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Emergency Control of Load Shedding Based on Fuzzy- AHP Algorithm

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***Abstract*—Load shedding is considered one of the methods used in emergency situations to avoid instability and quickest recovery. In load shedding, anti-instability and spreading, it is important to quickly propose a reasonable load shedding strategy that will allow rapid recovery frequencies and the frequency values are acceptable. This paper presented the building of load shedding strategy that includes pre-designed rules based on the Fuzzy-AHP algorithm. The Fuzzy-AHP algorithm calculates the importance factor of the load in the electrical system. Load shedding are performed with low priority loads to help reduce the economic losses. When the electrical system is determined to be unstable, immediately, the load shedding control commands is executed, so the decision-making time is shortened and the damage caused by the load shedding is reduced compared to the traditional methods. The effectiveness of the proposed method is checked on the IEEE 39-bus system.**

Keywords*— Load Shedding; fuzzy-AHP; power system stability; UFLS

I. INTRODUCTION

Controlling the load shedding in the electrical system requires both economic and technical efficiency. Thereby, it must ensure the power system continues to maintain stability and cause the least damage when the load has to be shed. The method of load shedding by under frequency relay (R81), or under voltage relay (R27) is the most commonly used method for frequency and voltage stability control, and maintenance stability of the system under the necessary conditions [1,2].

In conventional load-shedding, when the frequency or voltage fluctuates outside the pre-set operating range, the under frequency/under voltage relay will cut the load. Therefore, it will prevent the frequency/voltage reduce and its effects. The under frequency load shedding relays are set to cut a predetermined load capacity of 3-5 steps when the frequency reduce below the set threshold in order to keep the power system stable.

To improve the effectiveness of the load shedding, some load shedding methods are based on the declining frequency (df/dt) [3], or are used the second derivative to forecast the frequency and load shedding [4]. These methods mainly restore the frequency of allowable values and prevent the black out. To optimize the amount of load shedding, some intelligent methods were proposed such as: artificial neural networks (ANNs) [5,6], fuzzy logic, neuro-fuzzy, particle swarm optimization (PSO), genetic algorithm (GA) [7-9]. These publications are focused on under frequency load shedding in the steady state of operation of the power system. However, due to the complexity of the electrical system, in the emergency operating mode, these cases had a problem of the burden of calculation; the processing speed of the algorithm program was slow or has to shed the passive load after the frequency was under the threshold. It took much time and caused delay in load shedding decision leading to the instable power system. In particular, in the electricity market today, the need to ensure quality of power and reduce the economic losses associated with load shedding should be addressed.

In order to overcome the limitations of traditional methods, it is necessary to propose a new model for load shedding control based on rules that pre-design according to the Fuzzy-AHP algorithm. When the power system is unstable, the load shedding control commands immediately executes, so the decision-making time is shortened. The effectiveness of the proposed method is test on the IEEE 39-bus electrical system diagram.

II. MATERIALS AND METHODS

A. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty. In short, it is a method to derive ratio scales from paired comparisons [10, 11]. This method presents assessment method and criteria, and works collectively to arrive at a final decision. AHP is particularly well suited for case studies involving quantitative and analytical, making decisions when there are multiple standards-dependent alternatives with multiple interactions.

The steps of the AHP algorithm can be expressed as follows:

Step 1: Set up a decision hierarchy model.

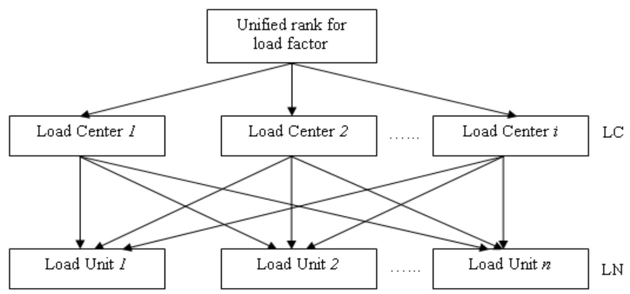

Fig. 1. AHP model of the arrangement of units

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Step 2: Build judgment matrix LC and LN that show the important factor between load centers (LC) and load nodes (LN) each other of the power system. The value of elements in the judgment matrix reflects the user's knowledge about the relative importance between every pair of factors.

