Analysis of Under-frequency Load Shedding (UFLS) Relay Setting during Disturbances

Irrine Budi Sulistiawati, Angga Budi Prastyo, Abraham Lomi, and Ardyono Priyadi

***Abstract*—Load changes on the system will affect the system stability itself. Load demand that exceeds the generated power will cause the system frequency to decline. Therefore, a load shedding procedure is required to improve the frequency. This research focuses on how to design a load shedding scheme that is activated by the operation of under frequency relay. There are two scenarios to analyze the system performance with a simulation, which are losing power on line about 128 MVA and generator loss power about 192 MVA. Those scenarios result in a decrease in the system frequency to 47.48 Hz and 47.90, respectively. After the load shedding scenario is performed, the frequency became an increase in the range of 51.54 Hz and 49 Hz within a few seconds.**

***Index Term*—load shedding, frequency, under frequency relay.**

I. INTRODUCTION

Power system must be able to provide a good quality of electricity supply, which is represented by maintaining the system voltage and frequency within the acceptable limits that have been regulated by the government [1]. But, in real condition, the occurrence of a disturbance, such as short circuit, generator loss, load changes, and switching on the transmission system, significantly influences the system frequency system. Frequency starts to fall when the power is unable to meet the power demand. As a consequence, the blackout will happen when that unbalanced condition is not resolved. To overcome this problem, a load shedding procedure can be implemented [2-6]. The purpose of the load shedding method using under frequency relay is to determine the base frequency and the rate of frequency decrease with the amount of load that has been released to overcome frequency decrease [2].

In this paper, the IEEE 3 generators and 9 buses system will be analyzed and simulated using ETAP software and identify the system response related to a frequency deviation. Moreover, the dynamic system responses will also be analyzed the impact of load shedding to overcome the system problem. In general, this paper is organized as follows.

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A load shedding scheme procedure is presented in section II, while simulation and discussion are presented in section III. Conclusions and contributions of the paper are highlighted in section IV.

II. LOAD SHEDDING SCHEME

Load shedding is the process of releasing some loads to compensate for the loss of generation on an electrical power system. If the load on the system reduced, then the system frequency is expected to return to normal, and the generator still operates without interrupted by overloaded or frequency decreased. When the load is released successfully, the generator will run in a new stable operating point, and the load amount is lighter, and frequency will be restored to normal condition. When the system frequency is detected to decrease, a load shedding procedure should be implemented step by step [3]. A relay such as a load shedding and under frequency relay is installed on the distribution networks to permit the operator to disconnect the line to avoid overloaded.

A. Manually load shedding

When the frequency decreases relatively slow, the load shedding procedure is done by the operator without executing immediately with the consideration of system safety and stability reason, and the load shedding is not executed immediately.

B. Automatically load shedding

The relay will detect the violation of frequency limit and take action automatically for load shedding without operator intervention.

C. Frequency decrease

The frequency is reduced because the generator trips to prevent blackouts, and the system becomes unstable.

D. Frequency Decrease Rate

The frequency decay is used to calculate the magnitude of the frequency decrease and amount of load that must be released to made generator free, and also to getting time work relay, i.e.,

$$\frac{df}{dt} = \left(\frac{P_S}{2GH}\right) \times f_0 \qquad (1)$$

Where:

df/dt : frequency decrease rate
P_s : overload
G : The average of MVA generators
H : The average of generator inertia constant
f_0 : nominal frequency

The average value of the inertia constant of the generator can be calculated by using the equation below:

$$H = \frac{H_1 MVA_1 + H_2 MVA_2 + ... + H_n MVA_n}{MVA_1 + MVA_2 + ... + MVA_n} \quad (2)$$

The total load to be released when frequency continues to decline is given by,

$$S_1 = S_{g1} \times \left(\frac{f_0}{f_1} \right) \quad (3)$$

Where:

S_1 = Generator remains power (MVA)

f_1 = Reference frequency

Total loads load that will be released is determined using the following equation

$$\Delta S_1 = S_0 - S_1 \quad (4)$$

Where S_0 is the total generator power, and ΔS_1 is the total of the released load.

