Prediction Model for Solar PV Rooftop Production

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Abstract

This research aimed to investigate the factors influencing the electricity production from solar PV rooftop systems using a forecasting model that was developed as part of this research. The results showed that the two factors affecting the electricity generation from solar PV rooftop systems are solar irradiance and temperature, as indicated by their correlation coefficient values. Solar irradiance is the most influencing factor. As such, irradiance data were taken to forecast and create the electricity forecasting model to predict the electricity generation through a stochastic model (following the proposed model) that predict solar irradiance. The resulting solar irradiance values were applied in the forecasting model, which is a regression equation, to calculate the daily electricity generation from the solar PV rooftop installation. The results are accurate forecasts of daily solar PV rooftop electricity generation.

Keywords:

Solar Rooftop, Electricity Generation Prediction, Randomized Number Model

1. Introduction

The oil crisis in the 1970s was the first reason to develop renewable energy sources, such as solar energy. One such technology is solar PV technology. Today, when the global concern has shifted to using cleaner and environmentally energy sources and climate change, development of Solar PV technology has intensified, leading to wider its deployment and commercialization. Solar PV can now be a major energy source to satisfy present and future energy demand. This is the case for Thailand, where electricity demand increased significantly in the last decades, particularly in the residential and business sectors [1].

For more than two decades now, Thailand renewable energy plan has continually targeted wider installation of solar PV systems around the country. Included in this plan are R&D activities to assure stability of electricity generation from solar PV systems. Many factors, particularly weather conditions, affect electricity generation from solar PV. These include solar irradiance, ambient temperature, humidity, wind speed, rainfall, and barometric pressure. There is a need to determine the effects of these factors on electricity generation by the solar PV and help maintain the stability of the electricity generation [2].

The stochastic model is a key tool for making predictions of weather conditions, or what is popularly called weather forecasts. It is a modeling tool for estimating probability distributions of potential outcomes by allowing for random variation in one or more inputs over time. The random variation is usually based on fluctuations observed in historical data for a selected period using standard time-series techniques [3].

The model can be used to forecast daily rainfall [4] and to simulate other impacts of climate change [5]. These climate factors are affecting solar PV electricity generation and there is a need to find the deviation coefficients to determine the effects of these impacts. Data are used in the model to forecast the effect on daily solar PV electricity production, and also, to determine the possible reduction in fossil fuel use that will help reduce global warming [6].

This research aimed to create a forecasting model for electricity generation from solar PV rooftop systems based on the factors affecting solar PV electricity generation that were mentioned earlier. The model will then be used to analyze how these factors affect electricity generation from solar PV rooftop installations.

2. Solar PV Rooftop Systems in Thailand

Energy forecasts from the Alternative Energy Development Plan (AEDP 2015) and Power Development Plan (PDP 2018) show that the peak demand will reach 29,969 MW in 24 April 2018, with an electricity generation capacity in 2037 of 77,211 MW of which 20,766 MW is renewable energy. This is about 27% of total targeted installed power capacity. These planning reports were prepared by Thailand Ministry of Energy [7] [8].

Solar PV rooftop systems aim to produce electricity for use on-site or in the installation areas. They do not need transmission and distribution lines like on-the-ground PV power plants such as solar farms. As mentioned earlier, many factors influence power production from solar PV, and therefore, it is also the same for solar PV rooftop power plants. These include solar radiation, sunlight direction, and climate factors such as ambient temperature, rainfall and cloud cover.

The most important among these factors is solar irradiation. The average solar irradiation in Thailand is around 19-20 MJ/m^2 with an average of 14.3% exposure. 50% of the country gets around 18-19 MJ/m^2 solar irradiation. Only 0.5% of the country has less than 16MJ/m^2 solar irradiation [10]. Thus, Thailand has the potential to produce electrical power from solar energy in all parts of the country [11].