$$LC = \begin{bmatrix} w_{D1}/w_{D1} & w_{D1}/w_{D2} & \cdots & w_{D1}/w_{Dn} \\ w_{D2}/w_{D1} & w_{D2}/w_{D2} & \cdots & w_{D2}/w_{Dn} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ w_{Dn}/w_{D1} & w_{Dn}/w_{D2} & \cdots & w_{Dn}/w_{Dn} \end{bmatrix};$$

$$LN = \begin{bmatrix} w_{K1}/w_{K1} & w_{K1}/w_{K2} & \cdots & w_{K1}/w_{Kn} \\ w_{K2}/w_{K1} & w_{K2}/w_{K2} & \cdots & w_{K2}/w_{Dn} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ w_{Kn}/w_{K1} & w_{Kn}/w_{K2} & \cdots & w_{Kn}/w_{Kn} \end{bmatrix} \quad (1)$$

where, w_{Di}/w_{Dj} is the relative importance of the *i*th load node compared with the *j*th load node; w_{ki} /$w_{kj}$is the relative importance of the *i*th load center compared with the *j*th load center. The value of w_{ki} /w_{kj}, w_{Di}/w_{Dj} can be obtained according to the experience of electrical engineers or system operators by using some "1 – 9" ratio scale methods. According to the principle of AHP, the weighting factors of the loads can be determined through the ranking computation of a judgment matrix, which reflects the judgment and comparison of a series of pair of factors. Therefore, the unified weighting factor of the load nodes of the power system can be obtained from the following equation:

$$w_{ij} = w_{Kj} \times w_{Di} \qquad D_i \in K_j \quad (2)$$

where, $D_i \in K_j$ means load node D_i is located in load center K_j.

Step 3: Calculate the largest eigenvalue and corresponding eigenvectors of judgment matrix.

To calculate the eigenvalue of matrix largest judgment, can use the root methods.

(1) Multiply all the components in each row of the judgment matrix.

$$M_i = \prod_i X_{ij} \text{ , i = 1, …, n; j = 1, …, n} \quad (3)$$

Here, n is the dimension of the judgment matrix A, X_{ij} is the element of the matrix A.

(2) Calculate the n th root of Mi

$$M_i = \prod_i X_{ij} \text{ , i = 1, ..., n} \quad (4)$$

Vector W *: $W^* = \left[W_1^*, W_2^*, \ldots, W_n^*\right]^T$ (5)

(3) Standardize vector W *

$$W_i = \frac{W_i^*}{\sum_{j=1}^{n} W_j^*} \text{ , i = 1, ..., n} \quad (6)$$

In this way, there are eigenvectors of matrix A,

$$W = \left[W_1, W_2, \ldots, W_n\right]^T \quad (7)$$

(4) Calculation of the largest eigenvalues of matrix A

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_j}{nW_i} \text{ , j= 1, ..., n} \quad (8)$$

Where, AWi represents the i-th component of the vector AW.

Step 4: Hierarchy ranking and check the consistency of the results.

B. The definition of the triangular fuzzy number and the operational laws of triangular fuzzy numbers [12]

The membership function $\tilde{M}(x): R \to [0,1]$ of the triangular fuzzy number $\tilde{M} = (l, m, u)$ defined on *R* is equal to

$$\tilde{M}(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in [l, m] \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

Where, l ≤ m ≤ u and, l and u are respectively lower and bound values of the support of $\tilde{M}$. According to Zadehs extension principle given two triangular fuzzy numbers $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$ (l_1 and $l_2 \ge 0$).

