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The Optimal Location Load Shedding using Electrical Distances

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***Abstract*— When the power system frequency exceeds the allowable values, power system blackout will happen. Therefore, frequency stability within the allowable range is essential. In the case of an emergency, when the large disturbances occur such as short circuits or generator trip, an effective load shedding plan is required to avoid collapsing the power system. This paper proposed a new method for determining the location of the load shedding by using the electrical distance. Load shedding are based on the electrical distance from the load to the fault location. The shorter the loads have electrical distance, the larger the capacity loads will shed. Experiment results showed the amount of load shedding is lower; the frequency response is faster than conventional load shedding.**

Keywords*— *load shedding, electrical distances, load shedding priority, the amount of load shedding, frequency stability

I. INTRODUCTION

There are many methods of load shedding. However, finding a simple, effective, accurate solution has always been the goal of many researches to date. One solution is to use intelligent computer programs for simulation combined with computer algorithms to find the optimal load shedding location.

Statistics on power system outages can be found in [1]. The total number of power system blackout cases since 2010 has accounted for nearly half of the historic decay.

Most of the causes of blackout started with a single incident (or related to each other as short circuit and protection relay fault). In most cases, the power system is capable of bringing the grid back to a safe operating state after an incident. However, if the automatic/manual control of the system can not bring the system back to its original state, the collapse of the elements on the grid will occur [2]. Therefore, load shedding is made as soon as the incident begins to avoid separation from the operation of other elements on the grid. This is necessary when all other control methods can not keep the power system stability.

When a fault or short circuit occurs, the electrical distance from the load around the short circuit point to the source will increase. This leads to the generator rotor angle instability, power oscillation, voltage fluctuations or voltage drop [2]. When a fault can cause a collapse of the system, it will require load shedding in the areas closest to the fault [3]. There are many methods to determining the load shedding location [4,5,6]. In the past, the Under Frequency Load Shedding (UFLS) method, the load was randomly selected on the grid when the frequency reached the load shedding threshold. This method is not effective because load shedding locations are spread across the grid and often are over load shedding or under load shedding. Then, Rate of Change of Frequency (ROCOF) is used to determine the location of the load shedding [7]. By combining voltage and frequency, the choice of load shedding position becomes more reasonable [8]. However, the calculation and prediction of voltages, which vary widely at different locations in the grid, require a number of complex methods of calculation.

In the modern power system, where system parameters are shared on SCADA systems [9], the information on the problem element in the system can easily be shared with other members through the Electric Power Systems Communications [10]. Therefore, it is easily to find the fault locations and control power system stability. In load shedding, when information about the power system fault can be sent to the loads, specific loads will be shed according to a pre-design plan.

Now a day, computer programs can simulate most of the situations on the grid and provide the appropriate solution. By knowing the fault information, the control and protection methods will be implemented according to the predicted fault situations.

This article proposed the method of calculating the position of load shedding when the system had serious incidents on the grid occur. This method is based on calculating the electrical distances of the load compared to the fault point, as shown in section 2. This method also considers the priority of load to find out the amount of load shedding of each load. The simulation results are based on the system frequency response when the load selection is shed.

II. MATERIAL AND METHODS

A. *Frequency deviation and power imbalance*

In the electrical system, when there is an imbalance between the generator power and the load power consumption, the generators will respond to the frequency according to the formula [11]:

$$\Delta P_m(t) - \Delta P_L(t) = 2H\frac{d\Delta f(t)}{dt} + D.\Delta f(t) \qquad (1)$$

where:

ΔP_m the mechanical power change (pu)

ΔP_L the load change (pu)

H the Inertia Constant. The larger the H-constant, the higher the capacity of the generator to meet the load variation.

D the equivalent damping coefficient. This coefficient represents the response of the load to the frequency change.

Δf the frequency deviation (pu)

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Transform the Laplace formula (1), received:

$$\Delta P_m(s) - \Delta P_L(s) = 2H.\Delta f(s) + D.\Delta f(s) \qquad (2)$$

Formula (2) is represented in block diagram as shown in Figure 1

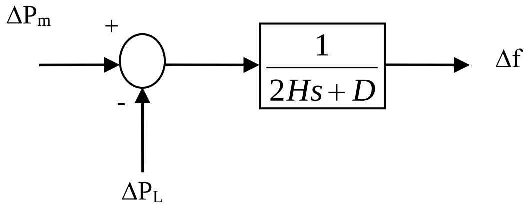

Fig. 1. The relationship between frequency and active power deviation.

