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LOAD SHEDDING ANALYSIS USING UNDER FREQUENCY RELAY (UFR) AT BOLANGI SUBSTATION USING ETAP SOFTWARE

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ABSTRACT

This study aims to analyze the performance of the load shedding system using Under Frequency Relay (UFR) at the Bolangi Substation as an effort to maintain the stability of the power system frequency. A supply disruption from Bayline Daya Baru (#2) occurred, namely a disturbance due to a lightning strike, which is an important background in this study. A decrease in frequency due to power imbalance can cause a total power outage (blackout), so a responsive UFR protection system is needed. Simulations were carried out using ETAP 19.0 software with a bayline release scenario to analyze the frequency response and effectiveness of automatic load shedding. The simulation results show that a frequency decrease of up to 48.60 Hz can be restored to 50 Hz in 2.47 seconds through gradual load shedding of 13.34 MW by UFR stages 2 and 4. This study provides an overview of the load shedding stages based on the frequency setting values and periodic UFR working times as well as the use of ETAP for continuous evaluation of the protection system at the substation.

Keywords: Bolangi Substation, Frequency, Load Shedding, Protection System, Under Frequency Relay (UFR)

1. Introduction

Electricity is a vital necessity that directly improves the quality of human life through lighting, communication, and various daily services. The electric power system consists of generation, transmission, distribution, and protection, which function to maintain a reliable energy supply. PT PLN (Persero), as the main electricity provider in Indonesia, is required to ensure the quality and continuity of supply to ensure consumer needs are met sustainably. As population and economic growth grow, demand for electrical energy increases, necessitating a reliable power system capable of maintaining a balance between demand and supply.

One important aspect in maintaining the stability of the electric power system is frequency. An imbalance between generated power and load power can cause a decrease or increase in frequency, which if not immediately addressed can result in a blackout.[1]. To maintain stability, the provision of active power must be adjusted to customer needs.[2]. A decrease in frequency occurs when the generated power is less than the load requirements, whereas if the generated power exceeds the load, the frequency will increase.[3]. This imbalance can pose a risk of total blackouts that are detrimental to both providers and consumers, so protective measures are needed in the form of load shedding by utilizing Under Frequency Relays (UFR).[1].

The Bolangi Substation in Gowa Regency, South Sulawesi, is a critical substation supplying electricity to hospitals, industries, and businesses. It receives 150 kV from Bayline Daya Baru #1 and #2 through a 60 MVA transformer that feeds the energy into a 20 kV distribution network with nine feeders. However, external disturbances such as lightning strikes often impact the reliability of electricity distribution and can potentially trigger automatic outages. Therefore, installing a UFR on the secondary side of the transformer is a crucial strategy, enabling rapid detection of frequency drops, maintaining system stability, and preventing blackouts.

2. Methods

2.1 Type of Research

This research is a quantitative descriptive study. It aims to describe the load shedding system at the Bolangi Substation and analyze the role and regulation of the Under Frequency Relay (UFR) in maintaining frequency stability.

2.2 Research Procedures

The research procedure involved collecting electrical system data, then simulating load shedding using an Under Frequency Relay (UFR) using ETAP. Several load shedding scenarios were tested to analyze the system's response to low-frequency disturbances, and the results were analyzed to assess the effectiveness of the UFR in maintaining system stability.

