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Load Shedding Strategy in Electrical Power System Using Under Frequency Relay

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Abstract: *Stability of power system can be defined as its property which keeps several parameters in the balanced operating condition when sudden disturbances occur. In the stable operating condition, mechanical power input in the prime mover poses an equilibrium state with the electrical power output. Such condition makes all generators spin in synchronized speed.Disturbances in a power system tend to make out-of-balance situations, which in turn force the engineers to develop a better power system management. One of power system management that needs a high concern is load shedding strategies. It highly depends on system frequency, since the frequency is the most sensitive value affected by imbalance condition.Load shedding strategy uses frequency relays as the devices to break the connection of circuit breakers by measuring system frequency. The relays can be programmed to break specific circuit breakers if the system frequency reaches a defined value set by programmers. By inspecting this strategy, there is a high expectation to make a better power system, especially in 500 kV interconnected power system in Java-Madura-Bali.*

Keywords: *load shedding, power flow study, under frequency relay, Java-Madura-Bali 500kV interconnected power system.*

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I. Introduction

Power system stability can be described as a characteristic of a power system to preserve balanced condition. It must be able to recover to normal operating mode promptly as the system undergoes abnormal condition [1].In a stabile operation condition, there is balance between input power from prime mover and output power to the load. This mode requires all generators run in synchronized frequency [2]. In reality, however, it is impossible to achieve stabile operation all around, since various disturbances always occur. The disturbances can be minor or major in scale. Minor disturbances occur due to continuous load changes, and the system always strives to survive under these conditions, while major disturbances include short circuit, power loss from the generator, or a sudden load in large capacity.If the system is not able to resolve, then it will lose the synchronous state. This situation will cause the rotor of the synchronous engines to swing due to the torque, which in turn causes acceleration or deceleration on the rotor and lead to frequency instability [3].

The main objectives of power distribution authority are for operating and maintaining the installation of the power system, for managing the execution of power supply system, and for managing the maintenance of the power transmission. To execute these tasks, the authority conducts studies to improve the quality of power systems, since the Distribution and Expense Control Centerset the balance of power plants and loads in maintaining the frequency close to the standard frequency of 50 Hz.

Load shedding is a procedure in a power system, which allows some loads to be released to maintain its stability. Load shedding occurs as the reaction to a decrease in frequency.It is due to an imbalance between the generated power and load consumption. The frequency reduction leads to a blackout that can cause losses to the power system. The remaining generators will soon be affected and cause loss of energy production. Several impacts include generator overheating, rotor vibration, and over-excitation.One of the factors that influence that systemability is frequency and voltage stability. Frequency andvoltage stability need to be considered during electrical powerplanning and operating to avoid system instability that cancause system blackout. Load shedding needs to be done torestore the system to normal condition after interference or system instability [4].

One method to analyze the power flow and transient stability is by using a computer-aided simulator. Transient stability software is a tool that isused to analyze the stability of power system after subjected alarge disturbance [5]. By using the load shedding strategy using under frequency relay, it is expected that the decrease of frequency in power system can be resolved without causing significant losses to the authority and its customers. The under frequency cases can be solved by Under Frequency Load Shedding (UFLS), given the amount of load to be shed and delay time according to the standard. This approach avoids the frequency from exceeding the standard;hence, the UFLS strategy is required for Java-Bali power system.

A generation loss is similar to generator power drop before a planned generator capacity expansion. In a moment before capacity expansion, the system should recover to normal condition after the fault has been resolved. In a new system, however, indicates that rotor angle, voltage, and frequency recovered a brief after such disturbance. It is proven that after generator capacity increasing, the critical interruption time is slightly longer than before [6].

An extension to the interconnected system could improve the stability due to a large number of generation. In case of disturbance, the stability of the system is proven to be improved (compared to pre-extension), which is indicated by faster recovery time of rotor angle, voltage, and frequency [7].

This research discusses the release of loads using UFLS. By using the load shedding strategy based on frequency relay, it is expected that the decrease of frequency in Java-Madura-Bali 500 kV interconnection network system will be resolved without causing significant losses to the authority and the subscribers. Such scenario will be created using a simulation of generator loss. For this purpose, preparation of the load shedding scheme and its performance testing on the Java-Madura-Bali 500 kV interconnection network system will be performed on 25% generation lost, provided that the frequency will return to normal operating limits within 45 seconds and the amount of load removed should be minimized.

