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Predicting the Monthly Optimum Tilt Angles of Photovoltaic Cell

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Abstract: *The study presents an application of the artificial neural network model to predict the monthly optimum tilt angles which lead to the prediction of the seasonal optimum tilt angles of photovoltaic cell, Maiduguri as the case study. The mathematical model data obtained served as the input parameters for the ANN modeling which are the; tilt angle, latitude angle, declination angle, latitude, longitude and the optimum tilt angles. The seasonal optimum tilt angles were obtained to be (Harmattan=15.13386º, Dry=32.2984º and Wet=49.6146º) respectively. Comparative study was made by using the developed ANN model and the mathematical model results to predict the monthly optimum tilt angles. While predicting the monthly optimum tilt angles, the maximum error was 0.62% and an R^2 = 0.89975. This study showed that the artificial neural network approach can successfully be used for predicting the monthly optimum tilt angles of PVC.*

Keywords: *ANN**,** tilt angle, photovoltaic, declination, and modeling..*

1.0 INTRODUCTION

Sun is the most important energy source of the world which is classified as a renewable energy source. The most significant feature of renewable energy is its endless supply. It is infinite. Renewable energy sources are clean and hygienic sources of energy that have a much lesser negative environmental impact than non-renewable energy sources. This is because they are cleaner and do not producepoisonous harmful gases. Moreover, fossil fuels are finite. They will certainly end one day. One of the applications of renewable energy technology is the installation of photovoltaic (PV) systems that generate power without emitting pollutants and requiring no fuel (Kurokawa & Ikki, 2001)**.** The sun which powers this system is approximately 150 million km from the earth. It has a surface temperature close to 5500ºC and it emits radiation at a rate of $3.8\text{x}10^{23}$kW per second on an average daily basis (Lovegrove & Dennis, 2006). It is worth to note that, only a small fraction of its radiations actually reaches the surface of the earth. Therefore, harnessing this fraction for daily activities becomes very vital in the reduction of the use of hydrocarbon energy sources and maintaining a green environment.

The tilt angle is defined as the angle between the solar panel surface and the horizontal plane. The orientation of the solar panel is also defined with respect to the horizontal plane and it is the angle between the line due south and the projection of the solar panel normal to the surface on the horizontal plane (Suhatme, 1996) .

Both the orientation and tilt angles have significant effects on the magnitude of the solar radiation reaching the surface of a panel and consequently affect its performance (m., 2011). The magnitude of solar radiation received by solar panel is a function of many factors such as atmospheric conditions, location latitude, load profile, the sunrise hour angle, the azimuth angle, geographical position and so on. It has been found that, for every location on earth with specific radiation characteristics, there is an optimal tilt angle for the best solar energy absorption. Thus, the solar radiations from the sun can be increased by varying the tilt angle of solar panels to an angle at which the solar radiations are maximum. The optimum orientation and tilt angle of a PV panel to the horizontal is central to the design, installation and consequently the generation of peak power needed. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the panel.

In recent years, many field of engineering have applied ANN where approving and beneficial results were produced. Some of the application areas include; Artificial neural network modeling of the energy content of municipal wastes in northern Nigeria (Oumarou, et al., 2017), Artificial neural network-based prediction of Adiabatic capillary tube characteristics with alternative refrigerant (Shodiya, et al., 2011). Determination of the tilt angle of photovoltaic panels in turkey (Sahin, 2019). Several authors have used different simulation methods to establish and determine the optimum tilt angle for specified areas all round. (Ibrahim, 1995)examined the optimum tilt angle for Cyprus. For maximum radiation the results were calculated by varying tilt angle from 0° to 90° with the increment of 10°. (Ahmad & Tiwari, 2009) analyzed the theoretical aspects of choosing a tilt angle for the solar flat-plate collectors used at ten different stations in the world and makes recommendations on how the collected energy can be increased by varying the tilt angle. (Koray & Arif, 2002)found that the optimum tilt angle changes between 0◦ (June) and 61◦ (December) throughout the year. In winter (December, January, and February) the tilt should be 55.7◦, in spring (March, April, and May) 18.3◦, in summer (June, July, and August) 4.3◦, and in autumn (September, October, and November) 43◦. (Bekker, 2004) stated that for Indian stations, the calculations are based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface. Here, the difference of this study from the studies realized with mathematical methods is using of artificial neural networks in determining the seasonal optimum tilt angles. In this study, the optimum tilt angles of Maiduguri previously measured were used. With data obtained, the artificial neural network was trained for forecasting of the seasonal optimum tilt angles of Maiduguri city. In other words, the seasonal optimum tilt angles of Maiduguri city were estimated by ANN.

