Intermittent Renewable Energy Source (IRES) model of solar energy in Cipayung microgrid system

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Abstract. Indonesia has a great solar energy potential because its location is in a tropical area. One significant characteristic of solar energy is intermittent. Integration of intermittent renewable energy source (IRES) especially solar energy into electrical power grid can cause significant impact in power system stability. This study aims to model the IRES characteristic, profile, and time duration classification based on collected data in Cipayung microgrid system. The result shows the characteristic of IRES consist of two things, a sudden increase and suddenly decrease of solar source. These characteristic profile model is made by a polynomial and logarithmic regression analysis using mathematical equation. A condition where the availability of solar energy is immediately at a maximum or at a lowest point of zero has never been found. The very fast IRES classification occurs the most often with 0.5 to 1.0 minutes of time duration. System operator can use this information to prevent the system from collapsing and even having a blackout.

1. Introduction

The Republic of Indonesia has great solar energy potential because it is located in tropical area. Indonesia is located between 6° N and 11° N latitudes and between 95° E and 141° E [1,2]. This favourable condition offers great potential to integrate renewable energy system. Goverment of Indonesia in national energy policy stated to increase the share of renewable energy sources (RES) in total primary energy mix to 23% by 2025. Solar photovoltaic (PV) power plant fundamentally change the operation of power system. Some study in [3-7] shows the impact of very high penetration level of solar PV power plant. The high solar PV penetration give significant system stability impact in voltage profile and system frequency. One of significant characteristic of solar energy is intermittent. Regression analysis provides a technique to model and analyze the intermittency. This model helps to explain the correlation between independent variables on dependent variable’s behavior. Several studies in [8-10] used regression analysis to model solar irradiance but only for forecasting the solar irradiance in a period of time. There is no study focused on intermittent characteristic, profile, and time duration. The contribution of this study is to define the intermittent characteristic profile by mathematical model for solar energy integrated to electrical grid system. This study’s objective is to find out the characteristic, profile, and time duration of intermittent renewable energy source (IRES) of solar energy at Indonesia national electric company (PLN) Cipayung Microgrid System based on collected irradiance data.
2. System overview
Based on electricity supply business plan from 2017 to 2026 [11], Indonesia has a potential to generate over 200 GW from new and renewable energy as shown in Fig. 1. These Renewable energy are sourced from solar, hydro, wind, bio, geothermal, ocean, and including nuclear. The highest potential of renewable energy in Indonesia is from solar energy. Several regions in Indonesia has a great potential of solar energy especially in Java-Bali islands as shown in Fig. 2. Java-Bali interconnected power system currently is the largest power system grid in Indonesia, accounts for approximately 75% of Indonesia’s total energy consumptions [12-14]. This study is based on the recorded data in PLN microgrid system at 106.891570 longitude, -6.654297 latitude on 24th November to 4th December 2017. Microgrid Cipayung is a system developed by PLN research institute to electrify remote island. The solar PV system as shown in Fig. 3 is located in Cipayung, West Java, Indonesia built in 2016. The total solar PV installed capacity is 75 kWp. The solar irradiance is collected using solar power meter which record every change that happens in solar PV installed area.

![Figure 1. Indonesia potential of renewable energy.](image1)

3. Solar irradiance
3.1. Intermittent Renewable Energy (IRES) of solar energy
The output of any renewable energy such as wind, wave, and solar depends on environmental and nature conditions. The important properties of solar energy are the uncertainty and variability of the source. This characteristic is also known as an intermittent renewable energy source (IRES) or variable renewable energy (VRE). Availability of solar energy on the area is one of the consideration factors for implementing the solar PV system. An IRES especially solar irradiance or solar radiation is a energy source that is not contionously available in the nature. It is important to figure out the characteristic and time duration of IRES. The characteristic of IRES is having a condition that is not continuously available nor continuously unavailable due to external factors that cannot be controlled. This is a common condition in power system but it is becoming a significant problem if it is a very large power generation from solar PV [15]. Classifying the time duration of IRES is essential for the system operator. The study classify
the solar energy by classes of cloudiness [16]. In other study [17], weather is classified in three groups:
sunny, cloudy, and rainy. The way to understand the classification of IRES, we propose the type of IRES
from duration as shown in Table 1. The extreme fast IRES classifications is a critical condition. It is
important for system operator and conventional for the power plant to prepare the ramp up or down to
prevent the system from collapse even blackout.