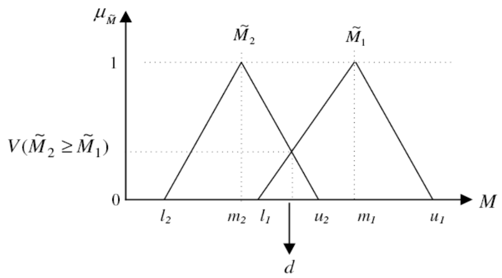

Fig. 2. The comparison of two fuzzy numbers $\tilde{M}_1$ and $\tilde{M}_2$

The extended addition is defined as:

$$\tilde{M}_1 \oplus \tilde{M}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (10)$$

The extended multiplication is defined as:

$$\tilde{M}_1 \otimes \tilde{M}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (11)$$

The inverse of triangular fuzzy number $\tilde{M}_1$ is defined as:

$$\tilde{M}_1^{-1} \approx \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (12)$$

C. Fuzzy - AHP Model

The conventional AHP approach may not fully reflect a style of human thinking. One reason is that decision makers usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values. As a result, fuzzy AHP and its extensions are developed to solve alternative selection and justification problems. Fuzzy-AHP method determines the significance of the load units in the power system, is performed by following these steps [12]:

Step 1: Identify main factors and sub-factors.

Step 2: Develop an AHP model based on these factors determined in Step 1.

Step 3: Calculate the weighting of the important factor of these load centers together and the important factor of load units in the same load center based on the judgment matrix was been fuzzy. Percentage of fuzzy about the important factor to measure the relevant weighting is given in Fig 3 and Table I. This rate was proposed by Kahraman [13] and was used to resolve the problems fuzzy implementation of decisions [13,14].

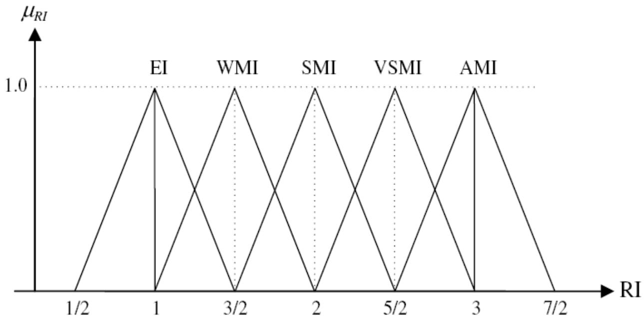

Fig. 3. Linguistic scale for relative importance

TABLE I. LINGUISTIC SCALES FOR DIFFICULTY AND IMPORTANCE

Linguistic scale for difficulty	Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	Just equal	(1,1,1)	(1,1,1)
Equally difficult (ED)	Equally important (EI)	(1/2,1,3/2)	(2/3,1,2)
Weakly more difficult (WMD)	Weakly more important (WMI)	(1,3/2,2)	(1/2,2/3,1)
Strongly more difficult (SMD)	Strongly more important (SMI)	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more difficult (VSMD)	Very strongly more important (VSMI)	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more difficult (AMD)	Absolutely more important (AMI)	(5/2,3,7/2)	(2/7,1/3,2/5)

Step 4: Calculate the weights in the sub-factors (load units) for the whole system. This weight is calculated by multiplying the numerator by the weighted coefficients by the weight of the respective principal factors.

According to Chang's Fuzzy-AHP method [15-17],

$$S_i \approx \sum_{j=1}^{m} \tilde{M}_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} \tilde{M}_{gi}^{j}\right]^{-1} \quad (13)$$

where,

$$\sum_{j=1}^{m} \tilde{M}_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right);$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} \tilde{M}_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i l}\right) \quad (14)$$

The degree of possibility of $\tilde{M}_2 = (l_2, m_2, u_2) \geq \tilde{M}_1 = (l_1, m_1, u_1)$ is defined as:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = sum[\min(\tilde{M}_1(x), \tilde{M}_2(y))]$$

$$V(\tilde{M}_2 \geq \tilde{M}_1) = hgt(\tilde{M}_1 \cap \tilde{M}_2) = \tilde{M}_2(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1 \\ 0, & \text{if } l_2 \geq u_1 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (15)$$

