FREQUENCY STABILITY ANALYSIS USING TIME DOMAIN SIMULATION METHOD (CASE STUDY OF TIMOR SYSTEM)

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ABSTRACT

Based on the 2021-2030 RUPTL, the addition of PLTU Timor 1 (2 × 50 MW) to the Timor system is carried out because electricity demand continues to increase. Therefore, a transient stability study is needed to determine the reliability of the system when a disturbance occurs. By utilizing the Time Domain Simulation (TDS) method, the research was conducted by simulating generator outage and 3-phase short circuit to study the frequency stability of the Timor system. From the simulation results, generator outage has a major influence on system frequency stability, especially simulated at PLTU Timor 1 unit 1. The disturbance caused a decrease in the lowest frequency, reaching 49.61 Hz, so it was not within the safe operating limits according to the operating guidelines for the Timor electricity system. For this reason, Manual Load Shedding (MLS) and the addition of generators at PLTD Cogindo and PLTMG Kupang Peaker are required. The action is carried out by paying attention to the rate of change of the next frequency. As for the 3-phase short circuit disturbance on one of the Bolok - Maulafa lines, the frequency increased to 50.06 Hz after the disturbance, which is still within safe operating limits.

Keywords: *Frequency stability, time domain simulation, generator outage, short circuit 3-phase*

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1. INTRODUCTION

Based on the 2021-2030 RUPTL, the projected sales of electricity in East Nusa Tenggara in 2023 grew by 8.4% from the previous year [1]. The government, through PLN, plans and conducts additional power generation by adding PLTU Timor 1 with a capacity of 2 × 50 MW in the 150 kV transmission network, which is expected to operate in August and November 2023. According to Suyono, the addition of a new generator unit in an existing system requires a transient stability study to determine the reliability of the system during a disturbance [2]. This must be done to design a power system that is resistant to various disturbances so that the system can continue to operate continuously without losing load and does not result in uncontrolled, widespread, and multilevel blackouts [3].

Power system stability can be broadly defined as a property of a power system that allows it to remain in a state of operating equilibrium under normal operating conditions and can return to an equilibrium state after experiencing a disturbance [4]. The balance of power between loads and generators is one measure of the stability of the operation of the electrical system. Therefore, a reliable control system is needed. If all generators continue to operate normally despite a disturbance, the system is said to be stable [5]. Power system stability can be divided into three categories: rotor angle stability, voltage stability and frequency stability [6]. These three stabilities can be disturbed by several factors, such as a sudden increase in capacity or load, the death of a generator or a short circuit on the system line [5][7]. These factors are disturbances to transient stability. Transient stability refers to the ability of a power system, under normal conditions, to return to normal within a short time after a major disturbance, such as a generator outage and a 3-phase short circuit [8][9].

In this study, the Time Domain Simulation (TDS) method in DIgSILENT PowerFactory software is used to analyze transient stability. TDS is a reliable and accurate method for solving transient stability problems. TDS is used to provide a simulation duration of more than 5 seconds until a more reliable stable or unstable state value is obtained [10]. M. Hammad and A. Hard [11], in the 9th International Renewable Energy Congress (IREC 2018) with a study entitled "Static analysis for voltage stability of the Northern Jordanian power system", showed that by using DIgSILENT PowerFactory, they get stability research results on power systems and transmission system modelling efficiently and stably. The same thing was also proven by R. Faizal, M. Nurdin, N. Hariyanto et al [12] in a study entitled "Sumatra-Java HVDC transmission system modelling and system impact analysis".

Transient stability analysis in this study was carried out to know the system's resistance to generator outage and 3-phase short circuit after the addition of generation capacity in the Timor system. The analysis is carried out by paying attention to frequency stability, which can be defined as the power system's ability to maintain frequency stability under normal conditions and overcome various disturbances that can cause an imbalance between generation and load. [13]. The research was conducted using DIgSILENT PowerFactory, software for simulating and analyzing transmission, distribution, and industrial systems. It certainly has complete features, including stability calculations [14][15]. With DIgSILENT, frequency stability analysis is carried out by simulating generator outage and 3-phase short circuit, which is then studied for system stability by paying attention to the system frequency response.