E. Under frequency Relay

When the system frequency drops until the frequency setting limit achieved, an under relay frequency will take action to restore the frequency to the normal frequency condition [4]. The frequency setting of the relay is determined by the frequency rate and the relay operation time. The frequency decrease rate is obtained from,

$$\frac{df}{dt} = \left(\frac{S_S}{2GH} \right) \times f_0 \quad (5)$$

Where

df/dt = frequency decrease rate,

S_S = deviation between load and power generator (MVA)

G = Rating of Generators (MVA)

H = Inertia constant (MJ/MVA)

f_o = Nominal Frequency (Hz)

The pick-up time and the trip time of the relay during the released load are calculated as follows:

$$t_{pick-up} = \frac{f_0 - f_1}{df/dt} \quad (6)$$

$$t_{trip} = t_{pick-up} + t_{CB} + t_{relay} \quad (7)$$

Where f_1 is the reference frequency of load shedding. The system frequency during the load released is calculated as,

$$f_{LS} = f_0 - \left(\frac{df}{dt} \right) \times t_{trip} \quad (8)$$

Where:

f_{LS} = frequency load shedding

df/dt = frequency decrease rate

f_0 = nominal frequency (Hz)

III. Test System and Simulation Results

In this paper, an IEEE 9-bus system with 3 generators is selected to simulate the scenario proposed, as shown in Fig. 1. The generator data, inertia, and system frequency are shown in Table I with the total power is 519.5 MW, and the total load is 330.618 MVA, as shown in Table II.

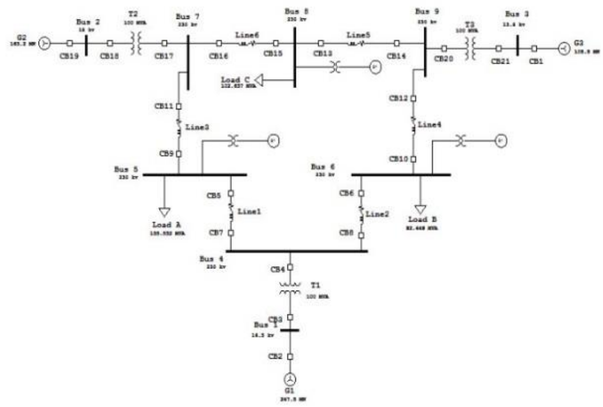

Fig. 1. IEEE 3 generators 9 buses system.

TABLE I. GENERATOR DATA

Generator	MW	MVA	Frequency	Inertia
G1	247.5	247.5	50 Hz	6.632
G2	163.2	192.0		2.312
G3	108.8	128.0		1.632

TABLE II. LOAD DATA

Loads	Power (MVA)
A	135.532
B	92.449
C	102.637
Total	330.618

To investigate the dynamic behavior of the system, two scenarios are considered in this simulation, i.e., line loss and generator loss. To perform the line loss scenario, circuit breakers of CB13.14 and CB10.12 were opened, and two transmission lines were disconnected, and generator G3 lost its power. As a result, the system frequency dropped to a specific value since the system unable to balance the power condition between the source and the load demand. The analysis results of the system scenario is shown in Table III.

TABLE III. RESULTS ANALYSIS

Type	Freq. decrease (hz)	Time Relay trip (s)	Load Shedding Frequency (hz)		Load released (MVA)
			Calculation	Simulation	
Line	3.55	0.7	47.48	47.14	128
Gen	1.46	1.5	47.9	44.72	192

It can be seen from Table III that the frequency is decreased of about 3.55 Hz to 47.48 Hz (calculation) and 47.14 (simulation) and the under-frequency relay trip at 0.7 seconds. The released load for this condition is about 92.84 MVA. The dynamic system response under the line-loss condition is shown in Fig. 2. To restore the system frequency and bring the system into a normal condition, such an amount of loads have to be released. Hence, the under-frequency relay will initiate the load shedding procedure. After the load shedding process was conducted, the system frequency is restored around its nominal values.

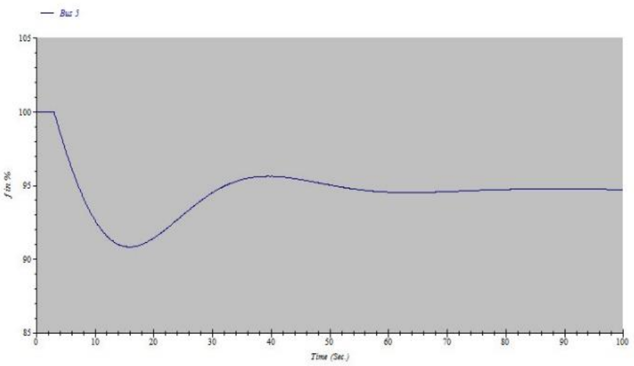

Fig. 2. Frequency response during two CB open.

The system dynamic response after load-shedding is shown in Fig. 3. It was observed that the disturbance occurs from 3rd to 6th seconds, as indicated in Figs. 2 and 3. Before load shedding takes place, the system frequency continuously decreased from 50 Hz to and 47.84 Hz. Moreover, after load shedding at 6.5th seconds, system frequency was restored and start to increase to 50 Hz for about 13.7 seconds. The comparison of the frequency system during the dynamic behavior before and after load shedding is shown in Fig.4.

