Minimizing Load Shedding in Electricity Networks using the Primary, Secondary Control and the Phase Electrical Distance between Generator and Loads

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Abstract—This paper proposes a method for determining location and calculating the minimum amount of power load needed to shed in order to recover the frequency back to the allowable range. Based on the consideration of the primary control of the turbine governor and the reserve power of the generators for secondary control, the minimum amount of load shedding was calculated in order to recover the frequency of the power system. Computation and analysis of the phase electrical distance between the outage generator and the loads to prioritize distribution of the amount power load shedding at load bus positions. The nearer the load bus from the outage generator is, the higher the amount of load shedding will shed and vice versa. With this technique, a large amount of load shedding could be avoided, hence, saved from economic losses, and customer service interruption. The case study simulation has been verified through using PowerWorld sofware systems. The effectiveness of the proposed method tested on the IEEE 37 bus 9 generators power system standard has demonstrated the effectiveness of this method.

Keywords—*Load shedding; primary control; secondary control; phase electrical distance*

I. Introduction

The imbalance active power between the generation and the load demand causes a decrease the frequency in the power system. The monitoring and control system will immediately implement the control solution to restore the frequency back to the allowable value. In [1], the primary and secondary control power plants are set by automatic controlled equipment or the power system operator. At this point, the spinning reversed powers are considered to restore the frequency. After implementing all possible control solutions that the system's frequency has not yet recovered to the allowable value, the load shedding is considered as the final solution to restore the frequency and maintain the active power balance between the generation and load demand.

In reality, load shedding is often used as a low cost and effective method to prevent the system blackout [2] and instability. A good load shedding option is to shed minimum load amount as soon as possible while simultaneously satisfying all constraints to maintain system stability. The traditional solutions for this problem are found in [3] and [4], and both papers use under frequency load shedding relay (UFLS) or under voltage load shedding relay (UVLS). These

conventional techniques are fixed amount of load shedding when the frequency or voltage deviates from the nominal value. According to [5], load cutting is usually performed on a step-by-step based on the expected load cutting schedules which determined on the general rules and operator experience. These tables indicate the amount of active power that should be shed at each step depending on the frequency variation. This could cause the over load shedding or the insufficient load shedding. The authors in [6], [7] and [8] present a method to estimate the amount load shedding, it is usually based on the frequency reduction, the rate of change of frequency (ROCOF) or swing equation. Intelligent load shedding methods have also been studied and developed such as artificial neural network (ANN) [9-10], fuzzy logic [11], genetic algorithm (GA) [12-13] and particle swarm optimization (PSO) algorithm [14-15]. These algorithms focus on determining when and how much load should be disconnected. The limitations of these methods have not determined the order of the load need to shed and have not properly distributed the amount of load shedding at the load buses. References [16] introduced a hybrid algorithm based on Genetic Algorithm (GA) and Neural Network (NN) for reducing the amount of load shedding and voltage collapse in power system. In [17] a load shedding technique based on sensitivity analysis and electrical voltage distance is used in order to get the distributed load shedding.

There are three requirements for a load shedding plan. First of all, the load shedding should be fast. Second, the frequency must be restored to allowable values. Finally, the amount of load shedding must be as low as possible.

In this paper, a new load shedding method based on frequency taking into account the effects of the primary control and the secondary control of the generators is presented. For this method, when the generator outage occurs, the turbine regulator of the generators will generate additional power into the grid. In case the system frequency does not recover to the allowable value, the frequency modulation power plants, as well as the other generators, will implement the secondary control strategy. After performing the secondary control that the frequency is still less than the permissible value, the load shedding must be done at the load buses. This amount of load shedding is determined by the quick, simple calculation formulas and it is lower than other traditional methods.

On the other hand, the Phase Electrical Distance (PED) analysis between the generator node and the load nodes is used to prioritize the distribution of the amount of load shedding at each bus in the power system. The closer the load bus is to the outage generator position; the smaller the phase electrical distance is. Therefore, the greater the amount of load shedding power required to disconnect at these nodes.

The effectiveness of the proposed load shedding strategy was demonstrated through the test on the 9-machine, 37-bus system, and the results are compared with a conventional under-frequency load-shedding scheme. Calculated and simulated results showed that the proposed method was less the amount power of load shedding than the UFLS relay method, thus reducing the losses and inconvenience caused to customers using electricity. Besides, the recovery time and rotor deviation angle still guaranteed within the allowable values and maintained the stability of the power system. Therefore, in emergency situations such as: large generator outage, ... this proposed method can be used to support and train the dispatchers and operators of power systems in assisting with decisions on load shedding at power companies.