2. RESEARCH METHOD

In this study, a quantitative method is used, by using secondary data in the form of generation data, transformers, lines, Timor system loads and Under Frequency Load Shedding (UFLS) Schemes which will then be used to conduct load flow study experiments (Load flow analysis) to determine the initial state of the system and simulation of disturbances in the Timor system transmission network using DigSILENT PowerFactory 15.1 software with the TDS method after the addition of the PLTU Timor 1. Furthermore, an analysis of the results obtained in the form of frequency response is carried out to assess system stability.

2.1 Research Flow Chart

The research flow chart can be seen in Figure 1.

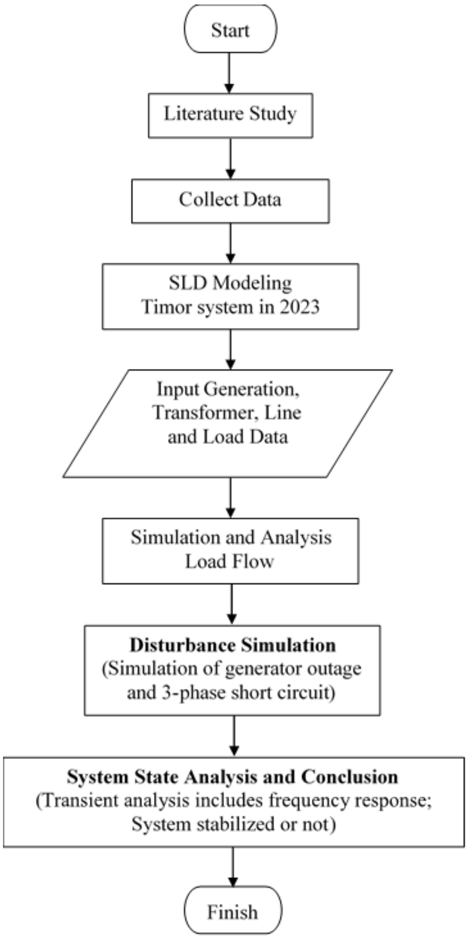

Figure 1. Research flow chart

Based on the research flow chart, the research flow can be explained as follows:

1. Literature Study
   Collect theories relevant to the research topic and compare existing methods so that a method that is suitable for this research is found.
2. Data Collection
   In the form of secondary data it is a single-line diagram of the Timor system, generation data, transformer data, load data, line data, and UFLS scheme.
3. Single-Line Diagram Modeling
   From the data obtained, a single line diagram (SLD) modelling of the Timor system was carried out by adding the PLTU Timor 1.
4. Load Flow Study
   This is done to know the system's initial state and ensure all data has been inputted.
5. Disturbance Simulation
   The simulation of disturbances, including generator outage and 3-phase short circuit disturbances using the TDS method, where with DIgSILENT PowerFactory, the power system differential-algebraic equations are solved by numerical integration, the exact disturbed trajectory can be obtained, then the transient instability is determined by empirically observing the trajectory during the entire simulation time. The length of simulation time usually depends on the experience from previous studies. The results of the TDS method are used to perform transient stability analysis until the system reaches stability or is unstable, and then the TDS program can be stopped. For more reliable results, the duration of the simulation time can be set to more than 5 seconds [10].
6. Transient Stability Analysis
   The frequency response of the 70 kV and 150 kV busbars transmission network was analyzed. Changes in the frequency response are observed within the limits set by the standard, which is ± 0.20 Hz from the nominal frequency of 50.00 Hz, except in short transient periods where the permissible deviation is ± 0.50 Hz from the nominal frequency of 50.00 Hz, as well as during emergencies [16].
7. Conclusion
   Draw conclusions about the condition of system stability caused by disturbances in the simulation of the Timor system after the addition of PLTU Timor 1.

3. RESULT AND DISCUSSION

3.1 Transient Stability Case Study on Timor System

From the data that has been collected, then the Single Line Diagram (SLD) modelling of the Timor electricity system is carried out using DigSILENT software with the addition of PLTU Timor 1, which is based on the 2021-2030 RUPTL. This plant is added through the Panaf substation with a voltage of 150 kV. Using the SLD, a load flow study was carried out to determine the state of the system first. The results of the load flow study are shown in Table 1 as follows.

