Application of Under-Frequency Relay (UFR) in Load Shedding Scheme for System Stability (A Case Study on PT. PLN Kendari)

Tachrir1*, Samuel Jie1, Bunyamin1, Abdul Djohar1
1Department of Electrical Engineering, Faculty of Engineering, Universitas Haluoleo, 93232 Kendari, Sulawesi Tenggara, INDONESIA

*Corresponding author’s e-mail: tachrir@gmail.com

Abstract. A reliable electric power system must maintain its operation in stable conditions with the support of various protection systems during normal operation or when a fault occurs. To minimize the frequency of blackouts in the system due to interference, transient conditions, or the increased load, this study simulated the load shedding scheme using under-frequency relays (UFR). The analysis was done in ETAP 12.6.0 software using the Transient Stability Analysis feature. In this simulation, discontinuation occurs in the CB (Circuit Breaker) generator which causes the generator to escape from the system in two conditions, namely Peak Load Time (PLT) and Off-Peak Load Time (OPLT). The study simulated scenarios where circuit breakers (CB) tripped due to a fault, causing a power plant to be disconnected from the grid. The scenarios were simulated in two conditions, during the peak load and off-peak load. The results show that during the peak load, the simulated Load Shedding Scheme 1 to 3 was occurred on the frequency of 49.3918 Hz, 48.72 Hz, and 48.0195 Hz, respectively. The respective disconnected loads on Scheme 1 to 3 were 4.529 MW, 41.84 MW, and 59.072 MW while the recovery times were 2.432 s, 0.081 s, and 0.626 s, respectively. Meanwhile, in the off-peak load, the UFR tripped at the frequency of 49.3958 Hz, 48.5855 Hz, and 47.75 Hz, the disconnected loads were 3.652 MW, 30.627 MW, and 43.93 MW, and the recovery time were 2.934 s, 0.588 s, and 0.592 s for Load Shedding Scheme 1 to 3, respectively.

1. Introduction
The increasing use of electricity could create problems for the system when it is unable to provide sufficient electricity to consumers, such as the overload condition.

The overload condition can be caused by the release of several generating units or the addition of a load on the system. When this condition exists, it will cause the frequency to drop from its nominal value which could lead to a total system blackout. Thus, load shedding schemes are developed to maintain the system so frequency and to avoid a total blackout.

The load shedding scheme uses UFR (under frequency relay) when it operates. In this study, we discussed the UFR application in the load shedding scheme developed by the State Electricity Company – West, South, and Southeast Region, Kendari Area. The application of UFR in the load shedding scheme is expected to stabilize the system as quickly as possible. The power capacity of several plants in Kendari is displayed in Table 1.
Table 1. Power capacity in Kendari system.

| Site                                                  | Power (MW) |
|-------------------------------------------------------|------------|
|                                                       | Peak Load  | Off-Peak Load |
| Wua-Wua Diesel Power Plant                            | 30.1       | 19.25         |
| Poasia Diesel Power Plant                             | 28.1       | 24.90         |
| Nii Tanassa Steam-Electric Power Station              | 19.7       | 19.10         |
| BGP Tanassa Diesel Power Plant                        | 9.0        | 7.00          |
| TOTAL                                                 | 86.9       | 70.25         |

The backbone of the interconnected Kendari electricity system is the 70 kV transmission lines connecting the Tanassa Substation to the Puuwatu Substation. Meanwhile, in the Kendari City, the electricity distribution uses a 20 kV distribution lines, which connect the Wua-wua Diesel Power Plant (DPP), Poasia DPP, and Puuwatu Substation.

2. Literature review

[1] conducted a research on the simulation of load shedding using frequency relays on the Cnooc Ses Ltd. electric power system. This study discusses a load shedding scheme caused by the overload condition by minimizing the amount of load released from the system while optimizing the recovery speed using UFR. The simulations were done in ETAP 7.0 software, with the results show that the UFR could properly detect the frequency drop due to the overload condition caused by the insufficient supply when a generator was disconnected from the system. The UFR also had a fast recovery time. Meanwhile, [2] simulated load shedding schemes on the 150/20 kV Tragi Sibolga distribution network system. In this simulation, two analyzes were carried out, namely load shedding variations and calculation of the ENS (energy not supplied) value using ETAP 7.0 software. The results show that the frequency recovery time took 4-10 seconds after a fault occurs, which depended on the 150/20 kV Tragi Sibolga feeders overload.

