

Ranking Load in Microgrid System Based on the Priority Weight Calculation of Power Supply

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ARTICLE INFO

Received: 15/12/2021
Revised: 05/1/2022
Accepted: 25/1/2022
Published: 28/2/2022

KEYWORDS

Ranking load;
Microgrid;
Covariance;
Criteria layer;
Scheme layer.

ABSTRACT

This paper proposes a method of ranking load in Microgrid system based on the calculation of priority weights on the continuity of power supply of the loads. The proposed method applies the covariance matrix of the criterion layer to determine values of each criterion. The fuzzy preference relation matrix is used to replace the pairwise comparison matrix of the scheme layer. The weight of the criterion layer and the scheme layer are combined to get the final weights of each load bus. This solves the problem of consistency factor when evaluating loads from experts and Microgrid system operators. The calculation of priority weighting on the continuity of power supply for loads supports system operators to be proactive in planning load shedding or load shedding due to system failures, thereby minimizing damage to the system and electricity customers. The proposed method is calculated on the diagram of the IEEE 16 bus Microgrid system with six sources and eight loads.

Doi: <https://doi.org/10.54644/jte.68.2022.1079>

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1. Introduction

A Microgrid is a small part of a distributed power system whose components include distributed generators, energy storage devices, and loads, all of which are controllable. Microgrid can create a self-sufficient energy system. From the main grid side, a Microgrid is considered as an equivalent generator that can disconnect the connection continuously and operate automatically once the main grid has a problem [1]. Therefore, the fact that Microgrid has to actively load shedding in optimizing operation or shedding the load for emergency incidents is a frequent occurrence, which requires Microgrid operators to have scenarios to cope with such situations. To ensure the initiative in shedding the load according to the plan or shedding loads due to incidents without too much impact on the benefits of the system, it is required that the loads in the system have a classification and ranking of level priority in uninterrupted power supply.

There are many research studies on the classification and ranking of loads in a Microgrid such as: In [2], a Microgrid system constantly evaluated and prioritized the loads in the system to propose load management strategies to control the regulation of power generation of the generators in the system. In [3] classified loads into three classes and considered loads as schedulable variables based on their characteristics and importance. From there, the Microgrid grid optimization reduced the operating costs of the system.

The methods used to classify loads in the power system as in [4] suggested the use of the ISODATA algorithm to classify customers based on customer-supplied information and load profile. In [5], a model of load classification according to a five-stage process was proposed based on the synthesis and analysis of studies on load classification in the smart grid environment, a classification method based on Fuzzy c-means (FCM) is presented. In [6], the authors showed how to extract the Characteristic Attributes in the Frequency Domain (CAFD) and use these CAFDs to form a hierarchy of load profiles that can be used as the system framework for customer load classification.

In this paper, we propose a method to rank the loads in the Microgrid system based on the reliability of power supply of the loads and the application of the theory of covariance between objects, forming the criteria layer and the scheme layer of the problem. From there, calculate the priority weight of continuity of power supply for the loads in the system. This solves the problem of consistency factor when evaluating loads from experts and Microgrid system operators. This calculation is consistent with the actual classification of loads according to the reliability of the power supply of Vietnam. It supports system operators to be proactive in scheduling load shedding or load shedding due to system failure, thereby minimizing damage to the system and electricity customers. The proposed method is calculated on the diagram of the IEEE 16 bus Microgrid system with six sources and eight loads.

2. Methodology

The priority load ranking in the Microgrid is important in ensuring the reliability of the power supply for the loads that are considered important and highly ranked in the system. The load in the system includes of 3 types of loads: type 1, type 2, and type 3 [7].

Type 1 load is a type of load that is supplied with power continuously, if the power fails, it will cause extremely serious consequences. For human life, this type of load is mines, hospitals, etc. For production and business: In steel mills, blast furnaces, data center, etc. In addition, it also disrupts order and security and affects politics and international affairs such as embassies, office buildings, public cultural works, etc. Type 2 load is a type of load that, if the power is lost, it will cause economic losses such as production shortages, increased by-products, waste of work, and not using the full capacity of the equipment. Type 3 load is a type of load that allows power failure, that is, civil works, welfare work, and residential areas [7].

In the power grid diagrams, the load buses usually have a large power. These load buses are actually all the loads on the Feeder that power those loads. These load nodes are actually all loads on the distribution line of that supply power to those loads. These loads are counted according to actual and summed up the percentages of type 1, type 2, and type 3 loads on that Feeder.

