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Performance Analysis of Grid-Connected PV Rooftop, at Sakon Nakhon Province, Thailand

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A B S T R A C T

The performance ratio (PR) based on IEC 61724 standard is calculated under the influence of seasonal variations and the capability of the system. On the other hand, The National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy proposed the weather-corrected performance ratio (PRcorr). This PRcorr index calculates the performance of the PV system which has taken the weather variations that influence the cell temperature into account. Both techniques were compared with the simulation program to analyze the PR index according to system conditions. The study site is the on-grid PV rooftop at Kasetsart University Chalermphakiat Sakon Nakhon (CSC). The PV panel is oriented to the southwest, 215 degrees azimuth. The angle of the inclination of the panel is 17 degrees. The result shows the trend of monthly PRcorr with little variations. At the same time, the PR value over the year has a lot of variations. The variation of PRcorr and PR is 2.39 and 5.07, respectively. PRcorr has low variability due to the correction of weather factors. The average cell temperature is an important variable. To calculate the average temperature of the panels, one year of data is needed to filter out distorted information. The system available condition is an important factor for the on-grid PV system at low voltage.

1. Introduction

Photovoltaic systems are currently being installed worldwide. The power received was estimated before the PV system was set up. And after installation, the energy generation potential of the PV system is measured. Due to the radiation and ambient temperature are different in each area. This paper is an extension of work originally presented in 16th ECTI-CON [1]. This paper examines the efficiency of the PV system in northeastern Thailand. The result will be a database of the energy generation potential of the PV plant in Sakon Nakhon province. According to the installation, the price per unit is much cheaper and at the same time the price of electricity is increasing. Manufacturers of equipment for the PV plant have increased, which has caused competition in the market. The amount of PV systems installation in Thailand has increased a lot, which is following the energy plan policy of the Thai government [2]. The installation of the PV system has spread throughout Thailand, both on the ground and rooftop. Therefore, many researches demonstrate the efficiency of the PV system, which influences people to install a clean energy plant.

The commonly used to assess the performance of a PV plant that is commonly used is the IEC 61724 standard. Following the IEC 61724 standard, the performance ratio (PR) is calculated by taking into account the radiation intensity, ambient temperature, wind speed, humidity, solar panels, and balance of system (BOS). The performance of the PV system depends on seasonal changes. Chong Li presented the calculation of PR with different PV types over the year in China [3]. The result shows that the performance ratio of poly-silicon PV increases from January to May and monthly array losses in summer are high. Then, the performance ratio of the PV system depends on location, PV module type, and the climate conditions. In 2019, Dhimish et.al. proposed the direction of the PV module for solar radiation that is important for energy production [4]. In addition, the azimuth angle is shown, which influences the maximum energy production. The suitable azimuth angle for the PV installation in the UK is -4 to 2 ^{o}C (the azimuth angle in the south is 0 ^{o}C). The data relation between irradiation and output power is to fitted regression. The R-square value is used to explain the variability data. High relative to R-squared, which is close to 1, means that the PV system generates the most electrical energy. Meanwhile, Singh demonstrated the

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performance ratio obtained by PVsyst at Naresuan University, Thailand [5]. The performance ratio in each month is quite stable, which differs from the actual operation of this variation every month. Therefore, the weather variations employ to calculate the PR index based on the IEC 61724 standard. The different climatic conditions in each month affect the PR value.

The weather-corrected performance ratio (PRcorr) is presented by the national renewable energy laboratory (NREL) of the U.S. Department of Energy [6]. This report suggests that the calculation of PR values according to climate change gives a low PR value and a fluctuation value. The weather variation should calculate the only factors that affect the cell temperature. According to research by Basson, the objective of this research is to reduce the sensitivity to climate data [7]. The result shows that the temperature correction has a significant effect to reduce the seasonal changes. Compare to the PR method, its value has significant variation. Syahputra proposed the PRcorr calculation in the real operation in the tropics and subtropics compare to the PR technique of IEC 61724 standard [8]. Also, the temperature coefficient for power is presented in the real operating condition as well. The value of the temperature coefficient varies in different irradiation. As a result, the range value of PRcorr is greater than PR. Therefore, the PRcorr index defined by NREL is also useful for benefit financing.

The design of the PV system involves an analysis of production capacity, often through a simulation program. PVsyst is another simulation program that helps the designer to define from PV sizing, the capacity of the inverter, to energy production estimation [9]. For the simulation, NASA or PVGIS weather data was always used [10]-[11]. To calculate the power ratio correctly, the weather data in the installation area should be measured. Using the estimation data in the simulation model may cause the result to deviate from the actual value [12].

