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Study on Impact of Solar Photovoltaic Generation by Atmospheric Variables using ANN, ANFIS and Image Processing Techniques

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Abstract

World faces an Energy crisis. Traditional forms of electricity production using coal, gas or oil may be cheap but come at a big cost of damaging the Environment. Oil and Gas prices fluctuates widely and creates an uncertainty on the energy supplies. Most countries recognize this problem of price instability and started implementing Renewable energy schemes to reduce the dependence on fossil fuels. India is one among the fastest growing developing countries which has considered Solar energy as one of the important Renewable energy. There exists a high degree of influence by several atmospheric variables like solar insolation, Temperature, Humidity, Wind speed, Air pressure etc. on solar photovoltaic (PV) system performance predictability and hence the study on the impact of these variables is most important to assess the performance of the solar PV systems in operation. The preliminary objective of the proposed research work is to understand and model the impact of atmospheric variables on the Solar PV energy generation. In the present research work, an Artificial Neural network (ANN) model is designed to model the energy output from a 10MW Solar PV power plant. Similarly, for the same power plant an Adaptive Neuro Fuzzy Inference System (ANFIS) model is designed to predict the PV output based on the Insolation values. A feed forward back propagation ANN model considered in the present work which feeds on Nine inputs like Global horizontal irradiance, Global diffused irradiance, Ambient temperature, Precipitation, Air pressure, Sunshine duration, Relative humidity and Surface temperature to the network. A comprehensive dataset comprising of 3960 individual data points pertaining to hourly data from 7AM to 6PM is considered for 365 days. For ANFIS system model, Global horizontal irradiance and Global diffused irradiance are considered as inputs. The ANFIS is trained based on Hybrid optimization approach. These results are validated through Clear sky radiation model with mean luminance calculated from sun images.

Keywords: ANN, ANFIS, WSI, FIS, Atmospheric Variables, Solar radiation, Sun image analysis

INTRODUCTION

Innovation and Growth are the two important parameters of socio – economic development of any country. It is vital for all the developing countries like India. Providing affordable, economical and clean power is the key challenge for all the countries without impacting the Energy security. Power is considered as the key factor for development and welfare of the human beings of the country. As the urban lifestyles are more technology enabled now a days, which demands more electricity. Growth of middle class and rising their income level along with using more electricity enabled appliances increases the demand to doubling by 2060. New cleaner energy technologies are needed to meet the climate targets and utility business models are pushed to the limits by tough policies of the government shifting the consumer demands. More stringent requirements of the policies for a low carbon future will force companies to make significant changes in their business models. Hence, any hindrance in power supply is a challenge to the whole economy of the developing countries like India with huge population and abundant natural resources. Energy security is the utmost fundamental important strategy for the economic growth and human development activities which reduces the poverty and increases the employment there by meeting the Millennium Development Goals (MDG) [3].

Electricity demand increases the demand supply gap in the country. Referring to the power and energy scenario in the country, Ministry of Power (MoP) and Ministry of New and Renewable Energy (MNRE) are contributing tremendously to the growth of affordable Renewable energy technologies such as Wind, Solar, Hybrid, Hydro etc. Referring to the Monthly report of October 2017 from Central Electricity Authority (CEA), India has installed capacity of 331117 MW power of which major share to the tune of 58% of installed capacity coming from Thermal powerplants powered by coal, gas and diesel. Nuclear holds around 2% share and all other alternate energy generation sources like wind, geothermal, solar, and hydroelectric contributes to a 32% of the power generation mix as shown in Figure 1 below.

