International Journal of Electrical, Energy and Power System Engineering
Vol. 07, No. 01, February 2024
e-ISSN: 2654-4644

Analysis of Under Frequency Load Shedding System

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Abstract— Load shedding is a protection scheme to maintain the stability of the electric power system. When there is an imbalance between the power generated and the load power, load shedding will release the load to restore power balance. This research aims to design and analyze the load shedding system at Private Company to see whether it is running well and meets the PRC-006-5 standard regarding the frequency operating limit, which must be in the range of 49.42 Hz to 50.58 Hz. The method that will be used in this research is to carry out testing with software and then analyze the power and frequency response due to the generator being removed from the system. The testing mechanism that will be carried out is to simulate the effect of a lack of power for the load supply on the load shedding system. From the research results, it is known that the existing load shedding scheme needs to be evaluated. Evaluation is carried out on steps 1 and 2, so that the load shedding limit for step 1 becomes 49.5 Hz and the pickup time for step 4 becomes 400 ms.

Keywords: Frequency Stability, Load Shedding, Under Frequency Load Shedding, Power Balance

INTRODUCTION

A vital entity within company sub-holdings, is dedicated to the refinement of crude oil into diverse oil and petrochemical products. In the realm of industrial operations, the significance of a reliable electrical system cannot be overstated, as it profoundly influences production quality. Ensuring the uninterrupted flow of the oil processing process is contingent upon the deployment of a robust electrical power system. The protection system employed at the refinery must exhibit both speed and precision in isolating interference, demonstrate selectivity, and maintain a high level of reliability. Moreover, the system's sensitivity is crucial for detecting interference at the smallest possible value. Recognizing this interdependence, private company prioritizes the implementation of efficient and reliable protective measures, thereby safeguarding the integrity of its oil processing operations and contributing to sustained industrial efficiency [1] [2]. The evolution of industry, the demand for electricity inevitably surges, necessitating a reliable and ample supply of electrical energy to meet escalating load requirements. Typically, power generation systems align with the rising load; however, disruptions in the electric power system can lead to imbalances between generated power and load power. These disturbances may manifest as issues like the removal of generators from

Received: November 25, 2023, Revised: January 20, 2024, Accepted: February 14, 2024
https://doi.org/10.31258/ijeepse.7.1.46-54

the system. It becomes imperative to address these challenges and ensure a stable and consistent supply of electrical energy to support the burgeoning needs of an advancing industrial landscape. Proactive measures in the power generation sector are essential to effectively managing and mitigating potential imbalances, reinforcing the resilience of the electric power system amidst growing industrial demands. [3], [4], [5]. The dependability of an electric power system is typically gauged by the stability of frequency, voltage, and the presence of ample power. Frequency serves as a key indicator reflecting the equilibrium between generated power and load. [6], [7]. A decline in frequency occurs when the generated power falls short of meeting load demands, often resulting from widespread generation loss. Failure to promptly rectify frequency deviations can lead to a complete electric power system outage, commonly known as a blackout. To avert such situations, it becomes imperative to implement load-shedding measures, strategically shedding portions of the load to restore the balance between power generation and demand and prevent the risk of system-wide failures. [8], [9]. Load shedding functions as a protective mechanism aimed at preserving the stability of the electric power system. It comes into play when there is an asymmetry between generated power and load power, releasing portions of the load to reestablish a balanced power distribution. Load-shedding processes can be executed either manually or automatically. The decision on which load to shed is contingent upon a scenario aligned with active power supply and load priority. Typically, the initial load to be shed is one with lower priority, ensuring a strategic and controlled reduction to prevent potential disruptions and maintain overall system equilibrium. [2], [3], [10], [11]. Under Frequency Load Shedding (UFLS) is a load-shedding mechanism where the load removal is structured into multiple stages. Each stage is programmed to trip when the frequency falls below a specific threshold for a predetermined duration, ensuring a systematic and controlled response to frequency deviations. [12], [13], [14]. Private company implements two Load Shedding systems with 4 load shedding steps, namely Under Frequency Load Shedding and Condition Based Load Shedding, both Load Shedding systems can run well to maintain the stability of the electric power system with the right algorithm. To see whether the Load Shedding system is running well, it can be done by carrying out a Load Shedding test and then analyzing whether the Load Shedding system can work well and can restore system stability and still meet the standards related to UFLS [15].