The northeastern region of Thailand is in an area that receives good solar radiation. From the data of the solar map potential improvement project for Thailand 2017, it is apparent that the average monthly daily radiation intensity is 20 to 22 MJ / m^2 per day [13]. In particular, the Kasetsart University Chalermphakiat Sakon Nakhon (CSC) is a campus of Kasetsart University in the province of Sakon Nakhon located in the northeastern part of Thailand with 17.28661 latitude and 104.1061 degrees longitude, as shown in Figure 1. The average solar energy is 17.91 MJ / m^2 per day, and in April the average solar energy is up to 20.84 MJ / m^2 per day. Topograpgy of Sakon Nakhon city is a flat plain with no tall buildings, and there is no large industry that causes air pollution. Therefore, the province of Sakon Nakhon is suitable for the installation of the PV system. Currently, both the public and private sectors in Sakon Nakhon Province are interested and have installed more PV systems. The production of electric power by solar cells, not only reduces the dependence on the main grid but also responses to the government policy. But many people want to know the energy efficiency of the PV system, which has different weather conditions in each area. Appropriate assessment of energy production potential to support decisions made by persons interested in the PV system.

Therefore, this research proposes an efficiency evaluation of a PV production system, based on the IEC 61724 standard and the weather-correct performance ratio of the NREL concept. The result from both concepts were compare to the PVsyst analysis result. The measure data in the study area is input to analyze the significant factors that influence the energy production of the on-grid PV system at low voltage.

Figure 1: Location of Sakon Nakhon, Thailand on Google map.

2. Solar Rooftop at CSC

CSC in Sakon Nakhon covers an area of 6.4 square kilometers. The Faculty of Science and Engineering is part of the University that teaches and provides useful research results to society. One of the research sections conducts clean energy research such as on-grid PV rooftop. The schematic diagram of the grid-connected PV system is shown in Figure 2. The PV system consists of 10 modules of the series, a single-phase 3.6 kW inverter and other equipment used for the installation of the PV system. For installation details, the PV module faces southwest, 215 degrees solar azimuth (north is 0 degrees angle). The angle of inclination of the plate is 17 degrees. The energy output from the PV generation flows at low voltage into the load center of the building. The rated voltage in Thailand is 230 volts.

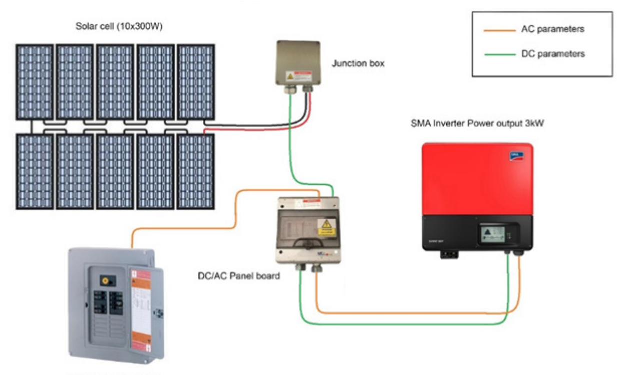


Figure 2: The schematic diagram of 3 kWp PV system

The specification for PV module and inverter is listed in Table 1. The cell type of PV module is poly-crystalline and the total area of PV panels is approximately 19.3 m^2. PV panels send DC power to the junction box via a cable. The cable made of aluminum with a cross-sectional area of 4 mm^2. The junction box contains a DC fuse (20 kA, 2 POLES), after which the DC power flows into the inverter and the AC power is obtained. The AC power flows back into the AC fuse in the junction box and then goes to the load center. The inverter is a grid-tie inverter of SMA type, Sunny Boy 3600TL-21.

Table 1: PV Module and Inverter Specifications

PV module	Spec.	Inverter	Spec.
Max. Power (Wp)	300	Rated AC Output Power (kW)	36.8
Open-circuit Voltage (V)	45.14	Maximum Current (A)	16
Short-circuit Current (A)	8.74	AC Nominal Voltage (V)	230
Max. Voltage (V)	37.01	Max. Input Current	15
Max. Current (A)	8.12	Input Voltage (V)	175-500
Temp. Coefficient	-0.4574 (%/°C)	Maximum Efficiency (%)	97

According to the SMA inverter, information about electrical energy on the inverter can be found on the website, as the data is transmitted via the university's intranet. The information on this website contains only some information, this is not enough to analyze the performance of the PV system. Consequently, sensors were installed to measure relevant data such as the radiant level, ambient temperature, module temperature, AC power and DC power being recorded at the same reference time. Large amounts of data may contain data discrepancies. Therefore, both the measuring instruments as well as the data acquisition tools are required to have low tolerances [14]-[15].

