M. Tech (Power System) MD TABISH ANSARI 2021

AI BASED APPROACH TO PREDICT THE SOLAR ENERGY IN SMART GRID ENVIRONMENT

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

POWER SYSTEM

SUBMITTED BY:

MD TABISH ANSARI

(2K19/PSY/10)

UNDER THE SUPERVISION OF

Prof. M. Rizwan

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

2021

DEPARTMENT OF ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

DECLARATION

I hereby certify that the work which is presented in the Major Project – II entitled "AI based approach to predict the solar energy in smart grid environment" in fulfilment of the requirement for the award of the Degree of Master of Technology in Power System and submitted to the Department of Electrical Engineering, Delhi Technological University, Delhi is an authentic record of my own, carried out during a period from January to August 2021, under the supervision of Prof. M. Rizwan.

The matter presented in this report has not been submitted by me for the award for any other degree of this or any other Institute/University.

MD TABISH ANSARI

2K19/PSY/10

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

SUPERVISOR CERTIFICATE

To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere. I, further certify that the publication and indexing information given by the student is correct.

Place: Delhi

Date: 02-09-2021

Prof. M. Rizwan

SUPERVISOR

(Professor)

ACKNOWLEDGEMENT

First and foremost, I express my deep sense of gratitude to Prof. M. Rizwan, Project Supervisor and Professor, Department of Electrical Engineering, DTU for his constant guidance, support, motivation and encouragement throughout the period of this work. Their readiness for consultation at all times, concern and assistance has been invaluable.

I am thankful to Prof. Uma Nangia, Head of Department and Electrical Engineering Department faculties in Electrical Department, DTU for their kind help, encouragement and knowledge throughout this course which helped me in completing my project work.

I want to thank Mr. Astitva Kumar and Mr. Mohammad Bilal (Research Scholar) for their support and all the staff of the UEE Lab, Electrical Engineering Department of DTU for their full cooperation.

I would like to thank my friends and all those who have helped me and encouraged me in completion of my dissertation in time.

Finally, I thank my parents for their moral support and confidence which they showed in me to pursue M. Tech at the advanced stage of my academic career.

Date: 02-09-2021

Md Tabish Ansari

2K19/PSY/10

M. Tech (Power System)

Delhi Technological University

ABSTRACT

Due to various environmental problems power generation using renewable energy resources is gaining popularity. Among all the renewable energy resources solar energy is most popular as it is readily available. Because of this electricity generation using solar photovoltaic system is becoming popular as it requires less maintenance and it is environment friendly. However variation in meteorological parameters and solar irradiance causes variation in power generated by solar photovoltaic system. This uncertainty can be tackled by using energy storage system, integrating energy management system. However for proper designing of energy management system forecasting becomes important. Forecasting helps in reducing the uncertainties in solar power generation. Therefore for proper designing and development of solar photovoltaic system forecasting of solar energy becomes very important. The main aim here is to minimize the impact of solar irradiance variation on the power developed.

In this dissertation short term solar energy forecasting is done using three methods namely fuzzy logic, artificial neural network, Particle Swarm Optimized artificial neural network. These three methods are used for forecasting purpose in various other fields. Fuzzy logic is based on human decision making. It takes decision based on vague and imprecise data. Artificial neural network is based on machine learning. However output provided by ANN is fluctuating in nature and is less accurate. So to increase its accuracy, optimization technique is used. PSO algorithm is used for improving the ANN and to get more accurate results. MATLAB is used for implementing these three technique for short term forecasting. Mean absolute percentage error (MAPE) is calculated for all the three methods. For fuzzy logic MAPE comes out to be 4.02%, for ANN MAPE comes out to be 4.12% and for PSO-ANN MAPE comes out to be 3.23%.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ABC Artificial Bee Colony

ANN Artificial Neural Network

ARE Absolute Relative Error

FFNN Feed Forward Neural Network

FIS Fuzzy Inference System

GA Genetic Algorithm

MAPE Mean Absolute Percentage Error

MIS Mamdani Inference System

MPPT Maximum Power Point Tracker

PSO Particle Swarm Optimization

PV Photovoltaic

SPV Solar Photovoltaic

LIST OF SYMBOLS

X_s	Normalized data
X	Original data
X_{max}	Maximum value in a data set
X_{min}	Minimum value in a data set
A_{max}	Upper limit
A_{min}	Lower limit
X_t	Actual data
Y_t	Forecasted data
a	Number of days
y	Output vector
b	Bias
w_i	Weights corresponding to input
x_i	Input vector
f	Activation function
r_1, r_2	Randomly generated number
c_1, c_2	Acceleration constant
w	Inertia constant

CHAPTER 1

INTRODUCTION

1.1: General

Global warming, excessive pollution, shortage of fossil fuel are some of the major challenges which the world is currently facing or are going to face in near future. One of the major contributors towards these environmental problem is the power sector. In India, out of total electricity generated in India, almost 70 to 80% comes from thermal power plant running on coal. Therefore in order to reduce the dependence on fossil fuel (i.e finite source of energy), world is moving towards adoption of renewable source of energy.

There are various sources of renewable energy like wind energy, solar energy, geothermal energy etc. Among these alternate source of energy, solar energy is the most popular. As solar energy is widely available so it is capable of meeting the ever increasing demand of energy of the world. As a result demand of solar PV system has been increasing. Therefore, research and development is being done in making PV system efficient, reliable and cost effective.

1.2: Solar Energy in India

This is the fastest developing renewable energy based power sector in India. As of 31 March 2021, total solar installed capacity of India is about 40.09 GW. Earlier Indian Government has set a target of achieving total solar installed capacity of 20 GW which was achieved 4 years earlier.

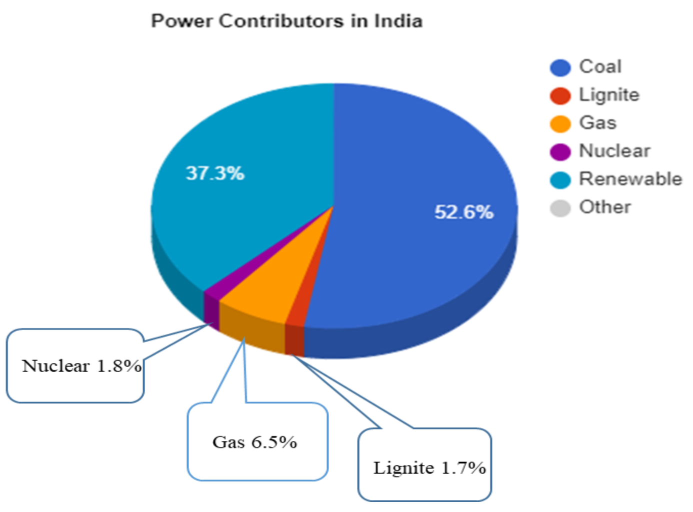

Figure 1.1: Graph showing various power contributors of India

Rooftop solar power accounts for 2.1 GW. Also large scale grid connected solar PV system is being developed by the Indian Government. But there are still several challenges associated with it. The best suited architecture for India is grid connected solar rooftop power generation. Various other sectors of government are also taking initiative for setting of solar PV plants like, Indian Railways is going to setup solar PV system of about 4 GW capacity along its track. Similar PV systems will also be established along the National Highways. As per the assessment conducted by the National Institute of Solar Institute (NISI), it was found that about 748 GW of solar potential can be covered by solar PV modules. Figure 1.1 shows the contribution of various sources of energy in generation of power in India (Source: https://powermin.gov.in/en/content/power-sector-glance-all-india) and Figure 1.2 shows the cumulative capacity of solar power installed in various state till 31 December 2020 (Source: Ministry of New and Renewable Energy)

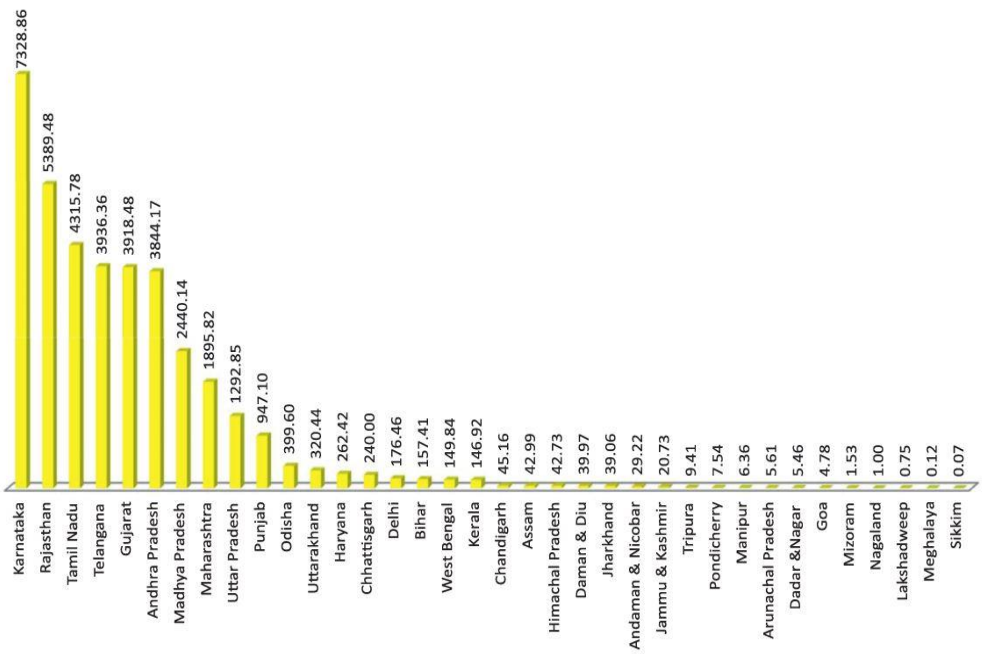

Figure 1.2: Cumulative capacity of total power installed

1.3: Solar Energy Forecasting

Forecasting in solar energy field deals with collection of data and analysis of data to predict solar energy and solar power. This is generally done for efficient energy management. As it is known that PV system are becoming popular for both domestic and industrial use. However one major disadvantage that it suffers is that output of SPV systems depends upon various meteorological parameters. These meteorological parameters are highly unpredictable because of these unpredictability the output poer fluctuates. Therefore solar energy forecasting becomes more important. However, one of the major challenges which solar energy forecasting faces is the need for short term solar energy forecasting. As solar irradiance depends upon various parameters like cloud cover surrounding temperature, wind speed, humidity etc. Short term solar energy forecasting means forecasting of solar energy for one hour advance to few days. In this dissertation short term solar energy forecasting is done using three methods: Fuzzy logic, Artificial Neural Network, and then Particle Swarm Optimized Artificial Neural Network. Forecasting becomes essential for proper designing of solar PV system.

1.4: Outline of Dissertation

This dissertation work consists of nine chapters.

Chapter 1: Brief introduction is given about why renewable source of energy are becoming popular, solar energy progress in India is discussed and solar energy forecasting is briefly discussed and overview of dissertation is given.

Chapter 2: Literature review is done in this chapter related to forecasting, fuzzy logic, ANN and different optimization technique.

Chapter 3: In this chapter basics of fuzzy logics is discussed, what are its various components, how it is implemented, how rules are applied to get forecasting. Different types of membership function is also discussed. Fuzzy logic model for short term forecasting is developed. Rule base for the development of fuzzy logic model is discussed. Membership function is chosen and number of membership function is also decided and finally MATLAB fuzzy logic toolbox is used to implement the fuzzy logic and results obtained are tabulated and compared against the actual data and relevant graphs are obtained.

Chapter 4: In this chapter basics of ANN is discussed, different layers of neural network is also discussed. Weights and biases and their effect of the neural network is also discussed. Various topologies which can be used is also discussed. In this chapter ANN is implemented using ‘nftools’ and its code is generated to get more control over function of ANN. Number of neuron used in the network developed are defined, network topology used is also defined and results are tabulated and compared with the actual data and percentage error is calculated and relevant graphs are obtained.

Chapter 5: In this chapter optimization basics is discussed. Various optimization technique like genetic algorithm, is also discussed. In this dissertation PSO technique is used so it is also discussed in details and its algorithm along with its functioning is also discussed. In this chapter PSO technique is implemented to ANN to get more accurate results. Algorithm for implementing the PSO-ANN is also explained and results are tabulated and compared against the actual data and percentage error is obtained and relevant graph are also obtained.

Chapter 6: In this chapter final conclusion of the dissertation is given and outcome and future work in this field is also discussed.

CHAPTER 2

LITERATURE REVIEW

2.1: Introduction

In this chapter, many research paper related to forecasting of solar energy, forecasting of solar power using different techniques are reviewed. This chapter has two section, in first literature review of research papers involving fuzzy logic and ANN in forecasting is discussed. In second section research paper related to optimization techniques in forecasting is discussed.

2.2: Fuzzy Logic and ANN

Solar energy forecasting using different ANN network model for different sky condition like sunny, hazy, cloudy condition for three different places is discussed in [1]. Different models were developed for different sky condition. It is found that radial bias function neural network model gives better result. Fuzzy logic approach for estimation of global solar irradiance using input parameters such as temperature, latitude, longitude, altitude, month of year and further this approach is used for predicting PV power output [2]. A short term PV power forecasting for grid connected PV plant is done using different forecasting model like GF5, MM5, and ANFIS in [3]. Energy forecast model was developed and tested using k-NN model, ANN based model. Solar power forecasting using fuzzy logic and ANN is presented in [4]. Here temperature and solar irradiance are taken as input and for fuzzy logic different membership function were used and it was determined that triangular membership function gives better result for centroid defuzzification. Solar forecasting with improved forecasting algorithm based on ANN with fuzzy logic pre-processing is presented in [5]. A pre-processing stage is integrated into ANN to perform real time analysis of weather information.