II. METHODOLOGY

A. Overview the Power Systerm Frequency Respond

First, the basic concepts of speed governing are best illustrated by considering an isolated generating unit supplying a local load as shown in Fig. 1.

The power system loads are a composite of a variety of electrical devices. For resistive loads, such as lighting and heating loads, the electrical power is independent of frequency. In the case of motor loads, such as fans and pumps, the electrical power changes with frequency due to changes in motor speed. According to [18], the overall frequency-dependent characteristic of a composite load may be expressed as:

$$\Delta P_e = \underset{Nonfrequency-sensitive-load-change}{\Delta P_L} + \underset{Frequency-sensitive-load-change}{D\Delta\omega} \qquad (1)$$

Where: ΔP_L Load component does not depend on frequency, eg heat load, lighting, ...; $D\Delta\varpi_r$: The change in load depends on the change of frequency, eg, motors, pumps, etc; ΔP_e: Deviation of power change; $\Delta\omega_r$: Deviation of angle speed change; D: The percentage change in load with percentage of change in frequency varies, D is from $1 \div 2\%$.

The governor with speed-droop characteristic can be used when two generators or more and adjust the speed (frequency) with deviation.
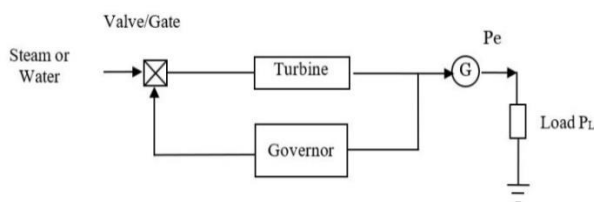

Fig. 1. Generator Provides Independent Load.

The author in [18] present the transfer function block diagram reflects the relationship between the load change and the frequency taking into account the governor characteristic, the prime mover and the load response is shown in Fig. 2.

The transfer function relating the load change, ΔP_L , to the frequency change, $\Delta\omega$, is

$$\Delta f(s) = \Delta P_L(s) \left[\frac{\frac{-1}{Ms+D}}{1 + \frac{1}{R}\left(\frac{1}{1+sT_G}\right)\left(\frac{1}{1+sT_{CH}}\right)\left(\frac{1}{Ms+D}\right)} \right] \qquad (2)$$

Where: K_G the amplification stage; ω_{ref} reference speed; T_{CH} "charging time" time constant; ΔP_{Valve} per unit change in valve position from nominal; Ms angular momentum of the machine in Laplace transform; R is equal to pu change in frequency divided by pu change in unit output; it is characteristic for the sliding speed adjustment; $R = \frac{-\Delta f}{\Delta P}$

The purpose of system simulation in the form of a transfer function is to calculate the time response of the frequency deviation when the load change step is ΔP_L. From the above description, frequency deviation in steady state it means the value of the transfer function is determined for s = 0:

The steady-state value of $\Delta f(s)$ may be found by:

$$\text{steady state} = \frac{\lim_{s\to 0}\left[s\Delta f(s) \right]}{} = \frac{-\Delta P_L\left(\frac{1}{D}\right)}{1 + \left(\frac{1}{R}\right)\left(\frac{1}{D}\right)} = \frac{-\Delta P_L}{\frac{1}{R} + D} \qquad (3)$$

When the power system has multiple generators with independent governors, the frequency deviation in steady state when the load change is calculated according to formula (4).

$$\Delta f = \frac{-\Delta P_L}{\frac{1}{R_1} + \frac{1}{R_2}...+\frac{1}{R_n} + D} \qquad (4)$$

or:

$$\Delta f = \frac{-\Delta P_L}{\frac{1}{R_{eq}} + D} \qquad (5)$$
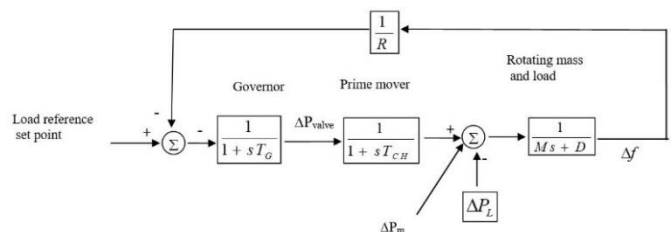

Fig. 2. The Transfer Function Block Diagram Describes the Relationship between the Load Changes and Frequency.