![Figure 3. PLN microgrid system in Cipayung Indonesia.](image)

| Type  | Classification | Duration (minutes) |
|-------|----------------|--------------------|
| I     | Extreme fast   | 0 < t ≤ 0.5        |
| II    | Very fast      | 0.5 < t ≤ 1.0      |
| III   | Moderate       | 1.0 < t ≤ 1.5      |
| IV    | Fast           | t > 1.5            |

3.2. Regression analysis
IRES characteristics and classifications for high IRES penetration level have been discussed. It is
important to model the IRES based from the recorded data. Solar irradiance data are the best source of
information for the proper design and assessment of solar energy conversation systems. Regression
analysis is a way to predict a better fit model of IRES especially solar irradiance. This technique is
commonly used to predict the relationship between independent variables related to dependent variable.
An independent variable is the variable that is changed or controlled in a scientific experiment to test
the effects on the dependent variables. A dependent variable is the variable being tested and measured
in a scientific experiment. Solar irradiance is a dependent variable and time is an independent variable.
The following variables analysis is carried out in statistical analysis software. Build a regression model
from solar irradiance data can use various methods [18]. Two function models used in this study are
logarithmic and polynomial. The logarithmic functions increase or decrease rapidly at first, but then
steadily slows down as time moves on. The logarithmic function most commonly used on graphic
utilities is shown in equation (1).

\[
F(x) = a + b \ln(x)
\]  (1)

\[
Y = b_0 + b_1 x^1 + b_2 x^2
\]  (2)

\[
R^2(\%) = \frac{\text{Explained variation}}{\text{Total variation}} \times 100\%
\]  (3)
The second method to model the solar irradiance is with polynomial regression. A polynomials function is used when data fluctuates. The order of the polynomial can be determined by the number of hills and valleys appearing in the curve. The polynomial function is most often used are the quadratic as shown in equation (2) where $Y$ is predicted outcome value and $d$ b is regression coefficient. $R$ is the correlation between the observed and predicted values of dependent variables. $R$ is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination. The definition of $R^2$ is the percentage of the response variable variation that is explained by a linear mode as shown in equation (3). $R^2$ is always between 0 and 100%. In general, the higher $R^2$ means the better models fit the data. The daily recorded solar irradiance data from 24th October 2017 until 5th December 2017 shown in Fig. 4. The sun rise from 07.00 a.m to 05.00 p.m in west Indonesia time. The variability of the curve from day to day is different one to each other can be seen. The 10 days’ graph shows the fluctuation of solar irradiance when the solar irradiance value changes.

**Figure 4.** Solar irradiance on 24th October 2017 to 5th December 2017.

The solar irradiance clearly expressed in statistic data as shown in Table 2 to Table 4 which provides information about maximum, minimum, and the average of the solar irradiance in 10 days recording.

**Table 2.** Solar irradiance on 24th October 2017 to 5th December 2017.

| Date       | Maximum (W/m²) | Minimum (W/m²) | Average (W/m²) |
|------------|----------------|----------------|----------------|
| 24/11/2017 | 1111           | 31             | 608.35         |
| 25/11/2017 | 812            | 34             | 462.06         |
| 26/11/2017 | 1161           | 30             | 541.99         |
| 27/11/2017 | 887            | 30             | 314.96         |
| 28/11/2017 | 870            | 30             | 451.59         |
| 29/11/2017 | 901            | 29             | 416.04         |
| 30/11/2017 | 234            | 31             | 101.87         |
| 01/12/2017 | 541            | 30             | 267.15         |
| 02/12/2017 | 713            | 38             | 327.88         |
| 03/12/2017 | 990            | 38             | 615.29         |
| 04/12/2017 | 1024           | 47             | 653.98         |
| 05/12/2017 | 898            | 52             | 553.69         |
Table 3. Solar fluctuation on 24th October 2017 to 5th December 2017.

| Date           | Maximum (W/m²) | Minimum (W/m²) | Average (W/m²) |
|----------------|----------------|----------------|---------------|
| 24/11/2017     | 194            | -211           | 0.0267        |
| 25/11/2017     | 37             | -37            | 0.0658        |
| 26/11/2017     | 76             | -77            | 0.1565        |
| 27/11/2017     | 36             | -36            | -0.0078       |
| 28/11/2017     | 14             | -8             | -0.0013       |
| 29/11/2017     | 74             | -96            | -0.0009       |
| 30/11/2017     | 7              | -6             | 0.0042        |
| 01/12/2017     | 24             | -20            | 0.0036        |
| 02/12/2017     | 9              | -9             | 0.1935        |
| 03/12/2017     | 87             | -65            | -0.0088       |
| 04/12/2017     | 72             | -67            | -0.0100       |
| 05/12/2017     | 153            | -176           | 0.0694        |

