The Solar Power Plant Prediction A case Study in Phitsanulok, Thailand

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The Solar Power Plant Prediction A case Study in Phitsanulok, Thailand

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Abstract. This research aims to find ways to predict the generated solar energy of 800 kW solar power plants. The investigated factors affecting on the plant consisted of irradiance, humidity, wind speed, ambient temperature, module temperature and real power. The plant located in Phitsanulok province, Thailand. Simple Regression Analysis and Multiple Linear Regression were used to analyse correlation. From the results, it is clear that solar energy directly depended on irradiance. Moreover it was an inverse of the module temperature. It is investigated that humidity and wind speed had not effect on solar energy generation. Furthermore real power value had little effect. Finally, the four correlations between generated solar energy and variables were used to predict. Four correlations were classified by temperature.

1. Introduction

Presently, the energy is in the many forms; oil, coal, wind, thermal, light electricity and so on. The electricity is the most versatile form of energy because it can easily transforms to other energy. Therefore the electricity has been used more and more [1]. However, the electricity needs natural resources to be generated. Oil, natural gas and coal are commonly the sources. Although they are sufficient to produce electricity, the process emits CO_2. According statistics of CO_2 emissions [2], it tends higher up in the rate 2.3% per year. The gas affects greenhouse effect. It is the cause of global warming. However the electricity consumption still rising about 2.2% per year [3]. For Thailand, although, Energy Conservation Act has been declared [4], energy consumption still rising [5]. The renewable energy sources are interesting. In the future, power plant needs to reduce energy production from fossil resources. It is replaced by renewable energy [6]. Although the renewable energy is the best choice, it is not replaced completely. It is very much investment for performance. Therefore, the development of renewable energy technology is needed [7]. Solar energy is interesting as renewable energy. Luckily, Thailand is located in a uniquely suitable location to take advantage of solar energy [8].

The solar power plant is promoted by Thai government [9]. Especially the government declares policies of promotion for spreading solar power plants [10]. However the investment of solar power plant is still expensive. To the highest efficiently use, features, and phenomenal have been understood. If technicians know well about solar power plant, they will do maintenance effectively. Therefore the prediction of solar power plant behaviour is important. It tells us about system efficiencies. To predict phenomenal of solar power plant, effecting factors have been studied. The example of effecting factor is the angel of installation which 15^{o} for Thailand location [11], [12]. Therefore the best direction solar tracking for generating at maximum energy was presented [13]. Furthermore, dusty or soiled surface are the factors effecting on electricity generation of solar power plant [14]-[16]. They affect lower

generation efficiencies. Hence modules have to be cleaned periodically. The prediction help technicians choose the time for cleaning effectively.
Therefore this paper presents solar power plant prediction. The prediction is gotten from effecting factors. The independent variable is generated energy. The dependent variables consist of irradiance, humidity, wind speed, ambient temperature, module temperature and power peak. Eventually the correlation of factors is gotten. It can predict the electricity from solar power plant.

2. Basic concept

2.1. Simple regression analysis

Linear simple regression analysis is used in this research to find correlation between the two variables. Simple regression analysis equation is show in equation (1).

$$Y_i = \alpha + \beta X_i + \varepsilon_i \tag{1}$$

Which; Y_i is dependent variable.
X_i is independent variable.
α is $Y_i$intercept (constant if $X_i = 0$).
β is slop or coefficient simple regression.

To estimate α and β are gotten by least squares method.

$$\widehat{Y_i} = a + bX_i \tag{2}$$

Which; a is α estimation value.
b is β estimation value.
$\widehat{Y_i}$ is estimation of Y_i.

$$a = \frac{\sum Y_i}{n} - \frac{\sum X_i}{n} \tag{3}$$

Correlation level between parameters is obtained by coefficient of determination (R^2). It is calculated by (4).

$$R^2 = \frac{b \times S_{xy}}{S_{yy}} \tag{4}$$

Where;

$$b = \frac{S_{xy}}{S_{xx}} \tag{5}$$

$$S_{xx} = \sum X_i^2 - \frac{(\sum X_i)^2}{n} \tag{6}$$

$$S_{yy} = \sum Y_i^2 - \frac{(\sum Y_i)^2}{n} \tag{7}$$

$$S_{xy} = \sum X_i Y_i - \frac{\sum X_i Y_i}{n} \tag{8}$$

If the coefficient of determination (R^2) is high, it shows Y and X are high correlation level.

