1. Introduction
Dependence of using stand-alone diesel generator in an isolated grid has been decreasing to minimize a large amount of fuel consumption. In recent years, the isolated grid starts to be complemented with the power generation based on renewable energy such as solar photovoltaic (PV) systems or wind generators. Also, the government of Indonesia has set a target of renewable energy mix 23% in 2025, with the current realization that it is still below 15%[1]. The integration of renewable energy, such as the PV system is not only used to achieve this target but also to reduce generation cost. However, the penetration of solar PV systems in the power system can lead to many operational stability issues due to its intermittency. For instance, in an isolated system having limited inertia, the loss of portion of generated power may lead to unacceptable low-frequency, which may lead to the system collapse [2].

In isolated networks consisting of a PV system and Diesel, the issue of frequency and power fluctuation problems due to the variability of energy production can be corrected with a Battery Energy Storage System (BESS) [3][4]. In this situation, BESS can absorb the excess power generated by the system and distribute it in conjunction with the diesel generator when the PV system produces a lower power. Currently, due to the high price of BESS devices, it is essential to select the size of the capacity of BESS appropriately, so that it does not significantly increase the investment cost. Hence, the sizing of the effective capacity of BESS on the power system with and energy requirements to reduce total BESS investment cost, are in general, two fundamental problems in the BESS deployment project.

A Discrete Fourier Transform (DFT) method on a multi-time scale perspective to allocate balance power between energy storage and diesel generator, and then determine their capacities is discussed in
DFT is considered as an accurate band-pass filter, which can distribute frequency efficiently. Liu et al. considered different ESS to handle imbalance power that concludes the Hybrid Energy Storage System (HESS) with battery and supercapacitor provides economical and effective results [6]. The battery ESS handles mainly the component that varies relatively slowly. The component corresponding to the middle frequency of imbalanced power is smoothed by the supercapacitor ESS. However, that research using wind energy as a renewable energy resource that more fast-changing power than solar energy and supercapacitor has a more significant advantage of it.

In this paper, the BESS is sized by using DFT, and then the implementation is validated by using the DIgSILENT PowerFactory application. First, the percentage of PV system penetration is selected following the average demand in one year. Then, the BESS is sized based on the imbalance power within one year by using the DFT method and various cut-off frequency bands. Each resulted BESS size is applied in the isolated grid model, and the stability is observed. The optimum size of BESS can be determined through a trade-off between the BESS size and the frequency deviation limit.

The paper is structured as follows: Section 2 provides the details of the methodology of determining optimal sizing BESS. Section 3 is devoted to simulation and result discussion. Section 4 provides the conclusion of this paper.

2. BESS Sizing Algorithm
The sizing algorithm is started by analyzing the required load of the system for every hour in one year. Thus, the average load and peak load are calculated. The amount of solar PV system, as well as the diesel generator capacity integrated into the system, is determined based on the load. The BESS size is obtained by evaluating the excess and the deficit of power at each time point, so-called imbalance power. Then, the Fourier Transform is employed to obtain the frequency domain of the imbalance power. An appropriate cut-off frequency is used to filter the likelihood of the mid-range imbalance magnitude. Then, BESS size is decided after evaluating the system frequency due to the outage of supply from the PV system. The algorithm flowchart of the BESS sizing is shown in Figure 1.

![Figure 1. The algorithm of BESS sizing](image)

2.1. Imbalance Power
The stability in electric power systems is determined by the balance between supply and demand, which can be indicated by the frequency of the system [7]. If the demand exceeds the power generation, then system frequency will decrease, and reciprocally, it will increase when power generation is more than the demand. This relationship is described by the swing equation as follows:
where $H$ is the normalized inertia constant, $\omega_s$ is the synchronous angular velocity, $P_{\text{demand}}$ is electrical load demand, and $P_{\text{supply}}$ is the supplied power. Therefore, the analysis of the system frequency can be started by evaluating the difference between the demand and supply, so-called imbalance power. Hence, it can be expressed as follows [5]:

$$P_{\text{imb}}(t) = P_{\text{pv}}(t) + P_g(t) - P_{\text{load}}(t)$$

(2)

where $P_{\text{imb}}(t)$, $P_{\text{pv}}(t)$, $P_g(t)$, and $P_{\text{load}}(t)$ are the imbalance power, PV output power, generated power by other generation, and load at time $t$, respectively.

