Research on system testability index allocation of substation digital metering system

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Abstract. In the testability engineering of measurement system, if the allocation of testability indicators is not combined with the overall scheme of the system, it will lead to the indicators too high to achieve or too low and thus lack of binding effect. At present, the test scheme for digital metering system can only effectively guarantee the accuracy and reliability of a digital metering device when it runs alone, and can not fully reflect the performance of this device when it runs as part of a complete system. Combining with the digital measurement system of substation, this paper introduces the engineering prediction method into the system, and designs the allocation scheme of testability index and an integrated framework for system-level testability scheme and index allocation. It has reference significance for optimizing the design scheme of testability, reducing the time and cost of testing, and improving the test efficiency.

1. Introduction

At present, State Grid Corporation of China has promoted smart substation throughout the entire power grid. All new substations above 220kV are smart substations, and existing substations are also undergoing intelligent transformation. Correspondingly, the metering system of substation has also changed from the traditional analog metering system to the digital metering system. At present, many test methods of digital metering system in intelligent substation are used to test and evaluate the performance of single equipment, but these test methods can only guarantee accurate and reliable measurement results when the digital metering device is running alone, and can not fully reflect the performance of device when it runs as part of a complete system, and it is difficult to find and deal with malfunctions in time due to factors such as transmission link or synchronous link problem[1-3]. Compared with traditional metering system, digital metering system is different in composition structure, information transmission mode and measurement principle. On the one hand, its failure mode is completely different from the traditional measurement system, on the other hand, its components are networked and intelligent. This paper introduces the test idea and built-in test module, which provides technical basis for condition maintenance and fault diagnosis of digital metrology system. In the digital metrology system, the actual test and maintenance project has not been carried out. At present, the research on test modeling and analysis methods of digital metrology system is not deep enough[1,4-5].
For this reason, this paper introduces the idea of system testability into substation digital metering system, and introduces the general application steps of testability analysis method in substation digital metering system, the distribution process of testability index, and the integrated framework for system-level testability scheme and index allocation. The research in this paper is of great significance for optimizing testability design, shortening test time, reducing test cost and improving test efficiency.

2. Testability prediction method
Determining reasonable testability index is the primary task of system testability design. Excessive testability index requirements will greatly increase the design difficulty, development cycle and development cost, and even lead to development failure. However, if the testability index is too low, it will not make full use of the system resources, and may not meet the final needs of the system testability. Therefore, in order to make the testability index more reasonable, accurate and feasible, it is necessary to make a preliminary prediction at the initial stage of the system design, and then compare the predicted value of the testability index with the required value. If the predicted value is slightly larger than the required value, it proves that the determined testability index is reasonable and can meet the expected testability requirements. If the predicted value is less than the required value, it shows that the current testability design of the system can not meet the requirement. It is necessary to improve the design to improve the testability index or reduce the initial index appropriately[6].

At present, there is no universal prediction method for preliminary estimation of whether testability indicators can meet the required values. The only popular method of testability prediction is the engineering prediction method. This method predicts the fault detection ratio (FDR) and the fault isolation ratio (FIR) through engineering statistics and calculations. The FDR refers to the ratio of the total number of faults that can be correctly detected by the unit under certain test conditions to the total number of faults that actually occur within a specified time. The FIR refers to the ratio of the total number of faults that can correctly isolated within a specified number of replaceable units in a specified time and under certain test conditions to the total number of faults that can be correctly detected at the same time[6-7].

In this paper, the engineering prediction method is introduced into the testability engineering of substation digital metering system. Its application process mainly includes the following contents:
- Analyze the hierarchical structure and composition of the substation digital metering system;
- Testability scheme analysis: analyze the working principle of pre-mission BIT (machine self-inspection), BIT in task and maintenance BIT, and its test scope, condition of end test, fault display and record, etc;
- Obtain FMECA (Failure Mode, Effects Criticality Analysis) data and reliability prediction data, in order to list all failure modes, master the impact of failure and failure rate of functional units or components, and the frequency ratio of failure modes;
- Index analysis: combining the data and analysis results obtained from the previous steps, identify whether the failure modes of each functional unit or component can be detected by BIT, which BIT operation mode can failure be detected, and which failure modes can not be detected, then fill in the testability prediction worksheet with the detectable failure rate data;
- Fill in test description form, BIT description form and external test description form according to test type;
- Calculate testability indicators. The formulas for calculating the failure detection rate and isolation rate of each component are as follows:

\[
FDR = \frac{\lambda_D}{\lambda} = \frac{\sum \lambda_{ii}}{\sum \lambda_i} \times 100\%
\]

\[
FIR = \frac{\lambda_I}{\lambda_D} = \frac{\sum \lambda_{iii}}{\sum \lambda_{ii}} \times 100\%
\]
\( \lambda_D \) is the total number of faults that can be correctly detected, \( \lambda \) is the total number of faults that actually occur in the system, \( \lambda_{IL} \) is the total number of faults that can be correctly detected to within the required fault resolution level;

