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Anfis Based Selection of PV Module Model Under Outdoor Characteristics in Ghardaia Site

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***Abstract*— This paper studies a model of the PV modules of different technologies by correlating the five parameters conventional model using an adaptive neuro-fuzzy inference system (ANFIS). The dependence of the model parameters with environmental conditions is studied using a set of common current - voltage characteristics carried out at outdoor conditions of an arid area located in Ghardaia (south of Algeria) for various real operating conditions of radiation and temperature. The comparison between measured and simulated values showed that the approaches of the adaptive neuro-fuzzy inference system (ANFIS) converge very well compared to the conventional model for all operating conditions.**

***Keywords*— Photovoltaic model, Outdoor characterisation, Neural network**

I. INTRODUCTION

The performances of PV module are directly influenced by solar irradiance and module temperature and by several other parameters such as tilt and azimuth angles. As a result of this understanding, the PV module behaviour under outdoor conditions stills of great concern of photovoltaic research field

An extensive works on PV module characterization studies had been focused on output electrical characteristic variations based upon the four most important electrical characteristics of PV module which are short circuit current (I_{SC}), open circuit voltage (V_{OC}), maximum current (I_m) and voltage maximum point (V_m) [1-4]. Following validation study of photovoltaic module models undertaken in previous work [1] [2] [3], it was found that the five parameters model described below reproduces the IV characteristic in an accurate manner for different technologies and under different operating conditions. In the scope of this work, these mentioned parameters have been studied as function of temperature and irradiance then a data base is assembled and used for correlation [3]. Firstly a simple regression correlation has been used; secondly an adaptive neuro-fuzzy inference system (ANFIS) correlation approach has been used, too in the aim to enhance the obtained results, accordingly.

II. MATERIALS AND METHOD

A. Materials

For PV different module technologies namely: Mono-crystalline silicon, Poly-crystalline silicon, triple-junction Amorphous and Thin film (CIS) have been put into characterisation tests under the outdoor conditions the site. table1, shows the standard conditions tested modules Characteristics

TABLE I. STANDARD CONDITIONS TESTED MODULES CHARACTERISTICS

Module	**ASE100**	**BP3160**	**US64**	**ST40**
Technology	***mc-Si***	***pc-Si***	***TJ a-Si***	***TF (CIS)***
ISC (A)	3.2	4.8	5.1	2.68
VOC (V)	42.3	44.2	21.3	23.3
Im (A)	2.8	4.55	4.1	2.41
Vm (V)	34.1	35.1	15.6	16.6
P (W)	95	160	64	40

The equipments used in these tests are:

- Photovoltaic field Array Tracer (PVPM 250V 40A model). It is a portable array tester and it uses a discharged capacitor that functions as 'load resistor'. Current and voltage are measured during the process of charging the capacitor.
- PV module frame support
-Calibrated reference solar cell was used for measuring irradiance and cell temperature. It consists of m-Si cell. A Pt1000 temperature sensor is glued to the backside of the centre cell. The Pt1000 sensor gives directly the cell temperature.
- PC for treatment. Figure 1 shows the synoptic of the test bench

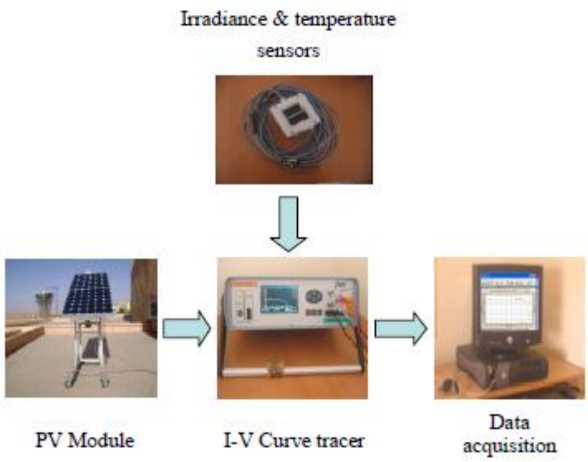

Figure 1. Synoptic of the test bench.