Fuzzy logic for energy forecasting is discussed in [6]. Dependence of solar irradiance on various parameters like humidity, air temperature, wind speed etc. is also discussed in this research paper. Wind energy is predicted with the help of fuzzy logic and ANN using wind speed and air density as parameters in [7]. It is found that ANN model gave better results and further can be used for wind power prediction. Solar irradiance forecasting using multi linear regression and fuzzy logic is presented in [8]. Five variables on which solar irradiance depends were chosen as input variables. They are time of day, temperature, wind speed, humidity and atmospheric pressure. Solar energy forecasting is done and it is found that fuzzy logic gives better result as compared to multi linear regression.

Power output profile of a grid connected 20 KW solar power plant using ANN is presented in [9]. MATLAB and Neuro-solution development environment is used in this paper for prediction purpose. Residential load forecasting is done using fuzzy logic in [10]. A new 2 input based fuzzy logic controller is discussed and ANN is used for analysing the output of the controller. A fuzzy logic scheme to extract maximum power from PV generator used in water pumping system is discussed in [11]. A fuzzy logic based MPP tracker is used to adjust the duty ratio of buck converter to maximize speed and water discharge rate. Impact of adaptive relaying in smart grid environment is analysed using fuzzy logic in [12]. Here short circuit current, fault impedance, location of fault from the end is taken as input and adaptivity of relay is analysed. Linear and non-linear models for short term solar irradiance forecasting is discussed in [13]. For linear model seasonal autoregressive model is used and for non-linear model non-linear autoregressive and regression tree are used. Non-linear auto regressive model gives better result. Fuzzy logic and neural network is used for forecasting under different sky and temperature condition is presented in [14].

2.3: Optimization Techniques

SPV system power forecasting using Extreme Machine Learning (ELM) is presented in [15]. Incremental conductance MPPT technique based on PI is simulated and single line forward network is used for training purpose and ELM algorithm is implemented whose weights are updated using particle swarm optimization. Solar power forecasting using genetic algorithm and ANN is presented in [16]. Working of GA in forecasting is discussed and how ANN works along GA is also discussed. It is found that forecasting using GA is much more accurate as compared to statistical method.

ANN optimized by various algorithm like PSO, GA, ICA and ABC is discussed in [17]. All these algorithm are used to then estimate the heating load of building for smart city planning. Training of ANN using PSO using initialization population approach known as PSOLL-NN to initialize the swarm in presented in [18]. This is then compared with standard PSO-NN and found that it performs better than the standard PSO-NN. Advance optimization technique like GA, PSO, ABC etc are discussed in [19]. Basics about various optimization algorithm, how they work, their advantages and disadvantages are discussed in this reference. Hybrid back propagation neural network based on PSO is proposed in [20]. The model proposed is used for predicting change in solar energy for shorter interval in tropical region. The results obtained shows that proposed technique is better than normal back propagation network. ANN-PSO approach used for SPV system is presented in [21]. Here ANN is used to predict the solar irradiation and PSO is used to optimize power generation and track solar power.

2.4: Conclusion

The literature review is done in this chapter in the relevant area for the present work “AI BASED APPROACH TO PREDICT THE SOLAR ENERGY IN SMART GRID ENVIRONMENT” in detail. The literature review is done to understand different forecasting technique, how ANN is used for forecasting, different advance optimization algorithm.

CHAPTER 3

DEVELOPMENT OF FUZZY LOGIC MODEL FOR SOLAR ENERGY FORECASTING

3.1: Introduction

Fuzzy logic concept was first introduced by Prof. Lotfi A Zadeh of University of California in 1965. It represents the decision making methodology of humans and it deals with the imperfect, imprecise and vague details and information. In simpler terms it can be said as the codification of common sense. In general sense fuzzy means things which are vague.

Any function or event whose outcome cannot be completely true or completely false are defined by fuzzy. It provides flexibility for reasoning and wider range of inaccuracies and uncertainties can be tackled easily. In Boolean logic only two outcomes are possible, it is either completely true (represented by 1) or completely false (represented by 0). However, unlike Boolean logic, fuzzy system does not indicate absolute truth or absolute false. It indicate how much a particular condition is true and can take any value between 0 and 1 [1]. Here 0 means absolute falseness and 1 means absolute truth. In simpler words we can say that in fuzzy logic, logic is not the fuzzy, but logic that used for describing fuzziness. Fig 3.1 shows how fuzzy logic is different form Boolean logic.

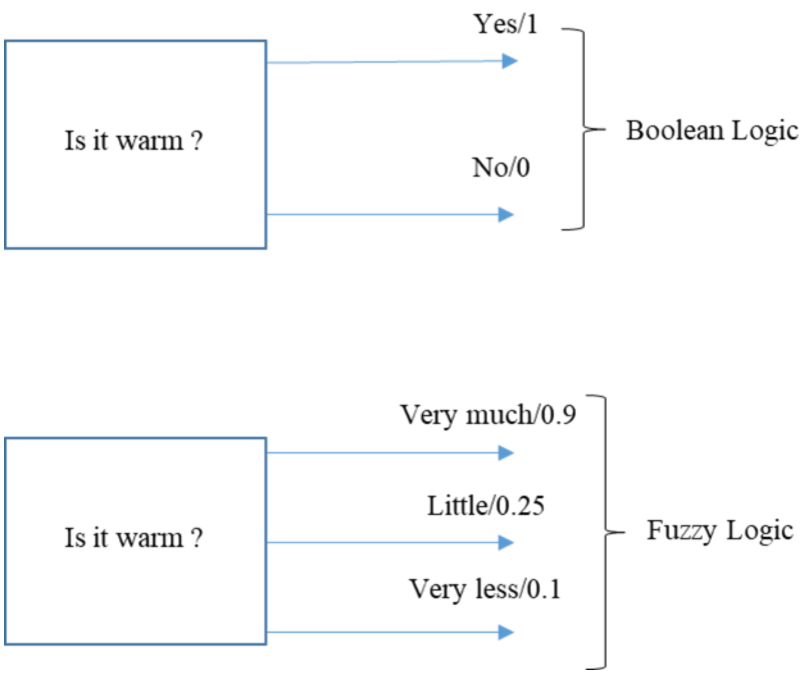

Figure 3.1: Fuzzy logic and Boolean logic

3.2: Components of Fuzzy Logic System

Fuzzy logic system consist of four components. Fig 3.2 shows the how different component of fuzzy system are related.

1. Rule Base
2. Fuzzification
3. Inference system
4. Deffuzification

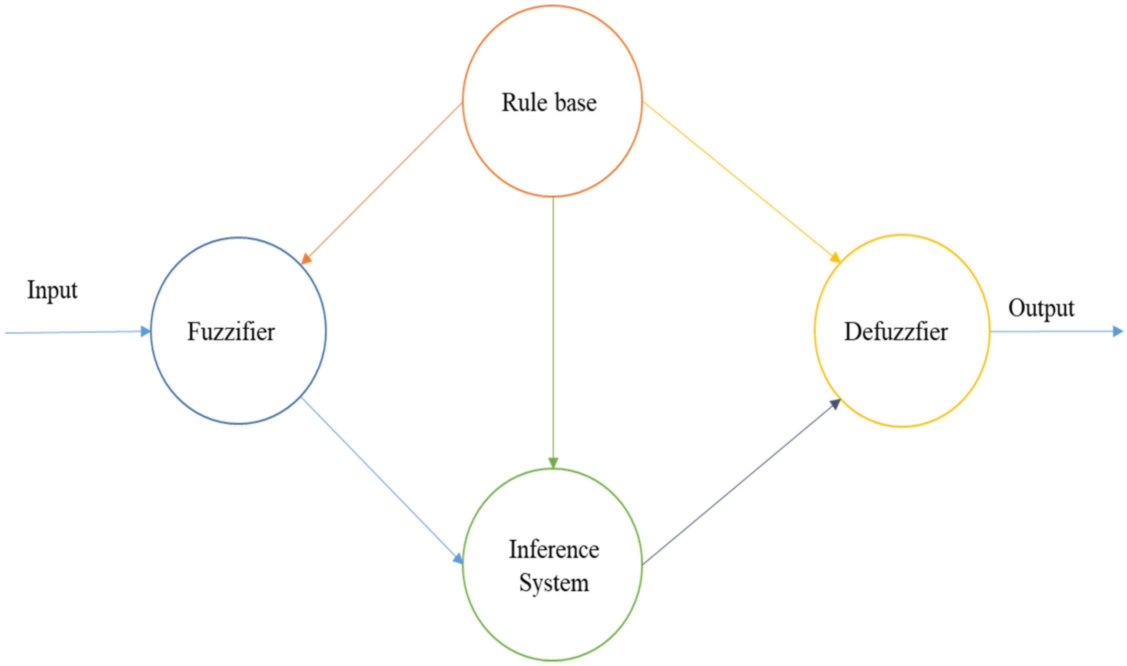

Figure 3.2: Components of fuzzy logic system

3.2.1: Rule Base

Fuzzy rules are required to predict the output based on the input provided. It consist of set of rules based on IF and THEN or AND-OR condition. The rules are formed on the basis of the data provided. If multiple output variables are there, then different values of from the corresponding IF parts are combined together with the help of OR operator.

3.2.2: Fuzzification

It is the process by which numerical values (input) of system are assigned in fuzzy set with certain degree of membership. Degree of membership varies from 0 to 1 and can be any values between them. If it takes 0 it means that the value is not present in given fuzzy sets and if it takes 1 it means that the value is completely present in that fuzzy set. However if it takes any value between 0 and 1 it means there is certain uncertainties whether that value belongs in that fuzzy set or not [2]. In simpler terms it converts crisp (i.e definite) values into fuzzy values here fuzzy sets are also known as membership function which are explained later in this chapter.

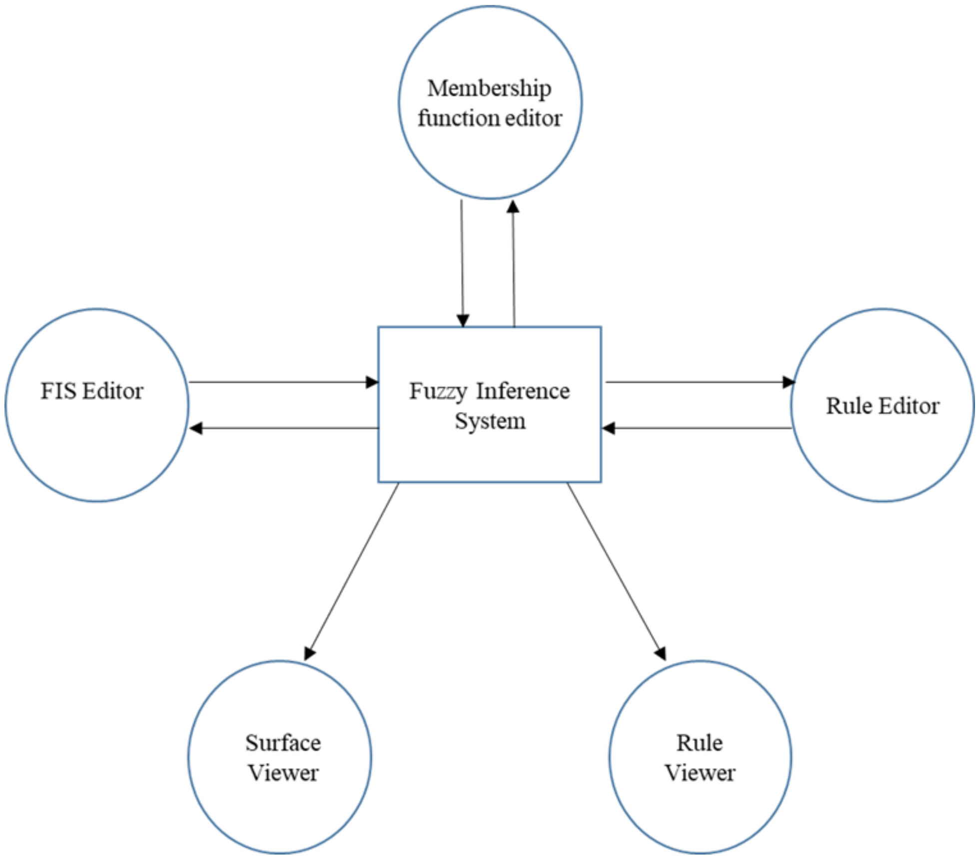

Figure 3.3: Components of fuzzy inference system

3.2.3: Inference System

It determines the degree of each fuzzy input with respect to the rules and decide which rule from the set of rules is to be used depending upon the input. The rules are then combined to get the required output. Fig. 3.3 shows the different component of fuzzy inference system (FIS).

It has the following characteristics:

1. The output provided by fuzzy inference system is always fuzzy. However its input can be crisp or fuzzy.
2. When FIS is used as controller then it is required to have fuzzy output.

3. Fuzzy variables are turned into crisp variable using defuzzification unit which would be there in the FIS.

Working of FIS can be explained by the following:

1. Crisp value is converted into fuzzy value using various fuzzification method.
2. Collection of database and rule base is formed.
3. Finally fuzzy value is converted into crisp value.

