Artificial Neural Network Based Modelling of Photovoltaic System

H. Parmar
Department of Mechanical Engineering,
Ujjain Engineering College, Ujjain (M.P.)- INDIA

Abstract- Photovoltaic system (PV) is alternate suitable option against conventional source of generating electricity. A typical photovoltaic system produces the electrical energy in terms of voltage and current. PV system is the environmental protection technique as well as saving of the electrical energy. This system reduces the level of chlorofluorocarbons (CFC) in the environment because it restricts the use of conventional method of generation of electrical energy. In this paper, an experimental study has been performed on PV system and modelling using artificial neural network. Artificial neural network (ANN) was constructed to predict symptoms of photovoltaic system for any climatic conditions. The symptoms of photovoltaic system were outlet voltage and outlet current. Feed-forward network was employed with Levenberg-Marquardt back-propagation (*trainlm*) algorithm used as the training function. The outputs from the network were obtained and validated with the experimental results. Among the constructed networks, the best prediction performance was observed in two-hidden-layered network with minimum error. The modelling of the photovoltaic system was carried out with neural network toolbox of MATLAB® with two inputs (Solar radiation and ambient temperature) and two outputs (Voltage and Current) value. The performance of the network was measured by mean square error (MSE). The proposed model may be used for any climatic conditions to predict the output from the photovoltaic system.

Keywords: Solar cell, Artificial Neural Network, Training function, Mean Square Error, modelling.

Abbreviations

CFC	Clorou florou carbon
PV	Photo voltaic
ANN	Artificial neural network
MSE	Mean square error
RBF	Radial basis function
IIR	Infinite impulse response
SAPV	Stand-alone photovoltaic
LOLP	Loss of load probability

I. INTRODUCTION

High penetration of photovoltaic (PV) systems is expected to play important roles as power generation source in the near future. This work presents an adaptive artificial neural network (ANN) for modelling and simulation of a photovoltaic system or photovoltaic array operating under variable climatic conditions. The convergence of back-propagation method was described by Vogl et al [1]. A solar cell also called as photovoltaic cell or photoelectric cell is a solid state electrical device that converts the energy of light directly into electricity by photovoltaic effect. Hontoria et al [2] have developed several methods for sizing of photovoltaic system and made improvement for obtaining loss of load probability (LOLP) curve based on the neural network is presented. Paoli et al [3] have used a Multi –Layer Perceptron (MLP) and an ad hoc time series pre-processing to develop a methodology for the daily prediction of global solar radiation on a horizontal surface. Chen et al [4] presented an advanced statistical method for solar power forecasting based on artificial intelligence techniques. This proposed method is suitable for operational planning of transmission system operator.

Izgi et al [5] applied ANN methodology to data obtained from a 750 W power capacity of solar PV panel. The main objective of this paper was to determine time horizon having the highest representative for generated electricity prediction of small scale solar power system applications. It was seen that 5 min time horizon gives the best solar power prediction for short term and 35 min could be used for medium terms in April. Mellita and Benghanemb [6] investigated using an adaptive radial basis function (RBF) network with infinite impulse response (IIR) filter in order to find a suitable model for sizing coefficients of the stand-alone photovoltaic

(PV) systems, based on minimum of input data. These sizing coefficients allow to the users of stand-alone PV systems to determine the number of solar panel and storage batteries necessary to satisfy a given consumption, especially in isolated sites where the global solar radiation data is not always available. Karatepe et al [7] presented a neural network based approach for improving the accuracy of the electrical equivalent circuit of a photovoltaic module. The equivalent circuit parameters of a PV module mainly depend on solar irradiation and temperature.

