A Preliminary Study of Solar Intermittency Characteristic in Single Area for Solar Photovoltaic Applications

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Abstract: Nowadays, the integration of renewable energy sources (RES) generation, especially solar energy, into the power grid is increasing rapidly. Likewise, as an archipelago country that occupies across the equator line, Indonesia has abundant sunny days throughout the year, regardless of the season. However, solar energy has nature variability and uncertainty depending on local weather conditions and cloud movement. Significant penetration from solar photovoltaic systems can lead to critical operation issues, including solar intermittency. This study analyses the solar intermittency characteristic in Jakarta based on historical solar irradiance data. This study also analyses cycle components, solar intermittency penetration level, and also duration level. The results showed that the solar intermittency phenomenon in single area appears at a significant level throughout the day. The solar intermittency dominates by a downward event where approximately 0.003 to 0.004%, with maximum intermittency of about 60% only in one minute. Moreover, continuous intermittency occurrences dominated by a downward trend, which 0.04% occur, continue to decrease up to 7 minutes. Furthermore, system flexibility is critical for a higher penetration level to compensate for the intermittency phenomena.

Keywords: Downward; Intermittency; Photovoltaics; Solar Irradiance; Upward.

1. Introduction

The power sector is a crucial aspect in this century to fulfilling the necessities of human life. Conventional energy from fossil fuels is currently limited and begin several environmental concerns. Alternative energy like renewable energy sources (RES) is widely favored to displace. Some kinds of RES are hydro, geothermal, biomass, tidal, wind, and solar, generating electricity. One popular type of RES with the most leading global potential is solar energy [1], [2]. The main energizer concerning solar energy is degrading global greenhouse gas (GHG) emissions level [3]. Indonesia is a vast archipelagic country between the western Sabang at longitude 95.011198 to easternmost Merauke at longitude 141.020354 and the most northern Miangas at latitude 5.907130 to southernmost Rote at latitude -11.107187. This country is an archipelago that lies across the equator line, with an almost entirely tropical climate. It has two major seasons, the dry season and the rainy monsoon season [4]. Due to the strategic position along the equator line, Indonesia has abundant sunny days throughout the year than other countries located far away from the equator line [5]. Near the equator line, the sun rises from the horizon and sets perpendicularly, regardless of the season. According to a study from [6], Indonesia has a relatively low propers photovoltaic tilt angle.

The sun shifts periodically from south to north and back to south every year in certain months, called the yearly sun path. For example, in Jakarta as the capital city (latitude -6.18 and longitude 106.83), the June solstice as shown by the green line signifies the sun is at its highest point while December solstice, as shown by the blue line, represents the sun is at its lowest point respectively (Figure 1). Also, the full path of the sun, day, and night is divided almost equally by the horizon, so there are always approximately twelve hours of daytime and twelve hours of nighttime over the year. This condition is an excellent opportunity for Indonesia to develop electricity based on

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RES, especially solar energy. On the other hand, the electricity demand increases robust economic growth combined with industrialization and urbanization [8].

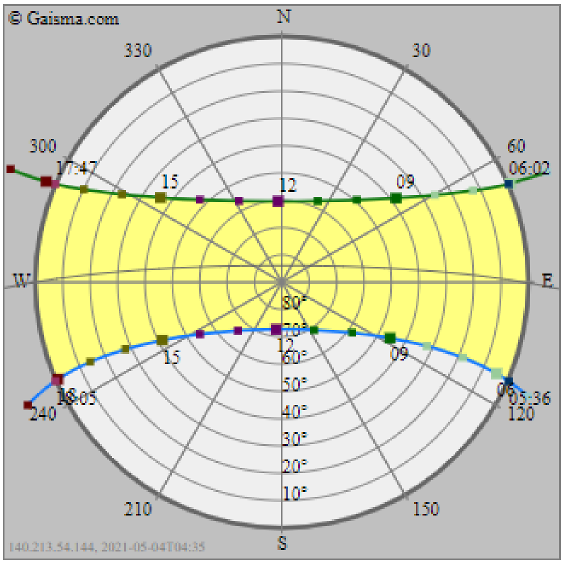


Figure 1. Indonesia (Jakarta Capital City) Sun Path Diagram [7]

The national energy general plan (locally known as RUEN) document as a government policy on national energy management states Indonesia aims to achieve 23 percent of new and renewable energy (RE) accounts for total national energy consumption in 2025 and 31 percent by 2050 [9]. Although reliance on fossil fuel has increased in recent years, Indonesia has started adding more renewable capacity to its energy mix as part of national plans, with significant concerns about global warming, decarbonization, and environmental pollution in line with the Paris agreement [10].

Along with some most tremendous potential of geothermal, hydropower, biomass, wind, and ocean energy, Indonesia also has abundant natural resources from solar because of its geographical location. Indonesia's surface receives from 4.6 kWh/m^2/day to 7.2 kWh/m^2/day solar irradiance intensity [11]. Moreover, Indonesia has gradually grown on solar photovoltaic system deployment, using utility-scale ground-mounted solar power plants, rooftop solar, and floating solar. Based on the government program, solar power penetration is predicted to continue to grow massively in Indonesia's future power system, in line with the expected reduction costs of solar photovoltaic technologies [12].

