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Forecasting Direct Normal Irradiation at Djibouti Using Artificial Neural Network

Ahmed Kayad Abdourazak, Abderafi Souad, Zejli Driss, Idriss Abdoulkader Ibrahim

***Abstract*—In this paper Artificial Neural Network (ANN) is used to predict the solar irradiation in Djibouti for the first Time that is useful to the integration of Concentrating Solar Power (CSP) and sites selections for new or future solar plants as part of solar energy development. An ANN algorithm was developed to establish a forward/reverse correspondence between the latitude, longitude, altitude and monthly solar irradiation. For this purpose the German Aerospace Centre (DLR) data of eight Djibouti sites were used as training and testing in a standard three layers network with the back propagation algorithm of Lavenber-Marquardt. Results have shown a very good agreement for the solar irradiation prediction in Djibouti and proves that the proposed approach can be well used as an efficient tool for prediction of solar irradiation by providing so helpful information concerning sites selection, design and planning of solar plants.

***Keywords*—Artificial neural network, solar irradiation, concentrated solar power, Lavenberg-Marquardt.

I. Introduction

DEVELOPMENT of renewable energy is the major concern all over the world without exception. And like many countries, Djibouti is also facing immense energy challenges with the intention to become the first African nation using 100% green energy. A Renewable Readiness Assessment (RRA) in Djibouti will be conducted over the coming months to evaluate its renewable energy as per the initiative and agreement between the International Renewable Energy Agency (IRENA) and the Minister of energy in charge of natural resources in May 2015 [1].

For solar energy based technologies such as solar thermal and specially CSP integration in Djibouti [2], the characterization of Direct Normal Irradiation (DNI) is very important by providing helpful information concerning sites selection. Global radiation is measured by Pyranometer and direct radiation is best measured by a Pyrheliometer. Artificial Neural Network techniques have become alternative methods to conventional techniques and are used in a number of solar energy applications such as to assess the solar irradiation [3]-[5].

In this study, solar irradiation prediction using ANN is the main objective and has a high importance for solar energy planning studies as direct measurements are not always widely available everywhere due to the cost.

Ahmed Kayad Abdourazak is with the Ecole Mohammadia d'Ingenieurs (EMI), Universite Mohammed V-Agdal de Rabat, Rabat, Morocco (e-mail: abdourazak_ahmed_kayad@univ.edu.dj).

Abderafi Souad is with the Ecole Mohammadia d'Ingenieurs (EMI), Universite Mohammed V-Agdal de Rabat, Rabat, Morocco.

Zejli Driss is with the SMADER, ENSA, Universite Ibn Tofail, Kenitra, Morocco.

Idriss Abdoulkader Ibrahim is with the Faculte des Ingenieurs (FI), Universite de Djibouti (UD), Djibouti, Djibouti.

TABLE I
Geographical Parameters for the Cities [9]

Site	Longitude (º)	Lattitude (º)	Altitude (m)
Djibouti	43,144855	11,585315	8
Arta	42,84831	11,525274	709
Holhol	42,928476	11,309223	438
Goubeto	43,002462	11,422485	330
Ali-Sabieh	42,710381	11,148087	718
Dikhil	42,371864	11,109685	503
Tadjoura	42,877836	11,787039	6
Obock	43,289995	11,96225	9

In the last years several studies have used ANN to estimate the solar radiation. Amit Kumar Yadav [6] has done a review of Solar radiation prediction using Artificial Neural Network techniques in order to identify suitable methods available in the literature and to identify research gaps. The ANN model concerning a multilayer feedforward networks is so considered as the most suitable method for exploiting solar energy [7] and essentially a multi-input non-linear model of neurons with the weighted connections [8]. And specialy a three-layered back propagation standard ANN model has been used, input, hidden and output layer.

In this sense eight locations of Djibouti have been selected and its geographical and monthly irradiation database were used to train, validate and test the neural network in order to estimate the output monthly direct radiation.

II. Material and Methods

A. Geographical and Meteorological Database

Table I and Fig. 1 shows the eight locations in different regions of Djibouti with theirs geographical parameters for each one (Latitude, Longitude and Altitude) [9].

