ASIIMETRIK
JURNAL ILMIAH REKAYASA DAN INOVASI
p-ISSN: 2655-1861, **e-ISSN:** 2716-2923
Volume **8** Number **1**, **2026**

Analysis of the Implementation of the Orya Hydroelectric Power Plant's Island Defense Scheme in the Jayapura Power System

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Received: 25/11/2025 Revised: 11/12/2025 Accepted: 03/01/2026

Abstract: This study aims to determine whether the islanding-based defense scheme at the Orya hydropower plant can effectively maintain the stability of the Jayapura radial power system during major disturbances. The system was modeled and tested in DIgSILENT PowerFactory under several outage scenarios, with a focus on the separation of the Orya–Sentani–Skyline corridor. The simulation indicates that maintaining post-disturbance operation within the nominal frequency of around 50 Hz and voltage variation of ±5% requires shedding 19.89 MW of load from selected feeders. After the scheme is activated, the islanded Orya subsystem settles at approximately 50.15 Hz, while the remaining grid stabilizes near 50.0 Hz—both within regulatory limits. These findings suggest that a combined load-shedding and islanding strategy can reduce the risk of cascading failures in Jayapura and may offer a practical template for other radial systems with limited redundancy.

Keywords: defense; load; shedding; islanding; PLTA



SDGs Problem Solving

The investigation on the islanding defense plan of PLTA Orya within the Jayapura power system is in line with SDGs Chapter #7. The study promotes dependable electricity availability and fortifies resilient energy infrastructure in regional systems by enhancing grid stability, reducing blackouts, and optimizing load shedding.

Conflict of Interest Statement: The author(s) declares that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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Conflict of Interest STATEMENT
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1. INTRODUCTION

A defence scheme in a power system is generally understood as a protective mechanism that steps in when frequency or voltage starts drifting from its normal operating range (Mubarok *et al.*, 2023). In practice, the scheme may involve Overload Shedding (OLS), Under-Frequency Load Shedding (UFLS), island operation, or combinations of these actions (Morrison and Das, 2023). OLS is typically activated when transmission assets fail to meet N-1 criteria, causing overloads that require part of the load to be disconnected (Naidu *et al.*, 2022; Bi and Wang, 2025). UFLS responds to sudden generation loss by shedding load in stages to arrest the frequency decline, and if this is still insufficient, the system may need to be split into smaller electrical islands (Prokof'ev and Sudolskii, 2022; Sun and Zhao, 2024).

The principle behind controlled islanding is straightforward: separate a subsystem that still has feasible generation–load balance so that at least part of the grid can continue operating. To make such an island viable, several conditions need to be satisfied—generation must slightly exceed demand, voltages must remain within limits, and no internal bottlenecks should appear (Kerdphol *et al.*, 2020; Redeker, 2024). Load shedding often accompanies this process, since even a technically isolated subsystem may not be stable without an appropriate reduction of local demand (Prokof'ev and Sudolskii, 2022; Sun and Zhao, 2024).

Although many studies have evaluated defence schemes in general contexts, most prior work focuses either on load shedding alone or islanding strategies applied to large interconnected networks. For example, Khausar and Firdaus examined island operation at the Teluk Lembu Substation (Khausar and Firdaus, 2016); Fernández-Porras et al., emphasized the timing of intentional separation (Fernández-Porras, Panteli and Quirós-Tortós, 2018); Haidar et al., discussed frequency performance in a PV-penetrated subsystem (Haidar, 2019); and Fatchurrahman et al., optimized defence-scheme parameters for the Central Kalimantan system (Fatchurrahman *et al.*, 2023). These studies provide valuable insights but do not fully address the specific challenges of radial grids with geographically scattered generation—conditions that strongly characterize the Jayapura power system.

This gap becomes more apparent when considering Jayapura's configuration. The system relies on several generation centers—Holtekam (130 MW), Jayapura (12 MW), and Orya (20 MW)—all tied together by radial 150 kV and 70 kV networks. Such a layout makes the system highly sensitive to disturbances; the loss of a single corridor can immediately isolate sizeable portions of the load. Despite this, no prior work has examined how an islanding strategy at PLTA Orya, combined with load-shedding settings derived from the System Strength Index (SSI), could reinforce system stability under major contingencies. The SSI approach itself is rarely integrated explicitly into islanding-based defence schemes in similar regional systems, which leaves an open methodological niche.

The present study attempts to fill this gap by evaluating a defence scheme that pairs controlled islanding of PLTA Orya with SSI-based determination of load-shedding requirements for the Jayapura grid. Using DIgSILENT PowerFactory, the study investigates how this combined strategy performs under realistic disturbance scenarios involving the 150 kV and 70 kV transmission corridors. The analysis aims to determine whether the Orya subsystem can maintain acceptable frequency and voltage levels and how much load must be shed to keep the island stable.

2. METHODOLOGY

Complete the technical details: system data (capacity, load, line ratings), DIgSILENT simulation type and settings, how the SSI is obtained, the full formula and step-by-step calculation of load shedding (leading to 19.89 MW), and the detailed logic of the islanding scheme and feeder shedding sequence.

