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TRANSIENT FREQUENCY STABILITY ASSESSMENT OF THE INTERCONNECTED SOUTH SULAWESI POWER NETWORK

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ABSTRACT: The power system consists of interconnected generation, transmission, and load centres, forming a complex electrical network called a grid. One of the significant challenges in power systems is ensuring stability—the system's ability to return to regular or stable operation (steady state) after experiencing significant disturbances such as generation loss, switching operations, sudden load changes, or faults like short circuits. Transient analysis plays a crucial role in determining the appropriate relay operation scheme, critical disconnection time for circuit breakers, and the transfer capability between systems, all of which must be optimised to maintain stability. This study simulates and analyses the frequency transient stability to assess system reliability during disturbances of the 150 kV South Sulawesi interconnected system. The study also determines the Critical Clearing Time (CCT) necessary to achieve the stable conditions of the interconnected system. The simulation is tested on the South Sulawesi interconnected system. The analysis results show frequency drops of about 0.0397% at GI Bantaeng and 0.0401% at the GI Punagaya bus, PLTU Jeneponto 1, and PLTU Jeneponto 2.

Keywords: interconnected system, frequency stability, critical clearing time, south Sulawesi network.

1. Introduction

The interconnection system consists of multiple power generation centres and substations (GIs), all interconnected through transmission lines to serve the loads across the distribution network [1]. These interconnected power grids significantly enhance the reliability and consistency of electricity generation. By sharing power generation between grids, load demands can be met even during disturbances, improving consistency and effective peak load sharing, two of the most crucial advantages of interconnected systems [2].

Power system stability refers to the system's ability to return to its normal (steady state) operating state after experiencing significant load switching or disturbances. To be considered stable, these disturbances must be minimised and harmonised within a specific timeframe [3]. Power quality issues are closely tied to stability, with transient stability being a key component [4]. Transient stability concerns sudden, significant disturbances—such as short circuits, transmission line trips, and sudden disconnections of loads or generators—that can impact generator performance [5][6].

Frequency stability, on the other hand, refers to a power system's capability to maintain a stable frequency during and after a disturbance, typically caused by significant changes in generation or load [7][8]. Maintaining a constant frequency in an AC power system, generally 50 Hz or 60 Hz, depending on the region, is critical for synchronising generators and loads and avoiding frequency deviations that can lead to instability, tripping, or load loss. Devices such as regulators, automatic generation controls, frequency relays, and energy storage systems are employed to achieve frequency regulation [9]. These devices adjust the power output of generators or loads by modifying speed, fuel supply, or load demand [10]. Load shedding will impact frequency and voltage changes in large systems [11]. According to the Sulawesi Grid Code standards as stipulated in the regulation of Permen ESDM No. 20 of 2020 [12], frequency drops and over-frequency events, or any frequency fluctuations in the system, must be maintained within the specified variation limits during disturbances as follows:

Table 1 Frequency variation range limit

Range Frequency	Limit Operating Time
51,50 Hz < f ≤ 52.50 Hz	Operates for at least 15 minutes
51,00 Hz < f ≤ 51,50 Hz	Operate for at least 90 minutes.
49,00 Hz ≤ f ≤ 51,00 Hz	Operates continuously
47,50 Hz < f < 49,00 Hz	Operate for at least 90 minutes
47,00 Hz < f ≤ 47,50 Hz	Operate for at least 6 seconds

Given the large number of generators and loads outlined in the Sulawesi transmission system development plan (RUPTL 2021–2030), coupled with transient stability issues in the South Sulawesi interconnection system, this study conducts a frequency transient stability analysis to assess system reliability during disturbances.

The interconnection system of Sulbangsel is considered in this case study since the system is integrated with renewable energy sources such as Sidrap and Jeneponte Wind power plant with a total installed capacity of about 142 MW. The operations of the Sidrap and Jeneponto wind power plants depend on the weather conditions, which will impact the system's daily stability. Based on the data of the existing interconnection system of South Sulawesi (Sulbangsel) in 2021, the total installed capacity of the generation is about 864.53 MW from the PLN and 1494.2 MW from the IPP (Independent Power Producer. Analysis for this system will perform the condition with the scenario mentioned in the case study.