An electric power system should have the power generated by the plants at least equal to the load they cover including the power losses that might occur on the system. However, for the security and reliability of the system, the power plants should also have a power reserve. When a generator is disconnected from the system, it could cause insufficient supply for the electricity demand. This will lead to a frequency drop as the turbine rotation is slower because of the higher load in a generator. As the frequency decreases, it will cause a total system blackout. [3] explains the solutions to overcome the total system blackout are as follows.

- Optimizing generator capacity
  The generator can be optimized by increasing the governor speed; thus, generating more power. In this solution, the reserve power of each generator is supplied to the system.

- Islanding operation
  To avoid a total system blackout when the frequency occurs drastically and the load shedding cannot overcome this condition, the generating system and the load that is still capable of being supplied can be divided into small groups. This is commonly known as islanding operation. The operation aims to save several sections of the electric power system that can still operate normally.

- Load shedding
  When the overload condition occurs in the electric power system that has optimized all of its generating power capacity, some loads should be disconnected to normalize the frequency. This process is commonly known as a load shedding. The load shedding has several stages according to the level of decreasing frequency. The criteria of a load shedding are as follows.
a. Load shedding is done gradually. If the first load shedding stage cannot recover the frequency, then it proceeds to the next stage.

b. The amount of load released should be as minimal as possible based on the required amount to improve the system frequency.

c. The load shedding starts from the load with the lowest priority in the electric power system. Therefore, all load should be classified initially based on specific criteria.

d. The load shedding must be done appropriately. Therefore, the relay delay time must be determined to detect whether the system frequency decreases due to the overload or other factors, such as the sudden addition of a large load into the system.

The generated power can be defined as the moment of force (torque) experienced by a generator that rotates at a certain angle per a period of time.

\[
P = \tau \frac{d\theta}{dt}
\]

with:
- \(P\) = the generated power (Watt)
- \(\tau\) = moment of force/mechanical generator coupling (Nm)
- \(\theta\) = rotation angle (rad)
- \(t\) = time (s)

The amount of change in the rotation angle of the generator that rotates per a period of time is the value of the generator's angular velocity.

\[
P = \tau \omega = \tau \cdot 2\pi f
\]

As can be seen in Equation (2), the change in active power generated by the generator changes the working torque. This change then subsequently affect the system frequency. Therefore, to maintain the magnitude of the system frequency, it is necessary to adjust the magnitude of the mechanical drive of the generator. Mechanical coupling driving the generator is related to the amount of fuel used to drive a prime mover or a turbine. To obtain the desired frequency that is constant in the allowable range, the amount of fuel used in the governor should be regulated as follows.

\[
T_G - T_B = J \frac{d\omega}{dt} = j2\pi \frac{df}{dt}
\]

with:
- \(T_G\) = the mechanical driving coupling of the generator (Nm)
- \(T_B\) = load torque (Nm)
- \(J\) = moment of inertia of the generator mechanical driver (kg.m²)
- \(\omega\) = rotation angle velocity of the generator (rad/s)
- \(t\) = time (s)

The frequency change rate is based on changes in the amount of generated power and the power needed by the load, which can be described by the swing equation of a generator as expressed in Equation (4).

\[
\frac{GH}{n_0} \cdot \frac{d^2\delta}{dt^2} = P_A
\]

with:
- \(G\) = generator rating (MVA)
- \(H\) = generator inertia constant (MJ/MVA)
- \(\delta\) = generator torque angle
- \(f_0\) = generator nominal frequency (Hz)
- \(P_A\) = accelerated power (MW)
The generator rotation velocity can be formulated using Equations (5) and (6).

\[ \omega = \omega_0 + \frac{d\delta}{dt} = \frac{2\pi f}{\omega_0} \]  \hspace{1cm} (5)

\[ \frac{d\omega}{dt} = \frac{d^2\delta}{dt^2} = \frac{2\pi f}{\omega_0} \frac{df}{dt} \]  \hspace{1cm} (6)

with:

\[ \omega_0 = \text{generator velocity at the nominal frequency (rpm)} \]

Then, it can be concluded that:

\[ \frac{df}{dt} = \frac{P_A f_0}{2GH} \]  \hspace{1cm} (7)

with:

\[ P_A = P_M - P_E \]

\[ P_A = \text{accelerated power (MW)} \]

\[ P_M = \text{generator mechanical power (MW)} \]

\[ P_E = \text{power demanded by the load (MW)} \]