METHODOLOGY

A. Research Data

In Figure 3 is a single line electrical diagram at Private Company. Where there are 8 power generator units installed, namely STG1 (Steam Turbine Generator 1), STG2, STG3, STG4, STG5, DGA (Diesel Generator A), DGB, GT (Gas Turbine). The green color indicates that the generator is operating, and the yellow color indicates that the generator is not operate. In normal operations, only 5 power generating units are operated, namely 3 STG units, 1 DG unit and 1 GT unit which are then distributed to 14 substations.

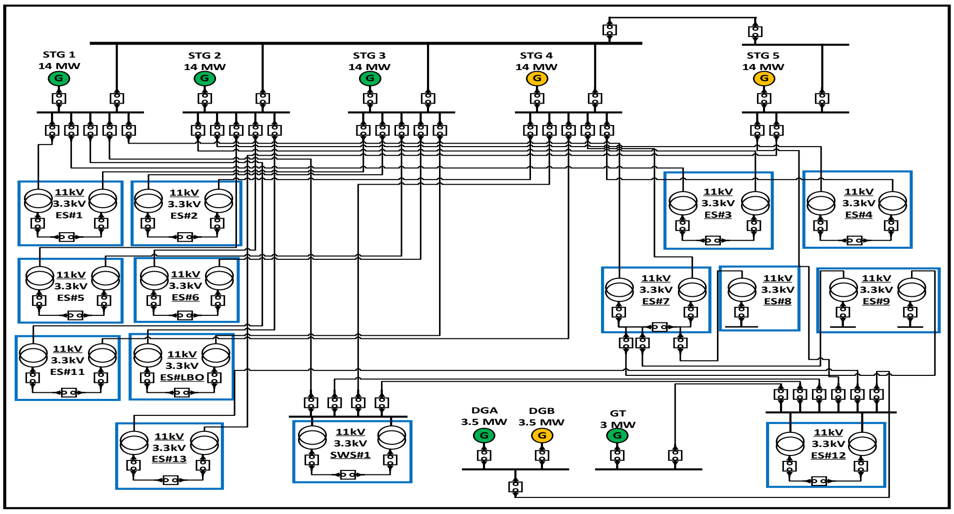

Figure 1. Electrical power system

Table 1 is the load shedding scheme at private company which consists of 4 load shedding stages. This research will carry out tests with existing schemes and then carry out analysis and evaluation of these schemes.

Table 1. Existing Load Shedding Scheme

Step	Frequency (Hz)	Generators Condition	Pick Up (ms)	Load (MW)
1	49.7	STG OFF ≥ 2	120	5.3
2	49.2		200	5.23
3	48.8		300	6.18
4	48.5		660	4.77

Table 2. Generator Condition

Scenario	Generator Condition
1	3 STG + DGA + GT
2	3 STG + DGA
3	3 STG + GT
4	3 STG
5	2 STG + DGA + GT
6	2 STG + DGA
7	2 STG + GT
8	2 STG
9	1 STG + DGA + GT
10	1 STG + DGA
11	1 STG + GT
12	1 STG
13	DGA + GT
14	DGA
15	GT
16	ALL Generator OFF

B. Experiment Scheme

The testing mechanism that will be carried out is to simulate the effect of a lack of power for the load supply on the Load Shedding system. Testing will be carried out by simulating all possible generator scenarios as in Table 2.

C. Under Frequency Load Shedding Standard

PRC-006-5 is a standard established by the North American Electric Reliability Corporation (NERC) that aims to establish design and documentation requirements for Under Frequency Load Shedding (UFLS) programs to withstand frequency degradation, assist frequency recovery after low frequency events, and provide system preservation action of last resort. The frequency must remain between steady conditions, namely between 49.42 Hz and 50.58 Hz or can be seen in Figure 3.

