Critical Contingency Assessment of the 150/275 kV Interconnected Power System

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Abstract. The 150/275 kV Southern Sumatra Interconnected System (in Bahasa: Sumbagsel) is crucial for providing reliable and sustainable electricity to the region. As network complexity and energy demand grow, challenges related to dynamic security intensify. This study assesses the system's ability to maintain stability during disturbances. Analyses using DIgSILENT PowerFactory software evaluated system responses to fault scenarios, particularly large generator losses, focusing on rotor angle, system frequency, and bus voltage after disturbances. One key novelty of this study is the comprehensive approach of evaluating the dynamic stability of the Sumbagsel system under a wide range of fault scenarios, including both typical and extreme disturbances, which has not been extensively addressed in previous studies. Results show that the Sumbagsel interconnection has critical points prone to dynamic instability. While the system can remain stable within safe limits if disturbances don't exceed handling capacity, mitigation measures like improved coordination between generation and transmission networks are necessary. Furthermore, the study introduces a novel methodology for assessing system stability that combines real-time dynamic simulations with contingency analysis, providing deeper insights into the system's vulnerabilities. This study aims to enhance the power system's reliability in the region and prepare it for future operational challenges.

Keywords: *Dynamic, Transient Stability, Interconnected System, DIgSILENT PowerFactory, Southern Sumatera, Sumbagsel.*

1 Introduction

Power system reliability is a key parameter that determines the stability of energy supply, which is increasingly important given the high dependence on electricity in almost every aspect of human life today [1]. Southern Sumatra (Sumbagsel), as a region with rapid economic growth, is in dire need of continuous and stable electricity supply to support various industrial and domestic activities. In this context, the existing 150/275 kV interconnection system becomes a key element in ensuring the stability of electricity supply in the region [2].

Currently, the protection system in this region still relies on conventional frequency-based protection schemes [3]. However, with the increasing complexity of the network and the growing demand for energy, it is time to develop more advanced and reliable protection schemes. Conventional protection schemes are often inadequate to deal with the new challenges arising from more complex power system dynamics [4]. Recent studies have highlighted that as power systems become more complex due to the integration of renewable energy sources and decentralized generation, conventional protection mechanisms are increasingly inadequate in addressing the new dynamics and ensuring system stability [5]. An effective method to assess and improve the resilience of these systems is Dynamic Security Assessment (DSA) [6]. DSA provides a thorough analysis of system performance after a disturbance by considering critical parameters such as frequency, voltage and rotor angle stability [7].

The objective of this research is to test different contingency scenarios and analyse the system response to disturbances to identify mitigation measures that can improve the reliability of the 150/275 kV interconnection system in Sumbagsel. This approach is expected to provide in-depth knowledge and practical solutions that can help maintain the stability and continuity of electricity supply in the region. Contingency analysis, such as for a 150 kV network, is crucial for evaluating system reliability against disruptions. It simulates the failure of generating units or transmission lines (N-1 condition), impacting system performance. Power flow analysis using tools like ETAP and Newton-Raphson methods helps assess the system's response and maintain reliability[8].

A. Sumbagsel Electricity System

Sumbagsel has a complex electricity system and is one of the key regions for energy supply in Indonesia [7]. Currently, the electricity system in this region is mostly part of the Sumatra Interconnection Grid, which connects different provinces and allows for more stable and reliable electricity distribution. However, some areas in Sumbagsel, particularly remote areas, still rely on isolated electricity systems. The map of the Sumbagsel electricity system is shown in Fig. 1 [9].

