Behavior Prediction Algorithm of Solar Radiation and Temperature in Cajicá, Colombia

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Received: 02.11.2016 Accepted:29.12.2016

Abstract- The forecast of meteorological variables such as solar radiation, temperature, humidity, wind speed or precipitation is a procedure that have been taking relevance last years, due to its importance for sizing energetic systems especially those based on renewables sources. This paper has as objective to design and develop a prediction algorithm using artificial intelligence to determine the future behavior of solar radiation and temperature in Cajicá, Colombia. In order to do that, a study of the Cajicá meteorological data from 2010 to 2015 was made and the data forecasted by the algorithm was validated with the data obtained through the application web POWER (Prediction Of Worldwide Energy Resource) developed by NASA. Obtaining as result a prediction tool able to forecast the increasing, decreasing or constant behavior of solar radiation with an average error of 3.4% and temperature with an average error of 9.9 %, which can be used to support the developing of energetic projects based on renewables energies in Cajicá.

Keywords forecast algorithm, Solar energy, Artificial intelligence.

1. Introduction

The repercussions around the world caused by the climate change have woken the interest in develop environmentally friendly technologies the past 20 years [1]. But another trigger to develop these kind of energetic projects is that the renewable sources are at moment the best solution against the lack of fossil resources for producing energy [2].

This trend has led to recognize the renewable energies production as un of the biggest contributor in the current worldwide economy. Proof of this is that in last year the consumption of solar energy increased 28% while the wind power increased 15% [3]. Nonetheless, the efficiency of these technologies need to improve, due to current systems such as solar panels have an efficiency between 30% and 45%, wind power turbines have from 50% to 60% and solar collectors have a maximum of 85% [4],[5].

In order to improve this efficiency, the new renewable energetic projects are including new designs, robust control, hybrid technologies and even the prediction of climate variables. Due to this, developments in renewable energies from first world countries has led to consider the solar radiation as one of the most important factors in the prediction of meteorological variables [6]. Its importance lies in its utility in the construction of environmental simulation systems such as greenhouses or farming, as well as a factor for sizing energetic systems such as photovoltaic plants [7], [8].

One of the most accurate way to forecast climate variables is through the application of artificial intelligence algorithms, cause this type of methods are able to identify behaviors or features although the fluctuation of the climate data that can acquired in one area. Example of this is the work [9] which did a review about different Artificial Neural networks techniques to identify a configuration and combination of methods that can reach the most accurate technic to predict solar radiation. Another example is the work developed in [10] which analyzed different methods to find the parameters necessary to take into account during the forecasting solar radiation in a specific area.

As example of current applications that uses artificial intelligence techniques to forecast is possible find the software METEONORM by METEOTEST, which uses information form meteorological stations around the world to forecast temperature, relative humidity, radiation, precipitation and hours of solar brightness through mathematical models for any place in its database [11],[12]. Another example is the web application POWER by NASA, which is able to forecast more than 10 climate factors for any latitude and longitude [13],[14].

On the other hand, in Colombia the tool used to forecast meteorological variables is the “Atlas de radiacion solar en Colombia” made by the IDEAM and UPME in 2005. This atlas uses the mathematical model of angstrom to made the prediction of solar radiation with the data collected from meteorological stations throughout Colombia [15],[16].. Due to that the atlas is out of date the forecasted data might be inaccurately but the worldwide applications give an average information that although is more accurate than the atlas still have a considerable error in comparison with the real climate behavior in Colombia.

Taking into account the previous information, this paper has as objective implement a prediction algorithm that allow identify the future behavior of solar radiation and temperature in the specific area of Cajicá, Colombia. For developing this work was used the collected data by a meteorological station since 2011 until 2015, this information was used to train an Artificial Neural Network (ANN) to forecast future climate conditions for the selected region. Obtained as a result, a tool oriented to be a information source that allow known future patterns of increasing, decreasing or constant of solar radiation and temperature during 2016, which are fundamental factors for sizing energetic systems based on solar energy.

2. Methodology

In order to make this paper, was required identify if the solar radiation and temperature data given by the POWER application have a considerable error, due to that the purpose of this algorithm is reduces that error. The Power application data error was calculated through a comparison between forecasted data for Cajicá with the data obtained from a meteorological station in Cajicá. After, the solar radiation and temperature data collected from 2010 to 2015 was used to train an Artificial Neural Network for identifying the behavior patterns and in this way forecast future patterns, this methodology is shown in figure 1.