Mellit et al [8] investigated the possibility of using an adaptive Artificial Neural Network (ANN), in order to find a suitable model for sizing Stand-Alone Photovoltaic (SAPV) systems, based on a minimum of input data. The model combines Radial Basis Function (RBF) network and Infinite Impulse Response (IIR) filter in order to accelerate the convergence of the network. Ashhab et al [9]studied the feasibility of PV solar systems and aims at developing the theory and application of a hybrid system that utilizes PV solar system and another supporting source of energy to provide affordable heating and air conditioning. Fadare [10] presented, an artificial neural network (ANN) based model for prediction of solar energy potential in Nigeria (lat. 4–14^o N, log. 2–15^o E) was developed. Standard multilayered, feed-forward, back-propagation neural networks with different architecture were designed using neural toolbox for MATLAB. Amori et al [11] modeled, simulated and analyzed the electrical and thermal performance of a typical single pass hybrid photovoltaic/thermal (PV/T) air collector for two selected case studies in Iraq. A Matlab computer simulation program is developed to solve the thermo-electrical model. Mellit and Kalogiroub [12] have been used to solve complicated practical problems in various areas and are becoming more popular nowadays. They can learn from examples, are fault tolerant in the sense that they are able to handle noisy and incomplete data, are able to deal with nonlinear problems and once trained can perform prediction and generalization at high speed. AI-based systems are being developed and deployed worldwide in a wide variety of applications, mainly because of their symbolic reasoning, flexibility and explanation capabilities.
India possesses a large variety of climates ranging from extremely hot desert regions to high altitude locations with severely cold conditions similar to northern Europe. Within India it is possible to define six regions with distinct climates. The six climates are normally designated as Hot and Dry, Warm and Humid, Moderate, Cold and Sunny, Cold and Cloudy and Composite suggested by Bansal and Minke, 1988 [13]. The present work analysed the performance of a PV system in Composite zone of India. A computer models has been trained with a training algorithm i.e. ***trainlm*** which is available in ANN toolbox of MATLAB. On the basis of performance index, the performance of PV system evaluated and compared with the network data.

II. OBJECTIVES OF WORK

The main objectives of this work are to generalise the artificial neural network based modelling of PV system which predicts the output from the system for any place and optimized the suitable training algorithm for such type of data with minimum error. Presented model can predict the output voltage and current for any location. The predicted output from the network may be useful in designing the PV system for any location.

III. METHODOLOGY ADOPTED

In order to achieve the objectives described above, the present work was carried out in the following phases-

- Problem identification.
- Arrangement of experimental setup.
- Experimental work conducted on photovoltaic system.
- Develop ANN models to simulate the system for any input data using ANN toolbox of MATLAB.
- Training of data with suggested efficient training algorithm.
- Extensive validation of the data with the model.

IV. EXPERIMENTAL SETUP AND OBSERVATIONS

The experimental work was performed on solar panels available in solar laboratory of Ujjain Engineering College Ujjain, M.P. - (India). The panel has area of 11.6 m^2, 25 modules and 900 watts capacity array.
The experimental arrangement is shown in Fig.1.

Fig.1 Photovoltaic system at Ujjain Engineering College, Ujjain (M.P.)-India.

To record input/output parameters from photovoltaic system for ANN modelling, the following instruments were used:-

- **Hot Wire anemometer**: Hot wire anemometer is used to determine air velocity.
- **Solarimeter**: Solarimeter is used to determine intensity of solar radiation. The photograph of solarimeter is shown in Fig.2.

Fig.2 Solarimeter.

- **Multimeter:** Multimeter is used to determine Voltage & Current produced at output terminals of solar panels.

The experimental observations are shown in Table 1.
Least count of Solarimeter = 0.01mA (1mA =730 watt/meter^2)
Least count of Hot wire anemometer for wind velocity measurement = 0.1m/s
Least count of Hot wire anemometer for temperature measurement = 0.1ºC
Least count of Multimeter for voltage measurement = 0.1 volts
Least count of Multimeter for current measurement = 0.01Amp

V. ARTIFICIAL NEURAL NETWORK

An artificial neural network (ANN), usually called neural network (NN), is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. Modern neural networks are non-linear statistical data modelling tools. They are usually used to model complex relationships between inputs and outputs or to find patterns in data.