2.1. Data Collection

The first stage involved collecting operational data from PLN UP3B Papua–West Papua. The dataset included the available generation capacities at Holtekam, Jayapura, and Orya; the peak system load of approximately 100 MW; the transfer capability of the 150 kV Holtekam–Skyline transmission corridor; the 70 kV line ratings between Orya, Sentani, and Skyline; and the transformer ratings at the Skyline substation. These parameters were then used as the basis for reconstructing the Jayapura power system in DIgSILENT (see Figure 1).

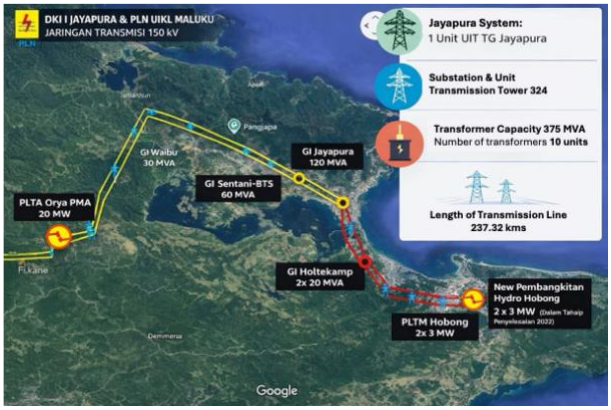


Figure 1. Topology of Jayapura's electrical system

A simplified representation of the actual network layout is shown in Figure 1, which illustrates the topology of the Jayapura electrical system, including the main generation centers, the 150 kV and 70 kV transmission corridors, and the substations that interconnect the grid. This topology serves as the structural reference for the DIgSILENT model used in the analysis.

2.2. System Modelling in DIgSILENT Software

The system model was developed as a single-line RMS dynamic model. Generator, transformer, and line parameters were entered according to PLN's technical records, while load points were represented as static P–Q elements with frequency sensitivity. The dynamic simulations used a time step of 5 ms and a 10-second window, enabling detailed observation of rotor angle and frequency variations during a contingency. Standard governor and AVR models were applied to all generators, and under-frequency relay characteristics were implemented to reflect the existing protection settings (Sidorenko and Togo, 2019).

2.3. System Strength Index (SSI) Determination

To quantify the system's tolerance to generation loss, the System Strength Index (SSI) was calculated using historical disturbance data. By plotting generator outage magnitudes against the corresponding frequency deviations recorded in the Jayapura system, a linear relationship was obtained, expressed as SSI = 2.2 +6.6 x. For a 1 Hz deviation from nominal frequency, the SSI value is 8.8 MW/Hz. This value was used in the subsequent load-shedding calculation.

2.4. Baseline Disturbance Simulation

Baseline simulations were conducted for four major disturbance scenarios without applying any defense scheme. These scenarios included the simultaneous loss of the Holtekam–Skyline 150 kV lines, the trip of the 150/70 kV interbus transformer at Skyline, and the loss of the Orya–Skyline and Sentani–Skyline 70 kV lines. The simulations showed that the most critical case occurs when the Orya and Sentani area becomes isolated from the main grid while still demanding more than 20 MW, despite PLTA Orya being able to supply only 8 MW. This imbalance leads to rapid frequency collapse and serves as the primary reference scenario for determining the necessary amount of load shedding.

2.5. Determination of Load-Shedding Requirement

The required load-shedding magnitude was determined using the standard equation:

$$LS = \Delta P_{Loss} - R + (SSI \times \Delta f) \quad (1)$$

with 20.1 MW of lost transfer, 12 MW of effective reserve at PLTA Orya, an SSI of 8.8 MW/Hz, and a permissible frequency deviation of 0.5 Hz, the calculated value was 12.5 MW.

A technical margin was applied, resulting in a minimum requirement of 14.2 MW. Examination of feeder loading at the Sentani and Orya substations showed that disconnecting the Rambutan, Inter 6, Inter 7, Cempaka, and Jeruk feeders yields a total of 19.89 MW, exceeding the minimum requirement and ensuring adequate frequency recovery. The shedding logic follows a sequential structure, beginning with the feeders carrying moderate loads and escalating to larger feeders if the post-disturbance frequency remains below the stabilization threshold (Song *et al.*, 2021).

2.6. Feeder Selection and Shedding Logic

The selection of feeders for load shedding was determined by examining the loading conditions at the Sentani and Orya substations. This assessment identified five feeders whose disconnection would provide the required reduction in demand while maintaining an appropriate balance within the islanded subsystem. The Rambutan feeder carries 3.64 MW, inter 6 carries 6.76 MW, inter 7 carries 5.64 MW, Cempaka carries 1.83 MW, and Jeruk carries 2.02 MW. These feeders were therefore designated as the primary shedding targets, as their combined load offers a sufficient margin to support post-disturbance frequency recovery and ensure stable operation within the isolated area.

The islanding defense scheme was simulated under the most critical disturbance scenario, namely the simultaneous loss of both 70 kV transmission lines supplying the Orya area. Under-frequency relays initiated the shedding of designated feeders according to the predefined sequence, after which an isolated subsystem was formed with PLTA Orya operating as the sole generation source. The performance of the islanded system was evaluated by observing its dynamic frequency response, the active power adjustment provided by the PLTA Orya governor, and the resulting voltage recovery at both the 70 kV and 20 kV bus levels.