The aim of this study is to predict the monthly optimum tilt angles of photovoltaic cell. Furthermore, the aim is to obtain the data using mathematical model equation and use the obtained data to develop the ANN model to predict the monthly optimum tilt angles. Moreover, compare the ANN results with mathematical model results.

2.0 MATERIALS AND METHODS

The data used in the prediction of the monthly optimum tilt angles of the photovoltaic cell in Maiduguri was obtained from the mathematical analysis model, where the number of months, tilt angle, latitude angles, declination angles, latitude longitude and optimum tilt angles serves as the input parameters. The table below shows the data from which the ANN architecture was generated.

Mathematical expressions used are;

Declination angle;

$$\delta = 23.45 * \sin(360*(284 + n)/365). \quad (1)$$

n is the number of days in a month

Lat angle = L – δ. Maiduguri's latitude is 11.831 deg. (2)

Bt=atand(((sind(L)*cosd(d)*cosd(Az)*cosd(h))-(cosd(L)*sind(d)*cosd(Az))+(cosd(d)*sind(Az)*sin(h))))/cosd(Zs). (3)

Where; Bt= optimum tilt angle, L=local latitude, Az=azimuth angle, d=day of the year, h=hour angle and Zs=zenith angle.

Table 1: Data obtained from the mathematical Model.

Months	**Tilt angle**	**Latitude angle (°)**	**Latitude**	**Declination angle(°)**	**Longitude**	**Optimum tilt angle(°)**
January	45	34.926	11.831	-23.096	13.500	10.1573
February	45	28.344	11.831	-16.340	13.500	15.9234
March	45	13.540	11.831	-5.985	13.500	25.6351
April	45	3.442	11.831	9.244	13.500	38.3730
May	45	-6.424	11.831	17.430	13.500	49.2803
June	45	-10.450	11.831	22.544	13.500	55.8155
July	45	-8.994	11.831	20.450	13.500	55.7623
August	45	-1.242	11.831	12.540	13.500	49.1330
September	45	14.340	11.831	2.434	13.500	37.7809
October	45	21.340	11.831	-9.440	13.500	25.4443
November	45	30.420	11.831	-18.340	13.500	14.9973
December	45	33.540	11.831	-22.500	13.500	9.9844

In developing the ANN model, the data is being divided into two sets of inputs and output. The inputs are; tilt angles, declination angle, latitude, latitude angle and the longitude and the optimum tilt angle as the output. Input–output is presented to the network, and the weights are adjusted to minimize the error between the network output and the actual value. Once training is completed, predictions from a new set of data may be done using the already trained network.

Artificial neural network (ANN) modeling

ANN is an algorithm that learns, decides and extracts results like the brain processes simultaneously reaching the result by using the obtained data in case of insufficient data. The neurons in the ANN are complex systems that are interconnected by different connection geometries, as in biological neurons. These systems solve problems which cannot be solved in a classical way by taking the working system of brain. A simple artificial neuron is a computation element with one or more inputs and an output. Figure below shows a neuron model with multiple inputs.

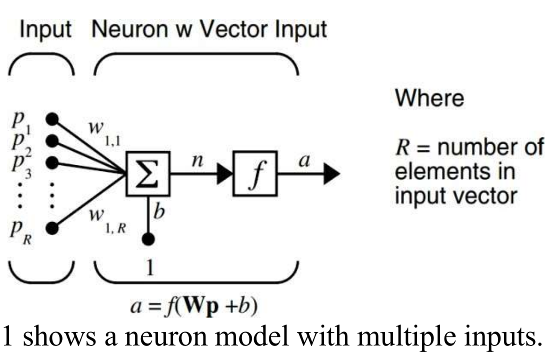

Fig. 1 shows a neuron model with multiple inputs.

The inputs (X) into a neuron are multiplied by their corresponding connection weights (W), summed together and a threshold (θ), acting at a bias, is added to the sum. This sum istransformed through a transfer function (f) to produce a single output (h), which may be passed, on to other neurons. The function of a neuron can be mathematically expressed as

$$h = f\,(\sum WX - \theta) \qquad (4)$$

Where the transfer function (f) of the neuron is the sigmoid activation function, being in the present work given as

$$f(x) = \frac{1}{1 + e^{-x}} \qquad (5)$$

In order to facilitate the comparisons between predicted values and mathematical model values, an erroranalysis, has been done using Mean Square Error (MSE) and the absolute fraction of variance (R^2). The MSE is given by:

$$MSE = \sum_j (t_j - o_j)^2$$

and the R^2 is given by

$$R^2 = 1 - \frac{\sum_j (t_j - o_j)^2}{\sum_j (o_j)^2} \qquad (6)$$

Where t_j is actual values, o_j is the predicted (output) values and n is the number of the data.