Where, R_{eq} is the modulation coefficient of the equivalent governor of the whole power system.

$$R_{eq} = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + ... + \cfrac{1}{R_n}} \qquad (6)$$

Set $\beta = \left(\dfrac{1}{R_{eq}} + D\right)^{-1}$ is the general frequency response characteristic of power system. It includes the adjustment characteristics of turbine mechanical power and load. From formula (4), obtain:

$$\Delta f = -\Delta P_L . \beta \qquad (7)$$

In [19], the effects of the governor speed droop and the frequency of load on the net frequency change are shown in Fig. 3.

B. Primary and Secondary Frequency Control in the Power System

Primary frequency control is an instantaneous adjustment process performed by a large number of generators with a turbine power control unit according to the frequency variation.

Secondary frequency control is the subsequent adjustment of primary frequency control achieved through the AGC's effect (Automatic Generation Control) on a number of units specifically designed to restore the frequency back to its nominal value or otherwise, the frequency-adjusting effects are independent of the governor's response called the secondary frequency control. The process of the primary and secondary frequency control was shown in Fig. 4.

Characteristic line (A) shows the effect of the governors: change the turbine power according to the change of frequency:

In balance mode, the intersection of the generator characteristic line (A) with the frequency characteristic of the load line (D) determines the frequency f_0 equal 50Hz (or 60 Hz). When the load increases ΔPL, the new characteristic line will be line (E): $P_t + \Delta P$
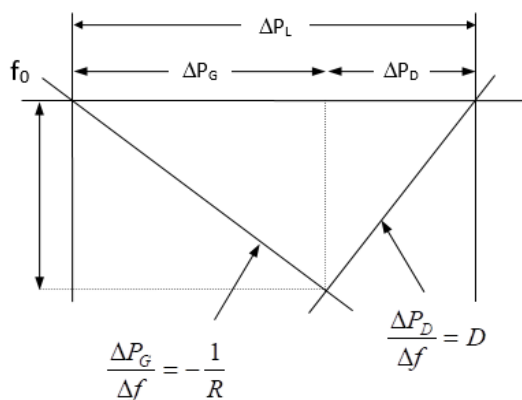

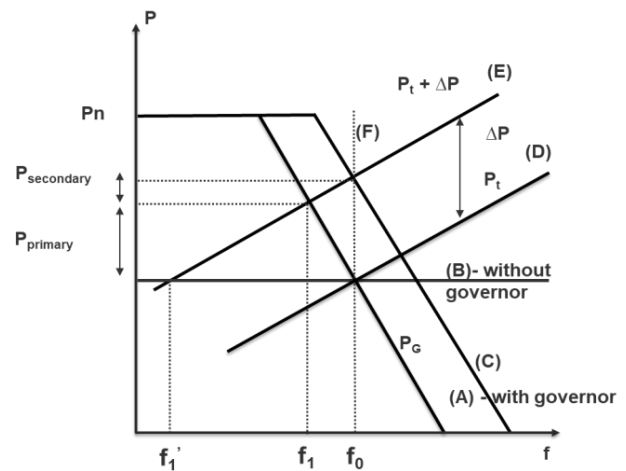Fig. 3.   Synthesized Frequency Response of the Power System.

Fig. 4.   The Relationship between Frequency Deviation and Output Power Deviation.

And, the intersection of the generator characteristic line (A) with the new load characteristic line (E) defines the new frequency f_1. Here, $f_1 < f_0$. Compared to the case where the generator does not have a governor, characteristic line (B), it is clear that: $f_1 < f_0$. According to the characteristic line (A) of the generator unit, the governor does not prevent the frequency reduction: $\Delta f = f_0 - f_1$

However, because the generator has the governor, it has helped to limit the large deviation of the frequency. Compared with the case the generators do not have a governor (B), the intersection with the new characteristic line of the load (E) will determine the frequency f_1: $f'_1 < f_1 < f_0$

Thus, the governor of the generator unit has the effect of reducing the large change of frequency known as the primary frequency controller. The efficiency of the primary frequency control depends on the slope of the speed-droop characteristic of the generator units. In the ideal case, the adjusting characteristic line (F) of the generator unit is vertical line, the frequency will not change until the power limit of the generator unit Pn.

