Research on Testability Index Allocation in Smart Substation Digital Metering System Based on Fuzzy Comprehensive Evaluation

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Abstract. The digital metering system has certain advantages in comparison with traditional metering systems in principle and performance, but the engineering application time is short. At present, there is a lack of research on the testability of digital metering systems. Reasonable determination of testability index allocation is an important issue to be addressed in the test requirements of digital systems. In this paper, the fuzzy comprehensive evaluation method is used to distribute the test index of smart substation system, which makes it more realistic. It can reflect the whole process of test distribution objectively and truly. Finally, combining with the communication network subsystem of substation, the proposed method is used to verify the testability distribution method, which shows that the method is feasible and effective.

1. Introduction

Too low test index will affect the maintainability and usability of smart substation equipment, but too high index will be unattainable, increasing the difficulty, cycle and cost of equipment development in the station, and even leading to the failure of development work. Reasonable determination of test index is an important issue to be solved in the test requirements of intelligent substation systems[1-2].

Testability allocation is the process of assigning required system testability and diagnostic index to sub-systems, equipment, components, or components, as their respective testability indicators are provided to the designer. Testability allocation is one of the important tasks of test design, and its main work is carried out in the program demonstration and preliminary design stage[3]. Testability allocation methods include equivalence allocation method, failure rate allocation method[4-7], allocation method considering failure rate and cost and comprehensive weighted allocation method. Most of these methods need the support of relevant parameters when they are used. For some newly developed equipment, due to its short use time, the corresponding reliability and testability data parameters are very scarce. Therefore, the results of analysis when using these methods for testability allocation are often rough[6][8-9].

Digital metering system has some advantages in principle and performance compared with traditional metering system, but its engineering application time is short. At present, there is a lack of research on the testability of the digital metering system[10]. In this paper, the fuzzy comprehensive evaluation method is applied to the smart substation system, and the test index allocation research is carried out, and the feasibility is verified by an example.
2. Fuzzy comprehensive evaluation

Comprehensive evaluation refers to the comprehensive evaluation of things or systems affected by many factors. When the evaluation factors are ambiguous, such evaluation is called fuzzy comprehensive evaluation. In the stage of program demonstration and preliminary design, the parameters affecting the factors of test distribution have certain ambiguity, which cannot be described by specific and accurate data, and there are many influencing factors and the influence degree of each factor on test distribution is different. It is necessary to consider the weighting of various factors, and fuzzy comprehensive evaluation is applicable to solve this problem[11-13].

3. Construction of fuzzy comprehensive evaluation model

Fuzzy comprehensive evaluation is based on fuzzy mathematics. Generally, the application of fuzzy comprehensive evaluation method to testability index allocation in digital metering system is as follows[14-15].

3.1. Determining the evaluation factor system

The main factors that measure the size of the test distribution are selected based on the factors that influence the system's test distribution. The main factors affecting the test distribution are importance, complexity, mean time to repair (MTTR), failure impact factor, cost factor, and so on.

- Importance (E1): Measured according to the importance of the subsystem. The greater the importance, the higher the testability of the allocation.
- Complexity (E2): Depending on the number of components that make up the subsystem and how easy it is to assemble. The higher the complexity, the higher the failure rate that should be assigned.
- MTTR (E3): Based on the repair time after the failure. Generally, for test items with small MTTR values, higher test indicators should be assigned.
- Failure Impact Factor (E4): Evaluated according to the impact on the system after a fault occurs. If the fault has a large impact, the testability of the allocation should be higher.
- Cost factor (E5): Evaluated based on the cost of implementing fault detection and fault isolation. To achieve low cost of fault detection and isolation, high test indicators should be assigned.

3.2. Determining Evaluation Set

According to the characteristics of the devices in substation, the evaluation set of the devices is given. It is assumed that the state of a certain type of device can be divided into good state, good state, normal state and fault state.

\[
V = \begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4
\end{bmatrix}^T = \begin{bmatrix}
\text{better} \\
\text{good} \\
\text{normal} \\
\text{bad}
\end{bmatrix}
\begin{bmatrix}
1 \\
0.8 \\
0.5 \\
0
\end{bmatrix}^T
\]

3.3. Determination of Index Weight of Performance Parameters

The weights of performance parameters are given by analytic hierarchy process. Through the analysis of the indicators, the weight of each indicator can be determined. The weight is composed of:

\[
W = \{w_1, w_2, \cdots, w_n\}
\]

Where, n is the number of index items and satisfies the normalization condition:

\[
\sum_{i=1}^{n} w_i = 1
\]

3.4. Establishment of Single Factor Evaluation Matrix

Fuzzy membership matrix R is the relationship matrix between the factor set and the evaluation set. It can be calculated by bringing the performance parameters of the subsystem into the membership function. Because the ridge distribution function has the characteristics of wide principal value interval
and gentle transition zone, it can better reflect the deterioration degree of equipment and the fuzzy relation of state space, so it can be used to calculate the membership degree of equipment deterioration degree corresponding to each state in each evaluation set. The corresponding figures of the ridge-raising, intermediate and falling functions are shown in Figure 1.