Table 1. Timor system load flow during WBP and LWBP 2023

Line		WBP 2023 (MW)	LWBP 2023 (MW)
150 kV	70 kV		
	-		
Bolok – Panaf (1)	-	32.7	20.5
Bolok – Panaf (2)	-	32.7	20.5
Bolok – Tenau (1)	-	4.9	8
Bolok – Tenau (2)	-	4.9	8
-	Bolok – Maulafa (1)	46.9	27.3
-	Bolok – Maulafa (2)	46.9	27.3
-	Maulafa – Naibonat (1)	23.4	11.2
-	Maulafa – Naibonat (2)	23.4	11.2
-	Naibonat – Nonohonis (1)	25.7	11.7
-	Naibonat – Nonohonis (2)	12.8	6.1
-	Nonohonis – Kefamenanu (1)	11.4	5.7
-	Nonohonis – Kefamenanu (2)	12.5	6
-	Kefamenanu – Atambua (1)	2.2	1.3
-	Kefamenanu – Atambua (2)	12.2	5.9

The disturbances simulated during Peak Load Time (WBP) and Outside Peak Load Time (LWBP) in 2023 can be explained as follows.

1. Generator Outage

In this case, 2 (two) simulations were carried out. Namely, the disconnection of one of the generators that had the largest capacity in the Timor system was carried out on all generators directly connected through Bolok substation 70 kV.

2. 3-Phase Short Circuit

In this case, a disconnection is made on one line from the dual line that has the largest load flow by providing a 3-phase short circuit fault on the line. In order for the details of the case study to be simulated to be better understood, it can also be explained through Table 2 as follows.

Table 2. Frequency Stability Simulation Case Study

	Cases	Action	Description
1	Generator *Outage* PLTU Timor 1 Unit 1	PLTU Timor 1 Unit 1 *trip*	WBP & LWBP
2	Generator *Outage* PLTU Bolok Unit 2	PLTU Bolok Unit 2 *trip*	WBP & LWBP
	Generator *Outage* PLTU IPP Kup. Baru Unit 1 & 2	PLTU IPP Kup. Baru Unit 1 & 2 *trip*	
3	*3-Phase Short Circuit* BOLOK-MAULAFA 1	CB BOLOK-MAULAFA 1 *open*	WBP

Based on Table 2, it can be seen that case studies 1 and 2 are simulations of generator outage disturbances. In the generator outage disturbance, simulations were carried out during WBP and LWBP in 2023. During WBP, the system supplies 119.09 MW, and during LWBP, the system supplies 73.47 MW. The 3-phase short circuit fault was simulated during WBP, where the simulation was carried out on one of the Bolok - Maulafa lines, which, at the time, was carrying 46.9 MW.

3.2 Simulation Results of Timor System Frequency Stability in Case Study 1

In case study 1, a generator outage simulation was carried out at the Timor 1 unit 1 PLTU, which at the time of the WBP had a capable power of 33 MW. The generator outage occurred at 2s with a simulation duration of 15s. Before 2s, as shown in Figure 2, the system frequency is stable at 50.00 Hz. When the generator outage occurred, the system frequency at all 70 kV busbars decreased to 48.87

Hz and began to rise again until it reached a new steady state at 49.61 Hz at the 8.99s. While at all 150 kV busbars, the frequency decreased to 48.86 Hz and began to rise again until it reached a new steady state at 49.61 Hz at 8.99s. Based on Timor's system operating guidelines, the frequency at 49.61 Hz has exceeded the safe operating limit (± 0.20 Hz from 50.00 Hz).

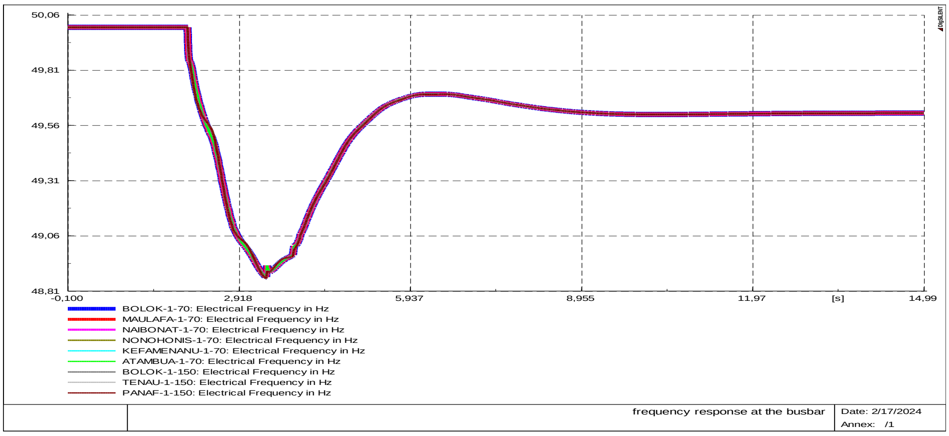

Figure 2. Frequency response of 70 kV and 150 kV busbars in case study 1 during WBP

