Operation Quality Evaluation of Power Communication Network Based on Business QOS Indicators

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Abstract. The development of the power communication network has brought new challenges to the comprehensive evaluation technology of the service quality and the business risk assessment technology. The existing service quality evaluation system does not take the service subnet indicator of the power communication network into consideration systematically, and it is difficult to meet the comprehensive evaluation requirements of the service quality of the whole network. Based on the characteristics of the power communication network, this paper constructs and stratifies its business QOS indicators. Then the indicators of each layer are introduced in detail, and the weight of each indicator in each layer is found by using the method of the analytic hierarchy process. Furthermore, the normalized value of each indicator is found by using the conversion function based on the analytic hierarchy process to make the defined indicator connotation close to the actual operational data and strengthen the comparability between the indicator in this paper. Finally, the operating quality of the power communication network is evaluated by the normalized value and the weight of each indicator combined with the example. The aim is to provide a theoretical reference for the development of the grid business risk management to ensure that the power communication network can operate in a low-risk state.

1. Introduction

With the development of the power grid, especially the accelerated construction of the smart grid, the demand for communication services in the power system is getting higher and higher. On the one hand, the service quality requirements of some special services have increased; on the other hand, with the addition of new energy sources, the scale of distributed energy and micro-grid has been expanding, which has led to many new business types in the power communication network[1]. This makes it difficult for traditional business evaluation index systems to content the needs of differentiated communication services. The main performance is that the business evaluation indicators are difficult to express in a unified way, which brings great difficulties to the establishment of the comprehensive evaluation index system. Moreover, with the rapid development of communication technology and the increasing complexity of network scale, the existing evaluation indicators are not updated synchronously according to network requirements and technologies. The evaluation technology and evaluation effect lag behind the development status of power communication networks[2]. This will inevitably lead to a decline in the indicators of the power communication network, resulting in a decline in the performance of the power system business, and the serious deterioration of the service quality will not meet the requirements for safe, stable and reliable operation of the power system[3]. Therefore, this paper will comprehensively analyze and construct the business QOS indicators, and...
use the analytic hierarchy process and numerical transformation to convert the value of the business QOS indicator into a normalized value with high contrast. Through the analysis of weights and normalized values, each indicator is evaluated to provide guidance for the risk assessment of the grid to improve the ability of the grid to operate stably and reliably.

2. Business QOS indicator

Grid operation requires multiple types of communication service support, and different service types have different QoS requirements. This makes different services have different effects on the operation of the grid, showing different importance. Common business types are as follows: 1) Control business: Such as relay protection, safety and stability control, dispatching data network, power transmission and transformation status detection, substation comprehensive monitoring, distribution network operation monitoring, distribution network automation, etc. 2) Switched network service: Such as administrative calls and dispatching phones, etc [4]. 3) Management business: Such as marketing business management system, communication intelligent management system, customer contact system, 95598 and fault repair management, power quality management system, customer electricity information collection, power market trading operations. 4) Information business: Such as data (disaster disaster) centers, SG-ERP and conference television systems, etc.

Because too many types of services are bad for data collection and monitoring, which can cause incomplete information easily. And the operational quality evaluation mainly adapts to the normal state of the network, and the degree of satisfaction of the performance indicators in this state, rather than the fault and failure state [5]. Therefore, this paper does not include all the above-mentioned services into the secondary indicators when constructing the business QOS indicator system. Instead, it summarizes the above-mentioned services and abstracts the services common of the above services into data services, audio services and flows. Media business and use it as a secondary indicator. At the same time, with the continuous advancement of the IP process, packet switching will become the main form of bearer network implementation. To adapt to this feature, the indicator system of this topic focuses on the quality and risk of packet switched networks. Therefore, when selecting the three-level indicator, the three indicators, such as transmission delay, packet loss rate and congestion rate, are used as the third-level indicator. The indicator architecture diagram is shown in Figure 1.
2.1 Business QOS single indicator

2.1.1 Transmission delay of data service, audio frequency service and streaming media service
The overall expression of the transmission delay of the data service, the audio frequency service, and
the streaming media service is:

\[ D_d = T_d + t'_d = (0.49L + T_{sd} + nT_p + T_{dd} + T_{tr}) + \sum_{i=1}^{n} t'_d \]  

(1)

Where 0.49L indicates the propagation delay of the optical cable length L in the path. T_{sd} indicates
the fixed processing delay of the source node. T_{dd} indicates the fixed processing delay of the
destination node, including the jitter buffer time. T_p indicates the fixed processing delay of the path
intermediate node, indicating the number of intermediate nodes; T_{tr} indicates the transmission delay of
the data packet in the path, which is related to the data rate and the packet length. The portion of
parentheses in the formula (1) represents a fixed delay component. t'_d indicates the random delay of
data queuing, scheduling, and waiting in the intermediate node.