See Fig. 3 $V(\tilde{M}_2 \geq \tilde{M}_1)$ in case $m_2 < l_1 < u_2 < m_1$ where d is the ordinate of the highest intersection point *D* between $\tilde{M}_1$ and $\tilde{M}_2$. To compare $\tilde{M}_1$ and $\tilde{M}_2$ need to both the values of $V(\tilde{M}_1 \geq \tilde{M}_2)$ and $V(\tilde{M}_2 \geq \tilde{M}_1)$. The degree possibility for a convex fuzzy number to be greater than *k* convex fuzzy numbers M_i (i = 1,2,. . .,k) can be defined by

$$V(\tilde{M} \geq \tilde{M}_1, \tilde{M}_2, \ldots \tilde{M}_k) = \min V(\tilde{M} \geq \tilde{M}_i), \text{ i} = 1,2,\ldots,k \quad (16)$$

Finally,

$$W = (\min V(S_1 \geq S_k), \min V(S_2 \geq S_k), \ldots, V(S_n \geq S_k))^T \quad (17)$$

is the weight vector, for k=1,2,…,n.

The weighting importance of the load units of the system is calculated by multiplying the weights of the load nodes with the weight of the corresponding load center.

Step 5: Sort by descending order of importance of each load unit to implement load shedding strategy by priority.

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TABLE II. SORT BY DESCENDING ORDER OF IMPORTANCE OF THE LOAD UNITS

Load Center	**Load**	**W**	**Notes**
LC1 LC1 LC3 LC4	L1 L2	W1 W2 ...	W1>W2> ....

D. Proposed method

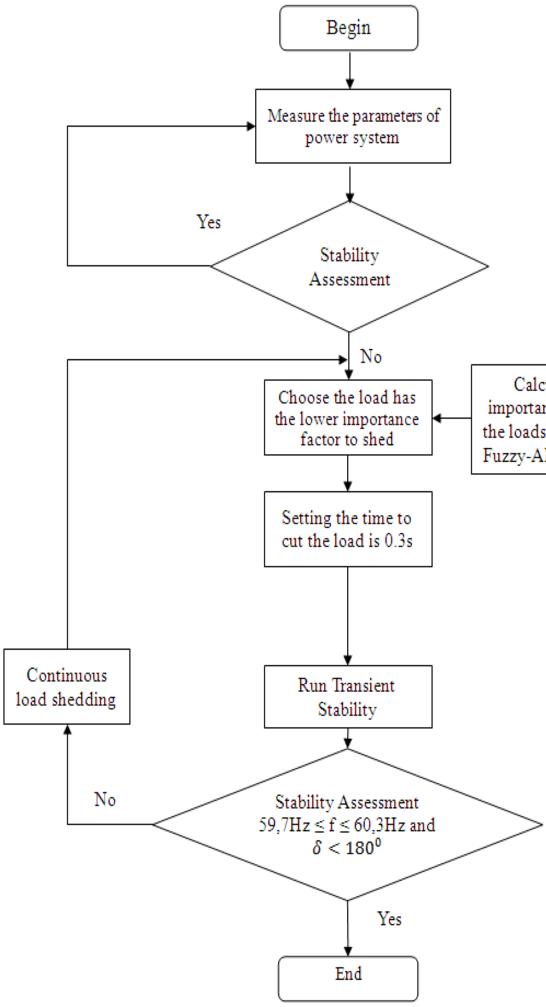

Fig. 4. Flowchart of steps using Fuzzy-AHP method to load shedding

III. SIMULATIONS AND RESULTS

To compare the effectiveness of load shedding base on Fuzzy-AHP, we simulation the proposed algorithm on the IEEE 39 bus system for using case proposed method and using traditional method.

Considering the loss of a generator causes the system to become unstable (frequency decreases less than 59.7 Hz or rotor deviation greater than 180^0 at the bus). Corresponding to each case, it will develop a "control strategy" in the load shedding to restore the parameters back to the initial stable state. This paper simulations using PowerWorld and observes the results obtained when applying the proposed load shedding.

