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Analysis of Solar Power Variability Due to Seasonal Variation and its Forecasting for Jodhpur Region Using Artificial Neural Network

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In 21st century solar power variability is an important issue due to grid integration. In these days grid integration is very popular because of heavy load. So solar power, wind power and conventional power are basic sources of grid integration. Solar power is playing a key role in grid integration. The main objective of this paper is to analyse solar power variability due to seasonal variation in Jodhpur. Jodhpur is known as sun-city for an average 320 sunny days in a year. Average solar insolation available in Jodhpur city is 5.7-6.0 kWh/m^2 per day. This is second highest insolation in the world. In this paper, the Solar power variability analysis is carried out based on the data collected from a typical 43 kW amorphous silicon solar photovoltaic system installed in Jodhpur. Mansoon, winter and summer seasons are used for analysis of variation in Photovoltaic Generation due to change of solar insolation. Output of solar photovoltaic system depends on solar insolation and in this paper we have analysed the variation in solar power according to rainy, winter and summer seasons and used artificial neural network to predict the power output from PV system. The paper showed that proposed ANN model is more accurate and study of variability in solar power can help in plant operation, power scheduling and dispatchability.

1.0 INTRODUCTION

Solar photovoltaic output is an important power source in renewable energy. Solar power depends on availability of solar insolation. So study of solar insolation is also a very essential part of solar power variability and study of solar power variability directly helps in integrated grid operations, planning, and maintenance [1]. In this paper we consider three main seasons for study of solar power variability such as summer, winter and mansoon. Solar photovoltaic power output varies with solar insolation and ambient temperature and it is found in our experimental data that solar insolation and ambient temperature changes according to seasons. Geographically Jodhpur is situated in western region of the India in the state of Rajasthan. As a developing country India needs a better energy management and environmental security. It is the biggest challenge for any developing country.

Solar insolation variation is the main issue of photovoltaic power output from PV system. Compared to conventional power, solar power is very difficult to dispatch due to uncertainty. So there is a need for study of solar power variability and analysis. In this experimental work data collected from a 43 kW grid connected Amorphous-Silicon (A-Si) solar PV system installed at IIT Jodhpur is used.

The electric power produced by a PV system can be consumed by the connected load and no power is taken from the main grid unless load connected to the system is less than capacity of

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the PV system [2]. The PV system under study has an age of less than 5 years. IIT Jodhpur has strong vision to explore the different R&D and tapping the solar resource to install a solar park at its permanent campus. The performance of a grid connected PV system depends on the climate factors and seasonal variation.

2.0 DATA OBSERVATIONS

A peculiarity of Jodhpur is extreme climatic conditions which are categorized by very hot and dry summer and cold and chilly winters. A little variation of solar insolation, ambient temperature in rainy, winter and summer season compare to other regions of India. The system output monitored at the PV inverters by a data acquisition system (Sunny Sensor Box) controlled by a measurement and analysis program (Sunny Sensor Web Box) mounted on the building shown in Figure 1. Following data are measured at a sampling rate of 15 min interval.

a. Solar insolation

b. Electrical power output of each PCU

c. Module temperature

d. Ambient temperature

e. Energy generated

FIG.1 SUNNY SENSOR WEB BOX

The above mentioned parameters are measured using Sunny Sensor Box and data is transmitted through Sunny Sensor Web Box connected via RS485 link with computer.

The PV system has a nominal peak power of 43 kWp and installed on the roof of the academic block I building which is shown in Figure 2-3. The overall surface area of the PV system is 652.34 m^2.

43 kW A-SI BASED SOLAR PV SYSTEM DESCRIPTION

FIG. 2 ACADEMIC BLOCK I BUILDING, LOCATED AT "IIT, JODHPUR" JODHPUR

It consists of 114 modules for a total of 38 array. Each array consist of 03 modules, which is connected to the inverter, each inverter have six array in which modules are connected in series and arrays are connected in parallel. Total numbers of inverters are six.

