International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 5, October 2023, pp. 4919~4930
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i5.pp4919-4930

Ranking load in microgrid based on fuzzy analytic hierarchy process and technique for order of preference by similarity to ideal solution algorithm for load shedding problem

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Article Info

Article history:

Received Dec 5, 2022
Revised Feb 20, 2023
Accepted Mar 9, 2023

Keywords:

Fuzzy AHP TOPSIS
Load importance factor
Load shedding
Ranking load
Voltage electrical distance
Voltage sensitivity index

ABSTRACT

This paper proposes a method to rank the loads in the microgrid by means of a weight that combines the criteria together in terms of both technical and economic aspects. The fuzzy analytic hierarchy process technique for order of preference by similarity to ideal solution (fuzzy AHP TOPSIS) algorithm is used to calculate this combined weight. The criteria to be considered are load importance factor (LIF), voltage electrical distance (VED) and voltage sensitivity index (VSI). The fuzzy algorithm helps to fuzzy the judgment matrix of the analytic hierarchy process (AHP) method, making it easier to compare objects with each other and remove the uncertainty of the AHP method. The technique for order of preference by similarity to ideal solution (TOPSIS) algorithm is used to normalize the decision matrix, determine the positive and negative ideal solutions to calculate the index of proximity to the ideal solution, and finally rank all the alternatives. The combination of fuzzy AHP and TOPSIS algorithms is the optimal combination for decision making and ranking problems in a multi-criteria environment. The 19-bus microgrid system is applied to calculate and demonstrate the effectiveness of the proposed method.

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1. INTRODUCTION

In the power system, the loads play an important role as electricity consumers. When a power shortage occurs, it is imperative to shed some of the load to ensure power balance and maintain the frequency within the allowable limits. The problem is distribution shedding power to the loads in an optimal way. Therefore, it is necessary to calculate the weights for the loads, this weight helps to rank the loads in the system and it is the weight to decide the amount of power shedding of each load. This weight needs to meet both the economic aspect and the technical aspect to ensure the optimal distribution.

Several investigations have been conducted on power system load shedding, as demonstrated in references [1]–[4]. The primary focus of these studies is on calculating the power that needs to be shed during times of excess demand. The techniques used for power shedding mainly address the technical aspects of the system, and do not take into account the economic costs associated with such shedding. Other studies have examined the problem of load ranking during shedding, as demonstrated in [5]–[7], these studies are interested in economic benefits when ranking loads according to their importance. However, technical issues were not mentioned.

There are many techniques used in the ranking problem as in [8]–[10] using the analytic hierarchy process (AHP) method to rank objects or criteria. However, the AHP method has a major disadvantage that the accuracy of the results depends on the subjective opinion of the proponent of the judgment matrix, which is not good for the ranking problem. In [11]–[13] fuzzy AHP method is used for ranking. Although the fuzzy AHP algorithm has solved the problem of subjectivity in proposing the judgment matrix. However, in the multi-criteria ranking problem, it is still not possible to optimize the ranking, because the closeness of the ranking objects has not been determined compared to the best solution in the multi-criteria environment. In [14]–[16] the ranking process is carried out using the technique for order of preference by similarity to ideal solution (TOPSIS) method. The TOPSIS algorithm has the advantage of giving good performance in a multi-criteria ranking environment. However, the input data of this method requires the evaluation of the subjects according to the criteria, so this method is not always applicable. In [17], [18] apply the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) that means: multicriteria optimization and compromise solution method for ranking. Although VIKOR is a good method in a multi-criteria ranking environment, it does not have a consistency check step, so the confidence of the ranking results will not be high if the input data is not guaranteed. These methods have certain advantages for their subjects and criteria. Besides, their disadvantages are also shown in the above studies. The accuracy of the ratings will depend on the accuracy and consistency of the input matrix. Fuzzy applying the fuzzy method of input matrices can solve this problem.

In this paper, the author proposes a load ranking method based on fuzzy AHP TOPSIS method. This method is proposed to calculate the weights of loads based on economic and technical criteria. In which, the economic aspect refers to the load importance factor (LIF), the technical aspect refers to the voltage electrical distance (VED) and voltage sensitivity index (VSI). The calculation of the weights of the loads is based on the criteria that help to rank the shedding priority of the load, the load with a low aggregate weight value (i.e. high shedding priority) will shed with a larger amount of power and vice versa. With the application of this distribution method, the system will ensure a balance between stabilizing operating specifications and minimizing economic losses caused by load shedding.