When the power system blackout occurs, the frequency deviation Δf exceeds the allowable range of the system due to a serious imbalance between the load and the power source. Therefore, in order to stabilize the power system frequency when the supply power is not sufficient for the load, the load shedding should be performed.

B. Electrical distances

The electrical distance between two bus in the grid is made up of the structure (wiring diagram) of that electrical system. There are a large number of buses that are linked together through wires and transformers that make up the grid configuration. The [Y_{bus}] matrix is calculated from the grid configuration that represents the link between the nodes [12, 13]. From here, finding the relative position between load and fault points on the grid is computed and compared.

In 1990, Patrick Lagonotte defined the electrical distance based on the grid structure [13]. In this paper, the phase distance follows the formula:

$$D_P(i,j) = |Z_{ii} + Z_{jj} - 2.Z_{ij}| \qquad (3)$$

Where:

$D_P(i,j)$: Electrical distance between node i and node j

Z_{ij} : Element of impedances matrix [Z_{bus}]

Frequency deviation is the result of power imbalance between the source and the load. Therefore, in order to simplify the search for the load shedding position, the formula (3) is used to calculate the electrical distance in this article.

III. PROPOSED METHODOLOGY

The algorithm for finding the load shedding position on the grid based on the electrical phase distance is proposed of four main steps as shown in Figure 2.

Step 1: Finding the location of the fault will cause the power system instability when it appears. Then, we calculate the electrical distance. By assuming the faults on the system, the simulation program will show the stability of the system. If the system is unstable at the assumed location, calculate electrical distances from the fault location to the surrounding loads.

Step 2: Consider the load that will be affected by the fault based on the calculated in step 1 and divide the loads into zones. These areas are the effective load shedding area. Therefore, a large amount of load in the fault area will be shed to limit the impact on other areas. The purpose is to divide the load into areas for load shedding to avoid a load near the source being cut too much, including both important load and high economic value loads, while a load that is roughly equivalent is cut too low. This helps to ensure the continuous supply of electricity to large amounts of critical loads.

When loading partitions, loads should be sorted in order of distance from near (i load) to far (i + 1 load, i + 2 load,...) from the consideration location.

By default, the load on the same bus with the fault component takes k = 0. The other loads will be partitioned according to (2). Area k will increase from 1 to n for the near-to-far loads.

D_i is the phase electrical distance from the i[th] load to the generator under consideration; i load and i + 1 load are considered to be the same area k when they meet the condition:

$$|\Delta D_{i+1,i}| < |\Delta D_{i+2,i+1}| \times \alpha \qquad (4)$$

where:

$\Delta D_{i+1,i} = D_{i+1} - D_i$: Distance deviation from i + 1 load to i load

$\Delta D_{i+2,i+1} = D_{i+2} - D_{i+1}$: Distance deviation from i + 2 load to i + 1 load

$\alpha < 1$: Coefficient of deviation (the smaller the coefficient, the less the difference in the between load areas).

Step 3: Determine the total power need to be cut. Based on the partitioning results in step 2, simulate load shedding to find the optimal load shedding.

Let δ be the load shedding coefficient ($0 \le \delta \le 1$). This is a parameter indicating the priority that is cut when the capacity of the load is reduced. On systems where many small loads are grouped into a large load group, a specific load with a coefficient δ as close as 1 indicates that it is a less important load in the system. For a large load consisting of many small loads connected to a system bus, the relationship between the amount of power that can be shed of the load and the coefficient δ is represented by the load shedding curve was shown in Figure 3.