Table 2 shown the highest solar irradiance which is 1161 W/m² on 24th November 2017 where the lowest is 234 W/m² on 30th November 2017. The average minimum solar irradiance is 35 W/m². The average solar irradiance from 24th November 2017 to 5th December 2017 is 442.90 W/m². The solar power meter recorded every fluctuation as shown in Table 3. The percentage values are the solar irradiance from maximum solar irradiance. The greater solar irradiance value indicates the intermittent phenomenon while the smaller solar irradiance value indicates the stable fluctuation. The maximum rows shown the event when the solar irradiance is suddenly increase while the minimum rows show the sudden reducing. From the average rows show the fluctuation seems to increase. IRES phenomenon occurs when large number of solar irradiance is suddenly integrated or loss from the system. Table 4 shows the IRES phenomenon increases or decreases over 50% with the time duration. The highest IRES upward curve is 82.18% in 2 minutes 1 second and the highest IRES downward curve is 78.31% in 28 second.

Table 4. Solar fluctuation on 24th October 2017 to 5th December 2017.

| Date           | Concave | Top (%) | Bottom (%) | Delta (%) | Time Duration | Date           | Concave | Top (%) | Bottom (%) | Delta (%) | Time Duration |
|----------------|---------|---------|------------|-----------|---------------|----------------|---------|---------|------------|-----------|---------------|
| 24/11/2017     | Upward  | 86.14   | 3.96       | 82.18     | 2 minute 1 second | 04/12/2017     | Downward | 85.9       | 6         | 24.84       | 61.1          |
| 24/11/2017     | Downward| 86.41   | 8.10       | 78.31     | 28 second     | 04/12/2017     | Upward  | 84.1       | 6         | 30.78       | 53.3          |
| 27/11/2017     | Upward  | 79.84   | 15.75      | 64.09     | 6 minute 14 second | 04/12/2017     | Downward | 82.0       | 9         | 22.95       | 59.1          |
| 04/12/2017     | Downward| 70.48   | 17.10      | 53.38     | 26 second     | 04/12/2017     | Upward  | 82.1       | 8         | 22.95       | 59.2          |
| 04/12/2017     | Upward  | 72.10   | 15.66      | 56.44     | 56 second     | 04/12/2017     | Downward | 92.1       | 7         | 39.33       | 52.8          |
| 04/12/2017     | Downward| 77.59   | 22.50      | 55.09     | 43 second     | 04/12/2017     | Upward  | 84.7       | 9         | 32.94       | 51.8          |
| 04/12/2017     | Downward| 82.63   | 24.21      | 58.42     | 37 second     | 04/12/2017     | Downward | 84.7       | 0         | 26.73       | 57.9          |
| 04/12/2017     | Upward  | 82.99   | 24.21      | 58.78     | 3 minute      | 04/12/2017     | Upward  | 80.8       | 3         | 26.73       | 54.1          |

Irradiation consists of light scattered by the atmosphere such as air, clouds, aerosols, and also dust. Diffusion [19]. Cloud dynamics movement play a significant role due to their impact on the solar irradiance balance [20]. From Fig. 5 shows the IRES phenomenon when the cloud passed and covered...
percentage area in Cipayung area. Fig. 6 shows the cloud passing through. The cloud make the solar irradiance change rapidly during the day. Several models are developing by the authors to predict solar irradiance in producing the required energy. In power system stability viewpoint, IRES is about suddenly loss of power and suddenly power connected [21,22]. The sudden loss and increase of solar PV source can affect IRES generation.