VI. NETWORK ARCHITECTURE

Typically, neural networks are adjusted, or trained, so that a particular input leads to a specific target output. The next figure illustrates such a situation. There, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically, many such input/target pairs are needed to train a network. The working of network is shown in Fig.3.

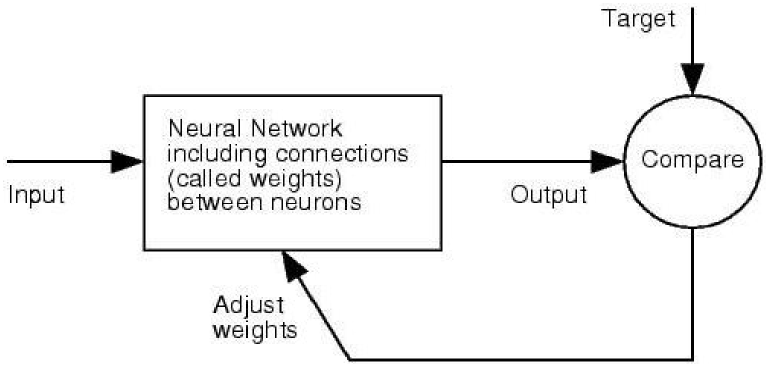

Fig.3 Line diagram of working of neural network.

Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, speech, vision, and control systems. Hornik [14] described a typical multi-layer feed forwarded neural network is shown in Fig.4.

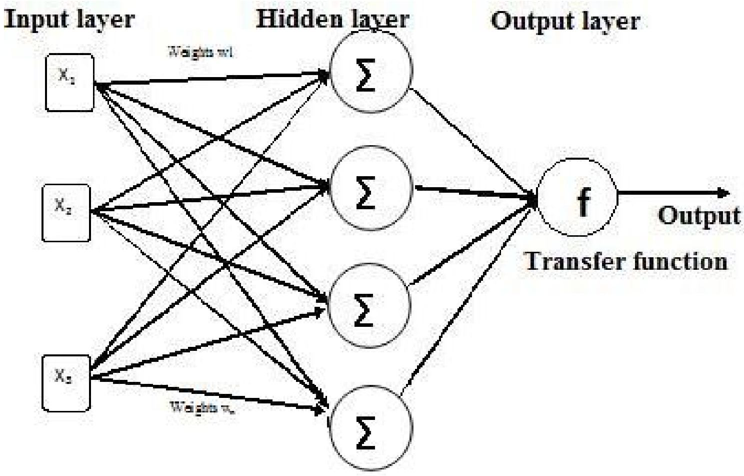

Fig.4 One-layer network with three input elements and four neurons.

For obtaining output from the network during training the summation of the weighted input is-

$$\mathbf{K_j = \sum P_i W_{ij}}$$

Where $\mathbf{K_j}$ = summation weighted input for the j^{th} neuron, $\mathbf{P_i}$ = input from the ith neuron to the j^{th} neuron, and $\mathbf{W_{ij}}$ = weight from the i^{th} neuron in the preceding layer to the j^{th} neuron in the present layer.

Two-layer feed-forward networks can potentially learn virtually any input-output relationship. Networks that train using back-propagation can have more than two hidden layers, which can make learning complex relationships easier for the network. The default back-propagation training algorithm is Levenberg-Marquardt (trainlm).

VII. TRAINING FUNCTIONS

The neural network models were developed using MATLAB®. Several training algorithms and network types are available in MATLAB® [15] . These algorithms can be broadly classified in following categories-

1. Gradient descent back-propagation - *traingd, traingdm, traingda, traingdx.*
2. Levenberg-Marquardt back-propagation – *trainlm, trainbr.*
3. Conjugate gradient back-propagation – *traincgb, traincgf, traincgp.*
4. Newton's method – *trainbfg, trainoss,*
5. Resilient back-propagation – *trainrp.*
6. Scaled conjugate gradient back-propagation – *trainscg.*
7. Random order incremental training – *trainr.*

In the present work, training of the input and output data were conducted with the help of feed forward neural network and the Levenberg-Marquardt back-propagation (*trainlm*) was used as training function to train the network. *trainlm* is a network training function that updates weight and bias values. The Mean Square Error (MSE) was used as the performance function for the analysis.