3. Performance Index of PV System

3.1. IEC 61724 Methodology

For analysis of system performance under standard IEC 61724. This standard has been used as a reference in many studies [16]. The indices specified in the standards are used to measure system performance, including assessing the losses that occur in the system.

Reference Yield (Y_R) is referred to as the reference irradiance generate power (H_t) under standard test condition (G_{STC}) (kwh/m^2), usually 1 kW/m^2. It is the calculation of the energy that is generated by this light intensity. The relationship is shown in equation (1).

$$Y_R = \frac{H_t}{G_{STC}} \qquad \left(kWh.kW_p^{-1}\right) \tag{1}$$

Array yield (Y_A) is the ratio of daily energy generation from PV array (E_{DC}) divided the kW of installed PV array (P_0). This parameter calculates the energy output per day and uses this value to calculate the average per month. Therefore, the average power of the DC part per day of each month is obtained. Y_A value is given by equation (2).

$$Y_A = \frac{E_{DC}}{P_0} \qquad \left(kWh.kWp^{-1}\right) \tag{2}$$

Final Yield (Y_f) is defined as the daily energy generation from PV plant (E_{AC}) divided by the total kW of installed PV array (P_0). This energy refers to the energy gained after passing the inverter or the AC power part. Y_f is calculated using equation (3)

$$Y_F = \frac{E_{AC}}{P_0} \qquad \left(kWh.kWp^{-1}\right) \tag{3}$$

Performance ratio (PR) indicates the actual energy production and the energy generated by the incident irradiation. Therefore, PR is the ratio of Final Yield (Y_f) to Reference Yield (Y_R). This parameter shows the efficiency of the system during solar conversion until the final electrical power is reached. Therefore, the PR index is influenced by all environmental factors and including the efficiency of the PV system. PR calculation is given by equation (4).

$$PR = \frac{Y_F}{Y_R} \times 100\% \tag{4}$$

According to the IEC 61724 standard, the system loss also occurring in the PV system is calculated. The loss is caused by the equipment in the system, such as the PV panel, cable wire, inverter, and other factors that cause the loss to increase.

The standard IEC 61724 also shows the loss value in the system as in equation (5). Array Capture Loss (L_A) is the loss from PV array. It the different value between Y_R and Y_A.

$$L_A = Y_R - Y_A \qquad \left(kWh.kW_p^{-1}\right) \tag{5}$$

Another loss value is system loss (L_S) that depended on equipment effect in the system such as inverter, wire and PV panels. It is calculated in equation (6).

$$L_S = Y_A - Y_F \qquad \left(kWh.kW_p^{-1}\right) \tag{6}$$

3.2. Weather Corrected Performance Ratio

According to the technical report of the national renewable energy laboratory (NREL) [6], the weather-corrected performance ratio (PRcorr) was presented. PRcorr is modified from the PR concept of IEC 61724. PRcorr was created by reducing the impact of fluctuating seasonal conditions, which also causes the PR value to fluctuate. Therefore, PRcorr has improved the formula in IEC61724. PRcorr focuses on the technique to obtain the cell temperature, which affects efficient PV generation. The formula PRcorr calculates the cell temperature based on irradiation and ambient temperature. The equation is shown in (7).

$$PR_{corr} = \frac{\sum_i EN_{AC\_i}}{\sum_i \left[P_{STC} \left(\frac{G_{POA\_i}}{G_{STC}} \right) \left(1 - \frac{\delta}{100} \left(T_{cell\_typ\_avg} - T_{cell\_i} \right) \right) \right]} \tag{7}$$

where

PR_{corr}: corrected performance ratio (%)

EN_{AC}: measured AC power generation (kW)

P_{STC}: total of installed modules' power rating at standard test condition (STC)

G_{POA}: the radiation measurement at plane of array (POA) (kW/m^2)

G_{STC}: irradiance at STC (1,000 W/m^2)

T_{cell}: cell temperature computed from measured meteorological data (°C)

$T_{cell\_typ\_avg}$: average cell temperature computed from one year of weather data using the project weather file (ºC)

δ: temperature coefficient for power (%/°C, negative in sign) that corresponds to the installed modules

i: a given point in time (day)

NREL shows that the use of an adapted reference cell to measure irradiance avoids the need to correct spectral variations as well. In the meantime, other weather effects such as snow losses, environmental pollution losses or the effects of variable irradiance on efficiency are not corrected. Corrections for these additional weather effects could lead to more consistent results.

