\frac{V_{mpp}+I_{mpp}R_S - V_{oc}}{n_S V_t}}}{n_S V_t R_{sh}} + \frac{1}{R_{sh}}} = 0 \tag{7}$$

Equations. (3) and (5) can be inserted into Equation (4), which will take the form

$$F4 = I_{mpp} - I_{sc} + \frac{V_{mpp}+I_{mpp}R_S - I_{sc}R_S}{R_{sh}} + \left(I_{sc} - \frac{V_{oc}-I_{sc}R_S}{R_{sh}}\right) e^{\frac{V_{mpp}\;+I_{mpp}\;R_S - V_{oc}}{n_S V_t}} = 0 \tag{8}$$

The first equations when constructing the model are the expressions of Io from Equation (3) and Iph from Equation (5), in STC

$$\mathrm{F5{=}Io{-}}(\mathrm{I_{sc}} - \frac{\mathrm{V_{oc}} - \mathrm{I_{sc}R_s}}{\mathrm{R_{sh}}})\mathrm{e}^{-\frac{\mathrm{V_{oc}}}{\mathrm{n_sV_t}}} = 0 \tag{9}$$

$$\mathrm{F6} = \mathrm{I_{ph}} - \mathrm{I_o}\mathrm{e}^{\frac{\mathrm{V_{oc}}}{\mathrm{n_sV_t}}} - \frac{\mathrm{V_{oc}}}{\mathrm{R_{sh}}} = 0 \tag{10}$$

The effects of the environment, e.g. temperature and irradiance on the values of (Isc, Voc, Im, and Vm) are include with differen methods [13]-[14].

3. LINEAR MODEL OF PHOTOVOLTAIC MODULE

The main objective of linearization is to transform and elemainte the nonlinearity model of a pv moduel into a simple equivalent model . The linearized system of a pv moduel can be written corresponding to equations (1,6-10) respectively as follow

$$\mathrm{A1} * \mathrm{X} = \mathrm{B1} * \mathrm{U1} + \mathrm{B2} * \mathrm{U2} \tag{11}$$

Where

$$\mathrm{X^T} = [\;\Delta\mathrm{I_o}\;\;\Delta\mathrm{A}\;\;\Delta\mathrm{I_{ph}}\;\;\Delta\mathrm{R_s}\;\;\Delta\mathrm{R_{sh}}] \tag{12}$$

$$\mathrm{A1(i,j)} = \frac{\partial\mathrm{Fi}}{\partial\mathrm{Xj}} \tag{13}$$

$$\mathrm{U1^T} = [\,\Delta\mathrm{V_{pv}}\;\;\Delta\mathrm{I_{pv}}\,] \tag{14}$$

$$\mathrm{B1(i,j)} = -\frac{\partial\mathrm{Fi}}{\partial\mathrm{U1j}} \tag{15}$$

$$\mathrm{U2^T} = [\,\Delta\mathrm{G}\;\;\Delta\mathrm{T}\,] \tag{16}$$

$$\mathrm{B2(i,j)} = -\frac{\partial\mathrm{Fi}}{\partial\mathrm{U2j}} \tag{17}$$

The Gauss–Jordan elimination method is a suitable technique for solving systems of linear equations of any size. This method involves a sequence of operations on a system of linear equations to obtain at each stage an equivalent system that is, a system having the same solution as the original system. The reduction is complete when the original system has been transformed so that it is in a certain standard form from which the solution can be easily read as follow.

$$\Delta\mathrm{V_{pv}} = \mathrm{CI}\,\Delta\mathrm{I_{pv}} + \mathrm{CG}\,\Delta\mathrm{G} + \mathrm{CT}\,\Delta\mathrm{T} \tag{18}$$

The constants CI,CG ,CT are defined in the appendix

4. LINEAR MODEL ESTIMATION ALGORITHM OF A PV PANEL

The estimation algorithm of linear model of a pv moduel for various temperature and irradiance conditions, are described in the following steps:

a. Step 1: This step is executed one time only to determine the first operating point as discussed in [17]. Newton-Raphson method is used to calculate the three unknown parameters (Rs, A, and Rsh) of PV panel model using Equations. (6), (7) and (8) the other parameters (I_o, and Iph) are calculated directly from Equations (9-10) respectively.
b. Step 2 : the number of iterations is determined exactly as follow

$$\text{No of iterations} = \frac{(G_{new}-G_{old})*(T_{new}-T_{old})}{\Delta G*\Delta T} \quad (19)$$