From the percentages of the load types, the improved AHP method is applied to calculate the priority weights of each load bus. From there, we can rank the order of the load buses that need to be guaranteed uninterrupted power supply in the entire electrical system diagram. In addition, based on the calculated priority weights, it is possible to calculate the amount of load power that needs to be shed at each load bus when the load has many competing priority loads. The process is shown in Figure 1.

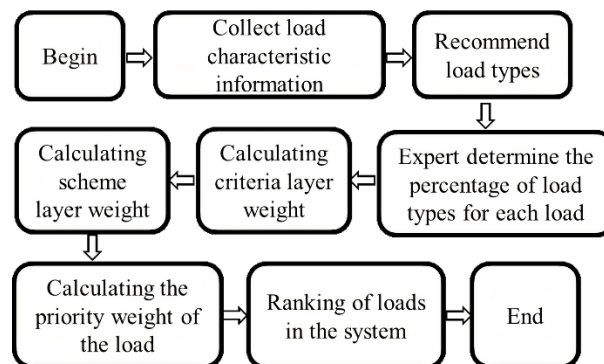


Figure 1. The process of performing priority load ranking

2.1. Covariance

The covariance between two real-valued random variables X and Y, with expected values $E(X) = \mu$ and $E(Y) = \nu$ is defined as follows: [8]

$$Cov(X, Y) = E((X - \mu)(Y - \nu)) \quad (1)$$

The covariance matrix of a set with m random variables is a square matrix ($m \times m$), where the diagonals (left to right, top to bottom) are the variances respectively correspondence of these variables

($\text{Var}(X) = \text{Cov}(X, X)$), while the remaining elements (not on the diagonal) are the covariances of two different random variables in the set.

The symbol X is a column vector, X_i is the component of this vector, we get equation (2).

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} \quad (2)$$

If the components of the column vector are random variables with definite variance (not too large to infinity), then the covariance matrix Σ_{ij} is a matrix whose component (i, j) is the covariance, the covariance matrix has the same form as equation (3).

$$\Sigma_{ij} = \text{cov}(X_i, X_j) = E[(X_i - \mu_i)(X_j - \mu_j)] \quad (3)$$

2.2. Criteria layer

Types of loads in the power system are considered components of the criteria layer. The covariance between each criteria is used to determine the relative importance of each criterion. The methods applied to find the priority factor of each load are based on the covariance matrix formed by the quantitative values of each criterion. Through transformation calculations, a comparison matrix is obtained. Then perform the decoding of these comparison matrices, which will result in the relative weight of each given criterion.

The process of forming a comparison matrix is presented as follows [9]:

Step 1: Assuming that there are n criteria, compute quantitative data for each criterion.

Step 2: Calculate the variance of each criterion from the quantitative data.

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (4)$$

Step 3: Calculate the covariance of each criterion from the quantitative data.

The definition of covariance is as follows: Let $X = \{x_1, x_2, \dots, x_n\}$ and $Y = \{y_1, y_2, \dots, y_n\}$ be 2 random variables, μ_x and μ_y are the average index of the random variables course X and Y respectively. The covariance $\text{Cov}(X, Y)$ between X and Y is determined as follows: [10]

$$\text{Cov}(X, Y) = \frac{1}{n} \sum_{i,j=1}^n (x_i - \mu_x)(y_j - \mu_y) \quad (5)$$

According to the theory of covariance and equation (4), the covariance matrix between the criteria C_i and C_j is calculated and expressed as C_{ij} . We get the covariance matrix C .

$$C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ C_{n1} & C_{n2} & \cdots & C_{nn} \end{bmatrix} \quad (6)$$

Where: c_{ij} ($i, j=1, 2, \dots, n$) is the covariance of the i^{th} row and j^{th} column, $c_{ij} = c_{ji}$. When the covariance between the two criteria is negative, take its absolute value.

Step 4: Convert the covariance matrix C to the relative covariance matrix B .

