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Output Power Prediction of Solar Photovoltaic Panel Using Machine Learning Approach

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ABSTRACT- Solar power-based photovoltaic energy conversion could be considered one of the best sustainable sources of electric power generation. Thus, the prediction of the output power of the photovoltaic panel becomes necessary for its efficient utilization. The main aim of this paper is to predict the output power of solar photovoltaic panels using different machine learning algorithms based on the various input parameters such as ambient temperature, solar radiation, panel surface temperature, relative humidity and time of the day. Three different machine learning algorithms namely, multiple regression, support vector machine regression and gaussian regression were considered, for the prediction of output power, and compared on the basis of results obtained by different machine learning algorithms. The outcomes of this study showed that the multiple linear regression algorithm provides better performance with the result of mean absolute error, mean squared error, coefficient of determination and accuracy of 0.04505, 0.00431, 0.9981 and 0.99997 respectively, whereas the support vector machine regression had the worst prediction performance. Moreover, the predicted responses are in great understanding with the actual values indicating that the purposed machine learning algorithms are quite appropriate for predicting the output power of solar photovoltaic panels under different environmental conditions.

Keywords: Solar photovoltaic, Output power, Machine learning, Support vector machine regression, Multiple linear regression, Gaussian regression.

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1. INTRODUCTION

The generation of electrical power, usage and storage are the key parameters for the development of any country. Due to the tremendous changes in technology and industrial sectors the demand for electrical power also increases [1]. Electric power can be generated by the help of un-replenishable and replenishable energy sources. The major drawback of non-renewable(conventional) power generation is its environmental pollution and unsustainable nature. However, at the present, electrical power generation is highly dependent on the conventional technique and for this reason, there is a need to promote a sustainable and environment-friendly source of electrical power generation [2]. Renewable sources of power generation like solar, wind, biomass, geothermal, tidal etc., has the potential to provide an environment-friendly and sustainable source of electrical power generation. In all renewable sources, solar energy has sufficient potential to meet the demand of future power generation. Therefore, solar energy could be considered an alternative source of power generation. The solar energy which is coming from the sun can be converted into electrical energy by the practice of a photovoltaic (PV) panel that works on the principle of the photovoltaic effect [3].

In general, the PV panels are installed in an open environment where it experiences a change in their output power due to the change in the operating parameters [4]. The operating parameter namely atmospheric temperature, solar radiation, relative humidity, panel surface temperature and time of operation are responsible for the change in PV panel output power [5]. Any changes in these parameters affect the panel output power considerably. The yield value of the PV panel is strongly dependent on the solar radiation that falls on its surface. In PV panel operation, solar radiation is linearly related to the output power and current whereas the output voltage is logarithmically related to solar radiation [6]. Atmospheric temperature is the other operating parameter that affects PV panel output and any increase in its value puts a proportional impact on the panel temperature, as a result of this, panel yield value decreases [7]. In a study, a negative impact on the panel output was observed due to a rise in its surface temperature [8]. In [9] the rate of reduction of output power and fill factor, with reference to panel temperature, were recorded as 0.65%/K and 0.2%/K [9]. Another study showed a decrement of 9% due to the 20% increase in panel temperature [10]. Humidity, which is defined

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as the percentage of water vapour in the atmospheric air, is the other operating parameter that reduces the overall performance of PV panels due to a rise in its level [11].

Therefore, a detailed investigation of operating parameters which are responsible for affecting the output power of PV panels must be conducted before their installation in any open environment. Before planning to install a solar power-based electric PV system detailed information on global solar radiation and operating conditions data is prime important [12]. The detailed information of operating parameters data helps in predicting the output power of the PV panel. The prediction model of output power for the purposed installation site needs to be reliable and accurate and is developed based on recent observations in the purposed site. The data required for the prediction model must be suited and dependable for predicting the output power of the PV panel. The introduction of machine learning in data prediction provides a high value of prediction in real-time that ensure the better decision and smart action without any human intervention. The main advantage of machine learning is it enables the usage of both structured and unstructured data during the preparation of the prediction model [13]. The iterative aspect of machine learning helps the developed model in adopting the new data independently. As a couple of studies are accessible which have concentrated on the impact of a few operating conditions on the performance of PV panels, consequently understanding the complicated connection between these conditions and PV panel power is required [14]. Therefore, the main motivation of the present paper is to develop computational models, that can predict the output power of PV panels, based on various machine learning approaches.