Solar PV rooftop systems have received greater attention under the "Feed-in Tariff (FiT)" policy of the Ministry of Energy. "FiT" is policy to support investments in the energy sector by the energy users themselves, such as residential/commercial building-owners and local communities. These energy users are encouraged to install their own solar PV rooftop systems. The FiT for solar PV rooftop systems started in 2013 with an initial target of 200 MW, targeting commercial (10-1000 kW capacities) and residential (up to 10 kW capacities) solar PV rooftop systems. The support is for a lifetime period of 25 years for those intending to go for commercial operations, i.e., selling power back to the grid. In 2015, the target was raised to 6,000 MW, however no new incentives were added on those that were initially provided in 2013 [12].

Fig. 1 Solar energy potential in Thailand 2019.

3. Stochastic model

The stochastic model is a tool in estimating the probability distribution of the probability result under the previous situation which randomizes the answer under the opportunity of the whole situations happening. The randomized result will rely on the situation happening in the past and will allow changing under the condition of time [6].

Determine X has separated distribution type as equation below:

$$X \in \begin{pmatrix} X_1, X_2, \dots, X_n \\ P_1, P_2, \dots, P_n \end{pmatrix} \tag{1}$$

p = probability, q = total of probability, from probability: $P_1, P_2, \dots, P_n \leq 1$ thus

$$q_0 = 0$$
$$q_1 = p_1$$
$$q_2 = p_1 + p_2$$
$$\vdots$$
$$q_n = p_1 + p_2 + \cdots + p_n = 1$$

Get function $0 = q_0 < q_1 < \cdots < q_n = 1$

and make function transformation f in random variable simulation X this cast such as below:

$$f(x) = \begin{cases} x_1, 0 \leq x < q_1 \\ x_2, q_1 \leq x < q_2 \\ \cdots \\ x_n, q_n - 1 \leq x \leq 1 \end{cases} \tag{2}$$

4. Research Tool and Procedure

4.1. Case Study in Chiangrai Rajabhat University

Chiangrai Rajabhat University was selected to be the location of the case study to apply the analytical tools for developing a forecasting model for electricity production from solar PV rooftop system. Chiangrai Rajabhat University is in the north of Thailand (19°54'30.89"N, 99°49'57"E.). The campus has an area of around 77,677.50 square meters. The campus used electricity around 4,782,148.80 unit per year.

Fig. 2 Map of area and location of Chiang Rai Rajabhat University.

4.2. Case Study in Chiangrai Rajabhat University Data Collection

Data on irradiance and temperature were collected from the weather station of the Energy and Smart Grid Technology Center for the 500 kWp solar PV rooftop system installed in the university. Data were collected every 30 seconds from 6:30 am to 6:30 pm only. The data collected is the mean within the 30-second periods. No data were collected in the evenings. In total, 1441 data were collected. Data collection was done in 2018.

Fig. 3 Showing the solar PV rooftop installed 500 kWp at Chiangrai Rajabhat University.

4.3. Model development

A mathematical stochastic model is applied because it is reflective of the real situation of the factors affecting electricity generation; solar irradiation and temperature, which are changing all the time. A model was created from data in 2018 (1441 data for model prediction), which then was then tested with using the detailed steps as follows:

4.3.1. Analyzing the factors affecting electricity production

- Analyzing using descriptive statistics the factors affecting electricity generation; temperature and irradiance.

- Analyzing the relationships of the data on irradiance and temperature and the amount of electricity generated, and finding the relationships between data using correlation coefficients.

4.3.2. Creating the mathematical model

- This the model to predict the amount of the electricity generated from the solar PV, using simple line regression function.

- The stochastic model is used to predict solar irradiance values.

4.4. Testing the model

4.4.1. Testing the model validity by testing the average results of the calculation of electricity production per day by doing calculations at intervals of 30 times, 60 times, 90 times, 500 times and 1000 times.

4.4.2. Testing the efficiency of irradiance parameter model by using the relative error between the mean of the total irradiance predicted by the stochastic model and the mean of the 2018 data on real, the testing results for 2019 was used to find the relative error.

4.4.3 Finding the relative error between the mean of the total from the electricity generation model and the mean of the real total from data in 2018 and 2019 and then finding the relative error.

5. The result of data analysis

5.1. The descriptive statistic value of the temperature and irradiance data

Table 1 The basic data of temperature and irradiance data in 2018.