2. METHOD

In the power system in general and the microgrid in particular, the loads need to be compared and evaluated for their importance. This helps the operator to evaluate and rank the loads. When there is a problem of lack of generating capacity in the grid, The load ranking results will be used in prioritizing power cuts to help the system restore power balance. The problem is what criteria are the basis for comparing and evaluating the loads. In this study, the criteria of LIF, VED and VSI are used as the basis to evaluate and rank the loads. In which, LIF criteria will be evaluated in economic aspect, VED and VSI criteria will be evaluated in technical aspect. The steps of this study are presented in the sequence in Figure 1.

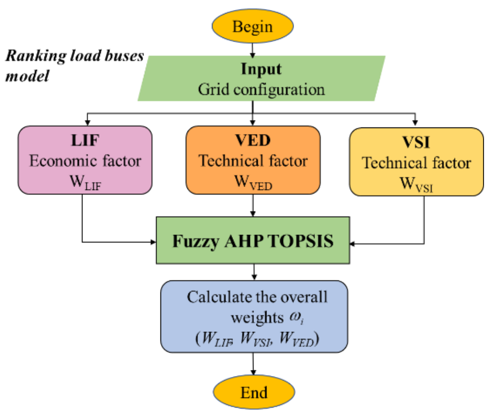

Figure 1. Flowchart illustrating the proposed method

2.1. Ranking of loads in the system

2.1.1. Criterion 1: LIF

LIF is calculated using the fuzzy-AHP algorithm, which was originally developed by Bernasconi *et al.* [19]. The fuzzy AHP method is used in a similar way to the AHP method, but with the addition of a fuzzy triangulation scale. This scale helps to facilitate the comparison of objects and eliminates the uncertainty inherent in the AHP method. In simpler terms, the fuzzy AHP method is an extension of the AHP method, incorporating a fuzzy scale to increase its effectiveness.

The fuzzy AHP method follows these steps: [20], [21]

Step 1: Establish a hierarchical model

Step 2: Set up the judgment matrix

A matrix derives from the opinions of experts when comparing objects with each other. Subjects will be evaluated in pairs according to the ratio-9 method [22]. The form of the judgment matrix is shown in formula 2.1.

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nn} \end{pmatrix} \tag{1}$$

Step 3: Calculate the eigenvalues and eigenvectors of the judgment matrix

Apply the sum method to perform the calculation steps of step 3 [22].

– Standardize each column in the judgment matrix

$$X_{ij}^{*} = \frac{X_{ij}}{\sum_{k=1}^{n} X_{kj}} \quad i, j = 1,2,\ldots,n \tag{2}$$

– Calculate the sum of all elements in each row of the matrix X*

$$W_i^{*} = \sum_{j=1}^{n} X_{kj}\,, \quad i = 1,2,\ldots.,n \tag{3}$$

– Normalizing W*

$$W_i = \frac{W_i^{*}}{\sum_{j=1}^{n} W_j^{*}}\,, \; i = 1,2,\ldots\ldots,n \tag{4}$$

This results in obtaining the eigenvector of the judgment matrix X

$$W = [W_1, W_2, \ldots., W_n]^T \tag{5}$$

– The maximal eigenvalue λ_{max} of the judgment matrix is calculated

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_j}{nW_i},\; j = 1,2,\ldots\ldots,n \tag{6}$$

here, $(AW)_i$ refers to the i^{th} element in the vector AW.

Step 4: Evaluate and ensure the consistency of the matrix

The judgment matrix proposed by experts only ensures consistency when the consistency ratio (CR) ≤10%. If CR is greater than 10%, it is necessary to re-evaluate and re-propose the judgment matrix [22].

$$CR = \frac{CI}{RI} \tag{7}$$

here, CR represents the consistency rate, CI represents the consistency index, and RI is a random index, it depends on the number of order n of the judgment matrix, the RI values are given by Zhu [22].

The CI Consistency Index was established by Saaty and calculated using the (8),

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{8}$$

Steps 3 and 4 of the process are designed to evaluate the consistency of the judgment matrix, which is a necessary condition for proceeding with the fuzzy in step 5.

Step 5: Set up triangular fuzzy number (TFN)

The fuzzy-AHP scale has three values: the lowest value lower (L), the middle value median (M) and the highest value upper (U). These values were selected based on the TFN ratio table [21]. The fuzzy set of triangles is presented in Figure 2. The membership function of the fuzzy triangle is given by (9).