Two important method of FIS are given below:

1. Mamdani Fuzzy Inference System.
2. Takagi Sugeno Fuzzy Inference System.

MAMDANI FUZZY INFERENCE SYSTEM: This system was proposed by Ebhasim Mamdani in 1975. It involves the following step for the determination of output:

1. Development and determination of fuzzy rules.
2. Using the membership function the input values are converted into fuzzy values.
3. In order to determine the rule strength, fuzzy inputs are combined according to the fuzzy rules.
4. By combining the rule strength and output membership function consequent of a rule is determined.
5. By combining the all possible consequent output is obtained.
6. Crisp output is developed and obtained.

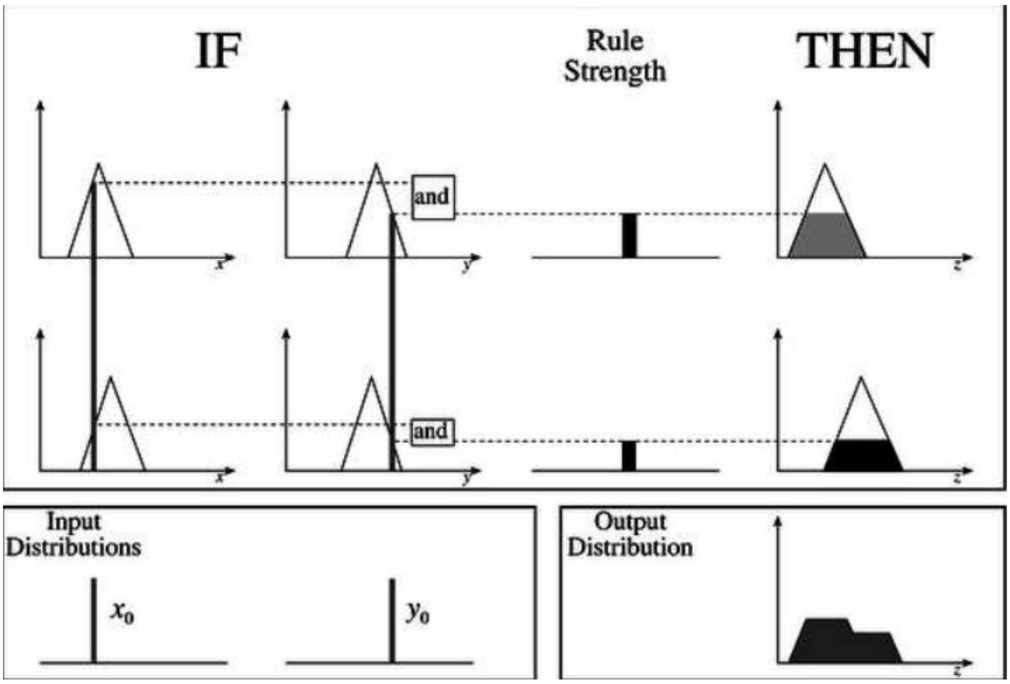

Figure 3.4: Working of MIS

IF-THEN rules format is used for MIS. In this dissertation MIS is used for solving fuzzy logic model. Fig 3.4 shows how MIS works.

TAKAGI SUGENO FUZZY INFERENCE SYSTEM: This model was proposed in 1985. It follows following rules format

If x is A and y is B THEN z=f(x,y)

Here A, B are fuzzy sets and are considered as antecedent and z = f(x, y) is a crisp function and is considered as the consequent. It involves the following steps:

1. Inputs are made fuzzy.
2. Fuzzy operators are applied to get the output.

3.2.4: Defuzzification

It is used for converting fuzzy values obtained from the FIS into crisp values. In simpler words defuzzification can be referred to as "rounding off". The most common algorithm which is followed for defuzzification is given as follows:

1. Membership function is cut at each truth value.
2. Results are obtained by combining with the help of OR operator.
3. For a particular area under curve centre of weight is determined.
4. Final result is given by the centre positions.

There are various methods which are used for the defuzzification purpose. Some of the popular ones are given below:

1. Max membership method.
2. Centroid or centre of gravity (COG) method.
3. Weighted average method.
4. Mean of maximum method.
5. Bisector of Area method.

In this report centroid or COG defuzzfication method is used. It is the most commonly used defuzzification technique. The most common type of membership function to be used is triangle. If the top part of the triangle is chopped or removed the remaining part forms a trapezoid. Then all the corresponding trapezoids are combined together i.e they are superimposed to get a single shape. Then centroid known as fuzzy centroid of this geometric shape is determined. The x coordinate of this centroid gives the defuzzified value.

3.3: Membership Function

It is a graph which explains how each input space is related to membership value between 0 and 1. Here the input space represent the universal set [6]. Membership function characterizes fuzziness or in other words it represents degree of truth in fuzzy logic. Member ship function has the following features:

1. Core
2. Support
3. Boundary

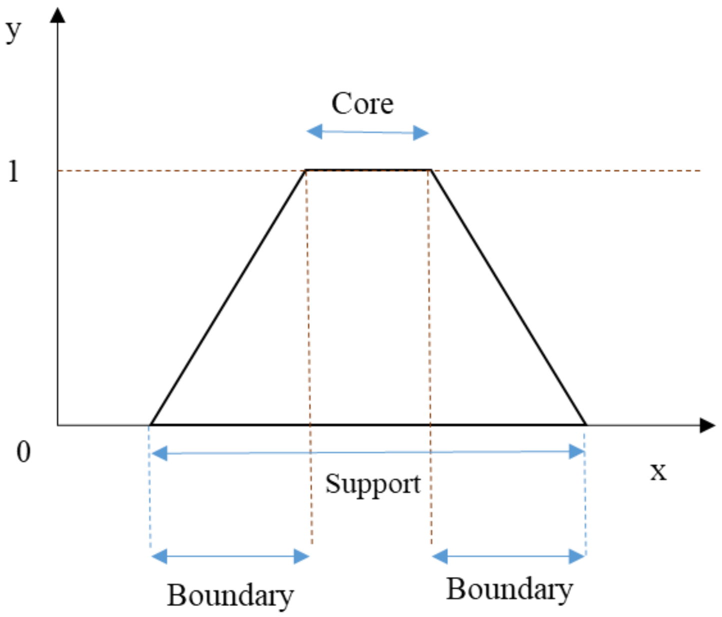

Figure 3.5: Features of membership function

Core is characterized by full membership in set. Support is characterized by non - zero membership. Boundary is characterized by non-zero but incomplete membership. Fig. 3.5 shows the features of trapezoidal membership function.

In this report triangular membership functions is used. However there are other types of membership function they are given as:

1. Singleton membership function
2. Gaussian membership function
3. Trapezoidal or triangular membership function.

3.4: Model Development

For the development of fuzzy logic model for solar energy forecasting purpose, MATLAB's fuzzy logic toolbox is used. Figure 3.6 shows the interface of the fuzzy logic toolbox. For inference system, Mamdani Inference System is chosen. Here MIS is so chosen because it is easily explainable and intuitive in nature. The model consist of 4 inputs which represents the solar irradiance measured at 4 different times i.e at 0900 hrs, 1000 hrs, 1100 hrs,1200 hrs [6]. With the help of fuzzy logic model solar irradiance at 1300 hrs is forecasted.

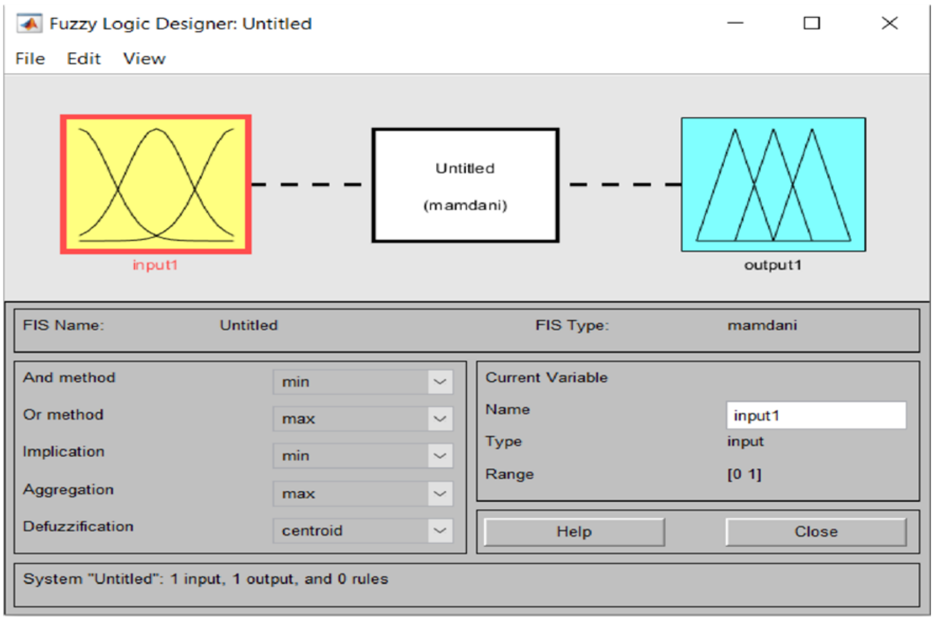

Figure 3.6: Basic interface of fuzzy logic toolbox

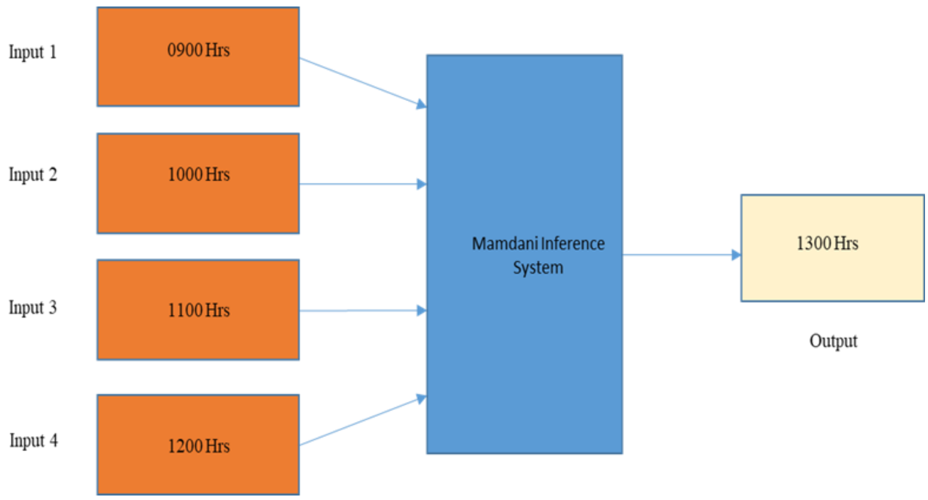

Figure 3.7: Block diagram of fuzzy logic model

3.5: Membership Function

For membership function triangular membership function is chosen. Figure 3.8 shows the triangular membership function used in this fuzzy logic model. As discussed earlier fuzzy logic model consist of 4 inputs and 1 output. For each input/output 6 membership function are defined. These membership function are defined as per the data. For defuzzification purpose centroid defuzzification is used. Centroid defuzzification produces least percentage error when used with triangular membership function.

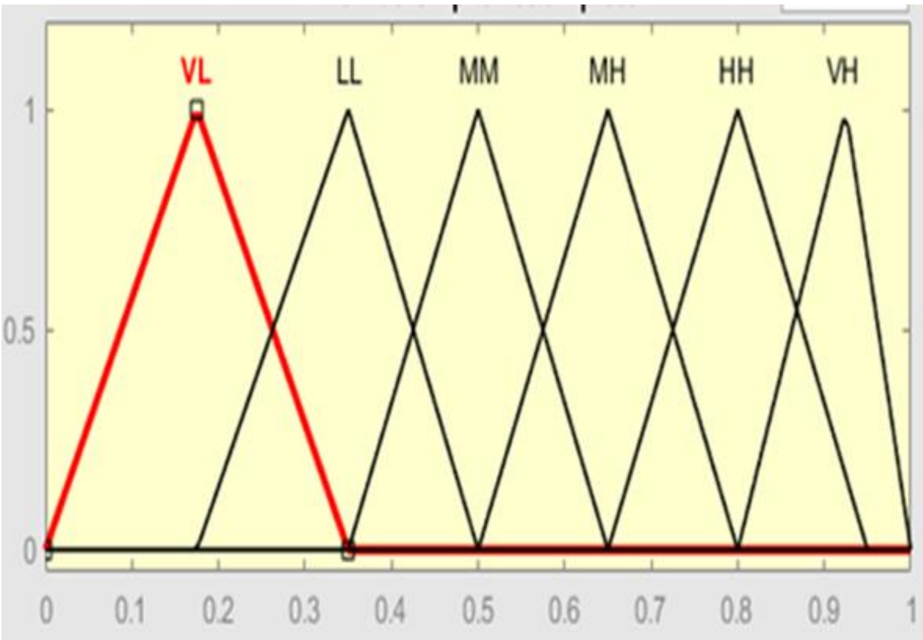

Figure 3.8: Triangular membership function used in fuzzy logic model

As 6 membership functions are defined these are very low (VL), low is shown by LL, medium is represented by MM, medium high is denoted by MH, HH represents high and very high is shown by VH. This is shown in Figure 3.8

3.6: Fuzzy Logic Algorithm

Figure 3.9 shows the flowchart explaining how the fuzzy logic model is functioning. First data is collected and is normalised using equation 1 (which is discussed later in this chapter). After data is normalized formulation of rules is done using fuzzy logic toolbox's rules editor. Once the rules and membership functions are defined, output is forecasted. Once the output is forecasted, it is checked with the actual data and error is determined. If the error is within limits the output is stored, but if it’s not in the limit then the rules are modified and the process is repeated again.

