Intelligent Nero modelling methods for PV panel system

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Abstract. Nonlinear system identification modelling for the temperature of photovoltaic (PV) panel has been conducted in this work. In the beginning, an experimental work has been extracted from previous work in order to collect the input (ambient temperature, humidity, irradiance and wind speed) and output (PV module temperature) parameters. Then, Neural Network time series and Adaptive Neuro-Fuzzy Inference System (ANFIS) models represented as system identification method to predict the temperature of PV panel as an output for the system. Both of modelling methods verified using mean square error (MSE). The effectiveness of all methods has been compared to know which method is the better. Finally, the achieved results stated that the ANFIS method recorded the lowest MSE of 2.2627\times10^{-7} compared with NARX method which recorded of 5.078. ANFIS technique proved that will be able to use it in the control process in future.

Keywords: Nonlinear Autoregressive Exogenous (NARX), ANFIS, System identification modelling, PV panel.

1-Introduction

In the last years, employment of solar energy has been increased in many countries due to increasing in the fuel prices and confined traditional resources. Photovoltaic (PV) conversion is the direct transformation of sunlight into electricity without any heat engine to interpose [1]. Using the solar energy reduces the environmental damage that results from burning of fuel used in power generation plants. The sun radiates an enormous amount of energy through nuclear fusion process. During one second, the sun converts about four million tons of the mass which mostly consists of the helium and hydrogen into energy producing solar radiation and neutrinos [2]. The amount of sunlight available is one factor to take into account when considering using solar energy. The most important characteristic of a photovoltaic panel is the Conversion efficiency, the solar radiation that is not converted into electricity is almost entirely transformed into heat. The efficiency is decrease while the temperature of PV cell rises [3]. Various factors can significantly affect PV electrical performance during operation, one of these factors is PV temperature which has great impact on PV performance particularly in hot weather such as summer season in Iraq where PV temperature reaches to 80 °C which leads to significantly decreasing in PV performance. In fact, more than 80% of the radiation falling on a PV cells is converted to thermal energy or reflected Cooling system is substantial in order to overcome problem at hot environment and high irradiation. Generally, there are several cooling techniques for cooling the PV panel and overcome PV temperature rising problem and enhance its performance such as air-cooling and water-cooling [4]. Studied different cooling methods trying to enhance the
performance of PV system, used: back, front and duel cooling. The results showed the dual cooling reduced PV temperature by 18% while front cooling and back cooling reduced PV temperature by 11% and 2% respectively. [5] Improved PV array efficiency experimentally by spraying water on front side of PV. The output hot water was used as heating water for houses, buildings etc. The result showed the electrical power of each one panel increased by 0.354 w/degree. [6] Used method of passive heat exchange as back cooling for PV panels. The result showed increasing in electrical and thermal efficiency that reached to 11.4% and 41.6% respectively, in a sunny day. [7] Designed a micro-heat pipe array to cool a PV panels. It was found that the cooling by water is more effective than cooling by air. [8] Suggested ducts that arranged in parallel with inlet and outlet channels on the back side of PV module. The results showed the temperature reduced from 68°C to 38°C and increased the efficiency from 8.6% to 12.5%. [9] found that using the air cooling increased the electrical efficiency by 2.6% and the output power 8.4% due to reduction in cell temperature about 4.7°C while by using water cooling, the cell temperature reduced by 8°C. This led to increase the PV efficiency by 3% and the output power by 13.9%. [10] Considered the appropriateness of artificial neural networks for 1 day ahead solar power generation estimating. [11] Estimating the everyday sun based radiation with two dynamic artificial neural networks (Feed forward Time Delay Neural Network and NARX) was proposed. As indicated by the creators, the two models had a palatable presentation. Built up an ANFIS model to foresee the ideal measuring coefficient of PV frameworks dependent on land arranges. The outcomes acquired were contrasted and broke down and counterfeit neural systems (ANN) demonstrating that ANFIS model displays the most exact outcomes.[12] Created an ANFIS model to anticipate month to month sun based worldwide radiation for PV framework estimating. The model showed a flat out rate blunder of 0.48, which yielded better outcomes contrasted with different strategies, for example, ANN.

The entirety of the past referenced investigations had a fundamental job in the improvement of this paper. It was created in three phases: right off the bat, the information assortment; also, NARX models and, at long last, ANFISE models with examination between two diverse system expectation models: NARX and ANFISE systems.