The solar energy source is one type of variable renewable energy (VRE) source besides wind energy. In particular, solar and wind power are different from most conventional generators. Depending on local weather conditions, they have unstable and uncertain power output (e., if the sun is shining on the earth or the wind is blowing). The uncertainty and variability of solar energy sources pose some critical issues, especially in power system operation. Several studies have examined the higher VRE penetration impact on electrical power systems [13]–[15]. The increased power generation based on RES has given some challenges concerning the quality of electricity, concluding that energy generation has to be reliable, stable, and competitive [16]–[19]. This condition is beneficial in the initial planning, operation, and management of solar power plants. Solar intermittency is uncertain, with many variations quickly, caused mainly by cloud movement [20]. Specific meteorological parameters such as solar irradiance, temperature, and humidity, respectively, on spontaneous factors. Such as clouds, nebulosity, aerosol content, and many more [21]–[23].

Increasing solar power penetration within a power grid requires fast action to balance the system frequency. The power system operator needs to mitigate the massive growth of grid-connected PV into the grid system. This condition has changed the behavior of the electrical power system. The high generation from solar energy during the day potentially leads to high solar intermittency. This condition will be a critical issue for power systems with high thermal power plants providing baseload in the energy mix. Grid flexibility needs to accommodate the change in both generation and load [24]. The solar power output has a turbulent-like spectrum and has a non-linear characteristic such as the unexpected high probability of correlated large irradiance fluctuations called the multifractal exponent [25], [26]. Typically, spinning reserve requirements need to balance the power generation and demand in the short term [27]. This condition leads to a higher fast ramp rate to respond to the intermittency condition. Without reasonable anticipation and planning, the imbalance remains, leading to a risk of blackout.

Nevertheless, different models can predict and analyze solar irradiance characteristics from other input variables such as latitude, longitude, and altitude [28]. These characteristics create challenges in existing power system management and operation. Indonesia's power generation sector is dominated by fossil fuels, particularly coal-fired power plants to generate electricity. This thermal power plant is designed to provide daily baseload with a low ramping rate to respond to load fluctuation. A power plant with a fast response to changes in its power output needs more following power plant as load fluctuates throughout the day. The duration of the solar intermittency phenomenon depends on cloudy and contradictory conditions [29]. The cloud can pass over the solar photovoltaic area and limit the power output [30]. The study [31] collected and processed the high resolution of solar irradiance and solar power output data to analyze the solar intermittency phenomenon. The study shows that the ramp rate events are more remarkable at a smaller timescale and drop exceeding 66% in only ten seconds. Another study shows the number of occurrences of high magnitude fluctuations over a year, particularly in the range of 500 W/m^2 - 900 W/m^2 for a time scale above 5 seconds [32].

Therefore, this preliminary study aims to analyze the solar intermittency phenomenon for solar power system application in the Indonesia power grid case as a representative of developing countries with a high share of solar power plants in the future energy mix. The variability of the generated solar photovoltaic system due to intermittency needs to compensate to maintain the system balance. The intermittency characteristics such as ramp rate level, duration, and the time of occurrence can help planners and system operators know the solar intermittency characteristics more accurately based on historical data. This study results can help utilities to prepare fast ramp rates based on historical data in specific areas. The condition of Indonesia's electrical power system, including national power system planning, RE potency, especially from solar energy, solar irradiance variability and characteristic, and the methodology explained in Section 2. Next, Section 3 describes the simulation results, including fast Fourier transform, intermittency level, and duration level analysis. Section 4 discusses the effects of solar characteristics, and section 5 summarises the findings from this study.

2. Materials and Methods

This section explains the recent Indonesia power system condition about the present power system condition and energy mix based on national energy policy and also Indonesia's electricity supply business plans (RUPTL) document from the PLN as a national electrical company. This section also presents solar irradiance variability based on historical recorded solar irradiance data, solar intermittency phenomenon overview, and methodology to analyze the solar intermittency characteristic, including cycle component, intermittency level, and duration level.

A. Indonesia Power System

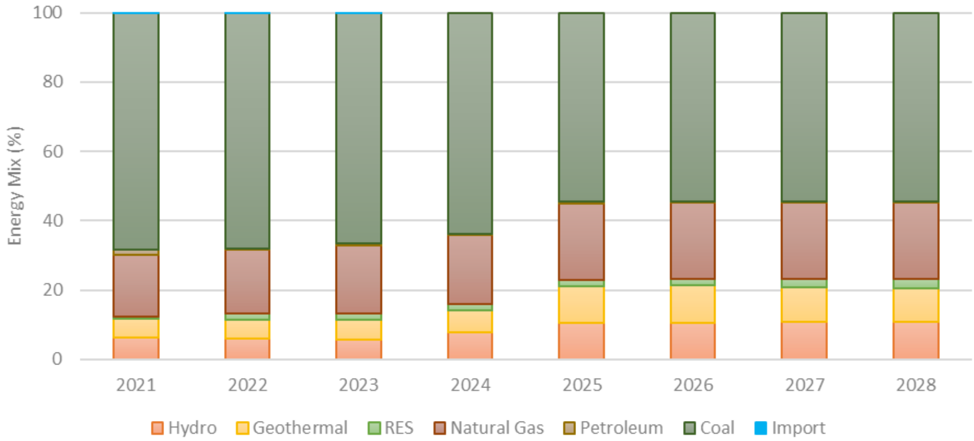


Figure 2. Share in Indonesia energy mix from 2021 to 2028.

