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# A Survey on Hybrid Wind and Solar Energy Forecasting using Artificial Neural Networks

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**Abstract: Due to plummeting non-renewable reserve of resources to produce electricity, renewable resources are being considered very seriously. One such paradigm is solarand wind power which is based on solar and wind energy. Transcending from conventional sources to non-conventional renewable resources needs the establishment of large scale solar and wind power plants. This requires large costs involved and hence the need for solar and wind energy forecasting. Previously statistical models were used for the prediction of solar and wind energy, but it didn't yield high accuracy. However, with the advent sophisticated optimization and data analysis tools such as Artificial Neural Networks, forecasting of renewables using Artificial Neural Networks has become an active area of research. The present paper introduces the need of renewable energy prediction and subsequently the use of Artificial Neural Networks for the same. Different ANN architectures and their properties are presented here for a clear understanding of the tools being used. Finally evaluation parameters are discussed which evaluate the performance of any proposed system.**

**Keywords:-**

**Solar Energy, Wind Energy, Artificial Neural Network (ANN), ANFS- Adaptive Neuro-Fuzzy System**



## I.Introduction

In recent years, the requirement for energy has been continuously increasing. Utilizing renewable energy resources is a high priority within energy production and management policies in many countries.[1] The

growing rate of demand for energy and the global warming phenomenon, which has raised a lot of concern about carbon dioxide emissions along with the high price of fossil fuel, has led governments to consider the utilization of new sources of energy. Several nuclear power-plant disasters and

their long-term effects on the nextgenerations' health and environment have also initiated a series of debates on eliminating nuclear power from the future energy policies for some countries. Solar and wind energy is a free and easily available source of energy and appears to be the fastest growing of renewable energy resources. Solarand wind power system's penetration in the existing power system possess problems as running problems (frequency, power balance, voltage support, and quality of power), planning and economic problems (including uncertainty in wind and solar power in to unit commitment, economic load scheduling, and spinning reserve calculations), etc.

Previously statistical models were used for the prediction of solar and wind energy and thereby solar and wind power, but it lacked accuracy due to

its inability to follow complex solar energypatterns accurately. Thus the focus started shifting on Artificial Intelligence tools to forecast solar energy. The subsequent sections introduce the basics of artificial neural network, its functioning and various architectures of artificial neural networks.

## II. Artificial Neural Network (ANN)

Work on artificial neural network has been motivated right from its inception by the recognition that the human brain computes in an entirely different way from the conventional digital computer.[5],[7] The brain is a highly complex, nonlinear and parallel information processing system. It has the capability to organize its structural constituents, known as neurons, so as to perform certain computations many times faster than the fastest digital computer in existence today. The brain routinely accomplishes perceptual recognition tasks, e.g. recognizing a familiar face embedded in an unfamiliar scene, in approximately 100-200 ms, whereas tasks of much lesser complexity may take days on a conventional computer. A neural network is a machine that is designed to model the way in which the brain performs a particular task. The network is implemented by using electronic components or is simulated in software on a digital computer. A neural network is a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use. It resembles the brain in two respects:

1. Knowledge is acquired by the network from its environment through a learning process.
2. Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques. Other advantages include:

1. **Adaptive learning:** An ability to learn how to do tasks based on the data given for training or initial experience.
2. **Self-Organization:** An ANN can create its own organization or representation of the information it receives during learning time.
3. **Real Time Operation:** ANN computations may be carried out in parallel, and special hardware devices are being designed and manufactured which take advantage of this capability.

The biological model of the neuron is shown in the figure. It consists of the cell body, axon hillock, action potential, synaptic terminal, axon of pre synaptic neuron and dendrites. Signals from different parts of the body travel through different parts and reach the neuron where the neuron processes it and produces an output. It should be noted though that the output of a neuron may also be fed to another neuron. A collection of such neurons is called a neural network. The neural network can perform simple to complex tasks depending on the structure of the neural network.After studying the basic biological model of the neural network, a mathematical model is envisaged to be designated. The mathematical model for such a neural network is given by:

$$\sum_{i=1}^{n} XiWi + \Theta \quad (1)$$

Where
Xi represents the signals arriving through various paths,
Wi represents the weight corresponding to the various paths
And Θ is the bias.

