Evaluation of the node importance of power communication network based on multi-factor evaluation indicators

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Abstract. The continuous development of smart grid has promoted the advancement of the power communication network. And what followed was the complexity of the topology of the power communication network being increasing. In order to evaluate the importance of the network node more accurately, an evaluation method based on the multi-factor evaluation indicators is proposed in this paper. This method integrates the service layer and the topology layer of the network, and then combines the node types, the load factors of the nodes and the probability of failure of the nodes and links as a comprehensive factor coefficient to evaluate the importance of the nodes. The simulation results show that the algorithm proposed in the paper can consider the indicators affecting the importance of the node of the power communication network more comprehensively. It can evaluate the importance of the node more effectively which has a good application value.

1. Introduction

The power communication network plays an indispensable role in the steady development of the power grid \cite{1}. In recent years, the acceleration of the deployment of smart grid has prompted the development of the power communication network to continue to rise, which has promoted the complexity of the topology of the power communication network, and the services carried on it have also been characterized by diversified types and positive growth in quantity \cite{2}. Studies have shown that if 5\% of the important nodes in the network fail due to human or natural damage, it will have a very serious impact on the operation of the network \cite{3-4}. Therefore, evaluating the importance of the network node and protecting them in a targeted manner can better maintain the stable operation of the power communication network \cite{5-6}.

The traditional methods of evaluating the node importance mainly include the node deletion method \cite{7}, the node contraction method \cite{8-10}, and the median method \cite{11-12}. The above are mainly the evaluation methods proposed for the complex network. The power communication network, as a branch of the complex network, its node importance should be evaluated by combining the general characteristics of the complex network and the power attributes unique to the power communication network. An evaluation algorithm named "transmission and grid" in the converged network was
proposed by Wu Runze, while the algorithm did not have a wide applicability [13]. Paper [14] combined the own factors of the power communication network and its degree of association with the power grid to complete the identification of the key nodes. This method had a good scalability and focused on the description of the network topology and the node type, while it did not consider the power service as one of the influencing factors. So the method cannot identify the key nodes accurately. The method proposed in paper [15] considered the topology and service conditions of the power communication network comprehensively. However, the evaluation results of the node importance were also different depending on the factor of the node type. Although the evaluation indicators used in the node importance evaluation methods proposed above overcome the singularity of the traditional methods, it is still not comprehensive enough to accurately evaluate the importance of different nodes, and cannot protect the important nodes of the power communication network effectively.

In view of the shortcomings of the above methods, the paper proposes a node importance evaluation method of the power communication network based on multi-factor evaluation indicators. Firstly, the service-based point weight is calculated by introducing the service importance, and the concept of the node importance combining service layer and topology layer is proposed by the network cohesion degree which is defined by converging the service layer and topology layer of the power communication network. Then, the factor coefficient based on the power factor and the factor coefficient based on the failure probability are respectively introduced to obtain the comprehensive factor coefficient as the weighted influence factor of the node importance combining service layer and topology layer. Finally, the comprehensive importance of the node is calculated to complete the comprehensive evaluation of the node importance.

2. The node importance combining service layer and topology layer

2.1. Service importance

The nodes of the power communication network carry various types of services. And the service importance of the node varies with the type of service the node assumes [16]. The feature indicator evaluation method is adopted in the paper because of the diversity of the service types undertaken by the nodes and the characteristic standards such as the bit error rate of each service of the power communication network to improve the accuracy of the evaluation results [17].

In the characteristic set \( P = \{P_k\} \) \((k = 1, 2, \ldots, K)\), \( P_k \) represents the different characteristics of the service with a total of \( K \) and the service set \( S = \{S_l\} \) \((l = 1, 2, \ldots, L)\) with a total of \( L \). \( S \) is mapped into a characteristic importance evaluation value matrix \( B_{kl} = [1, 2, \ldots, B_{k}] \) according to the evaluation criteria of the characteristic standard \( P_k \). Then the relative importance matrix of the service \( A^{(P)} \) is as follows.