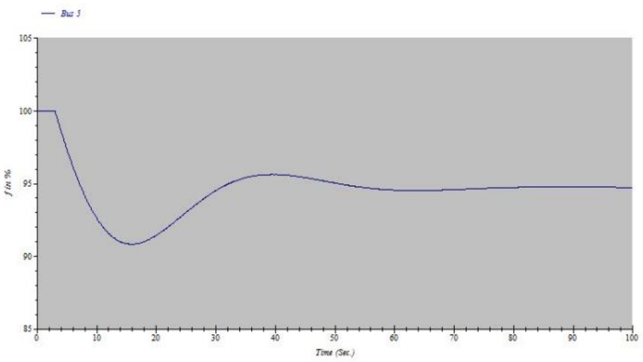

Fig. 3. Frequency response after load shedding.

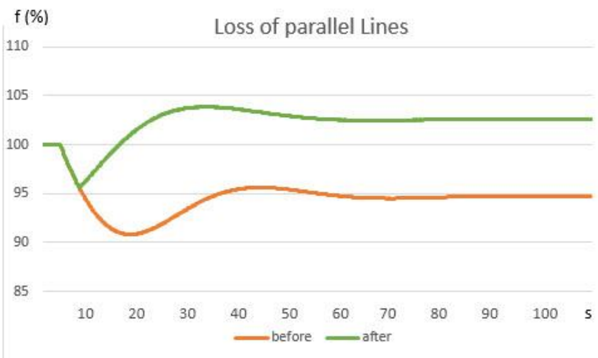

Fig. 4. Frequency response before and after load shedding.

The second scenario considers it was generator loss of power. It was assumed that under the disturbance condition, the generator G2 was removed from the system — consequently, the system lack of power generation. Hence, the system frequency severely deteriorated. The system dynamic response under loss of generator scenario similarly with Fig. 3, and load shedding action need to be performed to maintain system frequency. The dynamic behavior under load shedding perform shown in Fig. 5. In this scenario, the system frequency decrease to 47.9 (calculation) and 44.72 (simulation). It was monitored that the system attempt to back to its normal frequency. However, the frequency unable to restore to its normal condition but oscillates within a specified limits.

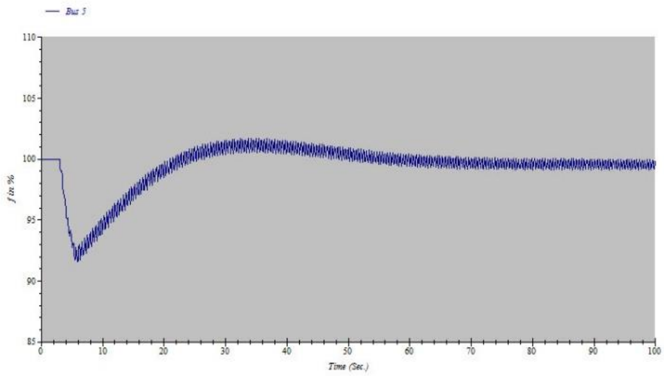

Fig. 5. Frequency response after load shedding.

It can be seen from Fig. 5; the system frequency rises up close to its normal value after load shedding implemented at 5.6 seconds. The system frequency returns to 49.83 Hz and becomes to new operational condition. On the other hand, when load shedding is considered, the system frequency enhanced from 44.72 Hz to 49.83 Hz and reaches the steady-state frequency condition of 49-51.54 Hz at 26.2 seconds.

Figure 6 shows the comparison between the frequency systems on a dynamic response before and after load shedding during the generation loss of power.

Fig. 6. Frequency response before and after load shedding.

When the generator loss implemented at 5.6 seconds, the system frequency decreases to 62% of its normal value for 15 seconds and increases to approximately 80% of its normal frequency. A new steady frequency of about 78% of its normal value and the system on its unstable condition.

In the other hand, when the load shedding implemented, the system frequency return to its normal value in about 4 seconds after a disturbance occurred and the system frequency reach its steady-state condition with the new system frequency of about 49.85 Hz.

IV. CONCLUSION

Two scenarios of disturbances such as line loss and loss of generation have been implemented and tested on an IEEE 9-buses and 3 generators system is presented. The comparison of those scenarios showed that the recovery system frequency of the loss of parallel lines slightly more higher than the loss of generation after load shedding. The dropped frequency is approximately 8-10% of its normal value for loss of parallel lines than the loss of generation of about 35-38% of its normal value. This is also impact to amount of loads that to released.

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