3.3. Performance Ratio by PVsyst Analysis

In general, the technique and analysis of the performance of the PV system needs to be calculated before the actual installation of the system. Therefore, the use of the simulation programs to analyze a process is necessary, which leads to losses in the system, energy and production performance. The PVsyst simulation program can analyze these parameters and generate solar radiation and other weather data in the study site.

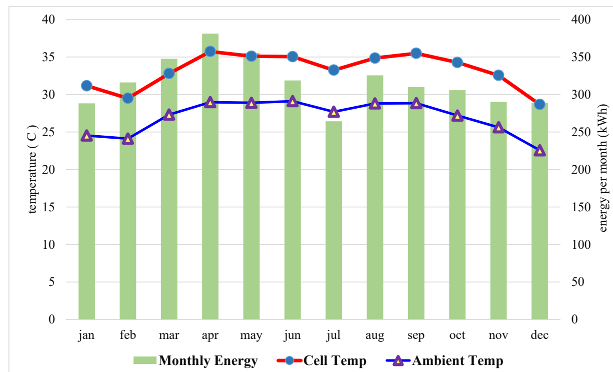
Therefore, when analyzing the performance of the PV system, the correct information needs to be entered compared to the actual value, including cable line, the inverter and PV module type. The installation properties are the actual value in the installation area, such as the azimuth angle and the tile angle of the module. The accuracy of the weather data entered into the simulation program must come as close as possible to the actual conditions and then the high accuracy output will be obtained. The analysis with this simulation program also analyzes the weather-corrected performance ratio [17].

4. Result and Discussion

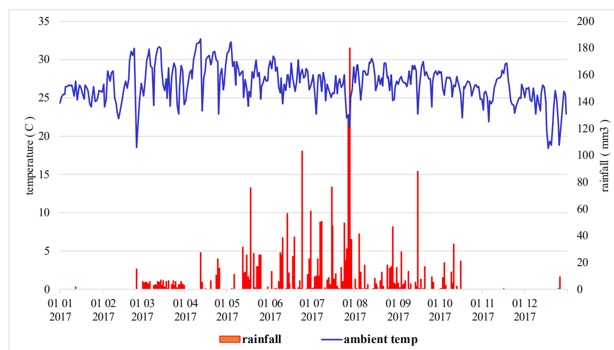
The results of this experiment are based on annual data for 2017. Figure 3 is the 3 kWp PV plant with the temperature sensor and radiation sensor. All data are collected to data logger. An energy meter is installed for the DC and AC power measurement of the PV system.

Figure 3: Plant Study at CSC, Sakol Nakhon

Figure 4 (a) shows the average cell temperature, the average ambient temperature, and the monthly energy of the PV system. The average monthly temperature data clearly shows that the panel temperature is higher than the ambient temperature. In 2017, the average ambient temperature is 26.97 ºC and the average cell temperature is 33.19 ºC. Figure 4 (b) shows the amount of rainfall every day. Note that the heavy rains occur in June, July, and August. As a result, the average ambient temperature also drops. In September and October, the rainfall begins to decrease and then the average ambient temperature gradually increases. In Sakon Nakhon province, from 28 to 29 July 2017, precipitation for both days was up to 310 mm^3, heavy rain caused a sudden flood. The result is a widespread power outage in Sakon Nakhon province. A major power outage meant that the inverter was also disconnected from the PV system. Therefore, the grid-connected PV system has dropped out of the main grid and does not need to generate power for a while.



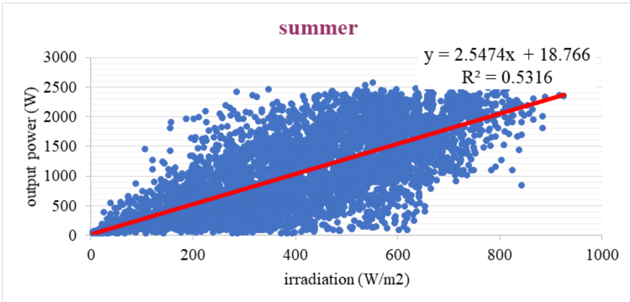
(a) Cell Temperature and Ambient Temperature Compare to Monthly Energy



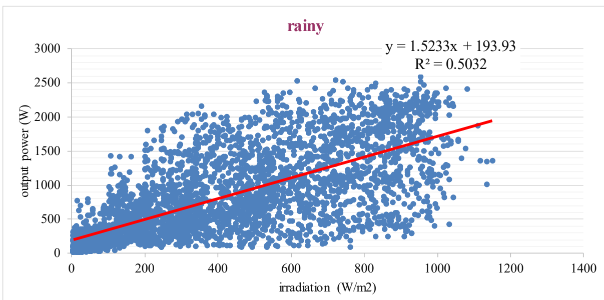
(b) Ambient Temperature and the Rainfall

