Prediction of PV Solar Panel Output Characteristics Using a Multilayer Artificial Neural Network (MLANN)

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Abstract. In this paper, PV solar collector was tested experimentally from 1st July to 31th August 2018 between 7:00 am and 6:00 pm under the weather conditions of Iraq. The PV output power was calculated by using the measured data of voltage and current obtained from experiments. To predict the PV solar output characteristics, four structures of a multilayer artificial neural network MLANN with Error Back-Propagation EBP were designed in MATLAB software. The MLANN structures have two inputs (temperature and irradiance) and three outputs (voltage, current and power). From experiment tests, a dataset of 434 hourly points was collected to investigate the structures of MLANN model. A 70% of the data used for training stage and 30% was distributed between the testing and validating stages. From test stage, the average of output value was taken for 14 numbers of data to compare with experimental values. The MLANN results show that the structures 2-4-4-1, 2-1-1-1 and 2-5-5-1 were the optimum testing model in the voltage, current and power output respectively with high accuracy and good agreement with experimental results.

Keywords: PV solar; ANN; Error Back-Propagation; output Power.

1. Introduction
The growing demand of electricity in the world made the PV solar systems as a major and important source that deserves attention, research and development. In recent years, most researchers have directed their researches to develop the photovoltaic solar technology in terms of increasing the efficiency of solar panels. These researches deal with the experimental studies and mathematical models. Experimental studies were investigated under different locations and climate conditions around the world. On the other side, the mathematical models were conducted using mathematical analysis, program algorithm and software etc. In the last period, an ANN machine was used in a wide range to forecast, predict and validate the PV solar output characteristics. According to the previous studies in literature, different architectures of ANN with different structures were used, including the type of ANN, number of structures, the type of propagation, source of collection data and input-output parameters. MLANN with feed-forward propagation was used by [1-3] to
predict the output power of PV solar panel. While, [4, 5] used backward propagation-MLANN to predict output power of PV solar panel. In addition, M. Hadjab et al. And A. Mallet et al. [6,7] investigated a MLANN with different structures to predict the output current and voltage of PV panel. On the other side, [8-11] were applied the single layer of the ANN with Feed-Forward propagation to predict the output power of PV solar panel. Some researchers used ANN is combining with analytical model to predict the I-V characteristics of PV. For example, Chen Zhang et al. [12] combined between the three-layer feed forward neural network and explicit analytical model (EAM) for predicting the output characteristics of the PV modules. The results of the combination model show that the EAM is efficient to obtain the curves of current and voltage of PV modules due to its simplicity and explicit expression. Siyi Wang et al. [13] built a model by combining between four ANNs to predict the output characteristics of PV modules. As a comparison between the model and the traditional single ANN results, the model shows better accuracy than the traditional ANN. In the present study, implementation and validation of a MLANN - Error Back-Propagation EBP was designed in MATLAB software for predicting the PV solar panel output characteristics. Four structures were used to check the best outputs and compare them with the experimental results.

2. Methodology of PV solar characteristics

Photovoltaic module is a set of solar cells connecting in series and parallel. The relation between the I-V outputs of solar module represented as a non-linear mathematical equation [14].

\[
I = N_p I_{ph} - N_p I_o \left[ \exp \left( \frac{V}{N_s n I_{mp}} \right) - 1 \right]
\]

The output power of the solar module can be expressed as [15]:

\[
P = IV
\]

Shower Np, Iph, I0, NS, n, K, T and q are number of parallel cells, diode current (A), dark saturation current (A), number of series cells, idealist factor, Boltzmann’s constant (1.38 \times 10^{-23} J/K), cell working temperature (°C) and Electron charge (1.602 \times 10^{-19} C) respectively.

3. Experimental setup and collected data

Experimental test was applied for a PV solar cell made from polycrystalline silicon model (Dusol DS60260W Dubai) with dimensions (170\times90) Cm² mounted on the roof of computer systems Department in Baqubah Technical Institute / Iraq (Figure 1). The specifications of solar cell where Maximum power \( P_{max} = 150\text{watt} \), Peak voltage \( V_{mp} = 22 \text{voltage} \), Peak current \( I_{mp} = 10 \text{ampere} \), area \( A = 1.6 \text{m}^2 \) and Efficiency=14\%. PV solar collector was tested
from 1st July to 31st August-2018 between 7:00 am and 6:00 pm under the weather conditions of Baqubah cities in the east of Iraq. The ambient temperature was measured using a digital temperature sensor (-50 - 70 °C) with an accuracy ± 1 °C while the solar radiation was measured using digital LUX METER type FUYI model LX-1010B. The output characteristics of PV solar panel I-V were measured using LED/LCD DC meter model SK85-CA wiring diagram. The PV output power was calculated by using the measured data of I-V obtained from experiments. Totally, 434 hourly data points were collected along the period of experimental tests.