	Temperature (^{O}C)	Irradiance (W/m^2)
Mean	37.92	481.340
Standard deviation	11.63	270.690
Minimum value	15.90	1.413
Maximum value	51.57	821.777

5.2. Relationship between the factors

5.2.1. The relationship between the temperature and irradiance, and the amount of electricity generated by finding the correlation coefficient is shown in Table 2 and 3. It can be seen clearly that these two factors had an impact on the electricity generation in a positive way. This allowed finding the relationship between the temperature and irradiance data.

Table 2 The value of the correlation coefficient of temperature and electricity generation.

	Temperature 2018	Electricity generation 2018
Temperature 2018	1.0000	0.9506
Electricity generation 2018	0.9506	1.0000

Table 3 The correlation coefficient value of irradiance and electricity generation.

	Irradiance 2018	Electricity generation 2018
Irradiance 2018	1.0000	0.9972
Electricity generation 2018	0.9972	1.0000

5.2.2. The temperature and irradiance have a positive relation, with a correlation coefficient of 0.9482. The close relationship between the two factors allow multiple linear regression. However, irradiance data have more positive relationship and that is why it was chosen in the forecasting model developed for solar PV electricity generation.

Table 4 The correlation coefficient value of temperature and irradiance.

	Temperature 2018	Irradiance 2018
Temperature 2018	1.0000	0.9482
Irradiance 2018	0.9482	1.0000

5.3. Mathematical model for forecasting

5.3.1. The forecasting model for electricity generation from solar PV rooftop systems

The mean of irradiance data and the mean of the amount of the electricity generation data were used to create the model via a simple linear regression function, and is given by the following equation:

$$\hat{y}_i = 0.0251x_i - 1.1779 \tag{3}$$

with a coefficient value = 0.9944, the most accurate value.

5.3.2. The stochastic model for forecasting irradiance

The first step is to find the data frequency in order to seek for the distribution of the irradiance mean, starting from the minimum and the maximum values of irradiance (1.4132 and 821.7769, respectively). Then, the range of the data distribution was determined, consisting of range 1,5,10,50 and 100. This is followed by finding the data distribution of the mean of irradiance in each range by the stochastic model as follows. Firstly, finding the probability of the happening (p), the probability total of the happening (q) and randomizing the value from 0 to 1. The randomizing of the value was done by the stochastic model. Comparing the distribution range of the total mean of irradiance data gained from the stochastic model and the total mean of the real irradiance data, it showed that the range, giving the closest value to the total mean of the real irradiance, was range 1. That is why, this range was used to forecast irradiance as shown in Table 5. It generated the electricity forecasting model for the solar PV rooftop from the equation:

$$\hat{y}_i = 0.0251x_i - 1.1779 \quad (4)$$

replacing x_i which was the irradiance forecasted by the stochastic model in the distribution data, range 1, and wherein the forecasting equation of the electricity generation per day were generated from this formula:

$$Y = \sum_{i=1}^{1441} \hat{y}_i \quad (5)$$

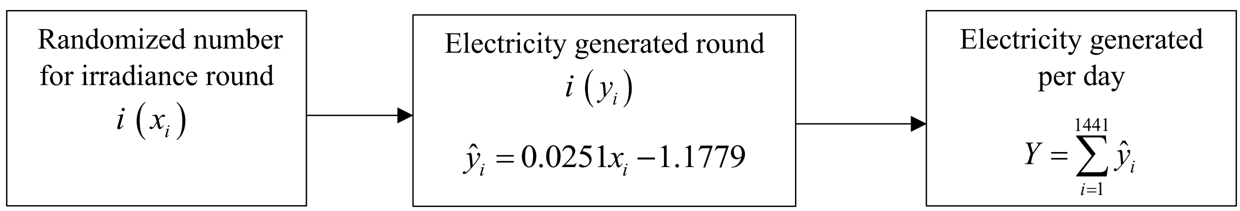

Fig. 4 The purpose stochastic model of the electricity forecasting from the solar PV rooftop.

Table 5 The comparison on the distribution range of irradiance data.