3. RESULTS AND DISCUSSION

3.1. Jayapura Power System Modeling

The Jayapura power system was modeled using DIgSILENT PowerFactory to analyze the operational conditions of the electrical network. The modelling process began with the collection of technical data from generation units, transmission and distribution networks, and system loads (Vergara and Pinzón, 2024).

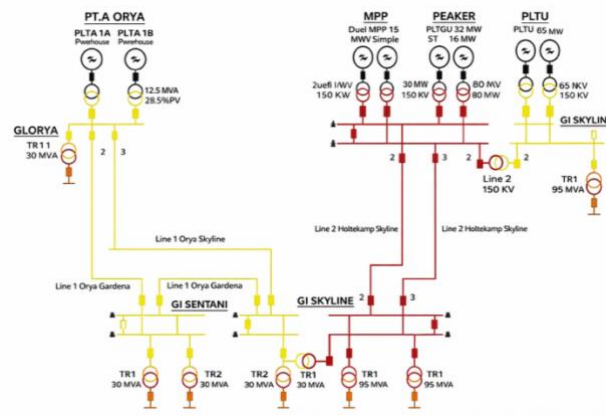


Figure 2. Single-line diagram of the Jayapura system

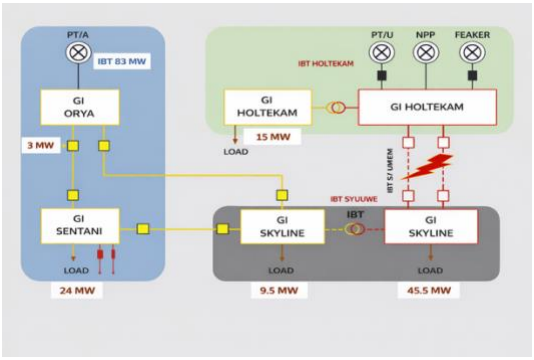
Figure 2 illustrates a single-line representation of the Jayapura power system developed at DIgSILENT PowerFactory as the basis for the simulation study. The model comprises an array of generating units, transmission corridors, and load centers, allowing a detailed assessment of how the network responds to various disturbance scenarios. The construction of this diagram is based on technical data obtained from power plants, 150 kV and 70 kV transmission lines, and major distribution substations, ensuring that the simulated conditions reflect the actual operational characteristics of the Jayapura system.

3.2. Initial Simulation (Without Islanding Scheme)

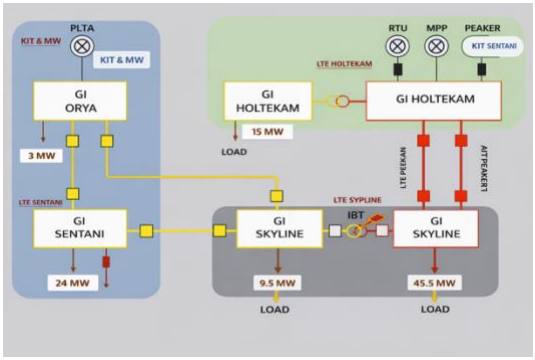
The defence scheme for the Jayapura power system must be tested under several disturbance scenarios to ensure its reliability. One of the schemes to be designed is the islanding-based defence scheme for the Orya hydropower plant (PLTA Orya). This scheme is intended to operate under the following disturbance conditions (Sihombing *et al.*, 2023):

1). Loss of the 150 kV Holtekam–Skyline 1 and Holtekam–Skyline 2 transmission lines (Scenario 1).
2). Loss of the 150/70 kV IBT transformer at Skyline Substation (Scenario 2).
3). Loss of the 70 kV Orya–Skyline and Sentani–Skyline transmission lines (Scenario 3).
4). Loss of the 70 kV Orya–Skyline and Orya–Sentani transmission lines (Scenario 4).

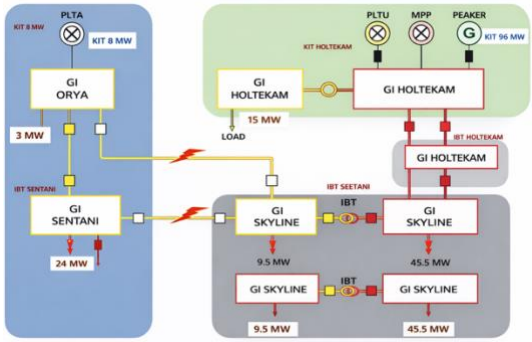
Scenario 1 simulates a disturbance in the form of a trip on both Holtekam–Skyline transmission lines (see Figure 3a). This event disconnects 76 MW of generation from the Holtekam site from the rest of the system. As a result, a significant power deficit occurs at the Skyline, Sentani, and Orya sites, which are supplied only by the Orya hydropower plant with a capacity of 8 MW. This condition creates a substantial power imbalance across the system.