- Result analysis: compare the predicted value with the required value to see if it meets the requirement, and put forward suggestions to improve BIT if necessary.

3. Testability index allocation

In system testability engineering, testability parameters can be used to describe the ability of system to detect and isolate fault modes. The quantified value is called testability index, which can measure the testability design level of the system. Because of the different testability characteristics of the system, many different testability parameters can be defined to describe the testability level of the system. According to the fault detection capability characteristics of the system, parameters such as fault detection time (FDT), fault detection rate (FDR) and false alarm rate (FAR) can be defined. According to the fault isolation capability characteristics of the system, parameters such as fault isolation time (FIT), fault isolation rate (FIR) and fault dismantlement rate (FFR) can be defined. The accuracy of system testability is reflected in FDR and FIR parameters, while the timeliness of testing is reflected in FDT and FIT parameters. These four parameters are universal, observable, controllable and verifiable in the testing and maintenance activities. They are generally regarded as the preferred parameter set to measure the testability level of the system. In the design stage of testability, the most concerned parameters are fault detection rate and isolation rate. The fault detection and isolation time can only be obtained by the actual test and maintenance process of the system. Therefore, in the testability design phase of the system, the fault detection and isolation time can be neglected, and only the fault detection rate and isolation rate can be analyzed and calculated[8-9].

Substation digital metering system is a complex multi-layer system. There are more or less differences in structure, function, performance and fault mode between different units at the same level or different units at different levels. It is unreasonable to directly use the overall testability index of the system as the index of hierarchical units, this testability design method is unreliable and fails to meet the level of testability required by the task[9]. The correct way is to use a reasonable method to determine the quantitative indicators of testability of each level unit according to the functional structure characteristics and test and maintenance requirements of each level unit of digital metering system. The specific flow of testability index allocation is shown in figure 1.

![Flow chart of testability index allocation](image-url)

Figure 1. Flow chart of testability index allocation.
4. **Scheme design**

Through the analysis and research, this paper considers that the testability configuration of substation digital metering system needs to consider the system structural characteristics and the technical characteristics and capabilities of its equipment suppliers, and gives a "context-based configuration". In system testability design, some test tasks can be considered as a whole, including system integration failures and test tasks that are difficult to self-test in device-level units. When testability schemes have taken these test tasks into account, only other remaining failures should be considered in the allocation of testability indicators. Based on this, this paper presents a system-level testability scheme and distribution integration design architecture, as shown in figure 2.

![Figure 2. A solution for integration of testability scheme design and allocation.](image)

Firstly, system faults are divided into two categories: internal faults of each unit and integrated faults between units. According to the system-level testability index requirements, the general contractor formulates the system test framework, optimizes the selection of system-level test and part of unit-level test, and forms a preliminary system-level testability scheme. Secondly, the main contractor removes the integrated faults and the unit-level faults that are clearly measurable in the system-level scheme from the system fault base (denominator in the detection rate index). Finally, the testability allocation is made for the remaining unit faults.

In the testability allocation of remaining unit faults, there are generally two indicators to participate in testability allocation, one is fault detection rate, and the other is fault isolation rate, other testability indicators need not be allocated.
5. Conclusion
The characteristics of information digitalization, optical transmission and communication networking of digital metering system in intelligent substation are related not only to the device itself, but also to the synchronization of transmission network and sampling time. At present, the test scheme of digital metering system in intelligent substation is to test the digital metering device separately, the impact of other factors from within the system was not considered. The test result can not fully reflect the performance of the whole system composed of various devices. This paper introduces the idea of testability and the method of engineering prediction into the testing work of digital metrology system, and the allocation scheme of testability index is designed. The integrated framework of system-level testability scheme and allocation of testability index is also proposed. The research in this paper can be used to guide the testability design of digital metrology system, and can effectively improve the testing efficiency and equipment maintenance level.

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