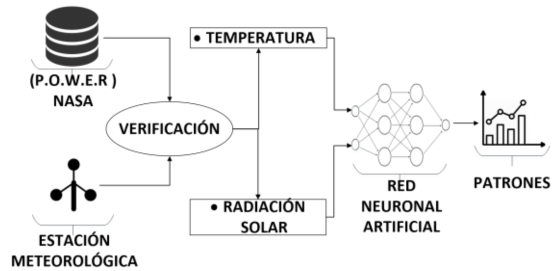

Fig. 1. Used Methodology.

2.1 POWER data error

In order to identify the error of the forecasted data made by the web application POWER for the selected area in Colombia, a meteorological station was taken into account to compare the forecasted data with measured data. The meteorological station is located in 4º56`42.2” N of latitude and 74º00`50.9” W of longitude, these geographic coordinates correspond to the location of the Nueva Granada Military University (UMNG) campus in Cajicá.

The previous geographic coordinates were used as inputs for the POWER application to predict solar radiation and temperature from November 2015 to February 2016. This data was compared with the data measured through the meteorological station, to determine the data error of POWER application.

2.2 Artificial Neural Network

For training the Artificial Neural Network (ANN), the data collected by the meteorological station since 2011 until 2015 was used. This data was normalized and was used to train two different ANN, one to predict solar radiation and other to predict temperature, in this way is possible obtain better performance for forecasting each variable.

Both ANN have 4 inputs (day, month, year and average temperature or average solar radiation) and are composed by 200 neurons in the hidden layer and 1 neuron in the output layer, as is shown in figure 2.

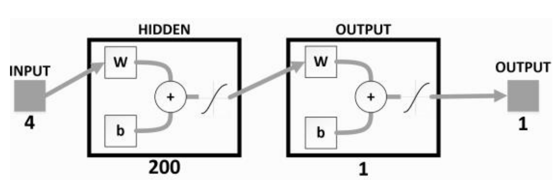

Fig. 2. Artificial Neural Network architecture.

Both the hidden layer as the output layer have as activation function sigmoidal tangent, represented by equation 1 [17].. This function allows work with data between -1 and 1, due to that the data is normalized this function allows obtain a better performance in the recognition of future data.

$$P(t) = \frac{1}{1 + e^{-t}} \quad (1)$$

Once the ANN achieves a data adjustment greater to 90%, then the ANN is appropriate to forecast solar radiation and temperature in Cajicá. This forecasting was designed to predict one future year, this means that the algorithm will able to predict behavioral patterns of temperature and solar radiation in Cajicá for the year 2016.

2.3 Hysteresis range for the behavioral patterns

Once forecasted the solar radiation and temperature is possible identify the parameters to define the patterns of each meteorological variable. First of all, is necessary define the reference point for each factor, these references are the daily average of solar radiation and temperature in Cajicá.

Due to that selected location have not seasons during the year, is possible assume the average daily value per day of temperature and solar radiation is almost the same every year. Taking into account this information, the collected data was used to define the average daily value of both factors per year.

Finally, averaging the values of the 5 years are obtain the reference point for the temperature and solar radiation in Cajicá, Colombia. This reference indicates the value of temperature and solar radiation that usually is present the most part of the year in Cajicá

Taking into account the previous information, is correct assume that any future value of temperature or solar radiation that are higher or lower to the reference, indicates that is a increasing or decreasing future behavior. But due to the variation of meteorological values the reference point must be a reference range to reduce these fluctuations.

The temperature in Cajicá presents a minimum value 10ºC and a maximum value 20ºC and knowing that the changes in temperature are slow, is possible assume that a change of ± 0.5ºC is enough to identify changes in the behavior of temperature specifically for Cajicá. The rules to identify each behavior are describing in table 1 [18].

Table 1. Rules to identify the behaviors of the temperature in Cajicá.

Behavior	**Range**
Constant	**<0.5ºC** **>-0.5ºC**
Increasing	**>= 0.5ºC**
Decreasing	**<= -0.5ºC**

On the other hand, the solar radiation in Cajicá presents a minimum value 4000 kWh/m^2 and a maximum value 8000 kWh/m^2 and identifying that the changes of irradiation occur in considerable amounts, is possible assume that a change of ± 500 kWh/m^2 is enough to identify changes in the behavior of solar radiation specifically for Cajicá. The rules to describe each behavior are shown in table 2 [19].