(a). Scenario 1



(b). Scenario 2



(c). Scenario 3

Figure 3. Simulates a disturbance

Based on the simulation results shown in

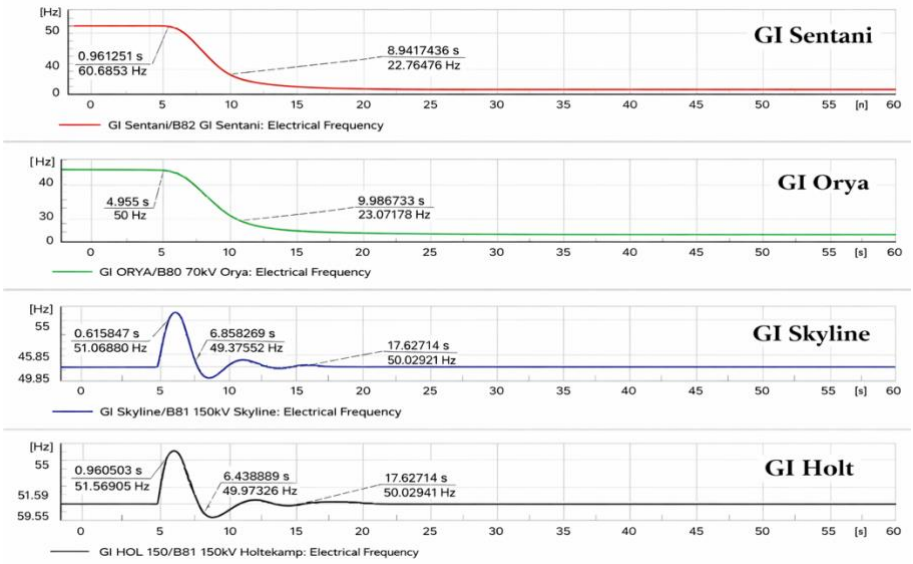


Figure **4**, when the two Holtekam–Skyline transmission lines trip, the frequency response at the Sentani, Orya, and Skyline sites drops sharply to 16 Hz. This indicates that these areas are unable to withstand the disturbance and experience a total blackout. In contrast, the Holtekam site initially experiences a frequency rise to 55.65 Hz, followed by a decline to 47.15 Hz, before eventually stabilizing at approximately 50.03 Hz. This demonstrates that the Holtekam site is still able to withstand the disturbance and does not experience a complete outage.

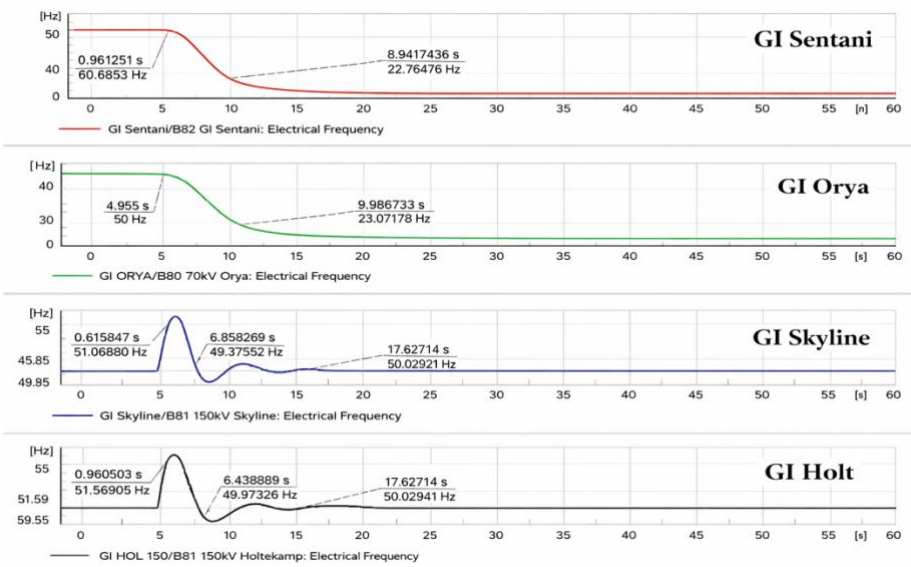


Figure 4. Frequency response for simulation scenario 1

Scenario 2 simulates a disturbance caused by the tripping of the 70/150 kV interbus transformer (IBT) at the Skyline Substation (see Figure 3b). This event interrupts a power flow of 29.5 MW to the 70 kV network at Skyline. As a result, the Sentani and Orya sites experience a power deficit, receiving supply only from the Orya hydropower plant, which has a capacity of 8 MW. This imbalance poses a risk to system stability within the affected area.