2. ABOUT THE SITE AND COLLECTION OF FIELD DATA

The selection of the site is a basic criterion for the installation of solar-powered PV panels. This is due to the importance of atmospheric factors, distance to residential areas and network connection, the impact of local residential life, and environmental risk. The inappropriate selection of the site affects the performance of the solar photovoltaic panels. Thus, the selected site should possess a good solar radiation profile throughout the day. For preparing the machine learning (ML) based output power prediction model, various input parameters were collected from the site which helps in making a good ML model. The collection of data was conducted during the month of February 2022 in the Indian state of Telangana which is having the geographical coordinates of 19.15 N and 77. 28 E. The site is situated in a remote location and endures a good solar radiation profile throughout the year which makes it more suited for the installation of solar photovoltaic panels. During the examination of the output power of solar PV panels at the site operating parameters such as solar radiation, ambient temperature, panel surface temperature, time of the day and relative humidity are considered. The output current and voltage of the panel are measured from 6 Am to 3 PM at every 30 minutes of interval. Based on the measured value of output current and voltage, the output power of the solar photovoltaic panel was calculated. The considered site on the Indian map and collected data from the site are presented in *figure 1* and *table 1*.

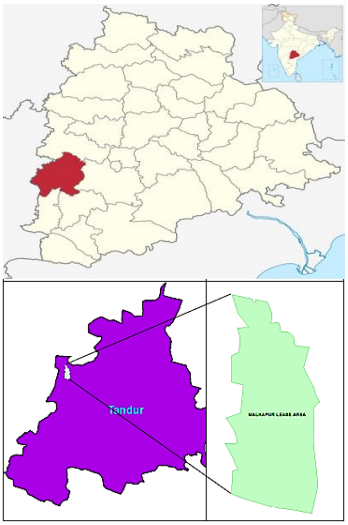

Figure 1: Study area on Indian Map

3. SELECTION OF MACHINE LEARNING APPROACH

This paper relates the Machine Learning Approach for predicting the output power of PV panels. Machine Learning is the subset of Artificial intelligence (AI), which explores the construction and analysis of algorithms that make predictions on data. In this paper machine learning approaches including support vector machine regression (SVMR), Gaussian regression (GR) and multi-linear regression (MLR) were used for predicting the output power of solar PV panels and identifying the appropriate ML algorithm. The proposed regression model of machine learning workflow is presented in *figure 2*.

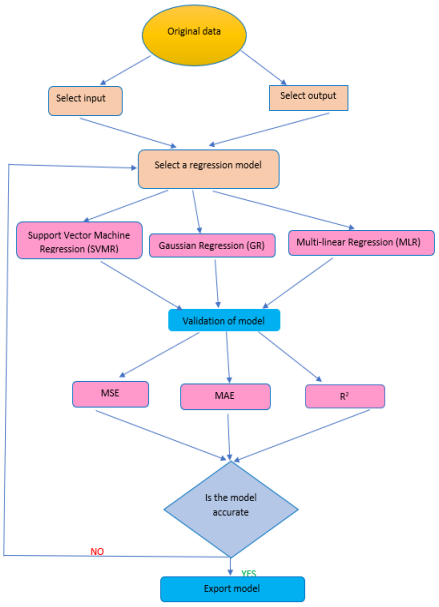

Figure 2: Proposed model of machine learning workflow for predicting the output power of PV panel

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Table 1: Data collected from the site