Indonesia's system planning is generally island-based as the biggest archipelago nation, such as Java-Bali (the most extensive system), Sumatera, Kalimantan, Sulawesi, Nusa Tenggara, Maluku, Papua, and other smaller systems. Transmission systems are generally inter-area connected with 500 kV, 275 kV, and 150 kV lines. Peak load demand positively correlates to economic increase, population growth, urbanization, industrialization, and consumer lifestyle [33]. PLN, as the electrical state-owned enterprise, has a monopoly on transmission and distribution systems. RUPTL document guides Indonesia's long-term power system development, i.e., Indonesia's book of electricity supply business plans for the next ten years. PLN's long-term guarantee supports future load and generation adequacy through Power Purchase Agreements (PPAs) for Independent Power Producers (IPPs). Because of the financial aspect, power plant planning from IPPs dominates by thermal power plant technology with PPAs take-or-pay (TOP) commercial clauses. Another side, PLN gets a command from governments to perform the portion of new and RE is 23% in 2025 and at least 31% in 2050.

Currently, the demand is powered mainly by thermal power plants and geothermal as baseload operations (Figure 2). In the RUPTL document, thermal coal form is the largest share of the energy mix in 2021 (68.2%) than other energy sources and identified set to account for 54.4% in 2028. Concerning RES, wind, biomass, ocean, and especially solar are still reckoning for a lower share of the energy mix than fossil fuel. Hydro (6.4%) and geothermal (5.2%) provide more significant claims than other RES. In 2025, PLN proposes to perform the national new and RE target (23% of the total energy mix). Some projects build power plants based on RES, especially solar photovoltaic systems [34].

Table 1. Renewable energy potency in Indonesia [35]

Renewable Energy Source	Potential in Giga Watt (GW)
Solar power [1]	5,374
Wind power	60.6
Biomass	30
Mini hydro	19.4
Geothermal [2]	17.5
Hydro pump storage	4.3

[1] In Giga Watt peak (GWp)
[2] Excluding the speculative and hypothetical potential

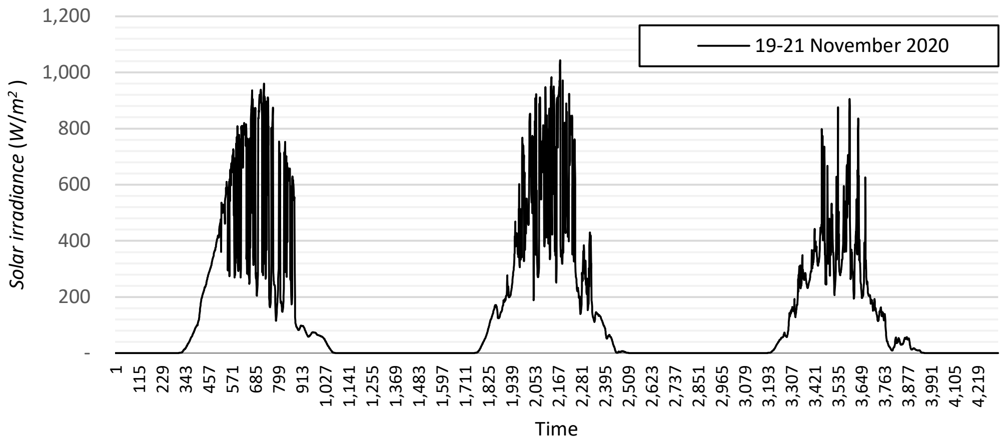
Indonesia's Government plans to achieve the new and RE targets concerning the national energy mix of 23% and 31% by 2025 and 2050, respectively. As Table 1 shows, energy potency in Indonesia determines from an extensive range of RES types. The potential for solar energy is very promising in Indonesia because of the highest resource, approximately 207,898 MWp. Based on the ambitious government program and PLN's long-term planning to corporate solar energy, solar photovoltaic system penetration is forecast to grow massively in Indonesia's future power system. Therefore, PLN must prepare the threat from variability, primarily intermittency phenomenon.

The flexibility system plays a crucial role in serving the variability in the supply and demand side. Limitations include higher ramp-rate capability, shorter start-up time, lower start-up costs, shorter minimum uptime and runtime, and lower technical minimum load (TML). A high ramp rate can make the power plant immediately compensate for the variability, especially from solar intermittency. Shorter start-up times capability helps power plants approaching full load quickly. Operating thermal power plants at lower loads increases the range of their operation and also gains flexibility. Because Indonesia dominates by thermal power plants, particularly coal-fire-based plants and combined heat and power (CHP), operational flexibility depends on some essential parameters, such as device temperature, pressure, flow rate, and degree of feedwater bypass.