The above characteristics of the primary adjustment process lead to the need for external intervention (by the automatic control device or by the power system operators) - that is the secondary frequency control process. The secondary adjustment characteristic is represented by the simultaneous shifting of the characteristic line (A) into the characteristic line (C) of the generator unit, with the slope unchanged.

This adjustment is equivalent to the creation of a static vertical adjustment characteristic line (F). Thus, the secondary adjustment is within the rated power range of the generator unit to restore and maintain the frequency within the allowable value.

C. Calculate the Minimum Load Shedding Power Considering the Control Characteristic of Turbine Mechanical Power and Load

Define In the 60Hz power system, the frequency deviation allowed Δf_p is 0.3 Hz ($\Delta f_p \leq -0.3$Hz). Therefore, when computed in relative unit (pu):

$$\Delta f_p \le \frac{-0.3}{60}(pu) \tag{8}$$

Thus, from formula (5) the relationship between the permissible change in frequency, the amount of secondary control power and the minimum load shedding power P_{LSmin} is calculated according to the proposed formula below:

$$\Delta f_p = -\beta.[\Delta P_L - (\Delta P_{\text{Secondary control}} + P_{LS\min})] \tag{9}$$

In this case, if $(\Delta P_{\text{Secondary control}} + \Delta P_{LS\min}) < \Delta P_{\text{Sacondary max}}$, then $\Delta P_{LSmin}=0$, otherwise the minimum power load shedding is calculated by the formula below:

$$P_{LS\min} = \Delta P_L - \left(\frac{-\Delta f_p}{\beta}\right) - \Delta P_{\text{Secondary Max}} \tag{10}$$

Where: Δf_p is the permissible change in frequency (pu); P_{LSmin} is the minimum amount of power required to shed (pu); $\Delta P_{\text{Secondary control}}$ is the amount of secondary control power addition to the system.

D. Load Shedding Distribution

The goal of the distribution the amount of load shedding power at load buses is to focus priority on load shedding at around or near the outage generators location. To do this, the concept of the phase electrical distance between two buses is used. The phase electrical distance between the outage generator and load buses is calculated using the proposed process in [20], which is performed as follows:

$$D_P(i,j) = D_P(j,i) = X_{ii} + X_{jj} - 2 \cdot X_{ij} \tag{11}$$

Obviously, two buses electrically very close will always have a very small phase electrical distance. The smaller the phase electrical distance, the nearer the distance between the loads and the generator, and therefore, the smaller the total impedance Z. When generator losses at bus n, the amount of load shedding at different load buses can be calculated in the same way as the principle of the load sharing in the parallel circuit. The general formula calculates the load shedding distribution at nodes according to the phase electrical distance:

$$P_{LSi} = \frac{D_{P,eq}}{D_{P,mi}}.P_{LS\min} \tag{12}$$

With

$$D_{P,eq} = \frac{1}{\sum_{i \ne m} \frac{1}{D_{P,mi}}} \tag{13}$$

Where: m is the number of generator bus; i: is the number of load bus; P_{LSi}: the amount of load shedding power for the i bus (MW); $P_{LS\;min}$: the minimum amount of load shedding

power to the restore of frequency back to the allowable value (MW); $D_{P,mi}$: the phase electrical distance of the load to the m outage generator; $D_{P,eq}$: the equivalent phase electrical distance of all load buses and generator.

III. CASE STUDIES-SIMULATION AND RESULTS

The effectiveness of the proposed method is tested on the IEEE 37 bus 9 generators system [21] single-line diagram which is shown in Fig. 5. The test system consists of 9 generators and 26 loads buses. The generator at Bus-31 are considered as the swing bus. Total the active power and the reactive power of the system are 1046.52 MW and 226.47 MVAR respectively under normal operating conditions. The maximum active power and reactive power of the system are 1087 MW and 449 MVAR. S_{base} = 100MVA for this test system. Parameters of the generators are shown in Table 1. The control solutions minimize the amount of load shedding and maintain steady-state frequency from 59.7 to 60 Hz.

To test the effectiveness of the proposed method, the outage situations of the generator units are calculated, simulated and tested the parameters. In the case of calculations and simulations, the spinning reserved power to control the secondary frequency is also considered. All test cases are simulated on PowerWorld GSO 19 software. The results are compared with the results of the traditional load shedding method using under frequency load shedding relay, and presented in Table 6.