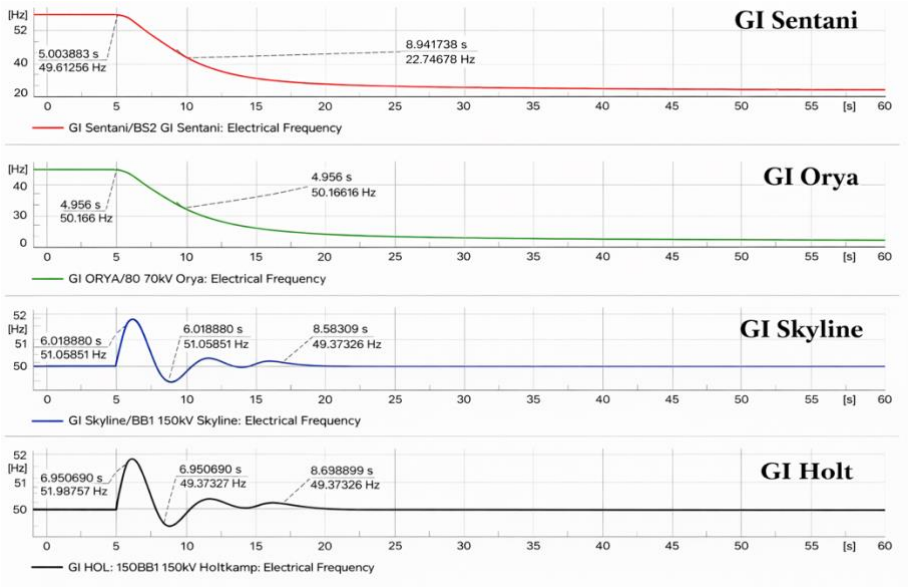


Figure 5. Frequency response for simulation scenario 2

According to the results shown in

Figure **5**, when the 70/150 kV IBT at Skyline trips, the frequency at the Sentani and Orya sites drops sharply to 23.0 Hz. This significant decline indicates that the system in these areas cannot withstand the disturbance and enters a total blackout state. In contrast, the Holtekam site and the 150 kV network at Skyline experience a frequency rise to 51.85 Hz, followed by a decrease to 49.37 Hz, before returning to a stable value of approximately 50.02 Hz. This response pattern shows that the Holtekam and Skyline 150 kV areas remain operational despite the major disturbance affecting the IBT.

Scenario 3 simulates a disturbance involving the tripping of the 70 kV Orya–Skyline and Sentani–Skyline transmission lines (see Figure 3c). This event cuts off 20.1 MW of power flow to the Sentani and Orya substations. Consequently, both sites experience a power deficit, receiving supply solely from the 8 MW Orya hydropower plant. This condition creates a mismatch between generation and load, which threatens system stability.

Based on the simulation results in Figure 6, the frequency at the Sentani and Orya sites drops drastically to 40.48 Hz when the 70 kV Orya–Skyline and Sentani–Skyline lines trip. This sharp decrease confirms that both areas fail to maintain stability and undergo a total blackout. Meanwhile, the Holtekam and Skyline sites experience a temporary frequency rise to 51.2 Hz, followed by a decline to 49.5 Hz, before stabilizing at around 50.00 Hz. This pattern suggests that the Holtekam and Skyline 150 kV systems can withstand the disturbance without experiencing total shutdown.

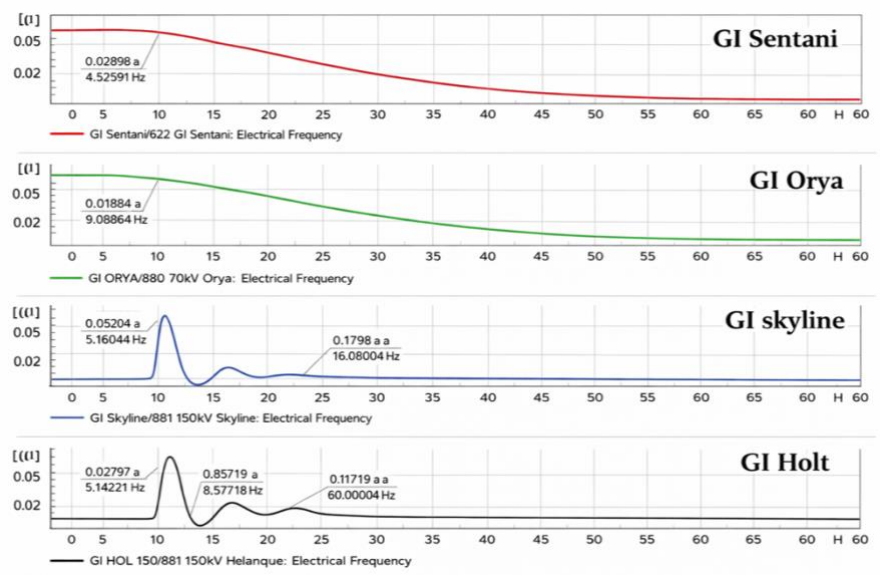


Figure 6. Frequency response for simulation scenario 3

In Scenario 4, which involves the tripping of the 70 kV Orya–Skyline and Orya–Sentani transmission lines, the frequency response at the Orya Substation (green line) shows a substantial surge, reaching 55.56 Hz. This surge reflects a surplus of generation caused by the separation of the Orya site from the larger network, leaving the Orya hydropower plant's active power output unmatched by local load. After the initial spike, the frequency gradually decreases to 52.2611 Hz. Given that the permissible operating frequency range of 51.5 Hz < f ≤ 52.0 Hz is limited to a maximum duration of 15 minutes, the system cannot be maintained under these conditions. At the Sentani, Skyline, and Holtekam substations, the initial disturbance causes a decrease in frequency to approximately 49.65 Hz, which then recovers and stabilizes in the range of 49.99–50.00 Hz (see Figure 7).