Furthermore, during the LWBP PLTU Timor 1 unit 1 supplies 18.7 MW. Generator outage occurs at 2s with a simulation duration of 20s. When the generator outage occurred, it can be seen in Figure 3 that the system frequency decreased at the 70 kV busbar and 150 kV busbar. Before 2s, the frequency stabilized at 50.00 Hz. After the generator outage occurred, the frequency at the 70 kV busbar and 150 kV busbar decreased to 49.18 Hz and then increased until it reached a steady state condition at a frequency of 49.61 Hz at 9.95s. Based on Timor's electrical system operating guidelines, the frequency response after the disturbance was not within the safe operating limits (± 0.20 Hz from 50.00 Hz).

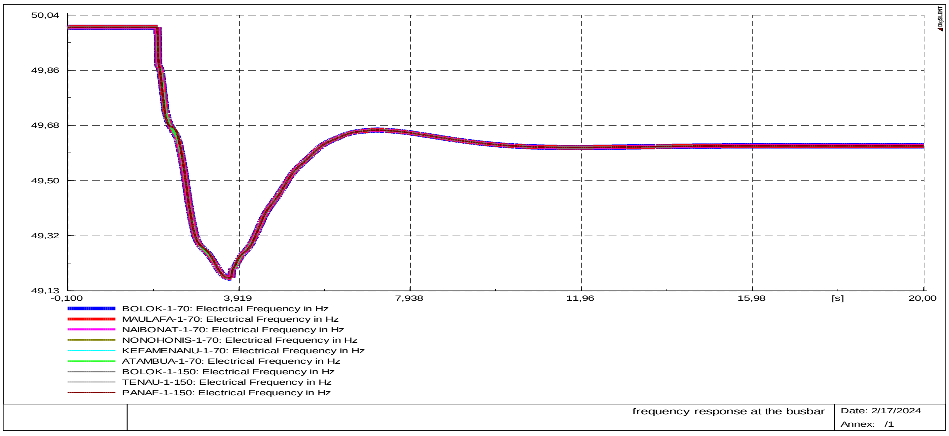

Figure 3. Frequency response of 70 kV and 150 kV busbar in case study 1 during LWBP

3.3 Simulation Results of Timor System Frequency Stability in Case Study 2

In case study 2, a generator outage occurred in all plants on the 70 kV side, namely the PLTU Bolok and the PLTU IPP Kupang Baru, which at the time of the WBP, each generator was supplying 13 MW. The generator outage occurred at 2s with a simulation duration of 15s. Before 2s, as shown in Figure 4, the system frequency is stable at 50.00 Hz. When the generator outage occurred, the frequency response at the 70 kV busbar rose briefly to 50.13 Hz and then dropped to 49.69 Hz. The system returns to the new steady state at 7.53s with a frequency of 49.84 Hz. While at all 150 kV busbars, the same frequency response occurred as the 70 kV busbar. Based on Timor's electrical system operating guidelines, the frequency response after the disturbance is still within safe operating limits (± 0.20 Hz from 50.00 Hz).

Furthermore, during LWBP, each generator supplies 10 MW. The generator outage occurred at 2s with a simulation duration of 20s. In Figure 5, the system frequency is stable at 50.00 Hz before 2s. After the generator outage occurred, the frequency at the 70 kV busbar and 150 kV busbar dropped briefly to 49.48 Hz and rose again until it reached a new steady state at 49.66 Hz at the 5.92s. Based on Timor's electrical system operating guidelines, the frequency is not within safe operating limits (± 0.20 Hz from 50.00 Hz).