Figure 4: The Weater Factors and Monthly Energy

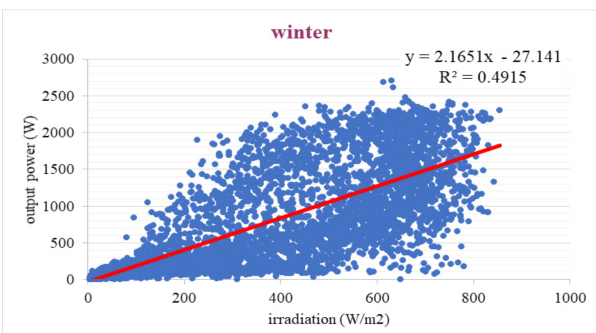
Because of the PV module faces southwest, 215 degrees solar azimuth, the irradiation data are grouped in the solar azimuth or sun path throughout the year. The sun path refers to the sun that appears daily in the sky. The path of the sun has different values (degrees) every day and causes seasons. From the Sun Orbit database at CSC, each month was grouped with similar orbits. It refers to the sunrise at 6 a.m. and the sunset at 6 p.m. The summer group consists of February, March, and April with an azimuth of the sun between 76 to 97 degrees in the east and 261 to 284 degrees in the west. Rainy season groups are May, June, July, August and September. The sun orbits of this group are between 71 and 80 degrees in the east and between 277 and 292 degrees in the west. The winter group with similar approaches to the movement of the sun are January, October, November, and December with an azimuth angle between 106 and 112 in the east and between 244 and 256 in the west. Taking into account the average movement direction of the sun per month, it can be divided into three types as described above. Each group has daily routes orbit that are close to each other. It should be obtained a similar sun intensity. The three groups season relate to the irradiation, shown in Figure 5.



(a) The Summer Group



(b) The Rainy Group



(c) The Winter Group

Figure 5: The Relationship between Solar Irradiation and Output Power

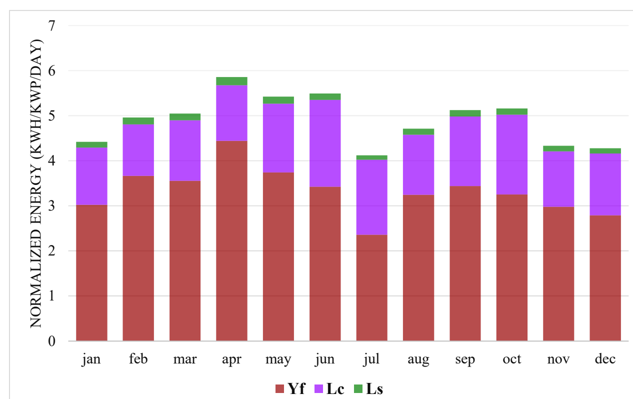
Figure 5 shows the relationship between solar irradiation (W/m^2) and electric power produced (W) according to the monthly groupings mentioned above. Curve fitting is a statistical method used to analyze the data. The R-square indicates the degree of proximity of the data. As the R-squared value approaches 1 or 100%, it means that all data points would fall on the adjusted regression line. According to Figure 5(a), the R-squared of the summer group is higher than the others. The R-squared of Figure 5(b) and Figure 5(c) is 0.5032 and 0.4915, respectively. The winter group has a minimum of R-square value. Since the energy output is approximately linear for irradiation in the study area. This means that the electrical energy generated by the PV system at this time is most valuable.

According to the monthly energy of CSC plant, the electrical energy generated by the PV system is compared with the R-square in Table 2. The summer group has the highest average monthly production capacity of about 348 kWh, while the winter group has the smallest R-square. The average energy during the winter group generated is 293 kWh/month. Therefore, the trend of maximum amount of energy will occur in Sakon Nakhon this month.

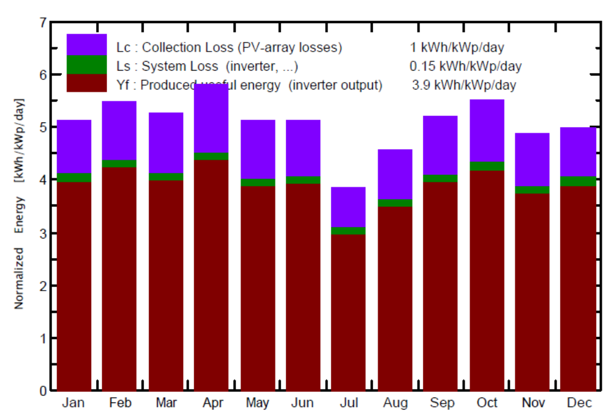
Table 2: Comparative Average Monthly Energy and R-square