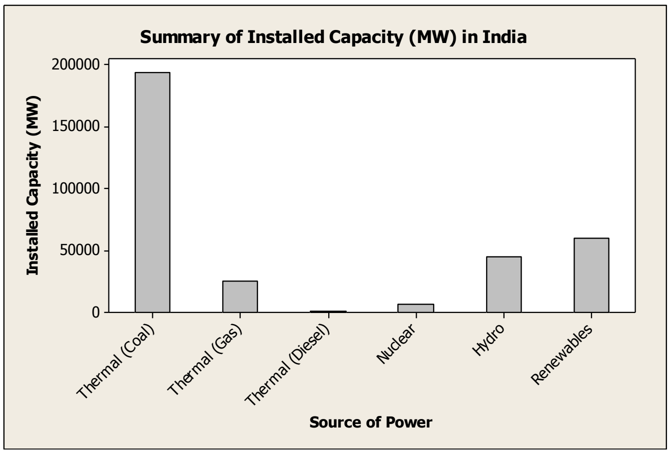

Figure 1: Summary of Installed capacity in India

The Power Ministry of Government of India is anticipating an additional capacity of around 30 GW which contributes to around 17% of the total power generation from the alternate energy sources with majority from renewables during the 12th plan period.

Also, the 12th plan document of the planning commission indicates that the domestic energy production will touch 844 million tons of oil equivalent (MTOE) by 2021-22 which is around 69% of the energy consumption with the balance power demand to be met by imports. India, as is blessed with the abundant supply of renewable energy resources, the energy thus generated can aid in bridging the demand-supply deficit to a greater extent. Renewable energy contributes approximately 16% within total installed capacity of 50014 MW [1].

India's National Solar Mission is the greatest initiative that the Government of India (GoI) has brought to rise the economic growth of the country without compromising on the sustainability. India receives abundant solar irradiation round the year; with over 300 sunshine days in a year. The country also receives a daily average irradiation varying from 4.5 to 7kWh/m2 [2] in most of the geographical areas.

The Ministry of New and Renewable Energy (MNRE) of GoI estimates potential of 100GW which in turn produces 170Million GWh at 1.7 million units per MW. Jawaharlal Nehru National Solar Mission (JNNSM) introduced by the GoI [2] increases the interest on Indian solar sector. To promote the Solar sector, the government is offering several incentives for renewable energy.

Photovoltaic (PV) panel is a variable power source which is the primary aspect of tapping the solar energy in solar PV technology. Energy yield from the PV power plant is one of the significant parameters which decides the performance of the PV plant. It is theoretically proved that many factors like temperature, humidity, wind speed, air pressure, air temperature, solar collector area etc. influence the yield. Energy analysis of solar photovoltaic power plant is a critical parameter to be measured and monitored every time as it decides the commercial viability of the plant to meet break even. In depth, detailed analysis has not been carried out in the country to understand the deviation among the targeted performance (output energy generation) and the actual performance with the solar plants commenced in India so far. The proposed Research is to develop mathematical models to study the impact of atmospheric variables on solar PV energy generation.

There are two approaches to forecast the solar energy generation like physical methods and statistical methods. Physical methods use physical equation for forecasting the solar energy generation which considers the generation process in association with forecasting weather data [5, 6].

However, a statistical method considers inherent laws to predict the output energy generation of the plant based on the historical data [7, 8]. The applicability and properties of these two methods are limited by the non-stationary behavior of solar PV energy generation because of the Earth's rotation.

Precise forecasting can be guaranteed based on reducing the non-stationary characteristics of solar energy output generation. Based on the literature survey carried out and the analysis of the field data, it was observed that the existing power prediction methods cannot provide precise forecasting results. Hence, an attempt has been made to use statistical methods as mentioned below:

1) Artificial Neural Network (ANN) is considered as one of the way to forecast solar energy generation and solar insolation from a solar PV system. ANN can be trained to overcome the disadvantages of traditional forecasting methods which are inefficient to solve difficult problems [13].

2) Adaptive Neuro Fuzzy Inference System (ANFIS) is considered because of its effectiveness in modelling with both attributes of neural network and fuzzy inference system. These two creates a neuro-fuzzy system architecture which gives benefit from feed forward calculation of the output and back propagation learning ability of the neural network without deviating from the principles of fuzzy systems.