Apply the (7), (9), (10) formulas calculate the system frequency, the amount of primary and secondary control power and the amount of load to be shed. The results of the computation of the outage generator situations are shown in Table 2.

In the test example, the sudden disconnection of the PEAR138 generator (bus 53) is simulated. Applying the equation (7) calculates the stable frequency value when the PEAR138 generator (bus 53) disconnects from the system. The frequency value is 59.6 Hz, and shows in Fig. 6.
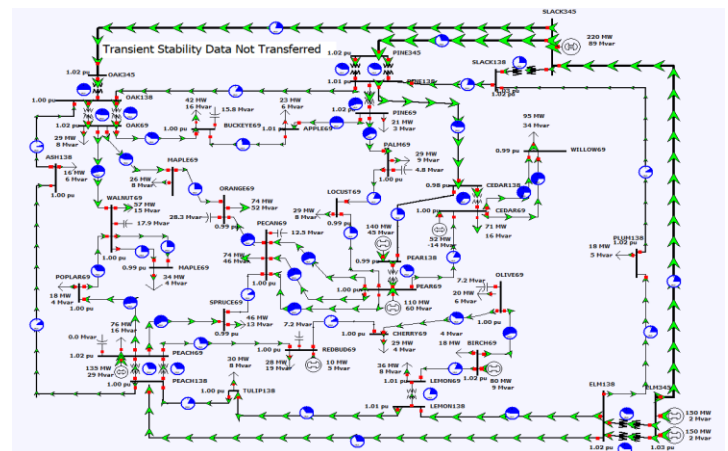

Fig. 5. The IEEE 37 Bus 9 Generators Test System.

TABLE I.   PARAMETERS OF THE GENERATORS IN THE IEEE 37 BUS 9 GENERATORS STANDARD POWER SYSTEM

No. Gen	Name of Gen. Bus	S.new MVA	S.old MVA	R.old p.u	R.new p.u	β (D=2%) pu	Max MW
1	REDBUD69	100	40	0.05	0.125	0.00425	35
2	ELM345_1	100	180	0.05	0.028	0.00482	150
3	ELM345_2	100	180	0.05	0.028	0.00482	150
4	SLACK345	100	250	0.05	0.02	0.00517	220
5	PEACH69	100	160	0.05	0.031	0.00473	150
6	CEDAR69	100	57	0.05	0.088	0.00431	52
7	BIRCH69	100	85	0.05	0.059	0.00442	80
8	PEAR138	100	150	0.05	0.033	0.00469	140
9	PEAR69	100	115	0.05	0.043	0.00454	110

TABLE II.   THE OUTAGE GENERATORS CASES

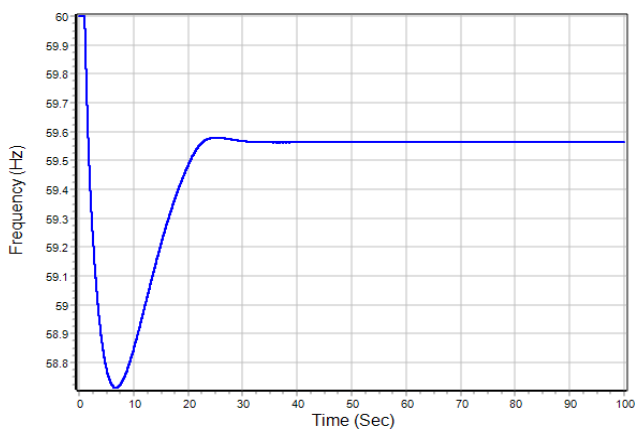| Name of Gen. Bus	Frequency (Hz)	In the allow range	The primary control power value (MW)	The secondary control power value (MW)	The amount of shedding power (MW)
REDBUD	59.97	Yes	10	0	0
ELM345#1	59.56	No	150	7.72	38.57
ELM345#2	59.56	No	150	7.72	38.57
PEACH69	59.62	No	134.6	15.22	13.89
CEDAR69	59.86	Yes	52	0	0
BIRCH69	59.79	Yes	80	0	0
PEAR138	59.6	No	140	18.2	15.42
PEAR69	59.7	Yes	110	0	0

Fig. 6.   The Frequency of the System when the PEAR138 Generator Disconnects.