Season group	average monthly energy (kWh)	R-square
Summer	348	0.5316
Rainy	315	0.5032
Winter	293	0.4915

For the performance analysis according to IEC 61724 standard, Figure 6 (a) shows the average monthly value of Y_f, L_c and L_s which is 3.33, 1.45 and 0.14 respectively. Compared to the result of PVsyst as shown in Figure 6 (b), Y_f, L_c and L_s which is 3.9, 1.0 and 0.15 respectively. Both techniques are similar energy generation such as the low Y_f is in July. The maximum system loss occurred in April, the IEC method shows 0.19 kWh/kWp/day and PVsyst is 0.169 kWh/kWp/day. The trend of the energy value obtained from the PVsyst program is higher than in the IEC technique, where the actual value is used for the calculation. Therefore, using the prediction program, the energy estimate is inflated. Overall, the amount of energy generation from PVsyst is high. However, the PV array loss is less than with the IEC technique, possibly the dust on the PV module. The system has been installed for almost 3 years and the panel has not been cleaned. Estimating these parameters will input all data as monthly averages. The result of the analysis may be inaccurate or deviate from the actual value.



(a) Y_f, L_c and L_s based on measure data



(b) Y_f, L_c and L_s from PVsyst analysis

Figure 6: Result from the measure data compare to PVsyst analysis

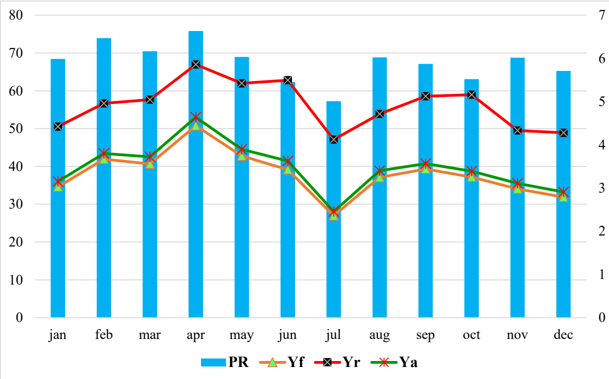


Figure 7: Performance of PV System at CSC

Figure 7 shows the calculation value of the PR index based on Y_F, Y_A, and Y_R data. The graphic shows a comparison of the performances of the grid-connected PV system. For each month of Y_F, Y_A, and Y_R, the line curves are similar. Y_F and Y_A are closed values, as this depends on the efficiency of the inverter and loss in cable. As a result, the average efficiency of the inverter is 96%. The maximum Y_R in April is 5.86 kWh.kW^{-1}, which according to the monthly energy value is 381 kWh. April is considered a hot season. The average temperature is generally high and most skies are cloudless. While July which in the rainy season has a low of Y_R and similar to monthly energy as well. The average Y_R in July is 4.12 and the monthly energy is 264 kWh. On the other hand, Y_F and Y_R lines are separated from each other. It means Y_R can covert to Y_F depend on the system efficiency. It also represents the amount of loss that has occurred in the PV system. The loss consists of the loss of the PV array loss, cable loss and the system loss caused by the efficiency of the inverter.

Every month the average power ratio is calculated. The maximum PR in April, February, and March is 75.8%, 73.94%, and 70.47%, respectively. On the other side, the minimum PR in July is 57.23%. At the end of the year, which is the winter season, monthly energy production tends to decline. Note that the low PR period is during rainy and winter season. PR parameter reflects the performance of the system for converting solar energy into electricity. A high PR also indicates a small loss in the system.

Based on IEC 61724 standard, the PR calculation is caused by the effects of all environmental factors on the PV system. As a result, the PR value fluctuates quickly. Therefore, some researchers do not think about these effects. The PR index should have suitable values to assess the potential of the system. The weather-correct performance is presented by NREL, which corrects the cell temperature. The irradiation and ambient temperature data are used to recalculate the performance of a PV system that directly affects the cell temperature. At the same time, the PVsyst has been used to calculate PR values as well. By creating a simulation model with system unavailability conditions of the main grid system. It indicates the percentage of the period in which the system is unavailable, consisting of 0%, 5%, and 10%. According to the measurement data, there are outage events in a few months. For January, September, October, November, and December are defined to the month of system unavailability condition, as shown in Table 3.