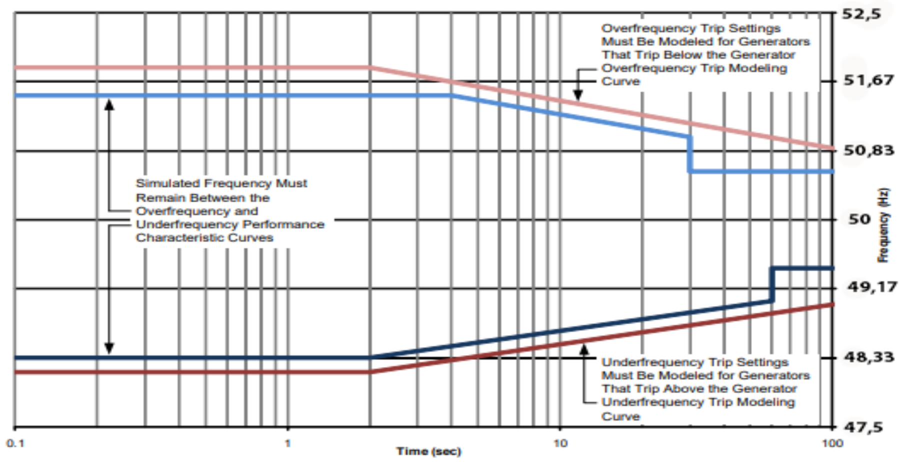

Figure 3. Performance and Modeling Curves

RESULT AND DISCUSSION

A. Testing of Existing Load Shedding Schemes

Based on the test results for all generator condition scenarios, the results obtained are as shown in the Table 3. From the test results in scenario 5, load shedding step 1 was carried out. If viewed based on power availability in scenario 5:

$$P_G = (2 \times 14) + 3{,}5 + 3$$
$$P_G = 34{,}5\ MW$$

The load that must be supplied is 34 MW, so in this condition there is no need to carry out load sheding. Furthermore, in scenario 12 the system does not meet the PRC-006-5 standard, frequencies below 47.5 Hz are only allowed for 0.1s, whereas based on the test results the frequency decrease occurs for 0.347s.

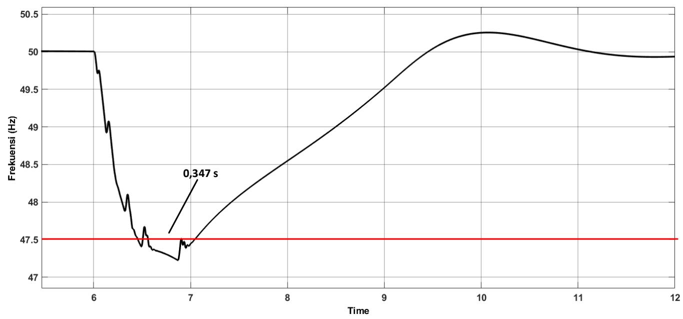

Figure 4. Frequency Response in Scenario 12

Table 3. Simulation Test Load Shedding Existing

Scenario	LF (Hz)	HF (Hz)	LS	Criteria
1	50	50	-	Yes
2	49,86	50,02	-	Yes
3	49,86	50,02	-	Yes
4	49,84	50,02	-	Yes
5	49,77	50,04	LS1	Yes
6	49,51	50,11	LS1	Yes
7	49,51	50,11	LS1	Yes
8	49,37	50,11	LS1	Yes
9	48,58	50,28	LS1, LS2, LS3	Yes
10	48,1	50,38	LS1, LS2, LS3	Yes
11	48,03	50,39	LS1, LS2, LS3	Yes
12	47,37	50,25	LS1, LS2, LS3, LS4	No
13	blackout	blackout	LS1, LS2, LS3, LS4	No
14	blackout	blackout	LS1, LS2, LS3, LS4	No
15	blackout	blackout	LS1, LS2, LS3, LS4	No
16	blackout	blackout	LS1, LS2, LS3, LS4	No

B. Evaluation of Load Shedding Schemes

From the test results, there are 2 conditions of concern, namely load shedding step 1 and step 2.

