Analysis of the Frequency and Voltage Changes While Load Shedding in the Multimachine System

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Abstract**—Main concern in the assessment of electric power system stability is the frequency and voltage profile of the system.To avoid the occurrence of blackout condition on the system, the stability of frequency and voltage need to be considered in the process of planning and operation of the system. This research will analyze the effect of load shedding by observing the changes in frequency and voltage system**.

Keywords**—*****Stability Frequency, Voltage Stability; Load Shedding*****.**

I. Introduction

The power system is said to be reliable if the system providesa constant and quality power supply continuously, and be able to maintain its stable condition when a disturbance occurs.Changes on the load system provide an effect on frequency deviation and voltage drop in the system [1]. If the system experiences the above condition in a long period, the system will lead to a blackout condition [2].

To bring the frequency to its normal condition, the system has to release such amount of loads [3]. A method of PV and QV curve is implemented to solve the load shedding problem in this study. This method will analyze and simulate on the practical system of Lombok's electrical system on a multi machines system. Results of this study are expected to explain how to release the loads on a special manner and also to contribute to the utility operator of the Lombok's power system as a reference when the system experiences instability and leads to decrease in frequency and voltage.

II. Methodology

A. Stability of Electric Power System

The power system stability in this research focuses on the stability of the frequency and voltage of the system due to some events such as three-phase fault, load changes or loss of power generation that lead to frequency deviation, or the system generations do not meet the system load demand [4]. This is also followed by voltage deviation. The decreased frequency and voltage will bring the system to blackout condition. To keep the system stable in operating condition when a disturbance occurs, the load is released to help the system return to its normal condition.This process is known as load shedding scheme. A simulation of Time Domain Simulation will perform the process of load shedding scheme and determine the critical time in which the frequency of the system returns to its normal operating condition on a multi machines model on Lombok's electrical power system. The parameters of the system to be considered on stability problem are described as follows.

1) Frequency Stability

Frequency stability refers to the ability of the power system to maintain a stable frequency when the system experiences animbalance of power between the generation and the load demand [1]. Reduced on active power generated will cause the frequency drop in the system and the generation does not meet the power load demand. The system frequency should return to its normal value with a release such amount the system load.

2) Voltage Stability

The voltage stability refers to the ability of the power system to maintain stable voltages on all buses in the system after the system is interrupted by the initial operating conditions [1,2]. The voltage decrease caused by the system has less reactive power to supply the load. If the voltage drops continuously this will cause the collapse voltage [2].

B. *Load* Shedding

Load shedding is an attempt to prevent system goes to an unstable condition. If the unstable condition occurs continuously, the system will lead to a frequency decrease, voltage drop, unstable of the phase angle of the system. In general, the instability of the system occurs when the load system increased, loss of transmission lines, failure of generators or other components from the system [5-7].

Load shedding is an ability to change the amount of power consumed by a given load bus [8, 9]. The loss of a generation resulting from a disruption to generator operation where the generating capacity reduced and insufficient power to supply the load demand of all customers or varying loads at any certain time. In this situation, the generation system inadequate to supply the load demand and the system tends to an unstable condition. An action to release the load should be immediately taken by the operator. Otherwise, the system will experience the risk to blackout stage [3].

C. Load on System

In a power system, changes in active power affect the frequency, while the load is dynamic. Furthermore, the relationship between active and frequency can be explained as follows. The force experienced by an object moving at a certain distance is defined as the force per unit time. In the generator, there is a rotating part, so the power review generated by the generator is the power generated by a rotating object and not a static object. Therefore, the generator generated power is defined as the moment of force (torque) experienced by the generator which rotates at a certain angle of time unity. The magnitude of the rotation angle change from the generator part which rotates the unity of time is the value of the speed of the generator.

$$P = \tau \times \omega = 2\pi f \tag{1}$$

Where:

P = Active power

τ = Torque

f = Frequency

From equation 1, the change in the generator active power will cause a change in torque. This torque change will affect the frequency, so changing the active power will result in a change in frequency directly.