3.7: Data and Rules

For the development of fuzzy logic model, data is used from the [6]. The data is for the month of October. The data is in normalized form and is normalised using equation 3.1. Table 1 shows the data. Equation 3.2 is used for finding the absolute relative error.

$$X_s = \frac{(A_{max} - A_{min})}{(X_{max} - X_{min})}(X - X_{min}) + A_{min} \quad (3.1)$$

Xs = Normalized data.

X = Original data.

Xmax = Maximum value in a data set.

Xmin = Minimun value in a data set.

Amax = Upper limit (0.9)

Amin = Lower limit (0.1)

$$\frac{1}{a}\sum_{t=1}^{n}\left|\frac{X_t - Y_t}{X_t}\right| \quad (3.2)$$

Xt = Actual Value.

Yt = Forecasted Value

a = Number of days

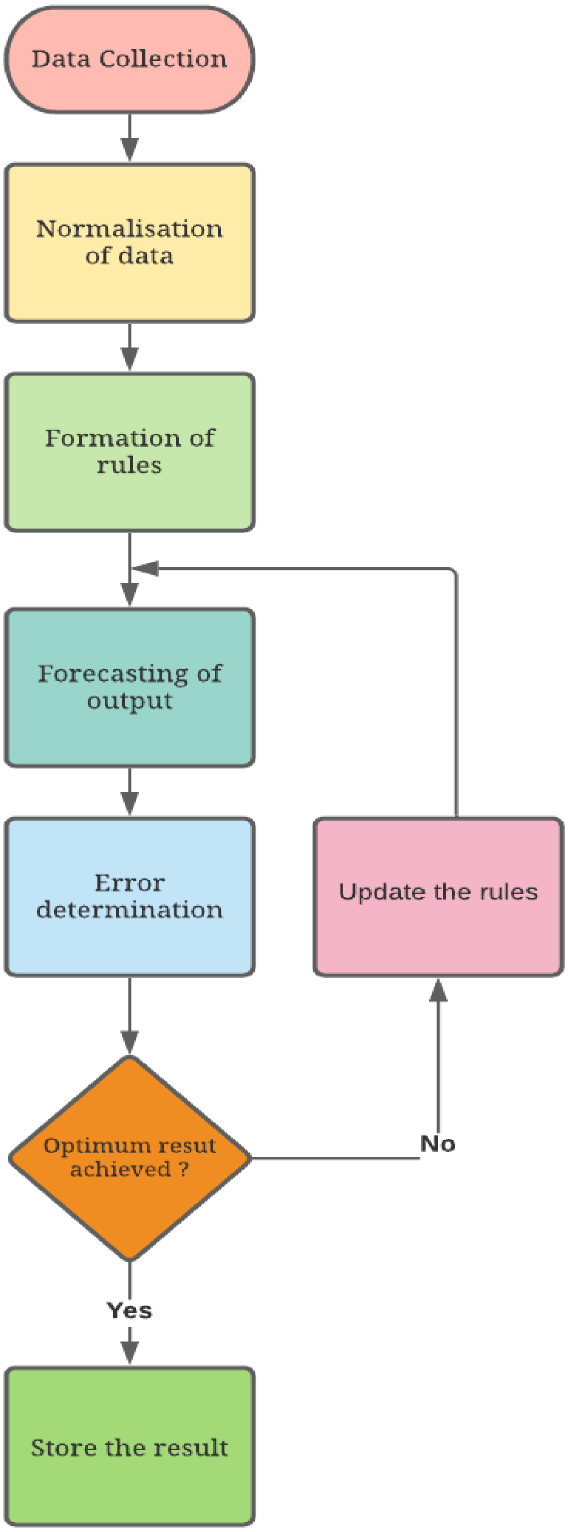

Figure 3.9: Fuzzy logic working flowchart

Table 3.1. Table Irradiance Data for October Month

Input				Output
0900hrs	**1000hrs**	**1100hrs**	**1200hrs**	**1300hrs**
0.848	0.786	0.812	0.858	0.898
0.858	0.808	0.882	0.676	0.646
0.716	0.785	0.845	0.863	0.796
0.817	0.808	0.877	0.875	0.580
0.784	0.741	0.720	0.830	0.823
0.817	0.708	0.810	0.753	0.803
0.731	0.740	0.793	0.376	0.732
0.696	0.638	0.803	0.800	0.741
0.857	0.852	0.887	0.882	0.841
0.877	0.854	0.896	0.871	0.830
0.837	0.780	0.800	0.781	0.776
0.836	0.789	0.772	0.780	0.733
0.819	0.745	0.762	0.365	0.381
0.100	0.100	0.100	0.100	0.100
0.739	0.730	0.766	0.737	0.653
0.850	0.752	0.793	0.815	0.750
0.809	0.702	0.779	0.772	0.712
0.734	0.747	0.809	0.805	0.772
0.795	0.764	0.781	0.767	0.685
0.703	0.650	0.718	0.693	0.559
0.674	0.717	0.707	0.710	0.584
0.602	0.630	0.695	0.713	0.603
0.618	0.665	0.729	0.650	0.583
0.567	0.599	0.658	0.638	0.549
0.486	0.490	0.596	0.577	0.480
0.570	0.581	0.672	0.669	0.572
0.553	0.578	0.698	0.698	0.626
0.567	0.580	0.689	0.667	0.561
0.430	0.665	0.134	0.417	0.498
0.472	0.506	0.479	0.683	0.550
0.412	0.520	0.569	0.481	0.458

Rules are formed on the basis of the data given. Here, a set of multiple predecessor fuzzy rules are developed for every one hour for short term solar energy forecasting the rules are shown in Table 3.2.

Table 3.2. Table Irradiance Data for October Month

S No.	INPUT 1	INPUT 2	INPUT 3	INPUT 4	OUTPUT
1	vh	hh	hh	vh	vh
2	vh	hh	vh	mh	mh
3	mh	hh	vh	vh	hh
4	hh	hh	vh	vh	vh
5	hh	hh	hh	vh	vh
6	hh	hh	hh	hh	hh
7	hh	hh	hh	ll	hh
8	hh	mh	hh	hh	hh
9	hh	vh	vh	vh	vh
10	vh	vh	vh	vh	hh
11	hh	hh	hh	hh	hh
12	hh	hh	hh	hh	hh
13	hh	hh	hh	ll	vl
14	vl	vl	vl	vl	mh
15	hh	hh	hh	hh	hh
16	vh	hh	hh	vh	hh
17	hh	mh	hh	hh	mh
18	hh	hh	hh	hh	hh
19	hh	hh	hh	hh	mh
20	mh	mh	mh	mh	mh
21	mh	mh	mh	mh	mm
22	mm	mm	mh	mh	mm
23	mh	mh	hh	mh	mm
24	mm	mm	mh	mh	mm
25	mm	mm	mm	mm	mm
26	mm	mm	mh	mh	mm
27	mm	mm	mh	mh	mh
28	mm	mm	mh	mh	mm
29	ll	mh	vl	ll	mm
30	mm	mm	mm	mh	mm
31	ll	mm	mm	mm	ll

3.8: Results

From the fuzzy logic model developed, the results are obtained. Then defuzzification of the results is done to get the output. Comparison is done between actual data and the forecasted output data (obtained from the fuzzy logic model). The results are tabulated in Table and for the performance evaluation of the fuzzy logic model absolute percentage error (ARE) is calculated. Figure 3.10 shows result for the 12th rule.

Table 3.3. Output data for fuzzy logic forecasting

S No.	**Actual Data (W/m^2)**	**Predicted Reading (W/m^2)**	**ARE (%)**
1	811	707.64	12.7
2	632	664.05	5
3	737	711.16	3.5
4	775.84	716.78	7.6
5	756.86	700	7.5
6	742.79	687.95	7.4
7	692.87	687.95	0.7
8	699.2	687.95	1.6
9	769.51	730.14	5.1
10	761.78	729.63	4.2
11	723.81	687.95	4.9
12	693.58	687.95	0.8
13	446.07	459.43	3
14	248.5	273.11	9.9
15	637.33	642.95	0.9
16	705.53	692.87	1.8
17	678.81	687.95	1.34
18	721	691.46	4.1
19	659.83	683.73	3.6
20	571.23	616.93	8
21	588.81	603.58	2.5
22	602.17	582.48	3.26
23	588.11	580.37	1.32
24	564.20	575.45	2.06
25	515.68	529.75	2.73
26	580.37	582.48	0.36
27	618.34	607.09	5.8
28	572.64	582.48	1.71
29	528.34	529.75	0.26
30	564.91	543	3.86
31	500.22	464.35	7.17

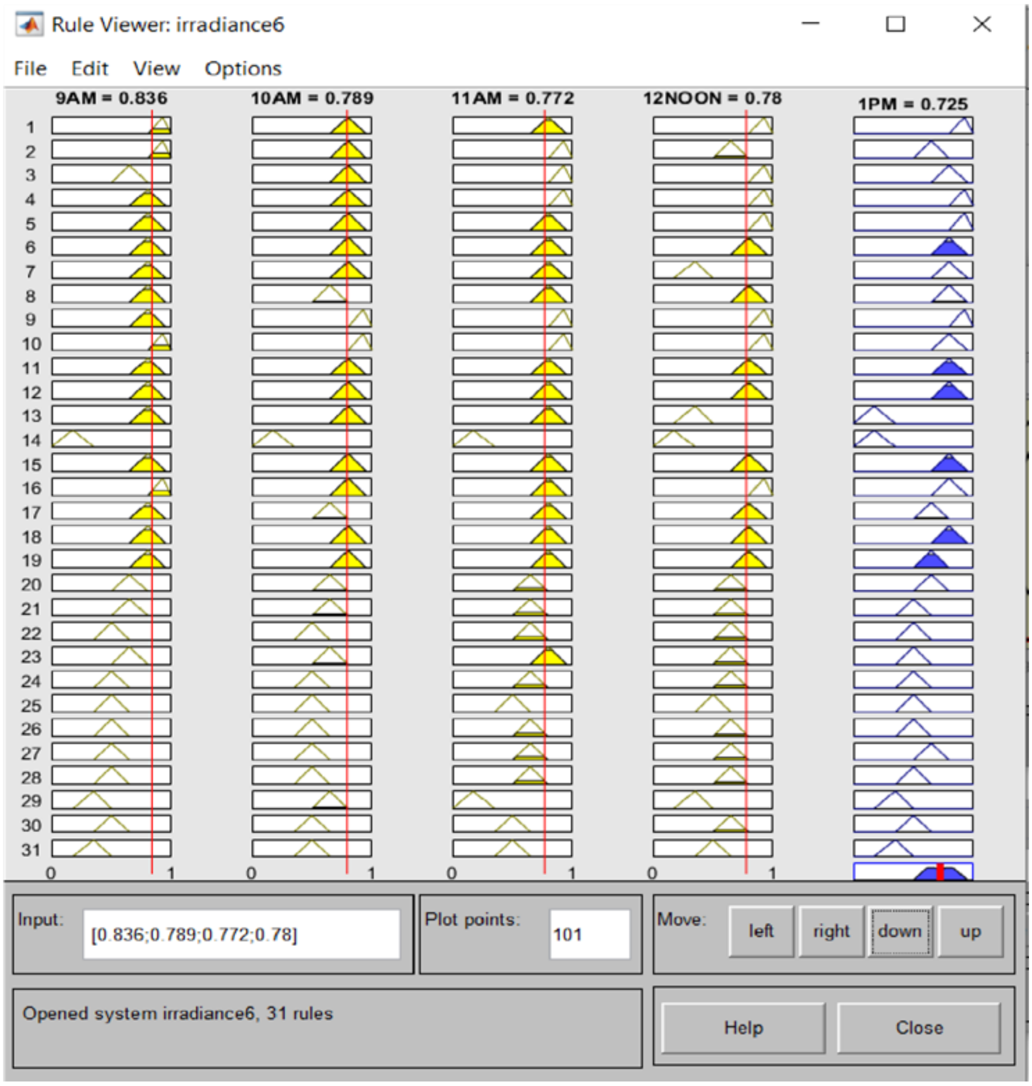

Figure 3.10: Rule viewer showing 12th rule output

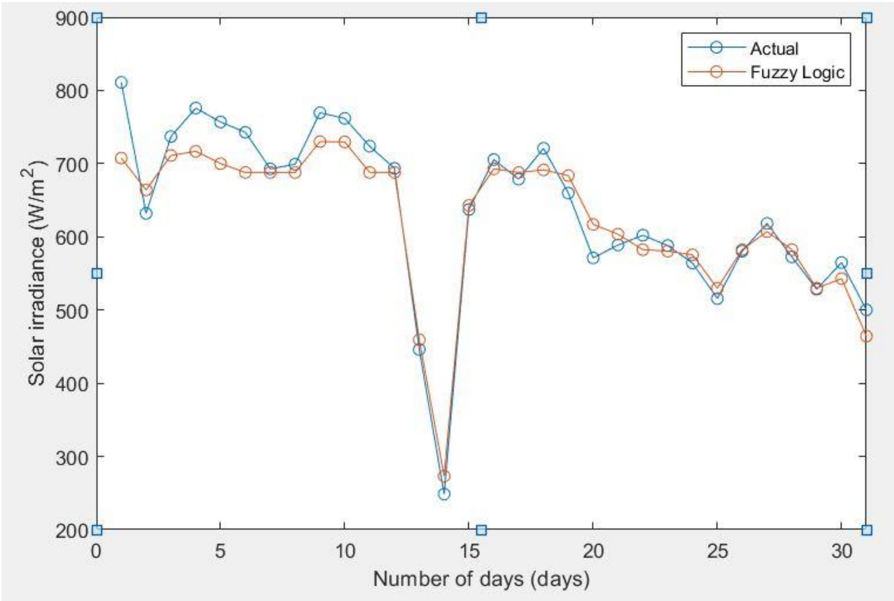

Figure 3.11: Graph comparing actual data and fuzzy logic data

3.9: Conclusion

In this chapter basics about fuzzy logic is discussed in details. Different component of fuzzy logic is also discussed. Triangular membership function is used in this report. For inference system Mamadani Inference System is chosen. For defuzzification purpose centroid defuzzification is chosen. From Table 3.3 it is clear that minimum absolute relative percentage error (ARE) comes out to be 0.26% and maximum absolute relative error comes out to be 12.7 %. Therefore, mean absolute percentage error (MAPE) of the fuzzy logic model developed comes out to be 4.02%. The error is quite low and hence fuzzy logic model developed is quite accurate and can further be used for forecasting.