Calculate the importance factor of load based on the Fuzzy - AHP algorithm:

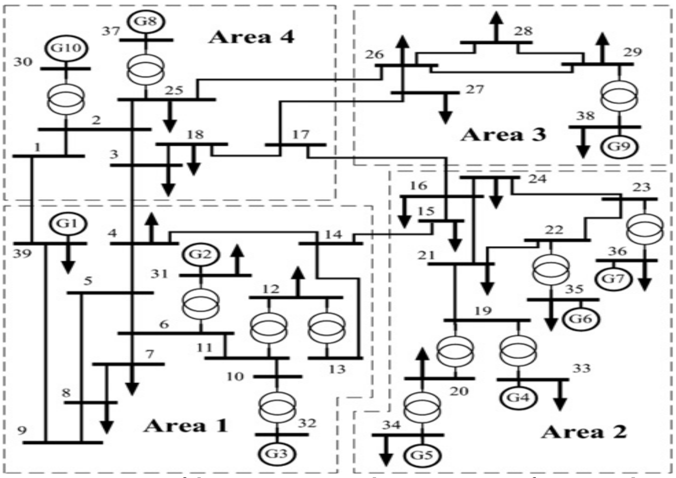

Fig. 5. Diagram of the power system 39 bus 10 generators for case study

Based on the grid of the elements and the number of the loads, divide the system into 4 load centers. This system is similar to a National grid, in which each loading area is a province (or possibly a cluster of provinces). The number of loads in the area is the transformer stations in that province.

Use the Fuzzy - AHP method to determine load and load center weights in the system. Follow the steps of the Fuzzy-AHP algorithm model:

Step 1: Identify the load centers and load units in the load center (main factors and sub-factors).

In this model, the system has four load centers LC1, LC2, LC3, LC4 and has 19 load units as shown in Table III.

TABLE III. SYNTHESIZE DIVISION OF LOAD CENTERS, GENERATORS AND LOADS

LC	GEN	LOAD	N. OF LOAD
LC1	G30,31,32	L4, 7, 8, 12, 31, 39	6
LC2	G33, 34, 35, 36	L15, 16, 20, 21, 23, 24	6
LC3	G38	L26, 27, 28, 29	4
LC4	G37, 39	L3, 18, 25	3

Step 2: Develop a hierarchical AHP model based on load centers and units Load identified in Step 1.

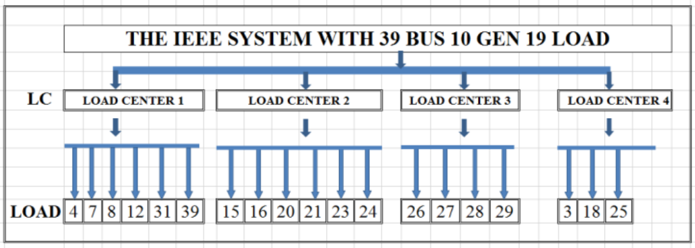

Fig. 6. Fuzzy-AHP model includes load centers and load units

Step 3: Determine the weighting coefficients of importance of load centers and load units using the judgment matrix. To do that, the matrices should be constructed between the load centers and between the loads together in each load center. Based on Table I and the experienced operators of electrical systems determine the main and the sub-factors. These factors were shown in the tables Table IV, Table V, Table VI, Table VII, and Table VIII.

TABLE IV. THE MAIN AND SUB-FACTOR MATRIX OF THE LOAD CENTER.

Ci	C1	C2	C3	C4
	1/1	3/2	2/7	2/5
C1	1/1	2/1	1/3	1/2
	1/1	5/2	2/5	2/3
	2/5	1/1	2/3	3/2
C2	1/2	1/1	1/1	2/1
	2/3	1/1	3/2	5/2
	5/2	2/3	1/1	2/5
C3	3/1	1/1	1/1	1/2
	7/2	3/2	1/1	2/3
	3/2	2/5	3/2	1/1
C4	2/1	1/2	2/1	1/1
	5/2	2/3	5/2	1/1

Where, C_i is the center of load i, i = 1 - 4. This is the 4 row x 4 column, with the value in each row consists of the main position in the middle row and two sub values in the two adjacent rows it. Similarly, the judgment matrices of load in LC1, LC2, LC3, LC4 load centers are calculated.