FIG. 3 A-SI BASED 43 KW ROOFTOP GRID TIED SOLAR PHOTO VOLTAIC SYSTEM

Figure 4 shows the daily variation in hourly solar insolation on the photovoltaic modules captured on 2^{nd}, 3^{rd} and 4^{th} of January, June and August day of each month for 24 hours.

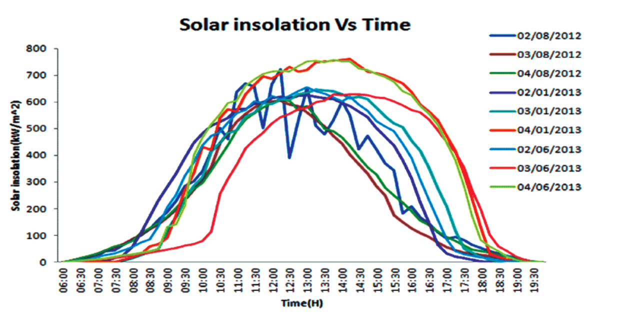

FIG.4 SOLAR INSOLATION OVER THE DAY

In this paper we consider three different seasons as different models such as Rainy (August), Winter (January) and Summer (June) model. Diurnal temperature variation in Jodhpur is very high. Figure 5 shows the temperature variation in different seasons, such as rainy, winter and summer.

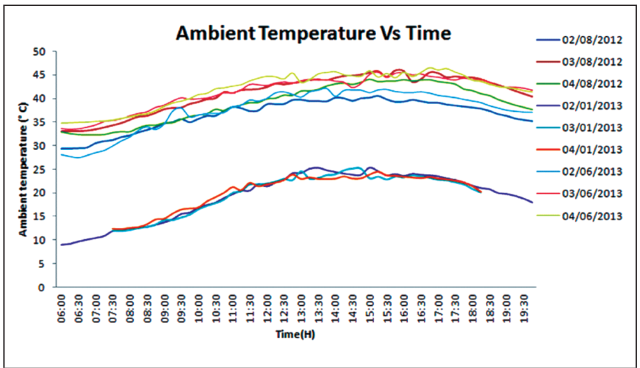

FIG. 5 AMBIENT TEMPERATURE DURING THE DAY

Table 1 shows the diurnal temperature variation in different seasons and Figure 6 shows the variation in module temperature in a typical rainy, winter and summer seasons.

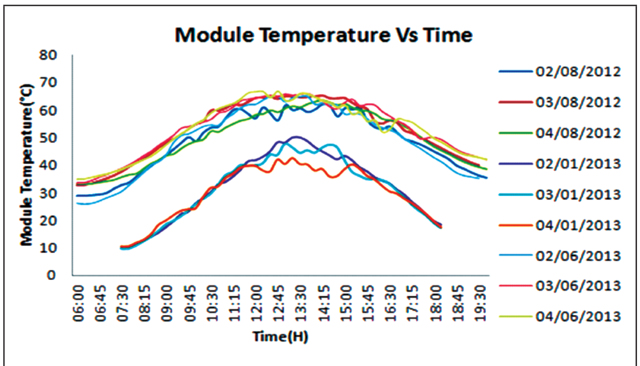

FIG. 6 MODULE TEMPERATURE DURING THE DAY

TABLE 1

DIURNAL TEMPERATURE VARIATION IN DIFFERENT SEASONS

Sl. No.	**Seasons**	**Tempera-ture, °C**		**Diurnal Temperature(Δt) (Δt)=Tmax-Tmin Temperature(Δt) (Δt)=Tmax-Tmin Temperature(Δt)**
		Min.	**Max.**	
1	Rainy	29.25	45.86	16.61
2	Winter	9	25.38	16.38
3	Summer	27.35	46.6	19.25

Figure 7 shows the variability in solar power during different seasons such as rainy, winter and summer. From the figure, it can be observed that solar power generation is varying highly during noon time of rainy and winter season. This is mainly due to cloud cover and low insolation.