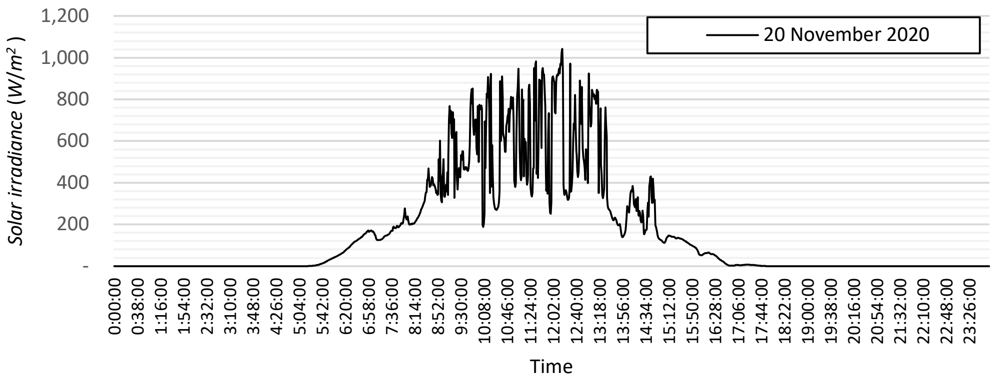
B. Solar Irradiance Variability

Solar flux is radiant energy from the sun incident on the earth's atmosphere. The measurement of this energy is called total solar irradiance. Solar Irradiance describes as power per unit area (W/m^2) received from the sun. This power measure in the form of electromagnetic radiation in the wavelength of the measuring instrument. Solar irradiance at the height of the atmosphere can be considered constant, about 1,366.1 W/m^2 and 3-4% variation due to changes in the distance of sun and earth. If solar radiation propagates through the atmosphere, it associates with atmospheric particles causing absorption and scattering. The quantity of diffuse irradiance can influence the number of particles, pollutants, and mainly clouds in the sky [36]. Integration for a high VRE penetration level of a solar photovoltaic system from a large solar power generation for distributed generation (DG) system aggregate and large utility solar power plants will require system flexibility. The intermittency characteristic from different locations is necessary to prepare various temporal variances on electrical power systems.

The limitation of this study is data records from a single point sensor to measure solar irradiance information only at a fixed location. Three months of data collected from the Duren Tiga weather station at PLN Research Institute, Indonesia, was obtained and processed to see the intermittency phenomenon in solar irradiance. The solar irradiance data plotted as W/m^2 as a function of time. The data was recorded at a 1-minute interval from measuring instrument data in loggers and sensors. From the analysis, the maximum value occurred at 1,304 W/m^2 on 22nd October 2020. The different variability conditions due to the cloud movement are shown in Figure 3. The first part in Figure 3 shows the 3-day solar irradiance raw signal output, which included different conditions. The second part offers the daily spectrum of the signal. The last part indicates the detail of the scope. With high-resolution data, the intermittency appearance can describe in time series. There are two kinds of solar intermittency, upward and downward events. Downward is an intermittency situation when the solar power decrease to a value (mainly in percent) in a short time and vice versa.



(a)



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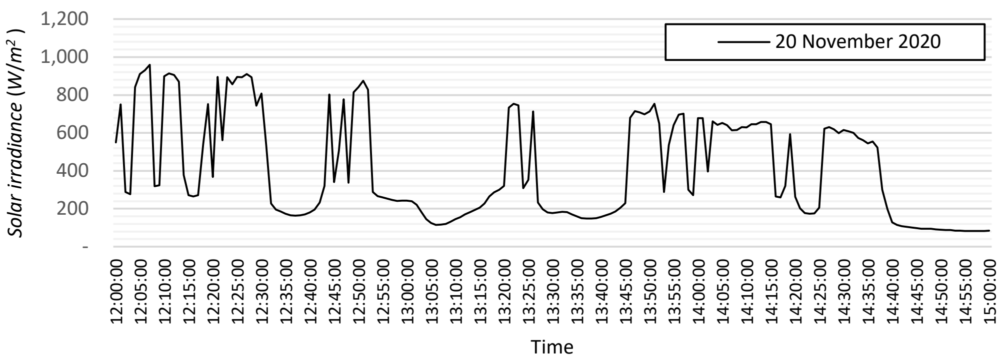

(c)

Figure 3. (a) Three consecutive days exhibiting different intermittent conditions, (b) Daily solar radiation sequence in selected days, and (c) a corresponding zoom showing huge intermittent phenomenon during 3 hours.

C. Solar Intermittency Characteristic

The system operator can use solar irradiance characteristics to evaluate the system's need for flexibility. The solar irradiance characteristic can describe in cycle component, intermittency level, and duration level. Accordingly, the rate characteristic (up or down) can be determined based on available measurement data. The study [37] identified oscillation amplitude variations (cycle component) using total solar irradiance using the Fourier transform bandpass filter and Hilbert. Another study from [38] demonstrates utilizing Fast Fourier Transform (FFT) to predict (cycle component) solar irradiance to provide clean energy for future years. Study form [39] shows the intermittency model as similar to the unexpected failure of conventional power plants with various factors such as stochastic and variable demand, duration of system outages, generation, and reserve costs for existing and new generators—another study from [24] defines the intermittency level and duration level as worst-case analysis. The transient event can cause a 1-s drop in power output from a photovoltaic system in a single sensor and number (MW) fluctuation from the system's rated power (baseline) [40].

This study will comprehensively observe the three solar irradiance characteristics using cycle component, intermittency level, and duration level variable. The past research [37], [38] uses the cycle component for oscillation amplitude and forecasting analysis, but in this study, FFT uses to observe the periodic trend in the solar irradiance measurement data. The second variable, intermittency level, will describe by the range of intermittency from level 1 to 10. As well as intermittency level, the duration level also simplifies into a range based on duration from level 1 to 10.

1) Cycle Component

FFT is a series of equations that transform the solar irradiance signal from the time spectrum to a representation in the frequency spectrum. FFT can observe the periodic trend or cycle component in the solar irradiance data. The frequency domain can reflect the typical solar irradiance history data characteristics, and the high magnitude corresponds to the high periodic frequency. In this study, FFT was applied to the solar irradiance data as discrete-time (DT) signals to find its frequency-domain representation. The FFT formula defines as equation (1), where N expresses the number in the interval 0 to 2π. The FFT equation employed requires an assumption that the data analyzed is a factor of 2. It means that data that cannot represent a factor of 2 will omit from the analysis in this study.

$$X[m] = \sum_{n=0}^{N-1} x[n] e^{-j2\pi \frac{mn}{N}} \; for\; m = 0,1,2,..,N-1 \tag{1}$$