\[
A^{(P)} = \begin{bmatrix}
    a_{11}^{(P)} & \cdots & a_{ul}^{(P)} \\
    \vdots & \ddots & \vdots \\
    a_{1l}^{(P)} & \cdots & a_{ll}^{(P)}
\end{bmatrix}
\]

(1)

\( a_{ij}^{(P)} \) refers to the relative degree of importance of service \( S_i \) than service \( S_j \) under the characteristic standard \( P_k \), in which \( S_i \) and \( S_j \) \((l, j = 1, 2, \ldots, L)\) are included in the service set \( S \). Then the element \( a_{ij}^{(P)} \) of the matrix \( A^{(P)} \) can be obtained by using the feature indicator evaluation method.

\[
a_{ij}^{(P)} = \begin{cases}
    1 & B_{k} \leq B_{ij} / B_{jk} \\
    2 / B_{i} & 2 \leq B_{ij} / B_{jk} < 3 \\
    1 / B_{k} & 1 \leq B_{ij} / B_{jk} < 2 \\
    0 & B_{ij} / B_{jk} < 1
\end{cases}
\]

(2)
Therefore, the element $a_{lj}$ of the integrated relative importance matrix $A$ is as follows.

$$a_{lj} = \sum_{k=1}^{K} P_{lj}^{(p)}$$

(3)

Taking the sum of the elements of each row of the matrix $A$ to obtain the comprehensive relative importance of service $S_l$.

$$a_{i} = \sum_{j=1}^{L} a_{j}$$

(4)

Normalizing the comprehensive relative importance to get the importance of service $S_l$.

$$\sigma_l = (1-k) \frac{a_{i} - (a_{i})_{\text{min}}}{(a_{i})_{\text{max}} - (a_{i})_{\text{min}}} + k \quad (k = 0.1)$$

(5)

The typical service importance of a certain province is obtained based on the feature indicator evaluation method mentioned above with considering the service quality indicators (transmission delay, bit error rate, etc.) and the grid impact indicators (safety zone, bearer mode, etc.) of the node in the power communication network as shown in table 1 [18].

### 2.2. Service-based point weight calculation

Define the network topology $G(V,E)$, node set $V = \{v_1, v_2, \ldots, v_n\}$ in which $n$ is the total number of nodes and the edge set $E = \{e_1, e_2, \ldots, e_m\}$ with the total number of edges $m$.

The tight connection between nodes in the power communication network is measured by the point weight which is defined as follows.

$$P_i^0 = \sum_{w: e_i} W_j$$

(6)

In equation (6), $E_i$ is the links connected to node $i$, and $W_j$ is the edge weight of the two adjacent nodes.

We can combine the types and quantities of services carried on the network link when calculating the edge weight between nodes and then define the service-based edge weight as follows.

$$W_j = \sum_{l=1}^{m_j} k_{jl} \cdot \sigma_l$$

(7)

In equation (7), $m_j$ is the total number of service types on the link $e_i$, $k_{jl}$ is the number of $l$-type service running on the link $e_i$, and $\sigma_l$ is the value of the service importance of the $l$-type service.

Therefore, redefining the point weight is as follows.

$$P_i = \frac{P_i^0}{n_i}$$

(8)

In equation (8), $n_i$ is the total number of links connected to node $v_i$.

### 2.3. Node importance combining service layer and topology layer

The network cohesion is obtained based on the service-based point weight defined above.

$$\delta(G_i) = \frac{1}{P \cdot l}$$

(9)
Table 1. Typical service importance of a province.