$V(M2 \geq M1)$

$$\mu\tilde{M}(x) = \begin{cases} 1, & \text{if } m_2 \geq m_1 \\ 0, & \text{if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{or} therwise \end{cases} \quad (9)$$

Step 6: Determine the weight value of the fuzzy vector

The formula (10) is used to calculate the geometric mean of the fuzzy comparison values for each criterion. Here, $\tilde{r}$ remains in the form of a triangular value [23].

$$\tilde{r} = (\prod_{j=1}^{n} \tilde{d}_{ij})^{\frac{1}{n}},\ i = 1, 2, \ldots, n \quad (10)$$

Step 7: Determine fuzzy weights for the criteria

- Calculate the vector sum of each $\tilde{r}$
- Obtain the inverse of the vector summation and rearrange the fuzzy triangular numbers in ascending order.
- Determine the fuzzy weight $\widetilde{W}_i$ for the criterion

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} = (lw_i, mw_i, uw_i) \quad (11)$$

Step 8: Defuzzification for weights $\widetilde{W}_i$

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \quad (12)$$

Step 9: Normalize for the value M_i, the alternative with the highest score will be evaluated for priority for decision making.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (13)$$

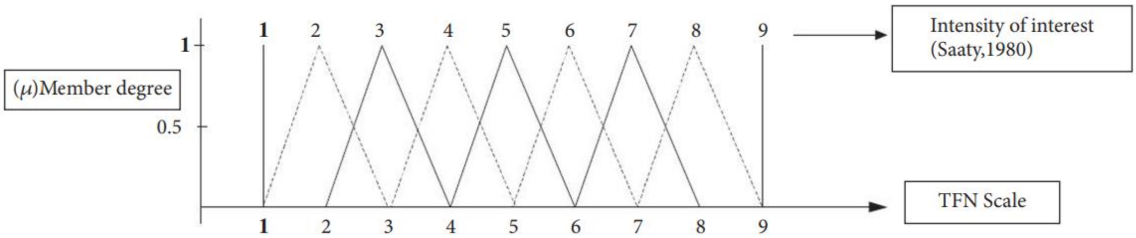

Figure 2. Fuzzy triangle set [21]

2.1.2. Criterion 2: VED

VED is the physical relationship in terms of voltage in the power system [24], [25]. Let $\alpha_{ij} = (\partial V_i/\partial Q_j)/(\partial V_j/\partial Q_j)$ represent the voltage drop on the ith load bus relative to the faulty source bus. The VED of i-bus and j-bus is defined by formula (14). To transform VED into weighted values, with m bus loads in the microgrid the VED weight normalization formula is presented as formula (15).

$$D_{V(i,j)} = D_{V(j,i)} = -\log(\alpha_{ij}.\alpha_{ji}) \quad (14)$$

$$W_{VED_i} = \frac{D_{V(i,j)}}{\sum_{1}^{m} D_{V(i,j)}} \quad (15)$$

Formula (14) indicates that the D_V decreases or α_{ij} increases as the distance between the buses becomes closer. In the event of a disconnection from the main grid, voltage fluctuations near the connection point can be significant, resulting in a higher voltage drop at buses with smaller VEDs. Therefore, to ensure effective voltage recovery of the system, larger load shedding power is required for buses with smaller VEDs and vice versa.

2.1.3. Criterion 2: VSI

VSI is a solution to help operators monitor the voltage drop of the system [25], [26]. VSI is calculated by formula (16). The primary goal of VSI is to determine the distance between the current operating point and the marginally stable point, with the aim of identifying the most sensitive buses in the system. These buses will be given a higher priority for load shedding, with a larger amount of power being shed from them. To transform VSI into weighted values, with m bus loads in the microgrid the VSI weight normalization formula is presented as (16).

$$VSI_i = \sqrt{\frac{\sum_{k=1}^{n}(1-V_k)^2}{n}} \tag{16}$$

here, V_k represents the voltage at bus k, and n denotes the total number of buses in the system (17),

$$W_{VSI_i} = \frac{VSI_i}{\sum_1^m VSI_i} \tag{17}$$

2.1.4. Calculate the aggregate weight of the criteria

Ranking in a multi-criteria environment requires a reasonable calculation, comparison and evaluation about the weights of the criteria. In this section, the fuzzy AHP TOPSIS is used to calculate the aggregate weights among the criteria. From there, the results of the load ranking in the system are determined. Section 2.1.1 showed the approach for implementing fuzzy AHP.

a. TOPSIS method

Hwang and Yoon [27] were the first to introduce TOPSIS, which is a technique for making multi-criteria decisions. The steps to implement TOPSIS are presents in [28]

Step 1: An evaluation matrix can be created with m alternatives and n criteria, so there is a matrix $(x_{ij})_{mxn}$.