Table 2. Rules to identify the behaviors of the solar radiation in Cajicá.

Behavior	**Range**
Constant	**< 500 kWh/m^2** **> -500 kWh/m^2**
Increasing	**>= 500 kWh/m^2**
Decreasing	**<= -500 kWh/m^2**

3. Results

In order to identify the error of the forecasted data given by the POWER application, the data collected between 20th November 2015 and 10th February 2016 was used to compare with the data given by the web application for the same period. Due to the variation of the meteorological data, the best way to observe the data error is through of knowing the offset of POWER data set regarding to the measured data set, this offset is shown in figure 3 and figure 4.

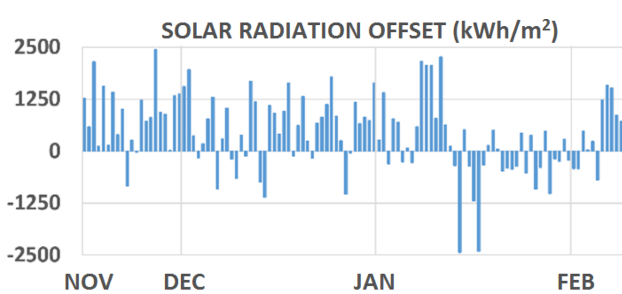

Fig. 3. Offset of Solar radiation web application data with regard to the measured data

The 0 axis in the figure 3 indicates the measured value of solar radiation per day, in the 4 selected months to compare the POWER data with the metrological station data. This means that the higher or lower values of solar radiation are the offset per day that have the POWER data with regard to the measured data in Cajicá.

The solar radiation data forecasted by the web application have an average positive offset of 894.78 kWh/m^2 and an average negative offset of -572.46 kWh/m^2, as is shown in figure 3. The average offsets indicate that the forecasted data of solar radiation by the POWER application have an average error of 13.69% specifically for Cajicá.

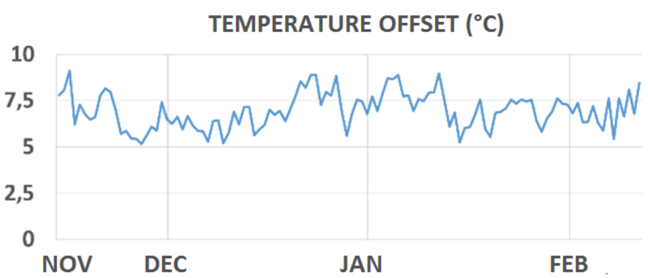

Fig. 4. Offset of temperature web application data with regard to the measured data.

The 0 axis in the figure 4 indicates the measured value of temperature per day, in the 4 selected months to compare the POWER data with the metrological station data. This means that the higher values of temperature are the offset per day that have the POWER data regarding to the measured data in Cajica.

The temperature data forecasted by the web application have an average positive offset of 6.45ºC, as is shown in figure 4. This offset represents that the forecasted data of temperature by the POWER application have an average error of 48.3% specifically for Cajica.

Knowing the error of the solar radiation and temperature data given by the POWER application, two artificial neural networks were trained to predict both variables in Cajica for the year 2016. The ANN trained with the solar radiation data reached a correlation coefficient of 0.99704, the forecasted values were compare with the measured data for the same period that was used to compare with the POWER data. This comparison determined that this ANN have an average error of 4,76%

On the other hand, the ANN trained with the temperature data reached a correlation coefficient of 0.99345. Comparing the forecasted values with the measured data from the selected period, evidenced that the forecasted data through the ANN have an average error of 10.14%

Once verified that the error of the ANNs is lower than the POWER application, was proceeded to identify the average daily value of solar radiation and temperature in Cajicá, using the collected data of the last 5 years by the meteorological station. Through this process was obtain that the average daily value of solar radiation is 4338.64 kWh/m^2 from 7 am to 5 pm and the average daily value of temperature is 14.28ºC for the same hours.

The 0 axis in figure 5 corresponds to the average daily value of solar radiation in Cajicá and according with the rules of behavior, any day that has more of + 500 kWh/m2 of that value has a increasing behavior, days with less than –500 kWh/m2 have a decreasing behavior and the other days have constant behavior.