| Serial number | Service type                                      | Load mode / level                      | Safety zone / level | Delay / level   | Bit error / level | Service importance |
|---------------|--------------------------------------------------|----------------------------------------|---------------------|-----------------|-------------------|--------------------|
| $S_1$         | Transmission line relay protection               | Dedicated channel / 6                 | I Zone / 4          | $\leq 10ms / 8$ | $\leq 10^{-7} / 4$ | 1.0000             |
| $S_2$         | Safety and stability control system              | Dedicated channel / 6                 | I Zone / 4          | $\leq 30ms / 7$ | $\leq 10^{-7} / 4$ | 0.9479             |
| $S_3$         | Dispatching telephone                            | Dispatching switch network, dispatching data network / 3 | I Zone / 4 | $\leq 150ms / 5$ | $\leq 10^{-5} / 1$ | 0.4425             |
| $S_4$         | Dispatching automation                           | Dedicated channel, dispatching data network / 5 | I Zone / 4 | $\leq 100ms / 6$ | $\leq 10^{-6} / 3$ | 0.7356             |
| $S_5$         | Protection information management                | dispatching data network / 4         | III Zone / 3        | $\leq 10min / 2$ | $\leq 10^{-5} / 2$ | 0.4083             |
| $S_6$         | Wide-area phase measurement                      | dispatching data network / 4         | I Zone / 4          | $\leq 30ms / 7$ | $\leq 10^{-9} / 5$ | 0.8941             |
| $S_7$         | Lightning location monitoring                    | Integrated data network / 2          | III Zone / 2        | $\leq 250ms / 4$ | $\leq 10^{-5} / 2$ | 0.2433             |
| $S_8$         | Substation integrated monitoring                 | Integrated data network / 2          | III Zone / 2        | $\leq 150ms / 5$ | $\leq 10^{-5} / 1$ | 0.1755             |
| $S_9$         | Electricity metering telemetry system            | dispatching data network / 4         | IIZ Zone / 3        | $\leq 500ms / 3$ | $\leq 10^{-6} / 3$ | 0.4903             |
| $S_{10}$      | Electricity market trading operation             | dispatching data network / 4         | IIZ Zone / 3        | $\leq 250ms / 4$ | $\leq 10^{-6} / 3$ | 0.5229             |
| $S_{11}$      | Power quality management system                  | dispatching data network / 4         | IIZ Zone / 3        | $\leq 500ms / 3$ | $\leq 10^{-5} / 2$ | 0.4278             |
| $S_{12}$      | Conference television                            | Dedicated channel / Integrated data network / 3 | IV Zone / 1 | $\leq 10ms / 8$ | $\leq 10^{-5} / 2$ | 0.3149             |
| $S_{13}$      | Information disaster recovery service            | Integrated data network / 2          | IV Zone / 1         | $\leq 250ms / 4$ | $\leq 10^{-5} / 2$ | 0.1651             |
| $S_{14}$      | Executive telephone                              | Integrated data network / Administrative exchange / 1 | IV Zone / 1 | $\leq 10ms / 8$ | $\leq 10^{-5} / 1$ | 0.1517             |
| $S_{15}$      | SG-ERP system                                    | Integrated data network / 2          | IV Zone / 1         | $\leq 500ms / 3$ | $\leq 10^{-5} / 2$ | 0.1000             |

In equation (9), $l$ is the average path length between nodes and $P=\sum_{i=1}^{n} P_i$ is the sum of the point weight. So the node importance combining service layer and topology layer $CBTNI(v_i)$ is as follows.

$$CBTNI(v_i)=1-\frac{\partial(G_0)}{\partial(G_i)}$$

In equation (10), $\partial(G_0)$ and $\partial(G_i)$ are the network cohesions before and after the contraction of the node $v_i$. 
3. Introduction of factor coefficients

3.1. The factor coefficient based on the power factor

\( CBTNI(v_i) \) can better assess the importance of nodes. However, the node importance varies due to the different node types in the actual power communication network. Therefore, the factor coefficient based on the power factor \( PF(v_i) \) is defined according to the different types of nodes.

The indicator set \( A = \{a_m\} \ (m = 1, 2, 3, 4) \) in the power factor is summarized firstly according to the actual situation when calculating \( PF(v_i) \). Among them, \( a_1, a_2, a_3 \) and \( a_4 \) represent the node level, the node size, the load level and the load size respectively \([19]\). And then the set of force level values \( \{S_n(a_m)\} \) of the node \( v_n \) under the indicator \( a_m \) is obtained according to the power factor evaluation rule, in which \( s_i(a_n) \in \{1,2,\ldots,S_n\} \). The relative force matrix of the nodes \( B^{(a_m)} \) under the indicator \( a_m \) is as follows.