TABLE V. MAIN AND SECONDARY COEFFICIENTS MATRIX OF LOAD CENTER 1, LC1

LC1	L4	L7	L8	L12	L31	L39
	1/1	2/3	2/3	2/7	2/5	5/2
L4	1/1	1/1	1/1	1/3	1/2	3/1
	1/1	3/2	3/2	2/5	2/3	7/2
	2/3	1/1	5/2	2/3	3/2	2/3
L7	1/1	1/1	3/1	1/1	2/1	1/1
	3/2	1/1	7/2	3/2	5/2	3/2
	2/3	2/7	1/1	2/5	2/3	2/5
L8	1/1	1/3	1/1	1/2	1/1	1/2
	3/2	2/5	1/1	2/3	3/2	2/3
	5/2	2/3	3/2	1/1	2/7	2/7
L12	3/1	1/1	2/1	1/1	1/3	1/3
	7/2	3/2	5/2	1/1	2/5	2/5
	3/2	2/5	2/3	5/2	1/1	2/3
L31	2/1	1/2	1/1	3/1	1/1	1/1
	5/2	2/3	3/2	7/2	1/1	3/2
	2/7	2/3	3/2	5/2	2/3	1/1
L39	1/3	1/1	2/1	3/1	1/1	1/1
	2/5	3/2	5/2	7/2	3/2	1/1

Load Center 1 includes 6 loads: L4, L7, L8, L12, L31, L39, matrix obtained for load center 1 is matrix 6 rows x 6 columns.

TABLE VI. MAIN AND SECONDARY COEFFICIENTS MATRIX OF LOAD CENTER 2, LC2

LC2	L15	L16	L20	L21	L23	L24
	1/1	2/3	2/3	2/7	2/5	2/3
L15	1/1	1/1	1/1	1/3	1/2	1/1
	1/1	3/2	3/2	2/5	2/3	3/2
	2/3	1/1	5/2	2/3	2/3	2/3
L16	1/1	1/1	3/1	1/1	1/1	1/1
	3/2	1/1	7/2	3/2	3/2	3/2
	2/3	2/7	1/1	2/5	3/2	2/5
L20	1/1	1/3	1/1	1/2	2/1	1/2
	3/2	2/5	1/1	2/3	5/2	2/3
	5/2	2/3	3/2	1/1	2/7	2/7
L21	3/1	1/1	2/1	1/1	1/3	1/3
	7/2	3/2	5/2	1/1	2/5	2/5
	3/2	2/3	2/5	5/2	1/1	2/3
L23	2/1	1/1	1/2	3/1	1/1	1/1
	5/2	3/2	2/3	7/2	1/1	3/2
	2/3	2/3	3/2	5/2	2/3	1/1
L24	1/1	1/1	2/1	3/1	1/1	1/1
	3/2	3/2	5/2	7/2	3/2	1/1

TABLE VII. MAIN AND SECONDARY COEFFICIENTS MATRIX OF LOAD CENTER 3, LC3

LC3	L26	L27	L28	L29
	1/1	2/5	2/3	2/3
L26	1/1	1/2	1/1	1/1
	1/1	2/3	3/2	3/2
	3/2	1/1	5/2	2/7
L27	2/1	1/1	3/1	1/3
	5/2	1/1	7/2	2/5
	2/3	2/7	1/1	2/3
L28	1/1	1/3	1/1	1/1
	3/2	2/5	1/1	3/2
	2/3	5/2	2/3	1/1
L29	1/1	3/1	1/1	1/1
	3/2	7/2	3/2	1/1

TABLE VIII. MAIN AND SECONDARY COEFFICIENTS MATRIX OF LOAD CENTER 4, LC4

LC4	L3	L18	L25
	1/1	2/3	2/3
L3	1/1	1/1	1/1
	1/1	3/2	3/2
	2/3	1/1	5/2
L18	1/1	1/1	3/1
	3/2	1/1	7/2
	2/3	2/7	1/1
L25	1/1	1/3	1/1
	3/2	2/5	1/1