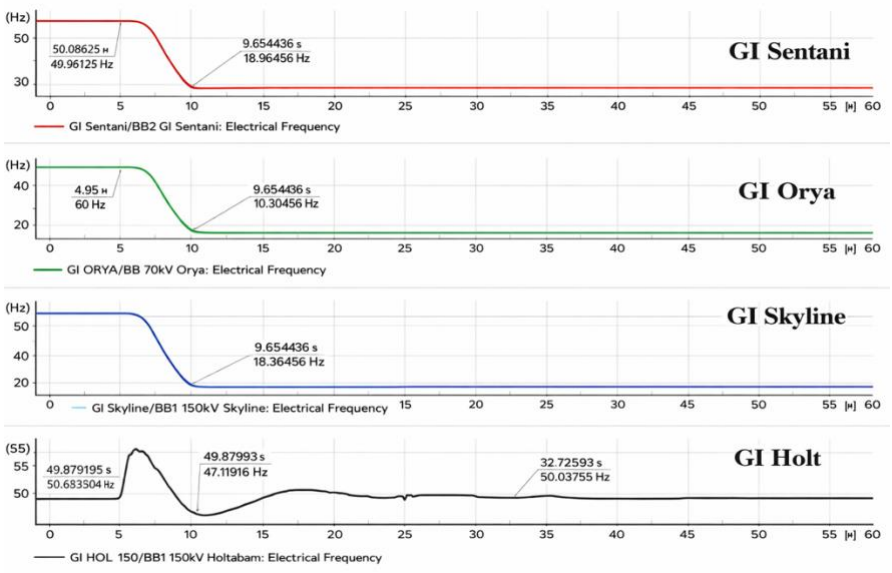


Figure 7. Frequency response for simulation scenario 4

Table **1** shown the summary of simulation scenario 1 – 4 results before applying the PLTA Orya Islanding defense scheme.

Table 1. Summary of simulation results before applying the PLTA Orya Islanding defense scheme

No	Substation	Simulation 1				Simulation 2				Simulation 3				Simulation 4			
		f (Hz)	HV (kV)	LV (kV)	Status	f (Hz)	HV (kV)	LV (kV)	Status	f (Hz)	HV (kV)	LV (kV)	Status	f (Hz)	HV (kV)	LV (kV)	Status
1	Holtekam 150 kV	50.03	153.7	73.1	Stable	50.02	153.5	73.0	Stable	50.01	153.0	72.7	Stable	49.99	152.2	72.3	Stable
2	Holtekam 70 kV	50.03	73.1	20.8	—	50.02	73.0	20.8	—	50.01	72.7	20.8	—	49.99	72.3	20.6	—
3	Skyline 150 kV	0	0	0	Blackout	50.02	152.6	20.6	—	50.01	151.9	20.5	—	49.99	150.8	20.3	—
4	Skyline 70 kV	0	0	0	—	0	0	0	Blackout	50.01	72.2	20.5	—	49.99	71.1	20.2	—
5	Sentani 70 kV	0	0	0	—	0	0	0	—	0	0	0	Blackout	49.99	70.2	20.4	—
6	Orya 70 kV	0	0	0	—	0	0	0	—	0	0	0	—	52.26	73.2	21.1	Blackout

3.3. System Strength Index of the Jayapura Grid

The System Strength Index (SSI) is an assessment parameter used to determine the system's tolerance limits when subjected to disturbances. From the 2024 data, a relationship was obtained between the loss of power supply from the tripped-out plant and the decrease in frequency (df/dt) as shown in Figure 8. This relationship is then solved using linear regression equations.

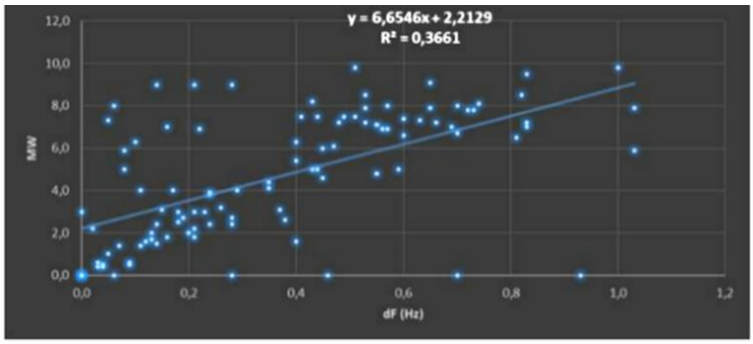


Figure 8. System Strength Index of the Jayapura grid

The SSI is formulated based on a compilation of generator disturbances occurring within a given period that result in frequency decline. The allowable frequency drop is limited to approximately 0.5 Hz from the nominal frequency (Bae, Kim and Kim, 2017; Bashir *et al.*, 2021). Based on Figure 8, the system strength index for the Jayapura grid is expressed as y = 2.2 + 6.6x. For a frequency drop of 1 Hz (x = 1), the corresponding system strength index is 8.8 MW/Hz.