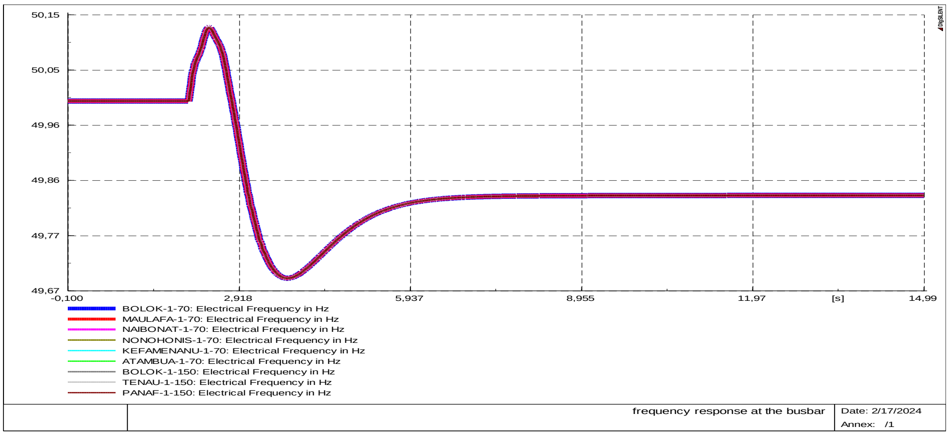

Figure 4. Frequency response of 70 kV and 150 kV busbars in case study 2 during WBP

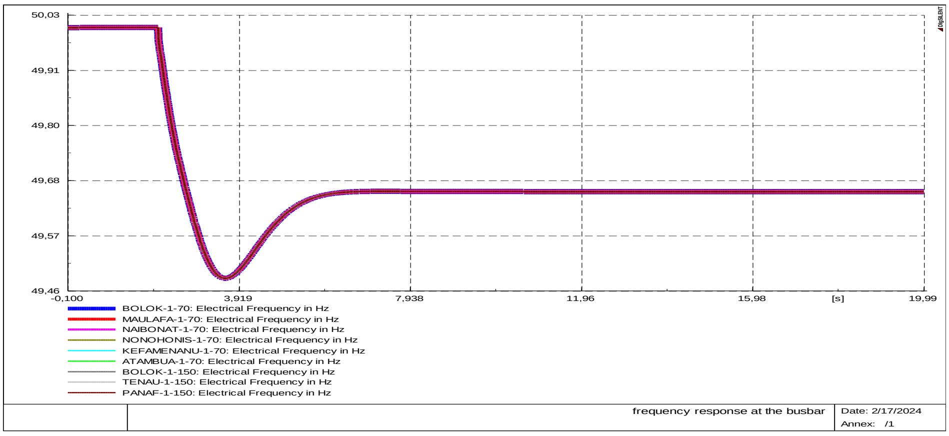

Figure 5. Frequency response of 70 kV and 150 kV busbars in case study 2 during LWBP

3.4 Simulation Results of Timor System Frequency Stability in Case Study 3

In case study 3, a 3-phase short circuit fault occurred on one of the Bolok - Maulafa lines. The fault was given at 2s and the circuit breaker (CB) opened at 3.55s to overcome the fault. As can be seen in Figure 6, the system frequency experienced fluctuations that tended to be high until it reached a new steady state condition.

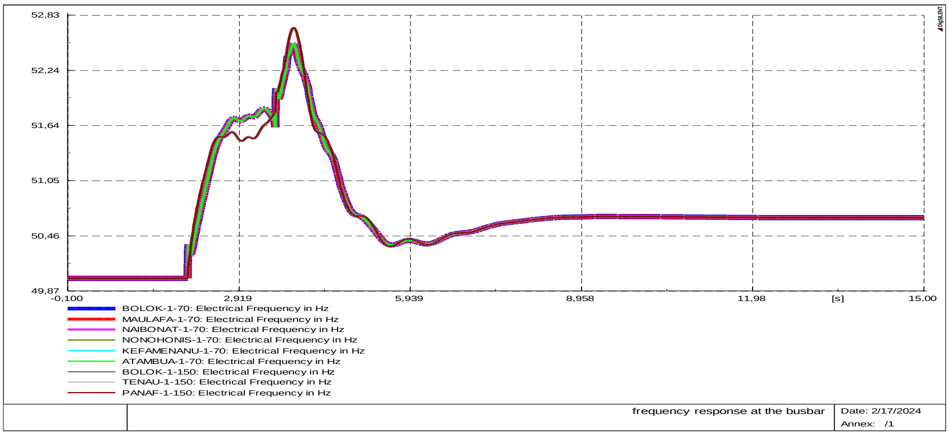

Figure 6. Frequency response of 70 kV and 150 kV busbars in case study 3

At the 70 kV busbar, the frequency fluctuates until it touches the highest point at 52.37 Hz and then reaches a new steady state condition at 50.06 Hz at the 11s. While at the 150 kV busbar, the frequency fluctuates until it touches 52.53 Hz and then reaches a new steady state condition at 50.06 Hz at the 11.38s. Based on Timor's electrical system operation guidelines, the frequency response after the disturbance is still within safe operating limits (± 0.20 Hz from 50.00 Hz).