The ETAP software simulates and analyzes transient disturbances. It offers an efficient means of modelling the single-line diagram of the South Sulawesi interconnected electrical system and evaluating the impact of transient stability on the system's performance.

2. Research Methods

Before conducting simulations and analysis, a transparent methodology must be established, detailing what will be simulated and how the results will be interpreted using data from the 150 kV South Sulawesi system network. This data comprises the system's generation, load, and line information. A power flow study (load flow analysis) is performed during the initial state using ETAP software to verify whether the system operates under normal or abnormal conditions. Following this, the case study for transient analysis is determined, and the system is simulated under transient disturbance conditions, including generator release and line release scenarios. The results of these transient simulations are used to analyse the frequency response to these disturbances, observing whether the system returns to stability within a set time frame based on the relevant standards. If the system is unstable, the time required for the circuit breaker (CB) to trip and stabilise the system, referred to as the Critical Clearing Time (CCT), will be evaluated.

2.1 Case Study

The single line diagram in Figure 1 depicts the interconnection of the 150 kV South Sulawesi electricity system used for transient frequency stability analysis. As of 2021, the 150 kV South Sulawesi transmission system comprises six generating units with a combined capacity of 975.263 MW. Transient stability simulations will be performed following the modelling and simplification of the 150 kV South Sulawesi electricity system in 2021.

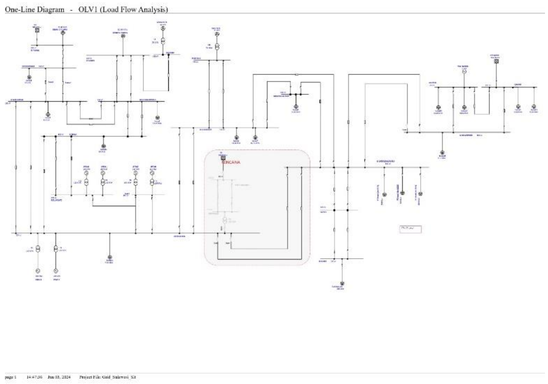

Figure 1. Electricity system 150 kV South Sulawesi.

The simulations in this paper will cover several scenarios, including generator trips and line losses, with the case studies described below.

Table 2. Transient Stability Case Study

Case	Case Description	Action	Power
1	Generator JPTO#4 trip	JPTO#4 *delete*	125 MW
2a	Trip one of the double-circuit lines	CB 10 open (GI Bulukumba-GI Bantaeng Switch line)	-
2b	Trip one of the double-circuit lines	CB 20 open (GI Jeneponto-GI Bantaeng New line)	-
3a	Double trip of the circuit line	CB 33 & 36 open (GI Talasa- PLTU Jeneponto line)	-
3b	Double trip of the circuit line	CB 80 & 81 open between (GI Punagaya - PLTU Jeneponto line)	-

3. Result and Discussion

3.1 *Case 1 Jeneponto generator unit 4 Off*

In this scenario, the system will experience a loss of power from the JPTO#4 generator, which has a capacity of 125 MW. This represents 12% of the total generation capacity of 975.263 MW in South Sulawesi. The frequency impact analysis is shown below:

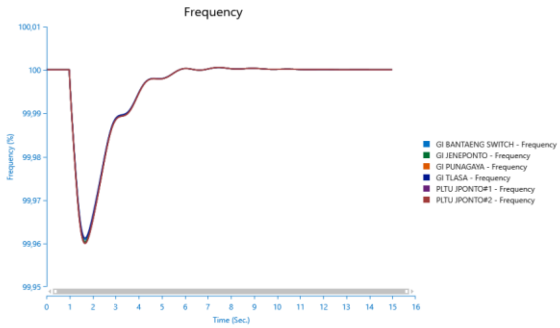

Figure 2. Frequency response when JPTO#4 generator trip

In this case, the focus is on the swing operation of the Jeneponto Unit 4 generator trip, which has been disengaged. Figure 2 demonstrates that the frequency remains within permissible limits after the largest generator is removed. During the disturbance, the frequency at the GI Bantaeng Switch, GI Jeneponto, and GI Talasa buses drops to 49.98 Hz, reflecting a 0.0397% decrease. In contrast, at the GI Punagaya bus, PLTU Jeneponto Unit 1, and PLTU Jeneponto Unit 2, it drops to 49.97 Hz, or 0.0401%. The frequency then gradually recovers to a steady state. As per the Sulawesi Grid Code standard, the system frequency is acceptable. The dip to 49.98 Hz is due to a loss of 62.5 MW of active power, causing a temporary drop, but the system stabilises shortly thereafter.

3.2 *Case 2 Single Circuit Tripping Disturbance on Double Circuit Interconnected Transmission Line (t=2s)*

A. *CB 10 open towards substation with large load*

When the circuit line between the GI Jeneponto bus and GI Bantaeng bus New CB 20 is disconnected with a high-capacity load, the focus is on the nearby buses affected by the disturbance: GI Bantaeng New, GI Bantaeng Switch, and GI Jeneponto. As shown in Figure 3, all frequency values at these buses increase by 0.0004% following the release of the CB on the double-circuit line, remaining within permissible frequency limits. During a brief disturbance, the frequency fluctuates slightly for GI Bantaeng New, GI Bantaeng Switch, and GI Jeneponto, but the oscillation diminishes and eventually stabilizes at 50.02 Hz. According to the Sulawesi Grid Code, the system frequency remains within a safe range.

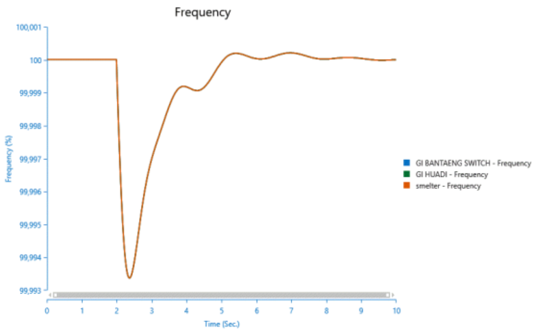

Figure 3. Frequency response when CB between bus 10 Bulukumba- bus GI Bantaeng Switch lines trips.

B. *CB 20 open towards substation with a small load*

When the circuit line between the GI Jeneponto bus and the GI Bantaeng New bus CB 20 is disconnected with a small capacity load, the primary parameters observed are at the nearest buses to the disturbance: GI Bantaeng New, GI Bantaeng Switch, and GI Jeneponto. As shown in Figure 4, the frequency values at these buses increase by 0.0004% due to the release of the CB on the double-circuit line, remaining within the acceptable frequency limits. During a brief disturbance, the frequency at GI Bantaeng New, GI Bantaeng Switch, and GI Jeneponto fluctuates slightly, but the oscillation decreases, stabilising at a steady frequency of 50.02 Hz. According to the Sulawesi Grid Code standard, the system frequency remains within a safe range.

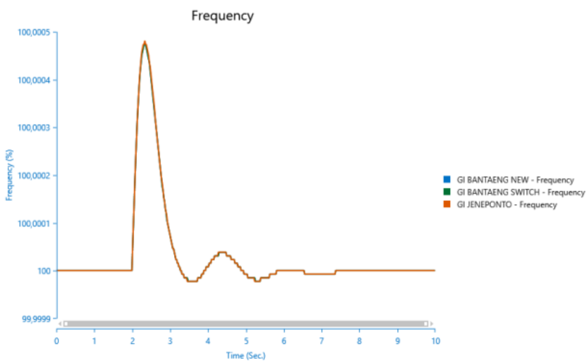

Figure 4 Frequency response when CB 20 between bus GI Jeneponto-bus GI Bantaeng New lines trip.

When the circuit line between GI Jeneponto bus - GI Bantaeng New bus CB 20 is released with a small capacity load.

