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Estimation of solar radiation with Artificial Neural Networks:

analysis and synthesis of published works

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Abstract — **before the discovery of the concept of analysis of neural networks, it was difficult, if not impossible, to estimate the solar radiation in the case where there was a lack of meteorological data (the most common case). The technology of artificial neural networks has allowed us to remedy this problem by its ability to learn from examples and fault tolerant in the sense that they are able to handle noisy and incomplete data. This paper reviews a statistical and analytical study of previous published works concerning the estimation of solar radiation by the artificial neural networks.**

We would like to note that this survey covers all journals falling under the subject "energy" at the famous scientific database "sciencedirect" (about 325 journal).

Keywords-component; estimation; solar radiation; artificial neural networks; synthesis

I. INTRODUCTION

Until now, renewable sources were completely discriminated against for economic reasons. However, the recent trend favors renewable energy sources in many cases compared to conventional sources. The benefits of renewable energy is that they are durable (inexhaustible), omnipresent (found everywhere in the world unlike fossil fuels and minerals), and essentially clean and environmentally friendly.

Among the renewable energy sources, solar energy is at the top of the list due to its abundance and distribution more uniform in nature. Solar radiation is an integral part of different renewable energy resources, in general, and, in particular, it is the main and continuous input variable from the practically inexhaustible sun. Consequently, knowledge of the intensity of solar radiation is essential to monitor the performance of renewable energy systems.

A large number of experimental and modeling work has been carried out for the calculation of solar irradiance. Recall, for example, linear models that consider a linear relationship between solar radiation, and sunshine duration (Angestrom-Prescott [1,2], Rietveld [3], Ahmad and Ulfat [4], Benson et al. [5], Raja and Twidell [6,7], Chegaar and Chibani [8], I. T. Toğural and H. Toğural [9], Katiyar and Pandey [10]), also non-linear models, based on a quadratic form of the relationship between the global solar radiation, and the maximum possible duration of sunshine (Ögelman [11], Bahel and al. [12], Lewis [13], Said and al.[14], Tarhan and Sari [15], Katiyar and al. [16], Al-Salihi and al. [17]) and they exist other models based on temperature data (Bristow and Campbell [18], Allen [19]) and models using fuzzy logic (Sen [18]).

II. ARTIFICIAL NEURAL NETWORKS

The artificial neural networks, also known as neural networks, are now a data processing technique well understood and controlled. Formally, a neural network is a mathematical function that are associated with input values, the output result and adjustable parameters called weights "Fig.1". From a data assembly representative of a system, it is possible to adjust its weights to learn the system and its environment may be subject to variations. This learning process is parsimonious universal approximators. For a nonlinear model with some precision, a neural network often requires fewer adjustable parameters than conventional methods of regression.

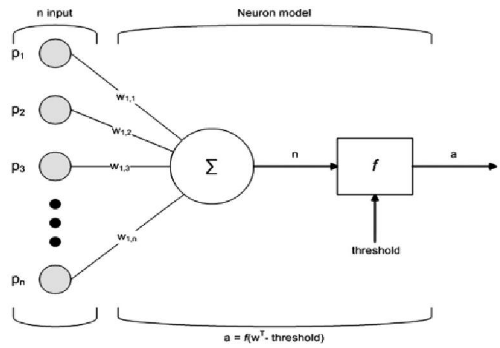


Fig.1 Neuron model

During the last two decades, ANN have proven to be excellent tools for research, as they are able to handle non-linear interrelations (non-linear function approximation), separate data (data classification), locate hidden relations in data groups (clustering) or model natural systems (simulation). Naturally, ANN found a fertile ground in solar radiation research [21][22].

There are two important problems concerning the ANN implementation: first, specifying the network size (number of layers in the network and number of nodes in each layer), second, finding the optimal values for the connection weights.

An insufficient number of hidden nodes cause difficulties in learning data whereas an excessive number of hidden nodes might lead to unnecessary training time with marginal improvement in training outcome as well makes the estimation for a suitable set of interconnection weights more difficult [23].