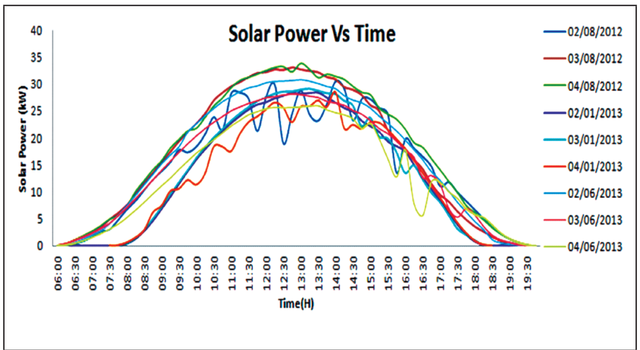

FIG. 7 VARIATION IN SOLAR POWER DURING THE DAY

Figure 8 shows the total energy output of 43 kW A-Si solar photovoltaic system in different seasons. Table 2 shows the variation in ambient parameters and solar power output of the PV system and energy generated in different seasons.

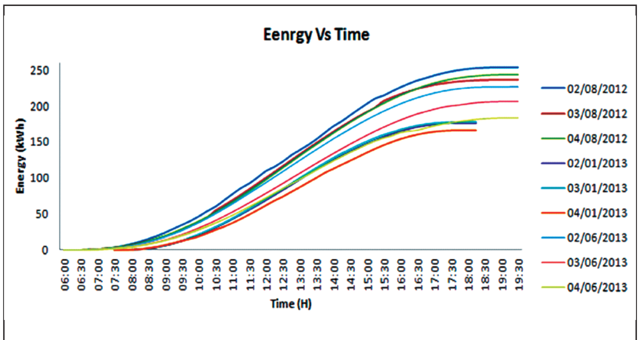

FIG.8 ENERGY GENERATION DURING THE DAY

TABLE 2

DATA OBSERVATION IN DIFFERENT SEASONS

Seasons	Date	Solar insolation max (W/m2)	Ambient Temperature max (°C)	Module Temperature max (°C)	Solar power max (kW)	Energy (kWh)
Rainy	02/08/2012	607.97	40.44	62.17	30.45	253.93
	03/08/2012	604.93	45.86	65.67	33.18	237.00
	04/08/2012	625.31	44.01	63.67	33.81	243.11
Winter	02/01/2013	629.97	25.38	50.08	28.35	175.67
	03/01/2013	646.3	25.06	47.55	29.25	178.24
	04/01/2013	654.8	24.39	42.46	28.57	166.23
Summer	02/06/2013	721.48	42.09	65.06	30.79	236.21
	03/06/2013	761.06	45.51	66.10	32.11	226.52
	04/06/2013	757.97	46.60	66.65	31.93	223.68

Energy generation during rainy season is high among all season. This is mainly due to the following factor:

a. Low ambient temperature

b. Low module temperature

In summer season the energy generation is low even though available solar insolation is high compared to rainy season due to the following factors:

a. High ambient temperature

b. High module temperature

In winter season the energy generation is lowest mainly due to the following factors:

a. Low solar insolation

b. Small Solar window

3.0 DEVELOPMENT OF ARTIFICIAL NEURAL NETWORK

A neural network (NN) is a mathematical model that is inspired by biological neural networks, like the human brain shown in Figure 9. Neural network usually used to model complex relationships between inputs and outputs or to find patterns in data [3-4]. The ANN consists of layers, the first layer has input neurons, which send data via synapses to the second layer of neurons (hidden layer) and then via more synapses to the third layer, which include the output neurons shown in Figure 10. More complex systems have more hidden layers with increased number of input and output neurons. The synapses store parameters called "weights" that manipulate the data in the calculations [5].