Input variables for the power forecasting model

Accurate solar irradiance data is one of the input to the formula to derive predicted output power. Predicting power output from solar photovoltaic power generation is closely related to weather forecast predictions. To predict the amount of solar energy generated, various atmospheric factors, such as solar irradiance, temperature, precipitation, wins speed, air pressure, sunshine duration, relative humidity, surface temperature etc. along with the conversion efficiency of PV modules, installation angles, dust on a PV module, and other random factors will be considered. All these factors affect PV energy generation output. Hence, while choosing input variables for a prediction model, consider deterministic factors strongly correlated with power generation. Time series data for a PV energy generation are strongly auto correlated and hence the historical data is considered as the parameters of input for the forecasting model. Table 1 provides the Pearson product-moment correlation coefficient (PPMCC) [14] among PV energy generation output and atmospheric variables. The value of PPMCC falls between -1 to +1, with positively correlated variables indicated by 1, negatively correlated variables by -1 and a no correlation among the variables by 0.

Table 1: Pearson product-moment correlation coefficient between PV energy generation output and atmospheric variables

Output variable	Input variables	PPMCC
PV energy generation output	Solar irradiance	0.993
	Temperature	0.458
	Precipitation	-0.132
	Wind speed	0.6
	Air pressure	0.387
	Sunshine duration	0.811
	Relative humidity	0.557
	Surface temperature	0.775

The above table clearly depicts that the PPMCC among energy generation which is the actual output from a solar photovoltaic power plant and solar insolation is greater than 0.9, which indicates that these two variables are highly correlated. Also, the PPMCC among energy generation output and temperature is more than 0.4, which indicates that these variables are positively correlated at low level. The PPMCC of power generation indicates a low and negative correlation. The correlation between PV output energy generation and wind speed is medium. It can be inferred from the data that two factors namely solar irradiance and temperature strongly affects the performance of PV system. Even though manufacturers specify most important electrical characteristics, they are specified under Standard Temperature Conditions (STC). It is imperative to model the performance of the PV cells under normal operating conditions

Proposed Forecasting System

In the present work, both ANN (Artificial Neural Networks) and ANFIS (Adaptive Neuro Fuzzy Inference System) employed to forecast solar energy generation output considering the impact of atmospheric variables. The systems are trained using historical data sets. Description of the two methodologies are presented below.

A. Artificial Neural Network (ANN)

Neural network based analysis is more applicable for non-linear mapping of inputs and output. Two basic philosophies used in this are Back propagation network and Probabilistic neural network. These are used to transform faults in the fundamental stage of the analysis. An ANN comprises of inputs selection, output generation, topologies for the network and weighted connection of several nodes. All the input features will significantly reflect the problem characteristics [15]. Choosing network topology is another extreme important task which will be achieved by carrying out an experiment for several times to optimize the hidden layers and nodes till it meets the overall training and prediction accuracy.

A total of 9 (nine) atmospheric variables namely Global horizontal irradiance, Global diffused irradiance, Ambient temperature, Precipitation, Wind speed, Air pressure, Sun shine duration, Relative humidity and Surface temperature are considered as input variables which impacts the solar PV generation output. Another network is designed by considering 4 (four) inputs like Global horizontal irradiance; Global diffused irradiance, Ambient temperature and Surface temperature. Similarly, a network with Global horizontal irradiance; Global diffused irradiance and Surface temperature as inputs along with another network which considers only Global horizontal irradiance to forecast the energy.

A Feed forward back propagation network algorithm is used in this present work. Two major functions, TRAINLM training function for training the network and LEANGDM function for adaptive learning is considered. Mean Square Error (MSE) is used as a one of the performance measure of the training network. In the present work, the total network comprises of 2 (two) layers which includes the hidden layer having 6 (six) neurons and considering TANSIG transfer function. Figure (2) illustrates a network structure modeled to forecast the solar energy output generation based on 9 (nine) different input parameters considered in this work.

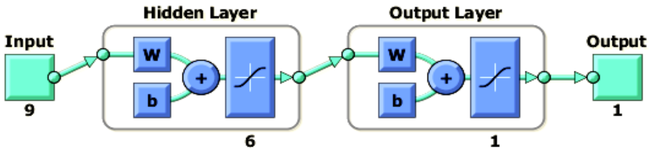

Figure 2: Network structure used for forecasting the solar PV energy generation output based on 9 atmospheric parameters as input

The network generates a Regression plot for the present work as shown in Figure (3). From the Figure (3) it can be observed that it has a high degree of correlation between the actual and predicted values.