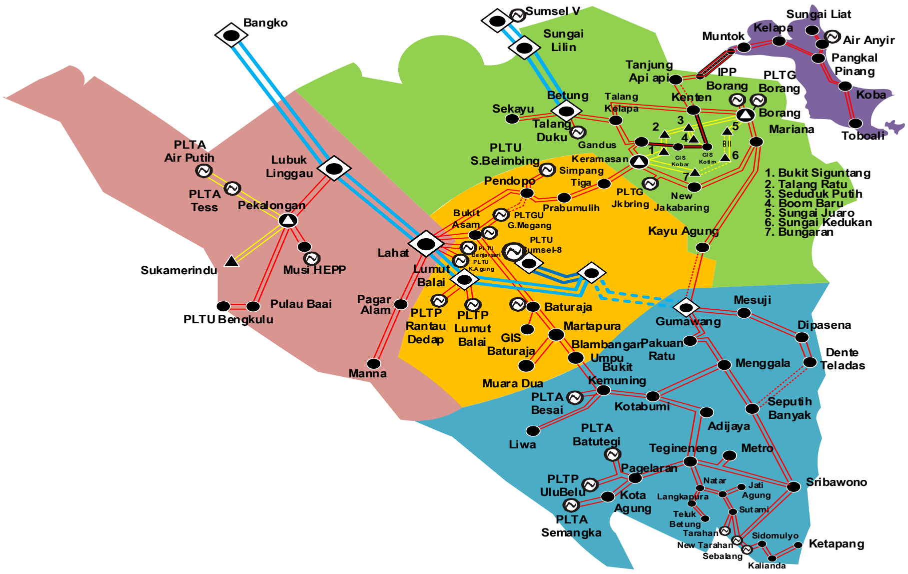


Figure 1 Sumbagsel Electricity System Map

The total capacity of the Sumbagsel power system is 4,493 MW. Of this, approximately 218.5 MW is supplied to Bangka and 767 MW to Central Sumatra. The peak load that Sumbagsel must carry is 2,673.5 MW. This means that the available power reserve or lap reserve is about 598.4 MW [11]. This situation shows that the available power reserve is very limited. With a reserve of only 598.4 MW, which is less than the capacity of the largest generator in the region, the system is in a critical state. In the event of an increase in load or a disturbance in the system, the existing power reserves may not be sufficient to maintain a stable and smooth supply of electricity. This insufficiency of power reserves, combined with the complexity of the system operation, makes the reliability of this system a major concern.

According to statistical data from Perusahaan Listrik Negara (PLN) in 2024, most electricity customers in the Sumbagsel region are residential customers, accounting for 85.76% of the total customers with a load factor of 60.32% [10]. In this study, the load data samples used include different load profiles with different daily load curves as shown in the following figure.

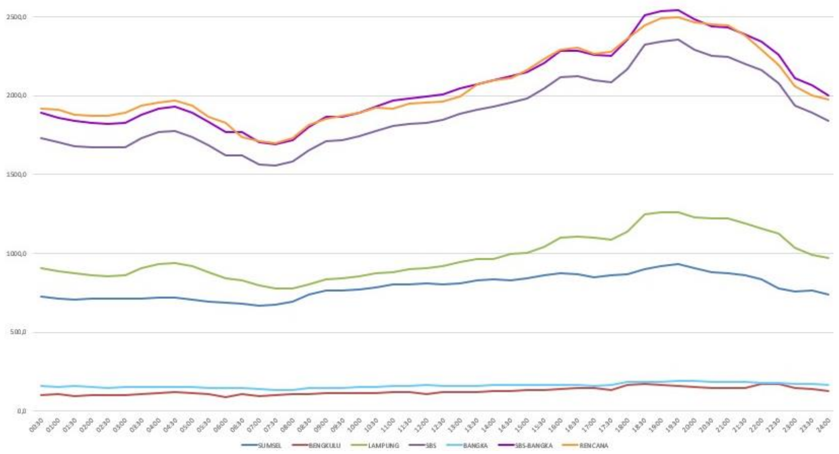


Figure 2 Daily Load Curve of Sumbagsel System

A. Existing Defense Scheme of Sumbagsel System

The defence systems currently implemented in Indonesia, including the Sumbagsel Electricity System, still use conventional defence systems based on grid parameters. The Sumbagsel system currently implements a defence scheme through underfrequency load shedding (UFLS) or protective load shedding and islanding operations. UFLS, which is a system safety scheme based on system frequency sensors, releases a certain amount of consumer load when underfrequency occurs to prevent cascading trips of power plants due to underfrequency, so that the frequency returns to nominal conditions/values [11]. The nominal normal frequency of 50 Hz is attempted to be no lower than 49.5 Hz or higher than 50.5 Hz, and in times of emergency and disturbance, the system frequency is allowed to drop to 47.5 Hz or rise to 52 Hz before the generating unit is allowed to stop operation. The existing defence scheme of the Sumbagsel system is shown in Fig. 3.