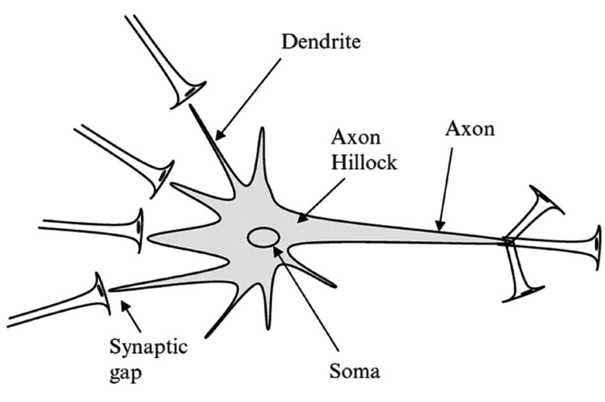

FIG. 9 STRUCTURE OF BIOLOGICAL NEURON

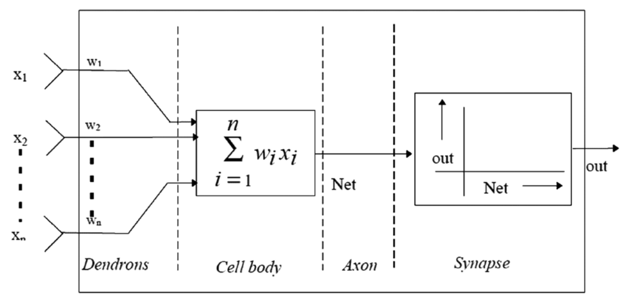

FIG.10 AN ELECTRICAL EQUIVALENT OF THE BIOLOGICAL NEURON.

The working of neural network is like a human brain [7-8]. In neural network, past data or events play an important role. Past data is very important for neural network. The non-linear and complex problem can easily handle with neural network. There is no need for any functional relationship between solar power and dependent. The neural network gets feedback from past data; generalize from previous examples to new ones, abstracts essential characteristics from input containing irrelevant data. The neural network helps in provide better and accurate results compared to statistical methods [4-6].

Following major steps are necessary to develop neural network:

a. *Selection of input parameters*

b. *Selection of neural network*

c. *Selection of perfect training algorithm*

d. *Selection of training parameter*

The input parameters such as module temperature, solar radiation, ambient temperature and wind velocity data has been recorded at IIT Jodhpur, India in energy laboratory. These selected input parameters have used for ANN training. In this paper multilayered feed-forward neural network is use for modeling of solar power forecasting. Figure 11 shows the ANN model for solar power forecasting and Table 3 shows the specific selection of neurons and layers provides accurate forecasting.

TABLE 3		
STRUCTURE FOR PROPOSED NEURAL NETWORK		
S. No	**Network parameters**	**Value**
1.	Number of input variable	4
2.	Number of output	1
3.	Number of input layer neurons	4
4.	Number of Hidden layer neurons	10
5.	Number of Hidden layer	1

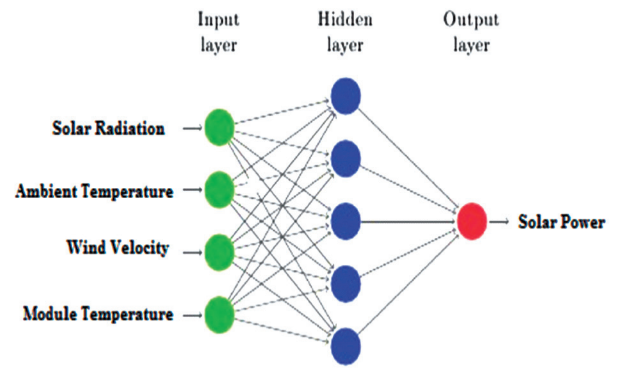

FIG.11 ANN MODEL FOR SOLAR POWER FORECASTING

In ANN model back propagation training algorithm is used with learning and momentum factors. During the training sum squared error is fed back to change the weight.

Advantages of proposed back propagation algorithm [9]:

a. *Fudge the derivative term.*

b. *Scale the data.*

c. *Direct input–output connections.*

d. *Vary the sharpness (gain) of the activation.*

e. *Use a different activation.*

f. *Use better algorithms.*

4.0 RESULT AND DISCUSSION

In this paper we observe the solar power variation in rainy, winter and summer season and Figure 7 show the solar power variability. Solar power variability forecasting helps in efficient solar power plant operation, energy integration, power scheduling and dispatch of solar power. The precision of the ANN model is quantified using two evaluation criteria: the Mean Square Error (MSE) the Root Mean Square Error (RMSE. For a given forecasting model, MSE and RMSE are evaluated as [10] in equation 1-2:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Yp - Ya)^2 \qquad \ldots(1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Yp - Ya)^2} \quad \ldots(2)$$

In this paper we propose ANN model for rainy, winter and summer season. The testing results of ANN models for different seasons shown in Figure 12, 15 and 18. The training and testing result of ANN model is shown in Figure 13, 16 and 19. Figure 14, 17 and 20 shows the regression analysis of ANN model. The results show that the training and testing performance in terms of RMS error of ANN model helps to provide better result comparison to measured actual PV generation.