Step 2: The matrix $(x_{ij})_{mxn}$ is then normalized to form the matrix $R=(r_{ij})_{mxn}$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}},\ i = 1,2,\ldots..,m,\ j = 1,2,\ldots..,n \tag{18}$$

Step 3: Determine the normalized weight of the decision matrix

$$t_{ij} = r_{ij} \otimes N_i,\ i = 1,2,\ldots.,m,\ j = 1,2,\ldots..,n \tag{19}$$

here, N_i is the weight of the criteria calculated in step 9 of the fuzzy AHP algorithm.

Step 4: Using the formula provided below, identify the ideal solution matrix consisting of both positive and negative ideal solutions:

$$A^+=\{(\max(t_{ij}\,|i=1 \text{ to } m)|\ j\epsilon J-),(\min(t_{ij}\ |\ i=1,2,\ldots..,m)\ |\ j\epsilon J+)\}=\{t_{wj}\ |\ j=1,2,\ldots\ldots,n\} \tag{20}$$

$$A-=\{(\min(t_{ij}\,|i=1 \text{ to } m)|\ j\epsilon J-),(\max(t_{ij}\ |\ i=1,2,\ldots..,m)\ |\ j\epsilon J+)\}=\{t_{bj}\ |\ j=1,2,\ldots\ldots,n\ \} \tag{21}$$

where, J+ ={j=1,2,.....,n|j} is considering the criteria that have a confident influence, J- ={j=1,2,.....,n|j} considering the criteria that have a harmful influence.

Step 5: Determine the distance from the alternatives to the ideal solution:

Alternatives distance from confident ideal solution A_w

$$d_{iw} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{wj})^2}\,, i = 1,2,\ldots.,m \tag{22}$$

and alternatives distance from harmful ideal solution A_b

$$d_{ib} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{bj})^2}\,, i = 1,2,\ldots\ldots,m \tag{23}$$

Step 6: Determine the relative nearness to the ideal result:

$$C_i^+ = d_{ib}/(d_{iw} + d_{ib}),\ 0 \leq s_{iw} \leq 1,\ i = 1,2,\ldots,m \tag{24}$$

Step 7: Rank substitutions by C_i^+(i=1, 2,…..,m).

The C^+ substitutions are arranged from largest to smallest. The substitutions with the largest C^+ value is the best result.

Step 8: Normalize the proximity of the substitutions to the ideal result to the weights of the respective loadsω_i using the (25)

$$\omega_i = \frac{C_i^+}{\sum_{i=1}^{n} C_i^+} \tag{25}$$

b. Fuzzy AHP TOPSIS technique

Essentially, the fuzzy AHP-TOPSIS method combines the fuzzy AHP method with the TOPSIS method. The implementation steps of fuzzy AHP-TOPSIS are as:

– Apply AHP method to propose hierarchical model, judgment matrix. Then compute the weights and check the consistency of the judgment matrix. Using the formula from (2) to (8).
– The judgment matrix is fuzzy according to TFN to easily compare the alternatives and form a decision matrix.
– Applying the fuzzy AHP method, the pairwise evaluation between the criteria and the substitutions is calculated to determine the weight vectors of the criteria and the decision substitutions: using formula from (9) to (13).
– The TOPSIS technique is used to standardize the decision matrix, determine the positive ideal and harmful ideal results to determine the C^+ proximity index to the ideal result, and finally rank all the substitutions: using the formula from (18) to (25).

3. RESULTS AND DISCUSSION

In order to demonstrate the effectiveness of the proposed method, a modified 19-bus microgrid system is used for the calculation cases [29]. The single-line diagram of the system is shown in Figure 3. Apply the fuzzy AHP-TOPSIS method to rank the loads that must be assessed based on the criteria.