1. PV Analysis

PV analysis is a correlation between active power (P) and voltage (V). For this analysis, P is lack of power and voltage in some critical load bus [4,8]. When a disturbance occurs, the frequency of the system will change as well as the voltage buses.The magnitude of the disturbance is calculated from the swing equation, where the rate change in frequency and in voltage [3]. This equation will compute the amount of load to be released. This also calculates the power difference between the generation and the load power.

$$\frac{2H}{f_0}\frac{df}{dt} = P_m - P_e = P_{diff} \tag{2}$$

2. QV Analysis

QV analysis is one of the concepts to investigate the problem of voltage instability in the system. The voltage on the critical bus is plotted against the reactive power on the bus. QV curve is the relationship between reactive power (Q) and voltage gain for the difference in value on active power (P) [1,10].

The total load to be released on each bus can be determined based on the voltage sensitivity of each bus. The QV analysis is described as follows:

$$P_i = \sum_{j=1}^{n} V_i V_j Y_{ij} * \cos(\delta_{ij} - \theta_{ij}) \tag{3}$$

$$Q_i = \sum_{j=1}^{n} V_i V_j Y_{ij} * \sin(\delta_{ij} - \theta_{ij}) \tag{4}$$

The equation for voltage sensitivity for each bus is

$$\frac{dQ_i}{dV_i} = \sum_{j=1}^{n} V_i V_j Y_{ij} * \sin(\delta_{ij} - \theta_{ij}) \tag{5}$$

To estimate the amount of this load, there should be a reciprocal consideration of the voltage sensitivity as a fraction of the amount of reciprocity of the voltage sensitivity. The reciprocity is considered because for higher slopes, the reciprocity will be smaller, then the lower loan amount will be released. Thus,

$$\frac{dV}{dQ} = \left(1 / \frac{dQ}{dV}\right) \tag{6}$$

$$\frac{dQ_i}{dV_i} = \left(1 / \sum_{j=1}^{n} V_i V_j Y_{ij} * \sin\left(\delta_{ij} - \theta_{ij}\right)\right) \tag{7}$$

The equation above gives a fractional value of the voltage sensitivity for each bus. The correlation between the amount of load to be released and the value of dV/dQ on each bus,

$$\frac{dV_i}{dQ_i} \quad \text{(the amount of load released from each bus)} \tag{8}$$

Total of the dV/dQvalues of all the buses are

$$\sum_{j=1}^{n} \frac{dV_i}{dQ}_i = \left(\frac{dV_1}{dQ_1} + \frac{dV_2}{dQ_2} + \ldots + \frac{dV_n}{dQ_n}\right) \tag{9}$$

The load released on each bus is a fraction of the total load required to be released in maintaining the balance of the system. The dV/dQ value fraction on each bus in respect of the total amount calculated is proportional to the total fraction of the load released on each bus.

$$\frac{\frac{dV_i}{dQ_i}}{\frac{dV_1}{dQ_1} + \frac{dV_2}{dQ_2} + \ldots + \frac{dV_n}{dQ_n}} \quad \text{(for each bus i)} \tag{10}$$

The complex power (S),

$$S_i = \frac{\left(\frac{dV_i}{dQ_i}\right)}{\left(\sum_{j=1}^{n} \frac{dV_i}{dQ_i}\right)} P_{diff} \tag{11}$$

Where: dQ/dV = Sensitivity voltage

dV/dQ = Reciprocal voltage sensitivity

Y = Admittance

S = Complex power

D. Newton-Raphson Method

The Newton-Raphson method is the most commonly used method for analyzing the system power flow. The idea of this method based on an initial guess at the point (x_i, $f(x_i)$) then it can be drawn a tangent line to cut the x-axis. The intersection with this x-axis is usually a better-estimated root value than the previously estimated. Besides using a geometric approach, this method can also be derived from the Taylor series expansion around the point$x = x_0$, i.e.,

$$f(x) = f(x_0) + (x - x_0) f'(x_0) + \frac{1}{2}(x - x_0)^2 f''(x_0) + O\left(|x - x_0|^2\right) \tag{12}$$

By ignoring the higher quadratic and high ordervariable and using$f(x) = 0$, then$x$ is obtained as

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)} \tag{13}$$

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \tag{14}$$

III. System Simulation

A simulation and discussion on Lombok's Electrical Power System are applied. Lombok system consists of 8 units of Substation, 5 units of Generation, and 10 units of an interconnected-hose tunnel into one electrical system [11]. Two model of scenarios are implemented to release the generator's power, i.e., a generator of PLTU Jeranjang Unit 3 and release the bus Cogindo. The simulation for a base case and the system frequency of 50 Hz is shown in Fig. 1.