3.0 RESULTS AND DISCUSSION

Artificial neural network modelling was applied to predict the monthly optimum tilt angles of photovoltaic cell in Maiduguri where the network has five input parameters; the tilt angle, latitude angle, declination angle, latitude and longitude with one output which that is the optimum tilt angles obtained from the mathematical modeling analysis.

In the study, a 12-month optimum tilt angles were predicted and graphics obtained from ANN model. The criteria used to measure the network performance were absolute fraction of variance (R^2) and mean square error (MSE). Where (R^2= 0.89975)

At the end of the study, the predicted results obtained from the ANN model was compared with the mathematical model results as shown below.

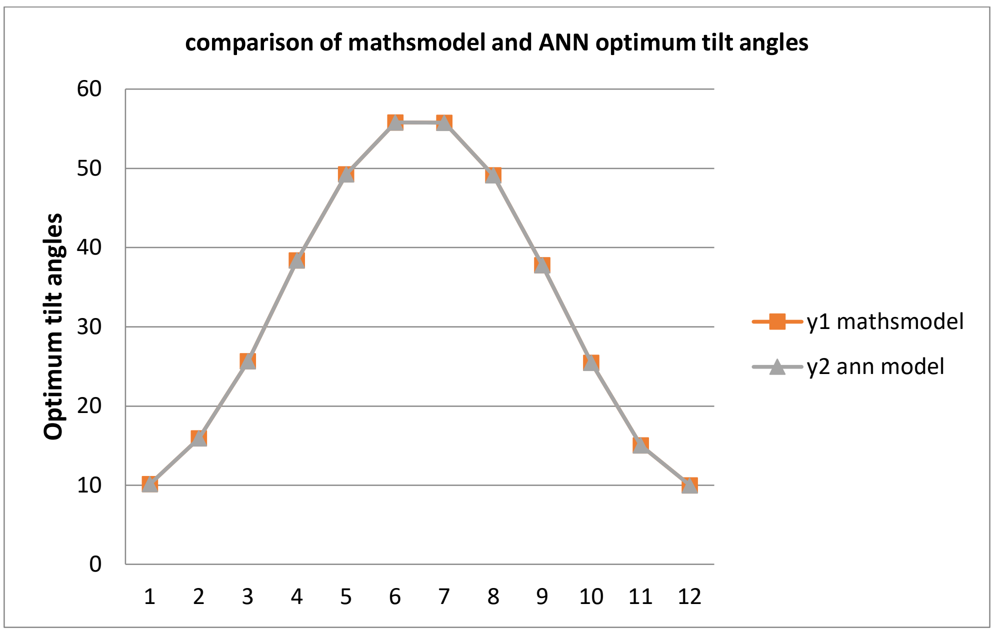

Fig 2. The graphic presentation of the monthly optimum tilt angles for the 12 months

Fig 2 shows the comparison of the mathematical model and ANN model result. The x-axis represents the 12 months while the y-axis represents the mathematical model result (y1) and the ANN model results (y2). Fig 2 clearly shows very closely how the two results relates, looking at the colours and marks/points on the graph it is seen that the ANN model results is overlapping the mathematical model result indicating how accurate the results predicted by the ANN model was.

Table 2. Comparison of monthly optimum tilt angles from the mathematical model to that of the predicted angles from ANN model.

Months	**Optimum tilt angle ○ (mathematical model)**	**Predicted Optimum tilt Angles ○ (ANN)**
January	10.1573	10.1522
February	15.9234	15.9174
March	25.6351	25.6291
April	38.3730	38.3682
May	49.2803	49.2753
June	55.8155	55.8105
July	55.7623	55.7563
August	49.1330	49.1324
September	37.7809	37.7758
October	25.4443	25.4391
November	14.9973	14.9962
December	9.9844	9.9783

Table 3. Predicted seasonal optimum angles (ANN) model.

Seasons	**Predicted optimum tilt angles (○)**
Harmattan	15.1386
Dry	32.2984
Wet	49.6146

4.0 CONCLUSION

At the end of this study, it has been seen that, the data used has been obtained from the mathematical model equations which were used to develop the ANN model for the prediction of monthly optimum tilt angles. Where the ANN model's predicted and the mathematical model's monthly optimum tilt angles were compared. It was observed that artificial neural network provided feedback quickly and in a short time. Also, it was proved that artificial neural network is successful in predicting the monthly optimum tilt angles.

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