Range	Total of irradiance (W/m^2)	
	Model prediction	Actual Irradiance
1	699332	693611.084
5	700145	693611.084
10	709030	693611.084
50	730000	693611.084
100	769500	693611.084

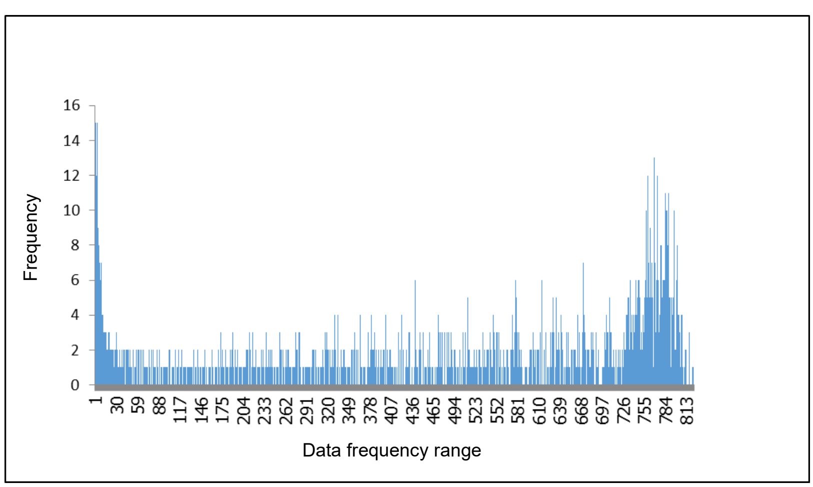

Fig. 5 The data distribution of the light intensity.

5.4. The testing results of the mathematical model

Step 1: Testing 30 times, 60 times, 90 times, 500 times and 1000 times, indicated that the testing results had the results closed to the real mean total as shown in Table 6.

Table 6 Testing results from the electricity generated forecasting model from the solar PV rooftop as determined.

Times	Electricity generated (kWh)
30	15500
60	15728
90	15752
500	15653
1000	15652

Step 2: Finding the relative errors

1. Finding the relative errors between irradiance obtained from she stochastic model and the total of the data mean of the real irradiance in 2018 and 2019, it was discovered that the relative error gained not more than 0.07, thus showing that it was very accurate.

Table 7 The relative errors of irradiance.

Times	Model prediction (W/m^2)	Actual irradiance 2018 (W/m^2)	Error 2018	Actual irradiance 2019 (W/m^2)	Error 2019
30	694522.533	693611.084	0.001	655094.135	0.060
60	694804.250	693611.084	0.001	655094.135	0.060
90	694388.377	693611.084	0.001	655094.135	0.060
500	694992.880	693611.084	0.002	655094.135	0.060
1000	695193.166	693611.084	0.002	655094.135	0.061

2. Finding the value of the relative errors between the mean total of the electricity generated forecasting model from the solar PV rooftop and the real total mean in 2018 and 2019, it was discovered that the value of the relative error obtained was not more than 0.030 showing that this model was very accurate.

Table 8 The value of the relative error of the electricity generated.

Times	Model prediction (kWh)	Actual electricity generated 2018 (kWh)	Error 2018	Actual electricity generated 2019 (kWh)	Error 2019
30	15656.264	15687.791	0.002	15289.638	0.024
60	15705.083	15687.791	0.001	15289.638	0.027
90	15724.970	15687.791	0.002	15289.638	0.028
500	15730.198	15687.791	0.002	15289.638	0.028
1000	15714.977	15687.791	0.001	15289.638	0.027

6. Discussions

The results of this study on the relationship of the factors affecting electricity generation from solar PV showed that solar irradiance is the direct factor affecting electricity generation [11]. This is in line with studies on the effectiveness of the solar power systems that looked at the factors such as temperature and irradiance, and which analyzed whole PV systems for efficiency in producing the electricity. Thus, this research looked at the values of the temperature and irradiance as the factors to be studied. The effect of the two factors on electricity generation can be clearly seen, and showed that a multiple linear regression cannot be created on the basis of these results.