The diagram below exhibits the derived mathematical model of the neural network. It can be seen that various signals traverssing different paths have been assigned names X and each path has been assigned a weight W. The signal traverssing a particular path gets multiplied by a corresponding weight W and finally the overall summation of the signals multiplied by the corresponding path weights reaches the neuron which reacts to it according to the bias Θ. Finally its the bias that decides the activation function that is responsiblefor the decision taken upon by the neuralnetwork.



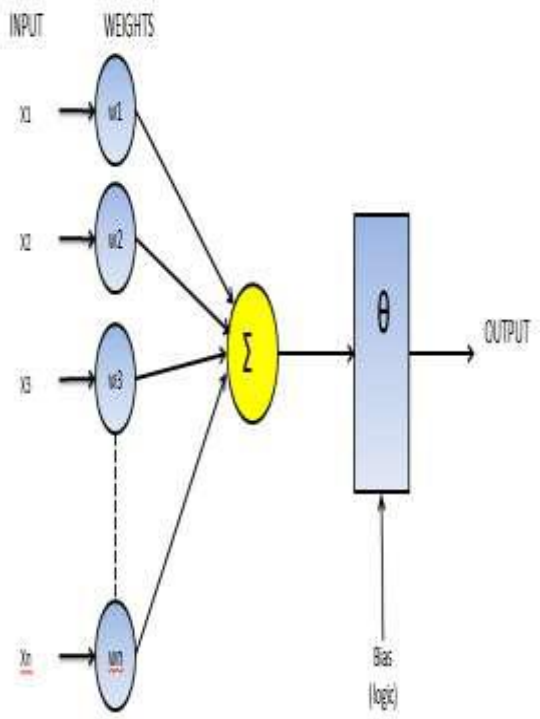



**Fig.1 Mathematical model of a neural network**

Neural networks can be used for tracking complex patterns in solar energyand subsequently predicting solar energy.

## III. Different ANN Architectures

There are various ANN architectures which can be used for the prediction of data. The most commonly used ones are discussed below.

### 1. Single Layer Feed-Forward Network

In a layered neural network the neurons are organized in the form of layers. In the simplest form of a layered network, we have an input layer of source nodes that projects onto an output layer of neurons, but not vice versa. This network is strictly a feed forward type. In single-layer network, there is only one input and one output layer

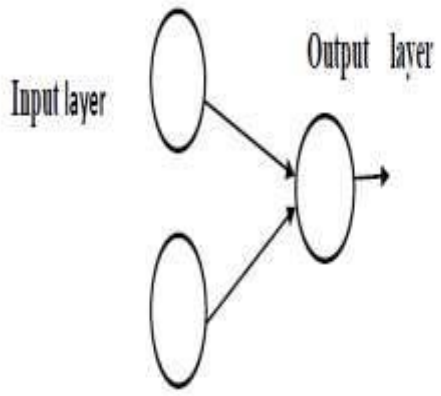



**Fig.2 Single Layer Feed Forward Network**

In feed forward networks, it's important to note that the flow of signal is from input nodes towards the output node but the signal cannot propagate backward from the output node towards the input layers i.e. feed back is not permissible.

### 2. Back-propagation Network (BPN)

BPN is a feed-forward network with three layers, namely input layer, hidden layer, and output layer, as shown in  The number of hidden layers can be more than one, depending on the complexity of the problem. In our study, we used one hidden layer to minimize the computational time and reduce complexity of training.

