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AN IDENTIFICATION AND ESTIMATION OF SOLAR ENERGY IN INDIA USING FUZZY LOGIC (AI) TECHNIQUE

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Abstract

The Solar energy offers a clean, renewable and domestic energy source and is essential component of a sustainable energy in future. For solar power generation, knowledge of global solar irradiance at a particular location is utmost important. Global solar irradiance can be divided into two components: the first is the diffuse solar radiation, which results from scattering caused by gases in the earth's atmosphere, dispersed water droplets and particulates; and the second is the direct solar irradiance, which is not scattered. Knowledge of global and diffuse solar irradiance is essential for research and engineering applications. This paper includes a brief study on the application of Artificial Intelligence (AI) methods in solar energy estimation and measurement. In this paper the Solar Energy in various metropolitan cities like New Delhi, Bhopal, Pune, Hyderabad and Chennai, is estimated using Fuzzy Logic. The output of the Fuzzy system represents the location where most of the Solar Energy is abundantly available.
Key Terms: - Artificial Intelligence (AI), Fuzzy logic, Solar Energy, Solar Irradiance.

I. INTRODUCTION

The Optimum site selection for generation of electricity from the solar energy is determined based on the available solar irradiance data at that location. The Solar irradiance data are important for design, sizing, operation and economic assessment of solar energy. However, the network of solar irradiance measuring stations is relatively rare throughout the world. In India, only IMD (India Meteorological Department) Pune provides data for quite few stations, which is considered as the base data for research purposes. However, hourly data of measured irradiance is not available even for those stations where measurement has already been done. Due to lack of hourly measured data, the estimation of solar irradiance at the earth's surface is essential.

There are number of models for the estimation of solar energy under cloudless skies. Three broadband models namely REST (Reference evaluation of solar transmittance), REST2 (Reference evaluation of solar transmittance, 2 band) and CPCR2 (Code for physical computation of radiation, 2 band) are used. Regression model is also used for estimating the solar energy considering sunshine duration as input. These models are not suitable to estimate the solar irradiance during monsoon months (June to September) or cloudy sky. The results obtained by these models are satisfactory, but these are only applicable for clear sky weather condition.

As we know that, in India around 50 to 100 days in a year are cloudy, so it is very difficult to predict the accurate results of solar irradiance using mathematical or regression model. The Direct Nominal solar irradiance data of India is shown in Fig 1, data is obtained by NREL (National Renewable Energy Laboratory), India.

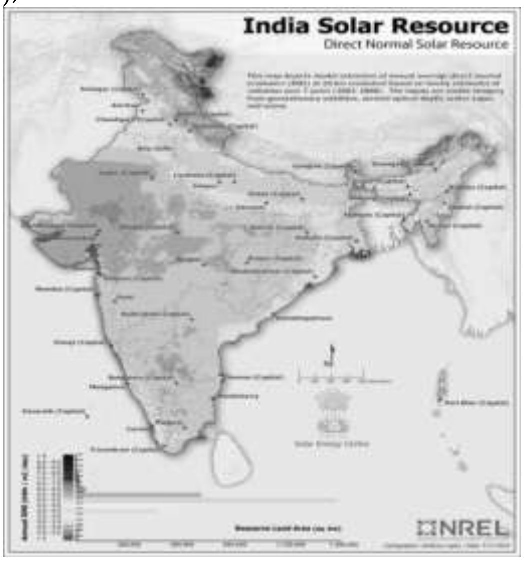

Fig 1 The Direct Solar Irradiance data in India by NREL

The uncertainty in atmosphere may occur due to the existence of dust, moisture, aerosols, clouds, or temperature differences in the lower atmosphere. Of all these factors, clouds can cause the maximum losses in the extraterrestrial solar energy reaching the surface at ground level. The atmosphere causes a reduction of the extraterrestrial solar input by about 30% on a very clear day to nearly 100% on a very cloudy day. Therefore, due to uncertainty in weather conditions, fuzzy based model is used to estimate the solar energy at a given location using different meteorological parameters such as sunshine duration and temperature as inputs.

The performance of the fuzzy based models is found better as compared to the mathematical and regression models. The percentage error in fuzzy models found are about 5% it is being used for many solar energy applications.

Artificial intelligence (AI) techniques have been used by various researchers in solar energy applications. This paper deals with an overview of these applications.