III. THEORY OF FIVE PARAMETERS MODEL

The behaviour of a photovoltaic generator may be closely represented by the five parameter model based on one diode equivalent circuit of a solar cell; it consists of a diode, a current source, a series resistance, and a parallel resistance [5-10]. The current source generates photocurrent (I_{ph}) which is a function of incident solar irradiance and cell temperature. The diode represents p–n junction of the solar cell. At real solar cells, the voltage loss on the way to the external contacts is observed. This voltage loss is expressed by a series resistance (R_s). Furthermore, leakage currents are described by a shunt resistor (R_{sh}). Using Kirchhoff's first law, the equation for the extended I–V curve is derived as shown by equation 1:

$$I = I_L - I_0\left[\exp\left(\frac{V + IR_s}{m\,V_t}\right) - 1\right] - \frac{V + IR_s}{R_{sh}} \qquad (1)$$

Where I is the output current of PV module, V is the terminal voltage of the cell or module, q is the electric charge ($1.6\ 10^{-19}$ C), k is the Boltzmann constant ($1.38\ 10^{-23}$ J/K), and T is the cell temperature (K). m is the ideality factor, I_L the photogenerated current under insolation, R_{sh}: shunt resistor; R_s: series resistor and I_0 is the diode saturation current. The five equivalent circuit parameters can be determined [6, 11-13] by using the available operating points on the I–V curve by the equations (2-7):

$$\left(\frac{dV}{dI}\right)_{V=Voc} = -R_{so} \qquad (2)$$

$$\left(\frac{dV}{dI}\right)_{I=Isc} = -R_{sho} \qquad (3)$$

$$m = \frac{V_m + I_m R_{so} - V_{oc}}{V_t\left[\ln\left(I_{sc} - \frac{V_m}{R_{sh}} - I_m\right) - \ln\left(I_{sc} - \frac{V_{oc}}{R_{sh}}\right) + \left(\frac{I_m}{I_{sc} - \frac{V_{oc}}{R_{sho}}}\right)\right]} \qquad (4)$$

$$I_0 = \left(I_{sc} - \frac{V_{oc}}{R_{sh}}\right).\exp\left(\frac{V_{oc}}{mV_t}\right) \qquad (5)$$

$$R_s = R_{so} - \frac{mV_t}{I_0}\exp\left(-\frac{V_{oc}}{mV_t}\right) \qquad (6)$$

$$I_L = I_{sc}\left(1 + \frac{R_s}{R_{sh}}\right) + I_0\left(\exp\frac{I_{sc}R_s}{mV_t} - 1\right) \qquad (7)$$

After the parameters calculation for different irradiance and temperature, these values were used to constitute a data base. To determine at any given solar radiation and cell temperature we used two approaches, which are simple correlations and ANFIS described below.

IV. CORRELATION OF THE FIVE PARAMETERS

To characterize a PV module as a power source, it is very important to take into consideration the dependence of all equivalent circuit parameters of PV module on irradiance and cell temperature, to be able to obtain the changing of the parameters over the whole range of operating conditions.
To determine this dependence, three simple correlations, equations (8-10) [18-23], were applied to all these parameters. Statistical criteria for choosing the best correlation, namely root mean square error (RMSE) and the correlation coefficient (CC), given by equation 11 and equation (12) respectively.

$$y_1 = a_1 * \frac{E}{1000}\left(1 + b_1 * (T - 25)\right) \qquad (8)$$

$$y_2 = a_2 * \frac{E}{1000} + b_2 * (T - 25) + c_2 \qquad (9)$$

$$y_3 = a_3 * \log\left(\frac{E}{1000}\right) + b_3 * (T - 25) + c_3 \quad (10)$$

$$RMSE = \left[\frac{\sum (I_{cal} - I_{exp})^2}{N}\right]^{0,5} \quad (11)$$

$$CC = \frac{\sum (I_{exp} - \overline{I_{exp}})(I_{cal} - \overline{I_{cal}})}{\sqrt{\sum (I_{exp} - \overline{I_{exp}})^2 \sum (I_{cal} - \overline{I_{cal}})^2}} \quad (12)$$

Where I_{cal} and I_{exp} are respectively, the calculated and measured currents and N: number of measured points.

y_1, y_1 and y_1 are the simple model parameters to be correlated with Temperature and Irradiance which are given by table 2 and table III.

V. Adaptive network-based fuzzy inference system (ANFIS)

Benefit from the neural network approximation capacity and the fuzzy adaptability (ANFIS). The two intelligent approaches may be achieve an adequate results in quality and quantities.

ANFIS uses a hybrid learning algorithm to identify parameters of Sugeno-type fuzzy inference systems. It applies a combination of the least-squares method and the backpropagation gradient descent method for training FIS membership functions (MFs) parameters to estimate a given training data set [14-17].

The ANFIS model programmed in MATLAB is used to predict each parameter using irradiance (E) as a first input of ANFIS model and PV cell temperature (T) as a second input. According to reach the error criterion setting in ANFIS function the input MFs parameters and output linear MFs of a Sugeno-type FIS structure is modified to reach best MFs that clustering input output data with minimum root mean square error (RMSE).