\[
B^{(a_m)} = \begin{pmatrix}
b^{(a_m)}_{11} & \cdots & b^{(a_m)}_{1n} \\
\vdots & \ddots & \vdots \\
b^{(a_m)}_{n1} & \cdots & b^{(a_m)}_{nn}
\end{pmatrix}
\]

In equation (11), \( b^{(a_m)}_{ij} \) is the rank value of the nodes \( v_i \) and \( v_j \) based on the relative force under the indicator \( a_m \). When \( i = j \), \( b^{(a_m)}_{ij} = 0 \); And when \( i \neq j \), the equation is as follows.

\[
b^{(a_m)}_{ij} = \begin{cases} 
1 & s_i(a_n)/s_j(a_n) > 1 \\
0.5 & s_i(a_n)/s_j(a_n) = 1 \\
0 & s_i(a_n)/s_j(a_n) < 1
\end{cases}
\]

Finding the sum of the row vector elements of the matrix \( B^{(a_m)} \) and we can obtain the relative force matrix of each node under the indicator \( a_m \).

\[
b^{(a_m)}_n = \sum_{j=1}^{n} b^{(a_m)}_{nj}
\]

According to the above method, the relative force matrix of each node under the four indicators is obtained in turn. Define the comprehensive relative force matrix of the nodes as follows.

\[
b^{\text{sum}}_n = \sum_{m=1}^{4} b^{(a_m)}_n
\]

The factor coefficient based on the power factor \( PF(v_i) \) is obtained by normalizing the elements in the matrix \( b^{\text{sum}}_n \).

3.2. The factor coefficient based on the failure probability

Both the node and the link will fail in the actual operation of the power communication network, and the probability of the link failure and the node failure has a great influence on the importance evaluation of the node with a positive relationship. This paper analyzes the operation status of multi-provincial power communication network in a certain year and summarizes the total number of node categories and links in each province in the year by processing a large number of operational statistics. The number of failures of the equipment of the transmission network, the service network and the support network in different types of nodes is counted to obtain the failure rate of the node. And the number of failures of links connected to different types of nodes in the actual power communication
network is counted to calculate the failure rate of different links. The node and link failure rate of the power communication network is shown in figure 1.

![Figure 1. Node and link failure rate.](image)

The failure rate is calculated as follows:

\[ FP(v_i) = p_i \cdot \frac{\sum_{j=1}^{k_i} e_j}{k_i} \]

(15)

In equation (15), \( p_i \) represents the node failure rate of the node; \( k_i \) is the number of links connected to the node and \( e_j \) is the link failure rate (The rate of the link failure between the two nodes is equal to the average value of the two-node link failure rate).

### 3.3. The comprehensive factor coefficient

The introduction of the factor coefficient based on the power factor \( PF(v_i) \) and the factor coefficient based on the failure probability \( FP(v_i) \) makes the evaluation of the node importance more accurate. However, the weight of the power factor indicator and the failure probability indicator are different. The following conclusion can be drawn by consulting relevant experts and summarizing them: \( FP(v_i) \) is smaller than \( PF(v_i) \). The fuzzy analytic hierarchy process is used in this paper to calculate the weight of the two factor coefficients, and the comprehensive factor coefficient of the node \( CFC(v_i) \) is obtained.

A priority judgment matrix \( A \) is constructed for the power factor indicator and the failure probability indicator firstly, and the elements of the matrix are defined according to the following rules.

\[ A = (a_{ij}) = \begin{cases} 
0.6, & \text{Indicator } i \text{ is slightly more important than indicator } j \\
0.5, & \text{Indicator } i \text{ and indicator } j \text{ are equally important} \\
0.4, & \text{Indicator } j \text{ is slightly more important than indicator } i 
\end{cases} \]

(16)

Then the priority judgment matrix \( A \) is as follows.

\[ A = \begin{pmatrix} 
0.5 & 0.6 \\
0.4 & 0.5 
\end{pmatrix} \]

(17)

Applying the following equation to the priority judgment matrix \( A \).