![Figure 1. Ridge Distribution Function Diagram](image)

There are n subsystems, which are scored by experienced experts on the importance, non-complexity, technical maturity, non-harsh environment, and non-length of working hours of each subsystem respectively. The full score is 10, the highest score is 10, and the lowest score is 10. According to the parameter range of each performance parameter index of equipment, the deterioration degree of each performance parameter index is substituted into the corresponding formula in formula 3-5, then the membership degree of each performance parameter index relative to the evaluation set can be calculated, and the membership matrix R can be constructed.

\[
G(x) = \begin{cases} 
\frac{1}{2} - \frac{1}{2} \sin \frac{\pi}{b-a} \left[ x - a \frac{x + b}{b} \right] & x \leq a \\
0 & a < x \leq b \\
1 & b < x \leq -b \\
0 & x < -b \\
\frac{1}{2} - \frac{1}{2} \sin \frac{\pi}{b-a} \left[ x - a \frac{x + b}{b} \right] & -a < x \leq a \\
0 & a < x \leq b \\
1 & x \leq a \\
\end{cases} 
\]

(4)

There are n subsystems, which are scored by experienced experts on the importance, non-complexity, technical maturity, non-harsh environment, and non-length of working hours of each subsystem respectively. The full score is 10, the highest score is 10, and the lowest score is 10. According to the parameter range of each performance parameter index of equipment, the deterioration degree of each performance parameter index is substituted into the corresponding formula in formula 3-5, then the membership degree of each performance parameter index relative to the evaluation set can be calculated, and the membership matrix R can be constructed.

\[
R = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{15} \\
r_{21} & r_{22} & \cdots & r_{25} \\
\vdots & \vdots & \ddots & \vdots \\
r_{n1} & r_{n2} & \cdots & r_{n5} \\
\end{bmatrix}
\]

(7)

3.5. Fuzzy comprehensive evaluation set

The fuzzy comprehensive evaluation set B can be obtained according to the following formula.


\[
B = W \circ R = (b_j) = \sum_{j=1}^{n} (w_j \cdot r_j) \quad j = 1, 2, \cdots, m
\]

(8)

Where, \( b_j \) is the number of scores for the \( j \)th system, \( W \) is the weight vector of the device performance parameters, and \( R \) is the membership matrix, \( \circ \) represents a generalized fuzzy synthesis operation. In the substation system, since the operator \( M (\cdot,+) \) is a comprehensive evaluation operator with prominent factors, the paper uses this operator for calculation.

4. Comprehensive evaluation examples

Taking the communication subsystem of a smart substation in a power supply company as an example, the system is composed of nine units, and the required testability index is 0.9352. The expert consultation method is used to score the importance, complexity, MTTR, fault impact coefficient and cost coefficient of each unit. The weight is determined by the analytic hierarchy process, and the above-mentioned method is used to perform test distribution of each unit. Testability allocation of elements, specific parameters and calculation results are shown in Table 1.

Table 1. Communication subsystem parameters and testability allocation table

| Unit No. | Characteristic Parameter | Importance | Complexity | MTTR | Fault Impact Coefficient | Cost Coefficient | Weight | Measured Value | bj |
|----------|-------------------------|------------|------------|------|--------------------------|-----------------|--------|----------------|----|
| 1        | Usability               | 10         | 3          | 7    | 2                        | 1                | 0.2360 | 99.95%        | 0.9557 |
| 2        | Response Time           | 10         | 7          | 9    | 9                        | 10               | 0.1528 | 1ms           | 0.9812 |
| 3        | Packet Loss             | 9          | 9          | 2    | 9                        | 10               | 0.0950 | 0.05%         | 0.9456 |
| 4        | Throughput Rate         | 5          | 3          | 1    | 8                        | 10               | 0.0572 | 80%           | 0.9228 |
| 5        | Accuracy                | 10         | 9          | 7    | 9                        | 1                | 0.2360 | 99.95%        | 0.9356 |
| 6        | Utilization Ratio       | 7          | 7          | 8    | 6                        | 1                | 0.0950 | 20%           | 0.9412 |
| 7        | Conflict Rate           | 5          | 7          | 3    | 7                        | 1                | 0.0572 | 0             | 0.9532 |
| 8        | Broadcasting Rate       | 1          | 3          | 2    | 4                        | 1                | 0.0354 | 380s          | 0.9812 |
| 9        | Multicast Rate          | 3          | 3          | 3    | 5                        | 1                | 0.0354 | 330s          | 0.9742 |

As can be seen from the above table, the communication network system is a complex subsystem in the intelligent substation. The factors that need to be considered in the evaluation of the state of the communication network by applying the analytic hierarchy process and the fuzzy comprehensive evaluation method are more specific. The method scientifically will be qualitative and the combination of quantitative results can make the calculation results more objective and comprehensive.

5. Conclusion

In this paper, the fuzzy comprehensive evaluation method is used to allocate the testability index to complex smart substation system. This method has the advantages of considering various influencing factors and quantifying the weight of each factor, and can objectively and truly reflect the test distribution. In the whole process, the paper finally combines the substation communication network subsystem, and uses the proposed method to verify the testability allocation method, which shows that this method is effective. This method combines several test distribution methods, each taking its advantages, the result is highly reliable.

Acknowledgments

The authors would like to express their gratitude to Jian-xing Li and Qiang Ye at Electric Power Research Institute of State Grid Fujian Electric Power Company for their useful advice. This research
was supported by the Project: Research on Hierarchical Testability Modeling and Analysis Method of Digital Metering System (NO. 52130418000X).

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