Solar irradiance has the most positive probability and is the most influencing factor. As such, the researchers had taken irradiance data to forecast and create the electricity forecasting model to predict the electricity generation through a stochastic model (following the proposed model) that predict solar irradiance. The resulting solar irradiance values were applied in the model, which is a regression equation, to calculate the daily electricity generation from the solar rooftop installation. The results are accurate forecasts of daily solar PV rooftop electricity generation. However, many previous studies often used the multiple regression function which might not be proper for analyzing the relationships of the factors.

7. Conclusion

The stochastic model and the simple linear regression function were selected for this research to study the factors that has the most positive relation to have a precise model and the least correlation coefficient value. The result of this research can be used to predict solar PV rooftop electricity production or other types of solar PV systems (e.g., on ground and floating). It can be used in the supply management of microgrids and applied in demand side management (demand respond). With a smart grid system, this opens the possibilities for prosumers to emerge from among solar PV rooftop systems, allowing for maximum contribution of electricity produced from solar PV rooftop systems to the grid.

References

[1] Department of Alternative and Conservative Energy. (2019). *Solar energy technology*. Retrieved April 1, 2020, from http://www.dedo.go.th/more_news.php?cid=1258filename=index

[2] Department of Alternative and Conservative Energy. (2013). *Thailand electricity produce by solar energy situation report.* Bangkok, Ministry of energy.

[3] Christian, L. E. F., Terence, J. O., Judith, B., Paul, D. W., & Valerio L. (2015). Stochastic climate theory and modelling. *Wiley Interdisciplinary Reviews Climate Change*, *6*, 63-78.

[4] Teepprapunnee, K. (2002). *Prediction of daily rainfall time series by Stochastic Method (case study: Samut Prakarn Province)*(master's thesis). Bangkok, King Mongkut's University of Technology Thonburi.

[5] Zacharopoulou, E., Tsoukalas, I., Efstratiadis, A., & Koutsoyiannis, D. (2019, April 7-12). *Impact of sample uncertainty of inflows to stochastic simulation of reservoirs.* European Geosciences Union General Assembly 2019, Vienna, Austria.

[6] Pascal, G., Serge, B., Stephen, B., Aidan, B., Hayley, J. F., Philippe, O., & Alain, D. (2011). Modeling climate change impacts on groundwater resources using transient stochastic climatic scenarios. *Water Resources Research*, *W12516*, *47*, 1-17.

[7] Ministry of Energy. (2019). *Thailand Power Development Plan 2018 (PDP 2018)*. Retrieved April 1, 2020, from http://www.eppo.go.th/images/POLICY/PDF/ PDP2018.pdf

[8] Ministry of Energy. (2015). *Alternative Energy Development Plan 2015–2036 (AEDP 2015)*. Retrieved April 1, 2020, from http://www.dede.go.th/download/files/ AEDP2015Final_version.pdf

[9] Department of Alternative and Conservative Energy. (2020). *Satellite imagery of solar energy potential map for Thailand, 2019*. Retrieved April 13, 2020, from http://www.dede.go.th/ewt_ news.php?nid=47736&filename=index

[10] Department of Alternative Energy Development and Efficiency. (2019). *The solar map*. Bangkok, Department of Alternative Energy Development and Efficiency, Ministry of Energy.

[11] Yoomak, S., Patcharoen, T., & Ngaopitakkul, A. (2019). Performance and Economic Evaluation of Solar Rooftop Systems in Different Regions of Thailand. *Sustainability, 11(23)*, 6647.

[12] Tantisattayakul, T., & Kanchanapiya, P. (2019). Financial measures for promoting residential rooftop photovoltaics under a feed-in tariff framework in Thailand. *Energy Policy*, *109*, 260 - 269.

[13] Kamkird, P., Ketjoy, N., Rakwichian, W., & Sukchai, S. (2012). Investigation on Temperature Coefficients of Three Types Photovoltaic Module Technologies under Thailand Operating Condition. *Procedia Engineering*, *32*, 376 - 383.

[14] Kamkird, P., Ketjoy, N., Rakwichian, W., & Sukchai, S. (2007). Performance of a-Si, p-Si, and HIT PV Technological Comparison under Tropical Wet Climate Condition. *International Journal of Renewable Energy, 2(2),* 23-35.