4.1 Results of ANN model for rainy season

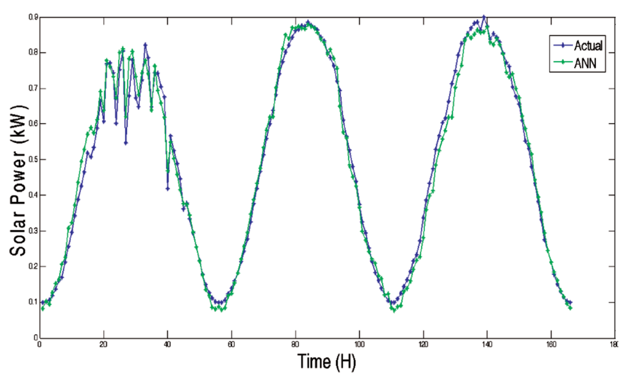

FIG. 12 THE FORECASTING RESULTS OF ANN MODEL FOR RAINY SEASON

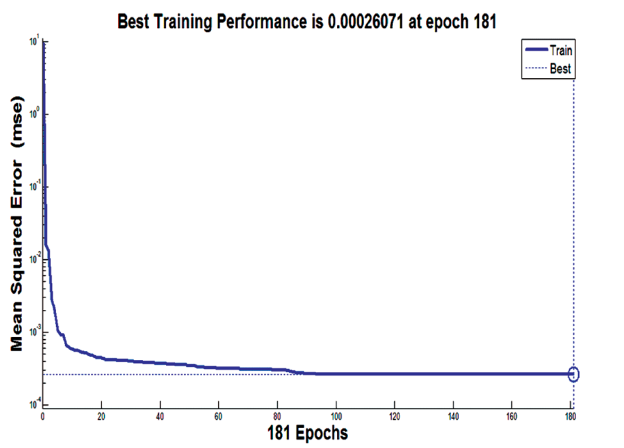

FIG. 13 SUM SQUARED ERROR DURING TRAINING OF ANN MODEL FOR RAINY SEASON

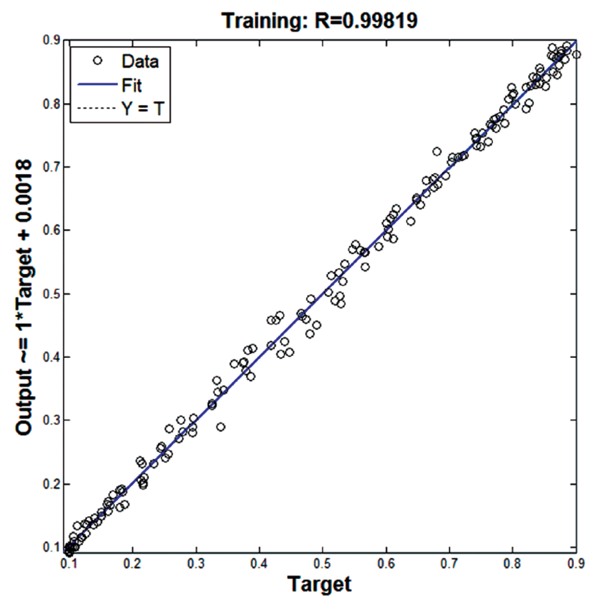

FIG. 14 FIGURE 16 REGRESSION ANALYSIS OF ANN MODEL FOR RAINY SEASON

4.2 Results of ANN model for winter season

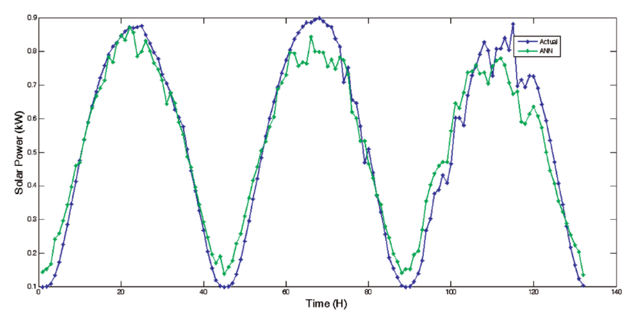

FIG. 15 THE FORECASTING RESULTS OF ANN MODEL FOR WINTER SEASON.