2- PV Experimental Work

In order to predict the actual PV panel model based module temperature as an output, an experimental design has been obtained from [13]. The system input consisted on radiation intensity, ambient temperature, wind speed and relative humidity. The experimental environment was in Baghdad city under coordinates of 33.33°N latitude, 44.39°E longitude, and 34 m elevation. two panels used in this work which are; one, the panel is type RNQ – 20D and made from a Mono-crystalline solar cells while, the other panel is type JP 01 that made from Poly crystalline solar cells. Many devices employed to collect input and output data such as digital multi-meter, regulator and battery. While, Thermocouple type k was used to obtain the panels temperature using a digital data recorder. The specifications of the used solar panels can see in Table (1).

| Table (1): Technical specification of the PV panel. type poly crystalline. (b) type mono-crystalline |
|-------------------------------------------------|---------------------------------|
| Model                                           | SR-100S                         |
| Maximum power (Pm)                              | 10W                             |
| Open circuit voltage(V∞)                        | 22V                             |
| Short circuit current (Isc)                     | 0.64A                           |
| Peak voltage (Vm)                               | 17V                             |
| Peak current (Im)                               | 0.59A                           |
| Short circuit current temperature coefficient(KI) | 2.1mA/°C                        |
| Open circuit voltage temperature coefficient(KV) | -0.79V/°C                       |
| No.of serious cells (Ns)                        | 36                              |
| No.of parallel cells (Np)                       | 1                               |
| Dimensions                                      | 285*350*mm                      |
Table (2): Technical specification of the PV panel type mono-crystalline

| Parameter                                      | SR-100S                  |
|------------------------------------------------|--------------------------|
| Maximum power (Pm)                             | 20W                      |
| Open circuit voltage (V∞)                      | 21.6V                    |
| Short circuit current (Isc)                    | 1.23A                    |
| Optimum operating voltage (Vmp)                | 17.5V                    |
| Optimum operating current (Imp)                | 1.14A                    |
| Temperature coefficient of (Pmax)              | -0.23%/°C                |
| Temperature coefficient of (V∞)                | -0.33%/°C                |
| Temperature coefficient of (Isc)               | 0.05%/°C                 |
| Max system voltage                             | 600 VDC (UL)             |
| Fire Rating                                    | Class C                  |
| Weight                                         | 2.2kg/4.8Ib              |
| Dimension                                      | 345*470*25mm             |
| STC                                            | Irradiance=1000W/m, T=25°C, Am=1.5 |

A theoretical model for the thermal performance of PV panel with heat sink as a cooling system was formulated. The proposed cooling system was consisted of an array of pin fins as a heat sink. The model also included the determination of the suitable dimensions of fins and arrangement. A mathematical model was built and solved using MATLAB package in order to calculate the thermal characteristic of PV panel with heat sink. In experimental part, three passive methods applied and tested in order to reduce the operating temperature of solar module.

3-NARX Model

Prediction is a kind of dynamic filtering, in which past values of one or more time series are used to predict future values. A neural framework is a movement of figuring that endeavours to see shrouded associations in a great deal of data through a methodology that imitates the way wherein the human personality works. Neural frameworks can conform to developing input; so the framework makes the best result without hoping to redesign the yield criteria. Dynamic neural systems, which incorporate tapped postpone lines, are utilized for nonlinear separating and expectation. The model nonlinear autoregressive with exogenous (Outer) inputs (NARX) is proposed in [14]. NARX foresee arrangement y (t) given (d) past estimations of arrangement y (t) and another outer arrangement x (t), which can be single or multidimensional. The condition that models the NARX arrange conduct for time arrangement expectation is appeared in Equation (1).

\[ y(t) = f(x(t - 1), x(t - 2), \ldots, x(t - d), \ y(t - 1), y(t - 2), \ldots, y(t - d)) \]  

(1)

In this investigation, we use NARX with one contribution for the temperature of sun based module time arrangement at time t-1, y(t-1), and another contribution with exogenous information at time t-1, x(t-1), to give a solitary yield information y(t), comparing to the estimation of the temperature of solar module one step forward. Figure (1) shows this architecture.
4-ANFIS Model

ANFIS is a multilayer arrangement mix of ANN learning calculations and a fluffy deduction framework (FIS) to delineate info parameters to yield esteem. ANFIS has a system type structure like that of a neural system, which maps contributions through information enrolment works and related parameters. Figure (2) represent the ANFIS design with x and y sources of info and F yield. A1 and A2 are the fluffy participations that fuzzified input x. Likewise B1 and B2 are the fluffy enrolments that fuzzified input y [14].