VIII. COMPARISON OF NETWORK AND EXPERIMENTAL OUTPUT

The outputs of the neural network were compared with the experiments and shown in Table 1.

Table1. Comparison of experimental and network output .

V_{exp}(volts)	V_{net}(volts)	Errors in V	I_{exp}(amp)	I_{net}(amp)	Errors in I
95.4	95.21	0.19	9.3	9.71	-0.41
95.2	95.16	0.04	8.82	8.85	-0.03
95.2	94.28	0.92	8.69	8.62	0.07
95.1	94.59	0.51	8.54	8.62	-0.08
95.6	95.57	0.03	8.01	8.44	-0.43
95.1	95.80	-0.70	7.32	7.79	-0.47
96	96.04	-0.04	7.06	7.54	-0.48
95.9	95.85	0.05	6.54	6.66	-0.12
96.5	95.98	0.52	5.62	5.95	-0.33
96.5	96.20	0.30	5.05	4.92	0.13
95.8	95.85	-0.05	4.29	4.26	0.03
96.8	96.24	0.56	3.58	3.32	0.26
96.3	95.91	0.39	8.9	7.85	1.05
96.3	95.36	0.94	9.1	8.36	0.74
96.3	95.97	0.33	9.45	9.48	-0.03
95.9	95.63	0.27	9.58	9.38	0.20
95.8	95.84	-0.04	9.71	9.72	-0.01
95.2	95.16	0.04	9.9	9.71	0.19

95.2	95.36	-0.16	10.01	10.10	-0.09
94.9	95.17	-0.27	9.85	9.87	-0.02
94.2	94.87	-0.67	9.91	9.98	-0.07
94.7	95.17	-0.47	9.5	9.71	-0.21
94.6	94.86	-0.26	9.8	9.82	-0.02
94.5	94.58	-0.08	9.67	9.63	0.04
94.3	95.67	-1.37	8.83	9.22	-0.39
94.2	94.62	-0.42	8.7	8.96	-0.26
94.6	94.14	0.46	7.96	8.30	-0.34
94.8	94.33	0.47	7.86	8.12	-0.26
94.5	94.74	-0.24	7.4	7.25	0.15
95.2	95.25	-0.05	6.48	6.57	-0.09
95.4	95.47	-0.07	5.96	5.89	0.07
96	95.35	0.65	5.49	5.56	-0.07
96.3	95.43	0.87	4.88	4.93	-0.05
96.5	96.33	0.17	4.15	3.92	0.23
96.8	96.42	0.38	3.5	3.30	0.20
90.5	92.76	-2.26	9.4	9.77	-0.37
91.2	91.79	-0.59	6.02	6.13	-0.11
92.3	92.54	-0.24	6.6	6.09	0.51
93.6	94.34	-0.74	5.64	5.21	0.43
93.2	91.35	1.85	10.7	10.83	-0.13
91.7	91.09	0.61	10.6	10.43	0.17
94	94.43	-0.43	8.7	8.79	-0.09
92.6	93.30	-0.70	8.94	9.05	-0.11
92.9	92.43	0.47	9.04	7.07	1.97
92.9	93.85	-0.95	8.68	8.99	-0.31
93	93.52	-0.52	8.53	8.70	-0.17
92.1	94.11	-2.04	8.06	8.30	-0.24
93.5	93.64	-0.14	7.69	8.02	-0.33
93.5	91.90	1.60	7.31	7.96	-0.65
93.3	92.43	0.87	7	7.62	-0.62

94.2	93.18	1.02	6.4	6.90	-0.50
92.5	93.89	-1.39	5.88	6.44	-0.56
94.3	93.78	0.52	5.35	5.92	-0.57
94.5	93.61	0.89	4.75	5.35	-0.60
94	94.42	-0.42	4.27	4.68	-0.41
92.5	94.96	-2.46	3.53	3.98	-0.45
94.2	93.87	0.33	3.17	4.19	-1.02

Mean Square Error of Voltage = 0.667015
Mean Square Error of Current = 0.203903

IX. RESULTS AND DISCUSSIONS

The performance of the neural network with training and validation is shown in Fig.5.