\[ r_i = \sum_{j=1}^{n} a_{ij} \quad (i = 1, 2, \ldots, n) \]

(18)
That is, the sum of the row elements of the matrix $A$ is determined and $u^T = (1.1, 0.9)^T$ is obtained. Then making the following mathematical transformation on the matrix $u^T$.

$$m_y = (r_i - r_j) / 2n + 0.5$$  \hspace{1cm} (19)

We can obtain a fuzzy consistent judgment matrix $M$.

$$M = (m_y)_{2x2} = \begin{pmatrix} 0.5 & 0.55 \\ 0.45 & 0.5 \end{pmatrix}$$  \hspace{1cm} (20)

The equation for calculating the indicator weights can be obtained by using the relationship between the elements of the matrix $M$ and the weights.

$$\omega_i = \frac{1}{n} \left( 1 + \frac{\sum_{j=-1}^{n-1} m_{ij}}{n\alpha} \right), \quad i \in [1, n]$$  \hspace{1cm} (21)

In equation (21), $\alpha \geq (n-1)/2$, and we make $\alpha = (n-1)/2$ in this paper. Then the weights of the power factor indicator and the failure probability indicator are respectively as follows.

$$\omega = (\omega_1, \omega_2) = (0.55, 0.45)$$  \hspace{1cm} (22)

The comprehensive factor coefficient $CFC(v_i)$ is as follows in summary.

$$CFC(v_i) = 0.55PF(v_i) + 0.45FP(v_i)$$  \hspace{1cm} (23)

4. Comprehensive node importance

Based on the above analysis, the nodes are comprehensively evaluated from the four perspectives of service, network topology, power factor and failure probability factor. The comprehensive node importance $CNI(v_i)$ is obtained by $CBTNI(v_i)$ and $CFC(v_i)$.

$$CNI(v_i) = CBTNI(v_i) \cdot CFC(v_i)$$  \hspace{1cm} (24)

The flow chart of the algorithm for calculating the comprehensive importance is shown in figure 2.

Figure 2. Flow chart of algorithm.
5. Case analysis

The power communication network topology in southeastern Sichuan Province is used as a model to verify the effectiveness of the algorithm proposed in this paper. As shown in figure 3, the network consists of 10 nodes and 14 links, in which node $v_4$ is the provincial dispatching center, node $v_{10}$ is the 220kV substation and the remaining nodes are the 500kV substations. The node set is $V = \{v_1, v_2, \ldots, v_{10}\}$, the link set is $E = \{e_1, e_2, \ldots, e_{14}\}$, and the service set is $S = \{S_1, S_2, \ldots, S_{15}\}$ shown in table 1, the dotted line is the flow path of the service.

![Figure 3. Model of power communication network.](image)

The service distribution on the 14 links in figure 3 is shown in table 2.