2.1.2 Peak packet loss rate of data service, audio frequency service, and streaming media service
The peak packet loss rate of data service, audio frequency service, and streaming media service is an
indicator to measure the reliability of quasi-real-time and non-real-time transmission of these three
services. This indicator indicates the maximum packet loss rate for data service, audio frequency
service, and streaming media service during a given observation period. The expression of the peak
packet loss rate is:

\[ \beta_p_{max} = MAX\left(\frac{1-n_i}{m_i}\right) \]  

(2)

Where n_i is the number of packets correctly received for the i-th data transmission, m_i is the total
number of packets transmitted for the i-th data transmission, and (1-n_i)/m_i is the packet loss rate for the
i-th data transmission. NUM is the total number of data transfers in the observation time window. The
transmission loss rate is a dynamically changing random variable. In order to facilitate the analysis and
calculation in engineering, the maximum value method is used to indicate the transmission loss rate of
three services.

2.1.3 Peak congestion rate for data service, audio frequency service, and streaming media service
The peak congestion rate of data services, audio services, and streaming services is an indicator to
measure the congestion of these three types of services. During a given observation period, the
indicator represents the maximum probability of transmission congestion, and its expression is:

\[ P_{c_{max}} = MAX\{P_r(S_i = C)\} \]  

(3)

Where (Si=C) indicates a congestion state. The occurrence of congestion state is related to many
factors, and the congestion probability Pr(Si=C) has strong dynamics and changes with time. This
indicator refers to the maximum probability of congestion in the three services within a given
observation time window.

3. Analytic Hierarchy Process and conversion function

3.1 Analytic Hierarchy Process
Analytic Hierarchy Process (AHP) refers to the decomposing of elements related to the overall goal of
decision-making into goals, criteria, and programs. On this basis, qualitative and quantitative analysis
methods are used. This method is a hierarchical weighted decision analysis method proposed by
American operations researcher Pittsburgh University professor Saty in the early 1970s⁶.

The AHP calculation’s steps are as follows:
3.1.1 Establish a hierarchical model
The goal of decision-making, the factors considered (decision-making criteria) and the decision-making objects are divided into the highest layer, the middle layer and the lowest layer according to the mutual relationship, and establishing a hierarchical structure diagram. The highest level is the problem to be solved. The lowest level refers to the alternative when making decisions. The middle layer refers to the factors considered and the criteria for decision making. For the adjacent two layers, the upper layer is called the target layer, and the lower layer is the factor layer [7]. This article corresponds to the three-level indicator of business QOS.

3.1.2 Construction judgment matrix A
When determining the weights between the various factors at each level, all factors are compared with each other, and relative scales are used for comparison to minimize the difficulty of comparing factors with different natures and improve the accuracy. For a certain criterion, the schemes under it are compared in pairs and rated according to their importance level [8]. Where \( a_{ij} \) is the comparison result of the importance of the element i and the element j, and the reference standard of the value is shown in Table 1.

| The importance of factor i compared with factor j | Quantitative value (scale) |
|-----------------------------------------------|--------------------------|
| Equally important                             | 1                        |
| Slightly important                            | 3                        |
| Stronger important                            | 5                        |
| Strongly important                            | 7                        |
| Extremely important                           | 9                        |
| Intermediate value of two adjacent judgments  | 2, 4, 6, 8               |

Table 1 lists the nine importance levels and their valuation, also known as scales. A matrix formed by the results of the pairwise comparison is called a judgment matrix. The nature of the judgment matrix is:

\[
a_{ij} = \frac{1}{a_{ji}} \quad (4)
\]