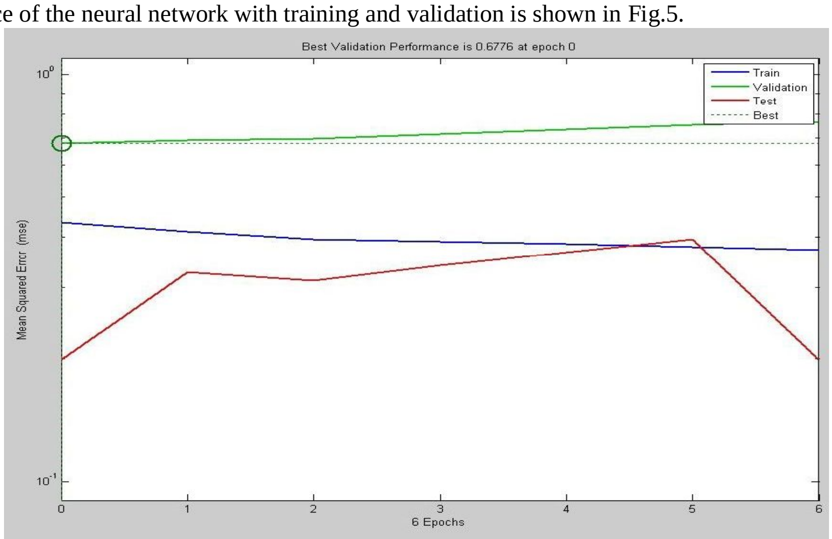

Fig.5 Performance plot of PV system.

A comparison between Experimental voltage and Network voltage is shown in Fig.6. The pattern of the graph shows the close agreement between the experimental and network output.

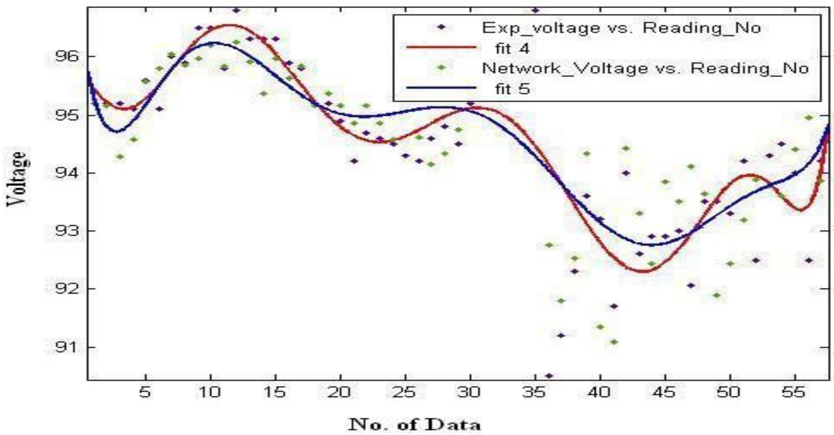

Fig.6 Comparisons between Experimental voltage and Network voltage.

Comparisons between Experimental output current and Network's output current is shown in Fig.7 with very close agreement. Both the output voltage and current from the network have minimum Mean Square Error (MSE) i.e. 0.667015 and 0.203903 respectively.