To convert the covariance matrix C to the relative covariance matrix B , we divide each covariance column c_{ij} by the covariance c_{ii} . The advantage of this transformation is that we will get a matrix with a principal diagonal of 1.

$$B = \begin{bmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{bmatrix} \quad (7)$$

Step 5: Forming the comparison matrix

$$a_{ij} = \frac{b_{ij}}{\sqrt{b_{ij} \times b_{ji}}}, \quad a_{ji} = \frac{1}{a_{ij}} \quad (8)$$

From equation (8), the obtained comparison matrix has the same form as equation (9).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (9)$$

Step 6: Calculating the weight of each criterion

The parameter P_i for each row of the comparison matrix A is calculated according to equation (10).

$$P_i = \prod_{j=1}^n a_{ij} \quad (i = 1, 2, 3, \dots, n) \quad (10)$$

$$\omega_i' = \sqrt[n]{P_i} \quad (11)$$

Normalize ω_i and calculate the weight of each criteria according to equation (12).

$$\omega_i = \frac{\omega_i'}{\sum_{i=1}^n \omega_i'} \quad (12)$$

Step 7: Check Consistency

The consistency index measures the consistency of comparison matrix. The consistency index is calculated using equations (13) and (14). [11]

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (13)$$

$$CR = \frac{CI}{RI} \quad (14)$$

Suppose the weight vector of the comparison matrix A is $\omega = (\omega_1, \omega_2, \dots, \omega_n)$, and using the weight vector ω multiplied by the comparison matrix A, we get the column vector $Q = (q_1, q_2, \dots, q_n)^T$. Applying equation (15) determines the value of λ_{max} .

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{q_i}{\omega_i} \quad (15)$$

The comparison matrix calculated by this method can overcome the subjective factors. Besides, the calculation results are synchronized and brought to the correct decision.

2.3. Scheme layer

The number of load buses in the system is considered as the number of scheme layers. Each criteria class in Section 2.2 will consider all scheme layers. Thus, the scheme classes will be reviewed multiple times depending on the number of criteria classes. The process of calculating the weight of the project class is presented as follows: [9]

Step 1: Calculating the quantitative value of each attribute value according to each criteria and calculating its corresponding variance as V_i .

V_i represents the variance between the attribute values of $n-1$ objects, excluding the i^{th} object. The larger the value V_i , the smaller the conflict of the i^{th} object with the system and the more important the i^{th} object. V_i is calculated according to equation (16).

$$V_i = \text{var.P} \quad (16)$$

Step 2: Establishing a fuzzy preference relation matrix.

The element in the fuzzy preference relation matrix P_{ij} is calculated based on the variance of the objects, and it is determined based on the equations (17) and (18).

$$P_{ij} = \frac{V_i}{V_i + V_j} \quad (17)$$

$$P_{ji} = 1 - P_{ij} \quad (18)$$

Where $i, j \in [1, n]$, the higher the P_{ij} value, the higher the priority for that object. The diagonal elements have a value of 0.5.

The establishment of fuzzy preference relation matrix by this method has partly solved the problem of subjectivity. Based on the calculation of the variance, the fuzzy preference relation matrix is easier to construct and the results are synchronized. [12]

Step 3: Establishing a consistency matrix \bar{P}

The element in the consistency matrix \bar{p}_{ik} is calculated based on the elements of the fuzzy preference relation matrix, equation (19) is applied to calculate the value of this element.

$$(\bar{p}_{ik})_{n \times n} = \left(\frac{1}{n} \sum_{j=1}^n (p_{ij} + p_{jk}) - 0.5 \right)_{n \times n} \quad (19)$$

1) For any $i, j, k \in [1, n]$, there have $\bar{p}_{ik} = \bar{p}_{ij} + \bar{p}_{jk} - 0.5$ the matrix \bar{P} has an acceptable consistency. Where, $\bar{p}_{ij} + \bar{p}_{ji} = 1$ and $\bar{p}_{ii} = 0.5$.

2) For any $i, j, k \in [1, n]$, if $\bar{p}_{ij} > 0.5$ denoted that scheme x_i is superior to scheme x_j , namely $x_i > x_j$.

3) For any $i, j, k \in [1, n]$, if $\bar{p}_{ij} < 0.5$ denoted that scheme x_j is superior to scheme

4) For any $i, j, k \in [1, n]$, if $\bar{p}_{ij} = 0.5$ denoted that scheme x_i is equally important as scheme x_j , namely $x_i = x_j$.

According to equation (19), the diagonal elements of the consistency matrix have a value of 0.5.

Step 4: Calculating the weight of the scheme layer.

Using the consistency matrix \bar{P} to determine the weight of the scheme layer.