2.2. Multiple linear regression

This method is use for analysing more than two variables correlation. Multiple linear regression analysis equation is show in (9).

$$Y_i = a + b_1X_1 + b_2X_2 + \ldots + b_kX_k \tag{9}$$

3. Experimental setup

3.1. The solar power plant

The 800kW solar power plant is located in Phitsanulok province, Thailand. There are 4000 solar modules. They are installed on the roof of building. Data had been collected by SCADA system a year ago. The energy, irradiance, humidity, wind speed, ambient temperature, module temperature and power were recorded. Normally this plant is cleaned 3 times a year.

Figure 1. Solar power plant in Phitsanulok province, Thailand.

3.2. The correlation analysis

All data were analysed by simple regression analysis and multiple linear regressions. Independent variable was electrical energy. Dependent variables were irradiance (kWh), humidity (%), wind speed (m/s), ambient temperature (°C), module temperature (°C) and real power (kW).

4. Experimental results

The data was recorded from Phitsanulok power plant. The data includes generated energy, irradiance, humidity, wind speed, ambient temperature, module temperature and real power. They were obtained by SCADA system. They were recorded for 1 year since January to December in 2015.

4.1. Simple regression analysis result

Simple regression analysis method was used for analysing. Six factors are plotted as figure 2 – figure 7. All data were obtained directly by SCADA system in real environment. The environment was not controlled. They were plotted without correction factors. The correlation is shown in table 1.

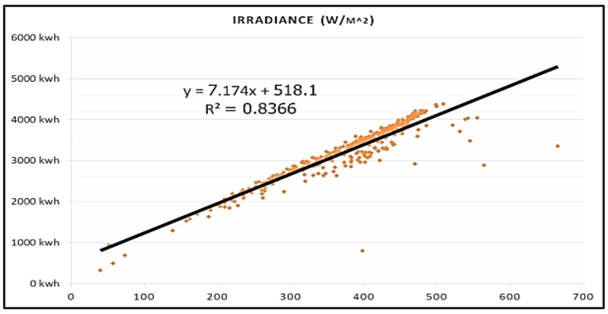

Figure 2. The plot of electrical energy and irradiance.

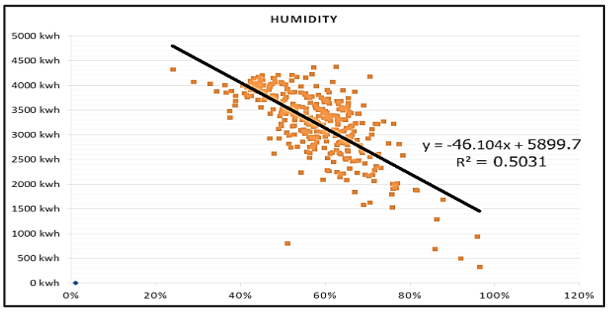

Figure 3. The plot of electrical energy and humidity.

The table 1 shows correlations obtained by two variables simple regression analysis method. The correlation and coefficient of determination (R^2) are computed by Matlab program. It is investigated that all correlations have less than 0.8507 coefficient of determination (R^2). Therefore, they cannot be use to predict the energy generation. However, simple regression analysis is not enough to summarize the correlation between investigated factors. Hence the multiple linear regression method is applied to analyse the correlation. Multiple linear regression method is use for analysing more than two variables correlation.

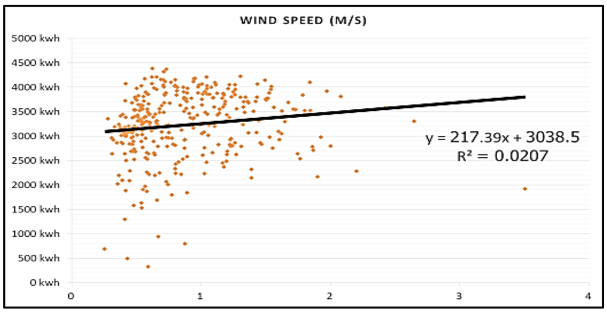

Figure 4. The plot of electrical energy and wind speed.