Where ΔG and ΔT are chosen according to accuracy requirement

c. Step 3 : the parameters of a pv model are calculated based on equations (17) as follow

$$X^T = \Delta X^T + X^T(\text{old}) \quad (20)$$

This step is repeated basen on : the number of iterations which are calculated in step2

d. Step 4: The Equation 18 is used for estimation of I-V curves of photovoltaic (PV) at various environement conditions where.

$$I_{pv} = \Delta I_{pv} + I_{pv}\,(\text{old})$$

$$V_{pv} = \Delta V_{pv} + V_{pv}\,(\text{old})$$

5. RESULTS AND DISCUSSION

In this study, KC200GT (multicrystal) solar module is used to ensure the effectiveness of proposed model. The typical electrical characteristics of these PV modules under the standard test conditions (STC) (module temperature, 25 ◦C, AM 1.5 spectrum, irradiance 1000W/m2) are listed in Table 1.

Table 1.Shows the data obtained from the datasheet for KC200GT solar module at 25 ◦C, AM1.5, and 1000 W/m2.

Parameter	KC200GT solar module
MaximumPower (Pmpp)	200 W
Maximum Power Voltage (Vmpp)	26.3 V
Maximum Power Current (Impp)	7.61 A
Open Circuit Voltage (Voc)	32.9 V
Short Circuit Current (Isc)	8.21 A
Temperature Coefficient of Voc(Kv)	- 0.123V/oC
Temperature Coefficient of Isc (Ki)	+ 3.18 mA/oC
number of cells (ns)	54

According to the algorithm which is presented in Section 4, the first operating point is determined as follow. These values are used in first time only. The validity of the proposed for the PV modules under different environmental conditions. Figure 2 shows the *I-V* model curves based equation (18), and the data sheet of the KC200GT PV module under different temperature conditions. It can be demonstrated that the *I-V* curves of the proposed model coincide with the experimental data. This distinguishes the high accuracy of the proposed PV model. The simulation results of the proposed model and the experimental data of this PV module under different irradiation conditions are indicated in Figure 3. No deviations can be noticed between the simulation and experimental results. This represents the verification of the validity of the linear PV model

Table 2. Identification of first operating point

Parameter	
V =Voc, I=0	(arbitry)
T= at 25 ◦C, and G=1000 W/m2	(arbitry)
A=1.5611	determined using
Rsh =2.8860e+06	Newton-Raphson
Rs =2.5241e-01	based on equations(6-8)
I_o =1.4352e-06	determined using
Iph =4.8	equations(9-10)

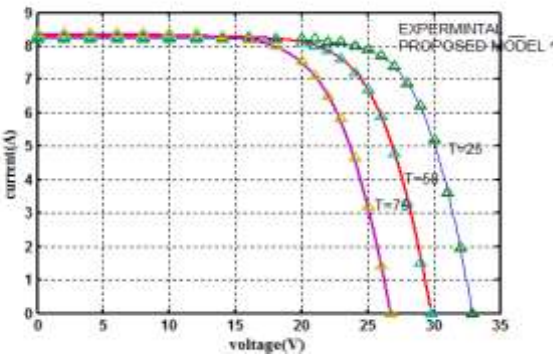

Figure 2. Voltage current characteristics of at different temperature

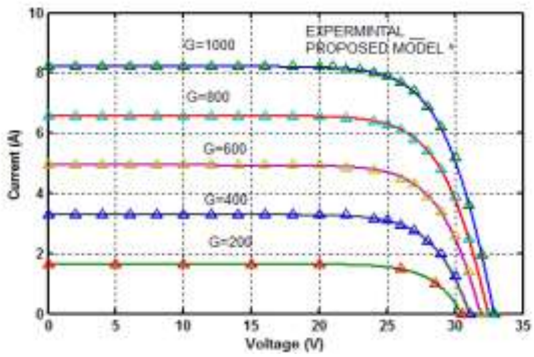

Figure 3. Voltage current characteristics at different irradiation

To evaluate accuracy of the proposed model, the corresponding normalized root mean square error percentage [nRMSE(%)] are calculated at different conditions and it compared with [nRMSE(%) of an accurate which are given in [18]-[19]. Table 3 gives the corresponding normalized root mean square error percentage [nRMSE(%)] calculated by

$$\mathrm{nRMS\%} = \frac{\sqrt{\frac{1}{N}\sum_1^N (E_i - T_i)^2}}{\sqrt{\frac{1}{N}\sum_1^N (T_i)^2}} * 100$$

where Ei is the estimated value, and Ti is true values obtained from data sheet. Table 2 gives the evaluated nRMSE(%) from Ref. [19] and evaluated nRMSE(%) corresponding to the theoretical 1-5 curves (Figure 2-3) it can be seen from this table II, the linear model has presented the best accuracy under different conditions. In additional to, the number of tunable parameters are lowered.