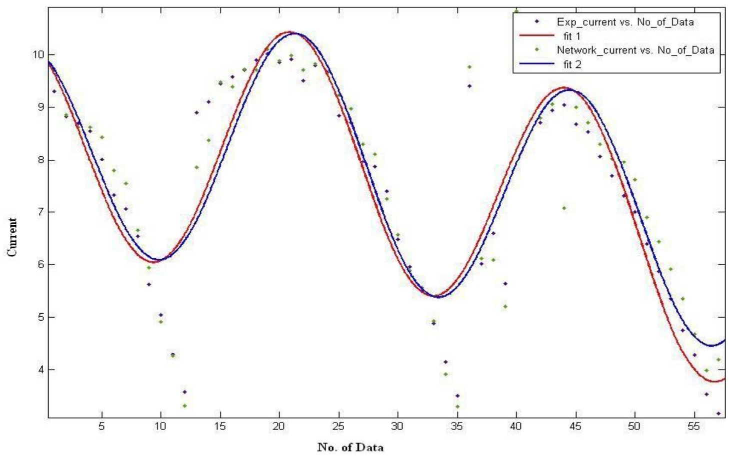

Fig.7 Experimental current and Network current.

The effect of solar radiation on the experimental and network output current is shown in Fig.8 and it was found that with the increase in radiation, the output current was increased with similar pattern.

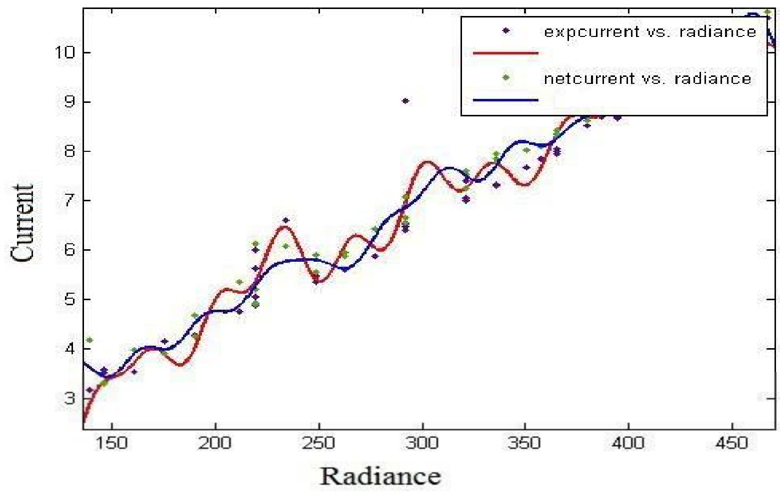

Fig.8 Comparison of experimental current and network current with radiance.

The variation of experimental voltage and network voltage with variation of solar radiance is shown in Fig.9.

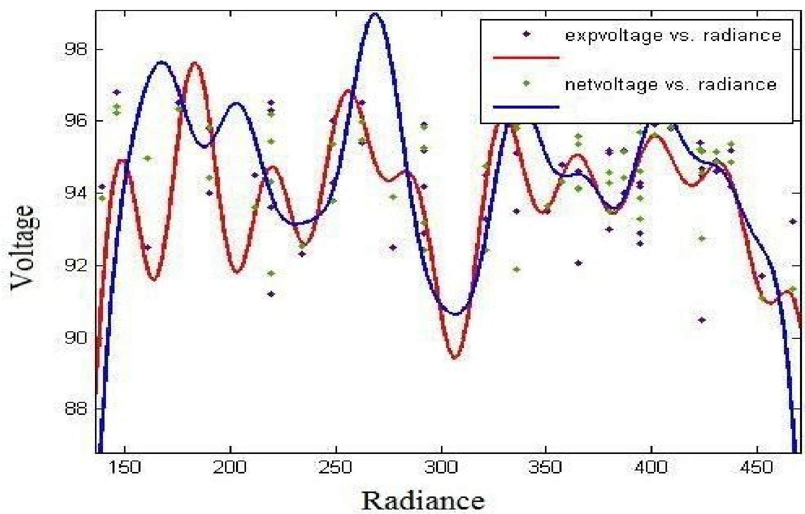

Fig.9 Variation of experimental voltage and network voltage with solar radiance.