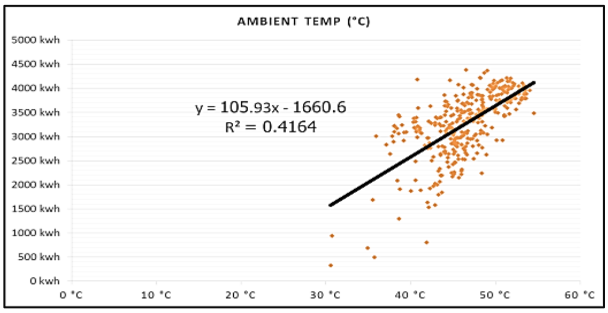

Figure 5. The plot of electrical energy and ambient temperature.

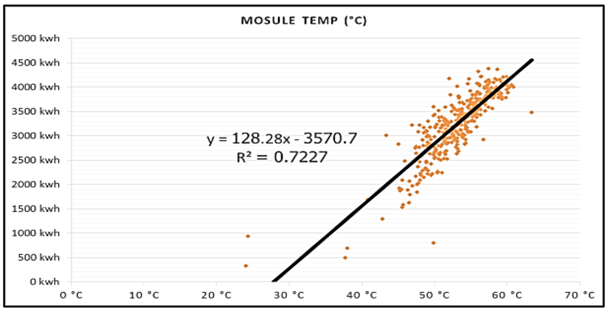

Figure 6. The plot of electrical energy and module temperature.

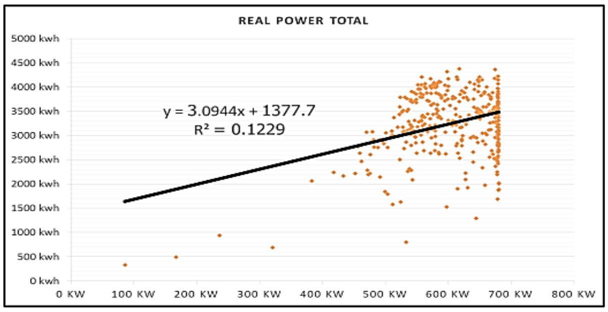

Figure 7. The plot of electrical energy and power peak**.**

Table 1. Two variables simple regression equation.

Factors	**Equation**	**R^2**
Irradiance (Ir)	kwh = 518.1 + 7.174Ir	0.8366
Humidity (H)	kwh = 5899.7 – 46.104H	0.5031
Wind speed (W)	kwh = 3038.5 + 217.39W	0.0207
Ambient temperature (AT)	kwh = -1660.6 + 105.93AT	0.4164
Module temperature (MT)	kwh = -3570.7 + 128.28MT	0.7227
Real power (P)	kwh = 1377.7 + 3.0944P	0.1229

4.2. Multiple linear regression results

The correlation between electrical energy and irradiance for each range of temperature is shown in figure 8. There are six ranges. The graphs show that the slopes slightly decrease, if the temperature increases. That means temperature has effect on electrical energy generation. Therefore all data can be analysed by multiple linear regressions analysis. The analysis is done for each range of temperature. The results of analysis are shown in table 2.

From table 2, coefficients of determination (R^2) can be calculated at 40.0-50 ^{o}C. The correlation cannot be determined at 35.0-40.0 ^{o}C. The coefficients of determination are more than 0.8507. It means that correlation can be use for predicting using following equation as shown in table 2. These equations will be used to analyse competency of generation and opportunity throughout the year.
The figure 9 shows comparison between predicted and real energy value. For the range of 35.0-37.5 ^{o}C and 37.5-40.0 ^{o}C, the correlation equations were replaced by correlation of 40.0-42.5 ^{o}C in range. Because the temperature is the nearest and coefficients of determination is the highest. It is investigated that the predicted value and real values is almost the same as shown in figure 9.