The weight of the scheme layer is calculated based on the advantages and disadvantages of the scheme. These values are obtained using equation (20) for the values of the elements in the consistency matrix \bar{P} .

$$r = \left\{ \begin{array}{l} 1 \\ 0.5 \\ 0 \end{array} \right\} \begin{array}{l} x_i > x_j \\ x_i = x_j \\ otherwise \end{array} \quad (20)$$

Where: r_{ij} is the priority index that scheme x_i compares with scheme x_j . The priority index of scheme x_i in the set of scheme X is calculated by equation (21).

$$R_i = \sum_{j=1}^n r_{ij} \quad (21)$$

The weight of the scheme layer is calculated based on the priority index R_i for scheme x_i in the set of scheme X and is determined by equation (22).

$$\omega(m_i) = \frac{R_i}{\sum_{i=1}^n R_i} \quad i \in [1, n] \quad (22)$$

Based on this weight calculation method, it is possible to determine the weight of the scheme layer by solving the fuzzy priority consistency of the schemes of the matrix P .

2.4. Priority weighting on continuity of power supply of each load

Based on the results of weight calculation of the criteria layer and the scheme layer, the weight of each object can be determined by equation (23).[9]

$$\omega_i = \sum_{i,j=1}^n \omega(i) \times \omega(m_j) \quad (23)$$

3. Case studies

Microgrid system is used for calculation according to the proposed method is IEEE 16 bus system including six sources and eight loads [13]. The single-line diagram of the system is shown in Figure 2.

Through collecting information about load characteristics, the results on the percentage of load types of loads are presented in Table 1.

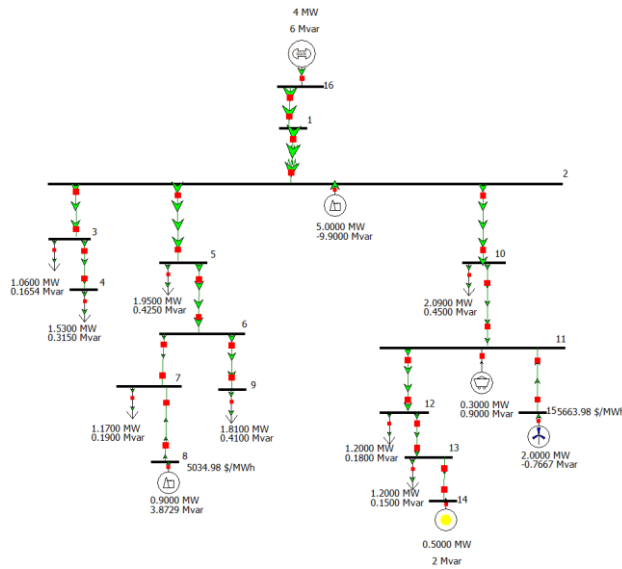


Figure 2. Single-line diagram of Microgrid IEEE 16 bus

Table 1. Rate percentage of load types in the system

Load bus	Load type 1	Load type 2	Load type 3
Load 3	0.120	0.290	0.590
Load 4	0.132	0.248	0.620
Load 5	0.240	0.230	0.530
Load 7	0.260	0.160	0.580
Load 9	0.151	0.227	0.622
Load 10	0.130	0.275	0.595
Load 12	0.220	0.180	0.600
Load 13	0.190	0.200	0.610

Based on percentage of Type 1, Type 2, Type 3 loads in each load bus, we apply equation (4) and equation (5) to calculate the variance and covariance of the elements of the covariance matrix. The covariance matrix can be established as follows:

$$C = \begin{bmatrix} 0.0026 & 0.0145 & 0.0064 \\ 0.0145 & 0.0018 & 0.0004 \\ 0.0064 & 0.0004 & 0.0008 \end{bmatrix}$$

The relative covariance matrix B is calculated by dividing each covariance column c_{ij} by the covariance c_{ii} .

$$B = \begin{bmatrix} 1.0000 & 8.2094 & 8.4890 \\ 5.5446 & 1.0000 & 0.4890 \\ 2.4554 & 0.2094 & 1.0000 \end{bmatrix}$$

Applying equation (8), establishes the comparison matrix A.

$$A = \begin{bmatrix} 1.0000 & 1.2168 & 1.8594 \\ 0.8218 & 1.0000 & 1.5281 \\ 0.5378 & 0.6544 & 1.0000 \end{bmatrix}$$

After obtaining the comparison matrix A, equations (10), (11), and (12) are applied to calculate the weight of the criteria layer. The results are presented in Table 2.