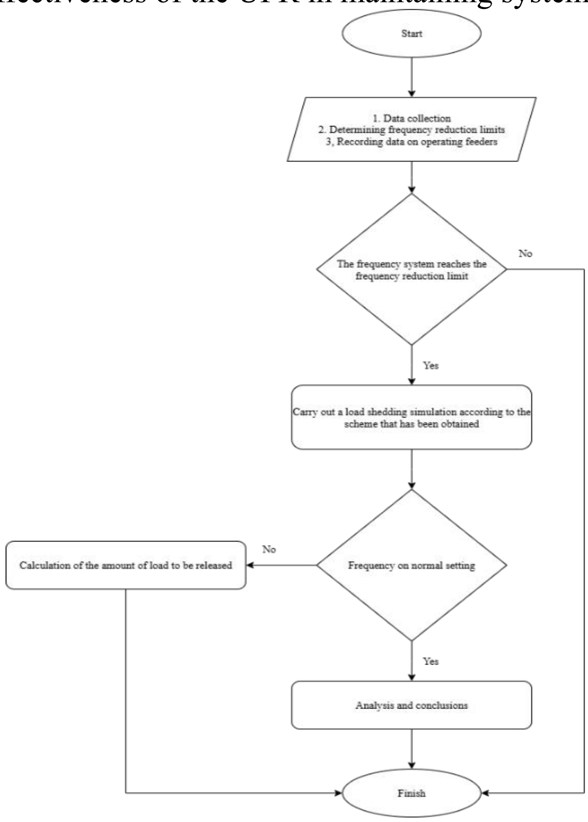

Figure 1. Research Procedure

2.3 Data Collection Techniques

This study collected data through documentation, observation, and interviews, namely by reviewing load data and load shedding frequency, observing field conditions at the Bolangi Substation, and interviewing supervisors to compare the results of the ETAP simulation with real conditions at the Bolangi Substation.

2.4 Data Analysis Techniques

The data analysis technique used in this study was conducted using technical data from the Bolangi Substation, such as system load and frequency values, and then simulating a frequency reduction scenario. The simulation analyzed how the UFR performs automatic load shedding and its impact on frequency stability. The simulation results were evaluated to assess the effectiveness of the UFR.

3. Results and Discussion

3.1 Results

Table 1. Load Data Each Feeder

No	*Feeder*	Load		
		MVA	MW	MVAR
1	Padi Valley	1,05	1,03	0,21
2	Bontomanai	1,32	1,26	0,39
3	SPMA	3,78	3,67	0,88
4	Yapika	1,58	1,53	0,36
5	Royal	2,51	2,48	0,37
6	Moncongloe	1,98	1,97	0,22
7	Paccelekang	3,58	3,4	1,13
8	Biringbilayya	3,89	3,82	0,71
9	Chengho	1,45	1,4	0,39
10	Samata	6,29	6,12	1,47
	Total	**27,43**	**26,68**	**6,13**

Table 1 presents the load data for each feeder used in this study at peak load time at the Bolangi Substation at 17.00 in April 2025.

Table 2. Total Power per Bayline

Load MW		Load MVar	
New Power (#1)	New Power (#2)	New Power (#1)	New Power (#2)
14,18	13,94	5,59	5,72

Table 2 shows the total power distributed by the Daya Baru bayline (#1) and the Daya Bar bayline (#2) at peak load time at 17.00 in April 2025.

Table 3. Important loads at Bolangi Substation

No	*Feeder*	Reason
1	Bontomanai	Mayora (Industry)
2	Padi Valley	Business
3	Yapika	Hospital

Table 3 shows that the Bolangi Substation has several priority customers served at the GI, so this grouping helps with protection planning.

a) Load Shedding Scheme

The load shedding mechanism is divided into seven stages as defined in the South Sulawesi power system.

1. Stage 1 = Frequency 49.20 Hz
2. Stage 2 = Frequency 49.00 Hz
3. Stage 3 = Frequency 48.80 Hz
4. Stage 4 = Frequency 48.60 Hz
5. Stage 5 = Frequency 48.50 Hz
6. Stage 6 = Frequency 48.40 Hz
7. Stage 7 = Frequency 48.30 Hz

Table 4. UFR Load Shedding Scheme of Bolangi Substation

<table>
<tr><th>Stage</th><th>Frequency (Hz)</th><th>Feeder Released</th><th>Load (MW)</th><th>Power Flow Results (MW)</th></tr>
<tr><td>2</td><td>49,00</td><td>Paccelekang</td><td>3,40</td><td>3,26</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">48,60</td><td>Biring Bilayya</td><td>3,82</td><td>3,67</td></tr>
<tr><td>Samata</td><td>6,12</td><td>5,87</td></tr>
<tr><td colspan="3">Total</td><td>13,34</td><td>12,80</td></tr>
</table>

b) Load Shedding Simulation Results

Table 5. Power Flow Results in the Electric Power System

Information	Power Flow Results
Beban MW	25,64
Beban Mvar	5,88
Daya MW	25,67
Daya Mvar	7,37
Rugi-rugi MW	0,034
Rugi-rugi Mvar	1,49

Table 5 presents the results of power flow simulation in the electric power system using ETAP 19.0.1 software.