The difference percent between real generated value and predicted value is shown in figure 10. It has shown that the highest error is about just -20%. Moreover the trend line of real generated energy is both higher and lower than predicted value. The line varies because solar cell modules are cleaned three times a year. The first time is on 21-23 February. The second time is on 12-14 July. The third time is on 12-14 November. Therefore generated electricity in mentioned duration trended higher than predicted value. Considering effect of irradiance as shown in figure 11, it is found that the irradiance for each seasons are not the same. The highest irradiance is in summer. The next is winter. And the lowest is rainy.

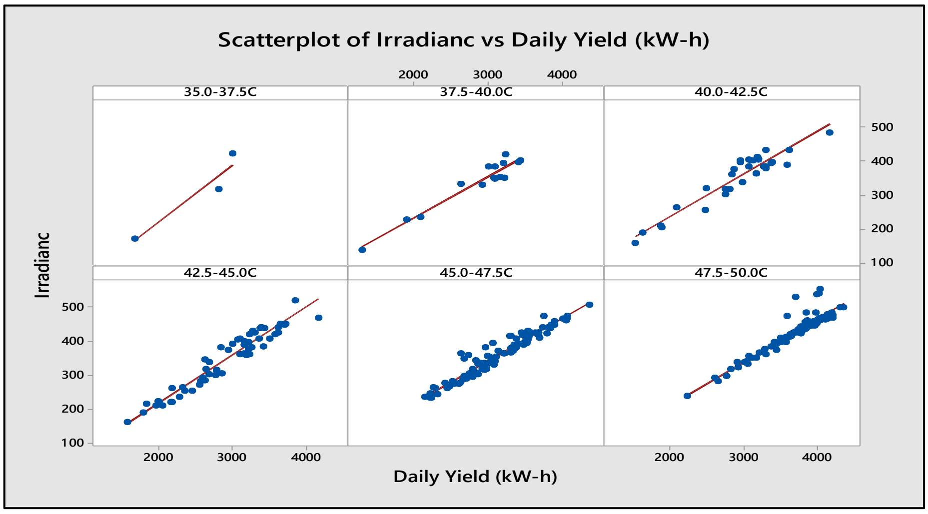

Figure 8. Scatter plot classified by module temperature.

Table 2. Multiple linear regression equation.

Temperature	**Equation**	R^2
35.0-37.5 °C	-	-
37.5-40.0 °C	-	-
40.0-42.5 °C	kWh = 6595 + 11.381Ir - 153.0MT	0.9634
42.5-45.0 °C	kWh = -247 + 8.622Ir + 87.9AT - 71.5MT	0.9524
45.0-47.5 °C	kWh = -1964 + 8.329Ir + 83.4AT - 41.1MT + 0.690P	0.9572
47.5-50.0 °C	kWh = -561 + 6.585Ir + 19.13AT + 0.811P	0.8969

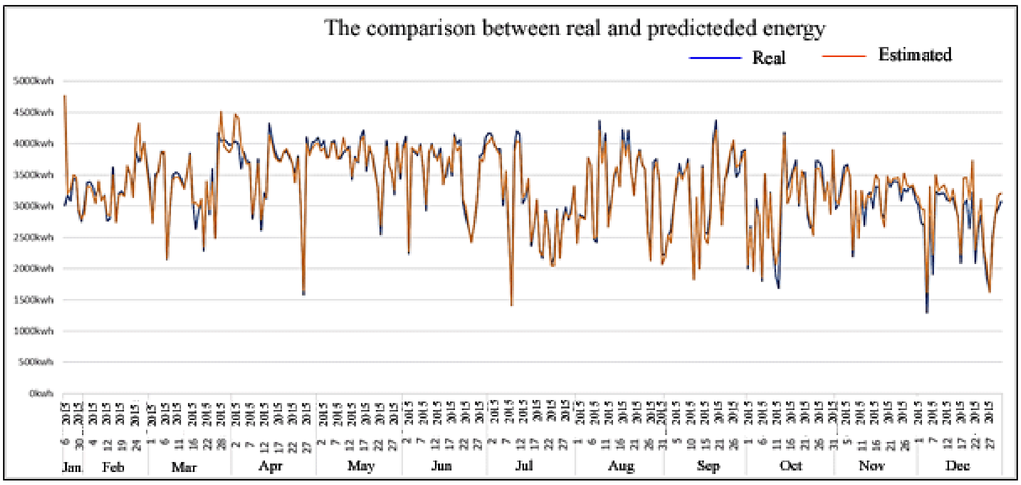

Figure 9. Comparison between real and predicted energy.