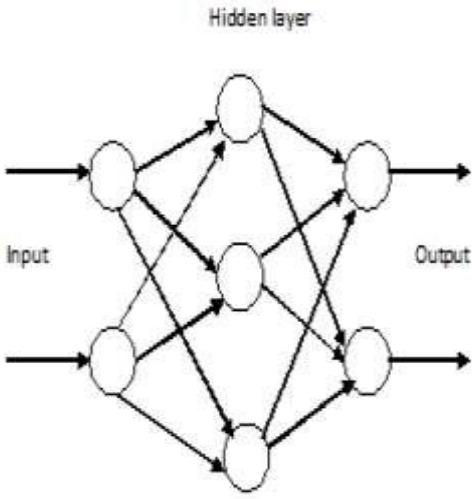



**Fig.3 Architecture of Neural Network with Hidden Layers**

Determining the number of layers and the number of processing elements per layer are important decisions, which are made by the programmer while creating and training the network. Training inputs are applied to the input layer of the network, and the desired outputs are compared at the output layer. The difference between the output of the final layer anddesired output is back-propagated to the previous layer(s). The back-propagated signals are usually modified by the derivative of the transfer function and the connection weights, which are usually, adjusted using the Delta Rule. The minimum mean square error between the actual output layer of the network and the desired output is minimized using the gradient descent algorithm. The performance of a neural network depends on the weights and the transfer function (input-output function) specified for the units.[8]

### 3. Radial Basis Function Network (RBF)

It is a three-layer network, namely the input, the output and the hidden layer, where each hidden unit in a hidden layer implements a radial activated function. The main advantages of RBF's over feed-forward networks are its accuracy and shorter computational time.

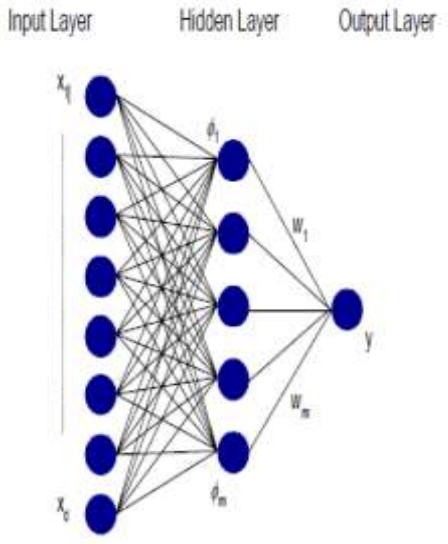



**Fig.4 RBF Network Architecture.**

The computation time is also a measure of the system's time complexity which is desired to be kept as low as possible for the system to be efficient. As Venkatesan and Anitha [16] explained, the response of the jth-hidden unit can be mathematically expressed as:

$$zj=\emptyset[|\frac{x-\mu j}{\sigma j^2}|] \qquad (2)$$

where

is Ø a strictly positive, radially symmetrical function (kernel) with a unique maxima at its center,

μj, and **σ**j is the width of the receptive field.

The error between the target and the desired output is minimized using gradient descent algorithm. [18]

### 4. Adaptive neuro-fuzzy inference system (ANFIS)

Fuzzy logic and ANN are modelling methods used influentially and effectively in the problems of engineering. The modelling of fuzzy logic method is a rule-based method using the feature of human thinking and decision making. On the other hand, ANN learns the problem by using its ability of learning and comes through successfully for data sets it did not come across before. The method of ANFIS was suggested by Jang [7] considering these advantages of ANN and fuzzy logic methods. ANFIS is an integrated form of ANN and fuzzy inference systems. The membership degree of input/output variables is determined in an ANFIS by the use of ANN's ability of learning. A conclusion is reached with the feature of reasoning and decision making of fuzzy logic method.[9]