To determine the optimal number of hidden nodes, the method commonly used is trial and error based on a total error criterion. This method starts with a small number of nodes, gradually increasing the network size until the desired accuracy is achieved.

One of the properties of ANNs is their ability to learn from their environment and to improve their performance through a learning process also called training process. Learning results in a change in the weights value wi,j connecting the neurons from one layer to another. The goal is to achieve equality between the actual output and simulated output. It is therefore necessary first to choose the learning algorithm and define the part of the data used for learning in relation to the total amount of data available.

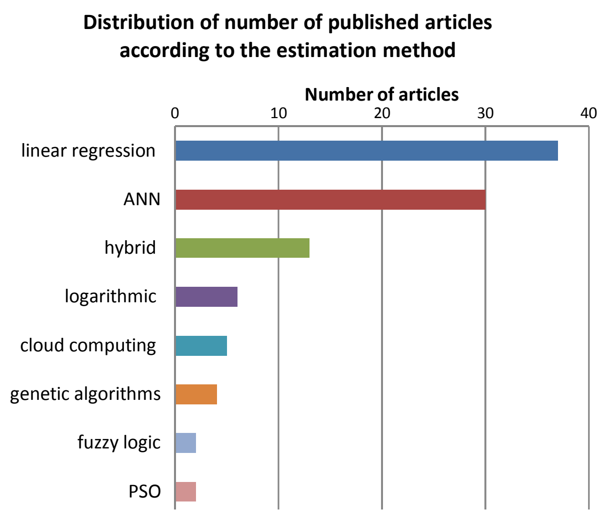
The various steps in the implementation of an optimized ANN consist in selecting:

- an ANN structure
- a transfer function type
- an ANN size (number of layers and of neurons per layer)
- a learning algorithm;
- a training/test set;
- input data

III. ANN APPLIED TO SOLAR RADIATION PREDICTION: LITERATURE SEARCH AND EVALUATION

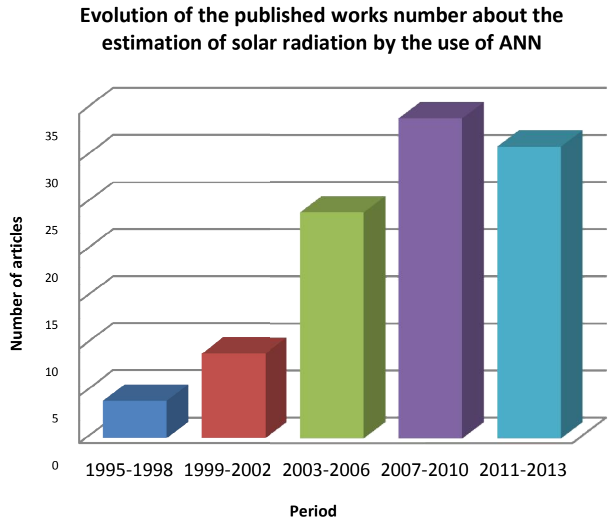
The concept of neural network analysis was discovered nearly 50 years ago, where it began in the occupation of its place gradually amid other techniques.

To see the evolution of this type of modeling compared to other types, we have made this chart, which shows us the number of published works according to the method of modeling followed.



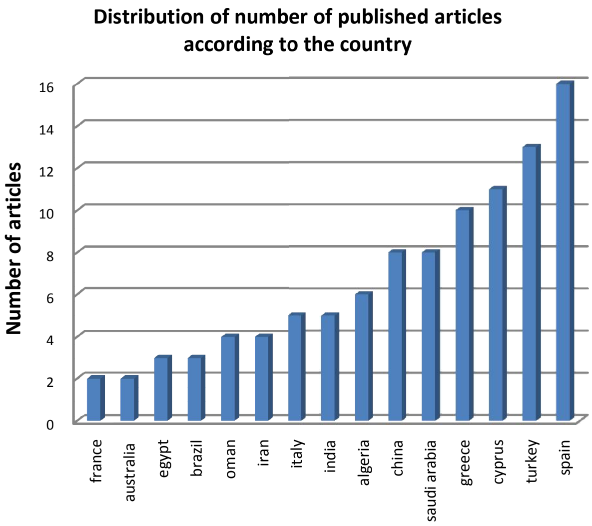
We can see simply that the use of ANN technology comes in the second place after "linear regression" Although it is a new technology in the prediction of solar radiation.