CHAPTER 4

SOLAR ENERGY FORECASTING USING ARTIFICIAL NEURAL NETWORK

4.1: Introduction

Artificial neural network (ANN) is as computing system based on biological neural network. It’s functioning is based on how the biological neuron presents in the brains of human being operate. Just like in human brain different neuron are connected, similarly in ANN different non-linear neuron are connected so that communication can take place.

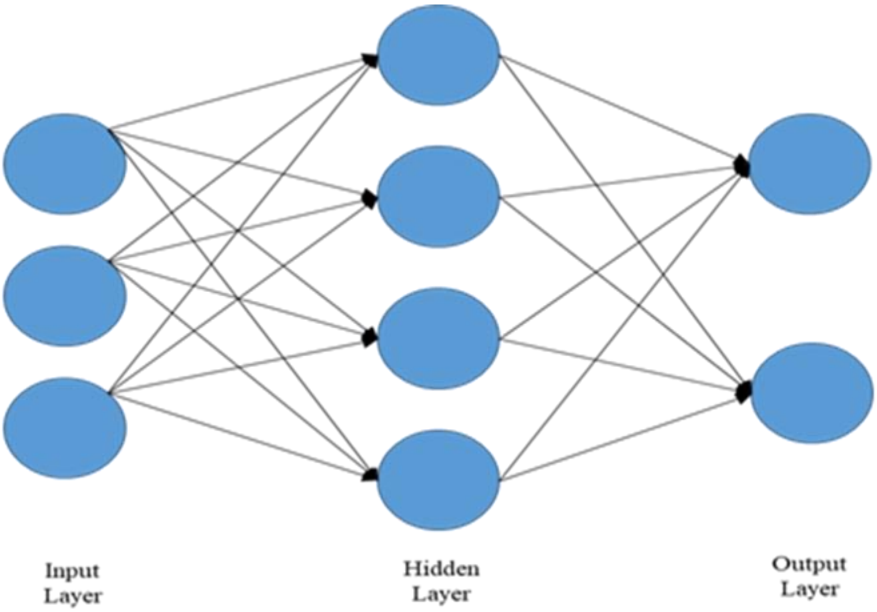

Figure 4.1: Basic structure of ANN

ANN are used for performing various task such as optimisation, recognition of pattern, forecasting and prediction services etc. Whether system is linear or non-linear, ANN can be applied to both the system [7], [8], [9]. For a complex system having complex relationship between input and output can be found easily with the help of ANN. ANN generally has three layers. First layer is the input layer. The input layer consist of data which is to be processed. Second layer is the hidden layer. This layer processes the data obtained from the first layer. The third layer is the output layer where data processed by the hidden layer is received. The Figure 4.1 shows the basic structure of ANN.

4.2: ANN Architecture

As it was discussed earlier that ANN consist of three layers. This is not necessary as it depends upon the user and applications. Also the number of neurons in each layer depends upon the requirement of the user and/or application. Figure 4.2 shows the architecture of ANN and how it operates. As we know that the input layer can have as many neurons as user like (generally it is equal to the number of input in that particular system). Each neuron represent an input in input layer [7]. They are then adjusted using weights and biases. How much will be the effect of the input on the output is decided by weights and activation of neuron even when input is zero is incurred by the biases. Majority of data fed is used for training, while remaining data is divided into equal parts and are used for validation check and testing.

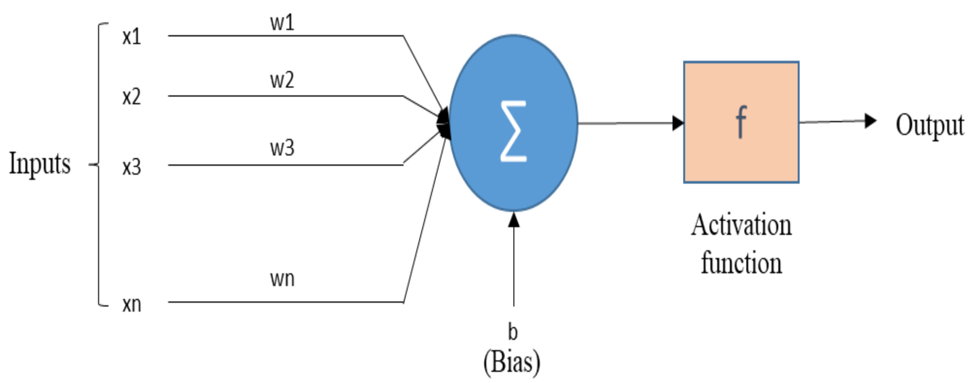

Figure 4.2: Architecture of ANN

$$y = f(b + \sum w_i x_i) \quad (4.1)$$

y = Output vector

b = Bias

w_i = Weights corresponding input x_i

x_i = Input vector

f = Activation function

4.3: Building Block of ANN

ANN consist of three parts:

1. Topology of network
2. Weights adjustment or learning
3. Activation function

4.3.1: Topology of Network

There are two types of network topology generally preferred in designing of ANN network. They are as follows:

1. Feed forward network
2. Feedback network

FEED FORWARD NETWORK: It is most widely used network topology in ANN. The network topology does not consist of any feedback path. Here data/signal flows only in one direction i.e from input to output. In this dissertation feed forward network is used [10]. Feed forward network is capable of learning relationship between input and specified output. There are two types of feed forward network:

1. Single layer
2. Multi-layer

Generally multilayer feed forward network is used. It usually consist of three basic layer input layer, hidden layer and output layer.

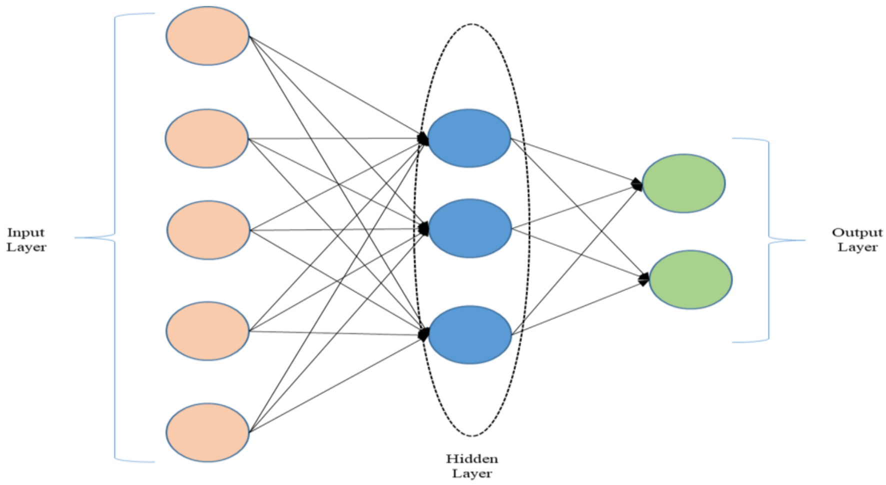

Figure 4.3: Feed forward network diagram

FEED-BACK NETWORK: From the name it is clear that network has a feedback path. The signal flows in both the direction. The system which uses feedback is non-linear and it changes dynamically until equilibrium is reached. Generally there are three types of feedback network:

1. Recurrent network
2. Jordan Network
3. Fully recurrent network

4.3.2: Weight Adjustment or Learning

By adjusting or modifying the weights corresponding to a connection between neuron, performance of artificial neural network can be optimized. There are three types of learning employed in artificial neural network:

1. Supervised learning
2. Unsupervised learning
3. Reinforced learning

SUPERVISED LEARNING: In this learning, input is given to the ANN network and output is obtained from this network. Once the output is obtained it is compared to the actual output and error is determined. If the output produced differs from actual output. Depending on the error, weights and biases are adjusted to get the desired results. Figure 4.4 shows the basics block diagram of supervised learning.

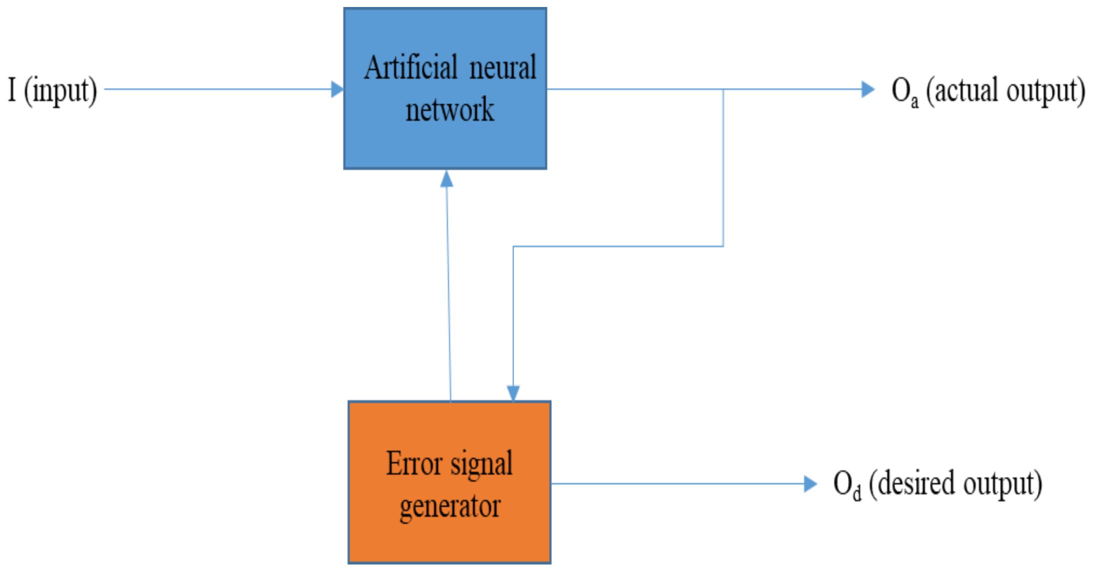

Figure 4.4: Supervised learning block diagram

UNSUPERVISED LEARNING: In this type of learning, error is not calculated. There is no feedback in this type of learning. Here network itself has to discover pattern from the input data, and relationship between input data and output data. Figure 4.5 shows the block diagram explaining unsupervised learning.

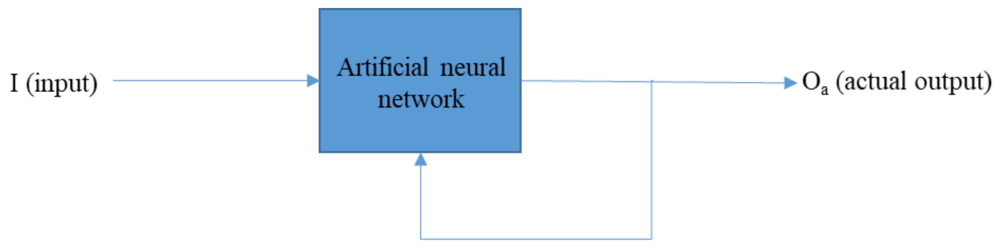

Figure 4.5: Unsupervised learning block diagram

REINFORCED LEARNING: It is similar to supervised learning. Here only input is provided and network has to find a way to obtain output. To help the network in finding output a reinforcement signal is provided. Feedback is provided in this type of learning. Figure 4.6 shows the block diagram explaining reinforced learning.