| Link $e_j$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ | $S_{11}$ | $S_{12}$ | $S_{13}$ | $S_{14}$ | $S_{15}$ |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|---------|---------|---------|---------|---------|
| $e_1$      | 1     | 0     | 1     | 1     | 2     | 1     | 4     | 3     | 6     | 7       | 2       | 1       | 4       | 4       | 3       |
| $e_2$      | 1     | 0     | 1     | 3     | 1     | 9     | 10    | 6     | 2     | 6       | 8       | 4       | 3       | 5       | 6       |
| $e_3$      | 1     | 0     | 0     | 4     | 1     | 3     | 5     | 2     | 4     | 4       | 3       | 2       | 2       | 4       | 5       |
| $e_4$      | 1     | 0     | 1     | 9     | 0     | 5     | 9     | 6     | 7     | 8       | 2       | 5       | 5       | 6       | 4       |
| $e_5$      | 0     | 0     | 2     | 15    | 5     | 17    | 15    | 6     | 5     | 4       | 9       | 3       | 3       | 7       | 5       |
| $e_6$      | 1     | 0     | 1     | 17    | 3     | 19    | 14    | 7     | 2     | 3       | 10      | 4       | 4       | 4       | 6       |
| $e_7$      | 0     | 1     | 1     | 5     | 7     | 6     | 9     | 4     | 3     | 3       | 4       | 3       | 2       | 4       | 6       |
| $e_8$      | 1     | 0     | 2     | 13    | 4     | 16    | 14    | 4     | 5     | 6       | 7       | 6       | 4       | 5       | 5       |
| $e_9$      | 1     | 0     | 1     | 10    | 8     | 20    | 18    | 8     | 4     | 3       | 3       | 2       | 6       | 4       | 5       |
| $e_{10}$   | 1     | 0     | 1     | 3     | 4     | 3     | 4     | 2     | 4     | 5       | 3       | 2       | 3       | 3       | 4       |
| $e_{11}$   | 0     | 1     | 2     | 3     | 2     | 4     | 5     | 2     | 4     | 6       | 3       | 2       | 4       | 4       | 2       |
| $e_{12}$   | 1     | 0     | 1     | 2     | 3     | 6     | 6     | 3     | 6     | 7       | 2       | 1       | 3       | 3       | 4       |
| $e_{13}$   | 1     | 1     | 0     | 2     | 2     | 4     | 3     | 5     | 8     | 4       | 6       | 5       | 2       | 4       | 3       |
| $e_{14}$   | 1     | 0     | 1     | 3     | 1     | 5     | 4     | 4     | 7     | 5       | 4       | 5       | 3       | 4       | 1       |

The importance of 10 nodes in figure 3 was evaluated and ordered by the method proposed in this paper, and the result is shown in table 3.
Table 3. Comprehensive node importance with its ranking.

| Node number | $CBTNI(v_i)$ | $CFC(v_i)$ | $CNI(v_i)$ | Node ranking |
|-------------|--------------|------------|------------|--------------|
| $v_4$       | 0.7601       | 0.4058     | 0.3084     | 1            |
| $v_7$       | 0.4239       | 0.0858     | 0.0364     | 2            |
| $v_3$       | 0.4306       | 0.0781     | 0.0336     | 3            |
| $v_6$       | 0.3065       | 0.0998     | 0.0306     | 4            |
| $v_9$       | 0.3642       | 0.0789     | 0.0287     | 5            |
| $v_5$       | 0.3053       | 0.0826     | 0.0252     | 6            |
| $v_8$       | 0.3427       | 0.0673     | 0.0231     | 7            |
| $v_1$       | 0.3028       | 0.0406     | 0.0123     | 8            |
| $v_2$       | 0.2870       | 0.0406     | 0.0116     | 9            |
| $v_{10}$    | 0.3443       | 0.0205     | 0.0007     | 10           |

The node contraction method, the cross-layer fusion method [20], the topology + power factor method [21] and the method proposed in the paper are compared and the comparison results of the four algorithms are shown in table 4.

Table 4. Comparison results of algorithms.

| Node number | Node contraction method | Cross-layer fusion method | Topology + power factor method | Algorithm of this paper |
|-------------|-------------------------|---------------------------|-------------------------------|-------------------------|
|             | Importance value Ranking| Importance value Ranking  | Importance value Ranking      | Importance value Ranking|
| $v_1$       | 0.3504                  | 7                         | 0.3028                        | 9                       | 0.0123                  | 8                        |
| $v_2$       | 0.3504                  | 8                         | 0.2870                        | 10                      | 0.0193                  | 9                        |
| $v_3$       | 0.4789                  | 2                         | 0.4306                        | 2                       | 0.2866                  | 2                        |
| $v_4$       | 0.6684                  | 1                         | 0.7601                        | 1                       | 0.6571                  | 1                        |
| $v_5$       | 0.2827                  | 9                         | 0.3053                        | 8                       | 0.1692                  | 7                        |
| $v_6$       | 0.2421                  | 10                        | 0.3065                        | 7                       | 0.1833                  | 6                        |
| $v_7$       | 0.3842                  | 3                         | 0.4239                        | 3                       | 0.2609                  | 3                        |
| $v_8$       | 0.3842                  | 4                         | 0.3427                        | 6                       | 0.2113                  | 5                        |
| $v_9$       | 0.3684                  | 6                         | 0.3642                        | 4                       | 0.2264                  | 4                        |
| $v_{10}$    | 0.3842                  | 5                         | 0.3443                        | 5                       | 0.0739                  | 10                       |