Meanwhile, the energy generated on the synchronous velocity per volt-ampere of the generator rating is called the inertia constant. The generator’s kinetic energy can be expressed by:

\[ GH = \frac{1}{2} I \omega^2 \]  \hspace{1cm} (8)

with:

\[ G = \text{generator rating (MVA)} \]

\[ H = \text{inertia constant (MJ/MVA)} \]

\[ I = \text{Moment of inertia (kg.m}^2\text{)} \]

\[ \omega = \text{rotation angle velocity (rad/s)} \]

3. Method

This study used ETAP 12.6.0 software to simulate the load shedding scheme due to a decrease in frequency with the help of transient stability analysis feature. The data used in this study were obtained from the State Electricity Company, Kendari Area. The data included the single line diagram of Kendari system, parameters of machines and generators, transformers, cables (transmission lines and feeders), peak load and off-peak load, UFR settings, and load shedding priority.

4. Results and discussion

Before the load shedding simulation was run, first we prepared the single line diagram of Kendari system. Then, the simulation was run to observe the power flow as displayed in Figure 1.
The simulation results show that the voltage on each feeder is as follows.
1. The voltage on the Wua-wua feeder was 19.51 kV.
2. The voltage on the Poasia feeder was 19.781 kV.
3. The voltages on the Puuwatu feeder, for the 66kV and 20 kV system, were 65.453 kV and 19.87 kV, respectively.
4. The voltages on the Tanassa feeder, for the 66kV and 20 kV system, were 65.595 kV and 19.783 kV, respectively.

Table 2 shows the frequency, the amount of load disconnected from the grid, and the recovery time. Meanwhile, Figures 2 and 3 illustrate the simulation results in each scenario during the peak load and off-peak load, respectively.

![Figure 1. Power flow of the Kendari system.](image)

![Figure 2. The frequency change in: (a) Scenario 1 (peak load), (b) Scenario 2 (peak load), Scenario 3 (peak load).](image)

| Scenario | Peak load | Off-peak load |
|----------|-----------|---------------|
|          | f (Hz)    | LS (MW)       | Recovery time(s) | f (Hz)    | LS (MW) | Recovery time(s) |
| Scenario 1 | 49.3918 | 4.529 | 2.432 | 49.3958 | 3.652 | 2.934 |
| Scenario 2 | 48.72  | 41.84 | 0.801 | 48.5855 | 30.627 | 0.588 |
| Scenario 3 | 48.0195 | 59.072 | 0.626 | 47.7525 | 43.93 | 0.592 |
When a fault occurred on a block of Sewatama#1 generators, which disconnected it from the grid at \( t = 0.2 \) s. This caused a power loss of 6.1 MW. The disconnected generators caused the frequency to decrease. When the frequency reached 49.3958 Hz at \( t = 2.786 \) s, the UFR worked in Stage 1 of the load shedding scheme to disconnect the load of 3.652 MW. The system returned to normal at 7.274 s after the fault occurred.

5. Conclusion
The results show that the UFR worked properly to detect a frequency decrease due to the overload condition caused by disconnected generators. However, the use of swing generator equations to get the optimal relay working frequency, the amount of disconnected load, and the selection of relay delay time should be determined appropriately. The UFR also had a good performance in the load shedding scheme to normalize the frequency on the overload condition during peak and off-peak load. The recovery time during the peak load and off-peak load ranged from 0.626 to 2.432 seconds and 0.592 to 2.934 seconds, respectively.

6. Acknowledgment
We would like to express our gratitude to the management of State Electricity Company – West, South, and Southeast Region, Kendari Area, including all staffs and operators who provided all data and information for this study.

References
[1] Nugraheni A 2011 Simulasi pelepasan beban dengan menggunakan rele frekuensi pada sistem tenaga listrik Cnooc Ses Ltd. Departemen Elektro Universitas Indonesia
[2] Tambunan R P T 2014 Simulasi pelepasan beban (load shedding) pada sistem jaringan distribusi Tragi Sibolga 150/20 kV (studi kasus pada penyulang Tragi Sibolga, Sumatra Utara) Jurusan Teknik Elektro Universitas Diponegoro
[3] Mahmud S 2014 Simulasi pelepasan beban dengan menggunakan relay frequency pada sistem tenaga listrik Cnooc Ses Ltd. North Business Unit menggunakan software ETAP 7.5 Jurusan Teknik Elektro, Universitas Muhammadiyah Semarang