52.0 Hz	Over Frequency
50.5 Hz	Excursion Upper Limit
50.2 Hz	Upper Limit of Normal Frequency
50.0 Hz	Nominal Frequency
49.8 Hz	Lower Limit of Normal Frequency
49.5 Hz	Excursion Lower Limit
49.2 Hz	UFR stage 1
49.1 Hz	UFR stage 2
48.9 Hz	UFR stage 3
48.8 Hz	UFR stage 4
48.7 Hz	UFR stage 5
48.6 Hz	Island Operation Stage 1
48.5 Hz	Island Operation Stage 2
48.4 Hz	Island Operation Stage 3
48.3 Hz	Island Operation Stage 4
48.0 Hz	Island Operation Stage 5
47.5 Hz	House Load Generation

Figure 3 Frequency Operation Table for Power Systems

2 Proposed Method

The proposed method for evaluating the dynamic safety of the 150/275 kV interconnection system in Sumbagsel is an iterative process that starts with modelling a generator loss fault scenario using DIgSILENT PowerFactory software.The process begins with determining critical parameters such as rotor angle, system frequency and post-fault bus voltage, which are calculated based on random variables such as generation capacity and network configuration.Next, simulations are performed to analyse the system response to a large generator loss disturbance. The results of the transient stability analysis are evaluated to identify critical points and failures in system performance. If the evaluation results show that the system is operating without failure, the simulation is extended with increased disturbance scenarios to test extreme conditions. If failures are detected, mitigation measures are implemented, including improved coordination between generation and transmission networks. The simulation is then repeated to assess the effectiveness of the mitigation measures and to ensure improved system resilience to disturbances. This method aims to improve the stability and reliability of the 150/275 kV Sumbagsel interconnection system and prepare the system for future operational challenges.

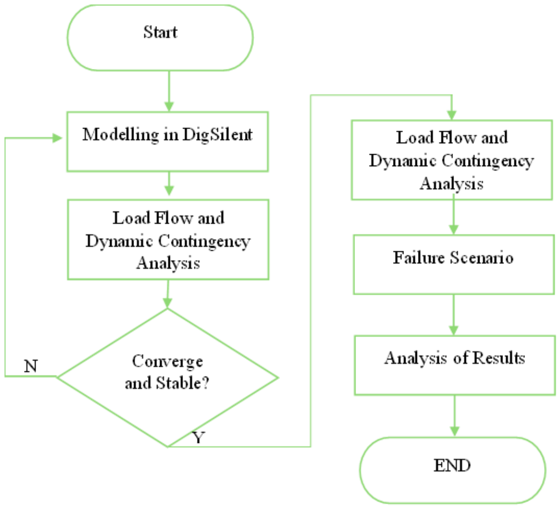


Figure 4 Flowchart of Contingency Evaluation in Dynamic Security Assessment

3 Cases and Simulation Results

This section presents the results of simulations of various generator loss fault scenarios in the 150/275 kV interconnection system in Sumbagsel. The simulations are performed to analyse the impact of generator loss at specific locations and to evaluate the stability of the system. Fig. 5 shows the single line diagram for the Sumbagsel region used in the dynamic safety assessment.