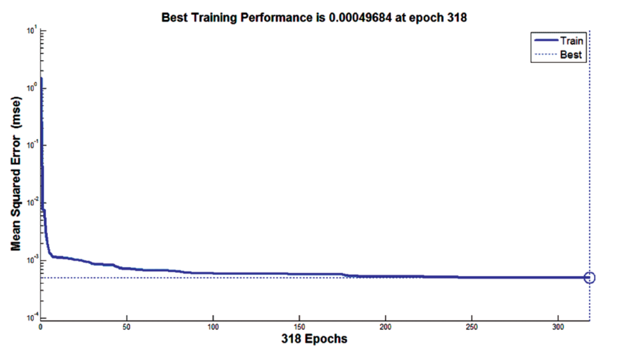

FIG. 16 SUM SQUARED ERROR DURING TRAINING OF ANN MODEL FOR WINTER SEASON

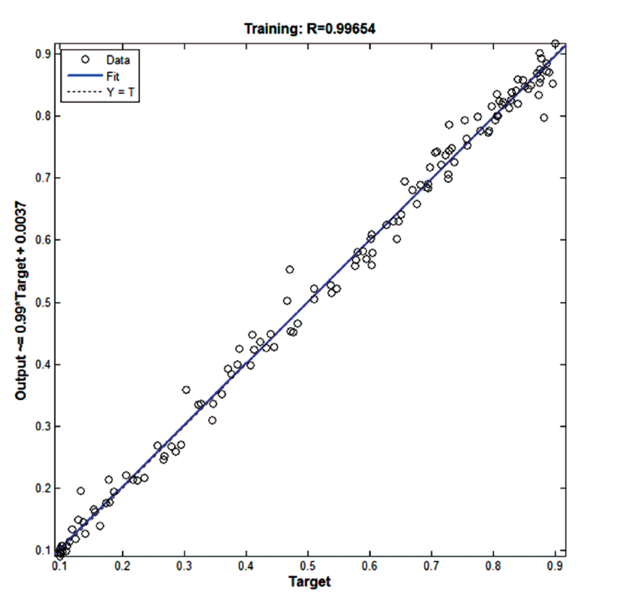

FIG. 17 REGRESSION ANALYSIS OF ANN MODEL FOR WINTER SEASON

4.3 Results of ANN model for summer season

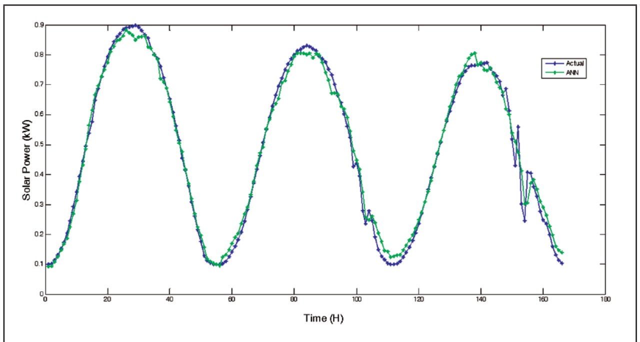

FIG. 18 THE FORECASTING RESULTS OF ANN MODEL FOR SUMMER SEASON

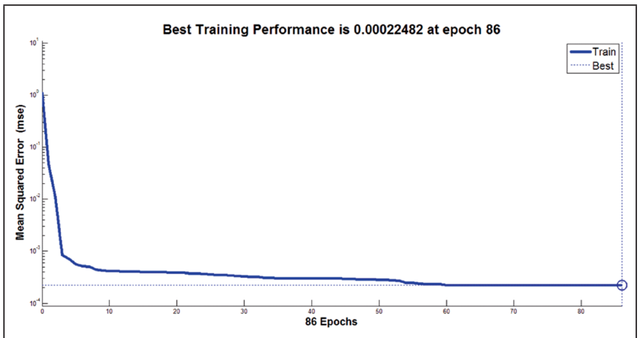

FIG. 19 SUM SQUARED ERROR DURING TRAINING OF ANN MODEL FOR SUMMER SEASON

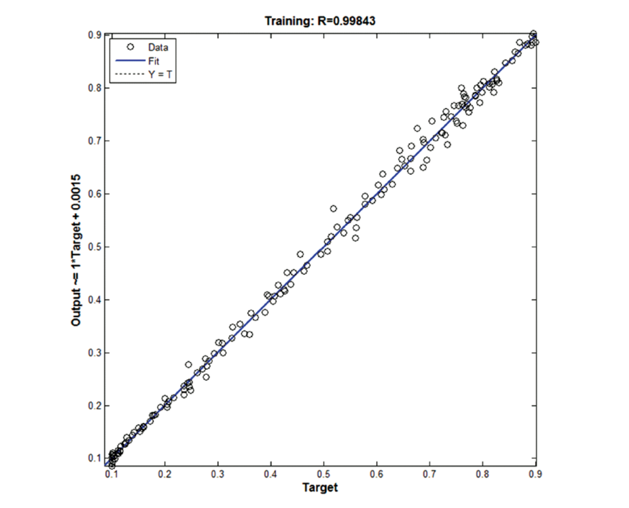

FIG. 20 REGRESSION ANALYSIS OF ANN MODEL FOR SUMMER SEASON

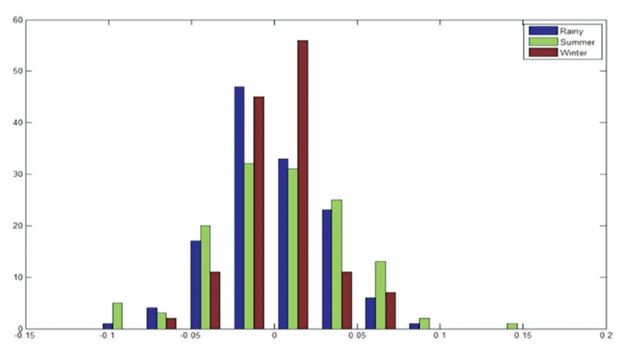

FIG. 21 HISTOGRAM OF ERROR ANALYSIS

Figure 21 shows the histogram of error analysis for seasons. It is very clear in error analysis that error variation in winter is more compare to rainy and summer season. Table 4 shows the predicted solar power measurements are close to the actual values for all seasons. A small deviation is observed for the calculated values. The root mean square errors are 0.3435, 0.3534 and 0.1231 for rainy, winter and summer season respectively.

TABLE 4

ERROR VALUES AND REGRESSION ANALYSIS OF ANN MODEL

Seasons / Values	Rainy	Winter	Summer
	2-4th August 2013	2-4th January 2013	2-4th June 2013
RMSE	0.3435	0.3534	0.1231
MSE	0.1512	0.1478	0.0417
Max. Error	0.0722	0.1528	0.1602
Min. Error	-0.0974	-0.1285	-0.0791
R	0.99859	0.99654	0.99843

5.0 CONCLUSIONS AND FUTURE WORK

In this paper all input parameter recorded in three major seasons of India such as rainy, winter and summer and it can be observe by measurement that in different seasons input parameter have a lot of variation comparison to other months and seasons so it found that particular rainy, winter and summer seasons are helpful for solar power forecasting.

The results show that the method based in ANN has been able to predict the solar in critical season.

As future work, the different time scale will use for solar power forecasting such as daily and monthly measurements. And apply this ANN model for solar power forecasting for different geographical location.Implement nature inspired hybrid computing techniques for solar power forecasting.

6.0 ACKNOWLEDGEMENT

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