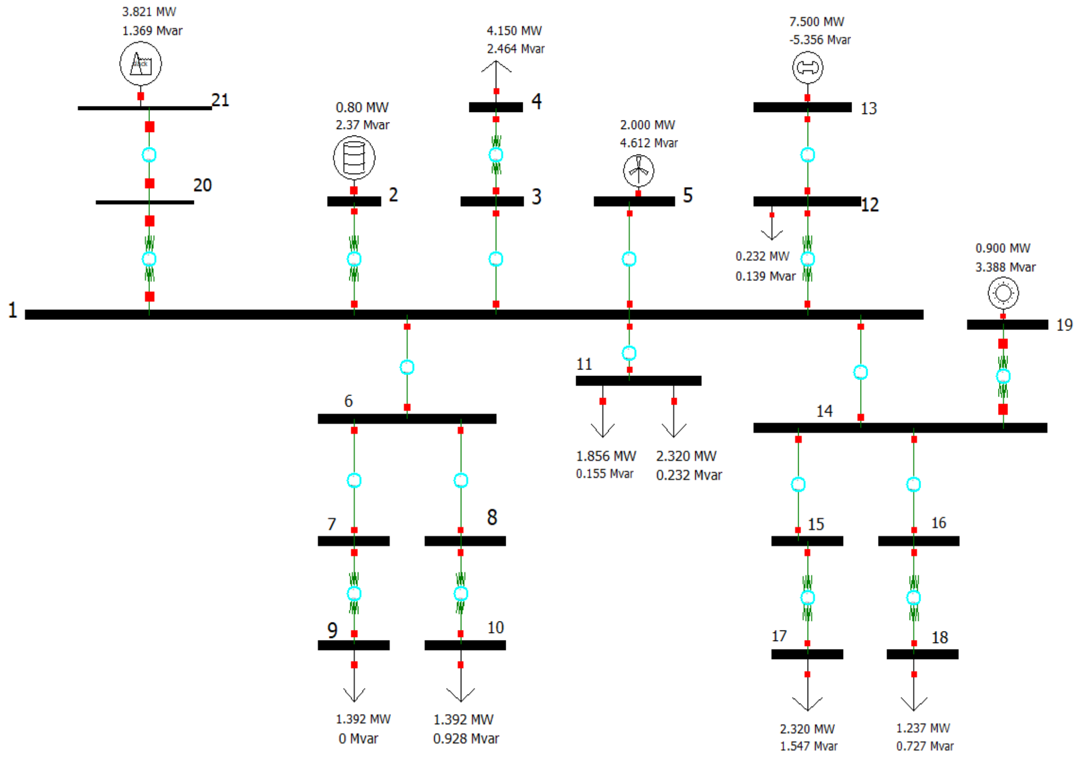

Figure 3. The single-line diagram of the test system

3.1. Criterion 1: LIF

Hierarchical model for load areas (LA) as illustrate in Figure 4. The judgment matrix of the LA and the judgment matrix of the load units in the area are evaluated by the experts of the system, the matrices are presented below. Apply from formula (2) to formula (8) to calculate the components according to the procedure of AHP algorithm. The values are presented in Table 1. The values of CR are all less than 0.1. Therefore, it is concluded that the opinions of experts in comparing objects in the judgment matrix meet the standard of consistency.

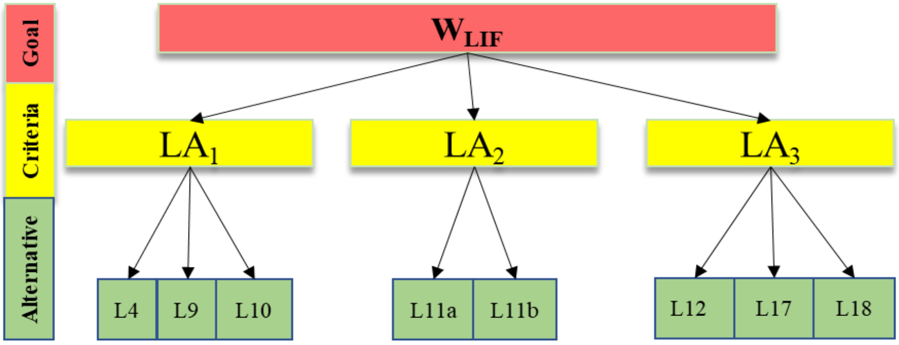

Figure 4. Hierarchical hierarchy of loads by area

$$\textit{Judgment matrix of LAs}\quad \begin{array}{c} \\ LA_1 \\ LA_2 \\ LA_3 \end{array}\begin{array}{c} \begin{array}{ccc} LA_1 & LA_2 & LA_3 \end{array} \\ \begin{pmatrix} 1/1 & 2/1 & 3/1 \\ 1/2 & 1/1 & 2/1 \\ 1/3 & 1/2 & 1/1 \end{pmatrix} \end{array}$$

$$\textit{Judgment matrix of LA}\,1\quad \begin{array}{c} \\ L_4 \\ L_9 \\ L_{10} \end{array}\begin{array}{c} \begin{array}{ccc} L_4 & L_9 & L_{10} \end{array} \\ \begin{pmatrix} 1/1 & 2/1 & 1/3 \\ 1/2 & 1/1 & 1/4 \\ 3/1 & 4/1 & 1/1 \end{pmatrix} \end{array}$$

$$\textit{Judgment matrix of LA}\,2\quad \begin{array}{c} \\ L_{11a} \\ L_{11b} \end{array}\begin{array}{c} \begin{array}{cc} L_{11a} & L_{11b} \end{array} \\ \begin{pmatrix} 1/1 & 2/1 \\ 1/2 & 1/1 \end{pmatrix} \end{array}$$

$$\textit{Judgment matrix of LA}\,3\quad \begin{array}{c} \\ L_{12} \\ L_{17} \\ L_{18} \end{array}\begin{array}{c} \begin{array}{ccc} L_{12} & L_{17} & L_{18} \end{array} \\ \begin{pmatrix} 1/1 & 1/2 & 3/1 \\ 2/1 & 1/1 & 5/1 \\ 1/3 & 1/5 & 1/1 \end{pmatrix} \end{array}$$