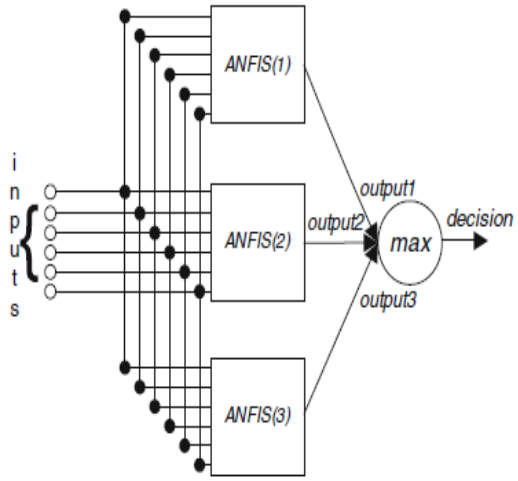



**Fig5. The ANFIS Architecture**

## IV. Activation Functions

The activation function could be chosen from the following list: logistic sigmoid function, hyperbolic tangent function, or linear function. It is also possible to create a hybrid artificial neural network with different activation functions in different layers. However, there should be at least one non-linear activation function used in an ANN structure in order to retain its ability to solve non-linear problems.

Activation functions tell us about the type of decision the neural network takes. Based on the type of decision the neural network has to take, a mathematical function called the activation function needs to be designed.

The most commonly used activation-function features are shown in Table.1

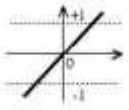
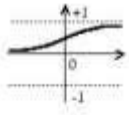
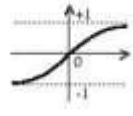
| Activation Function | Mathematical Equation | Graphical Representation |
|---|---|---|
| Linear | $f(x) = x$ |  |
| Logistic sigmoidal | $f(x) = \frac{1}{(1+e^{-x})}$ |  |
| Hyperbolic tangent | $f(x) = \frac{1-e^{-2x}}{1+e^{2x}}$ |  |

**Table.1 Different Activation Functions**

It was shown that the activation function plays a very important role in the accuracy of artificial neural network results, but if a network could be trained successfully with a particular activation function, it would be highly probable that other activation functions would also result in an acceptable training. Linear activation functions have been used by some investigators in input and output layers. For the hidden and output layers, non-linear activation functions are used. Some studies show that the linear activation function in the output layer combined with a nonlinear activation function for a single hidden layer has positive effects on the performance of the ANN. This work adopts that ANN structure.

## V. Previous Work

**Utpal Kumar Dasa et al.** proposed that photovoltaic power generation has been a key concept in the recent days of research on solar power forecasting. In this proposed method also the optimized mechanisms for photovoltaic power have been considered. The maximum value of photovoltaic power has to be harnessed for greater performance. This renewable resource of solar energy is very useful for meeting the ongoing high energy demands. As the fossils have been utilized too much and they are on the verge of depletion, there is this need to switch to renewable resources. The peak outcomes are met easily with this system. This system approach works better than the rest of the methods**.** This solar power prediction method is quite helpful for the desired results that are the objective.

**Derong Liu et al.** proposed an adaptive dynamic programming is the key concept in this study. The solar power is difficult to be derived from the fluctuating solar irradiation energy.This variable nature of the solar irradiation quantity is due to many atmospheric conditions. So any scheduling energy mechanism can work well with such kind of energy variations. So in this research work the authors worked on scheduling of residential variable solar energy using dynamic programming concept. This concept showed good results in term of

obtaining the solar power and the throughput was good as well. The only flipside was that the adaptive capability of the dynamic approach had to be set properly otherwise it gave improper outcomes. This ensured the stability of the overall methodology.

**N. Chettibi et al.** proposed an artificial Intelligence and machine learning concept has been used widely in the current times. Neural networks are a part of the artificial intelligence concept which is very useful for training with datasets. They possess much flexibility and accuracy in terms of performance metrics. So in this study the authors tried to use the approach of adaptive neural networks to monitor a micro grid. Grid based systems contain many intricate portions which have to be designed very carefully. Also maintaining these values is very important. Hence a hybrid AC/DC model of micro grid is implemented using the neural network method. The outputs that were obtained for this mechanism were quite impressive. Also the time delay and lags were nearly absent. It turned out to be a really effective and well formulated approach.

**R. Amaro e Silva et al.** proposed a aolar energy is one of the most sought after renewable resources of today. As the non renewable sources are getting over fast, there is this urgent need to turn towards the renewable resources. Spatio-temporal solar forecasting is an area that has not been explored much. Hence in this work, the researchers tried to gauge the effect of network layout on such spatio temporal prediction schemes. Network layout is an important feature that adds to the overall network lifetime and throughput of the system. Many different methods are employed based on the type of outcome that is anticipated. This approach yielded satisfactory outcomes for the particular type of solar prediction. It showed moderate results with all types of solar power forecasting.