II. Power System Analysis

Power in Electrical System

Power is defined as conduction rate of electrical energy in a closed circuit. Transmitted power in a specified period absorbed by a load is a product of voltage and current. In 3-phase AC power system, three types of power are known: [8]

1. Virtual power, expressed in VA (volt-ampere);
2. Active power, expressed in W (watt); and
3. Reactive power, expressed in VAr (volt-ampere reactive).

Complex power is composed of the three power types mentioned. Active power is the real component, while reactive power represents imaginary one. Virtual power plays a special role in expressing the absolute value of the complex power. Hence, it is a vector resultant.

Load Shedding

Load shedding is a form of automatic or manual releasing action to protect generating units operation against the possibility of black out. Load shedding must be automatically performed because of power supplies reduction. These are automatically performed by detecting frequencies or by observing insufficient power plant operating conditions (when generating capacity is less than the total load).Generators in a power system often get unavoidable disturbances, an e.g., sudden rise of loading exceeding the source capacity, bus disturbance, or generator deleting. The inability of a plant to supply electrical energy is usually characterized by a decrease in frequency.The power system should be able to provide electricity to customers with a constant frequency. The frequency deviation from the nominal value should always be within the allowed tolerable range. Active power has a close relationship with the frequency value in the system, while the system load is always changing over time. In this case, there must be an adjustment between the active power generated according to the load. This adjustment is done by regulating the coupling magnitude of the generators.There are three ways of setting the frequency, that is, (1) setting the active power on the generator side, (2) load shedding, and (3) power transfer.

III. Method Of Research

To achieve the goal of the research, a flow chart diagram is designed as indicated in Figure 1. In general, the steps of the research methodology can be described as follows:

Step 1: Standard undertook;
Step 2: Modeling of the Java-Madura-Bali 500 kVinterconnection system;
Step 3: Composing of the loss of generating unit scenario and the data acquiring;
Step 4: The frequency profile analysis as the result of above experiment;
Step 5: The arrangement of load shedding priority;
Step 6: The arrangement of initial load shedding scheme;
Step 7: Testing of the scheme using generator deletion scenario and its adjustment; and
Step 8: Creating confirmation of the final load shedding scheme.

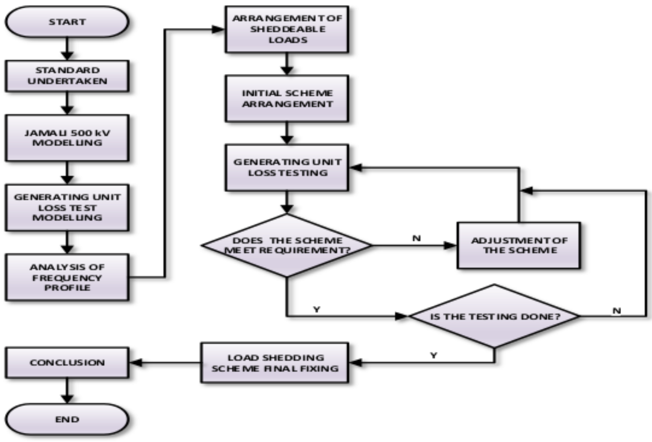

Fig. 1. The step sequences of the research methodology.

The stepsequences in Figure 1 are based on the stability concept as shown in Figure 2. Power system stability is tried to be analyzed by using transient stability model, rather than steady-state or dynamic stability one. The disturbance caused by the loss of generating unit will create system instability. Frequency stability analysis is then used to figure these instabilities, which compromised by a load shedding scheme. Finally, the stability is expected to recover as the result of the scheme.

Standard Undertaken

This stage is done by collecting the references related to transitional stability and data on the Java-Madura-Bali 500 kV interconnection network system. This stage was obtained from papers and textbooks relevant to the discussion by field conditions and pre-existing research results.

Modeling of Java-Madura-Bali 500 kV Interconnected System

At this stage, the single-line diagram of practical system of 500 kV Java-Bali-Madura interconnected system is modeled and simulated which consists of 61 generator units (from 12 generating units), 28 buses, and 25 load units.

Loss of the Generating Unit Test

At this stage, the objective is to design of loss of generating unit scenario by using a combination of several generators removed by the total amount of generation. This generating unit loss scenario is done through simulation without using a load shedding scheme. The combination of several generator losses ranges from 500 MW to 10,000 MW. The entire loss event of the generating unit starts from T = 5 s to facilitate the observation of system behavior before the loss of the generator occurs, whilethe length of the simulation is set at 50 seconds.