Table 1. CR of judgment matrices

Load area judgment matrix	Judgment matrix LA_1	Judgment matrix LA_2	Judgment matrix LA_3
CR=0.010<10%	CR=0.022<10%	CR=0 because there are only 2 objects	CR=0.004<10%

Applying TFN to transform the judgment matrix according to the TFN criteria set, the conversion results are from Tables 2 to 5. This transformation helps to fuzzy the judgment matrices and form fuzzy triangles, which makes the objects compared with each other in more detail. Thereby improving the accuracy of the judgment matrix.

Table 2. Load area judgment matrix according to the TFN criteria set

	LA_1			LA_2			LA_3		
LA_1	1/1	1/1	1/1	1/2	1/1	3/2	1/1	3/2	2/1
LA_2	2/3	1/1	2/1	1/1	1/1	1/1	1/2	1/1	3/2
LA_3	1/2	2/3	1/1	2/3	1/1	2/1	1/1	1/1	1/1

Table 3. Judgment matrix LA_1 according to the TFN criteria set

LA_1	L10			L9			L4		
L10	1/1	1/1	1/1	1/2	1/1	3/2	1/2	2/3	1/1
L9	2/3	1/1	2/1	1/1	1/1	1/1	2/5	1/2	2/3
L4	1/1	3/2	2/1	3/2	2/1	5/2	1/1	1/1	1/1

Table 4. Judgment matrix LA_2 according to the TFN criteria set

LA_2	L11a			L11b		
L11a	1/1	1/1	1/1	1/2	1/1	3/2
L11b	2/3	1/1	2/1	1/1	1/1	1/1

Table 5. Judgment matrix LA_3 according to the TFN criteria set

LA_3	L18			L17			L12		
L18	1/1	1/1	1/1	2/3	1/1	2/1	1/1	3/2	2/1
L17	1/2	1/1	3/2	1/1	1/1	1/1	2/1	5/2	3/1
L12	1/2	2/3	1/1	1/3	2/5	1/2	1/1	1/1	1/1

Step 4: Calculate the fuzzy mean using formula (10), the results are shown below.

Fuzzy mean of load areas			
$\tilde{r}_1$	0.794	1.145	1.442
$\tilde{r}_2$	0.693	1.000	1.442
$\tilde{r}_3$	0.693	0.874	1.260

Fuzzy mean of load area 1			
$\tilde{r}_1$	0.630	0.874	1.145
$\tilde{r}_2$	0.644	0.794	1.101
$\tilde{r}_3$	1.145	1.442	1.710

Fuzzy mean of load area 2			
$\tilde{r}_1$	0.707	1.000	1.225
$\tilde{r}_2$	0.816	1.000	1.414

Fuzzy mean of load areas			
$\tilde{r}_1$	0.874	1.145	1.587
$\tilde{r}_2$	1.000	1.357	1.651
$\tilde{r}_3$	0.550	0.644	0.7

Step 5: Calculate the fuzzy weights using the formula (11), the results are shown below.

Fuzzy weights of load areas		
L	M	U
0.192	0.379	0.661
0.167	0.331	0.661
0.167	0.289	0.578

Fuzzy weights of load area 1		
L	M	U
0.159	0.281	0.473
0.163	0.255	0.455
0.289	0.464	0.707

Fuzzy weights of load area 2		
L	M	U
0.268	0.500	0.804
0.309	0.500	0.928

Fuzzy weights of load area 3		
L	M	U
0.217	0.364	0.655
0.248	0.431	0.681
0.136	0.205	0.327

Step 6: For defuzzification and normalizing the final weights, use formulas (12), (13), the results are shown below.

LA	M_i	N_i
LA 1	0.411	0.360
LA 2	0.387	0.339
LA 3	0.345	0.302

LA_1	M_i	N_i
L10	0.305	0.281
L9	0.291	0.269
L4	0.487	0.450

LA_2	M_i	N_i
L11a	0.524	0.475
L11b	0.579	0.525

LA_3	M_i	N_i
L18	0.412	0.378
L17	0.454	0.417
L12	0.223	0.205

After calculating the weight values based on each LA and each load unit in LA, the weight of the load unit based on criterion 1 is presented in Table 6. The weighting results according to criterion 1 show the importance of the loads, the larger the number of weighted loads, the more important they are and vice versa. Then, the results of the weights of the loads according to criterion 1 will be combined with the weights of the loads according to criterion 2 and 3 to get the final weight for the load ranking.