2.2. Fourier Transform

Fourier transform is used to convert the time domain into the frequency domain. Hence, the imbalance power is decomposed based on its likelihood to occur within one year [6]. The following is the Fourier transform synthesis equation and analysis [8]:

$$P_{\text{imb}}(f) = \text{FFT}(P_{\text{imb}}(t)) = \sum_{t=0}^{N-1} P_{\text{imb}}(t) W_N^t f, \quad f = 0, L, N - 1$$

(3)

$$P_{\text{imb}}(t) = \text{IFFT}(P_{\text{imb}}(f)) = \frac{1}{N} \sum_{f=0}^{N-1} P_{\text{imb}}(f) W_N^{-tf}, \quad f = 0, L, N - 1$$

(4)

where $N$ is the total number of the data points, $W_N^t f = e^{-j\frac{2\pi}{N}tf}$, $X[f]$ is the imbalanced power caused by the solar PV system in a time domain, and $X[f]$ is the frequency-based imbalanced power [9][10].

2.3. BESS Power Sizing

The power capacity of BESS is calculated based on the cut-off frequency that is applied in the frequency domain of imbalance power. The cut-off frequency is limited by the lower and upper frequency limits. Whereas, the upper and lower frequency limits are determined based on the range percentage at the middle value of the frequency spectrum.

$$\tilde{P}_{\text{imb}}(f) = \begin{cases} P_{\text{imb}}(f) & f_L < f < f_U \\ 0 & \text{others} \end{cases}$$

(5)

$$\tilde{P}_{\text{imb}}(t) = \text{IFFT}(\tilde{P}_{\text{imb}}(f))$$

(6)

$$P_{\text{BESS}} = \max(\tilde{P}_{\text{imb}}(t))$$

(7)

where $\tilde{P}_{\text{imb}}(f)$ is the imbalance power in the frequency domain after filtered by lower limit frequency ($f_L$) and upper limit frequency ($f_U$), $\tilde{P}_{\text{imb}}(t)$ is the associated filtered-imbalance power in the time domain, and $P_{\text{BESS}}$ is the required power capacity of BESS in MW.

2.4. BESS Energy Sizing

The energy capacity of BESS is calculated through cumulative energy required within one year. Thus, the energy capacity is determined as follows [6]:

$$e(t) = \int_0^T \tilde{P}_{\text{imb}}(t) dt$$

(8)

$$E_{\text{BESS}} = \frac{\max(e(t)) - \min(e(t))}{\text{DoD}}$$

(9)

where $e(t)$ is the cumulative energy required at time $t$, $E_{\text{BESS}}$ is the required energy capacity of BESS in MWh, and $\text{DoD}$ is BESS depth of discharge specification.
3. Simulation and Results

The isolated grid system used in this study case consists of the diesel generator, solar PV system, BESS, and the cluster of loads. For the security purpose, the actual data is normalized and processed in per-unit value. The load and solar power data over one year are used to demonstrate the application of the proposed method. The penetration ratio of the PV system is varied from 10% to 50% of the peak load. Whereas, the diesel generator size is set to satisfy the remaining required power. However, BESS is set to be first operated during the day to fulfill the load. The cut-off frequency band is also varied from 10% to 50% in the middle of the frequency spectrum.

3.1. Result of BESS power capacity for frequency stability

The calculation of BESS power capacity is implemented through a model developed in DlgSILENT PowerFactory to investigate the system frequency performance. PV power output degradation is applied, and the resulted system frequency is recorded. Hence, the appropriate size of BESS to maintain the system frequency when there is a change in the PV output power can be determined. The lower cut-off frequency band used to maintain the system frequency means a lower BESS power capacity required, and thus, it leads to lower investment.

Figure 2 shows the result of BESS power capacity calculation for each PV penetration and the applied cut-off frequency band, as well as the system frequency result for each scenario of PV outage. Figure 2(a) shows system frequency output with a 10% PV Penetration. In this scenario, battery usage is not required because the system is still able to maintain the frequency when PV experiences a 100% decrease in production, namely 0.9812 p.u. where this value is within the acceptable limit of the grid code in Indonesia (0.95 p.u) for a transient disturbance.