3.1.3 Hierarchical ordering and calculation of weight
In this paper, we use the sum and product method to calculate the weight. First, normalize each column element of A to get the general term of the column normalization element is:

\[
\bar{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (5)
\]

Then, the normalized matrix of the columns is summed to obtain a column vector whose general term is:

\[
\bar{w}_i = \sum_{j=1}^{n} \bar{a}_{ij} \quad (6)
\]

Finally, the column vector is normalized to obtain the weight vector W, and the element general term is:

\[
w_i = \frac{\bar{w}_i}{\sum_{i=1}^{n} \bar{w}_i} \quad (7)
\]

3.2 Conversion function
In order to further enhance the comparability between indicators, this paper introduces a conversion function. According to the physical meaning and assignment principle of the index, combined with the
nature of the index, we use the generalized Logistic function as the transfer function of this paper to realize the conversion of the index evaluation value to the normalized index value \([9]\).

The expression of the generalized Logistic function is:

\[
f(t) = \frac{1}{1 + \exp(-B(t - M))}
\]  

(8)

Where \(t\) is the evaluation value of the indicator, and the two parameters \(B\) and \(M\) are determined by the physical meaning of the specific indicator and the comparability principle of the comprehensive evaluation. And according to the physical meaning of the indicator, the generalized Logistic function is divided into two categories, which are positive (P) and negative (N). Each type of conversion function corresponds to an indicator property.

Positive-type conversion function is abbreviated as P function, and its expression is:

\[
f_P(t) = \frac{1}{1 + \exp(-B(t - M))}
\]  

(9)

Key point value: \(f_P(-\infty) = 0\), \(f_P(M) = 0.5\), \(f_P(+\infty) = 1\). \(f_P(t)\) is used to achieve numerical conversion of positive indicators.

Negative-type conversion function is abbreviated as N function, and its expression is:

\[
f_N(t) = 1 - \frac{1}{1 + \exp(-B(t - M))}
\]  

(10)

Key point value: \(f_N(-\infty) = 1\), \(f_N(M) = 0.5\), \(f_N(+\infty) = 1\), \(f_N(t)\) is used to implement the numerical conversion of the negative indicator.

4. Instance verification

According to the above discussion, the second-level indicators of the service QOS indicator are data service, audio frequency service and streaming media service. The third-level indicator is data service transmission delay, peak data packet loss rate, peak data traffic congestion rate, audio frequency service transmission delay, peak packet loss rate of audio frequency service, peak traffic congestion rate of audio frequency service, streaming media service transmission delay, peak packet loss rate of streaming media service and peak traffic congestion rate of streaming media service. According to the actual survey results of the power communication network, the judgment matrices of the second-level indicators and the third-level indicators are shown in Table 2,3.

Table 2. AHP judgment matrix of business QOS second-level indicators.

| Judgment matrix | Data service | Audio frequency service | Streaming media service |
|-----------------|--------------|-------------------------|------------------------|
| Data service    | 1            | 3                       | 5                      |
| Audio frequency service | 1/3      | 1                       | 3                      |
| Streaming media service | 1/5       | 1/3                     | 1                      |

According to formula (5), (6), (7), the weight vector of the QOS secondary indicators of the three types of services can be obtained as \([0.61 \quad 0.29 \quad 0.10]^T\).

Table 3. AHP judgment matrix of business QOS third-level indicator

| Judgment matrix | Transmission delay | Peak packet loss rate | Peak congestion rate |
|-----------------|--------------------|-----------------------|---------------------|
| Transmission delay | 1                  | 1/7                   | 1/5                 |
| Peak packet loss rate | 7                  | 1                     | 3                   |
| Peak congestion rate | 5                  | 1/3                   | 1                   |
Using the AHP method, the weight vector of the business QOS third-level indicator is $[0.07 \ 0.65 \ 0.28]^T$. According to the actual project status, the weight vector of the data service, audio frequency service and streaming media service indicators is also $[0.07 \ 0.65 \ 0.28]^T$. In this way, the weight vector of the nine third-level indicators of the service network is $[0.043 \ 0.397 \ 0.171 \ 0.020 \ 0.189 \ 0.081 \ 0.007 \ 0.064 \ 0.028]^T$.