According to Chang's Fuzzy-AHP method [15], the formula (13) computes:

$$S_1 = (3.19, 3.83, 4.57) \times \left(\frac{1}{23.57}, \frac{1}{19.33}, \frac{1}{15.72}\right) = (0.14, 0.20, 0.29)$$

$$S_2 = (3.57, 4.5, 5.67) \times \left(\frac{1}{23.57}, \frac{1}{19.33}, \frac{1}{15.72}\right) = (0.15, 0.23, 0.36)$$

$$S_3 = (2.73, 3.50, 4.67) \times \left(\frac{1}{23.57}, \frac{1}{19.33}, \frac{1}{15.72}\right) = (0.19, 0.28, 0.42)$$

$$S_4 = (3.45, 4.33, 5.40) \times \left(\frac{1}{23.57}, \frac{1}{19.33}, \frac{1}{15.72}\right) = (0.19, 0.28, 0.42)$$

Using (15), (16):

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$V(S_1 \geq S_2) = \frac{0.15-0.29}{(0.20-0.29)-(0.23-0.15)} = 0.80$; similar $V(S_1 \geq S_3)$=0.53; $V(S_1 \geq S_4)$=0.55;
$V(S_2 \geq S_1)$=1; $V(S_2 \geq S_3) = \frac{0.19.0.36}{(0.23-0.36)-(0.29-0.19)} = 0.76$;
similar $V(S_2 \geq S_4)$=0.77;
$V(S_3 \geq S_1)$=1; $V(S_3 \geq S_2)$=1; $V(S_3 \geq S_4)$=1
$V(S_4 \geq S_1)$=1; $V(S_4 \geq S_2)$=1; $V(S_4 \geq S_3)$=1.
Using (16):
$d'(C_1) = V(S_1 \geq S_2, S_3, S_4)$=min(0.80,0.53,0.55)=0.53
$d'(C_2) = V(S_2 \geq S_1, S_3, S_4)$=min(1,0.76,0.77)=1
$d'(C_3) = V(S_3 \geq S_1, S_2, S_4)$=min(1,1,1)=1
$d'(C_4) = V(S_1 \geq S_4, S_2, S_3)$= min(1,1,1)=1
Thus, W'=(0.53,0.76,1,1), from which the weights or vectors are calculated W=(0.16,0.23,0.30,0.30) based on the formula $W_i = \frac{W_i^*}{\sum W^*_i}$.

Similar to such calculation, find the weights of each load center and of each load in the center. The results for the remaining cases are shown in Table IX.

TABLE IX. WEIGHT OF LOADS IN EACH CENTER.

Weight	LC1	LC2	LC3	LC4
W1	0,1519630935	0,0992308192	0,1371793201	0,2895529185
W2	0,2152410974	0,2162023778	0,3872652285	0,6625677390
W3	0,0560022057	0,1111338061	0,1122063232	0,0478793425
W4	0,1767634431	0,1002503983	0,3633491282	-
W5	0,2023422316	0,2294871676	-	-
W6	0,1976879287	0,2436954311	-	-

After obtaining the values W_{kj} and W_{di}, compute the coefficients of gross coefficient combined W_{ij} of each load. The value is calculated by the formula W ij = W_{kj}.x W_{di}, that is, multiply by two the weighted values of the load and the weight of the center together. Weights W_{kj} in the same load center is the same and equal to the value W_{kj}. After calculating the important factor of each load unit at each stage from Fuzzy-AHP calculations, arrange loading units in descending order of priority as shown in Table X. The more important loads are, the greater the W_{ij} are.