X. CONCLUSIONS

Solar power generation has emerged as one of the most rapidly growing renewable sources of electricity. Solar power generation has several advantages over other forms of electricity generation as it reduces dependence on fossil fuels. Solar power production has several environmental advantages. Photovoltaic technology is proven, reliable, and has no moving parts. As the size and generating capacity of a solar system are a function of the number of solar modules installed, applications of solar technology are readily scalable and versatile. Due to various advantages of solar power, its use for the power generation has become very popular.

The plate form of MATLAB was used in order to construct artificial neural network. Artificial neural network was used for solving artificial intelligence problems without necessarily creating a model of real biological systems. The real, biological nervous system is highly complex: artificial neural network algorithms attempt to abstract this complexity and focus on what may hypothetically matter most from an information processing point of view. Thus ANN helps us in obtaining an artificial network which can help us in gaining output for different places or for different values of input.

The results from network were compared with experimental output and concluded that Network output and Experimental output is in close agreement.

The following Mean Square Error (MSE) was obtained for voltage and current:

Mean Square Error of Voltage = 0.667015

Mean Square Error of Current = 0.203903

REFERENCES

[1] Vogl, T.P., Mangis, J.K., Rigler, A.K., Zink, W.T., and Alkon, D.L., "Accelerating the convergence of the backpropagation method," *Biological Cybernetics*, Vol. 59, 1988, pp. 257-263.

[2] Hontoriya,L, Aguilera, J., Zufiria, P., "A new approach for sizing stand alone photovoltaic systems based in neural networks". *Solar Energy*,78,(2005), pp 313-319.

[3] Paoli, C., Voyant, C., Musselli, M., Nivet, M., "Forecasting of pre processed daily solar radiation time series using neural networks". *Solar Energy*, 84, (2010), pp 2146-2160.

[4] Chen, C., Duan, S., Cai, T., and Liu, B., "Online 24-h solar power forecasting based on weather type classification using artificial neural network". *Solar Energy*, 85, (2011), pp 2856-2870.

[5] Izgi E., Oztopal A., Yerly B., Kaymak M.K., Sahin A.D., "Short–mid-term solar power prediction by using artificial neural networks". *Solar Energy*, 86 (2012) 725-733.

[6] Mellit A., Benghanem M., "Sizing of stand-alone photovoltaic systems using neural network adaptive model". *Desalination* 209 (2007) 64–72.

[7] Karatepe E., Boztepe M., Colak M., "Neural network based solar cell model". *Energy Conversion and Management* 47 (2006) 1159–1178.

[8] Mellit A., Benghanem M., Hadj Arab A., Guessoume A., " An adaptive artificial neural network model for sizing stand-alone photovoltaic systems: application for isolated sites in Algeria". *Renewable Energy* 30 (2005) 1501–1524.

[9] Ashhab M.S., Kaylani H., Abdallah A., "PV solar system feasibility study". *Energy Conservation and management*, Article in press (2012).

[10] Fadare D.A., "Modelling of solar energy potential in Nigeria using an artificial neural network model". *Applied Energy* 86 (2009) 1410–1422.

[11] Amori K.E., Taqi Al-Najjar H.M., "Analysis of thermal and electrical performance of a hybrid (PV/T) air based solar collector for Iraq". *Applied Energy* 98 (2012) 384-395.

[12] Mellit A., Kalogiroub S.A., "Artificial intelligence techniques for photovoltaic applications: A review". *Progress in Energy and Combustion Science* 34 (2008) 574–632.

[13] Bansal,N.K,.and Minke,G.,1988, *Passive Air Conditioning*, Kernforsch- ungsanlage Julich GmbH Zentralbibiliothek, Julich, 19, 104.

[14] Hornik K., "Approximation capability of multi layer feed forward networks as universal approximations". *Neural networks*, (1991), 4, pp251-7.

[15] MATLAB Version 7.9.0.529 (R2009b).