According to the relevant data in the operation data of the power communication network and the maintenance records, the evaluation values of all the third-level indicators can be calculated by the equations (1), (2), and (3). Through calculation the average transmission delay of the data service is 60ms, the peak packet loss rate is $10^{-5}$, and the peak congestion probability is $10^{-3}$. The QoS index values of audio frequency service and streaming media service can be obtained in the same way.

According to the large difference between the values of these third-level indicators, it is not conducive to analysis and comparison. This paper compares the indicators from the perspective of indicator weight and normalized value. The weight of the third-level indicator has been obtained above. The index will be normalized by the conversion function of equation (8). Since these nine third-level indicators have the same characteristics, that is, the increase of the index value will lower the evaluation result of the overall target, so these indicators are negative indicators and need to be transformed by the negative-type conversion function $[10]$. Therefore, the calculation is performed using the equation (10). According to the performance indicators of various types of business and the basic principles of operational quality evaluation.

The conversion function of the delay class indicator is determined as:

$$f_{N-D}(t) = 1 - \frac{1}{1+\exp(-0.055(t-50))}$$  \hspace{1cm} (11)

The conversion function of the peak packet loss rate and the peak congestion rate is:

$$f_N(t) = 1 - \frac{1}{1+\exp(-1.1(\log t+5))}$$  \hspace{1cm} (12)

Therefore, the data collection calculation results and the transformed results of the third-level indicator are shown in Table 4.

| the third-level indicators                          | The weight of third-level indicator | Data collection calculation result | Converted value |
|----------------------------------------------------|------------------------------------|-----------------------------------|----------------|
| Data service transmission delay.                   | 0.043                              | 60ms                              | 0.366          |
| Peak data packet loss rate                         | 0.397                              | 1.00E-04                          | 0.250          |
| Peak data traffic congestion rate.                 | 0.171                              | 1.00E-05                          | 0.500          |
| Audio frequency service transmission delay.        | 0.020                              | 30ms                              | 0.750          |
| Peak packet loss rate of audio frequency service   | 0.189                              | 1.00E-04                          | 0.250          |
| Peak traffic congestion rate of audio frequency service | 0.081                              | 1.00E-04                          | 0.250          |
| Streaming media service transmission delay.        | 0.007                              | 20ms                              | 0.839          |
| Peak packet loss rate of streaming media service   | 0.064                              | 1.00E-05                          | 0.500          |
| Peak traffic congestion rate of streaming media service | 0.028                              | 1.00E-06                          | 0.750          |

After the transformation, the index value varies between $[0,1]$, and various indicators have strong comparability. The radar chart can be used to visually represent the values of the converted indicators, as shown in Figure 2.
As can be seen from Figure 4-1 and Table 4-3, the weighted results calculated by theory are consistent with the normalized values calculated from the actual data. That is, the transmission delay of the streaming media service has the smallest weight value, but the normalized value is the largest, indicating that the transmission delay of the streaming media service has the least impact on the performance of the service network. The peak value of the packet loss rate of the data service has the largest weight value, and the normalized value is the same as the peak value of the audio frequency service packet loss rate and the peak value of the audio frequency service congestion rate, indicating that the three QOS indicators have the greatest impact on the performance of the service network. Based on the above-mentioned index values, when formulating the risk management and control measures for the grid business, we should consider more factors that have a greater impact on the performance of the service network, such as the packet loss rate and congestion rate of the audio frequency service, and the packet loss rate of the data service. For the factors that have a small impact, you can take a little care when making measures. This will save network resources while ensuring that the power communication network can operate in a low-risk state.

5. Conclusion
In view of the phenomenon that the existing power communication network's index system can't keep up with the development of the actual power industry, this paper proposes a set of index system for the service network in the power communication network. In order to make the proposed system hierarchical, the paper divides the business network index system into three levels, and introduces in detail the characteristics and calculation methods of each indicator in each layer. Further, in order to compare the degree of influence of each indicator on the service network, an analytic hierarchy process and a transfer function are introduced. By using these two algorithms, the weights and normalized values of the indicators are respectively obtained. Then the paper analyzes and evaluates the impact degree of each indicator in the service network from the weight and normalized value of each indicator. The level of impact of each indicator on the performance of the service network is found out. Through the evaluation of each level, theoretical guidance can be provided for the formulation of risk management measures for the grid business.

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