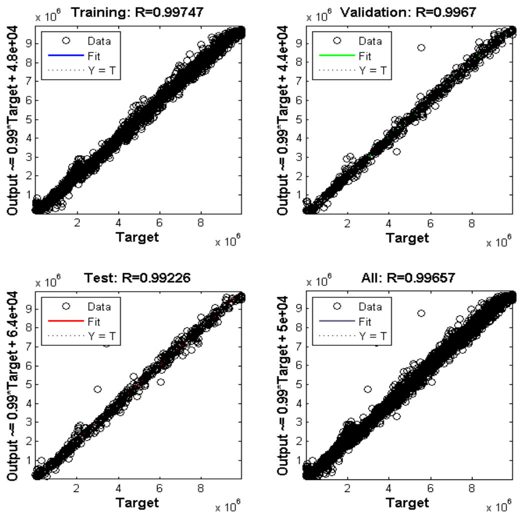

Figure 3: Regression plot of an Artificial Neural Network (ANN) forecast model

B. Adaptive Neuro-Fuzzy Inference System (ANFIS)

The second methodology used in the present work is Adaptive Neuro-Fuzzy Inference System (ANFIS). It is a class of adaptive networks. This network is functionally equal to Fuzzy Inference System. ANFIS [16] uses a hybrid learning algorithm to identify the parameters of fuzzy inference system. For any given training dataset, it applies Back propagation method and Least Square method to train Fuzzy Inference system.

ANFIS is considered for the present work because of several features and benefits which has got which includes (1) its ease of implementation for a given network (2) Its fastness and accuracy in training the network (3) its strongest generalization abilities (4) excellent explanation facilities through the entire fuzzy rules (5) its easiness to incorporate linguistic and numeric knowledge for problem solving. Any neural network is implemented a fuzzy system to it when its structure identification and parameter identification are achieved by defining, adapting and optimizing the topology and parameters of the neuro fuzzy network. This network is then regarded as an adaptive fuzzy inference system considering all learnings of the fuzzy rules from the data and an interfacing architecture in a linguistic manner. In the present work, optimization has been achieved through Hybrid methods. Figure (4) is generated as the output of the analysis of Solar energy generation.

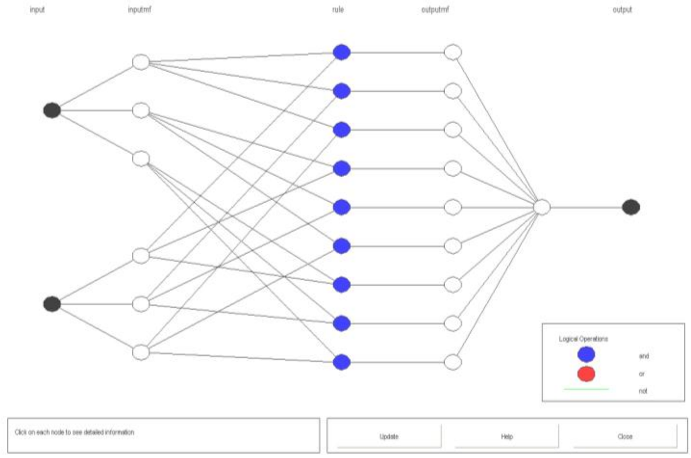

Figure 4: ANFIS model structure to forecast solar energy generation output of the PV system

The output for different inputs during the training of ANFIS is illustrated in the Figure (5)

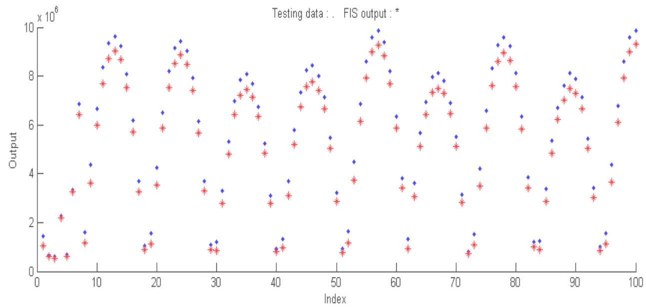

Figure 5: Plot of testing data versus the FIS output

The validation considering checking data is illustrated in the Figure (6)