- Step 1: Load shedding

The step 1 load shedding threshold limit is 49.7 Hz with a pickup time of 0.12s, referring to the ANSI/IEEE C37.106-1987 and PRC-006-5 standards that this value is too high, so load shedding will be too sensitive, and which can cause load shedding to release the load too quickly. Determination of load shedding frequency limits must consider the permitted operating frequency limits. Considering the high stability and the standard limit, the new threshold value is 49.5 Hz.

- Step 2: Load Shedding

In scenario 12 the frequency reduction cannot be reversed quickly; it can be said that load

https://doi.org/10.31258/ijeepse.7.1.46-54

shedding step 2 cannot work properly. The step 2 load shedding threshold is 48.5 Hz with a pickup time of 0.66 s. To increase the speed of frequency recovery, this can be done by increasing the load shedding threshold or pickup time.

Referring to the ANSI/IEEE C37.106-1987 and PRC-006-5 standards, increasing the step 4 frequency threshold is not recommended because it will make the load shedding system too sensitive and can make the system not run well. So, the evaluation was carried out by reducing the pickup time. Based on testing, it was found that the ideal pickup time for this system was 0.4s. So that after the evaluation is carried out, the new load shedding setting values are as shown in the Table 4.

Table 4. New Scheme Load Shedding

Step	Frequency (Hz)	Generator Condition	Pick Up (ms)	Load (MW)
1	49.58	STG OFF ≥ 2	120	5.3
2	49.2		200	5.23
3	48.8		300	6.18
4	48.5		400	4.77

C. New Testing Load Shedding Scheme

After evaluating the load shedding parameters, better results were obtained, which can be seen in Figure 5 In the old load shedding scheme load shedding step 1 was carried out, whereas with the new load shedding scheme no load shedding was carried out and the frequency was still within the limits permitted by PRC 006-5. So, the system becomes more reliable because the load can still be supplied and the frequency is within safe limits.

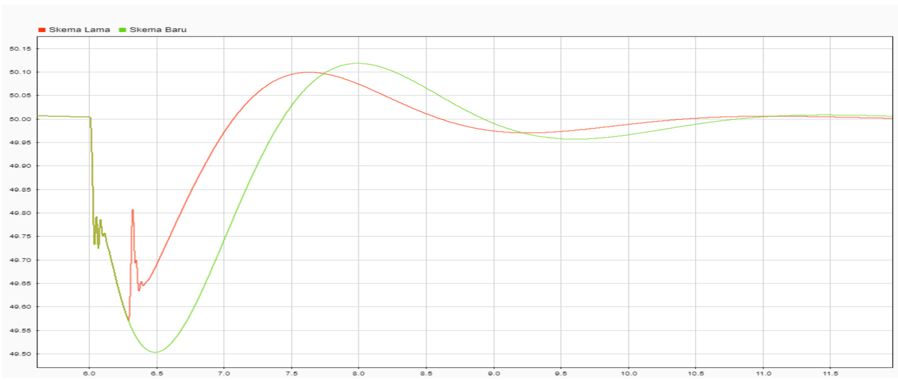

Figure 5. Frequency Response of Scenario 5 After Evaluation

Figure 6 is a comparison between the old scheme and the new load shedding scheme in case 3, scenario 4, where in the old load shedding scheme the frequency reduction does not meet the PRC-006-5 standard, whereas with the new scheme the frequency reduction can be within the limits permitted by PRC- 006-5.