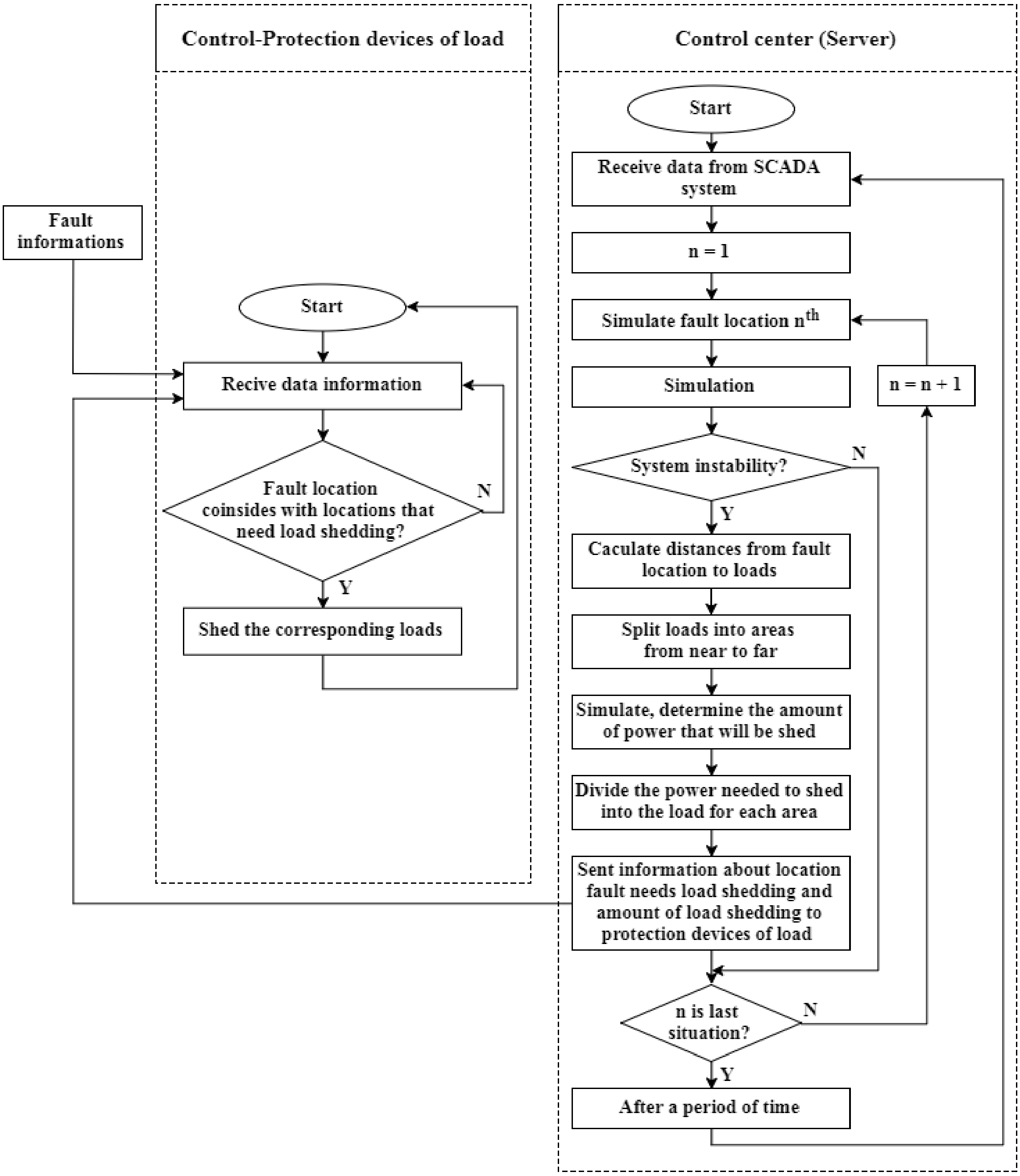

Fig. 2. The algorithm chooses the load shedding position by the electrical distance

In Figure 3, i load is not important load. Because of a load reduction coefficient, i load can cut more power. Similarly, the $i + 2$ important load and the $i + 1$ balanced load are a balanced load between the amount of load that can be cut and the importance of the load. When we implement load shedding, to keep the critical loads, the total load near the area of the fault will not be cut off. Area load shedding coefficient δ_k, ($0 \le \delta_k \le 1$), is used to determine the amount of load that needs to be cut in area k. The coefficient δ_k for the nearest incident area is the largest and then decreases further. The larger the coefficient, the greater the efficiency of the load shedding, but the total power load shedding of areas near the fault area will be greater.