Table 6. Weights based on LIF

Load	LA	Normalized value of loads in LA	Normalized value of LA	Weight of loads according to criterion 1 (LIF)
L4	LA_1	0.450	0.360	0.162
L9	LA_1	0.269	0.360	0.097
L10	LA_1	0.281	0.360	0.101
L11a	LA_2	0.475	0.339	0.161
L11b	LA_2	0.525	0.339	0.178
L12	LA_3	0.205	0.302	0.062
L17	LA_3	0.417	0.302	0.126
L18	LA_3	0.378	0.302	0.114
Total				1.000

3.2. Criterion 2: VED

Calculate the weight of the VED criteria established on the J4 matrix in the Jacobian matrix extracted from the 19 bus microgrid test diagram with the support of Powerworld simulation software. Apply the formula (14) to calculate the VED from the grid-connected bus to the load buses in the microgrid system. Applying formulas (15), the weighted results of the load according to VED (W_{VED}) in Table 7.

3.3. Criterion 3: VSI

The voltages of the buses are taken from the system in normal operating mode and extracted from the 19 bus microgrid test diagram with the support of Powerworld simulation software, the voltage values are in pu units. Applying formulas (17), (18), we get VSI results and load weights according to VSI (W_{VSI}), the outcomes are shown in Table 7. In Table 7, the weight values of the two criteria, VED and VSI, are shown. These values represent the technical evaluation criteria of the loads, specifically in terms of the voltage aspect of the system. As the microgrid tested in the study is a distribution grid, the quality of the voltage plays an important role in the operation of the system. After calculating the weights of the loads according to each criterion, using the fuzzy AHP-TOPSIS technique to calculate the final combined weight and use this weight to rank the loads. The comparative judgment matrix between the criteria given by the experts, the results are presented below.

$$Judgment\ matrix\ of\ \text{criterions}$$

$$\begin{array}{c} \\ LA_1 \\ LA_2 \\ LA_3 \end{array} \begin{pmatrix} LA_1 & LA_2 & LA_3 \\ 1/1 & 2/1 & 3/1 \\ 1/2 & 1/1 & 2/1 \\ 1/3 & 1/2 & 1/1 \end{pmatrix}$$

Apply formula (2) to formula (8) to calculate the components according to the procedure of AHP algorithm. The results show that the CR=0.048<0.1. This shows that the matrix has a suitable consistency. Applying TFN to transform the judgment matrix of criterions according to the TFN criteria set, the conversion outcomes are shown in Table 8. From the pairwise evaluation matrix data, apply the formula from (10) to (13) to calculate the weighted value of the 3 criteria. The outcomes are shown in Table 9.

Table 7. Weight of loads according to VED and VSI

Load	VED	W_{VED}	Voltage (pu)	VSI	W_{VSI}
Load 4	3.36204	0.10054	0.99222	0.02681	0.12529
Load 9	4.46078	0.13340	0.98984	0.02600	0.12151
Load 10	4.84452	0.14487	0.98495	0.02351	0.10987
Load 11a	2.53565	0.07583	0.99675	0.02772	0.12958
Load 11b	2.53565	0.07583	0.99675	0.02772	0.12958
Load 12	4.84085	0.14476	1.00008	0.02776	0.12977
Load 17	5.22671	0.15630	0.99559	0.02756	0.12882
Load 18	5.63354	0.16847	0.99243	0.02687	0.12557
Total		1.00000			1.00000

After determining the importance between the criteria, proceed to build a decision matrix based on the weight values in Tables 7 and 8. The outcomes are shown in Table 10. The standardized conclusion matrix and the standardized conclusion matrix with weighted are built according to the formulas (18) to (20). The results are presented in Tables 11 and 12. The difference in load ratings in this method is that after the weights are normalized, the idea is to measure the distance between the substitutions to the ideal solutions so that the evaluation is more optimal. Applying the formula from (21) to (25), the outcomes are presented in Tables 13 to 15.