After the PEAR138 generator suddenly disconnects, the frequency value is less than the allowable value. Therefore, the primary control and secondary frequency control which presented in section II.B for frequency recovery should be implemented. The primary control process is done automatically by the turbine governor after the PEAR138 outage generator. The value of the primary control power of each generator turbine is shown in Table 3.

Because the recovery frequency is less than the allowable value, so the secondary control is implemented after the primary control. The spinning reversed power of the generators will be mobilized to perform the secondary control. In this case, the secondary control power is 18.2 MW. The frequency of the system after the implementation of the secondary control is shown in Fig. 7.

TABLE III.   THE VALUE OF THE PRIMARY CONTROL POWER OF THE GENERATORS

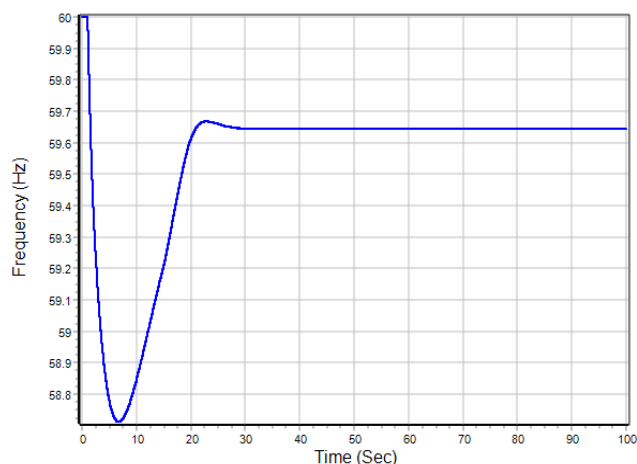| Generator	The increased primary control power of each generator (MW)
REDBUD69 (bus 14)	5.2
ELM345#1 (bus 28)	23.6
ELM345#2 (bus 28)	23.6
SLACK345 (bus 31)	32.8
PEACH69 (bus 44)	21
CEDAR69 (bus 48)	7.5
BIRCH69 (bus 50)	11.2
PEAR138 (bus 53)	0
PEAR69 (bus 54)	15.1
	Total = 140 MW

Fig. 7. The Frequency of the System after the Implementation of Primary and Secondary Control.

Thus, after performing the secondary control, the recovery frequency is 59.65 Hz and has not yet returned to the allowed value. Therefore, the final solution is load shedding. Equation

(10) is applied to calculate the minimum amount of load shedding power to recovery the frequency in allowable value.

$$P_{LS\,\min} = \Delta P_L - \left(\frac{\Delta f_p}{\beta}\right) - \Delta P_{Secondary\,Max}$$

$$= 1.4 - \left(\frac{0.3}{0.0047\,x60}\right) - 0.182 = 0.1542\,pu = 15.42MW$$

After calculating the minimum discharge capacity, the distribution of the layoffs at the loaded buses is done. The lay-off power distribution is based on the phase-to-phase reciprocal sensitivity value between the PEAR138 transmitter and the load buttons.

After calculating the minimum load shedding power, the load shedding distribution at the load buses is calculated. The amount of load shedding at load buses based on the phase electrical distance between the PEAR138 generator and the load buses. Calculation steps at Section II.D are applied to calculate the phase electrical distance between the PEAR138 generator and the load buses. The calculated results are shown in Table 4.