Figure 2(b) shows the result of system frequency for 20% PV penetration. The system without BESS in this scenario shows that the system is still capable of maintaining its stability at a maximum degradation of 100% PV. The maintained output frequency in this scenario is 0.953 p.u.

The 30% PV penetration scenario is shown in Figure 2(c). In this scenario, the use of BESS is needed because a system without BESS can only maintain its frequency at 0.912 p.u. The optimum sizing BESS in this condition is the size with a cut-off frequency band of 40%, where BESS can maintain stability with a system frequency output of 0.952 p.u. However, these conditions are only able to stabilize at a maximum condition of 75% PV degradation output power.

Figure 2(d) shows the scenario of 40% PV penetration. The system output frequency in this scenario is also required BESS. In this condition, the size of BESS with a 40% cut-off frequency band is not to be able to maintain stability in the condition of 75% PV degradation output power. However, the maximum degradation that can be maintained is 50% PV outage with the size of BESS at a 40% cut-off frequency band. The frequency stability output value is 0.956 p.u.

For a 50% PV penetration scenario, a 40% cut-off frequency band value is only able to maintain PV stability when production decreases by 25%, as shown in Figure 2(e). However, the sizing BESS at a cut-off frequency band of 30% is also able to maintain stability in these conditions with a value of 0.95 p.u. Hence, the most optimal BESS power capacity to reduce investment prices and to be able to maintain stability at grid code limit regulation is using a 30% cut-off frequency band for this scenario.

3.2. Validation of energy capacity

The sizing algorithm proposed in this paper is aimed to maintain the system frequency stability where there is a sudden degradation of PV output power. In case the required demand is higher than the sum of PV output power and BESS discharge power, then the generator is set to produce additional power. By doing so, two purposes can be achieved, such as maintaining system frequency stability as well as minimize the utilization of diesel generator. BESS energy capacity imposes the available energy in BESS to perform this function. If the energy capacity is not adequate to maintain successive PV output power degradation, then the system frequency stability cannot be maintained. Therefore, it is required to validate if the available energy stored in BESS is enough to perform this function.
Figure 2. The result of system frequency in accordance with the loss of supply from PV (PV outage) and the cut-off frequency band for each PV penetration. (a) 10%, (b) 20%, (c) 30%, (d) 40%, and (e) 50% PV penetration

Table 1 shows the result of the required BESS energy capacity for PV penetration of 30% and for a cut-off frequency band of 40%, which are considered to be capable of maintaining the system frequency stability when 75% PV degradation occurs, as explained in the previous section.

| PV Penetration (%) | Cut-off frequency band (%) | BESS power capacity (p.u.) | BESS energy capacity (p.u. hour) |
|-------------------|---------------------------|----------------------------|---------------------------------|
| 30                | 40                        | 0.0625                     | 1.88                            |

Table 1. The result of BESS size to maintain system frequency stability

Figure 3 shows the result of energy capacity validation. It is performed for four consecutive days that have different irradiance characteristics. The first and second days have low irradiance, while the third and fourth days have a normal irradiance. BESS can provide the power to the system when there is a deficiency without any additional generator supply unless the required load exceeds the total of PV output power, base generator, and BESS. This result indicates that the sizing of BESS energy capacity is suitable to perform the BESS function to maintain system frequency.
4. Conclusions
This paper proposes a frequency-based approach to measuring the battery energy storage system (BESS) to maintain the balance of the power of an isolated system with solar PV penetration, thus maintaining the stability of the network frequency with the fluctuations of solar irradiance considered. The experiment applies the Fast Fourier Transform to obtain the optimum size of BESS power for the lower capacity required to maintain its stability and reduce the investment cost.

The experiment results show that the output frequency requires a different cut-off frequency band scenario for each PV penetration to be acceptable limit allowed by the grid code. The system with 10% and 20% PV penetration does not require BESS to be able to maintain its stability when there is a degradation PV output of 100%. The system with 30% and 40% PV penetration requires BESS sizing with a 40% cut-off frequency band to be within the required limits of the grid code for 75% and 50% PV degradation, respectively. Whereas, the 50% PV penetration system requires a 30% cut-off frequency band to maintain its stability at 25% PV degradation. The experiment also shows that the resulted BESS energy capacity satisfies the requirement for maintaining the system frequency stability.

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