Table 2. E NRMSE(%) of the different PV models for KC200GT moduel

	G=1000 T=25	G=600 T=25	G=200 T=25
NRMSE(% OF MODELE IN [18]	6.35 [18]	4.36 [18]	6.55 [18]
NRMSE(% OF MODELE IN [19]	1.12 [18]	2.15 [18]	1.29 [18]
NRMSE(% OF THIS WORK	0.47	0.57	0.66

Table 3 gives the evaluated nRMSE(%) corresponding to the theoretical 1–5 curves based linear model and experimental data for KC200GT at different temperatures. It can be observed that the theoretical 1–5 curves are sufficiently accurate for the experimental data. This proves the validity of the proposed parameter identification technique for PV modules.

Table 2. NRMSE(%) of the linear model at different temperature

G	T	NRMSE(%)
1000	25	0.47
1000	50	0.39
1000	75	0.69

6. CONCLUSION

The target of this study is to obtain an linear PV model which plays an important role in linear control approach and simulation studies of the PV power systems. The mathematical model of the PV module is a nonlinear I-V characteristic that includes several unknown parameters because of the limited information provided by the PV manufacturers. So, a linear model of photovoltaic panels has been developed and implemented. From the present analysis, one can draw the following main conclusions:

1. The proposed method estimate the parameter of a pv without any the conversion problem .
2. The calculated (I-V) curves based on proposed model are in good agreement with the experimental data of KC200GT module for different effects of the environment (temperature and irradiance). Also, the maximumvalue of corresponding normalized root mean square error percentage [nRMSE(%)]less than 1%
3. The proposed model can be used for linear control approach and simulate large-scale PV systems with low-cost computer platforms

APPENDIX

By simplification of equations (13-17), CI,CG ,CT can be defined as follow

$$CI=\frac{C18}{c17}$$

$$CT=-\frac{C15}{c17}$$

$$CG=-\frac{C16}{c17}$$

where

$$C_1=\frac{I_{sc,ref}}{G_{ref}},c3=\frac{AK}{q}\ln\left(\frac{Go}{G_{ref}}\right)+K_v, c4=\frac{1}{Go}\frac{AKTo}{q}, c5=-\frac{e^{-\frac{V_{oc}}{n_s V_t}}}{R_{sh}}$$

$$c6=\left(1+\frac{R_s}{R_{sh}}\right)e^{-\frac{V_{co}}{n_s V_t}}, c7=-\left(\left(I_{sco}-\frac{V_{oc}-I_{sc}R_s}{R_{sh}}\right)e^{-\frac{V_{oc}}{ktTo}}\right)\frac{1}{(ktTo)}$$

$$c8=\left(\left(I_{sco}-\frac{V_{oc}-I_{sc}R_s}{R_{sh}}\right)e^{-\frac{V_{oc}}{ktTo}}\right)\frac{ktV_{oc}}{(ktTo)^2}$$

$$c9=c3(c5+c7)+c6K_i+c8, c10=c4(c5+c7)+c6C_1$$

$$c11=c9e^{\frac{V_{oc}}{ktT}}+\frac{I_o e^{\frac{V_{oc}}{ktT}}}{(ktT)}c3-\frac{I_o e^{\frac{V_{oc}}{ktT}}ktV_{oc}}{(ktT)^2}+\frac{c3}{R_{sh}}$$

$$c12=C_{10}+\frac{I_o e^{\frac{V_{oc}}{ktT}}}{(ktT)}c4+\frac{c4}{R_{sh}}$$

$$C13=-I_o\left(e^{\frac{V_{pv}+I_{pv}R_s}{ktT}}\right), C14=\left(1-e^{\frac{V_{pv}+I_{pv}R_s}{ktT}}\right)$$

$$C15=\left(c11+\frac{-V_{pv}\,ktC13}{(ktT)^2}+\frac{-I_{pv}\,R_s ktC13}{(ktT)^2}+C14C9\right)$$

$$C16 = (C_{12} + C14C10)$$

$$c17 = \left(\frac{TC13}{(ktT)} - \frac{1}{R_{sh}}\right)$$

$$C18 = 1 - \left(\frac{R_s C13}{(ktT)} - \frac{R_s}{R_{sh}}\right)$$

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