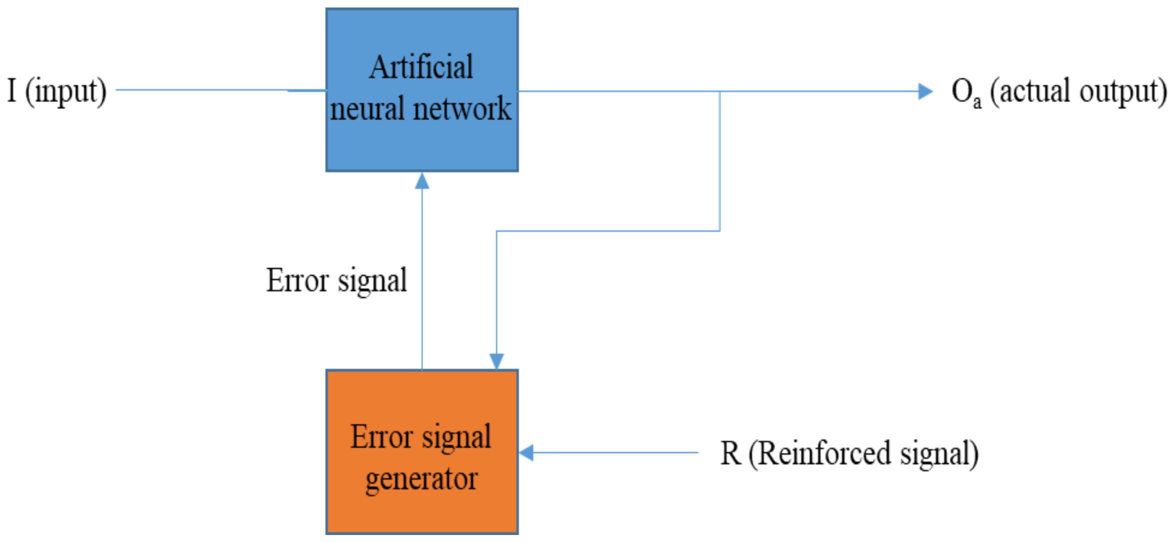

Figure 4.6: Reinforced learning block diagram

4.3.3: Activation Function

It is the extra effort which is provided with the input to get desired output. Some of the activation functions are as follows:

1. Linear Function
2. Sigmoid Function

4.4: Model

For the development of ANN model in this dissertation MATLAB software is used. MATLAB has several application which deals with ANN and one of them is 'nftools'. Here 'nftools' application is used for the development of ANN model. Here data used for ANN model is given in Table 3.1 in Chapter 3. But first data is stored in MS-EXCEL file. 'nftools' application is also used for generating MATLAB code for the given ANN model which provides more control in designing the ANN model. Number of neuron here takes is 15. As discussed in the previous chapter, here feed forward neural network (FFNN) is used. As the model developed is feed forward network type so there is no feedback. Back propagation algorithm is used here as it is type of supervised learning. Here weights and biases are allocated by the software itself.

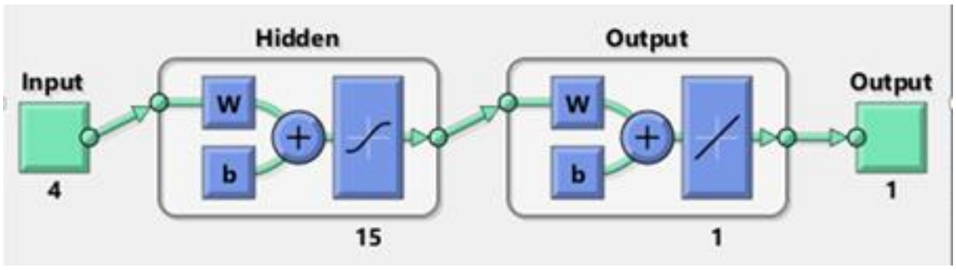

Figure 4.7: ANN model developed using nftool

Here training of ANN network is done by using 'Levenberg-Marquardt Algorithm'. This algorithm is considered as the fastest back propagation algorithm. As discussed in the previous chapter that some part of data is used for training the network and remaining part of data is used for validation and testing purpose. So in the ANN model developed:

1. 70 % of data is used for training the ANN network.
2. 15 % data is used for validation check
3. 15 % data is used for testing

4.5: ANN algorithm

The flow chart given below explains the how the ANN model developed operates.

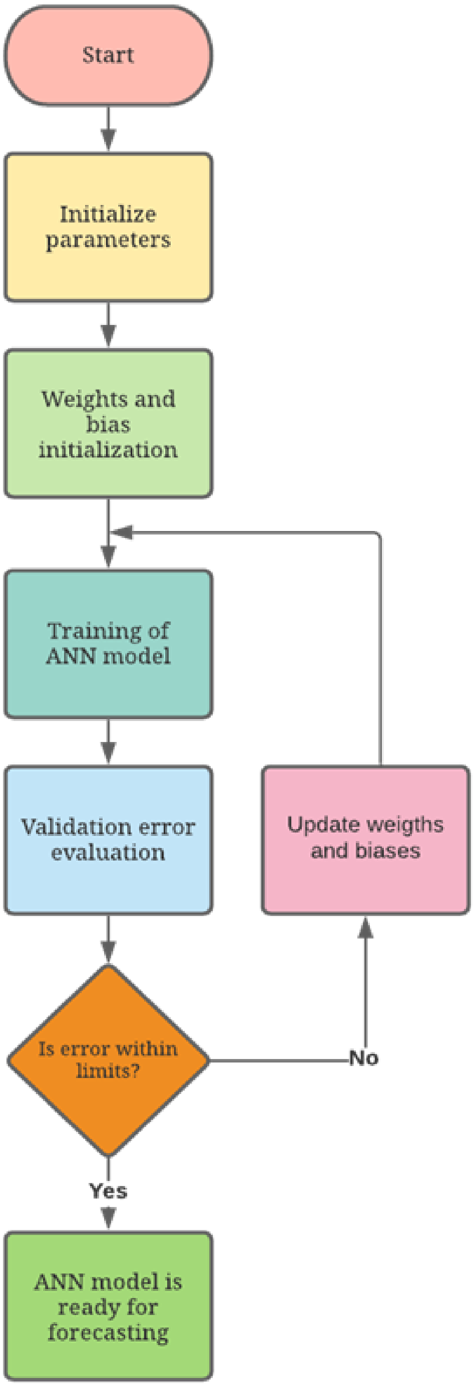

Figure 4.8: Flowchart of ANN model

4.6: Results

The results are tabulated in Table 4.1. Data for the ANN model is obtained from Table. The data is for the month of October. Normalized data is used and it is normalized using equation. For percentage error calculation equation is used.

Table 4.1. ANN forecasting result

Actual Data (W/m^2)	ANN Output (W/m^2)	ARE (%)
811	763.2	5.8
632	638.03	0.95
737	740	0.4
775.84	761.1	1.9
756.86	741.4	2.04
742.79	704.1	5.21
692.87	577	16.72
699.2	723.81	3.46
769.51	765.3	0.58
761.78	762.5	0.1
723.81	714	1.34
693.58	713	2.88
446.07	573	28.52
248.5	245	1.4
637.33	667	4.56
705.53	746.1	5.78
678.81	715.6	6
721	714	0.91
659.83	698	5.78
571.23	637	11.56
588.81	626.7	6.44
602.17	617	2.5
588.11	578.3	1.7
564.20	550.8	2.37
515.68	506.5	1.78
580.37	575.4	0.86
618.34	595.1	3.75
572.64	575.4	0.48
528.34	535.4	1.14
564.91	578.9	2.35
500.22	501	0.18

Figure 4.9 shows the validation performance of the ANN model developed. Figure 4.10 shows the regression plot obtained for the ANN model developed.

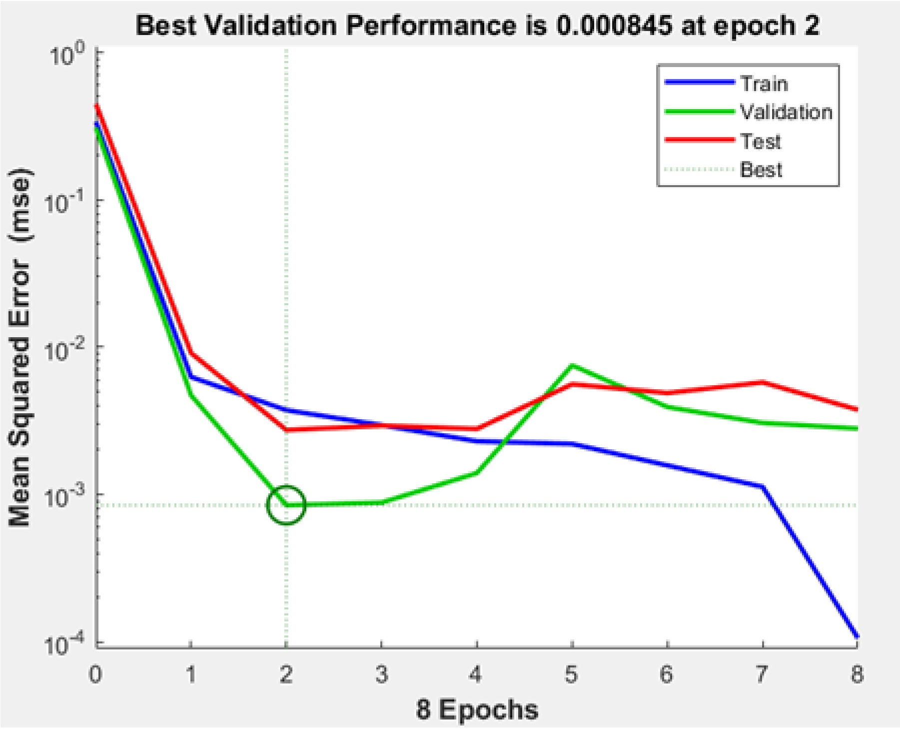

Figure 4.9: ANN model validation performance

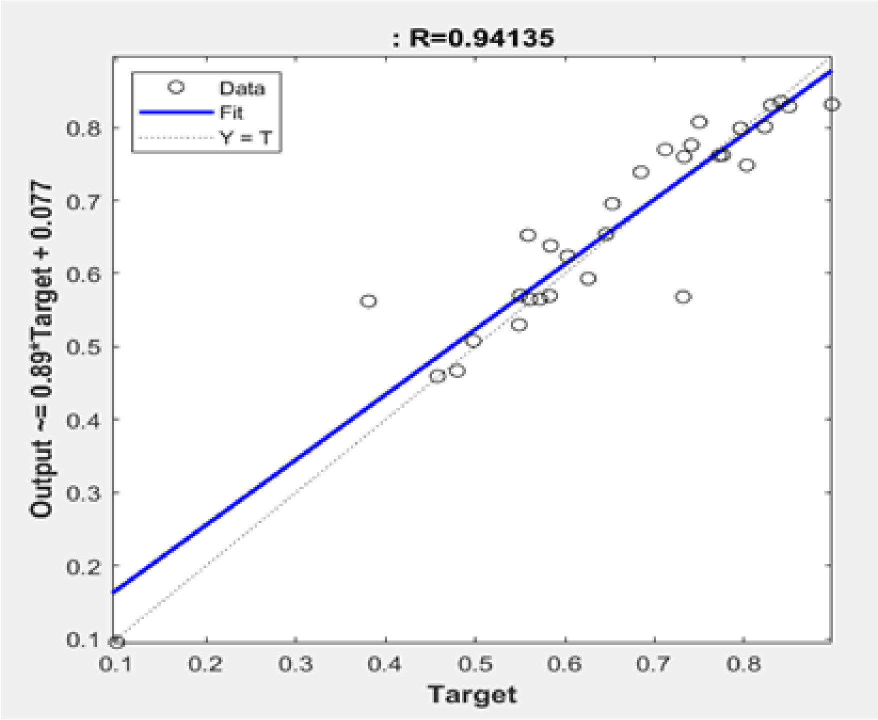

Figure 4.10: ANN model regression plot

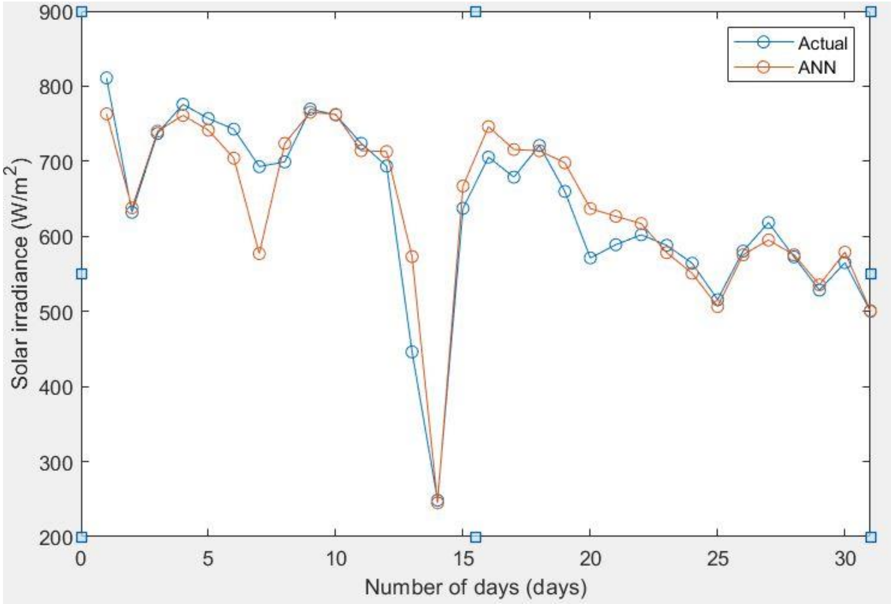

Figure 4.11: ANN data and actual data comparison

Figure 4.11 shows the comparison of the actual data and the data obtained from the ANN model developed. The minimum absolute percentage error calculated comes out to be 0.1% and maximum absolute percentage error comes out to be 28.52%. Hence mean absolute percentage error (MAPE) comes out to be 4.18%.

4.7: Conclusion

In this chapter basics about artificial neural network is discussed. In this dissertation multilayer neural network is used. Supervised learning is applied in the ANN model developed. Feed forward neural network is used for the development of ANN model. For learning backward propagation is used. Here forecasting using ANN is simple and effective and percentage error comes to be very low. MAPE is 4.18% for the ANN model developed. Hence the forecasting using ANN is quite accurate. However it is less accurate as compared to fuzzy logic. In the further chapters optimization techniques are studied and suitable optimization technique is applied to ANN to increase its accuracy.