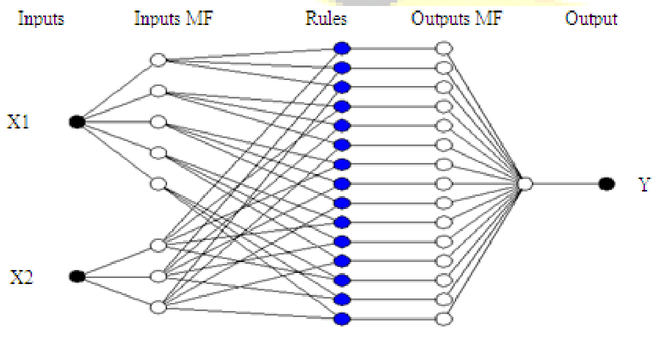

Figure 2. Four layers ANFIS architecture

VI. Results and Discussions

The obtained results from the simple correlations were presented on table II, it is obviously showed the better correlation of model parameters of the ST40 module except I_0 for which a bad correlation is remarked.

For more improvement, the ANFIS is used to predict model parameters according real operating conditions. The output of different ANFIS proposed models was compared with the real field output of each parameter. The 5×3 inputs MFs model is selected regarding to a low RMSE error between estimated and measured data as seen in Table 3. Different inputs membership functions were used for each parameter to reach minimum RMSE, namely symmetric Gaussian function (gaussmf), Gaussian combination membership function (gauss2mf), difference between two sigmoidal membership functions (dsigmf) and Generalized bell-shaped membership function (gbellmf). Table 3 shows clearly the improvement of correlation of model parameters of all tested modules, especially for the BP3160 module.

VII. Conclusion

Two correlation methods have been applied and compared to select five parameter results of for different PV modules technologies, in accordance of the outdoor real variation of Temperature and irradiance loosely to a semi arid site of Ghardaia.

A simple regression correlation is used first, then an ANFIS correlation has been performed. A data base has been obtained for the two different experimental methods, through a simulation study, the obtained results averred a satisfied accuracy between the measured and estimated electrical data. The results obtained by the ANFIS model present more accurate results than the simple correlations for different PV modules technologies, which averred that the proposed ANFIS models present better correlation for most PV modules parameters.

A recurrent experimental on the mentioned PV module characteristics under different outdoor conditions of the site seemed to be improved by ANFIS. The proposed ANFIS correlation may be used for further characteristic translation, closed to specific desert climate changes.

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TABLE II. SIMPLE CORRELATION MODELS PERFORMANCE OF TESTED PV MODULES

		ASE95		BP3160		US64		ST40	
Param.	**Equa..**	***RMSE***	***CC***	***RMSE***	***CC***	***RMSE***	***CC***	***RMSE***	***CC***
IL	(9)	0.0369	0.9981	0.0634	0.9985	0.0753	0.9979	0.0163	0.9996
m	(10)	0.2256	0.7025	0.4168	0.0519	0.9422	0.6911	0.2085	0.9790
Rs	(10)	0.4807	0.9694	1.9074	0.7153	0.1568	0.7441	0.2436	0.9625
I0	(8)	8.6880e-007	0.7594	1.0285e-006	0.0981	2.1015e-007	0.4281	1.7892e-007	0.8695
Rsh	(10)	168.1766	0.7937	284.0563	0.4945	40.3984	0.5941	28.2668	0.9671

TABLE III. ANFIS PERFORMANCE OF TESTED PV MODULES

	ASE95			BP3160			US64			ST40		
	RMSE	***CC***	***MF***	***RMSE***	***CC***	***MF***	***RMSE***	***CC***	***MF***	***RMSE***	***CC***	***MF***
IL	0.03	0.999	gauss2mf	0.04	0.9995	gbellmf	0.037	0.999	dsigmf	0.007	0.9998	gbellmf
m	0.04	0.748	gbellmf	0.06	0.9093	gaussmf	0.220	0.839	gbellmf	0.014	0.989	gbellmf
Rs	0.04	0.986	gbellmf	0.06	0.9994	gbellmf	0.043	0.872	gbellmf	0.013	0.990	gbellmf
I0	1.63E-08	0.768	gbellmf	1.48E-07	0.9190	gaussmf	1.09E-07	0.687	gbellmf	8.14E-08	0.844	gbellmf
Rsh	62.99	0.888	gauss2mf	166.35	0.7569	gbellmf	15.008	0.910	gauss2mf	2.245	0.993	gbellmf