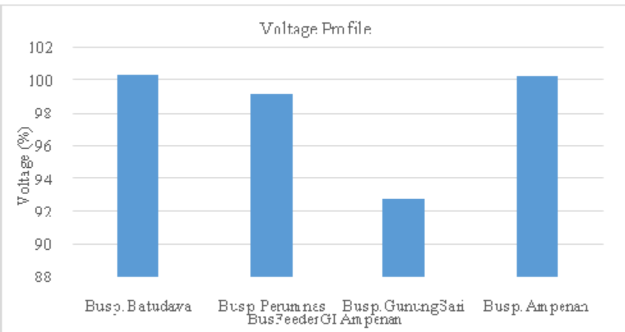

Fig. 1. Voltage Profile Bus Feeder GI Ampenan

It can be seen from Fig. 1, the lowest voltage profiles of about 92.73% at bus Gunung Sari, while the highest voltage profiles of about 100.37% at bus P. Batudawa. The rest buses are 99.18% and 100.23% at bus P. Perumnas and bus P. Ampenan respectively.

A. Scenario 1

In this scenario, the generator lost its power and the system will lack active and reactive power to supply the load demand, and the frequency and voltage on each bus decrease. A simulation for first-second disturbance and its response are ploted at the third second as shown in Fig. 2.

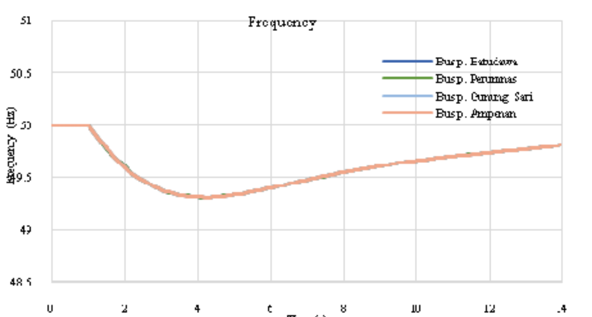

Fig. 2. Response frequency on bus feeder GI Ampenan

It can be seen from Fig. 2, the frequency of Ampenanand Gunungsari substations is decreased gradually from 50 Hz to 49.31 Hz, the lowest frequency in the system when the generator PLTU Jeranjang lost or released its power at the first second, while Bus Belching and Bus Perumnas dropped to 49.38 Hz in the third second.

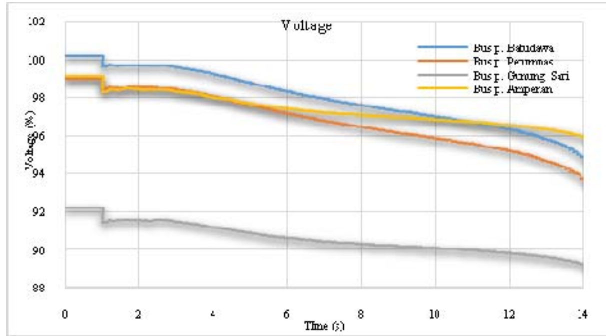

Fig. 3. Plotting voltage at feeder GI Ampenan

The voltage profiles of the system buses are shown in Fig. 3. The voltages at the buses are decreased as well as the frequency decreased 94.84%, 93.72%, 89.23%, and 95.91% during 14 seconds for bus Batubara, bus Perumnas, bus Gunung Sari, and bus Ampenan, respectively.

After the generator loss its power, a load shedding procedure has been taken. The change of the frequency and voltage after load shedding are shown in Fig. 4 and Fig. 5, respectively.

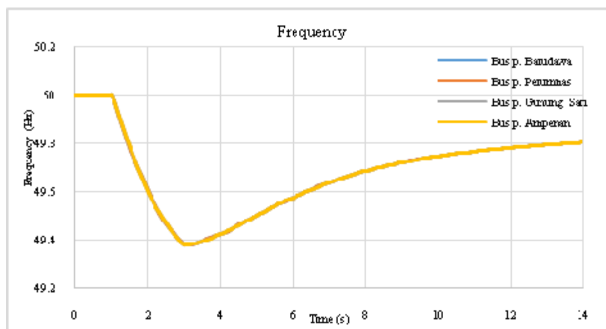

Fig. 4. Frequency on bus feeder GI Ampenan after load shedding.