CHAPTER 5

FORECASTING OF SOLAR ENERGY USING PSO OPTIMIZATION TECHNIQUE

5.1: Basic

In simple terms optimization can be described as the process by which the best outcome is obtained for a given solution under certain specified circumstances. Engineering system during construction maintenance includes certain decision which have certain goals associated with. These goals are to maximize benefits and minimize effort.

Optimization definition is "Procedure for finding circumstances which give highest or lowest value of function. Here the function can be effort required or benefit required". Initially the optimization problems involved lot of tedious and complex calculation and estimate has to be done to predict data. But now a days as fast computers have been developed so these calculation can be done easily and hence optimization problems can be handled very easily using fast digital computers.

5.2: Optimization Model Building

For the optimization model development five steps are generally followed.

1. Data collection
2. Defining and formulating problem
3. Development of model
4. Performance validation and evaluation of model
5. Application and interpretation of model results.

DATA COLLECTION: Most important phase in the development of model. It generally takes time but it is the core of the model development process. Data accuracy can have significant effect on the developed model's accuracy.

DEFINING AND FORMULATING PROBLEM: It involves the following step:

1. Identifying the variables
2. Development of objectives of model
3. Formation of constraint of model.

However structure and complexity of model should be evaluated. Important components of the problem should be identified. Independent variables, equations for describing the system should be determined.

MODEL DEVELOPMENT: It involves:

1. Estimation of parameters
2. Development of software
3. Development of input

It is a repetitive process in which it is required to return to definition and formulation.

PERFOEMANE VALIDATION AND EVALUATION OF MODEL: Here in this step model developed are validated for the model. For the performance evaluation mean square error is calculated. Here one important thing is that data used for validation check should be different from the data used for testing.

5.3: Components of Optimization Problem

Optimization problem generally involve determining the variable values that either maximize or minimize the value of objective function while fulfilling the constraints. It has the following components:

1. Objective function.
2. Constraints
3. Variables
4. Search space and search landscape.

OBJECTIVE FUNCTION: It is the mathematics function, which is to be maximize or minimize while following the constraints on the variable. Generally the optimization problems have single objective function. It is explained using an example given below.

Let us consider a unknown variable vector ‘y’ and we have to find the value of these unknown vector which either maximize or minimize the f(y) which is the objective function. Here two other functions are also provided $a_i(y) <= 0$ and $b_j(y) = 0$ these two are the inequality and equality constraint. However the constraint are not necessary to define the optimization problem, they can be define without them.

VARIABLES AND CONSTRAINTS: Variables or unknown parameters control the objective function. These are necessary for defining objective function. However constraints are not necessary. It depends upon the problem, some problem require constraints whereas some problem do not require any constraints. Constraints are mainly two types:

1. Functional constraints: They limit the behaviour of the system
2. Geometric constraints: They are used for representing limit or physical behaviour.

SEARCH SPACE AND SEARCH LANDSCAPE: Search space is basically all the possible combination of the input. Search landscape is the all the possible input and their corresponding objective function values. Depending upon the relation between input and output search landscape can be unimodel or multimodel. A unimodel search landscape has only one optimum solution which is the best solution. There are no local optima. A multimodel search landscape has multiple local solution.

5.4: Optimization Techniques

Generally stochastic optimization algorithm is used now a days for solving the problem. There are two types of stochastic algorithm:

1. INDIVIDUAL BASED ALGORITHM: Here one solution is obtained. Then that solution is further improved and evaluated. Number of iterations taken here are minimum.
2. POPULATION BASED ALGORITHM: Here a set of solution is used for determining global optimum. Here initial solution is constantly improved.

Generally population based algorithm is used for solving various optimization problem. Population based algorithm has three types:

1. EVOLUTIONARY: It is inspired by the laws of the nature. Best individual are combined together to get next best individual. Genetic Algorithm optimization is the best example of this type.
2. PHYSICS BASED: These type of algorithm imitates the physical laws of the nature.
3. SWARM BASED: These algorithm mimic the behaviour of groups of animals like bees, ants, birds etc. Particle swarm optimization algorithm, Ant colony

optimization algorithm, Grey wolf optimization algorithm etc. are some the famous algorithm techniques of this type.

Some of the famous optimization algorithm are as follows:

1. Genetic Algorithm (GA)
2. Particle Swarm Optimization (PSO)
3. Artificial Bee Colony (ABC)
4. Grey Wolf Optimization (GWO) etc…

GENETIC ALGORITHM: The algorithm is based on the theory of evolution and the survival of the fittest. This algorithm by using certain operators known as crossover, mutation and selection, it searches for the solution by natural selection [18].

GA incorporates the variable into solution of finite length. Genetic algorithm searches from the given population among the solutions instead of starting its search from single point. Initial Population is randomly created. Operators are by GA to get optimum solution.

ARTIFICIAL BEE COLONY ALGORTIHM: This algorithm is based on the food searching behaviour of the bees. Here artificial colony of bees has 3 parts: employed bees, onlooker bees and scout bees. Place where food is available is searched by employed bees. Once they have found the food, they perform a waggle dance which indicate the amount of food available [18]. Onlooker bees then identifies the dance and depending upon the food availability they follow the employed bees. When food source for a employed bee becomes abandoned they then start behaving as scout bees and start the search of new food source.

This behaviour of bees are used for solving the optimization problem by dividing bees population into employed and onlooker bees. Employed bees look for solution and value of objective function. Onlooker bees choses source of food according to the probability value associated with source of food.

5.4.1: Particle Swarm Optimization Techniques

This optimization techniques is based on the behaviour of birds in a swarm. This optimization technique was developed by Eberhart and Kennedy. It is an evolutionary computation technique. In this optimization technique ‘particles’ are there. They are considered as the solution. These particles move in search landscape. Each particle has best solution known as ‘pbest’. Global best values known as ’gbest’ are also determined by the PSO.

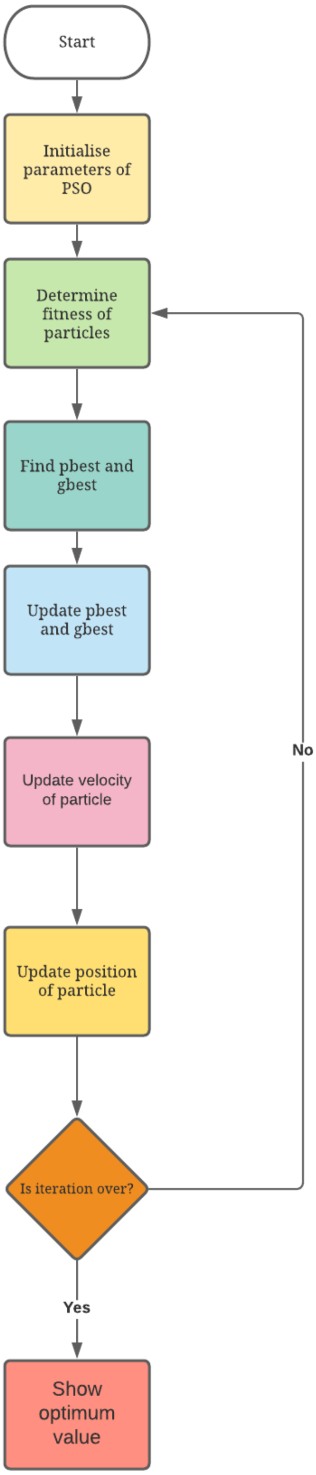

Figure 5.1: Flowchart of PSO algorithm

To achieve 'gbest' velocity and position of the particles have to change continuously so that best solution is reached by the particles. The velocity and position of particles are updated continuously till solution is achieved.

$$V_{t+1} = wV_t + c_1 r_1 (P_t - X_t) + c_2 r_2 (G_t - X_t) \qquad (5.1)$$

$$X_{t+1} = X_t + V_{t+1} \qquad (5.2)$$

Equation 5.1 shows the velocity vector and equation 5.2 shows the position vector. Intensity of movement of the particles is determined from equation 7.1 and position of particles in search land scape is determined from equation 5.2. r_1 and r_2 are randomly generated numbers having value between 0 and 1. c_1 and c_2 are acceleration constant and w is the inertia constant. Figure 5.1 shows the flow chart explaining the functioning of the PSO algorithm. Following steps are followed for PSO optimization:

1. Initialize the PSO parameter. These are population size, inertia weight, termination criteria, maximum velocity and constraints.
2. Random population equal to population size is generated. Value of design variables is contained by population member.
3. Values of the objective function is obtained for all population member. From the values pbest and gbest are identified.
4. Velocity of particles is continuously updated.
5. Particles position is continuously updated.
6. For all the particle value of objective function is determined. Pbest is continuously updated and finally gbest is obtained.

5.5: ANN-PSO Introduction

As discussed earlier, that output of ANN can be influenced by controlling the weights and biases. When ANN is normally used, weights and biases are assigned randomly. If the ANN training is repeatedly done, then value of weights and biases are changed after each training. So it becomes difficult to determine the optimum value of weights and biases to get the optimum results. So in order to solve this problem optimization techniques can be used. The optimization algorithm used here is Particle Swarm Optimization (PSO has been discussed in previous chapter). With the help of PSO, optimum value of weights and biases of ANN is determined for which mean square error is minimum. Coding for the ANN optimized by PSO is done in MATLAB.

5.6: ANN-PSO Algorithm

Step 1: First create a MATLAB file for the objective function here it is mean square error of ANN. PSO is used to minimize the mean square error by finding optimum values of weights and biases.

Step 2: Create another MATLAB file for writing PSO algorithm. Here define the ANN parameters like number of neurons, what training function is used, whether it is feed forward or feedback network etc.

Step 3: Now define the parameters for the PSO algorithm like number of particles, maximum number of iteration, constraints, constant etc.

Step 4: Initially when PSO start, it will determine the velocity and position of each particle after each iteration and will keep updating the velocity and position of each particle.

Step 5: It will also continuously determine the value of objective function i.e mean square error and will keep on updating after each iteration till best solution is obtained. Here best solution means lowest mean square error.

Step 6: Once the gbest is determined then corresponding weights and biases are stored. Weights and biases of ANN is then replaced by the new weights and biases found using PSO algorithm.

Step 7: ANN optimized by PSO is now ready to be used.

5.7: ANN-PSO result

Table 5.1 shows the result obtained for the data given in Table 3.1 in chapter 3. From the table we can see that the minimum absolute relative error comes out to be 0.25 % and maximum absolute relative error comes out to be 7.72% and mean absolute percentage error comes out to be 3.23%. Figure 5.2 shows the regression plot obtained for PSO optimized ANN and Figure 5.3 shows the comparison between actual and ANN-PSO result.

Table 5.1. Output data table for ANN-PSO

Actual Data (W/m^2)	ANN-PSO output (W/m^2)	ARE (%)
811	764	5.8
632	641.5	1.5
737	735.1	0.25
775.84	793.4	2.3
756.86	698.5	7.72
742.79	708.3	4.64
692.87	653.5	5.68
699.2	714	2.1
769.51	784.3	1.8
761.78	778	2.1
723.81	695.7	3.8
693.58	677.4	2.33
446.07	476.3	6.7
248.5	242.2	2.5
637.33	652.1	2.3
705.53	733.6	3.9
678.81	706.2	4
721	702.7	2.5
659.83	679.5	2.9
571.23	609.2	6.2
588.81	622.6	5.74
602.17	595.8	1.05
588.11	602.8	2.5
564.20	595.8	5.6
515.68	520	0.83
580.37	574.8	0.96
618.34	571.2	7.6
572.64	584.6	2.1
528.34	530.4	0.4
564.91	560.7	0.7
500.22	510.1	1.26

5.8: Conclusion

In this chapter basics of optimization, different types of optimization techniques, why optimization is done is discussed. As in this dissertation Particle Swarm Optimization technique is used, so PSO algorithm is discussed in details. PSO algorithm technique is applied to ANN to get the optimized ANN model which is further used in forecasting.