Table 2. Criteria layer weight

	C₁	C₂	C₃
ω(i)	0.4238	0.3483	0.2279

The values of the attribute according to each criteria and its corresponding variance V_i are calculated based on the application of equation (16) values of Table 1. The results are presented in Table 3.

Table 3. Variance between attribute values

Load bus	C₁	C₂	C₃
Load 3	0.0024	0.0014	0.0009
Load 4	0.0026	0.0019	0.0007
Load 5	0.0024	0.0020	0.0002
Load 7	0.0020	0.0013	0.0008
Load 9	0.0029	0.0020	0.0007
Load 10	0.0026	0.0016	0.0009
Load 12	0.0027	0.0017	0.0009
Load 13	0.0030	0.0019	0.0008

Based on the variance of the objects in Table 3, the equations (17) and (18) are applied to calculate the element in the fuzzy preference relation matrix P_{ij} . From the element values of the fuzzy preference relation matrix P, the equation (19) is applied to establish a consistency matrix \bar{P} .

Equations (20) and (21) are applied to calculate the priority index of the scheme layer. The results are presented in Table 4.

Table 4. Priority index of the schemes in the consistency matrix \bar{P}_1, \bar{P}_2 and \bar{P}_3

	Load bus	$R_{\bar{P}_1}$	$R_{\bar{P}_2}$	$R_{\bar{P}_3}$
R₁	Load 3	1.5	1.5	6.5
R₂	Load 4	4.5	5.5	2.5
R₃	Load 5	2.5	6.5	0.5
R₄	Load 7	0.5	0.5	4.5
R₅	Load 9	6.5	7.5	1.5
R₆	Load 10	3.5	2.5	7.5
R₇	Load 12	5.5	3.5	5.5
R₈	Load 13	7.5	4.5	3.5
	Total	32	32	32

The weight of the scheme layer is calculated based on the priority index R_i , equation (22) is applied to calculate the weight of the scheme layer $\omega_{(mi)}$. The results are presented in Table 5.

Table 5. *The weight of the scheme layer*

Load bus	$\omega_{(mi)}$	C_1	C_2	C_3
Load 3	$\omega_{(L1)}$	0.0469	0.0469	0.2031
Load 4	$\omega_{(L2)}$	0.1406	0.1719	0.0781
Load 5	$\omega_{(L3)}$	0.0781	0.2031	0.0156
Load 7	$\omega_{(L4)}$	0.0156	0.0156	0.1406
Load 9	$\omega_{(L5)}$	0.2031	0.2344	0.0469
Load 10	$\omega_{(L6)}$	0.1094	0.0781	0.2344
Load 12	$\omega_{(L7)}$	0.1719	0.1094	0.1719
Load 13	$\omega_{(L8)}$	0.2344	0.1406	0.1094

Based on the results of the weights of the criteria layer and the scheme layer, the weight of each load object can be determined by the equation (23). The rank of loads and priority weights of continuity of power supply for the loads in the system are presented in Table 6.

Table 6. *The priority weights of continuity of power supply for the loads in the system*

Load bus	Rank of load	The weight of each object ω_i
Load 3	7	0.0825
Load 4	4	0.1373
Load 5	6	0.1074
Load 7	8	0.0441
Load 9	1	0.1784
Load 10	5	0.1270
Load 12	3	0.1501
Load 13	2	0.1732
Total		1.0000

Based on the results of the load ranking, the loads with the higher W_{ω} value are more important and they are ranked in order of little or no load shedding priority. In other words, the more weighted the load, the smaller the percentage of power shedding, and vice versa.

4. Conclusions

The article has proposed a method to rank the load buses in the Microgrid system. The priority weights of continuity of power supply for each load bus are calculated by applying the theory of covariance and forming the criteria layer and scheme layer of the problem. This method is applied to avoid inconsistencies in the opinions of experts and get the results synchronization.

The ranking of load buses based on the priority weight of power supply continuity contributes to rank the load buses in the Microgrid system. In other words, it is actually the priority ranking of Feeders based on the percentage of Type 1, Type 2, and Type 3 loads in each Feeder. From there, it can serve to set the load shedding priority order of the load shedding relays or to plan when there is a lack of power or shedding load in emergency situations.

In the future work, we will consider load characteristics and load Types that change continuously over time.

Acknowledgments

This work belongs to the project grant No: B2020-SPK-03 funded by Ministry of Education and Training, and hosted by Ho Chi Minh City University of Technology and Education, Vietnam.

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