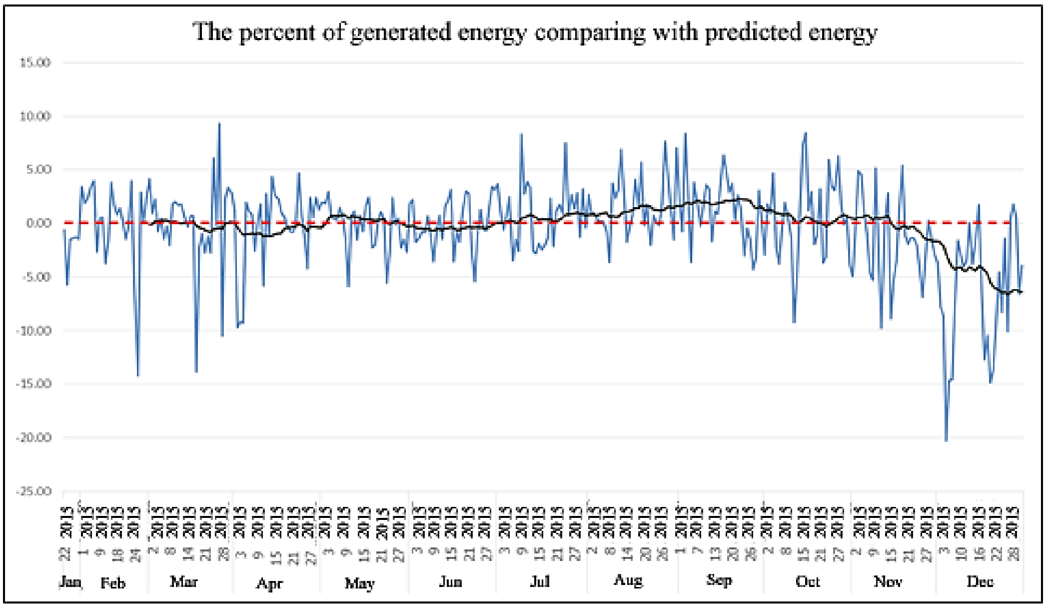

Figure 10. The percent of generated energy comparing with predicted energy.

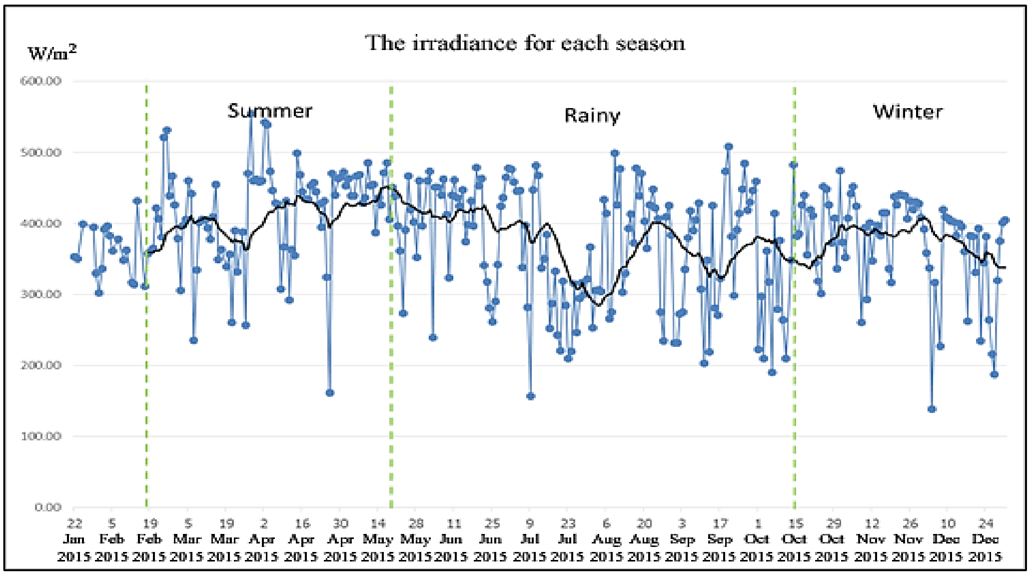

Figure 11. The irradiance for each season.