However, in the last twenty years; this technique has seen a remarkable development, who summarizing this following chart:



We note a marked increase in the number of published works, up to 100% between the period and the period that followed. And this proves the efficacy of ANNs technology.

The use of ANN to predict solar radiation, taking a global dimension, due to their high precision. The following chart reviews the most important countries that have adopted this technique to estimate solar radiation.



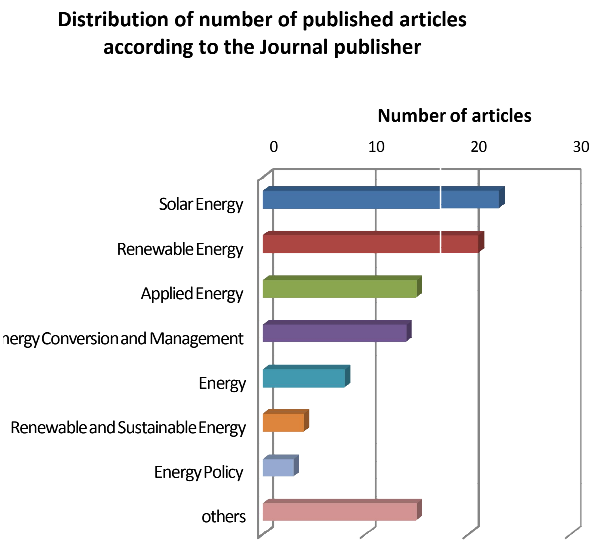
We note through the scheme somewhat interesting developing and poor countries about solar energy research, and this is what would take them to the technical progress and solve some of its economic and development problems.

It also does not deny that interest reverting also to its geographical location in so-called "Sunbelt".

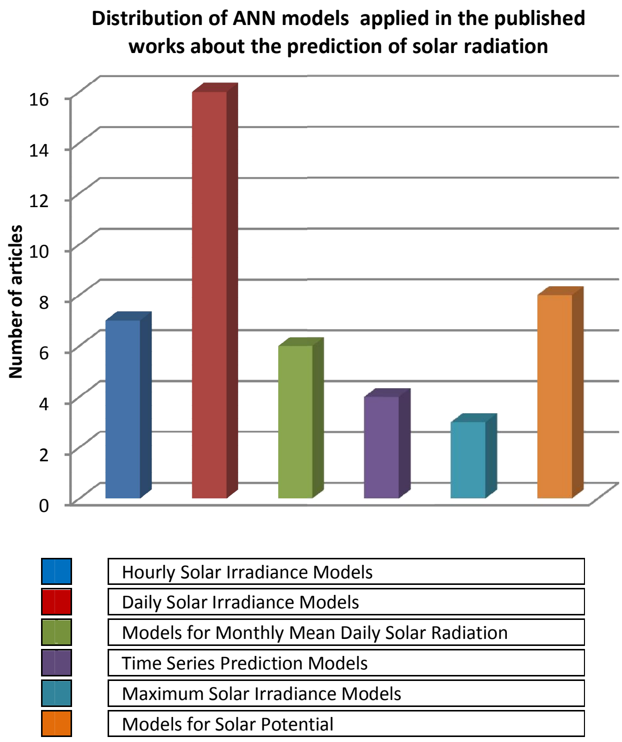
Recall the most important researchers by country:

- Spain: A. Linares-Rodríguez et *al.* [24], G. Landeras et *al.* [25], L. Hontoria [26], J.L. Bosch [27], G. López [28,29]
- Turkey: O. Şenkal [30,31], A. Sözen et *al.* [32,37], F. O. Hocaoğlu [38]
- Cyprus: S. A. Kalogirou [39,43]
- Greece: F.S. Tymvios et al[44], A. Sfetsos et *al* [45]
- Saudi Arabia: M. Mohandes [46,49]
- China: Y. Jiang [50,51]
- Algeria: A. Mellit et *al.* [52,57]
- India: S. Alamet *al*. [58,59]

So, this published works were distributed also according to journal publisher in this scheme



Moreover, In order to facilitate understanding and analysis of published works, we try to group them through the main objective of the model applied.