The intersection between the straight line δ_k and the load shedding curve is the required power need to shed of the area k. In figure 3, $P_{1(i)}$ is the amount of power needed to cut the load i, which is also the amount of power to be cut in the area 1 P_1. The amount of power need to cut in are 2 is

$$P_2 = P_{2(i+1)} + P_{2(i+2)}.$$

In the simulation for optimal load shedding, the loads in the k area near the fault position will be prioritized for load shedding. When the P_k load shedding capacity exhausts and the system is still unstable, the load will be shed in the next area. By this simulation, the minimum amount of load shedding will be calculated, which will help the load shedding achieve better results.

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Step 4: Provides information on the location of the power system blackout, load need to be shed and the power need be to cut to load protection device. When the disturbance occurs, the location of the disturbance will be transmitted to the control and protection device of the load through the communication network.

The control and protection device will check to see at the location of the disturbance that it has cut the load at its location or, if so, it will transmit a command and cut amount of load it has installed. It makes the application of the load shedding method more practical.

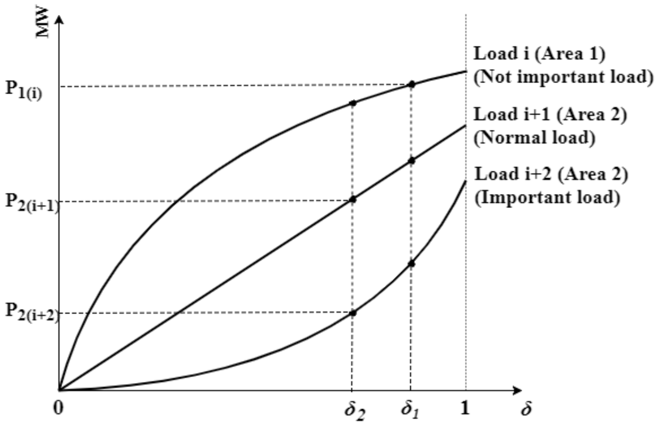


Fig. 3. Determine the power need to load shedding based on load shedding curve and area load shedding coefficient

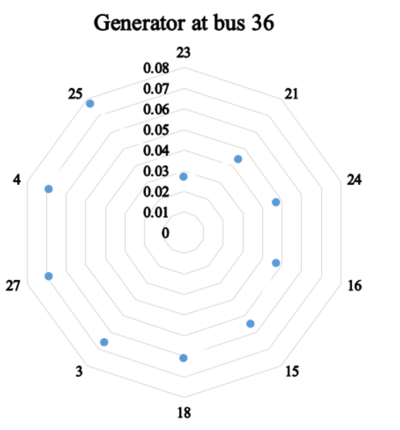
IV. TESTING AND RESULTS

The proposed method is tested on the IEEE 39 bus, 10 generators and 19 loads. In the case study, assuming the generator fault at bus 36, simulation results showed that after the disturbance, frequency decline seriously and collapse the power system. Therefore, it is necessary to apply the proposed method to select the load shedding loacation.

A. Results calculate electrical distance and load partition

Applying step 1 of the proposed method, 10 loads that are closest to the generator at bus 36 divided into areas.

A diagram of the electrical distance from the bus 36 to the loads is given to compare with the partition result from the program (Figure 4).



Load bus	Area
Load 23	1
Load 21	2
Load 24	2
Load 16	2
Load 15	3
Load 18	4
Load 3	5
Load 27	6
Load 4	6
Load 25	7

Fig. 4. Load shedding area for generator at bus 36

B. Results of calculating the amount of load shedding

Because there is no adequate information to determine the load shedding curve according to load shedding coefficient, the load shedding coefficient is chosen: $\delta_1 = 0.85$; $\delta_2 = 0.8$; $\delta_3 = 0.75$.

The maximum capacity load shedding of each load and load areas are calculated according to the proposed method and shown in Table 1.