According to figure 5, the solar radiation in Cajicá for the year 2016 will have 50 days with increasing behavior distributed between January, February, July and September. Will have 94 days with a decreasing behavior distributed in May, August and from October to December. Finally, will have 221 days with constant behavior distributed all year round.

The 0 axis in figure 6 corresponds to the average daily value of temperature in Cajicá and according with the rules of behavior, any day that has more of + 0.5ºC of that value has a increasing behavior, days with less than –0.5ºC have a decreasing behavior and the other days have constant behavior.

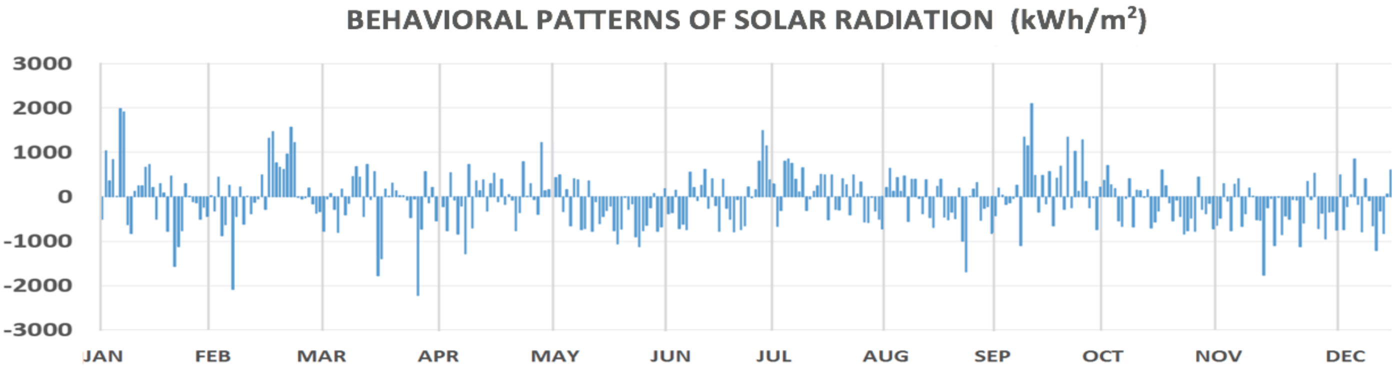

Fig. 5. Behavioral patterns of solar radiation for the year 2016.

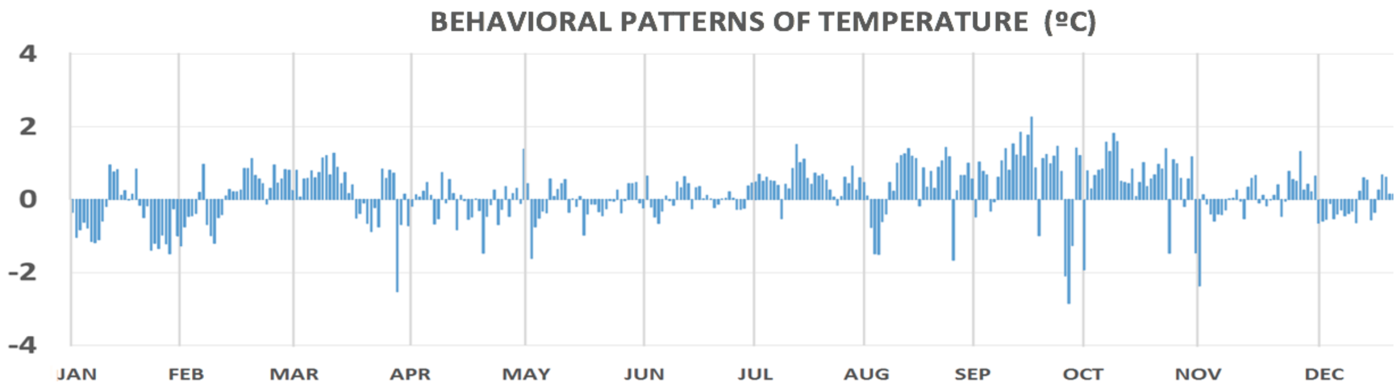

Fig. 6. Behavioral patterns of temperature for the year 2016.

According to figure 6, the temperature in Cajicá for the year 2016 will have 127 days with increasing behavior distributed between February, March and between July and November. Will have 62 days with a decreasing behavior distributed in January and between April and July. Finally, will have 176 days with constant behavior distributed all year round.