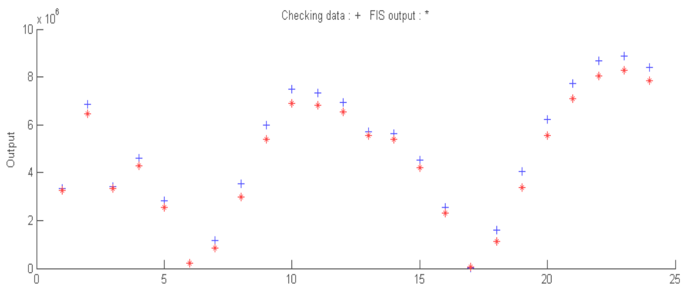

Figure 6: Plot of testing data versus the FIS output

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Estimating Solar Irradiance from Ground based Sky Images

Localized images of the sky constitute high temporal and spatial resolution. A ground based whole sky images can have this. This basically allows fine grained cloud observation. In the present work, ground-based whole sky images taken are used to estimate the solar irradiance. Sky cameras used in the present work which provide additional information about cloud movement and cloud coverage. This is not available in the data available from weather station.

The proposed approach is illustrated with the help of Figure (7) below.

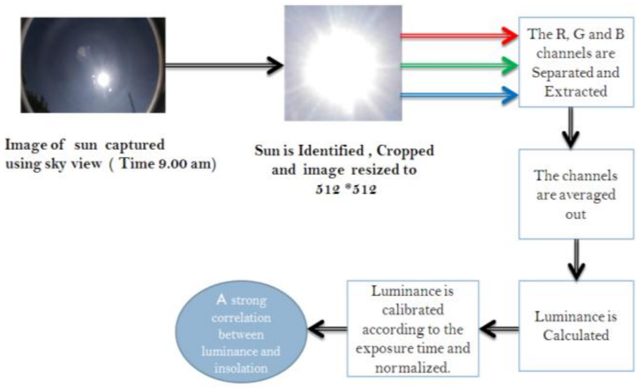

Figure 7: Illustration process to extract luminance and solar irradiance from sun image

Firstly, sun image captured by the camera. A patch of square of defined size 512x512 nearer to the sun is cropped. Using the mathematical formula, mean luminance of the cropped image is computed by averaging the HSL (Hue, Saturation, Luminance). Some of the capturing settings might differ from one image to another. Hence to bring standardization, ISO and aperture are considered as constant and exposure time is kept variable. The computed luminance is then divided by the exposure time. The output number is interpreted as the relative luminance. This is the luminance which is captured by the camera. At last, all the luminance values are normalized regarding the clear sky radiation across the entire day.

RESULTS AND DISCUSSION

In the present work 9 atmospheric variables namely Global horizontal irradiance, Global diffused irradiance, Ambient temperature, Precipitation, Wind speed, Air pressure, Sun shine duration, Relative humidity and Surface temperature are considered as inputs to train the proposed forecast system. The data pertains to a 10 MW solar photovoltaic power plant in Marikal, Telangana state. The Latitude of the site is 13.9928N and Longitude is 77.4587E. The site is located at an altitude of 548 meters from the mean sea level.

The Data format considered to train the proposed model comprises of 3960 individual data sets pertaining to hourly data for 365 days. The data hour is considered from 7 am to 6 pm. Each individual data set comprises 9 data points pertaining to different parameters being employed in the forecast system. The sample data set used in the training of ANN PV forecast model is given in the Table 2. The details of the database used in this study are given in Table 3.

