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Application of fuzzy-analytic hierarchy process algorithm and fuzzy load profile for load shedding in power systems

Trong Nghia Le*, Huy Anh Quyen, Ngoc Au Nguyen

Faculty of Electrical and Electronics Engineering, HCMC University of Technology and Education, 1 Vo Van Ngan Str., Thu Duc Dist., Ho Chi Minh City, Viet Nam

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ABSTRACT

In an electrical competitive market, load shedding decision support systems are needed to find the ways to process load shedding to satisfy both economic and technical conditions. This paper proposed the Fuzzy Analytic Hierarchy Process algorithm (Fuzzy-AHP) and fuzzy logic for load profile approach to determine the weight of the load nodes of the system and select the control strategy when the system operates at various load levels. Weights of the load nodes were calculated by triangular fuzzy numbers in the pair comparison. These results combined with the fuzzy logic for load profile to draw out the suitable control strategies for various load levels in case of emergency. The effectiveness of the algorithm was demonstrated through the experiment of load shedding of IEEE 37 bus compared with traditional AHP algorithm.

Introduction

When all the available controls can't maintain a stable frequency of electrical power systems, load shedding will be used as a last resort and effectively to restore the frequency return to permissible limits [1,2]. Although successful at certain levels, traditional load shedding methods based on under frequency or voltage relays had disadvantages as follows: only consider the declining frequency or voltage of the system, the shedding power amount was scaled according to each threshold reduce the frequency, in this case the results were often less accurate; load shedding capacity of a step sometimes was so large, it causes excessive load curtailment, the plans did not have the flexibility to increase the number of load shedding steps [3,4].

To improve the effectiveness of load shedding, some load shedding methods based on frequency, voltage and QV sensitivity in the load buses. However, these approaches only interested in aspects of decreasing frequency, or voltage, but did not interest in the economic aspects, meaning that the suspension of power supply to the load will cause damages to various load types. In some cases, the speed of processing algorithm programs was relatively slow [5]. Moreover, on today the electricity market, the load shedding needs to consider the economic indicators and the important factor of the loads in order to reduce to the minimum of the damages.

There were a lot of Fuzzy-AHP methods that were proposed by various authors [6–10]. This paper presented the application of the Fuzzy-AHP algorithm and fuzzy logic for load profile to load shedding. When using this method, the load shedding considered to the important factor of the load to cut the less important loads before and contribute to reduced damages. Also, coefficients did not measure correctly will be evaluated effectively using fuzzy techniques to resolve the limitations of the previous studies.

Approach methods

Analytic hierarchy process algorithm

Analytic hierarchy process algorithm [11,12] is performed by following these steps (see Fig. 1):

Step 1: Set up a decision hierarchy model
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.

* Corresponding author.

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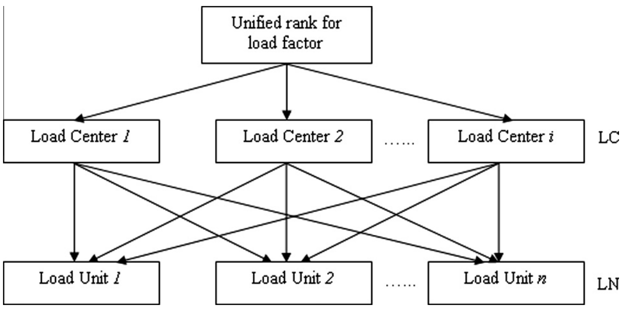

Fig. 1. Analytic hierarchy process scheme.