Combined with the topology model of the power communication network and the actual operation of the network, it can be known through the analysis that node $v_4$ is the provincial dispatching center with more service on it, so its node has the highest importance. Nodes $v_1$, $v_3$, $v_5$, $v_6$, $v_7$ and $v_9$ are all 500kV substations, but $v_3$, $v_5$, $v_6$, $v_7$ and $v_9$ are connected to node $v_4$ which has a higher power factor. And the failure rate of the link connected to $v_4$ is large. So $v_3$, $v_5$, $v_6$, $v_7$ and $v_9$ are more important than the nodes of $v_1$ and $v_2$, $v_3$ and $v_7$ have more service on the link than $v_5$, $v_6$, $v_8$ and $v_9$, and the node type and load factor of $v_7$ are higher than $v_3$, so node $v_7$ is more important than node $v_3$, $v_6$ and $v_8$ have a relatively high service volume, while $v_6$ is connected to $v_4$ and $v_7$, $v_8$ is connected to $v_4$ and $v_{10}$, node $v_6$ has a higher node type, load factor and failure probability, so node $v_6$ is more important than node $v_9$. We can see from the topological position that both $v_5$ and $v_3$ are connected to node $v_10$, and node $v_8$ has more service than node $v_5$, but node $v_5$ is connected to node $v_4$ which makes node $v_5$ has a higher load factor and failure probability. Therefore, node $v_5$ has a relatively high node importance. It can be seen from figure 3 that the positions of nodes $v_1$ and $v_2$ are symmetrical. The node contraction method and the topology + power factor method cannot distinguish the importance of the two nodes, but the service carried on node $v_1$ is more than node $v_2$. Therefore, the method proposed.
in this paper can be used to calculate that the importance of the node $v_1$ is more important than node $v_2$. Node $v_{10}$ is a 220kV substation with the lowest node importance.

According to the evaluation results of node importance of the above four evaluation algorithms, the nodes are ranked by high and low, and each node is attacked one by one by deliberate attack [22]. The service failure rate is used as an evaluation indicator to obtain the relationship between the node ranking and service failure rate as shown in figure 4.

![Figure 4. Node ranking and service failure rates.](image)

It can be seen from figure 4 that the relationship between the node ranking and the service failure rate obtained by the method proposed in this paper is decreasing overall with the service failure rates of nodes $v_4$ and $v_7$ are both more than 0.3 and the service failure rates of other nodes are less than 0.3. And the change rule of the polyline is basically consistent with the ranking order of the node importance which verifies the rationality of the algorithm. We can see from the figure that the service failure rates of nodes $v_2$ and $v_{10}$, nodes $v_6$ and $v_9$ do not conform to the strict monotonous decreasing regular pattern which is because that the method proposed in this paper not only considers the topology and service characteristics, but also combines the power factor and indicators such as the failure probability of nodes and links. The node contraction method and the topology + power factor method ignore the service carried by the node are also affect the evaluation result which lead to that the variation of the polylines obtained by the two methods are irregular. The cross-layer fusion method is the original algorithm of the method proposed in this paper. But this method does not have enough practical significance in the actual network because the topology and service indicators are considered while the node type and the failure probability of node and link are ignored in this method. The method proposed in this paper comprehensively considers the topological structure, service, power factor and failure probability which can effectively distinguish the importance degree of nodes in the power communication network. This method is more reasonable for the identification of the key nodes of the power communication network.
6. Conclusion
The factors which affect the evaluation result should be considered as comprehensively as possible when evaluating the importance of node in the power communication network. The method proposed in this paper takes the comprehensive factor coefficient based on the power factor and the failure probability as the weighted influence factor of the node importance combining the service layer and topology layer of the power communication network to identify the key nodes. The example analysis and the comparison between the algorithms show that the method proposed in this paper is suitable for the evaluation of the node importance in the power communication network which can evaluate the node importance more accurately and effectively.

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