3.4. Frequency and Voltage Operating Standards for the Power System

According to the Ministry of Energy and Mineral Resources Regulation (Yulianto *et al.*, 2019; Ginting, Bekti and Utami, 2023), the power system (Grid Code) for Nusa Tenggara, Maluku, and Papua must operate within the frequency limits presented in Table 2 and the voltage variation limits shown in Table 3.

3.5. Determination of Load-Shedding Requirements

Load shedding is an emergency action taken to maintain power system stability when available generation is insufficient to meet demand. The required magnitude of load shedding is determined from the difference between available generation and the load that must be supplied.

Table 2. Frequency operating limits

Frequency Range	Allowable Operating Duration
51.5 Hz < f ≤ 52.0 Hz	Minimum 15 minutes
51.0 Hz < f ≤ 51.5 Hz	Minimum 90 minutes
49.0 Hz ≤ f ≤ 51.0 Hz	Continuous operation
47.5 Hz < f < 49.0 Hz	Minimum 90 minutes
47.0 Hz < f ≤ 47.5 Hz	Minimum 6 seconds

Table 3. Voltage variation limits

Nominal Voltage	Normal Condition
150 kV	+10%, –10%
66 kV	+10%, –10%

The load-shedding calculation follows the equation (Pradnya, Arjana and Wijaya, 2016; Premnath and Sofroniou, 2025):

$$\sum P_{LS} > (\Delta P_G - SR) + (\Delta P_G - K \cdot \Delta f_{ss}) \quad (2)$$

where $\sum P_{LS}$ is Load to be shed (MW); ΔP_G is Generator outage (MW); K is System Strength Index (MW/Hz); Δf_{ss} is post-shedding frequency deviation from nominal (Hz); and SR is Spinning reserve (MW). From equation (2), the following values are used $\Delta P_G = 18.37$MW (loss of power flow to Sentani and Orya substations); $SR = 0.524$MW (difference between installed and available PLTA capacity); $K = 8.8$ MW/Hz (Jayapura SSI) and $\Delta f_{ss} = 50 - 47.5 = 2.5$Hz, so $\sum P_{LS} > 14.2$ MW. Therefore, more than 14.2 MW of load must be shed.

Table 4. Feeders at Sentani and Orya substations

No	Substation	Feeder	Load (MW)	Remarks
1	Orya	Genyem	2.57	
2		Taja	0.52	
3		Weir	0.24	
4	Sentani	Cempaka	1.83	Target
5		Rambutan	3.64	Target
6		Inter 6	6.76	Target
7		Inter 7	5.64	Target
8		Jeruk	2.02	Target
9		Int4 Sentani	4.02	
Total			27.21	

Based on Table 4 these feeder data, the feeders selected as load-shedding targets are Rambutan, Inter 6, Inter 7, Cempaka, and Jeruk, with a combined load of 19.89 MW. This value satisfies the requirement, as it exceeds the calculated minimum shedding value of 14.2 MW.

3.6. Simulation of the Defence Scheme (PLTA Orya Islanding Configuration)

After determining the required load-shedding magnitude, the next step is to simulate the islanding scheme at PLTA Orya. The simulation aims to examine the system's active power, frequency, and voltage response when the PLTA Orya islanding scheme operates (see Figure 9).

The simulation focuses on the outage of the 70 kV Orya–Skyline and Sentani–Skyline transmission lines, as this scenario is representative of the other disturbance cases.

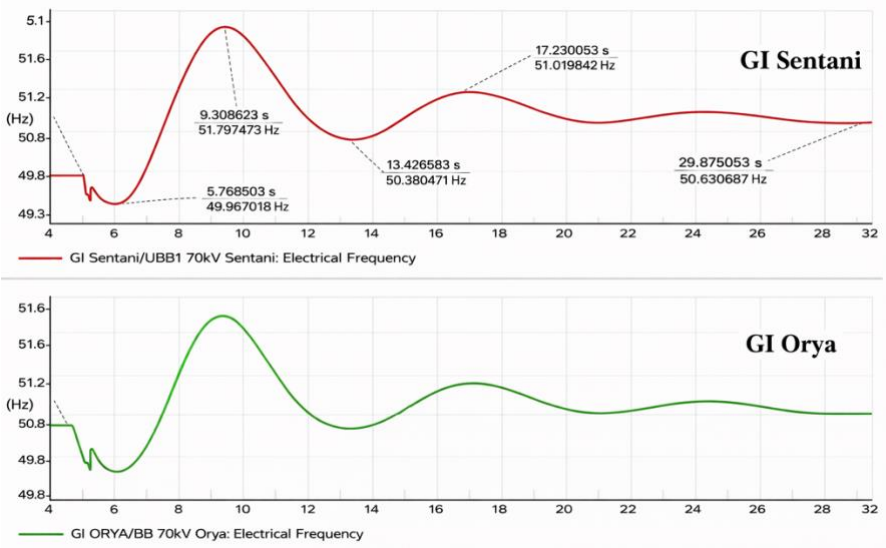


Figure 9. Frequency response under the PLTA Orya islanding defence scheme

When the power supply to Sentani and Orya substations is interrupted, frequency at both sites drops to 49.67 Hz. As shown in Figure 8, frequency then rises to 51.78 Hz due to the shedding of 19.89 MW of load involving the Rambutan, Inter 6, Inter 7, Jeruk, and Cempaka feeders.