Meteorological data concerning the average solar irradiation of the 8 sites, in form of monthly ($Wh/m^2/day$), have been taken from the Solar and Wind Energy Resource (SWERA) and German Aerospace Centre (DLR) as we can see in Tables II and III [10].

The SWERA Renewable energy Resource Explorer (RREX) is an online Geographic Information System (GYS) tool for viewing renewable energy resource data through which the current solar energy data were collected. The data from SWERA was combined with the German Aerospace Centre (DLR) solar energy data obtained from atmospheric databases based on the longitudinal and latitudinal location of the areas of Djibouti. As shown in the data of Table III, Djibouti receives

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Fig. 1 Mapping of Djibouti

TABLE II
MONTHLY SOLAR IRRADIATION DATA ($Wh/m^2/day$) [10]

Site	Jan	Fev	Mar	Apr	May	Jun
Djibouti	6560	5920	5080	6250	6260	3510
Arta	5590	5360	4510	5640	5970	3800
Holhol	5110	5150	4280	5510	5740	3690
Goubeto	5320	5180	4470	5800	5990	3510
Ali-Sabieh	5860	5430	4420	5150	5120	3520
Dikhil	6280	5820	4470	5050	5070	3550
Tadjoura	6300	6220	5250	6260	6100	3610
Obock	5950	5890	4990	5900	6040	3590

varying solar irradiation ranging from 3.2 KWh/m^2 to 7.33 KWh/m^2 per day.

B. Artificial Neural Network Approach

In this paper, Artificial Neural Networks are used for modeling the solar resource of Djibouti with meteorological and geographical database which are inferred using an algorithm to establish a forward/reverse correspondence between the longitude, latitude, altitude and the mean monthly solar irradiation.

The network consists of a Multilayer preceptor (MLP) standard three layers [11]: Input, hidden and output

TABLE III
MONTHLY SOLAR IRRADIATION DATA ($Wh/m^2/day$)(CONTINUED) [10]

Site	Jul	Aug	Sep	Oct	Nov	Dec
Djibouti	3680	4260	4710	6700	7130	6010
Arta	3740	4300	4010	6250	6400	4820
Holhol	3520	4040	3750	6030	6230	4250
Goubeto	3490	4010	4050	6270	6380	4590
Ali-Sabieh	3500	3980	***3200***	5660	6430	4970
Dikhil	3610	3940	3210	5400	6340	5400
Tadjoura	3550	3940	4370	6650	***7330***	6210
Obock	3650	4180	4450	6400	7020	5800

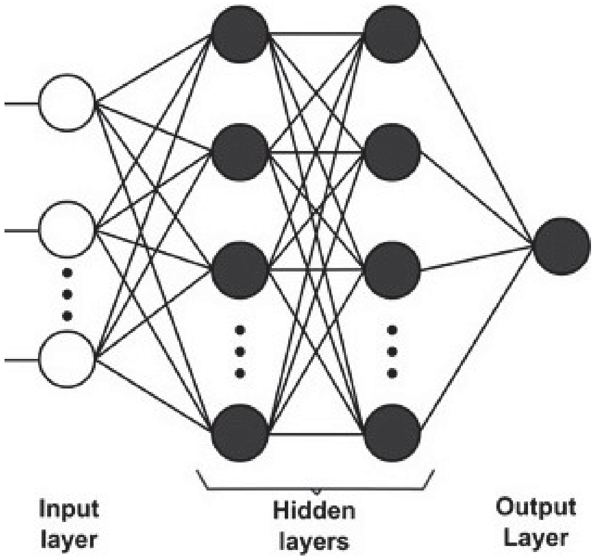

Fig. 2 ANN Architecture [15]

layer. And the back propagation learning algorithm of Lavenberg-Marquardt (LM) has been used in feedforward under Matlab through a non-linear Logistic Sigmoid $f(x)$ as transfer functions [12], which is the most commonly used in the renewable energy domain. And each output of the network with a normalised value is obtained by [13]:

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

where x is the weighted sum of the imputs [13], [14].

$$x_i = \sum w_{i,j} y_j + b_i \tag{2}$$

A schematic diagram of the basic architecture is shown in Fig. 2 [15]. Five basics steps were followed in order to design the ANN model: Collect data, preprocess data, build the network, train and test performance of the model.