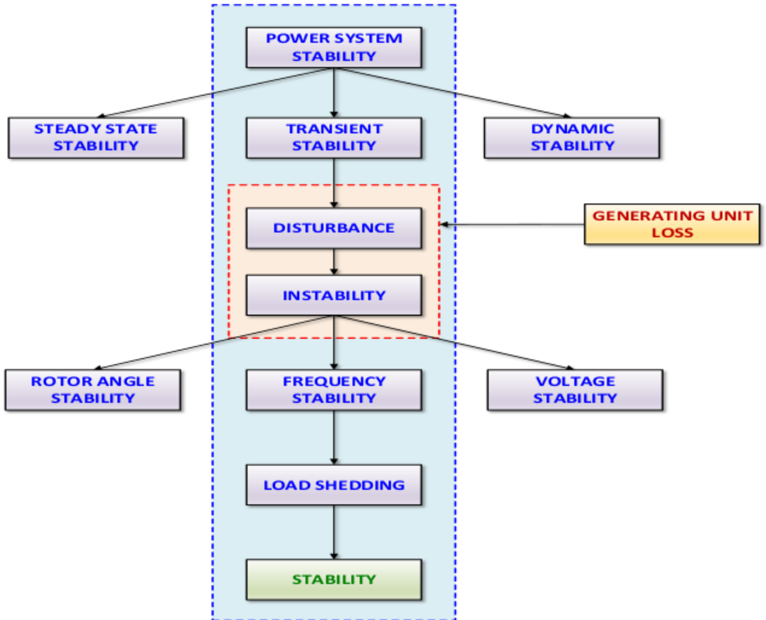

Fig. 2. The basic concept of stability.

Load Selection

At this stage, the load data is sorted according to the magnitude of the load in ascending order (from smallest to largest). Previously determined first loads that should not be removed because they are important loads.

Initial Scheme Composing

At this stage, the preparation of the load shedding scheme will be used as the initial reference. The compilation of this scheme is based on the result of frequency profile analysis, i.e., the time to reach certain frequency points, the dropping rate of frequency, and the estimated load released.

The Testing of Scheme

In this stage, the load shedding scheme is tested using a generator loss scenario. The scenario will be attempted, ranging from 500 MW to 7,000 MW, and it should be ensured that the system frequency returns to its normal operational position before T = 50 s (or before T + 45 s). The 7,000 MW figure is chosen as the capability of the load shedding scheme (with 28.8% of total load, slightly larger than 25% of total load, assuming for 100% load).

Confirmation of Final Scheme

The final step in this research is to establish a load shedding scheme that has been formed and changed in the testing as a final load shedding strategy that can withstand load losses of up to 25%. Conclusions will also be composed at this stage.

IV. Results And Discussions

Generator Loss Scenario and Experiment

In this phase, a combination of generating unit loss scenario will be created. The combination of the omitted generator will be randomly chosen, while the accumulated magnitude of the eliminated generation power is determined from the smallest to the largest. The total generation loss power will be ranging from 500 MW to 10,000 MW. All the type of chosen generator is voltage control generators, excluding Suralaya Power Plant.

Frequency Profile Data Acquisition

After scenario of the generating unit, loss combination is set, the next step is to test the generating unit loss on the 500 kV Java-Madura-Bali and retrieve the resulting frequency profile.Determination of the limits of operational frequency is based on the provisions of the energy and powerauthorityin Indonesia, among others [9]:

1. The upper limit of the normal operational frequency (in this case ignores the over-frequency limit as it addresses the under-frequency), which is denoted by f_0 which is specified at 50 Hz;
2. The upper limit of the excursion frequency, which is denoted by f_1 determined at 49.8 Hz;
3. The upper limit of the load-shedding frequency, which is denoted by f_2 is determined at 49.5 Hz; and
4. The upper limit of the blackout frequency, which is denoted by the specified f_3 of 48.4 Hz.

In the initial rule, frequencies below f_3 are islanding condition. Because this study does not address any islanding conditions, the system is not allowed to enter frequency below f_3, and the condition is labeled "blackout". So for catastrophic conditions to be avoided, the system should not reach the blackout frequency (below f_3). To maintain the stability of the system, the frequency must be immediately restored to the normal operational position (above f_1) before T + 45 s (maximum 45 seconds after the loss of generation).