- *Hourly Solar Irradiance Models:*

Hontoria et al. [60,61] made use of the concept of atmospheric transmittance in an effort to generate hourly solar radiation series by using ANN, they proposed a 'RNA' type Multi-Layer Perceptron.

Sfetsos et al. [62] focus on forecasting of hourly solar radiation by using two artificial intelligence based techniques: ANNs and adaptive neuro-fuzzy inference systems hese include linear, feed-forward, recurrent Elman and Radial Basis neural networks, together with the adaptive neurofuzzy inference scheme.

- *Daily Solar Irradiance Models*

Kemmoku et al. [63] used Multistage ANN to forecast the daily insolation of the next day. The input data to the network are the average atmospheric pressure, predicted by another ANN, and various weather data of the previous day. The results obtained shown a prediction accuracy of 20%.

- *Models for Monthly Mean Daily Solar Radiation*

Mohandes et al. [64] adopted a back-propagation algorithm for training several multi-layer feed-forward neural networks. The input nodes of the neural networks are: latitude, longitude, altitude and sunshine duration. The results for the testing stations obtained are within 16.4% and indicate the viability of this approach for spatial modeling of solar radiation.

- *Maximum Solar Irradiance Models*

Kalogirou et al. [65] applied a multi layer recurrent architecture employing the standard back-propagation learning algorithm. The input data that are used are those which influence mostly the availability and intensity of solar radiation, namely, the month, day of month, Julian day, season, mean ambient temperature and mean relative humidity (RH). The sensitivity of predictions to 20% variation in temperature and RH give correlation coefficients of 0.9858 to 0.9875 respectively, which are considered satisfactory. This is considered as an adequate accuracy for such predictions.

- *Time Series Prediction Models*

Paoli et al [66] used a 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. The modeling of the series begins with the selection of a suitable mathematical model (or class of models) for the data. Then, it is possible to predict future values of measurements. They compared their model compared to other prediction methods (AR, ARMA, k-NN, Markov Chains, etc.).

- *Models for Solar Potential*

Al-Alawi and Al-Hinai [67] used ANNs to predict solar radiation in areas not covered by direct measurement instrumentation. The input data to the network are the location, month, mean pressure, mean temperature, mean vapour pressure, mean relative humidity, mean wind speed and mean duration of sunshine. The ANN model predicts solar radiation with an accuracy of 93% and mean absolute percentage error of 7.3.

IV. CONCLUSION

The renewable energies will be in the near future sources of our driving energies; Scientists are in permanent and continuous search for alternatives to fossil energy; if they did not find which wished for in the ground or deep sea, they have their wonderful ways to drawn it from the sun, air, or water.

However, solar energy remains the typical alternative to conventional energies. Because it is the major natural energy that are not implemented. And engineers and scientists continue in a large number of countries their research and experiences to exploit the solar energy. Among the most important research, the use of artificial neural networks to predict solar radiation.

In this paper, we try to do a chronological summary of recent studies on the use of Artificial Neural Networks (ANN) applied to the estimation of solar radiation.

What is very interesting to note is that in less than 20 years of applications of ANN to solar radiation studies, a great variety of neural training approaches have been used (different learning algorithms, architectures etc) and a multitude of input variables have been explored (meteorological, geographical etc). What is common in almost all of these studies is the validation of the respective proposed methodology with independent data.

Moreover, artificial neural networks technology gives us broad areas of research so that we can estimate the solar radiation at different levels: monthly mean, daily, hourly, even in places so that we do not have the meteorological data.

In the end, we say that this article allowed us to take a superficial look around the ANNs technique application in solar radiation prediction, hoping to be more profound in the future.

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