Table 6. Power Flow Results for Each Feeder

No	Feeder	Load		
		MVA	**MW**	**MVAR**
1	Padi Valley	1,0	0.98	0,20
2	Bontomanai	1,26	1,21	0,37
3	SPMA	3,63	3,52	0,84
4	Yapika	1,51	1,47	0,34
5	Royal	2,41	2,38	0,35
6	Moncongloe	1,90	1,89	0,21
7	Paccelekang	3,44	3,26	1,08
8	Biringbilayya	3,73	3,67	0,68
9	Chengho	1,39	1,34	0,37
10	Samata	6,04	5,87	1,41
Total		**26,31**	**25,59**	**5,85**

Table 6 presents the results of the power flow simulation for each feeder in the ETAP 19.0.1 software.

Table 7. Duration of Frequency Decrease

Frequency Decrease (Hz)	Duration (s)
50,00 – 49,00	0 – 0,011
49,00 – 48,60	0,011 – 0,015

Table 7 shows the duration of the frequency decrease due to the disturbance that occurred, namely the release of the new power bayline (#2) resulting in an increase in load demand because the supply from the new power bayline (#1) cannot meet the required load demand, so that the frequency decreases over time until it reaches 48.60 Hz due to the large amount of power required compared to the available power. The lowest frequency decrease occurs at a frequency of 48.60 Hz at 0.015 seconds. Therefore, load shedding must be carried out to return to the normal frequency of 50 Hz

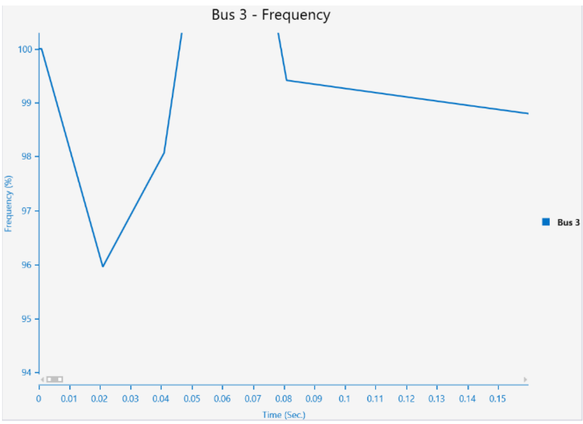

Figure 1. Frequency Response of the New Power Bayline Bus Release

Table 8. Frequency of Load Shedding Stages

Phase	UFR Trip (Hz)	UFR Trip (%)
2	49	98
4	48,6	97,2

Table 8 presents the trip percentages in stages 2 and 4.

Action Summary

Event ID	Time (Sec.)	Device Type	Device ID	Action
Freq. Relay	0.821	Protective Device	CB6	Open
Freq. Relay	1.212	Protective Device	CB1	Open
Freq. Relay	1.212	Protective Device	CB3	Open

Figure 2. Load Shedding Action List

When the frequency reaches 49.00 Hz at 0.011 seconds, UFR stage 2 works by ordering CB 6 to release the load on the Paccelekang feeder at 0.821 seconds. After carrying out the load release stage 2, the frequency has not returned to normal. The frequency decreases to 48.60 Hz at 0.015 seconds, so that UFR stage 4 orders CB 1 and CB 3 to release the load on the Samata feeder and Biringbilayya feeder at 1.212 seconds. The working time of the frequency relay is not always constant and is highly dependent on the transient conditions of the system [4].

Table 9. Frequency Recovery Duration

Pemulihan Frekuensi (Hz)	Durasi (s)
48,60 – 49,00	1,32 – 2,12
49,00 – 50,00	2,12 – 3,79

Table 9 shows the frequency recovery duration after load shedding due to a disturbance, namely the release of the new power bayline (#2).