The result of Generating Unit Loss

The final frequency category achieved is at T + 45 s from each scenario. Loss of generation up to 1,500 MW does not affect the system since the frequency still operates on the normal condition of about 50 ± 0.2 Hz limit. In thisscenario, the generating unit loss of about 2,940 MW, the frequency decreased at the excursion limit. A 4,120 MW, generator loss scenario, decreases the frequency further at the load shedding limit. All scenarios for losing the generator (scenarios 1, 2, 3, and 4) do not show frequency recovery, so in scenarios 3 and 4 there must be a load shedding action to recover the frequency to normal operation.

Load Selection and Initial Scheme of Load Shedding

To select the load to be shed, the first thing to note is the importance of the load. Some loads that should not be shed due to the importance of national security and the presence of important industries in the loads include:

1. Cilegon, because there is a large steel smelting furnace plant.
2. Muara Karang, because there is the Senate building, presidential palace, and Halim Perdanakusuma Airport.
3. Balaraja, because Soekarno-Hatta Airport is on the load.
4. West Surabaya, because this load connect tomany heavy industries and the Juanda Airport.

Table 1 shows the initial scheme of the load shedding.

Table 1: Initial load shedding scheme.

Load	Freq (Hz)	Delay Time (s)	Step	P (MW)
Ujungberung	49.80	0.3	1	886.692
Madiracan	49.80	0.3		
Gresik	49.80	0.3		
Suralaya	49.80	0.3		
Kembangan	49.70	0.3	2	2164.438
Tasikmalaya	49.70	0.3		
Tanjungjati	49.70	0.3		
Cibinong	49.70	0.3		
Ngimbang	49.70	5.0	2-a	975.963
Depok	49.80	15.0	1-a	1023.483
Cawang	49.60	0.2	3	2094.744
Grati	49.60	0.2		
Gandul	49.30	0.3	4	1136.777
Bandung Selatan	49.10	0.3	5	1214.385

Table 1 also reveals the cumulative weight of the load that shows the relationship between the amounts of load shed with the frequency limits as described previously, adjusted to the requirement for the load size to be shed so that the system can recover to the normal operating frequency f_0. Relay time is calculated based on the time division required to accumulate the largest loss of generator to reach the blackout f_3, of 4.21 seconds, divided by 12 loads to be shed.In this scheme, each step is labeled using the sequence of a natural number when the step uses the initial relay delay time. Meanwhile, when using a relatively long relay delay then the steps are labeled using the sequence of the original with the same trigger frequency, using the longer delay time, added with the "-a" suffix.

Testing of Scheme and Its Adjustment

In this section, a scheme-testing step will be performed with several test scenarios. Meanwhile, adjustments are also performed to the scheme according to the magnitude of the power loss of the generator.After all, scenarios have been tested, and during the testing process, adjustments have been made to the initial load shedding scheme to form the final load shedding scheme as shown in Table 2.

Table 2: Final scheme of load shedding after adjustment.

Load	Freq (Hz)	Delay Time (s)	Step	P (MW)
Ujungberung	49.80	0.3	1	886.692
Madiracan	49.80	0.3		
Gresik	49.80	0.3		
Suralaya	49.80	0.3		
Kembangan	49.70	0.3	2	2164.438
Tasikmalaya	49.70	0.3		
Tanjungjati	49.70	0.3		
Cibinong	49.70	0.3		
Ngimbang	49.70	5.0	2-a	975.963
Depok	49.80	15.0	1-a	1023.483
Cawang	49.60	0.2	3	1059.022
Grati	49.55	0.2	4	1035.722
Gandul	49.60	5.0	3-a	1136.777

The scheme has been undergoing adjustment through the elimination of Bandung Selatan from the scheme. Moreover, step 5 has been changed into step 3-a.

Testing Results

Starting from 1,300 MW loss, the Figure 3 displays that no load shedding action occurred. The system frequency begins to decrease following a 1300 MW generating unit loss. However, after about 10 seconds, it slowly recovered to nearly 50 Hz. During the simulation time range, the frequency stays at the normal category.

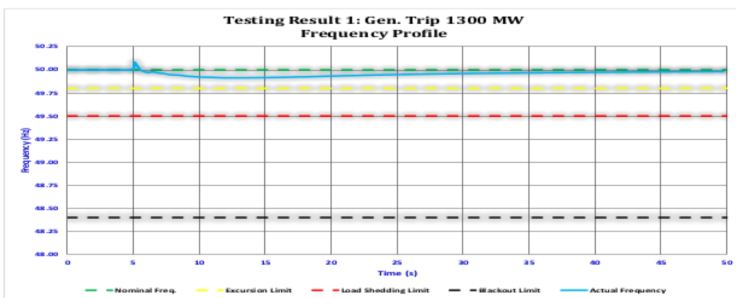

Fig. 3. The frequency profile of 1300 MW generating unit loss.