One promising type of flexibility is the energy storage system (ESS), i.e., battery storage, compressed air energy storage (CAES), hydro pump storage (HPS), flywheel energy storage, superconducting magnetic energy storage (SMES), or supercapacitor. Considering solar intermittency, continuous, and variability nature of solar irradiance, installing storage system play an essential role of control fluctuation, improve the reliability of stability. There are many kinds of ESS, especially battery energy storage systems (BESS), with several characteristics such as energy storage density, charge and discharge rate, life cycle, cost, and maximum frequency response. Using the FFT approach, resolving the solar power and plot into the frequency domain to observe the frequency, secondly, according to the response characteristics of different ESS types. The higher power magnitude components are located in the lower frequency range. Therefore, a BESS could consider as a high energy density ESS device. Less proportion of value makes the day more stable and fewer fluctuations. Since the corresponding time parameter was more significant in the lower frequency range, resulting in higher energy density in the lower frequency range. Therefore, a BESS could consider as a high energy density ESS device [41].

2) Intermittency Level

Integrating VRE power, especially solar, into the power system will be closely related to penetration. The higher the penetration level, the higher the intermittency level. Since integration efforts, such as stability and power quality, are connected directly to the penetration level of VRE, it is essential to have a commonly defined term. Penetration level can express in several ways [42].

$$VRE\ penetration\ (\%) = \frac{Total\ amount\ of\ annual\ energy\ produced\ (TWh)}{Gross\ annual\ electricity\ demand\ (TWh)} \tag{2}$$

$$VRE\ capacity\ penetration\ (\%) = \frac{Installed\ VRE\ power\ capacity\ (MW)}{Peak\ load\ (MW)} \tag{3}$$

$$Maximum\ share\ of\ VRE\ (\%) = \frac{Maximum\ VRE\ power\ generated\ (MW)}{Maximum\ load\ (MW)} \tag{4}$$

The percentage of annual demand covered by VRE energy in a specific region shows by equation (2). The total installed VRE capacity is related to the peak load over a certain period, shown by equation (3). The power balance considers the minimum demand, the maximum VRE power generated, and the exchange power shown by equation (4).

This study focuses on solar irradiance before it converts into electrical energy regarding the level of penetration. The intermittent phenomenon will have almost the same pattern at the photovoltaic output power. Solar intermittency is the percentage of the solar irradiance measurement (P_s) value to the maximum value (P_m) based on historical data in a specific area, as shown in equation (5).

$$Intermittency\ level\ (\%) = \frac{P_s}{P_m} \tag{5}$$

This study simplifies the intermittency level into a range based on recording data, as shown in Table 2. Level 1 of intermittency is a condition where upward and downward events occur with a change of 0% to 10% during the measurement interval (one minute). This condition is prevalent because sunlight power fluctuates, and the trend tends to increase towards midday and decreases towards the afternoon. The higher the intermittency level, the greater the range of changes that occur. Some high levels will be very uncommon except in unusual conditions, such as a solar eclipse. However, it still needs to be considered because the eclipse cycle appears periodically.

Table 2. Level and range of solar intermittency [42].

Intermittency Level	Range of Intermittency
1	0-10%
2	10–20%
3	20-30%
4	30-40%
5	40-50%
6	50-60%
7	60-70%
8	70-80%
9	80-80%
10	90-100%

Table 3. Duration level and range of time of solar intermittency.

Duration Level	Range of Duration
1	0-1 minute
2	1–2 minute
3	2-3 minute
4	3-4 minute
5	4-5 minute
6	5-6 minute
7	6-7 minute
8	7-8 minute
9	8-8 minute
10	9-10 minute

3) Duration Level

The intermittency duration is also required to investigate the power system stability issues and study the dynamic response from solar intermittency. Sudden shadow due to passing clouds also can impact the power quality. The duration for a passing cloud to shade an entire solar photovoltaic system depends on the installation area, geopotential air temperature, zonal wind velocity, meridional wind velocity, vertical wind velocity, and relative humidity. Level 1 of duration is a condition with intermittency, upward and downward in the period of 0 to 1 minute, as shown in Table 3. Level 2 is a condition where the intermittency trend continues to rise or fall for up to 2 minutes. The higher the duration level, the longer the duration of successive changes. Different duration levels are associated with different management strategies and costs. Multiple high-duration levels are as rare as intermittent levels. Astronomical symptoms such as a solar eclipse can affect its time duration.

D. Methodology

To analyze the solar intermittency, the proposed method conducted in this study define in Figure 4. This methodology has three stages: (1) cycle component; (2) solar intermittency level; and (3) duration level of intermittency. The first analysis is the cycle component in solar irradiance. The FFT method utilizes to observe the periodic trend in the solar irradiance data in the DT signal to find its frequency-domain representation. The frequency spectrum can indicate the recurring characteristics of the solar irradiance history data. High power magnitude correlated to the high periodic frequency. Furthermore, this analysis could be directive as an energy density value for ESS utilization.

The second analysis is solar intermittency level (upward and downward event) on measurement data. The intermittency level classifies into ten-level based on its percent range. The higher-level means, the higher the intermittency range from its maximal irradiance, has occurrences in historical data. Understand the intermittency level of solar irradiance; we can plan the flexibility system like fast reserve margin to compensate for changes quickly.

The third analysis is the duration level of solar intermittency caused by cloud cover on the photovoltaic module. The duration level classifies into ten-level based on its length of time. The higher level means the longer intermittency continues to up or down. To understand the duration level of solar intermittency, we can plan the range of power plant operations to gain continuous power output.