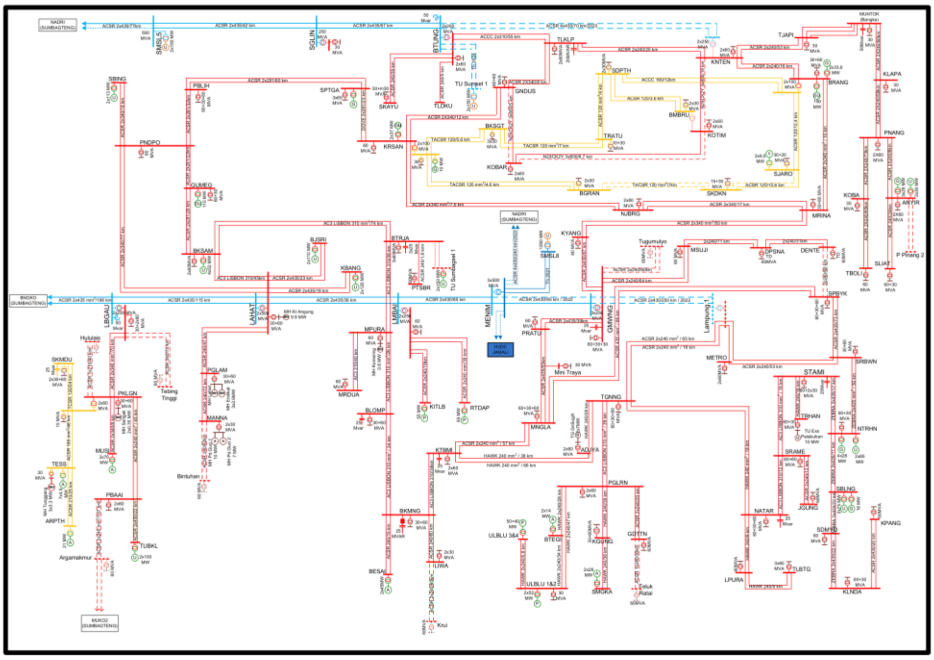
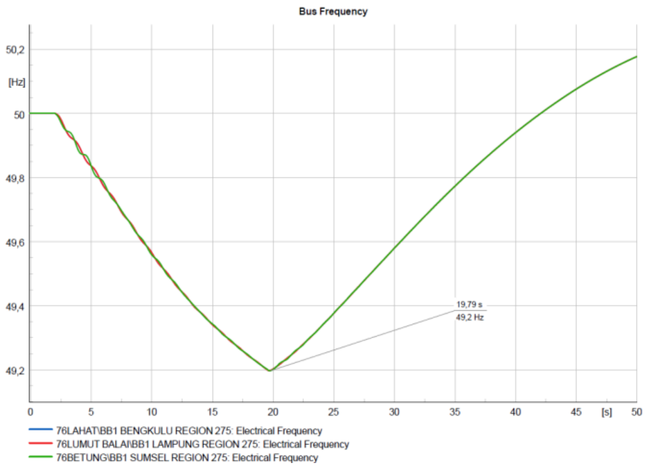


Figure 5 Single line diagram of Sumbagsel

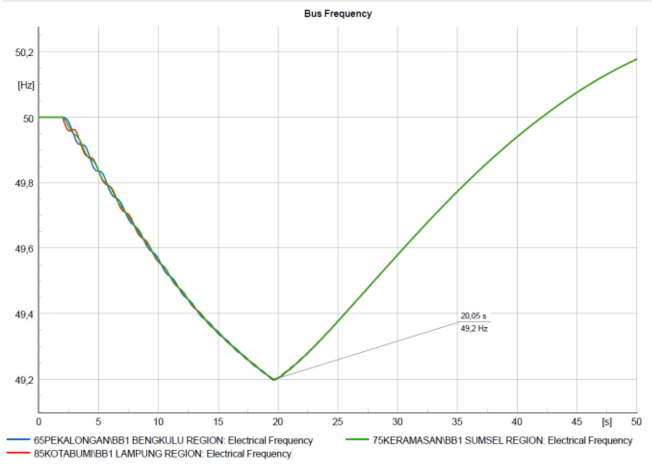
3.1 Generator failure of the PLTP ULBLU 1

The selection of the geothermal power plant (in Bahasa: Pembangkit Listrik Tenaga Panas Bumi (PLTP)) ULBLU 1 as a contingency scenario is based on its significant generation capacity in the Sumbagsel 150/275 kV interconnection system. The loss of large amounts of power from these plants can drastically affect the balance between supply and demand, affecting frequency stability, bus voltage and rotor synchronization. In addition, their strategic location, supplying power to high consumption areas, makes it important to include in fault simulations. This scenario assesses the system's ability to sustain large disturbances and whether additional mitigation, such as better coordination between generation and transmission, is required to maintain overall system stability.

The system frequency response is shown in Fig. 6. This graph shows how the system frequency changes over time in response to disturbances or load changes. The frequency response is an important indicator of system stability as it reflects the ability of the generation and control mechanisms to maintain a stable frequency when generators are subjected to disturbances.