ANFIS model is created by five-layer engineering (Figure 2), where every one of the hubs in a similar layer have a comparable capacity [15]. Layer 1 is made out of participation work hubs. This layer changes over the crisped contribution to fluffy qualities, giving the contributions to the accompanying layers. The yield of this layer is given by:

\[ O_{1,1} = \mu A_i(x) \]
\[ O_{1,2} = \mu B_i(y) \]

Where \( \mu \) is the participation work, \( O_{1,1} \) is the enrolment esteem for the fresh information sources x and y, and the subscripts 1 and I speak to the layer number and hub number, individually. Layer 2 contains the standard hubs. The hubs in this layer compute the terminating quality of a standard \( w_i \) as:

\[ O_{2,i} = w_i = \mu A_i(x) \mu B_i(y) \]

In layer 3, every hub figures the proportion of the I-the standard's terminating solidarity to the total of all guidelines terminating quality (\( \tilde{w}_i \)):

\[ O_{3,1} = \tilde{w}_i = \frac{w_i}{w_1 + w_2} \]
Layer 4 figures the standard yields dependent on the ensuing parameters (Equations (2) and (3)) and the yield of the past layer:

\[ O_{4,i} = \bar{w}_i f_i = \bar{w}_i (p_i x + q_i y + r_i) \quad (6) \]

At long last, layer 5 processes the general yield adding every one of the information sources sign to get the yield model worth.

\[ O_{5,i} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (7) \]

5- Model approval

The confirmation procedure of the outcomes is considered as one of the significant strides to quantify the exhibition of numerical calculations. Model approval was utilized to check model estimation execution through estimating and looking at genuine information (input-yield) acquired by the test arrangement with the anticipated information (yield) created by SI. Mean square blunder (MSE) was utilized to approve the dynamic conduct execution of the PV temperature by contrasting the real and anticipated information esteems. The type of mean square mistake was spoken to as:

\[ \varepsilon(t) = \frac{1}{N} \sum_{t=1}^{N} (y(t) - \hat{y}(t))^2 \quad (8) \]

Where \( y(t) \) is the actual output and \( \hat{y}(t) \) is the predicted output. [15]

6- Results and Discussion

Approach containing steps is utilized to appraise the temperature of the PV cluster. The system input consisted on radiation intensity, ambient temperature, wind speed and relative humidity, figure (3) show these variables, whilst the system output was temperature of PV panel and figure (4) illustrates the output. Representing dynamic data: 1650 time steps of 4 elements.

At using NARX system, the range selected for the preparation, testing, and approval sets was 70%, 15%, and 15%, individually, of the time arrangement utilized as information sources. Firstly, it was fixed number of neuron (Nn) at 10 and change number of delay (Nd) from 2_10, each MSE is detailed in the table (3) at this table found the best MSE at Nd=10. Secondly, it was fixed number of delay at 10 and change number of neuron from 2 _10. In table (3), it was found the best MSE at Nn=9, So, it was taken 9,10 for Nn and Nd, respectively, as show in table (4). From this table, it was found the MSE for all NARX system was 5.078. Figure (5) show the block diagram of the system, figure (6) illustrates a flowchart of the methodology employed, figure (7) displays predict the error and figure (8) offers the actual and predict temperature of PV panel.
Fig. (3): illustrates the input data

Fig. (4): illustrates the output data

Fig. (5): Block diagram
Fig. (6): NARX methodology flowchart.

Fig. (7): illustrates predict the error
Fig. (8): illustrates actual and predict temperature of PV panel.