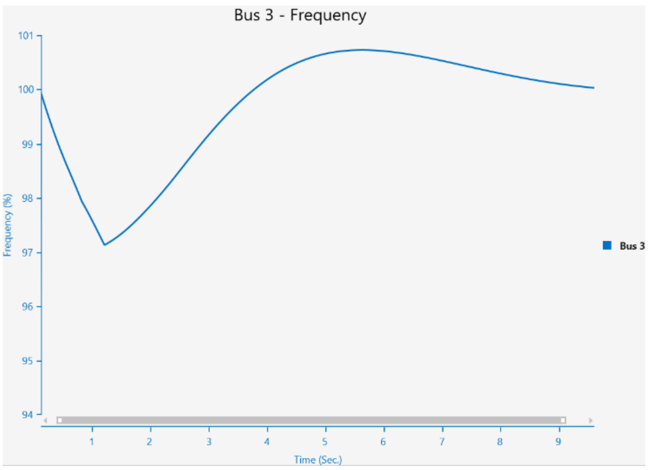

Figure 3. Bus Frequency Response During Load Shedding

Figure 3 shows that after the load shedding by UFR stages 2 and 4, the frequency began to rise slowly from 48.60 Hz to 49.00 Hz within 0.8 seconds from 1.32 seconds to 2.12 seconds. Then, the frequency returned to its normal position of 50 Hz at 3.79 seconds for 2.47 seconds from 48.60 Hz to 50 Hz with a total load shed of 13.34 MW.

3.2 Discussion

The UFR (Under Frequency Relay) detects frequency drops resulting from an imbalance between generating power and load. If left unchecked, this condition can lead to a power system collapse. Simulations at the Bolangi Substation showed that when the power supply from Bayline Daya Baru (#2) was lost, the system frequency immediately dropped to 48.60 Hz. Under these conditions, the UFR operates according to its characteristics by gradually shedding the load according to the frequency settings at each stage.

The simulation results show a gradual activation, with stages 2 (49.00 Hz) and 4 (48.60 Hz) operating sequentially. This mechanism allows the system to gradually recover the frequency. In less than 4 seconds, the frequency returned to 50 Hz. This emphasizes the critical importance of setting the relay's operating time; it must be fast enough to prevent further frequency decline, but not too fast to prevent unnecessary load shedding.

Load grouping also takes priority into account, with non-critical feeders disconnected first, thus preserving critical sectors. ETAP-based simulations have proven effective in designing, testing, and verifying UFR arrangements, while ensuring protection remains relevant to changing system conditions over time.

This study specifically analyzes actual disturbances in the form of lightning strikes on Bayline Daya Baru (#2) and power deficits due to the dry season. With this approach, the study not only tests the effectiveness of Under Frequency Relay (UFR) in theoretical scenarios but also demonstrates its performance under real-world conditions that frequently occur in the field.

Furthermore, this study used ETAP 19.0 with transient stability analysis simulation, which can depict the system's dynamic response during load shedding. This provided more detailed results regarding the frequency reduction and recovery process, including the recovery duration (3.918 seconds) and the total load shed (12.2 MW). This information is more detailed than previous studies that only presented general frequency changes.

4. Conclussion

This study found that a frequency drop at the Bolangi Substation due to lightning strikes and supply deficits could be restored to 50 Hz in 3.918 seconds through gradual load shedding of 12.2 MW by the UFR. This finding confirms that proper UFR settings are crucial for maintaining power system stability and preventing blackouts. Furthermore, the implication is that UFR settings need to be adjusted to local conditions and prioritize critical loads to optimize load shedding effectiveness.

However, this study has limitations because it focused only on a single substation and one specific type of fault scenario. The results cannot be generalized to broader interconnected systems with various types of faults. Therefore, future research is recommended to encompass more complex interconnected systems, test a variety of fault scenarios, and explore the integration of UFR with smart grid technology and digital protection systems for more comprehensive and applicable results.

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