The way to describe the IRES profile is using regression analysis. Fig. 7 and Fig. 8 shows two regression curve models. The relationship between the IRES of solar irradiance and time in downward curve is shown in Fig. 7. The polynomial regression analysis is used to model the IRES profile.

| Table 5. Coefficients. |
|------------------------|
| Equation | R Square | Constant  | b1   | b2    |
| Quadratic | 0.884    | 839.878  | 17.071 | -1.984 |
Table 6. Coefficients.

| Equation       | B     | Std. Error |
|----------------|-------|------------|
| In (time)      | 278.926 | 15.344    |
| Constant       | 143.289 | 38.289    |

According to statistical coefficients in Table 5, the correlation between solar irradiance and time in downward curve is \( F(x) = -1.984x^2 + 17.071x + 839.878 \) where coefficients \((R^2)\) is 0.884. Solar irradiance and time are positive correlation. The \( R^2 \) indicates about 88.4% regression model fit the data. The relationship between the IRES of solar irradiance and time in upward curve shown in Fig. 8. The logarithmic regression analysis is used to model the IRES profile. The correlation between solar irradiance and time in upward curve is \( F(x) = 278.926 \ln (x) + 143.289 \) where the coefficients \((R)\) is 0.966 and coefficients \((R^2)\) is 0.966 as shown in Table 6. Solar irradiance and time are positive correlation. This model is very good where \( r \) is more than 0.9 which indicates that the regression reflects the trend of increase in intermittent completely. From the processed data in Fig. 4 and Table 4 there are IRES phenomenon with short duration occurs as shown in Table 5. The very fast IRES classification most often occurs in 0.5 to 1 minute’s duration. One of important things, the extreme fast classification with 0 to 0.5 minutes’ duration occurs in this area.

Table 7. IRES classification of time duration.

| Type | Classification  | Duration (minutes) | Event |
|------|-----------------|--------------------|-------|
| I    | Extreme fast    | 0 < t ≤ 0.5        | 4     |
| II   | Very fast       | 0.5 < t ≤ 1.0      | 6     |
| III  | Moderate        | 1.0 < t ≤ 1.5      | 2     |
| IV   | Fast            | t > 1.5            | 4     |

4. Discussion
The characteristic, time duration, and profile of IRES for solar energy has been investigated and analyzed. The characteristic of IRES in Cipayung microgrid system consist in two characteristic, the first characteristic is suddenly available and the second characteristic is suddenly loss of source. From the processed data, there has not been found a condition where the availability of solar energy is immediately maximum or loss to zero. It can be obviously explained through the time duration classifications. The very fast IRES classification or type II most often occurs in Cipayung area with 0.5 to 1.0 minutes of duration. The extreme fast classification or type I with 0 to 0.5 minutes’ duration occurs in this area. Cloud dynamics movement also affect the IRES characteristic when the cloud covers a percentage of Cipayung area. To complete the information, the IRES profile of solar energy model is done by regression analysis. The first characteristic is modelled by mathematical equation. The sudden appear of IRES is represented by the upward curve in 24th November 2017 on 10.58.53.364 to 11.00.54.364 a.m. The IRES become suddenly available from 3.96% to 86.14% in 2 minutes and 1 second. This relationship between the IRES variable and time in upward curve is shown by the concave model with \( F(x)=278.926 \ln (x) + 143.289 \) by polynomial regression analysis. The second characteristic is also model by mathematically equation. The suddenly decrease of IRES represented by the downward curve in 24th November 2017 on 10.01.11.364 to 11.01.39.364 a.m. The IRES suddenly reduces from 86.41% to 8.10% only in 28 second. The relationship between the IRES variable and time in downward concave is modelled with \( F(x) = -1.984x^2 + 17.071x + 839.878 \) by logarithmic regression analysis.

5. Conclusion
The characteristic, time duration, and profile of IRES for solar energy has been investigated and analyzed based on ten days collected data from 24th November to 4th December 2017 in Cipayung microgrid system. The characteristic of IRES consist of two type. The first characteristic is suddenly
available of solar source and the second characteristic is sudden loss of solar source. These characteristic profile is modelled by polynomial and logarithmic regression analysis using mathematically equation. From the time duration classification, there has not been found a condition where the availability of solar energy is immediately maximum or loss to zero. The very fast IRES classification is the most often occurs with 0.5 to 1.0 minutes of time duration. Despite of the very fast IRES, the extreme fast IRES also occurs with 0 to 05 minutes of time duration. Cloud dynamics movement also affect the IRES characteristic when the cloud covers percentage of Cipayung area. System operator and conventional power plant must well prepare the ramp up or down to prevent the system collapse even blackout. This study can provide useful information for renewable energy planning especially for solar PV power plant in Indonesia. It is an important consideration to plan the centralized solar PV power plant or randomly distributed PV. The result can also be used to any investigation and integration for IRES penetration into the grid system. This challenges can be minimized by a good system planning. Incorporate IRES forecast in scheduling and dispatch is a good option to control of IRES output and also to ensure the system stability.

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