3.5 Discussion of Simulation Results of Timor System Frequency Stability

Based on the results obtained, it can be seen that generator outages greatly affect frequency stability, especially those that occur in PLTU Timor 1 unit 1. In case study 1, during WBP and LWBP, the system lost power supply due to generator outages, resulting in a frequency drop to activate UFLS to help the system return to a new steady state. During WBP, the UFLS released 19.155 MW of load at 3.39s. While during LWBP, UFLS released a load of 6.153 MW at 3.72s. It can be seen in Figure 2 that the frequency drops to its lowest point at 48.87 Hz on the 70 kV side and 48.86 Hz on the 150 kV side during WBP. During LWBP, the frequency drops to its lowest point at 49.18 Hz, as shown in Figure 3.
The active UFLS helps the system to prevent the frequency from experiencing a continuous decline. Therefore, the system frequency can be the steady state in a new condition at 49.61 Hz during WBP and LWBP. This figure is certainly outside the safe operating limits based on Timor's electrical system operating guidelines (± 0.20 Hz from 50.00 Hz). To restore the frequency within safe operating limits, further actions that can be given are conducting Manual Load Shedding (MLS) and requesting additional power to the remaining plants or requesting several other plants to enter the system. Additional generation can be done at PLTD Cogindo and PLTMG Kupang Peaker because the plant is the fastest synchronized with the system. The action is carried out by paying attention to the rate of change of the next frequency until the frequency is at the normal operating limit.
In case study 2, the generator outage that occurred in all plants on the 70 kV side did not affect the frequency stability during WBP. The disturbance caused the system to lose 39 MW during WBP. It can be seen in Figure 4 that the system frequency increased until it touched 50.13 Hz and then dropped to the lowest point at 49.69 Hz at 3.77s before the system reached a new steady state at 49.84 Hz, which, of course, this nominal is still within the safe operating limits. Therefore, no additional action is required. Furthermore, during LWBP, the disturbance that occurred caused the system to lose 30 MW during LWBP. In Figure 5, it can be seen that this causes the frequency to decrease to 49.48 Hz at 3.59s and then reach a new steady state at 49.66 Hz, which is not within the safe operating limits. To solve the problem, additional measures can be taken as described earlier in case study 1, by paying attention to the rate of change of the subsequent frequency until the frequency reaches the safe operating limit.
From case studies 1 and 2 during WBP, it can be seen that in case study 1, the power loss due to generator outage is 27.71% of the total generation power (119.09 MW), which is smaller when compared to case study 2, where the power loss is 32.75% of the total generation power. In case study 1, there was a generator outage at PLTU Timor 1 unit 1, which resulted in a frequency that was not within safe operating limits. This is because PLTU Timor 1 is the plant with the largest capacity, so it plays an important role in maintaining system stability.
In case study 3, the 3-phase short circuit disturbance that occurred in one of the Bolok –Maulafa lines did not have much impact on frequency stability. When a disturbance occurs, the frequency fluctuates quite high, but after the disturbance is removed, the frequency can return to steady state in a new condition at 50.06 Hz, which, of course, is still within the safe operating limits, so no further handling action is required.

4. CONCLUSION

Generator outage greatly affect frequency stability when compared to 3-phase short circuit that occurs on one of the Bolok - Maulafa lines. Generator outage that occurs in PLTU Timor 1 unit 1 during WBP and LWBP has a major impact on frequency stability, wherein the new steady state, the frequency is at a nominal 49.61 Hz so that handling action is needed by conducting MLS and adding generation that can be done at PLTD Cogindo and PLTMG Kupang Peaker. The generator outage that occurs in all plants on the 70 kV side, namely PLTU Bolok and PLTU IPP Kupang Baru causes the steady state frequency in the new state at a nominal 49.66 Hz during LWBP. While at the disturbance, the 3-phase short circuit does not have a big influence on frequency stability. Overall from the simulations that have been done, generator outage can cause instability in the system, especially in frequency stability.

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