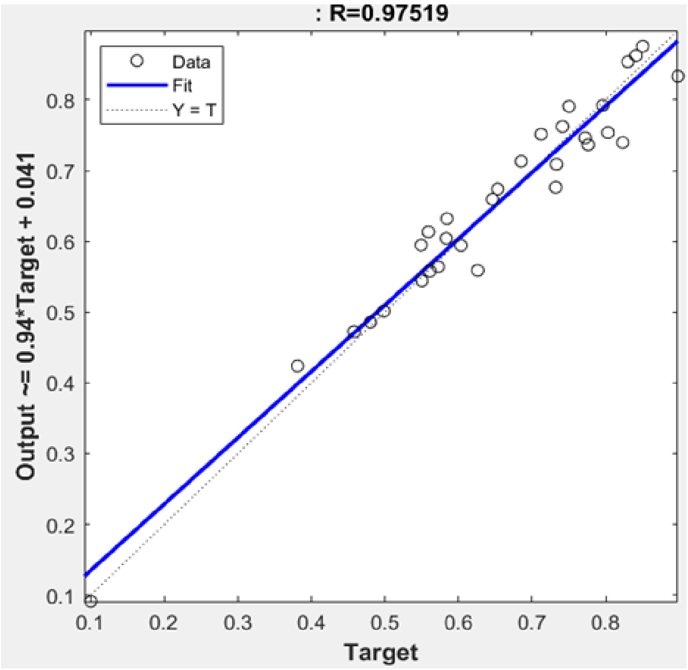

Figure 5.2: Regression plot for ANN-PSO result

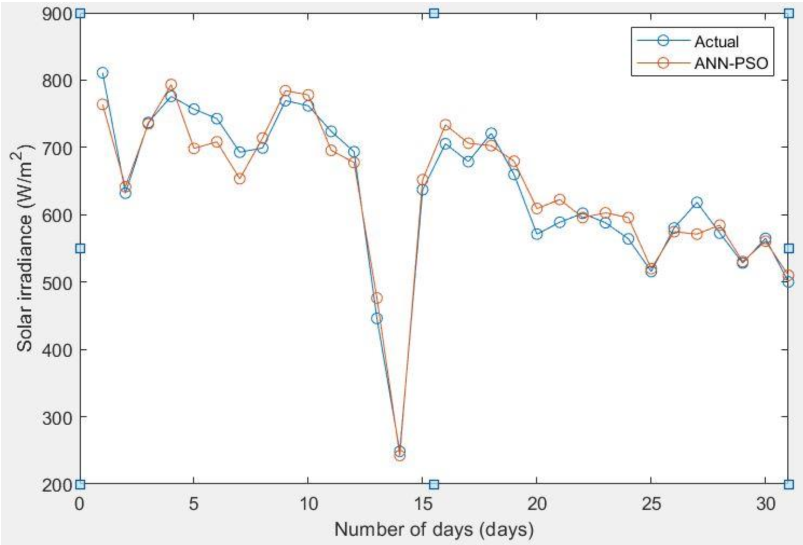

Figure 5.3: Graph comparing actual data and ANN-PSO data

From the mean absolute percentage error obtained it is clear that the output of ANN is improved by optimization and this improvement is significant. For ANN MAPE was 4.18% and for ANN-PSO MAPE was about 3.23%. This is significant improvement over ANN result. Accuracy is significantly increased and also when comparing to fuzzy logic the ANN-PSO gives better result.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1: Conclusion

The main objective of the work presented in this dissertation was to understand the forecasting of solar energy for solar photovoltaic system. For the forecasting, short term energy forecasting is done and for this purpose three methods were chosen namely fuzzy logic, ANN and PSO optimized ANN. In this dissertation we are able to understand the working of fuzzy logic, how it is used for forecasting, how it tackles the continuously varying parameters, different types of neural networks and how neural networks work and how ANN can be used for forecasting purpose and various optimization techniques were also studied and PSO algorithm was chosen to improve the result of ANN. Main reason behind choosing PSO algorithm was that it is simple to understand, easy to implement and less complex. Fuzzy logic gives better results as compared to ANN because it takes into account sudden and vague variations of data. In ANN, the network has to be trained multiple times to get the accurate result. In order to improve the ANN result, neural network is optimized by PSO. Comparison is also done among the three techniques and it is found that generally fuzzy logic (MAPE: 4.02%) gives better result as compared to ANN (MAPE: 4.12%) but when ANN is optimized using PSO (MAPE: 3.23%) algorithm, ANN results are improved and better results are obtained.

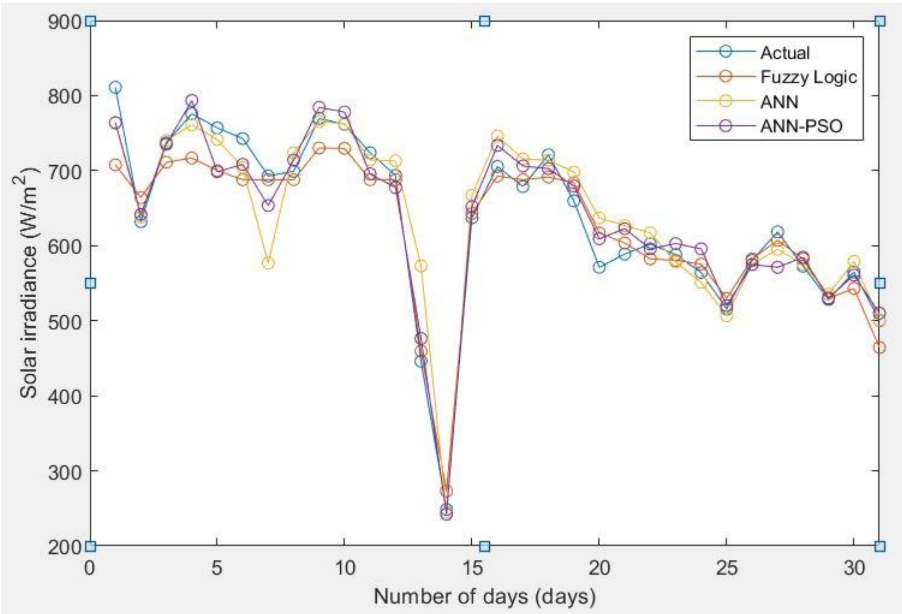

Figure 6.1: Graph comparing three methods output with actual data

Table 6.1. Output data table for three methods

Actual Data (W/m^2)	Fuzzy Logic output (W/m^2)	ANN output (W/m^2)	ANN-PSO output (W/m^2)
811	707.64	763.2	764
632	664.05	638.03	641.5
737	711.16	740	735.1
775.84	716.78	761.1	793.4
756.86	700	741.4	698.5
742.79	687.95	704.1	708.3
692.87	687.95	577	653.5
699.2	687.95	723.81	714
769.51	730.14	765.3	784.3
761.78	729.63	762.5	778
723.81	687.95	714	695.7
693.58	687.95	713	677.4
446.07	459.43	573	476.3
248.5	273.11	245	242.2
637.33	642.95	667	652.1
705.53	692.87	746.1	733.6
678.81	687.95	715.6	706.2
721	691.46	714	702.7
659.83	683.73	698	679.5
571.23	616.93	637	609.2
588.81	603.58	626.7	622.6
602.17	582.48	617	595.8
588.11	580.37	578.3	602.8
564.20	575.45	550.8	595.8
515.68	529.75	506.5	520
580.37	582.48	575.4	574.8
618.34	607.09	595.1	571.2
572.64	582.48	575.4	584.6
528.34	529.75	535.4	530.4
564.91	543	578.9	560.7
500.22	464.35	501	510.1

6.2: Future Scope

The future work is to study and apply more AI based forecasting technique for forecasting of power generated by SPV system, for different configuration. Effect of other parameters on solar power forecasting will be studied. As in this work short term forecasting is done. So in future long term forecasting will also be done. AI techniques will also be employed in forecasting of power generated from wind energy system. Following works are to be done in the future regarding this work:

- Hardware implementation of AI techniques for forecasting.
- Integrating AI forecasting technique for development of smart SPV system.
- Development of smart Energy Management System.

LIST OF PUBLICATION

On the basis of the work presented in this dissertation two conference papers are written and submitted in SCOPUS indexed conferences.

1. Md Tabish Ansari, M.Rizwan, “ Solar Energy Forecasting using Fuzzy Logic and Artificial Neural Network” 2021 International Conference on Smart Grids, Structures and Materials (ICSGSM 2021), Vijayawada, Andhra Pradesh.
2. Md Tabish Ansari, M.Rizwan, “ANN and PSO based Approach for Solar Energy Forecasting: A Step Towards Sustainable Power Generation” 2021 3rd International Conference on Recent Development in Control, Automation and Power Engineering, Noida, Uttar Pradesh.

REFERENCES

1. Gulnar Perveen, M. Rizwan, Nidhi Goel and Priyanka Anand (2020) Artificial neural network models for global solar energy and photovoltaic power forecasting over India, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, DOI: 10.1080/15567036.2020.1826017
2. M. Rizwan, Majid Jamil, Sheeraz Kirmani, D.P. Kothari, "Fuzzy logic based modeling and estimation of global solar energy using meteorological parameters", Energy, Volume 70, 2014, Pages 685-691, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2014.04.057
3. L. Alfredo Fernandez-Jimenez, Andrés Muñoz-Jimenez, Alberto Falces, Montserrat Mendoza-Villena, Eduardo Garcia-Garrido, Pedro M. Lara-Santillan, Enrique Zorzano-Alba, Pedro J. Zorzano-Santamaria, "Short-term power forecasting system for photovoltaic plants, Renewable Energy", Volume 44, 2012, Pages 311-317, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2012.01.108
4. Z. P. Ncane and A. K. Saha, "Forecasting Solar Power Generation Using Fuzzy Logic and Artificial Neural Network," 2019 Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa (SAUPEC/RobMech/PRASA), Bloemfontein, South Africa, 2019, pp. 518-523, doi: 10.1109/RoboMech.2019.8704737
5. B. Sivaneasan, C.Y. Yu, K.P. Goh, Solar Forecasting using ANN with Fuzzy Logic Pre-processing, Energy Procedia, Volume 143, 2017, Pages 727-732, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2017.12.753.
6. A. Chugh, P. Chaudhary and M. Rizwan, "Fuzzy logic approach for short term solar energy forecasting," 2015 Annual IEEE India Conference (INDICON), New Delhi, India, 2015, pp. 1-6, doi: 10.1109/INDICON.2015.7443206.
7. M. Rizwan, S. Saini and U. Singh, "Prediction of wind energy using intelligent approach," 2012 IEEE 5th India International Conference on Power Electronics (IICPE), Delhi, India, 2012, pp. 1-5, doi: 10.1109/IICPE.2012.6450459.
8. Mehta, Sahil & Basak, Prasenjit. (2019). Solar irradiance forecasting using fuzzy logic and multilinear regression approach: a case study of Punjab, India. International Journal of Advances in Applied Sciences. 8. 125-135. 10.11591/ijaas.v8i2.pp125-135.
9. R. M. Ehsan, S. P. Simon and P. R. Venkateswaran, "Artificial neural network predictor for grid-connected solar photovoltaic installations at atmospheric

temperature," 2014 International Conference on Advances in Green Energy (ICAGE), Thiruvananthapuram, India, 2014, pp. 44-49, doi: 10.1109/ICAGE.2014.7050142

10. S. M. M. Alam and M. H. Ali, "A New Fuzzy Logic Based Method For Residential Loads Forecasting," 2020 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), Chicago, IL, USA, 2020, pp. 1-5, doi: 10.1109/TD39804.2020.9299999.
11. F. A. O. Aashoor and F. V. P. Robinson, "Maximum power point tracking of photovoltaic water pumping system using fuzzy logic controller," 2013 48th International Universities' Power Engineering Conference (UPEC), Dublin, Ireland, 2013, pp. 1-5, doi: 10.1109/UPEC.2013.6714969.
12. C. Mishra, D. K. Mohanta and M. J. B. Reddy, "Impact of adaptive relaying in Smart Grid," 2014 14th International Conference on Environment and Electrical Engineering, Krakow, Poland, 2014, pp. 169-174, doi: 10.1109/EEEIC.2014.6835858.
13. A. D. Orjuela-Cañón, J. Hernández and C. R. Rivero, "Very short term forecasting in global solar irradiance using linear and nonlinear models," 2017 IEEE Workshop on Power Electronics and Power Quality Applications (PEPQA), Bogota, 2017, pp. 1-5, doi: 10.1109/PEPQA.2017.7981691.
14. S.X. Chen, H.B. Gooi, M.Q. Wang, “Solar radiation forecast based on fuzzy logic and neural networks”, Renewable Energy, Volume 60, 2013, Pages 195-201, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2013.05.011.
15. Manoja Kumar Behera, Irani Majumder, Niranjan Nayak, Solar photovoltaic power forecasting using optimized modified extreme learning machine technique, Engineering Science and Technology, an International Journal, Volume 21, Issue 3, 2018, Pages 428-438, ISSN 2215-0986, https://doi.org/10.1016/j.jestch.2018.04.013.
16. Pattanaik, Debasish, Mishra, Sanhita, Khuntia, Ganesh Prasad, Dash, Ritesh and Swain, Sarat Chandra. "An innovative learning approach for solar power forecasting using genetic algorithm and artificial neural network" Open Engineering, vol. 10, no. 1, 2020, pp. 630-641. https://doi.org/10.1515/eng-2020-0073
17. Le, L.T.; Nguyen, H.; Dou, J.; Zhou, J. A Comparative Study of PSO-ANN, GA-ANN, ICA-ANN, and ABC-ANN in Estimating the Heating Load of Buildings’ Energy Efficiency for Smart City Planning. Appl. Sci. 2019, 9, 2630. https://doi.org/10.3390/app9132630
18. H. T. Rauf, W. H. Bangyal, J. Ahmad and S. A. Bangyal, "Training of Artificial Neural Network Using PSO With Novel Initialization Technique," 2018 International

Conference on Innovation and Intelligence for Informatics, Computing, and Technologies (3ICT), 2018, pp. 1-8, doi: 10.1109/3ICT.2018.8855743.
19. Rao R.V., Savsani V.J. (2012) Advanced Optimization Techniques. In: Mechanical Design Optimization Using Advanced Optimization Techniques. Springer Series in Advanced Manufacturing. Springer, London. https://doi.org/10.1007/978-1-4471-2748-2_2
20. Aljanad, A.; Tan, N.M.L.; Agelidis, V.G.; Shareef, H. Neural Network Approach for Global Solar Irradiance Prediction at Extremely Short-Time-Intervals Using Particle Swarm Optimization Algorithm. Energies 2021, 14, 1213. https://doi.org/10.3390/en14041213
21. Ibnelouad, A, El Kari, A, Ayad, H, Mjahed, M. Improved cooperative artificial neural network-particle swarm optimization approach for solar photovoltaic systems using maximum power point tracking. Int Trans Electr Energ Syst. 2020; 30:e12439. https://doi.org/10.1002/2050-7038.12439