It can be seen from Fig. 4, the system recovery it frequency from 49.36 Hz at third second to 49.89 Hz in the sixth second.

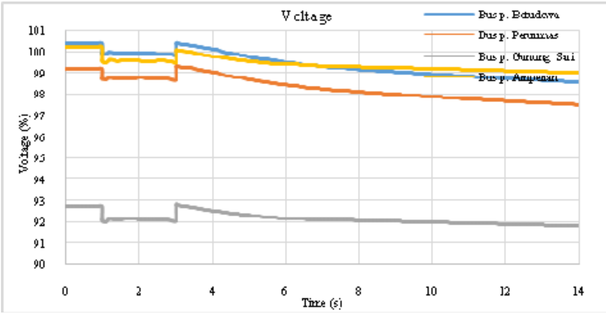

Fig. 5. Voltage profile after Load Shedding on GI Ampenan

The voltage profiles at Ampenan Substation are increased after load shedding process. The voltages at bus Batudaya, Perumnas, Gunungsari, and Ampenan are improved from 98.85% to 100.14%, 98.67% to 99.04%, 92.04% to 92.52%, and 99.48% to 99.77%, respectively.

B. Scenario 2

In this scenario, the Cogindo bus is released, the power flow is shared among the rest buses. The first step is to release the bus at the first second. The frequency profiles of the buses are plotted in Fig. 6.

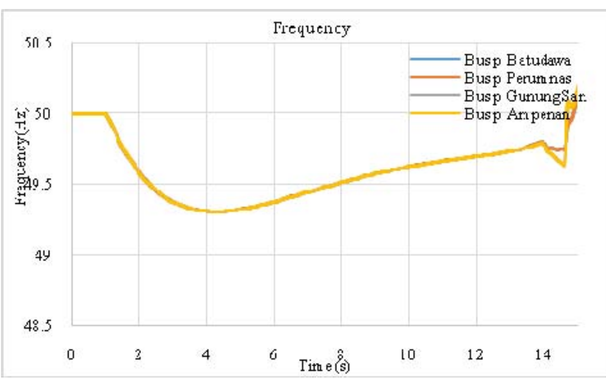

Fig. 6. Frequency feeder GI Ampenan

It can be seen in Fig.6, the frequency of Ampenan feeder decreases from 50 Hz to 49.37 Hz in the third seconds.

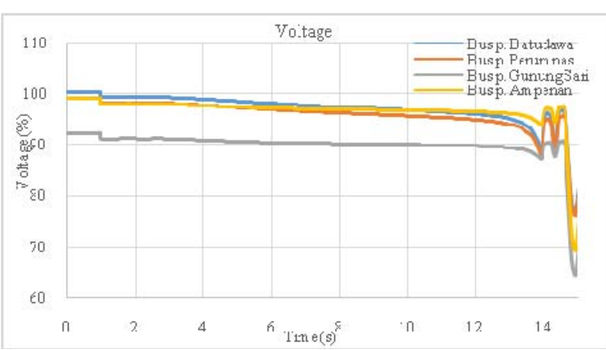

Fig. 7. Plotting voltage on bus feeder GI Ampenan

Figure 7 shows that the voltage on the bus Ampenan getting lower as a result of the release of the Cogindo bus where the voltage on buses Barrels, Perumnas, Gunungsari, and Ampenan become 95.11%, 93.99%, 89.95%, and 96.69%, respectively.

When the Cogindo bus is released, the frequency at and voltage profiles of the system are decreased from 50 Hz to 49.37 at Ampenan feeder and the voltages is about 89.95% at Gunungsari bus. To overcome the problem caused by the Cogindo bus released, an action of load shedding is implemented. The frequency and voltage profile after the load shedding process at Ampenan substation can be seen in Fig. 8 and Fig. 9.