TABLE 1.
LOAD SHEDDING CAPACITY ACCORDING TO PROPOSED METHOD

Area	Load	P load	δ_k	P load shedding	P area LS
1	23	247.5	0.85	210	210
2	21	274	0.8	219	729
	24	308.6		247	
	16	329		263	
3	15	326	0.75	245	245

C. Simulation results

Simulation with load shedding steps and load shedding capacity are shown in Table 1. In order to compare the effectiveness of the proposed load shedding method and traditional load shedding method, the total load to be shed and the shedding time will be the same as the traditional method. At 1st second the trouble at generator 36 occurs, table 2 shows the steps of load shedding during simulation. At step 1, the amount of load shedding is 5% of the load, when the time is the frequency reaches 59.3Hz. At step 2, the amount of shedding capacity is 15% of the load; the time of load shedding is the frequency reaches 58.9Hz. The frequency, voltage and phase angle of the generators at some of the buses on the system are shown in Figure 5.

Comparative results showed that the intelligent load shedding method based on the phase distance for a stable time faster than the conventional method. When the system implements the second load shedding, the smart load shedding scheme results are in faster frequency recovery (60.21Hz after 53 seconds). The traditional load shedding method achieves a slower frequency (60.01Hz after 100 seconds). In this experiment, the recovery time of proposed load shedding approach is faster than 2 times the traditional load shedding method.

V. CONCLUSIONS

By dividing the load into zones and selecting the load shedding factor for each region based on the electrical distance from the load to the fault location. The problem of finding the ideal load shedding target and determining the load shedding capacity of each load is solved. The experimental results showed that the recovery frequency is very good when using this selection method.

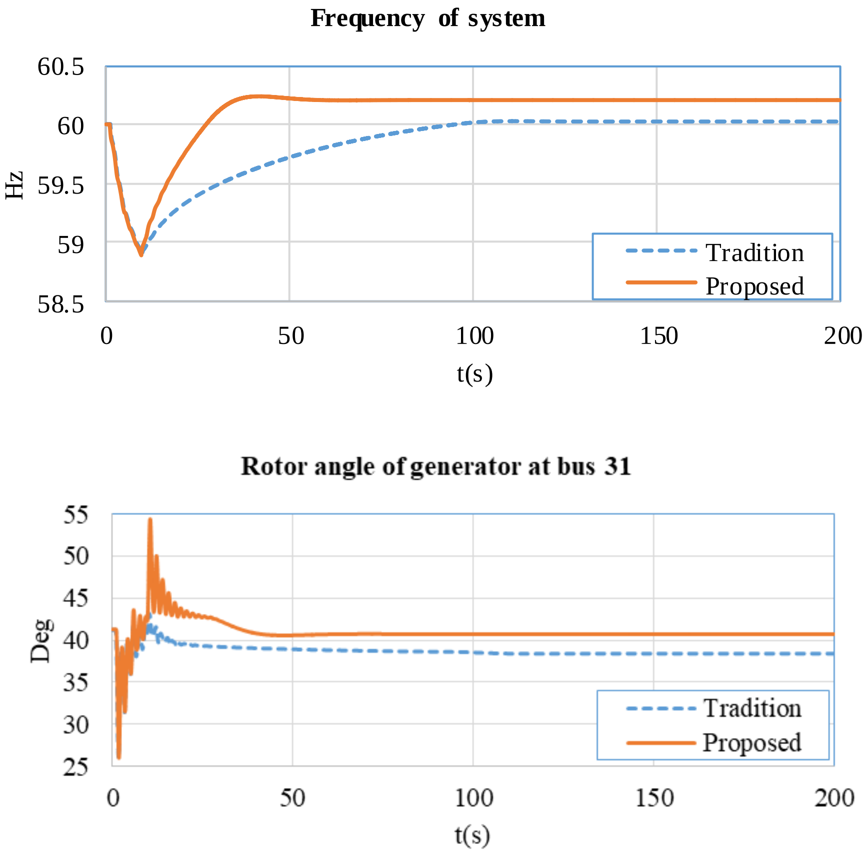


Fig. 5. Compares the effectiveness of the traditional method and the proposed

Knowing the location of the fault, which affects the stability of the system, the computer finds and adjusts the elements around the fault point automatically. It helps the program to protect the power system continuously and reliably.

Extensively, controlling the elements of the electrical system by partitioning based on the electrical distance can be applied to many other optimal control algorithms.

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