(a)



(b)

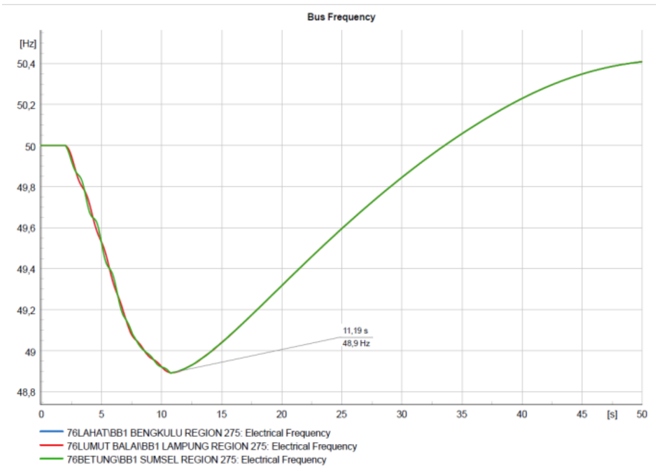
Figure 6 frequency of (a) 275 kv, (b) 150 kV buses

The frequency in the power system dropped significantly when the PLTP ULBLU 1 generator failed. The frequency on the 150 kV bus was recorded at 49.2 Hz at 20.5 seconds and on the 275 kV bus at 49.2 Hz at 19.79 seconds. This drop indicates that the system has almost reached the lower limit of acceptable frequency, which is 49.2 Hz, the starting point of the UFR (Under Frequency Relay) stage 1.

After reaching this low point, the frequency immediately increased again, indicating that the system was able to recover quickly from the disturbance. Based on the recorded frequency sequence, there was no deeper drop until further stages of UFR were reached, such as island operation or house load generation.

3.2 Generator Failure of PLTU Tarahan 3 and PLTU Tarahan 4

Steam power plant (in Bahasa: Pembangkit Listrik Tenaga Uap (PLTU)) Tarahan 3 and PLTU Tarahan 4 make an important contribution to the supply of electricity to areas with high electricity consumption, such as major cities and industries in Sumbagsel. With this large capacity, these two plants also play an important role in maintaining the stability of the electricity system, particularly in terms of ensuring a balance between electricity supply and demand. A disruption or failure in one or both of these plants can have a significant impact on the stability of frequency, voltage and overall system load.



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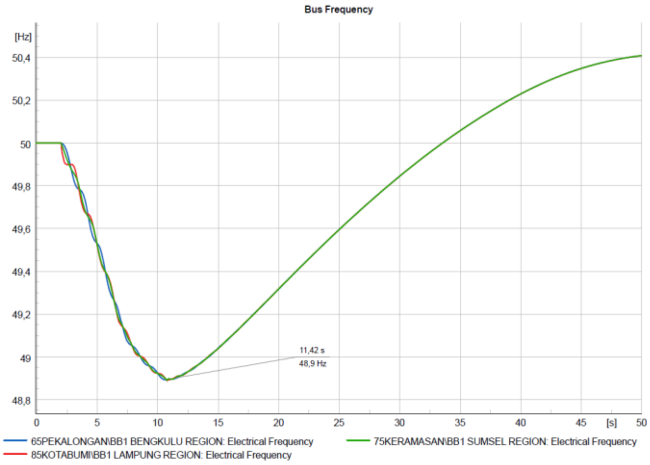


(b)

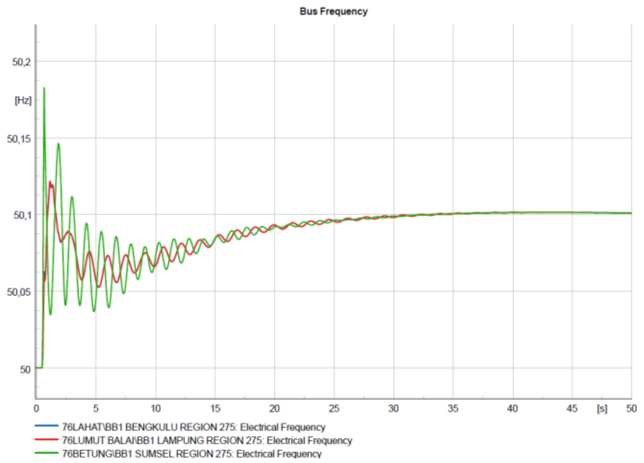
Figure 7 frequency of (a) 275 kv, (b) 150 kV buses

Fig.7 shows the frequency on the 275 kV bus recorded at 48.9 Hz at second 11.19 s and the 150 kV bus recorded at 48.9 Hz at second 11.49 s. It can be concluded that the system experienced a frequency drop close to UFR level 3 (48.9 Hz), which is the level at which Under Frequency Load Shedding (UFLS) begins to be applied. Although the frequency did drop to this point, the drop was short lived and the frequency immediately rose back to a more stable level.