II. AI-TECHNIQUES USED IN SOLAR ENERGY ESTIMATION AND MEASUREMENTS:

A. Applications of Artificial Neural Networks

i. A Multi-Layer Perceptron (MLP) network for forecasting 24 h ahead solar irradiance is used. The mean daily irradiance and the mean daily air temperature are used as input parameters in the proposed model. The output was represented by the 24 h ahead values of solar irradiance. The power produced by using the developed MLP predictor shows a good prediction performance for 4 sunny days (96 h). And this approach has many advantages with respect to other existing methods and it can easily be adopted for forecasting solar irradiance values of (24-h ahead) by adding more input parameters such as cloud cover, pressure, wind speed, sunshine duration and geographical coordinates.

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ii. Artificial neural network (ANN) models for estimating and modeling daily global solar radiation have been developed. They have developed six ANN models by using different combination as inputs: the air temperature, relative humidity, sunshine duration and day of year. For each model, the output is the daily global solar radiation. For each of the developed ANN-models the correlation coefficient is greater than 97%. The results obtained render the ANN methodology as a promising alternative to the traditional approach for estimating global solar radiation.

iii. The air temperature, day of the year and relative humidity values are considered as input in a neural network for the prediction of global solar radiation (GSR) on horizontal surfaces. For one case, only the day of the year and daily maximum temperature were used as inputs and GSR as output. In a second case, the day of the year and daily mean temperature were used as inputs and GSR as output. In the last case, the day of the year, and daily average values of temperature and relative humidity were used to predict the GSR. Results show that using the relative humidity along with daily mean temperature outperforms the other cases with absolute mean percentage error of 4.49%. The absolute mean percentage error for the case when only day of the year and mean temperature were used as inputs was 11.8% while when maximum temperature is used instead of mean temperature is 10.3%.

iv. An artificial neural network model to predict the diffuse fraction on an hourly and daily scale using as input the global solar radiation and other meteorological parameters, like long-wave atmospheric emission, air temperature, relative humidity and atmospheric pressure is used. The neural network is more suitable to predict diffuse fraction than the proposed regression models at least for the specific sites examined.

v. The solar potential is estimated by using artificial neural networks utilizing meteorological and geographical data. The maximum mean absolute percentage error was found to be less than 6.74%. The predicted solar potential values from the ANN are given in the form of monthly maps. Artificial neural networks for the estimation of solar radiation in India, uses latitude, longitude, altitude, month, mean diffuse radiation and mean beam radiation data in the input layer of the network. Solar radiation is the output. The selected ANN structure is shown in Fig. 2.

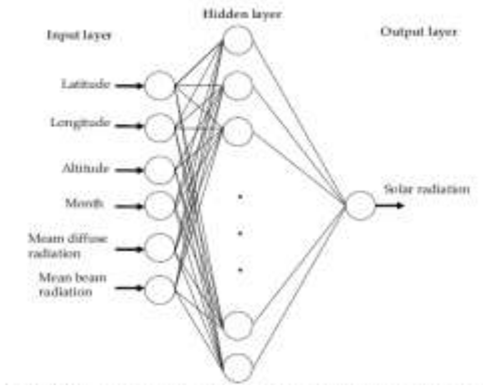

Fig.2 ANN architecture used for the prediction of solar radiation with six neurons in the input layer

B. Applications of fuzzy logic

i. A fuzzy logic algorithm, for estimating the solar irradiation from sunshine duration measurements is used. The fuzzy approach has been applied for three sites with monthly averages of daily irradiances in the western part of India. The fuzzy algorithm developed herein does not provide an equation but can adjust itself to any type of linear or nonlinear form through fuzzy subsets of linguistic solar irradiation and sunshine duration variables. It is also possible to augment the conditional statements in the fuzzy implications used in this method to include additional relevant meteorological variables that might increase the precision of solar irradiation estimation. The application of the proposed fuzzy subsets and rule bases is straightforward for any irradiation and sunshine duration measurements in any part of the world.

ii. The Takagi-Sugeno fuzzy systems for modeling daily global solar radiation are used. The results obtained from the proposed model have been compared with two models based on higher order statistics; the fuzzy model provides better results in the prediction of the daily solar radiation in terms of statistical indicators.

iii. A multipurpose sun tracking system using fuzzy control is developed. Sugeno fuzzy inference system was utilized for modeling and controller design. In addition, an estimation of the insolation incident on a two axis sun tracking system was determined by fuzzy IF-THEN rules. The step tracking that is considered in the design of multi-purpose sun tracking systems is taken every four minutes (one degree movement by the sun), and hence, less energy is needed for driving the sun trackers.