A normalization process was applied to the network and data were set respectively to **70%** for Training, **15%** for Validation and **15%** for Testing by randomizing. The output from the network is compared to the target and this is evaluated with mean squared error (MSE).

The plots regression value between output and target will be also determined in depicted from the validation performance MSE with database of 6 sites for training, 1 site for validation and finally 1 site for testing.

III. RESULTS AND DISCUSSION

The database was collected over Djibouti and the the neural network model with 10 hidden neurons, especially backpropagation method, was used in order to predict the monthly mean radiation.

Our developed network using Matlab (R2015a) show a very good accuracy in prediction by setting the normalised data of

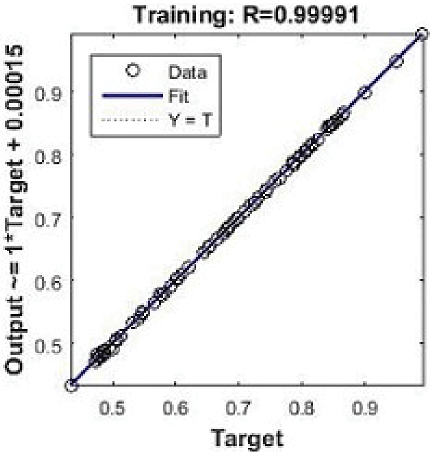

Fig. 3 Plot Regression-Training

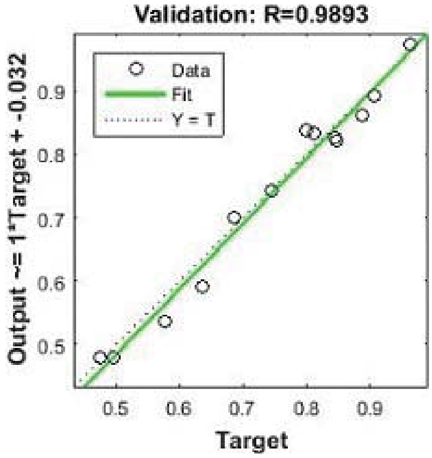

Fig. 4 Plot Regression-Validation

longitude, latitude, altitude and monthly solar irradiation for the learning state.

The regression plots shown in Figs. 3-6 depict that the fit is reasonably good for all data sets, with a good agreement between the target concerning the measurements data from Solar and Wind Energy Resource Assessment (SWERA) and the predicted direct normal irradiation (DNI) output of the network. When the ANN model is developed on training data set, the reliability of the model is confirmed by application to test data samples.

According to the derived results, the obtained value of regression based on the training data set R_{train} was 99.991% while the regression value of testing R_{test} was about 97.929% for this model.

Fig. 7 illustrate that solar radiation data is a good fit with validation performance of 0.00062153 at epoch 5 as confirmed by the value regression coefficient of 0.99313 for all in Fig. 6 which shows the relationship between the output of the network and the target. And we notice the agreement of actual and predicted results of proposed ANN model as the accumulation of the predicted test and train data are near the experimental line and proves the preciseness of this model.

IV. Conclusions

This paper focuses on the prediction of solar irradiation using artificial neural network and the results confirms that the ANN model can be well used for estimating the solar potential over Djibouti. The geographical and meteorological database of Djibouti, Arta, Holhol, Goubeto, Ali-Sabieh, Dikhil, Tadjoura and Obock have been inferred for this study as training and testing data in the neural network. ANN model can be useful and seems promising for evaluating the solar resource at the locations in Djibouti which lack ground measurement or no monitoring stations. The method provides helpful information for sites selection in case of Concentrating Solar Power (CSP) integration and planning of future new solar plants. Future work can be also done in addition by developing a spatial mapping of the solar energy potential over