Ambient temperature (°C)	Relative humidity (%)	Solar radiation (W/m2)	PV panel temperature (°C)	Voltage (V)	Current (A)	Time of the day	Power (W)
28.8	84.9	850	46.4	19.4	0.51	6:00 AM	9.894
28.6	87.5	950	51.3	19.5	0.59	6:30 AM	11.505
29.2	85.2	900	50.5	20.1	0.54	7:00 AM	10.854
29.5	84.2	840	50.1	20.2	0.49	7:30 AM	9.898
30.4	82.5	920	53.2	20.2	0.55	8:00 AM	11.11
31.6	78.9	950	54.6	20.25	0.58	8:30 AM	11.745
33.1	76.7	960	57.2	20.3	0.6	9:00 AM	12.18
33.4	78	1020	59.2	20.5	0.61	9:30 AM	12.505
32.9	73	1050	60.3	20.6	0.63	10:00 AM	12.978
33.1	78.1	1080	61.4	20.75	0.64	10:30 AM	13.28
33.4	77.3	1090	61.5	20.85	0.66	11:00 AM	13.761
33.4	75.8	1110	62.8	20.9	0.67	11:30 AM	14.003
33.8	73.7	1140	63.5	21.1	0.69	12:00 AM	14.559
34.2	70	1210	65.1	21.2	0.71	12:30 PM	15.052
34.1	73.5	1160	64.8	21.05	0.68	1:00 PM	14.314
33.4	72	1120	62.1	20.85	0.67	1:30 PM	13.9695
34.2	74	1130	63.2	20.6	0.66	2:00 PM	13.596
32.7	75.1	1040	59.9	20.4	0.62	2:30 PM	12.648
31.2	75	1020	57.4	20.2	0.61	3:00 PM	12.322

3.1 Support Vector Machine Regression (SVMR)

SVR identify the non-linearity in the data and provides a skillful prediction model. In SVR a random set of boundaries is set for prediction by designing an upper and lower range of margin which can be seen from *equation (1)* and *equation (2)*. The representation of the best fit line in the SVR model is presented in Equation (3).

$y= f(x)+\varepsilon$ upper range margin (1)

$y= f(x)-\varepsilon$ lower range margin (2)

$y= \omega x+ b$ best fit line (3)

where ε is the width of margin, y is the output variable, x is the independent variable and b is the constant of the predictor line.

3.2 Gaussian Regression

In machine learning models, the Gaussian regression model comes under those few models that can solve any complex system analytically. It is a nonparametric Bayesian approach to regression that makes waves in the area of machine learning [17]. The Bayesian nonparametric method helps in selecting the model at an appropriate level of complexity which consists of random variables and provides the gaussian distribution profile for all input-output data sets. Gaussian process regression provides a dependable estimate of its own uncertainty, and it provides more flexibility to the prediction model with respect to interpolation. For any data set ('S') Gaussian Process (GP) can be defined as a set of random variable X_t where 't' is a subset of S and it can be represented by equation (4) belongs such that

$\{ X_t: t \in S \}$

$\forall \in N, \forall t_1 \ldots\ldots\ldots\ldots t_n \in S, (X_{t1} \ldots\ldots\ldots\ldots X_{tn})$ (4)

3.3 Multiple Linear Regression

To establish the linear relationship between a single dependent variable and more than one independent variable Multiple Linear Regression (MLR) could be the best choice for regression algorithms. MLR model performs better for more complex relationships which require more specific calculation by appropriate consideration of the data set. It helps to predict the behavior of the response variables with respect to the movement of predictor variables. For input varies from X_1 to X_n, the output Y of MLR can be written by *equation (5)*.

$Y= b_0 + b_1X_1+b_2X_2+\ldots\ldots\ldots\ldots\ldots\ldots+ b_nX_n$ (5)

4. RESULTS AND DISCUSSION

The different machine learning approaches were used to predict the output power of solar photovoltaic panels. The feasibility of these approaches was shown by comparing the predicted data with the real one. Table 2 presents the prediction data of the output power of solar PV panels. The performance of ML algorithms was examined based on various parameters such as MAE, MSE, R^2 and accuracy. Table 2 indicates that the MLR algorithm gives a better performance with MAE, MSE, R^2 and accuracy values of 0.04505, 0.00431, 0.9981 and 0.99997 respectively.