C. Application of Adaptive Network based Fuzzy Inference System (ANFIS)

i. The daily solar radiation is estimated from meteorological data sets with local linear regression (LLR), multi-layer perceptron (MLP), Elman, NNARX (neural network auto-regressive model with exogenous inputs) and adaptive neuro-fuzzy inference system (ANFIS). They used five relevant variables for estimating the daily solar radiation (extraterrestrial radiation, daily maximum temperature, daily mean temperature, precipitation and wind velocity). In general, they have concluded that the ANFIS model does not have the ability to estimate solar radiation precisely, but LLR and NNARX models are the most suitable models for the area under study.

ii. A neuro-fuzzy dynamic model for forecasting irradiance and ambient temperature is used. The medium term forecasting (MTF) gives the daily meteorological behavior. It consists of a neuro-fuzzy estimator based on meteorological parameters' behavior during the days before, and on time distribution models. As for the short term forecasting (STF), it estimates for a 5 min time step ahead, the meteorological parameters evolution. According to normalized root mean square error (NRMSE) and the normalized mean bias error (NMBE) computation, the meteorological estimator carries out satisfactory estimation of the meteorological parameters.

iii. A new model based on neuro-fuzzy for predicting the sequences of monthly clearness index is used and applied it for generating solar radiation, which has been used for the sizing of a PV system. A hybrid model is proposed for estimating sequences of daily clearness index by using an ANFIS; the proposed model has been used for estimating the daily solar radiation. An application for sizing a PV system is presented based on the data generated by this model. Fig. 3 shows the proposed ANFIS-based prediction for the monthly clearness index.

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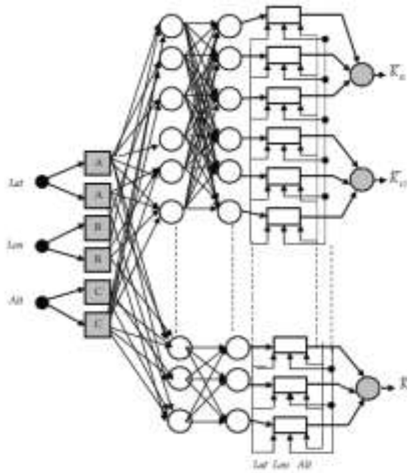

Fig.3 The proposed ANFIS-based prediction for monthly clearness

D. Applications of genetic algorithms

i. The optimal sizing of PV array, storage battery capacity, inverter capacity, backup diesel generator set capacity and operational strategy of a solar diesel mini-grid of an isolated island-Sandwip in Bangladesh using genetic algorithms is carried out. This study reveals that the major share of the costs is for solar panels and batteries. Technological development in solar photovoltaic technology and development in batteries production technology make rural electrification in isolated islands more promising and demanding.

ii. A genetic algorithm to optimize the multi-level rectangular and arbitrary gratings is used. Solar cells with optimized multi-level rectangular gratings exhibit a 23% improvement over planar cells and 3.8% improvement over the optimal cell with periodic gratings. Solar cells with optimized arbitrarily shaped gratings exhibit a 29% improvement over planar cells and 9.0% improvement over the optimal cell with periodic gratings. The enhanced solar cell efficiencies for multi-level rectangular and arbitrary gratings are attributed to improved optical coupling and light trapping across the solar spectrum.

E. Applications of data mining

i. Only one application is found in this area. In this method data mining is assisted by theoretical calculations for improving dye-sensitized solar cell performance. This method led to new knowledge about the influence of imidazole (crystalline heterocyclic compound used mainly in organic synthesis) derivatives as additives in an electrolytic solution on the cell performance. Data mining combined with theoretical calculations successfully elucidated a new research direction for developing an improved electrolytic solution for dye-sensitized solar cell using base additives.

III. FUZZY LOGIC IN IDENTIFYING SOLAR ENERGY POTENTIAL

The fuzzy logic is used in identifying solar potential of a region because fuzzy proved to be a good

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concept in providing the uncertainties which are present, while the solar energy potential of an area is identify using the classical methods. For identifying the solar energy potential various factors affecting it like amount of solar radiation falling on a region per year, average sun hours for a region, latitude of the area, connectivity to road, slope of the terrain, population of the area, hydro graphic features, easy access to road and power grid, environmental constraints, land use etc. are studied. For the sake of simplicity three of these parameters namely latitude, solar irradiance of an area received in a year and the average number of solar hours had been focused. For every constraint a fuzzy graph is made and depicted as below:

A. Amount of Solar Irradiance Received:

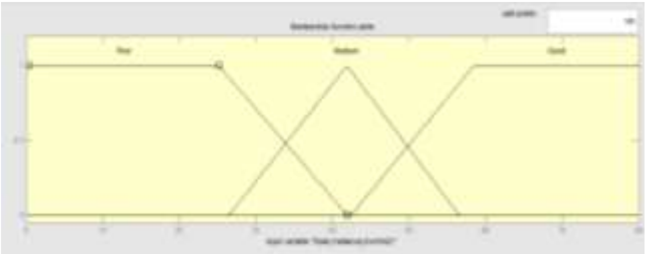

Fig.4. Amount of Solar Irradiance Received in (Kwh/m^2)

Fig.4. Defines the membership functions that are determined based on the available Solar Irradiance data on graph shown in Fig.1.