Table 2: Sample data set considered in ANN forecast model for training purpose

G_Gh	G_Dh	Temperature	Precipitation	Wind speed	Air pressure	Sunshine duration	Relative Humidity	Surface Temp	Generation (Wh)
119	75	24.5	0	1.5	940	30	62	25.2	1427822
76	76	24.7	0	0.8	940	1	63	24.9	661493
70	70	24.7	0	3.3	940	0	68	24.8	603147
237	227	25.5	0	1.8	940	3	62	27.3	2273217
78	78	25.4	0	1.5	940	0	63	25.6	679218
341	312	26.3	0	1.8	940	5	59	29.1	3325077
660	350	27.8	0	2	940	46	55	33.9	6843644
345	289	28.2	0	1.3	940	10	51	31.3	3404523
431	203	28.7	0	2.8	940	42	48	32.2	4596684
264	123	28.8	0	1.2	941	38	50	31	2831750

Table 3: Database utilized in this study

Data sources	**Installed capacity**	**Sampling data**	**Measurement item**	**Total number of data points**
Marikal solar power plant	10 Mega Watts	Average values for 60-minute	(i) PV generation (ii)Atmospheric temperature (iii) Solar irradiance (Global and Diffused) (W/m2) (iv)PV module temperature (v) Ambient temperature (vi) Wind speed (vii) Precipitation (viii) Duration of sunshine (ix) Atmospheric pressure	71280

In the present work, a forecasting tool is deigned in the form of a Graphical User Interface (GUI). The GUI is coded using MATLAB R2012a and the simulations are run in an Intel Core i5 system with a RAM of 8 GB. The screen shot of the present work is shown in the Figure 8.

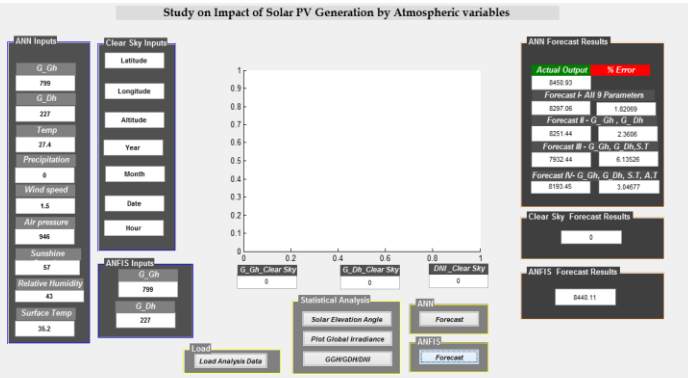

Figure 8: Screen shot of the proposed forecast system

The proposed GUI has the following functions

- It has provision to feed the different atmospheric variables related to solar PV energy generation
- It has provision to enter the site datalike latitude, longitude, altitude of the site location and also the time, day, month and year of prediction
- It has a built in clear sky based forecast model to predict the irradiation for a particular geo location for a specific day and time.
- It has two forecasts for both ANN and ANFIS

The results of the forecast model are validated by testing through different data points illustrated using the following Table 4.

Table 4: Data Points used in validation for PV forecast

VARIABLE	**SET 1**	**SET 2**	**SET 3**	**SET 4**	**SET 5**
G_Gh (Global horizontal) (Wh/m2)	70	853	78	303	799
G_Dh (Global diffused)(Wh/m2)	70	93	78	112	227
Ambient temperature (deg C)	24.7	27.4	25.4	22.3	27.4
Precipitation	0	0	0	0	0
Wind speed (m/s)	3.3	1.3	1.5	0.6	1.5
Air pressure (Pa)	940	948	940	944	946
Sunshine duration	0	60	0	39	57
Relative humidity (%)	68	43	63	68	43
Surface temp (deg C)	24.8	35.9	25.6	25.1	35.2

The result of the forecast for the above data set is discussed in the following section;

Table 5: Forecast for PV generation by ANN – Forecast I (considering all 9 atmospheric variables)

Data point	SD1	SD2	SD3	SD4	SD5
Actual value	603	9155	679	3540	8450
Predicted value	604	9082	675	3600	8297
% Error	0.17	0.8	0.6	1.7	1.8

Table 6: Forecast for PV Generation by ANN – Forecast II (considering Global horizontal and diffused radiation)

Data point	SD1	SD2	SD3	SD4	SD5
Actual value	603	9155	679	3540	8450
Predicted value	569	9067	675	3153	8252
% Error	5.6	0.9	0.6	10.9	2.3