Table 8. Pairwise comparison matrix between criteria

Criterion	C 1			C 2			C 3		
C 1	1	1	1	2	5/2	3	1	3/2	2
C 2	1/3	2/5	1/2	1	1	1	1/3	1	2
C 3	1/2	1/3	1	1	3/2	2	1	1	1

Table 9. Weight value of criteria

$\tilde{r}$				Fuzzy weight $\widetilde{W}_i$				Defuzzification weights (M_i)		Normalized weights (N_i)	
$\tilde{r}_1$	1.260	1.554	1.817	$\widetilde{W}_1$	0.446	0.589	0.717	M_1	0.584	N_1	0.446
$\tilde{r}_2$	0.481	0.737	1.000	$\widetilde{W}_2$	0.245	0.324	0.395	M_2	0.321	N_2	0.245
$\tilde{r}_3$	0.794	0.794	1.260	$\widetilde{W}_3$	0.309	0.409	0.497	M_3	0.405	N_3	0.309

Table 10. Decision matrix

Criterion	Decision Matrix							
	L4	L9	L10	L11a	L11b	L12	L17	L18
Criterion 1	0.162	0.097	0.101	0.161	0.178	0.062	0.126	0.114
Criterion 2	0.101	0.133	0.145	0.076	0.076	0.145	0.156	0.168
Criterion 3	0.125	0.122	0.110	0.130	0.130	0.130	0.129	0.126

Table 11. Normalized decision matrix

Criterion	Normalized decision matrix							
	L4	L9	L10	L11a	L11b	L12	L17	L18
Criterion 1	0.419	0.251	0.262	0.417	0.461	0.160	0.326	0.296
Criterion 2	0.249	0.331	0.359	0.188	0.188	0.359	0.388	0.418
Criterion 3	0.334	0.323	0.293	0.345	0.345	0.345	0.343	0.334

Table 12. Standardized conclusion matrix with weighted

Criterion	Standardized conclusion matrix with weighted							
	L4	L9	L10	L11a	L11b	L12	L17	L18
Criterion 1	0.187	0.112	0.117	0.186	0.205	0.071	0.145	0.132
Criterion 2	0.061	0.081	0.088	0.046	0.046	0.088	0.095	0.102
Criterion 3	0.103	0.100	0.090	0.107	0.107	0.107	0.106	0.103

Table 13. Confident ideal solution A^+ and harmful solution A^- of each criterion

Criterion	Solutions	
	A^+	A^-
Criterion 1	0.20527	0.07140
Criterion 2	0.10249	0.04613
Criterion 3	0.10677	0.09039

Table 14. Distance between alternatives to ideal solutions

Distance	Alternatives							
	L4	L9	L10	L11a	L11b	L12	L17	L18
d_{iw}	0.045	0.096	0.091	0.060	0.056	0.136	0.060	0.073
d_{ib}	0.117	0.054	0.062	0.116	0.135	0.042	0.090	0.084

In Table 15, the final weight values for each load are presented. These weights are used to calculate the proximity to the best solution, which in turn determines the ranking of the loads based on these values. The relative closeness C^+ are arranged from largest to smallest. The alternative with the largest C^+ value is the best resolution. Therefore, based on the values in Table 15, the order of importance from high to low is arranged as follows: L4, L11b, L11a, L17, L18, L10, L9, L12. Loads with a low ranking (i.e., small weight) are the less important loads and will be prioritized for power reduction when it comes to load shedding.

Table 15. The relative closeness C^+

Load	Ci+	ω_i	Ranking
L4	0.720	0.170	1
L9	0.360	0.085	7
L10	0.405	0.096	6
L11a	0.659	0.156	3
L11b	0.705	0.167	2
L12	0.251	0.059	8
L17	0.598	0.141	4
L18	0.533	0.126	5
Total		1.000	

4. CONCLUSION

The fuzzy algorithm helps to fuzzy the judgment matrix of the AHP method, thereby making it easier to compare objects and eliminating the uncertainty of the AHP technique. The results of the fuzzy AHP method are guaranteed to be accurate, consistent and easy to perform object comparisons thanks to the combination of the advantages of these two methods. The TOPSIS algorithm is used to normalize the conclusion matrix containing the weights of the criteria, determine the confident ideal resolution and the harmful ideal resolution to calculate the comparative nearness to the ideal conclusion and finally rank all alternatives. The confident ideal conclusion is defined as the sum of the best achievable values for each attribute. Therefore, the combination of fuzzy AHP-TOPSIS algorithms is the optimal combination for decision making and ranking problems in a multi-criteria environment. In the next work, the application of data processing techniques in statistics to improve the input data for the AHP technique, thereby improving the certainty and consistency of the results. The cost-by-power functions will be considered to more specifically evaluate the level of economic efficiency.

ACKNOWLEDGEMENTS

This study belongs to the project with grant No: T2022-63 funded by the Ho Chi Minh City University of Technology and Education, Vietnam.

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