Table (3) - Training and predicting error results at fixed: a- Nn=10, b- Nd=10

| No. of Neuron | No. of delay | MSE Training | MSE Validation | MSE Testing | MSE | No. of Neuron | No. of delay | MSE Training | MSE Validation | MSE Testing | MSE |
|---------------|--------------|--------------|----------------|-------------|-----|---------------|--------------|--------------|----------------|-------------|-----|
| 10            | 2            | 4.371        | 3.540          | 3.750       | 4.66| 2             | 10           | 4.550        | 4.614          | 4.47         | 5.69|
| 10            | 3            | 3.206        | 4.822          | 4.450       | 4.19| 3             | 10           | 3.710        | 3.640          | 4.45         | 5.36|
| 10            | 4            | 3.954        | 4.146          | 4.968       | 5.03| 4             | 10           | 4.360        | 7.770          | 8.78         | 5.93|
| 10            | 5            | 3.750        | 3.560          | 5.230       | 5.05| 5             | 10           | 3.440        | 6.970          | 3.50         | 5.23|
| 10            | 6            | 2.870        | 4.59           | 7.290       | 5.03| 6             | 10           | 3.840        | 5.860          | 7.40         | 6.49|
| 10            | 7            | 2.369        | 8.022          | 3.850       | 4.86| 7             | 10           | 3.410        | 5.430          | 5.77         | 6.86|
| 10            | 8            | 3.280        | 3.760          | 5.905       | 4.68| 8             | 10           | 3.290        | 4.450          | 6.73         | 5.25|
| 10            | 9            | 3.540        | 4.080          | 4.620       | 6.30| 9             | 10           | 2.970        | 5.590          | 5.50         | 5.11|
| 10            | 10           | 3.032        | 8.050          | 4.280       | 4.01| 10            | 10           | 2.930        | 4.240          | 5.36         | 6.57|

Table (4) - Training and predicting error results

| Number of Neurons | Number of delay | MSE Training | MSE Validation | MSE Testing | Mean Squared Error |
|-------------------|-----------------|--------------|----------------|-------------|--------------------|
| 9                 | 10              | 3.085        | 4.718          | 6.172       | 5.078              |

Preparing of the ANFIS model is practiced through a progression of ages playing out an improvement procedure to limit the contrasts between test information and reproduced yield. Figure (9) show a flowchart of the methodology employed For our implementation, data for training and checking were 850 and 800, respectively, the best zero-request Surgeon ANFIS engineering contains an info layer with five hubs, two summed up ringer melded enrolment capacities per each information hub, the ages were 10, a standard layer with 32 hubs, a yield participation work with 32 consistent hubs, and one yield relating to TPV,Sim Figure (10), Figure (11) it shows predict error percentage, while figure(12) displays actual and predict temperature of PV panel. At MFs=2, MSE=2.2627e-07. However, MSE=0.1072 at MFs=3, as show in table (5). The plan was change the MFs from 2_10, but it was noticed that when MFs increase, the error increase too, so, the best choice was MFs=2.

At a comparison between the Mean Square Error (MSE) which predicted by ANFIS and NARX models, in table (3) the MSE is 5.078 while the MSE in table (4) is 2.2627e-07 and 0.1072 that is mean the forecast delivered by the ANFIS method is relatively better.
Fig. (9): ANFIS methodology flowchart.
Fig. (10): ANFIS engineering model for estimation of PV temperature.

Fig. (11): Shows predict error

Fig. (8): illustrates actual and predict temperature of PV panel.
7- Conclusions
The thermal model utilized in foreseeing the temperature of PV module is significant as the module temperature influences its capacity yield. The thermal model where utilized in anticipating the module temperature of PV module working in Baghdad ecological conditions. A careful inquiry was performed dependent on the considered information parameters to choose the arrangement of the ideal mix of data sources that has the most impact on expectation of PV temperature. The NARX and ANFIS models were built by using 1650 data base composed of radiation intensity, ambient temperature, wind speed and relative humidity's were used to compare the two models. In the first model No.of neuron was changed from 2_10 until reached to the lower MSE, the best result fixed and change No.of delay from 2_10 . Whilst, the second model depended on selection the No.of MFs and membership function type. It very well may be construed from the outcomes that with respect to foreseeing the PV temperature ANFIS based figure conveys better results when contrasted with the NARX based gauge, where the MSE was 5.078 by NARX method and 2.2627e-07 by ANFIS method.

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Table (5) - Results of the ANFISE model

| Number of MFs | Minimal Training RMSE | Minimal Checking RMSE | Mean Squared Error | Number of nodes | Number of fuzzy rules |
|---------------|------------------------|-----------------------|--------------------|-----------------|----------------------|
| 2             | 2.1e-05                | 4.59e-04              | 2.2627e-07         | 92              | 32                   |
| 3             | 7.8e-05                | 3.27e-01              | 0.107              | 524             | 243                  |
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