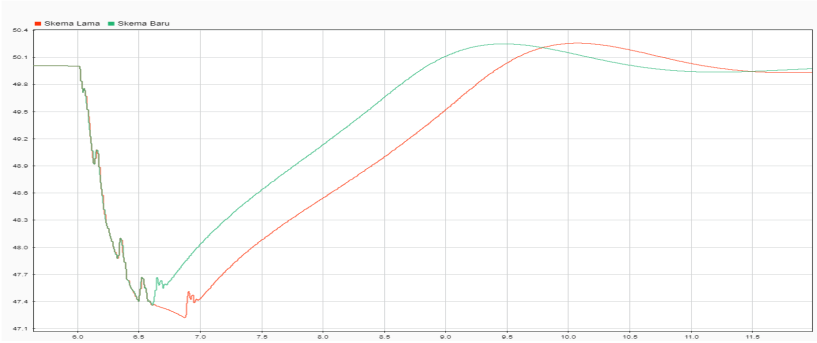

Figure 6. Frequency Response Of Scenario 12 After Evaluation

After testing with the load shedding scheme, the results obtained are as shown in Table 5.

Table 5. Comparison of Existing Schemes And New Schemes

S	Existing Scheme				New Scheme			
	LF (Hz)	HF (Hz)	LS	Criteria	LF (Hz)	HF (Hz)	LS	Criteria
1	50	50	-	Yes	50	50	-	Yes
2	49,86	50,02	-	Yes	49,86	50,02	-	Yes
3	49,86	50,02	-	Yes	49,86	50,02	-	Yes
4	49,84	50,02	-	Yes	49,84	50,02	-	Yes
5	49,77	50,04	1	Yes	49,5	50,12	-	Yes
6	49,51	50,11	1	Yes	49,42	50,13	1	Yes
7	49,51	50,11	1	Yes	49,41	50,14	1	Yes
8	49,37	50,11	1	Yes	49,31	50,11	1	Yes
9	48,58	50,28	1,2,3	Yes	48,62	50,28	1,2,3	Yes
10	48,1	50,38	1,2,3	Yes	48,02	50,14	1,2,3	Yes
11	48,03	50,39	1,2,3	Yes	48,02	50,14	1,2,3	Yes
12	47,37	50,25	1,2,3,4	No	47,36	50,25	1,2,3,4	Yes
13	-	-	1,2,3,4	No	-	-	1,2,3,4	No
14	-	-	1,2,3,4	No	-	-	1,2,3,4	No
15	-	-	1,2,3,4	No	-	-	1,2,3,4	No
16	-	-	1,2,3,4	No	-	-	1,2,3,4	No

From Table 6 the new load shedding scheme provides better results, where in scenario 5, the old load shedding scheme activates step 1 which should not need to be done, with the new scheme this condition can be avoided. Furthermore, in scenario 12, the old scheme does not meet the PRC 006-5 standard, with evaluation of the new scheme being able to maintain the frequency within the limits permitted by PRC 006-5.

CONCLUSION

The research results, it is known that the existing load shedding scheme needs to be evaluated. From the test results in scenario 5, Private Company load shedding scheme carried out step 1 load shedding which should not have been done. And in scenario 12 load shedding cannot restore the frequency quickly so the frequency reduction does not meet the PRC-006-5 standard, namely frequencies below 47.5 Hz which occur for 0.3 s and in the PRC 006-5 standard it is only allowed for 0.1 s. Evaluation is carried out on step 1 and step 2, so that the load shedding limit for step 1 becomes 49.5 Hz and the pickup time for step 2 becomes 400 ms. After evaluation, the load shedding system can run better where the load shedding system does not shed unnecessary loads and can meet the PRC 006-5 standard.

ACKNOWLEDGMENT

The authors gratefully thanks to Department of Electrical Engineering, Faculty of Engineering, Universitas Riau for supporting this research.

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RIAN DIKA delved into the realm of Power Electronics and Renewable Energy during his academic pursuits. His journey led him to contribute as a laboratory assistant of Laboratory at Universitas Riau, showcasing his commitment to hands-on learning and practical applications. He is educational background and hands-on experience highlight his dedication to the fields of Power Electronics, Renewable Energy, and Electrical Machines. His journey from SMAN 1 Kuantan Hilir to serving as a laboratory assistant, he is a testament to his continuous pursuit of knowledge and practical skills in the dynamic field of electrical engineering.

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