In this case, the parameters seen are the closest buses to the disturbance, namely GI Bantaeng New, GI Bantaeng Switch, and GI Jeneponto. It can be seen in Figure 4 that all frequency values at the bus above have increased by 0.0004% due to the release of the CB on the double-circuit line still within the allowable frequency limits. And when there is a momentary disturbance, there is a frequency fluctuation for the GI Bantaeng New bus, GI Bantaeng Switch, and GI Jeneponto whose value is not too large then the oscillation decreases until it reaches a steady state at a frequency of 50.02 Hz each. Based on the Sulawesi Grid Code standard, the system frequency is still in a safe range.

3.3 *Case 3 Fault Double-Circuit Tripping of Interconnection Transmission Line (t = 2s)*

A. CB opens towards a generator with a large load

When the double-circuit line between the GI Talasa bus and PLTU Jeneponto Unit 1 CB 33 & 36 is disconnected with a large capacity load, the nearest buses affected by the disturbance are GI Punagaya, GI Talasa, and PLTU Jeneponto Units 1 and 2. As shown in Figure 5, the frequency decreases by 0.0004% due to the release of the CB on the double-circuit line, still within the allowable frequency limits. During the disturbance, frequency fluctuations occur at GI Punagaya, GI Talasa, and PLTU Jeneponto Units 1 and 2. Still, these fluctuations are minimal, and the oscillations gradually decrease until reaching a steady state at 49.99 Hz. According to the Sulawesi Grid Code standard, the system frequency remains within a safe range.

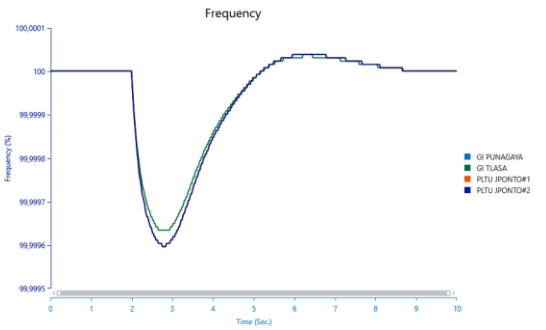

Figure 5 Frequency response when CB 33 & 36 between bus PLTU Jeneponto unit 1 & unit 2-bus GI Talasa New lines trip.

B. CB opens towards a generator with a small load

When the circuit line between PLTU Jeneponto Units 1 & 2 and GI Punagaya CB 80 & 81 is disconnected with a small capacity load, the parameters observed are the nearest buses to the disturbance: PLTU Jeneponto Units 1 & 2 (0.6%), GI Punagaya (0.3%), and GI Talasa (0.5%). As shown in Figure 6, the frequency increases due to the release of the CB on the double-circuit line, remaining within the allowable frequency limits.

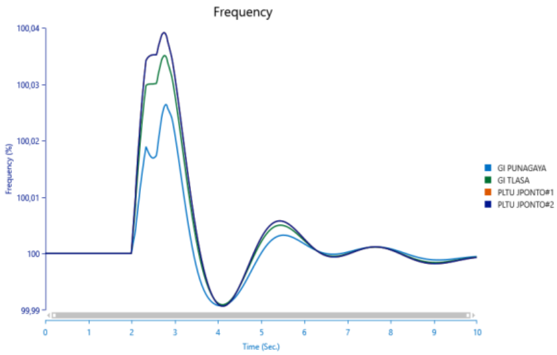

Figure 6 Frequency response when CB 80 & 81 between PLTU Jeneponto unit 1 & unit 2-GI Punagaya lines trip.

During a brief disturbance, there are minor frequency fluctuations at PLTU Jeneponto Units 1 & 2, GI Punagaya, and GI Talasa, but the oscillations decrease and stabilise at 50.02 Hz. According to the Sulawesi Grid Code, the system frequency remains within the safe range.

4. Conclusion

Based on the existing data of the South Sulawesi interconnection system and simulation analysis, the South Sulawesi system, with the three fault scenarios performed, remains stabilised, and the frequency drop is still within the range of acceptable limits, based on the grid code of the South Sulawesi System.

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