In order to validate the forecasted behavioral patterns by the ANNs, were used data collected from January to February by the meteorological station to compare with the ANN data. Obtaining as a result, that the ANN forecasted solar radiation values with an average error of 9.9%.

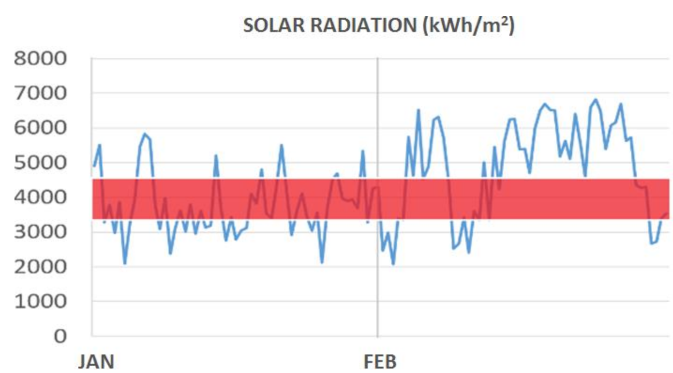

Fig. 7. Behavior of solar radiation in Cajicá for the year 2016.

The ANN predicted an increasing behavior of solar radiation for February, this behavior was registered by the measured data in Cajicá by the end of the month, as is shown in figure 7. In which the red line indicates the range of solar radiation values corresponding to the constant behavior.

On the other hand, the same comparison was made for the temperature data forecasted by the ANN, obtaining as a result that that the ANN forecasted temperature values with an average error of 3.4%.

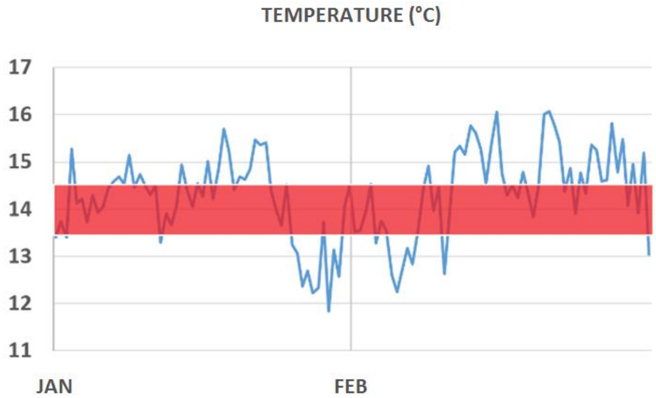

Fig. 8. Behavior of temperature in Cajicá for the year 2016.

The ANN predicted a decreasing behavior of the temperature between January and February, this behavior also was registered in the measured data in Cajicá the last days of January and the firsts days of February, as shown figure 8. In which the red line corresponds to the range of temperature values associated with the constant behavior.

4. Conclusion

The algorithm achieved predict values of temperature and solar radiation with an average error of 3.4% and 9.9% respectively. These errors were lower than the forecasted data for Cajicá Colombia by POWER application by 3.7% for solar radiation and by 44.9% for temperature.

The error in the forecasted data of solar radiation is equivalent to an offset of ± 431.44 kWh/m^2, due to this offset is lower than the value selected for the behavioral rules (± 500 kWh/m^2), the algorithm was able to predict solar radiation behavior with a small error that has minimum influence in the identification of future behavioral patterns in Cajicá, Colombia.

On the other hand, the error in the forecasted data of temperature is equivalent to an offset of ± 0.48ºC, due to this offset is lower than the value selected for the behavioral rules (±0.5ºC), the algorithm was able of identify the behavior change in the temperature in Cajicá, although that this changes are not higher than 3ºC between one day another.

Through the prediction of the behavioral patterns of increasing, decreasing or constant, the algorithm reduced the error presented by the POWER the web application specifically for future values of meteorological variables in Cajicá. this is due to that the algorithm does not predict exact values instead of that, predict behavior of climate factors. This type of forecasted data can be used for climate characterization in a specific area, which is the first step in the development of any project based on renewable sources.

The implementation of this methodology in other cities in Colombia, will allow not just characterize the climate behavior, but also make studies that identify the effects of meteorological phenomena such as EL NIÑO or LA NIÑA in the meteorological behavior of the cities, with the purpose of develop solutions to counter or take advantage of these effects.

Acknowledgements

The authors would like to express their special gratitude to the Research Vice-chancellorship of Nueva Granada Military University

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