TABLE IV.   THE PHASE ELECTRICAL DISTANCE BETWEEN GENERATORS AND THE LOAD BUSES

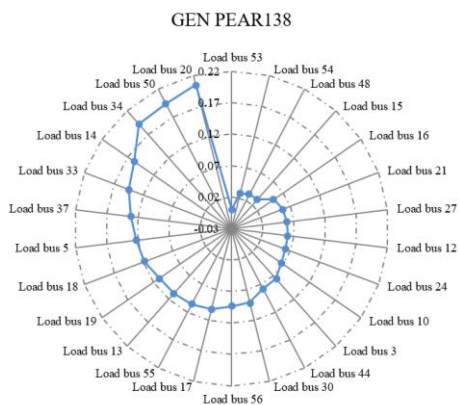| Order by the phase electrical distance increases	Generator REDBUD69 (BUS 14)	Generator ELM345 (BUS 28)	Generator PEACH69 (BUS 44)	Generator CEDAR69 (BUS 48)	Generator BIRCH69 (BUS 50)	Generator PEAR138 (BUS 53)	Generator PEAR69 (BUS 54)
1	Bus 14	Bus 56	Bus 44	Bus 48	Bus 50	Bus 53	Bus 54
2	Bus 34	Bus 30	Bus 30	Bus 21	Bus 20	Bus 54	Bus 15
3	Bus 44	Bus 12	Bus 3	Bus 54	Bus 33	Bus 48	Bus 53
4	Bus 20	Bus 3	Bus 12	Bus 53	Bus 34	Bus 15	Bus 48
5	Bus 30	Bus 44	Bus 24	Bus 15	Bus 30	Bus 16	Bus 16
6	Bus 3	Bus 10	Bus 15	Bus 16	Bus 14	Bus 21	Bus 27
7	Bus 12	Bus 54	Bus 54	Bus 27	Bus 44	Bus 27	Bus 24
8	Bus 50	Bus 15	Bus 5	Bus 24	Bus 3	Bus 12	Bus 12
9	Bus 33	Bus 53	Bus 16	Bus 12	Bus 12	Bus 24	Bus 21
10	Bus 15	Bus 16	Bus 53	Bus 10	Bus 56	Bus 10	Bus 10
11	Bus 54	Bus 27	Bus 27	Bus 44	Bus 15	Bus 3	Bus 44
12	Bus 24	Bus 48	Bus 10	Bus 3	Bus 54	Bus 44	Bus 3
13	Bus 5	Bus 24	Bus 56	Bus 30	Bus 24	Bus 30	Bus 30
14	Bus 16	Bus 17	Bus 48	Bus 56	Bus 53	Bus 56	Bus 55
15	Bus 53	Bus 19	Bus 14	Bus 55	Bus 10	Bus 17	Bus 56
16	Bus 27	Bus 33	Bus 18	Bus 17	Bus 16	Bus 55	Bus 17
17	Bus 56	Bus 21	Bus 37	Bus 13	Bus 27	Bus 13	Bus 13
18	Bus 10	Bus 18	Bus 33	Bus 19	Bus 48	Bus 19	Bus 19
19	Bus 48	Bus 5	Bus 17	Bus 18	Bus 5	Bus 18	Bus 18
20	Bus 18	Bus 13	Bus 21	Bus 5	Bus 18	Bus 5	Bus 5
21	Bus 37	Bus 37	Bus 19	Bus 37	Bus 17	Bus 37	Bus 37
22	Bus 17	Bus 55	Bus 34	Bus 33	Bus 37	Bus 33	Bus 33
23	Bus 21	Bus 14	Bus 13	Bus 14	Bus 21	Bus 14	Bus 14
24	Bus 19	Bus 50	Bus 55	Bus 34	Bus 19	Bus 34	Bus 34
25	Bus 13	Bus 34	Bus 50	Bus 50	Bus 13	Bus 50	Bus 50
26	Bus 55	Bus 20	Bus 20	Bus 20	Bus 55	Bus 20	Bus 20

Fig. 8. The Phase Electrical Distance between the PEAR138 Generator and the Load Buses.

The phase electrical distance relationship between the PEAR138 generator and the load buses is shown in Fig. 8. Observe Fig. 8, which shows that the load buses nearer to the outage generator the lower PED; and the further to the outage generator, the greater the PED.

The priority load shedding distribution for each load bus is calculated based on the following principle: The nearer the load bus from the generator outage, the greater the amount of shedding power. Equation (12) in Section II.D is applied to calculate the amount of disconnection power value at the load buses. Calculated results are presented in Table 5.

TABLE V. THE LOAD SHEDDING DISTRIBUTION AT LOAD BUSES

Load bus	The shedding power at the load buses (MW)
Bus 3	0.578513
Bus 5	0.362864
Bus 10	0.67826
Bus 12	0.736799
Bus 13	0.412951
Bus 14	0.283504
Bus 15	1.372672
Bus 16	0.862628
Bus 17	0.437589
Bus 18	0.376409
Bus 19	0.408538
Bus 20	0.217464
Bus 21	0.776333
Bus 24	0.720498
Bus 27	0.764106
Bus 30	0.488855
Bus 33	0.308558
Bus 34	0.23262
Bus 37	0.34066
Bus 44	0.5695
Bus 48	1.418488
Bus 50	0.229534
Bus 54	1.615205
Bus 55	0.420893
Bus 56	0.476559

In order to compare the effectiveness of the proposed method, the load shedding method using under frequency load shedding relay is used to compare. The process of UFLS is implemented when the frequency reduces below the frequency setting threshold. The load is usually cut step-by-step based on the load shedding table that pre-designed based on the general rule and operator experience. These tables guide the amount of load that should be cut at each step depending on the decrease of frequency. These values are shown in Table 6.