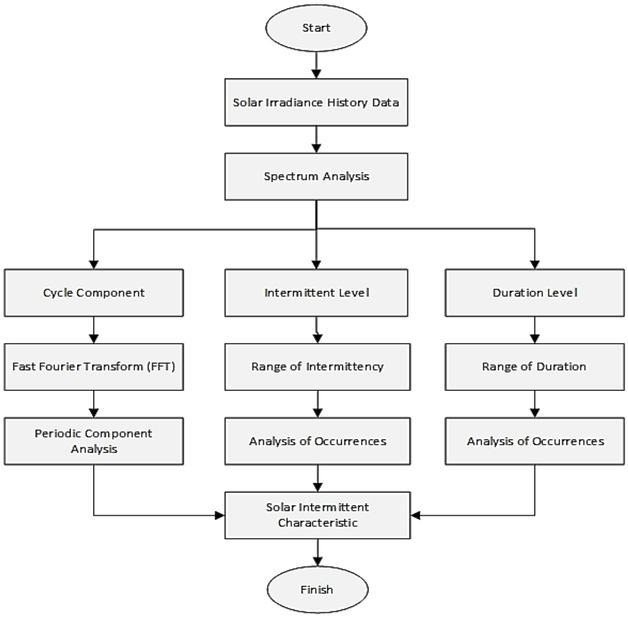

Figure 4. The flow chart of solar intermittency analysis.

3. Results

As the output of any solar photovoltaic system, the variability of generated power due to uncontrollable solar intermittency needs to compensate to maintain system stability. One-minute recorded horizontal irradiance data from 1st October to 10th December 2020, from the Duren Tiga solar photovoltaic system field at PLN Research Institute, Indonesia, was used for this analysis.

By implementing the FFT function, the frequency spectrum plot shows in Figure 5. The first high magnitude corresponding frequency converted to about 12 hours (from 6 a.m. to 6 p.m.) for 4,096 sampling data set. From the FFT method, the highest magnitude is 1,164,333 kWh/m^2 in 24x10^{-5} Hz. The results indicate that the intermittent frequency tends to occur almost every minute or shows high variability in this area. It is needed to proceed with a solar intermittency and duration level analysis to know the comprehensive variability characteristics. By analyzing the solar irradiance data set, the daily cycle is evident because the daily periodicity of the sunlight determines the daily process of the solar irradiance profile. This analysis also confirms the daily cycle from a mathematical point of view.

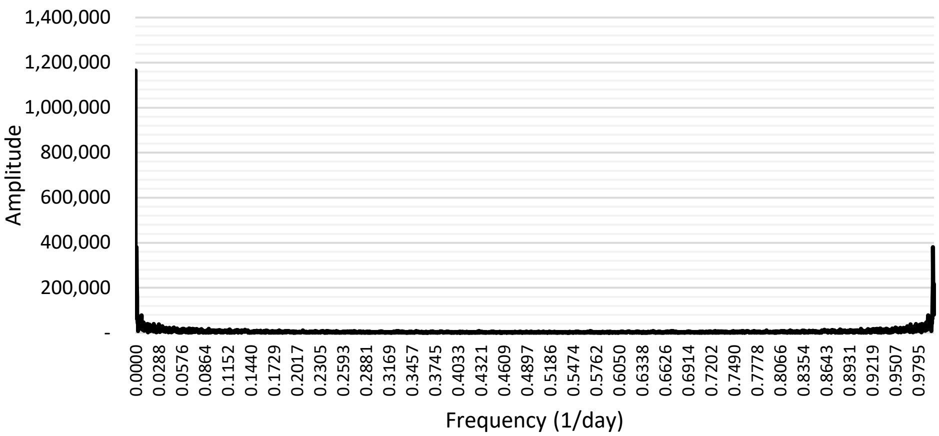

Figure 5. Frequency domain of solar irradiation data recorded during three months.

The comprehensive solar variability requires identifying; the intermittency level analysis then determines how profound the changes are. Research of the data shows that there was a total of 98,985 occurrences of solar intermittency (upward and downward) events spread over various levels (Figure 6). The information is dominated by a downward rate of 69,506 occurrences, while the remaining 29,479 are upward rates. The data analysis shows that the intermittency level generally occurs from level 1 to level 6, where the most significant occurrences happen at level 1, both upward and downward. The most critical solar irradiance level that occurs is at level 6. Level 6 is a condition with 50% to 60% changes from the maximum solar irradiance only in one minute. In that period, there were three times downward rates and one time of upward rates. It demands to proceed with a solar duration level analysis to know the comprehensive intermittent characteristics.

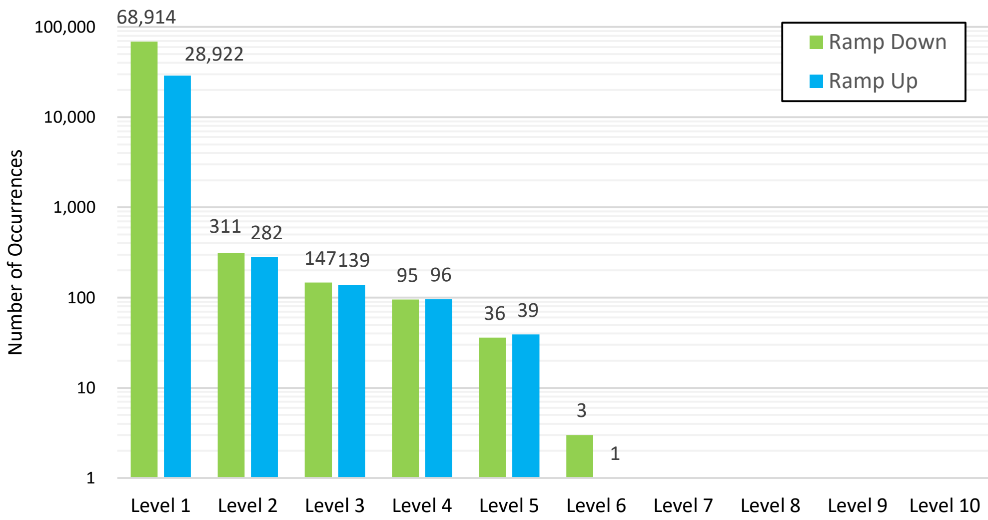

Figure 6. Upward and downward rate level only in one minute during three months.