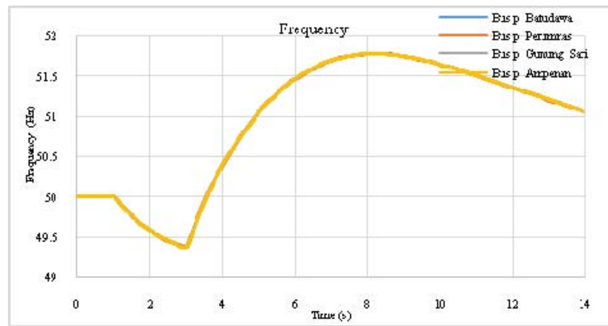

Fig. 8. Frequency profile after load shedding onAmpenan substation.

It can be seen from Fig. 8, after the load shedding process during bus Cogindo released the frequency at Ampenan substation increases from 49.37 Hz to 51.64 Hz.

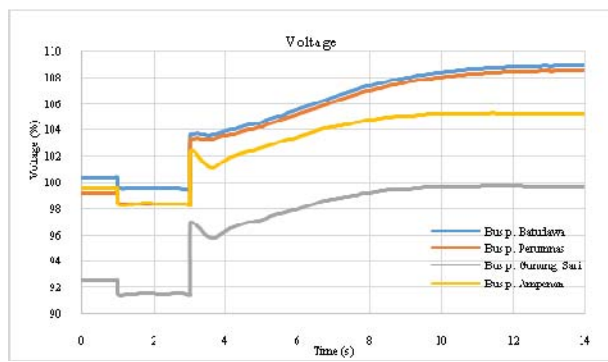

Fig. 9. Voltage profile after load shedding on GI Ampenan

The voltage at Ampenan substation increases after the load is released at the third second of about 99.44% to 108.31%. The voltage bus at Perumnas improved from 98.27% to 107.95%, and bus Gunungsari rises from 91.44 to 99.19%. The overall frequency decrease and moment inertia during the disturbance in Lombok Power system are shown in Table I.

TABLE I. MOMENT INERTIA AND FREQUENCY CHANGES RATE

Disturbance	The rate of decrease in frequency	Moment Inertia
Lossof Generator	0,511042	0,5563
Lossof Bus	0,521027	4,3755

The rate of frequency and moment of inertia are 0.511042 Hz and 0.5563 during the generator loss and 0.521027 Hz and 4.3755 during the bus loss, respectively.

C. *The power difference between supply and demand*(P_{diff})

The disturbance occurs in the system creates a power difference between power generated and load demand as shown in Table II.

TABLE II. POWER DIFFERENCE

Disturbance	P_{diff}
Lossof Generator	11,51141 MW
Lossof Bus	91,19015 MW

D. *Complex Power Calculation (S) Released*

The complex power (S) computes based on the voltage magnitude sensitivity and fractional values of the voltage sensitivity of each critical buses. The voltage sensitivity profiles, fraction values of the voltage profiles, and the total of all voltage sensitivity are shown in Table III.

TABLE III. VOLTAGE SENSITIVITY

Disturbance	Bus	dQ/dV	dV/dQ	$\sum_{i=1}^{n}\frac{dV_i}{dQ_i}$
Loss of generator and loss of bus	Bus p. Batudawa	0,0867945	11,5214686	1031,466
	Bus p. Perumnas	0,0616109	16,2308496	
	Bus p. Gunung Sari	0,0616111	16,2308496	
	Bus p. Ampenan	0,0867945	11,5214686	

The total of complex power released during the disturbances is shown in Table IV.

TABLE IV. TOTAL LOAD MUST BE RELEASED

Disturbance	Bus	Complex Power (MVA)
Loss of generator	Bus p. Batudawa	0,181
	Bus p. Perumnas	0,181
	Bus p. Gunung Sari	0,181
	Bus p. Ampenan	0,181
Loss of bus	Bus p. Batudawa	1,434
	Bus p. Perumnas	1,434
	Bus p. Gunung Sari	1,434
	Bus p. Ampenan	1,434

After removing the load, the frequency and voltage of the system are returned to its normal condition and the system run in stable condition.

IV. CONCLUSION

A practical system of Lombok electrical power system has been selected for simulation purposes for load shedding scenario during the disturbances occurred based on PV and QV method. A scenario of generating loss and bus loss showed a difference frequency and voltage profile. The frequency and voltage decreased on each bus from the normal condition.

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