Output power prediction of the solar photovoltaic panel using various machine learning algorithms is presented in *figure 3* to *figure 5*. After examining *table 2* and analyzing *figure 3* to *figure 5*, it can be seen that MLR provides better performance when compared to SVMR and GR algorithms. There is not a significant difference in the accuracy and R^2 result of GR and MLR algorithm but MAE and MSE show a higher value for GR algorithm. This makes GR algorithm less accurate than MLR algorithm. While, the Support vector machine regression provides the poor performance, due to the more noise effect which introduce because of weakness of soft margin optimization issue. The similar type of work is done by [14] but that work is done on different data set which is collected from [15] for the ML algorithms of SVM and GPR where it was found that GPR provides the optimal performance of the predicator model. However, our model is prepared on the data

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sets which are measured during the field study. In the present work, it is observed that multi-linear regression (MLR) gives better performance over the GPR and SVR.

Table 2: Results of ML algorithms for output power of solar PV panel

Algorithms	MAE	MSE	R^2	Accuracy
MLR	0.04505	0.00431	0.99818	0.99997
GR	0.29665	0.15262	0.93586	0.99530
SVMR	0.74343	1.30482	0.45170	0.93000

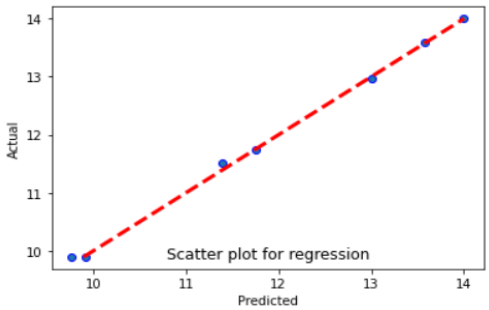

Figure 3: Output power prediction of solar photovoltaic panel using MLR ML algorithms

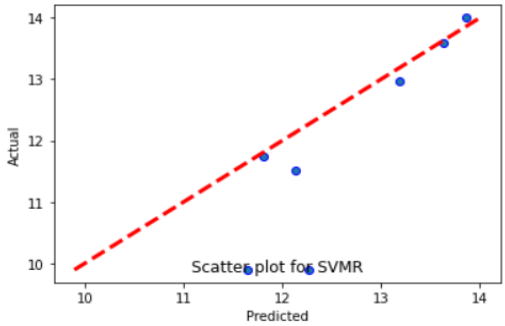

Figure 4: Output power prediction of solar photovoltaic panel using SVMR ML algorithms

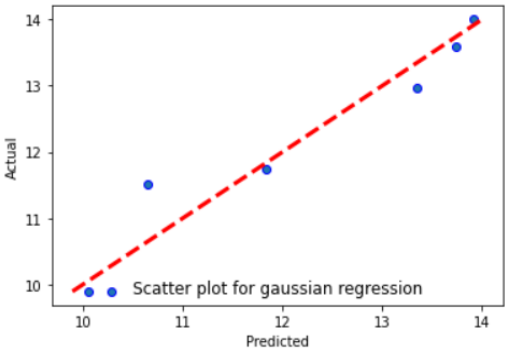

Figure 5: Output power prediction of solar photovoltaic panel using GR ML algorithms

5. CONCLUSION

The solar powered PV panels are the main source of clean energy that helps in developing the environment friendly, stable economic and sustainable kind of electric power. The appropriate prediction of the output power of solar photovoltaic panel helps in the optimal transition of energy from conventional power source to solar power. Subsequently, the prediction of output power of solar PV panel which can help the planning and scheduling of viable output electric power to accomplish the energy demand of the world market. In the present study, various machine learning algorithms such as multiple linear regression (MLR), Gaussian regression (GR) and support vector machine regression (SVMR) are considered to predict the output power of solar photovoltaic panels based on the various input parameters namely, ambient temperature, solar radiation, panel surface temperature, relative humidity and time of the day. The result of this study indicates that among the proposed machine earning algorithms MLR provides the better results with MAE, MSE, R^2 and accuracy value of 0.04505, 0.00431, 0.9981 and 0.99997 respectively. This implies that the developed ML model have high reliability and accuracy for prediction of output power of solar PV panel. Further, this study affirmed that the proposed machine learning models could be engaged for predicting the output power of solar PV panel. Even though the proposed model shows reliable and accurate performance but there is a need to consider the other parameters like size of the panel, dust conditions, tilt angle and wind speed in future research work.

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