Table 7: Forecast for PV generation by ANN – Forecast III (considering Global horizontal, diffused radiation and Surface temperature)

Data point	SD1	SD2	SD3	SD4	SD5
Actual value	603	9155	679	3540	8450
Predicted value	535	8969	649	2777	7932
% Error	11.2	2.0	4.4	21.5	6.1

Table 8: Forecast for PV generation by ANFIS (considering Global horizontal and diffused radiation**)**

Data point	SD1	SD2	SD3	SD4	SD5
Actual value	603	9155	679	3540	8450
Predicted value	644	9153	744	3455	8440
% Error	6.5	0.03	8.8	2.4	0.12

In the present work, an algorithm for insolation computation also been demonstrated. This insolation has been computed from ground-based whole sky imagers (WSIs) through method explained above. The Figure (9) illustrates the plot of computed luminance versus time.

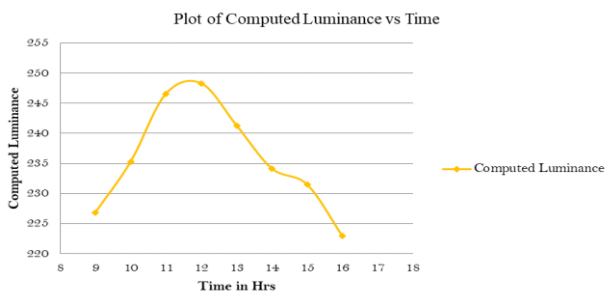

Figure 9: Plot of computed luminance vs. Time

Figure (10) illustrates the plot onsite insolation measured with help of solar pyrometer installed at the specific location

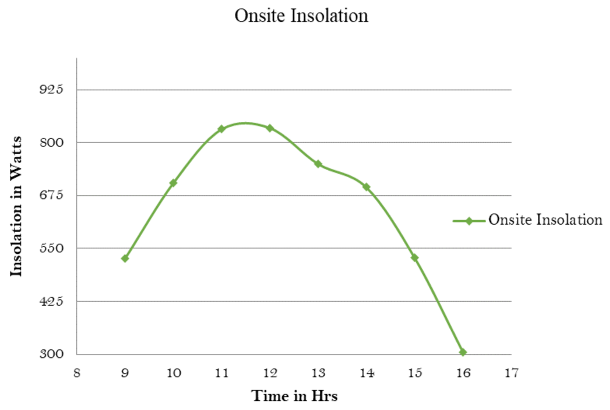

Figure 10: Onsite insolation

The proposed approach has been used to compute and compare with the computed insolation and actual onsite insolation. The results are illustrated with the help of following Table 9 and plot is depicted using Figure (11).

Table 9: Tabulation of estimated insolation compared with onsite insolation

Time (hrs)	Estimated insolation	Onsite insolation	Percentage error (%)
9.00	562	526	6.8
10.00	728	704	3.4
11.00	862	832	3.6
12.00	846	835	1.3
13.00	779	749	4.0
14.00	704	694	1.4
15.00	542	527	2.8
16.00	562	526	6.8

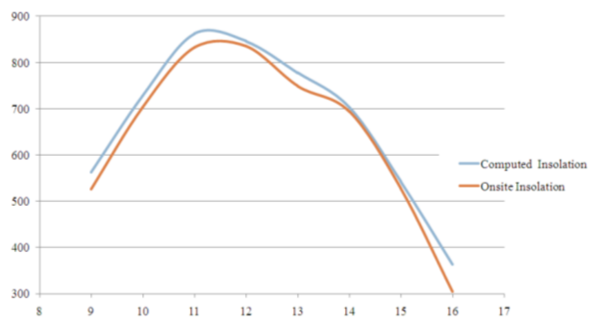

Figure 11: Plot of computed insolation and onsite insolation

CONCLUSION

In this the authors have successfully presented a model for forecasting the PV generation based on environmental factors and correlated the results with actual generation. A new approach to measure insolation using whole sky images has also been successfully demonstrated. The results validate the suitability of the proposed approaches in predicting PV power output.

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