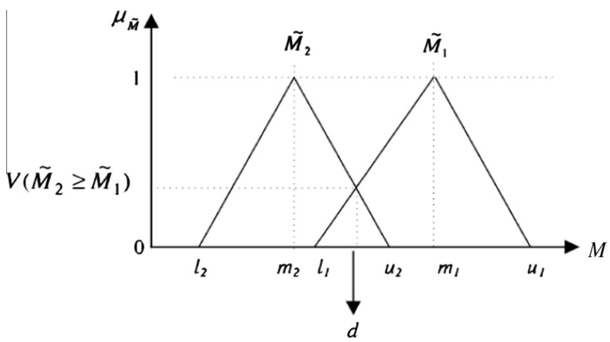

Fig. 2. The comparison of two fuzzy numbers $\tilde{M}_1$ and $\tilde{M}_2$.

$$\mathrm{LC} = \begin{bmatrix} w_{D1}/w_{D1} & w_{D1}/w_{D2} & \cdots\cdots & w_{D1}/w_{Dn} \\ w_{D2}/w_{D1} & w_{D2}/w_{D2} & \cdots\cdots & w_{D2}/w_{Dn} \\ \vdots & & \vdots & \\ w_{Dn}/w_{D1} & w_{Dn}/w_{D2} & \cdots\cdots & w_{Dn}/w_{Dn} \end{bmatrix}; \quad \mathrm{LN} = \begin{bmatrix} w_{K1}/w_{K1} & w_{K1}/w_{K2} & \cdots\cdots & w_{K1}/w_{Kn} \\ w_{K2}/w_{K1} & w_{K2}/w_{K2} & \cdots\cdots & w_{K2}/w_{Dn} \\ \vdots & & \vdots & \\ w_{Kn}/w_{K1} & w_{Kn}/w_{K2} & \cdots\cdots & w_{Kn}/w_{Kn} \end{bmatrix} \tag{1}$$

where w_{Di}/w_{Dj} is the relative importance of the ith load node compared with the jth load node; w_{ki}/w_{kj} is the relative importance of the ith load center compared with the jth 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:

$$w_{ij} = w_{kJ} \times w_{Di} \quad D_i \in K_j \tag{2}$$

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

Step 3: Calculate the maximal eigenvalue and the corresponding eigenvector of the judgment matrix.

Step 4: Hierarchy ranking and consistency check of results.

The definition of the triangular fuzzy number and the operational laws of triangular fuzzy numbers [13]

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

$$\tilde{M}(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in [l, m] \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where $1 \leqslant m \leqslant u$ 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 $l_2 \geqslant 0$).

The extended addition is defined as:

$$\tilde{M}_1 \oplus \tilde{M}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{4}$$

The extended multiplication is defined as:

$$\tilde{M}_1 \otimes \tilde{M}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{5}$$

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

$$\tilde{M}_1^{-1} \approx \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{6}$$

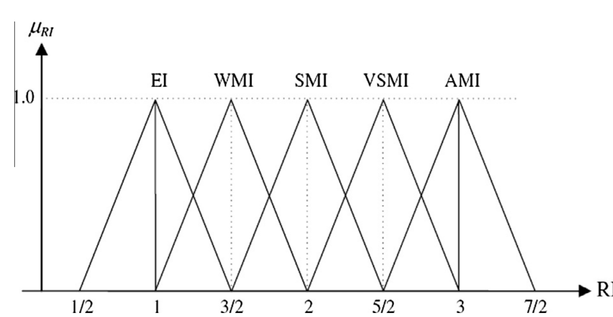

Fig. 4. Linguistic scale for relative importance.

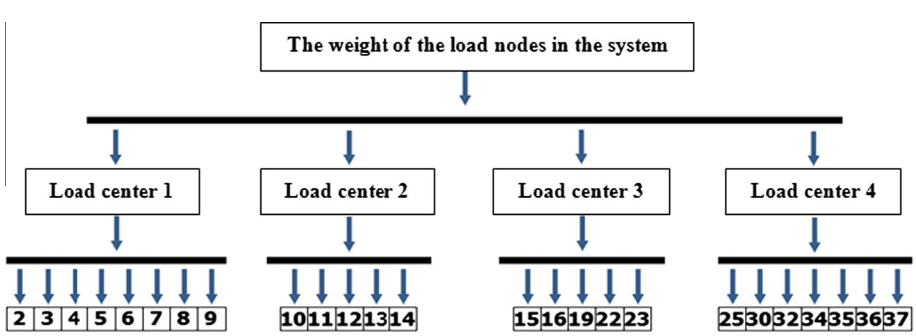

Fig. 3. Fuzzy-AHP model includes load centers and load units.