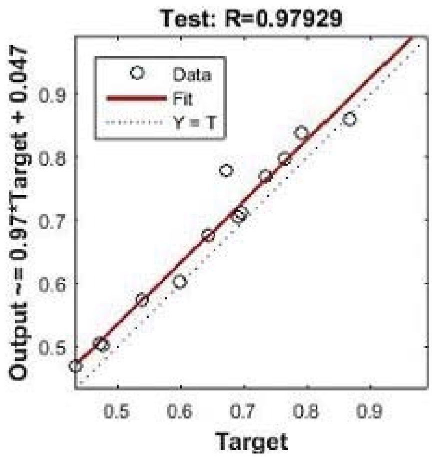

Fig. 5 Plot Regression-Test

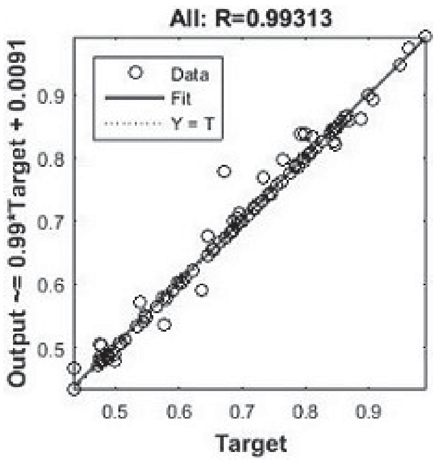

Fig. 6 Plot Regression

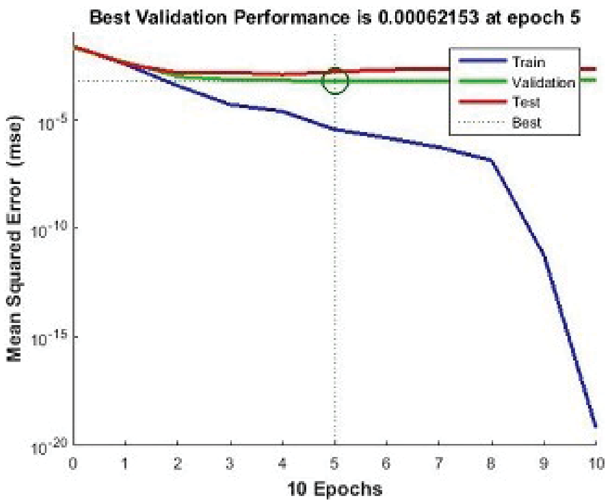

Fig. 7 Validation Performance

Djibouti and also in order to improve the performance of the model.

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Ahmed Kayad Abdourazak was born in 1985 in Djibouti. He graduated in Mechanical Engineering in 2009 from the Higher National School of Electricity and Mechanics of Morocco. He is currently a PhD student at Mohammadia School of Engineers in Rabat, Morocco . And his research interests are mainly in the fields of solar energy. From 2010, he was assigned for working as assistant at Djibouti University Institute of Technology and Industrial.

Souad Abderafi is Professor at Ecole Mohammadia d’Ingenieurs (Moroccan school of engineering), where she received her doctorate (PhD) in Chemical engineering, in March 2003 and promoted as Professor in 2007. Her main research interests are industrial process modeling. Many of her research articles have been accepted for publication in international journals and conference. ResearchGate reports many citations to her work in various international journals (Fluid Phase Equilibria, Industrial & Engineering Chemistry Research; Food Chemistry, ...) and in the edition of the book (Poling B.E., Prausnitz J.M., O’Connell J.P., The Properties of Gases and Liquids; McGraw-Hill; New York; 2001).

Driss Zejli started his professional activities as researcher in the National Center of Scientific and Technical Research (CNRST-Morocco) in 1986. He was co-founder of the Unit of Renewable Energy Economy and Technologies (TEER) at the CNRST in 1995. He headed this unit from 2005 to 2014. In September 2014, he moved to the National School of Applied Sciences (ENSA-K). He has been Chair of the NGO named “Moroccan Society of Renewable Energy Development” (SMADER) since March 2013. He is author and co-author of many papers, conferences and books on both renewable energies and renewable energy powered desalination. He organized and co-organized many scientific meetings.

Idriss Abdoulkader Ibrahim received his Ph.D degree from the Department of Nano-Optics at the University of Franche-Comte (France) in 2010. Dr. Abdoulkader is working as an Assistant Professor in Physics at the Faculty of Engineers at the University of Djibouti since 2010, where he is currently the Dean of the Faculty of Engineers. He has supervised four Ph.D students and co-authored more than 41 papers in international journals and conferences. His research interests in the fields of nano-photonic devices, finite element method and material absorption for solar energy domain.