4. Methodology of ANN model

In an ANN, the neuron received the input signal from an external source to multiply it with identical weights and checks the result; if it’s exceeded the threshold the signal will be released and sent to the output depending on the ANN activation function [16]. As shown in Figure 2, the summation of weight called net input to unit \( (i) \) from unit \( (j) \) and denoted as \( (w_{ij}) \). The output signal is written as a function of the ANN inputs [17]:

\[
O = f\left( b_3 + w_5 . f\left( b_1 + w_1 i_1 + w_3 i_2 \right) + w_6 f\left( b_2 + w_2 i_1 + w_4 i_2 \right) \right)
\]  

(3)
The free parameters of ANN (biases $b$ and weights $w$) play a big role in output signal. An error back-propagation method was applied to calculate the weight matrices. The accuracy of weights depends on the minimum error of the output $\{z(k); 1 \leq k \leq K\}$ in training stage [18-20]. The error was calculated using the sum of the square error:

$$E = \sum_{k=1}^{K} [e(k)]^2 = \sum_{k=1}^{K} [d(k) - z(k)]^2 = \sum_{k=1}^{K} [d(k) - f(W_x(k))]^2$$  \hspace{1cm} (4)

$[W_x]$: Weight matrix, $[x]$: input vectors, and $d$ is the desired target value. The mean square error (MSE) is one of the common methods used to evaluate the performance of the ANN model.

$$MSE = \frac{\sum_{i=1}^{N} |X_{predicted} - X_{measured}|^2}{N}$$  \hspace{1cm} (5)

5. Proposed MLANN

The features of the proposed MLANN model are presented in the following procedures:

a) A dataset of 434 hourly points was collected to investigate the structure of ANN model.

b) Totally 70% of the data used for training stage and 30% used for testing and validating stages.

c) Error Back-Propagation was selected in training algorithm.

d) From testing stage, the average of output values was taken for 14 number of data

e) The number of neurons ($j$) was calculated according to the equation in the study of [21]

\[ j = n/2, 1*n, 2*n, 2*n+1 \] (n: number of inputs). Therefore, the number of neurons in hidden layer was 1, 2, 4 and 5.

f) As a result of neurons, the ANN structures (2-1-1-1), (2-2-2-1), (2-4-4-1) and (2-5-5-1) were used in ANN model

g) The activation function ‘tansig’ was used in hidden layer and ‘purlin’ in the output layer.

h) The main parameters (LR = 0.005, EG = $1 \times 10^{-6}$, epochs = 2000, and Momentum factor = 0.1) were selected to complete the connecting and operating of MLANN.

i) MSE and the coefficient of determination ($R^2$) were selected as indicators to evaluate the performance and accuracy ANN. Where the value of $R^2$ indicates to the accuracy between of the curve fit of expected and observed values depending on the independent parameters such $R^2 =1$ is the optimum fit value and $R^2=0.9$ to 0.99 is a very good fit value.

6. Results and discussions

PV solar panel was tested experimentally from 1st July to 31th August 2018 between 7:00 am and 6:00 pm in order to investigate the ability of MLANN with Error Back-Propagation to predict and validate the PV solar output characteristics. Figures (3-5) show the best validation performance of MLANN in voltage, current and output power structures respectively. The
performance of MLANN in the best structure of each output includes the $R^2$, MSE and the number of epochs. Table 1 presents the performance of MLANN in best structure of output characteristic. As shown in the table, the maximum $R^2$ was recorded 0.982 in validating of the power structure with epoch 4 and MSE = $6.4 \times 10^{-4}$. In current and voltage structures, the epoch was recorded about 3 and 12, MSE as $6.4 \times 10^{-4}$ and $1.64 \times 10^{-3}$ and $R^2$ (0.991 and 0.733) respectively.
Table 1. Determination coefficients ($R^2$), mean square error (MSE) and number of epochs for best MLANN structure.

| Best structures | $R^2$ Training | $R^2$ Validating | $R^2$ Testing | $R^2$ All | MSE      | Epoch |
|-----------------|---------------|-----------------|--------------|----------|----------|-------|
| Voltage         |               |                 |              |          |          |       |
| 2-4-4-1         | 0.935         | 0.991           | 0.895        | 0.945    | $1\times10^{-3}$ | 3     |
| Current         |               |                 |              |          |          |       |
| 2-1-1-1         | 0.848         | 0.733           | 0.895        | 0.853    | $1.64\times10^{-3}$ | 12    |
| Power           |               |                 |              |          |          |       |
| 2-5-5-1         | 0.943         | 0.982           | 0.900        | 0.963    | $6.4\times10^{-4}$ | 4     |

Figures 6-8 show the relationship between the measured and the MLANN outputs with a number of data for voltage, current and power. The graphs of MLANN represent the best structures (2-4-4-1), (2-1-1-1) and (2-5-5-1) were used in predicting the PV solar characteristics; voltage, current and power respectively. According to the figures, the pattern of the graphs is compatible and very close between them.
Figure 6. Comparison between the experimental voltages with the best MLANN structure-voltage according to the number of data

Figure 7. Comparison between the experimental current with the best MLANN structure-current according to the number of data
Figure 8. Comparison between the experimental power with the best MLANN structure-power according to the number of data

The voltage, current and power outputs of PV solar panel were predicted after performing the MLANN simulation using a radiance and ambient temperature obtained from experiments. Figures 9-11 demonstrate the convergence between the experiments output values and output values obtained from the MLANN based on irradiance. As shown in the Figure 9, we can see a good match between the voltage measured and voltage predicted with maximum difference voltage about 0.66 V. In Figure 10, the maximum difference between the measured current and predicted current was obtained 0.53 ampere while the maximum difference of output power was obtained 6.3 W as shown in Figure 11.

Figure 9. Voltage curve (experimental and MLANN) with radiance
7. Conclusions

A PV solar panel was tested experimentally and a MLANN with Error Back-Propagation was designed in MATLAB software to predict the output characteristics. From the behavior of MLANN model, we can conclude that the:

a) MLANN model can predict with high accuracy and good agreement with experimental results.

b) Although, a good match between the measured values and MLANN values, we notice that the performance of MLANN influenced by numbers of hidden neurons.

c) Structures 2-4-4-1, 2-1-1-1 and 2-5-5-1 show the best performance in predicting the voltage, current and power outputs respectively.
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