Table 3 shows the PRcorr, PR index based on measured data and PR index analysis by PVsyst. The maximum PRcorr in April is 82.05%, as PR is 75.8%. But in PVsyst calculation, the maximum PR with system unavailability 0%, 5%, and 10% are 78.9% in December, 75.7% in January and 44.7% in February and July respectively. For average PRcorr, PR and PR of PVsyst at 0% are 77.34%, 67.52%, and 77.15% respectively. The variation calculation value is based on statistical techniques. Therefore, the standard deviation is chosen. For standard deviation analysis, the PR and PRcorr are 2.39 and 5.07 respectively.

Table 3: Comparative Average Monthly Performance Ratio (%)

Month	PRcorr	PR	System Unavailability (%)		
			0	5	10
January	74.51	68.42	78.10	75.70	57.40
February	76.37	73.94	77.70	75.30	77.70
March	77.18	70.47	76.10	64.70	76.10
April	82.09	75.80	75.90	73.60	75.90
May	77.96	68.97	76.50	74.10	76.50
June	79.86	62.36	77.20	64.30	77.20
July	73.86	57.23	77.70	66.70	77.70
August	79.67	68.85	77.50	75.00	77.50
September	77.82	67.11	76.50	74.10	57.90
October	76.20	63.07	76.50	74.20	58.50
November	77.49	68.74	77.20	63.80	59.30
December	75.01	65.24	78.90	67.30	61.00
Average	77.34	67.52	77.15	70.73	69.39
Std.	2.39	5.07	0.89	4.87	9.39

PRcorr is significantly higher than PR and the line trend is quite stable, which does not change significantly during the year. While the standard deviation value of PVsyst is tended to increase with the strong value of system unavailability. The PRcorr value varies slightly because the cell temperature was influenced by radiation and ambient temperature. While other weather factors based on the NREL concept are un-correct such as pollution, snow or shading. PRcorr is therefore very valuable and encourages people to be more interested in PV production.

For the other hand, PVsyst analysis, the average PR with 0% system unavailability is similar to PRcorr, but the standard deviation value has very little variation. The standard deviation increases with high system unavailability because the energy output from the PV system cannot flow to electrical load, such as fault event or temporary power from utility. Therefore, the PR with 0% system unavailability is calculated based on the weather corrected condition.

The PR value is a performance indicator that combines the effects of various factors such as the intensity of light falling on the PV module, cell temperature, shading, or device malfunctions in the system. When analyzing these factors, some factors are not related to the weather. However, when weather factors are used to calculate the PR value, it is low and changes rapidly.

Use the PVsyst to determine the monthly energy. The monthly energy output from the PV system is compared with the result of PVsyst, shown in Table 4. The maximum energy in April is 381 kWh, similar to PVsyst, the maximum output in April is 395 kWh. When calculating deviations from the actual values, the maximum is 19% and the minimum is 13%. For average monthly with 10% system unavailability is closely the true value. Because it is stipulated that the PV system will not be able to supply electricity according to the actual incident (fault in the utility grid). Therefore, a high energy forecast is created for electricity from a PV system that can deliver at any time. Therefore, the use of the analysis program must take these events into account. These events often occur in areas with poor electrical reliability.

Table 4: Comparative Monthly Energy (kWh) with PVsyst Prediction

Month	Monthly Energy	System Unavailability (%)		
		0	5	10
January	288	371	330	273
February	316	358	358	358
March	347	372	372	372
April	381	395	395	395
May	355	363	363	363
June	319	355	355	355
July	264	278	278	278
August	326	327	327	327
September	310	357	311	271
October	306	391	345	299
November	290	338	298	259
December	288	365	321	282
Total (kWh)	3790	4269	4054	3831
Avg. per month	316	356	338	319
Error (%)	-	19	15	13

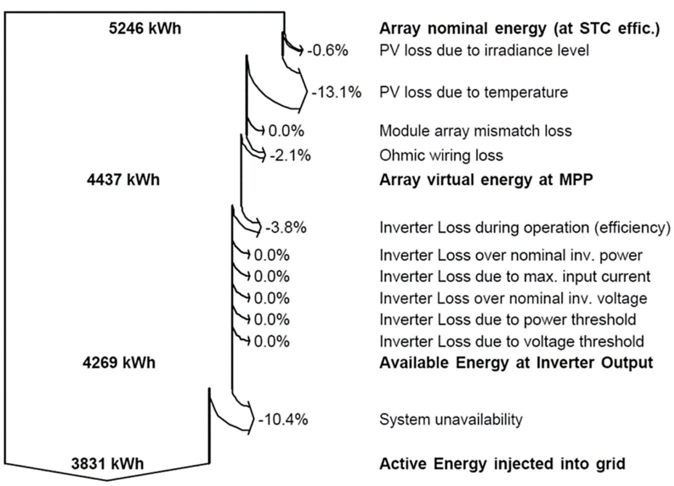


Figure 8: output from PVsyst analysis

The result from PVsyst,as shown in Figure 8, power loss calculation occurs in the PV system that has various types of loss. Nearly 13.1% power loss due to temperature. The high temperature leads to an increase in power loss and then to a reduction in the output power. The parameters used to analyze the PRcorr are derived from the device specification and the actual data in the experimental area. The important parameter is the average cell temperature (Tcell_typ_avg) each month which for average annual is 38.84 ºC. The temperature coefficient for maximum power (δ) is -0.004574 which applies for over the year.