The frequency and the rotor angle comparison between the proposed method and the UFLS method are presented in Fig. 9 and Fig. 10.

It can be seen that the proposed load shedding method has less the amount of shedding (77.85 MW) than the UFLS. Here, the recovery frequency value of the proposed method is lower than the UFLS method. However, this value is still within allowable parameter and acceptable range (59.7Hz). Especially, when considering the phase angle recovery time of the proposed method is equivalent to the UFLS method, although this method has less the amount of load shedding than UFLS method. This can be explained by the fact that a large load at load nodes close to the generator are disconnected causing the phase angle to recover faster.

TABLE VI. THE UFLS SCHEME USING LOAD SHEDDING TABLE [4]

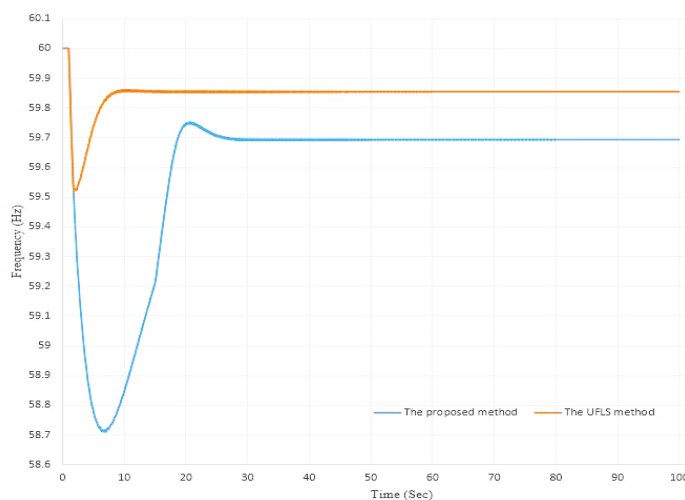| The steps UFLS	Frequency (Hz)	Time delay (s)	The amount of load shedding (the percent of total load) (%)	Total amount of load shedding (%)
A	59.7	0.28	9	9
B	59.4	0.28	7	16
C	59.1	0.28	7	23
D	58.8	0.28	6	29
E	58.5	0.28	5	34
F	58.2	0.28	7	41
J	59.4	10	5	46

Fig. 9. The Frequency Comparison between the Proposed Method and the Traditional Method.

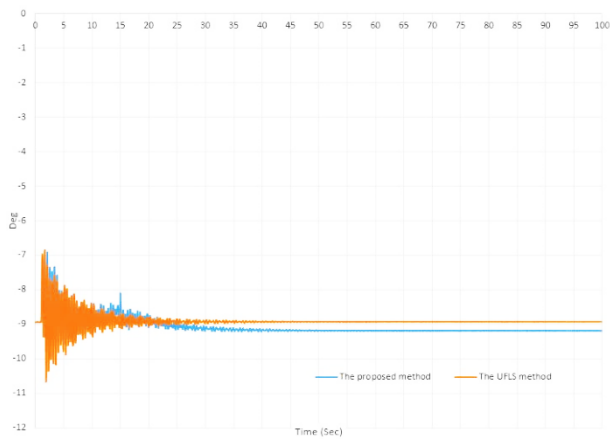Fig. 10. The Rotor Angle Comparison between the Proposed Method and Traditional Method.

IV. CONCLUSIONS

A load shedding method considers to the primary and secondary control elements of the power plant to calculate the minimum amount of load shedding power and restore the frequency back to the allowable value. The proposed method ensures the frequency and rotor angle stability of the system in case of a severe generation–load mismatch. The selection of location and distribution of load shedding power at load buses are based on the phase electrical distance concept.

The effectiveness of the proposed method has been demonstrated on a 9-machine, 37-bus system under different test cases. The performance of this is found to be better than that of a conventional UFLS scheme. The test results show that the proposed method results in reduced amount of load shedding while satisfying the operating conditions and limitations of the network. In the future work, the load shedding problem should consider the following factors: minimum the economic and technical losses, cost of customer service interruption, penalty costs, ... To solve this multi-objective problem, algorithms such as Genetic, PSO, and Fuzzy logic combined with ANN should be considered.

ACKNOWLEDGMENT

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