Figure4 shows frequency recovery of 2,055 MW loss. The recovery process is shown slower than before, but still in the normal category range. No load shedding occurs in this scenario.

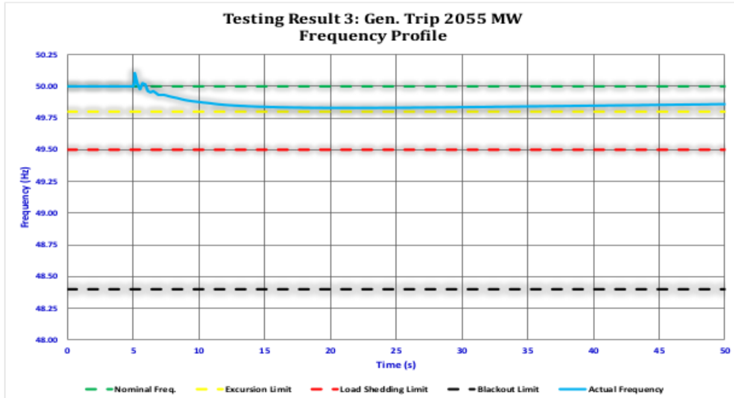

Fig. 4. The frequency profile of 2055 MW generating unit loss.

In Figure 5, there was four-step load shedding occurred, as 4890 MW generating unit loss from the system. The four-step load shedding takes 6187 MW of the total load to be shed from the system. The frequency dropped to blackout level when there was no load shedding scheme applied.

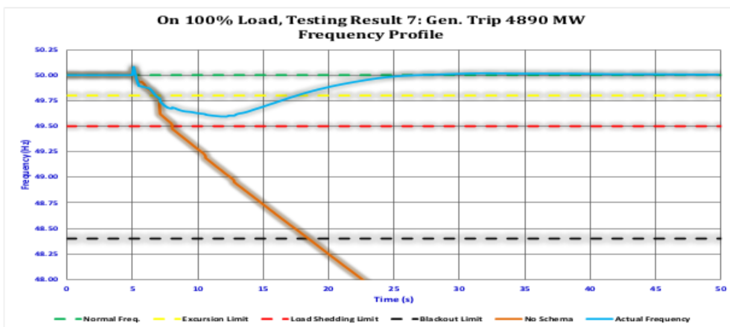

Fig. 5. The frequency profile of 4890 MW generating unit loss.

All seven steps of load shedding were triggered when 7,003 MW generating unit is loss, as shown in Figure 6. In this case, 8282 MW of load is shed from the system. The frequency also dropped to the blackout level when the load is not shed.

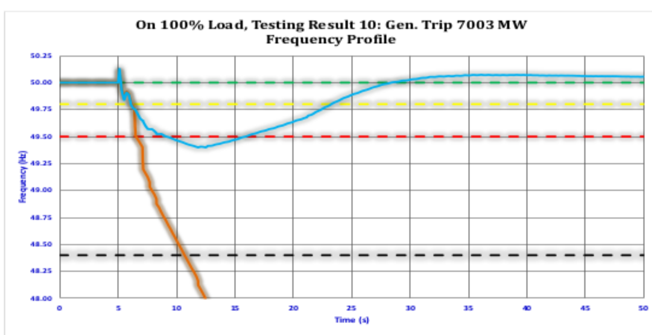

Fig. 6. The frequency profile of 7003 MW generating unit loss.

Up to 7003 MW generation loss, the frequency successfully recovers to the normal operation limit under 45 second. The test proofs the endurance of the final load shedding scheme composed in this study.

The finalscheme, as shown in Table 2, is composed of seven steps, with the first 4 steps immediately performed, and the rest performed in a longer delay to anticipate lack of frequency recovery rate in step 1 through 3.

V. Conclusion

Two conclusions have been obtained from this research. The analysis of frequency profile has been performed after execution of the scenario of generating unit loss in Java-Madura-Bali 500 kV interconnected system. Furthermore, load shedding scheme and its performance test has been successfully created on Java-Madura-Bali 500 kV interconnected system, up to 25% of generating unit loss, and a frequency recovery under 45 seconds.

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