PLTA Orya adjusts its active power output in response to these frequency changes, as illustrated in Figure 10. This adjustment enables the system to restore frequency to its nominal value of 50.0 Hz. The results indicate that the system remains stable and the islanding defence scheme operates effectively as intended.

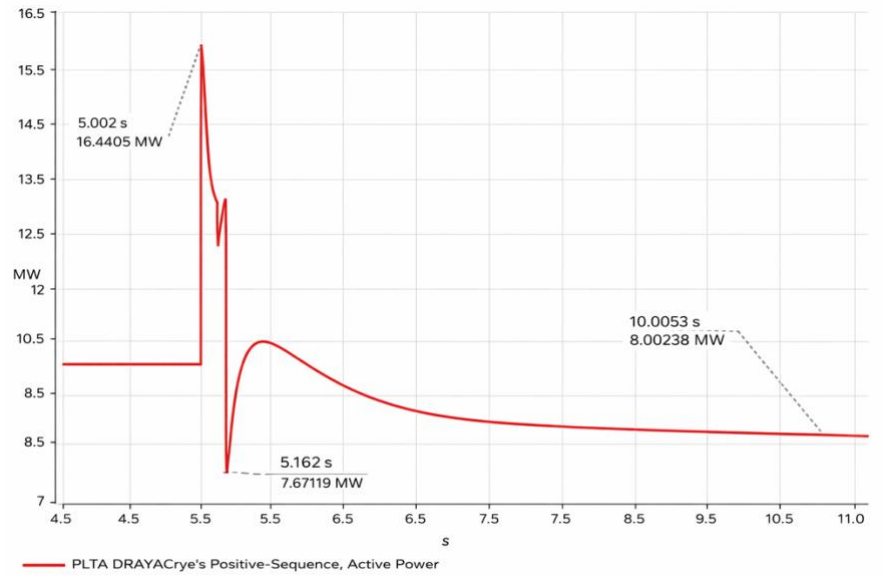


Figure 10. Active power response of PLTA Orya

In general, the voltage response at the Sentani and Orya substations shows brief deviations at both 70 kV and 20 kV levels (see Figure 11). However, all voltage values remain within the acceptable ±5% range of 1 p.u. The simulation results for the PLTA Orya islanding defense scheme are summarized in Table 5.

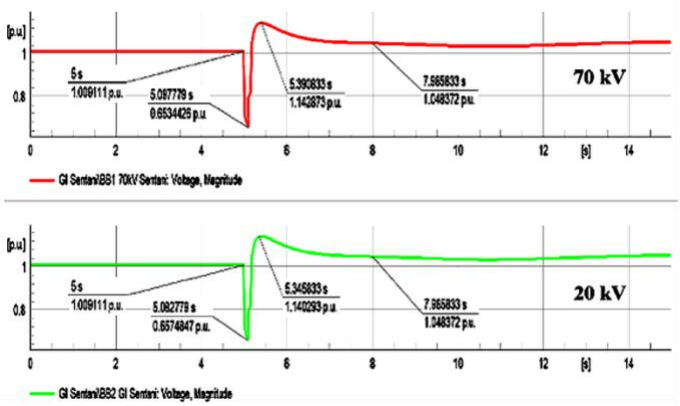


Figure 11. Voltage response at Sentani substation

Table 5. Summary of simulation results for the PLTA Orya islanding defence scheme

No	Substation	f (Hz)	HV (kV)	LV (kV)	Status	Notes
1	Holtekam 150 kV	49.99	153	72.8	Stable	Holtekam Island
2	Holtekam 70 kV	49.99	72.8	20.8		
3	Skyline 150 kV	49.99	151.9	20.5		
4	Skyline 70 kV	49.99	72.2	20.5		
5	Sentani 70 kV	50.15	73.3	21.5	Stable	PLTA Orya Island
6	Orya 70 kV	50.15	73.9	21.3		

4. CONCLUSION

Through this study, the effectiveness of the defense scheme applied to the Jayapura interconnected power system—combining two protection strategies, namely load shedding and controlled islanding—was evaluated. The assessment was carried out across four stages of disturbance scenarios, beginning with load-shedding actions (Scenarios 1 to 3) and concluding with a combined load-shedding and islanding configuration (Scenario 4). Based on the simulation results and the analysis of the PLTA Orya islanding defense scheme, maintaining system stability at the nominal frequency of 50 Hz and voltage within ±5% following a major disturbance requires shedding a total of 19.89 MW from the Rambutan, Inter 6, Inter 7, Cempaka, and Jeruk feeders. The cost implications associated with implementing this defense scheme under the various scenarios—particularly when considering future system-interconnection expansions or the revitalization of PLTA Orya's available capacity to match its installed rating—represent an important area for further investigation.

ACKNOWLEDGMENTS

The authors express their appreciation to the Load Dispatch Center (UP3B) of PT PLN UIW Papua and West Papua for providing the necessary data.

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