**Yi Wang et al.** proposed that a power source remains the top notch power house for the world today. For optimum benefits, this has to be clubbed with accurate and effective methods that can increase the efficacy of the system. Large quantity of data is also the reason for going the data centric methods. In this approach proposed, the researchers come up with the idea of probabilistic net load prediction for specific PV domains. This system provided 95% accuracy and precision with the methods and the metrics were also quite improved and as per the requirements. The concept was data driven as the large pool of data was involved that was the main information store for all he executable methods.

**Hanmin Sheng et al.** proposed a weighted Gaussian process regression. The solar power that is acquired is of shorter duration and hence it is called short term solar power prediction. The weighted Gaussian process is a relatively conventional method but coupling it with regression method improves the overall functionality of the procedure.Many different methods are employed based on the type of outcome that is anticipated. This approach yielded satisfactory outcomes for the particular type of solar prediction. It showed moderate results with all types of solar power forecasting.This variable nature of the solar irradiation quantity is due to many atmospheric conditions. So any scheduling energy mechanism can work well with such kind of energy variations. The results are seen with this concept application is very good with 96% accuracy and better tolerance towards any third party noise.

**D.W. van der Meera et al.** showed that major focus of this research study was on the probabilistic prediction of the consumption of electrical energy and also solar power generation and the total need of an individual building utilizing the Gaussian process. As it is a common concept of the data following a specific pattern and these emulate the Gaussian pattern. So this helps in designing the approach related to the given data. A single building may have specific set of characteristics and may exhibit some demands. So to evaluate the requirements of the prediction metrics for it, it is essential to get the measure of the solar irradiation power right. All the data that is probabilistic is considered and applied for processing of the system. This is a good Gaussian centric approach where the information resembles the Gaussian random variable pattern approach.

**Tarlochan Kaur et al.** gave a research that consisted development of five different ANN models

for short-term wind speed forecasting. In this work of study, they employed train BR and train LM algorithm for the training purposes. These 5 different approaches were used to bring the best performance metric out of each one of them. These models varied on the basis of number of neurons and number of iterations. Following the training it was found that the optimal metric for the configuration was of 4 input neurons, 19 hidden layer neurons and 1 output layer neuron. As there was no data pre-processing implemented, the system exhibited 70% accuracy with 30% error metrics.

**P. Ramasamy et al.** put forth a paperthat forecasted the daily average wind speeds for11 different pertaining to mountain regions of Himachal Pradesh located in India to harness the wind energy power. It was done using ANN model that utilized recorded data of Hamirpur for the year 2012. Ann model was deployed as for training and testing. LM algorithm was used as the training algorithm. The fluctuations in the wind speed was found to be between 1.28 to 3.80m/s. So they concluded that such measure of wind speed is enough for meeting small power needs

**VI. Evaluation Parameters**

Since errors can be both negative and positive in polarity, therefore its immaterial to consider errors with signs which may lead to cancellation and hence inaccurate evaluation of errors. Therefore we consider mean square error and mean absolute percentage errors for evaluation. Mean Square Error is defined as:

$$MSE = [\sum_{i=1}^{n}(X - X')^2]/n \quad (3)$$

Mean Absolute Percentage Error is defined as:

$$MAPE = [\sum_{i=1}^{n}(X - X')/X']/n \times 100\% \quad (4)$$

Here,
X is the predicted value,
X' is the actual value and
n is the number of samples.

**VI. Conclusion:**

**It can be concluded form the above discussions that Artificial Neural Networks can be effectively used for solar and energyprediction even though solar and wind energymay exhibit complex time series behaviour. Various Neural Network Architectures have been discussed with their salient features. Finally the evaluation parameters used for the evaluation of any prediction model to be designed have been explained with their physical significance and need.**

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