B. Duration of Sunlight Available in a Day

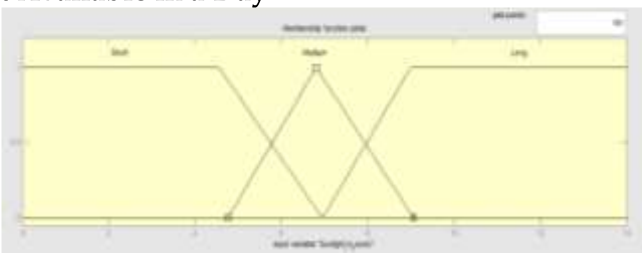

Fig.5 Duration of Sunlight Available in a Day (in hours)

Fig.5. Defines the membership functions that are determined based on the available Sunlight in a Day of a particular area.

C. Latitude of Specific Area

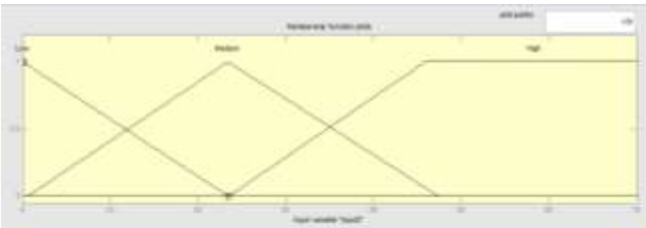

Fig.6 Latitude of Specific Area (in degrees)

- Fig.6. Defines the membership functions that are determined based on the latitude in degrees of a particular area. Weights are used to show the significance of each property.

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Weighting function assigns weight to participating constraints according to their importance in identifying solar energy potential in a Good potential: low latitude, high solar irradiation, high solar hours, etc.

- Average potential: medium latitude, medium solar irradiance, medium solar hours, etc.
- Poor potential: high latitude, poor solar irradiance, low solar hours, etc.

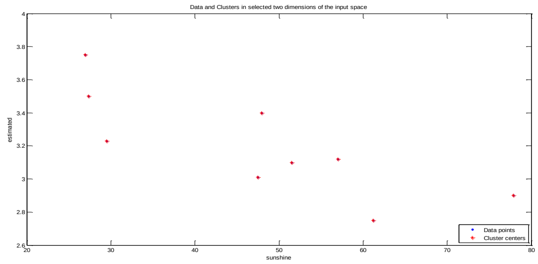

Fig.7. **S**olar estimated Cluster data

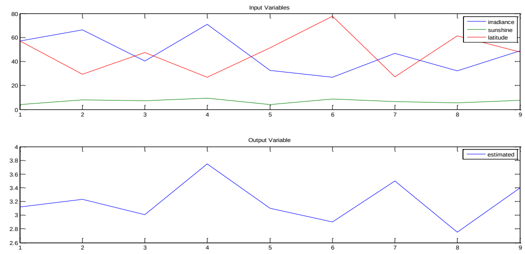

Fig.8 Fuzzy Output o f Solar Estimated data with three input variables

Fig.7 represents the estimated solar data points of solar energy estimation with available sunshine data. And Fig.8 represents the Fuzzy output showing the solar energy estimation with three input variables such as Solar Irradiance, Sunlight and Latitude of the particular area. This method is most useful for estimating solar energy estimation in a particular area. In India it is observed that the most suitable area for generation of electricity through solar energy is Gujarat near Bhopal and surroundings of this area.

IV. CONCLUSIONS

In this paper, application of Artificial Intelligence techniques for estimation of solar energy of a particular area is presented. Solar Energy in various metropolitan cities like New Delhi, Bhopal, Pune, Hyderabad and Chennai, is estimated using Fuzzy Logic. Like all other approximation techniques, Fuzzy logic technique has relative advantages and disadvantages. The output of the Fuzzy logic system represents the estimated solar energy potential of a particular area and also identifies the location at most of the Solar Energy is abundantly available.

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