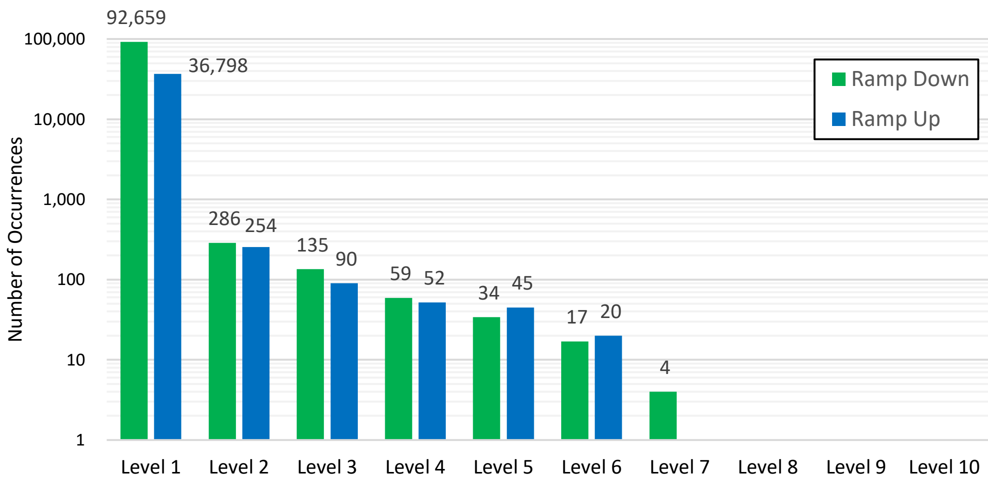

Figure 7. Duration level of upward and downward rate during three months.

The intermittency duration level analysis then determines how long the variability events (upward and downward -down) are. The solar intermittency occurrences of continuous ramping also analyze through intermittency duration level (Figure 7). Investigation of the historical data shows that 130,453 occurrences of endless solar intermittency events spread over various duration levels. The information is dominated by downward rates of 93,194 occurrences, while the remaining 37,259 are upward rates. The data analysis shows the continuous solar intermittency duration from level 1 to level 7, where most events at level 1 are both upward and downward. The most lengthened duration level that occurs is at level 7. Level 7 is a condition where solar intermittency increases or decreases in the range of 6 to 7 minutes. In that period, there were only four times continuous downward.

From the data analysis, there are two solar intermittency phenomena, upward and downward events. Upward rates affirmed that solar irradiation tends to increase and vice versa. Both upward and downward events, approximately 98% to 99%, occur at level 1 (Table 4). This analysis must be a normal condition where variability is in the 0% to 10% from the maximum solar irradiance that has occurred—the worst solar intermittency approximately 0.003 to 0.004%, both upward and downward at level 6.

At the solar duration level, approximately 98% to 99% of upward and downward events occur at level 1 (Table 5). This analysis also must be a normal condition where solar intermittency duration is less than 1 minute because of the daily solar profile. The most prolonged solar intermittency duration occurs approximately 0% to 0.04%, both upward and downward events at level 7.

Table 4. Percent of ramp rate need of occurrences at each solar intermittency level [42].

Intermittency Level	Upward	Downward
1	98.111%	99.148%
2	0.957%	0.447%
3	0.472%	0.211%
4	0.326%	0.137%
5	0.132%	0.052%
6	0.003%	0.004%
7	0.000%	0.000%
8	0.000%	0.000%
9	0.000%	0.000%
10	0.000%	0.000%

Table 5. Percent of the duration of occurrences at each solar intermittency level [42].

Duration Level	Upward	Downward
1	98.763%	99.426%
2	0.682%	0.307%
3	0.242%	0.145%
4	0.140%	0.063%
5	0.121%	0.036%
6	0.054%	0.018%
7	0.000%	0.004%
8	0.000%	0.000%
9	0.000%	0.000%
10	0.000%	0.000%

After we prepared the intermittency characteristic in Duren Tiga, Jakarta, Indonesia, we confront the results of the photovoltaic power output from the grid-connected solar photovoltaic system in the exact location. From the past data, 14th November 2020 is a cloudy day. We can determine based on our proposed method on that day there is Level 6-5 (Level 6 downward rate and Level 5 duration level) solar intermittency at 10.52 a.m to 10.57 a.m. It means, in that location, there is Level 6 (50-60% reducing) solar energy, and Level 5 (4-5 minutes) continues downward. The solar irradiance decreases from 901 W/m^2 to 441 W/m^2 or approximately 52%

only in 5 minutes. We can see in Figure 8, at the same time, the power output decrease from 37.220 W to 17.864 W or approximately 53%. It is clear because the solar power output depends on solar power as primary energy.