For the on-grid PV system inclement weather such as rain, strong wind will cause the main power system to always fail, such as voltage drop or momentary power outage. These unusual weather conditions cause the inverter protection to work. The inverter's function is to disconnect the circuit so that the energy output of the inverter is zero. Figure 9 demonstrates the real power (P) value with interval time (15 minutes). The red circle is the point of the momentary power outage. Sometimes a power failure occurs for a very short period, such as 2 or 5 minutes. The inverter cuts off the circuit and then turns it on when the main grid can be re-energized. Therefore, the average AC data, for interval time 15 minutes, is reduced. At the mentioned point, the real power (kW) decreases abnormally. These unusual weather conditions cause the inverter protection system to work. Therefore, some monthly energies are reduced even though the cell temperature is low or irradiation is high.

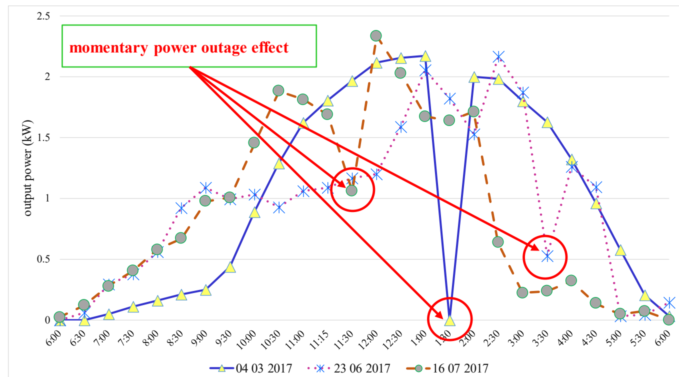


Figure 9: The monentary power outage effect in the on-grid PV system

5. Conclusion

This article presents the technical calculation of the conversion potential of solar energy up to the final electrical power. The technique used is the IEC 61724 standard and the index proposed by the NERL. PVsyst is a simulation model to estimate the energy and the performance ratio with the real conditions. The study site is Kasetsart University Chalermphakiat Sakon Nakhon (CSC). The PV equipment consists of the total PV installation is 3 kWp and 3.6 kW single phase of grid-connected inverter. The energy generation from the PV system flow to the load center of the building at CSC.

The irradiation data show that the R-squared distribution is high, about 0.5316, in February, March, and April, which means high energy production. In April, the maximum monthly energy is 381 kWh. The minimum energy generation occurs in July, about 264 kWh, because of heavy rain and no more the irradiation. For the average of Y_R, Y_A and Y_F is 4.91%, 3.47%, and 3.33%, respectively. The maximum performance ratio of the PV system is 75.80% in April. The average PR is 67.52%, which is influenced by weather factors. Compare to the PRcorr index, which is based on the NREL concept, the maximum PRcorr in April is like the PR index at 82.09% and the average PRcorr at 77.34%. For PVsyst calculation, the average PR with 0% system unavailability is close to the PRcorr and the average PR is decrease with more the system unavailability.

The PRcorr value tends to be less variable over the year. Therefore, PRcorr is usually higher than PR due to the weather-related effects. The effect refers to the cell temperature caused by ambient temperature and irradiation. On the other hand, the average ambient temperature is 26.97 ºC and the average cell temperature, which is normally high, is 33.19 ºC. Another factor is rain. The occurrence of heavy rain, even if the temperature drops. However, this affects the amount of energy that receives from the PV production system.

Therefore, when judged by these two techniques, it was found that finding the potential of the system with PRcorr is higher than PR. Because the correct temperature of the panel results in higher production efficiency as the effects of seasonal changes are reduced. Techniques for determining the average temperature of the panel are important for the analysis of PRcorr. PVsyst is useful to estimate the performance ratio of the PV system with the measurement data in the study area. In the case of the grid-connected PV system, if the main grid has some problems due to voltage drop or outage. The PV system is disconnected from the main grid, even though the PV system capable of producing electricity. Finally, both PRcorr and PR calculations are affected.

Conflict of Interest

The authors declare no conflict of interest.

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