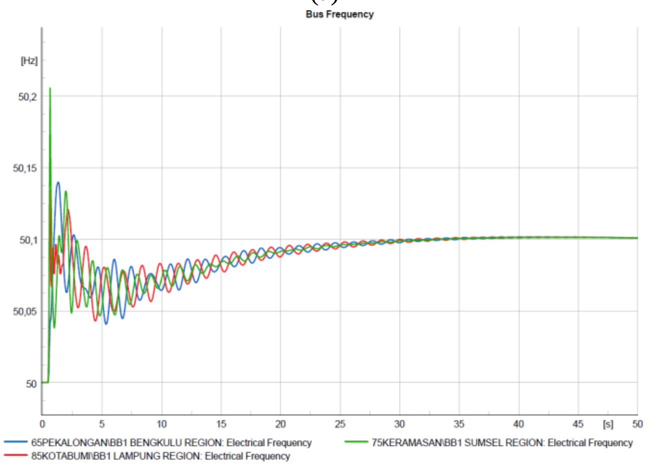
This shows that although the system was in a critical condition at the time of the frequency drop, the protective measures implemented managed to quickly resolve the power imbalance and prevent a further drop to UFR level 4 or island operation. This rapid recovery demonstrates the effectiveness of the protection system in maintaining grid stability and preventing major disturbances.

3.3 Short Circuit OHL 150 kV Kayu Agung - Gumawang 1

This section refers to the experiment or simulation of a short circuit on the 150 kV overhead line (OHL) between Kayu Agung and Gumawang 1. The purpose of this test is to evaluate how the system responds to a fault such as a short circuit, which can have a significant impact on the stability of the power system. By simulating this fault, the system's ability to detect, isolate and recover from such disturbances can be evaluated, ensuring continuity of service and protection of equipment in the 150 kV Sumbagsel interconnection system. This type of experiment is crucial for determining the effectiveness of protection mechanisms and the overall reliability of the transmission network.



(a)



(b)

Figure 8 frequency of (a) 275 kv, (b) 150 kV buses

Fig. 8 shows the bus frequency curve of the system that experienced a short circuit at OHL 150 kV Kayu Agung - Gumawang 1. After the disturbance, the frequency on the 275 kV and 150 kV buses oscillated in the range of 50 Hz to 50.15 Hz, indicating the initial response of the system to a sufficiently large disturbance. The increase in frequency in the range of 50.08 Hz to 50.15 Hz illustrates the temporary fluctuations due to the disturbance, but this is still within controllable limits.

The frequency began to stabilise at 50.1 Hz, still within normal and acceptable limits, at the 25th second after the disturbance. This frequency stability indicates that the system successfully responded to the disturbance and maintained its operational reliability. The frequency fluctuations that occurred after the disturbance and the return to 50.1 Hz indicate that the system has an effective regulation and control mechanism to maintain stability and return the frequency to its nominal value.

4 Conclusion

The simulation of generator failure in the 150/275 kV Sumbagsel interconnection system shows that the failure of large generators can affect frequency and voltage stability. In the PLTP ULBLU 1 failure scenario, the frequency on the 150 kV and 275 kV buses drops to 49.2 Hz, close to the lower limit of the normal frequency (UFR level 1), but the system can recover quickly thanks to protections such as the Under Frequency Relay (UFR) and load shedding, which prevent a further drop. Failure scenarios at PLTU Tarahan 3 and 4 also showed a frequency drop to 48.9 Hz (UFR level 3) but stabilised after a rapid recovery. For the OHL 150 kV Kayu Agung - Gumawang 1 short-circuit fault, the frequency briefly oscillated in the range of 50 Hz to 50.15 Hz, but stabilised at 50.1 Hz after 25 seconds, indicating that the system has an effective regulation mechanism.

Overall, the simulation results show that the Sumbagsel interconnection system has good resilience to large disturbances and effective protection to maintain stability. To improve the resilience of the system in the future, it is necessary to conduct further simulations and tests under more severe conditions. The development of mitigation measures and new strategies will be crucial to strengthen the response to disturbances and improve the overall reliability of the system.

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Acknowledgement

The authors would like to sincerely thank PLN (Perusahaan Listrik Negara) for their valuable support throughout this research. Their technical assistance and access to resources have greatly contributed to the progress and success of this study.