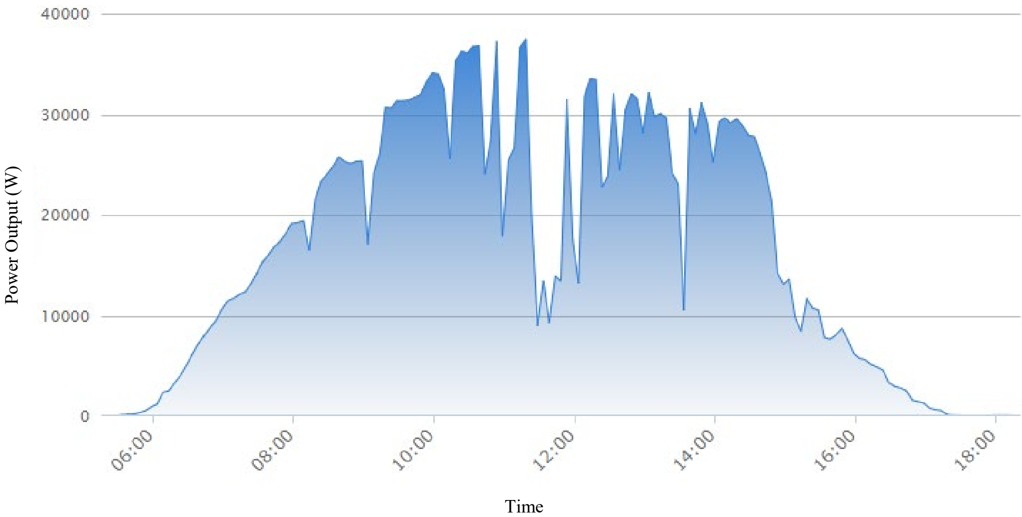

Figure 8. Actual power output from Duren Tiga grid-connected photovoltaic system.

4. Discussion

As we can see from the data analysis above, the solar intermittency characteristic an area can describe with cycle analysis, intermittency level, and duration level. Cycle component analysis shows the high variability in the measurement area. To find out the nature of solar variability, then subsequent study; solar intermittency and duration level. In solar intermittency analysis, we found the intermittency phenomenon dominate by a downward rate of 69,506 occurrences—the worst solar intermittency approximately 0.003 to 0.004% at level 6. Level 6 is a condition where there is maximum intermittency of about 60% only in one minute. Apart from seeing the solar intermittency level, it is also essential to see continuous solar intermittency in the unit of duration level. It is necessary to know the constant trend of solar intermittency after one minute change. Analysis of the historical data shows that 130,453 occurrences of continuous solar intermittency events spread over various duration levels. The duration level dominates by downward rates of 93,194 occurrences which 0.04% occur at level 7. Level 7 is a condition where there is solar intermittency continues to decrease up to 7 minutes.

In some countries, solar intermittency and grid integration are two fundamental issues to the uptake of large-scale solar power. The study from [43] tries to characterize the effect of high penetration solar intermittency on Australian Electricity Networks, produced several critical findings that help understand the challenges and opportunities behind solar photovoltaic integration level. Studies from [44] show the essential knowledge of solar intermittency characteristics based on location, size, and how they integrate, i.e., concentrated or dispersed, will affect the degree of voltage stability.

This study's results identified the system planner's need for a flexible system with the specific ramping capability to respond to critical times' upward and downward periods. The solar intermittency characteristic will reference and overview the power output condition for the grid-connected solar photovoltaic system. The frequency spectrum in cycle component analysis indicates the high variability in the solar irradiance records. To overcome the situation, the generators in the system will experience more cycling to compensate for the intermittency phenomenon. In addition, the power system dispatcher needs to manage the generation in short periods to balance demand and supply. High power magnitude correlated to the high periodic frequency. This preliminary analysis could be directive as an energy density value for ESS utilization. The intermittency level classifies into ten-level based on its percent range. Understand the intermittency level of solar irradiance; the system planners can plan the needed flexibility system like fast reserve margin to compensate for quick changes or define the specific specification for new power plant. The duration level also classifies into ten-level based on its length of time. Understand the duration level of solar intermittency; the system planners can plan the range of conventional or based load power plant operations to gain continuous power output.

5. Conclusions

This study presents a solar irradiance analysis for solar photovoltaic system application in Indonesia as a tropical country. The research and evaluation of the intermittency phenomenon based on historical measurement data are proposed. The solar intermittency characteristic was also presented, including cycle component analysis, intermittency level analysis, and duration level analysis. The results showed high solar irradiance variability in every minute caused by cloud cover and movement. Furthermore, the solar intermittency analysis shows the intermittency phenomenon dominates by a downward event of 69,506 occurrences where approximately 0.003 to 0.004% with maximum intermittency of about 60% only in one minute.

Moreover, there were 130,453 occurrences of continuous intermittency dominated by downward rates, of which 0.04% occur continues to decrease up to 7 minutes. The higher intermittency and duration level needs to increase the system flexibility. However, the power system planner and system operators in National Electrical Company should adequately deal with this solar intermittency characteristic.

Future works could calculate the multi-area analysis to improve the solar intermittency characteristic, explore the penetration level of grid-connected solar power system into the power system, investigate the technical and economic impact for power system operation, explore the optimum flexibility system option, and also predict the worst intermittency possibility based on machine learning approach.

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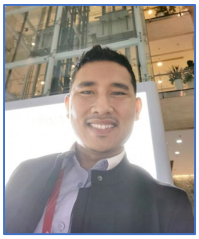

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