TABLE X. ARRANGE LOADING UNITS BY THE WEIGHT FACTOR OF THE LOAD FACTOR W_{IJ}

No	Loads	The important factor of load units	LC	The important factor of load centers	The important factors
1	L18	0,6625677390	LC4	0,3037660388	0,2012655775
2	L27	0,3872652285	LC3	0,3037660388	0,1176380244
3	L29	0,3633491282	LC3	0,3037660388	0,1103731254
4	L3	0,2895529185	LC4	0,3037660388	0,0879563431
5	L24	0,2436954311	LC2	0,2318391143	0,0564981329
6	L23	0,2294871676	LC2	0,2318391143	0,0532041017
7	L16	0,2162023778	LC2	0,2318391143	0,0501241678
8	L26	0,1371793201	LC3	0,3037660388	0,0416704187
9	L7	0,2152410974	LC1	0,1606288080	0,0345739209
10	L28	0,1122063232	LC3	0,3037660388	0,0340844703
11	L31	0,2023422316	LC1	0,1606288080	0,0325019915
12	L39	0,1976879287	LC1	0,1606288080	0,0317543763
13	L12	0,1767634431	LC1	0,1606288080	0,0283933012
14	L20	0,1111338061	LC2	0,2318391143	0,0257651632
15	L4	0,1519630935	LC1	0,1606288080	0,0244096506
16	L21	0,1002503983	LC2	0,2318391143	0,0232419636
17	L15	0,0992308192	LC2	0,2318391143	0,0230055852
18	L25	0,0478793425	LC4	0,3037660388	0,0145441182
19	L8	0,0560022057	LC1	0,1606288080	0,0089955675

From Table X, it is found that load L8 has the largest order number (19th) that is the load has the lowest priority and will be cut off first. Load L18 with the smallest ordinal number (numbered 1st), meaning that this load has the highest priority and will be cut off in the end in any case.

From here, the following order can be given: L8, L25, L15, L21, L4, L20, L12, L39, L31, L28, L7, L26, L16, L23, L24, L3, L29, L27, L18.

The Fuzzy-AHP method is used to determine the arrangement of load units in priority order at all times and the load shedding system will cut the load on the system smallest number before.

Apply the proposed method proceed to load shedding the load until the frequency of recovery return to a value greater than 59.7Hz. The results of frequency simulation were shown in Fig. 7.

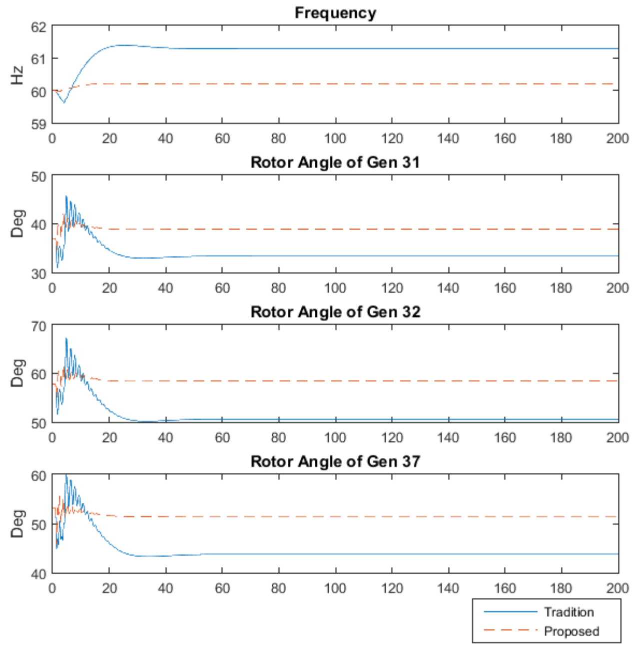

Fig. 7. Compares the effectiveness of the traditional method and the proposed method

Compared the load shedding methods based on traditional method (under frequency load shedding) and Fuzzy-AHP algorithm, in both cases the frequencies were restored to allowed values. However, the load shedding according to Fuzzy-AHP algorithm had total load shedding capacity lower than under frequency load shedding. Especially, the frequency recovery time and rotor angle of Fuzzy-AHP method are faster than traditional method.

IV. CONCLUSIONS

Load shedding based on Fuzzy-AHP algorithm is applied in the emergency situations to maintain stability of the power system. This paper proposed a new method to build load shedding strategies according to the pre-designed rules based on Fuzzy-AHP algorithm. The implementation of load shedding was made immediately after evaluating the instability of the power system, helping the system to recover faster in emergency. Simulation results on the IEEE 39 bus system showed that the effectiveness of the proposed method.

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