4.3. Effect of module temperature

From figure 12, it shows temperature influences on solar power plant. Five constant irradiances are recorded at different temperature. They consist of 350, 550, 750, 950 and 1150 W/m^2. It is investigated clearly that the irradiances directly influence on real power. If the irradiance increases, the real power increases. It can be summarized that real power is a dependant of irradiance. On the other hand, generated real power inversely varies with the temperature. If temperature increases, real power decreases. Therefore if the temperature increases, the generated electrical energy also decreases.

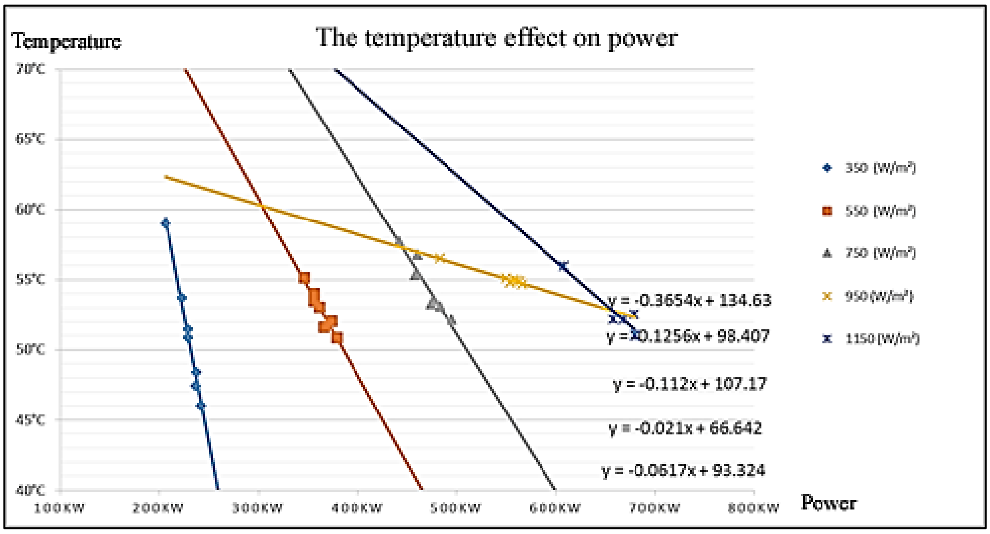

Figure 12. The temperature effect.

5. Discussion

From the results, it is investigated that the correlation equation in table 2 can predict generated electricity from solar energy. The highest error percent is about -20%. While generated energy is sometime higher than predicted value because the solar power plant are cleaned in that period. Therefore the automatic warning can be developed using prediction system. For example at error percent about -30% in the long time, the maintenance is scheduled. In the worst case, for example if the error percent about -70% or lower, the warning is alarm. Technicians have to check system immediately.

In the point of effecting factor, it can be summarized that irradiance directly influence on solar power plant. The ambient and module temperature are also effect factors. Moreover at the temperature is more than 45 ^{o}C, the real power is an effecting factor. On the other hand, humidity and wind speed had no effect on solar energy generation. The result of factors is shown in table 3.

Table 3. Effecting factors on solar power plant.

Temp**erature**.(^{o}C)	**Effecting Factors**					
	AT	MT	H	Ir	W	P
40.0-42.5	-	/	-	/	-	-
42.5-45.0	/	/	-	/	-	-
45.0-47.5	/	/	-	/	-	/
47.5-50.0	/	-	-	/	-	/

6. Conclusion

From the results, it can be concluded as follow;

1. The correlation equation can use to predict the generated value. The prediction is used following rang of temperature. There are four equations. Each equation depends on effecting factors as shown in table 3.
2. The solar module cleaning can improve efficiency of solar power plant. Cleaned solar cells can more generate energy.
3. The most effect occur from irradiance factor. It directly influences on solar power plant. If the irradiance increases, the energy generation increases.
4. The temperature effects on generated electrical energy. As the temperature increases, the generated electrical energy decreases.
5. Humidity and wind speed have no effect on energy generation in solar power plant.

7. References

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