Research on Case Design of Electric Energy Meters Reliability Detection Based on Equivalent Class

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Abstract. The existing test scheme of the automatic reliability testing device for electric energy meters has the problem that it is difficult to achieve comprehensive and efficient test according to the requirements of technical specifications. In order to improve the optimal design level of automatic reliability test scheme for electric energy meters, three common fault types, i.e. protocol consistency, limit type test and fault tolerant type test, are analyzed. Then on this basis, the design requirements of their common test items, the design ideas of test schemes and the basis of conformity judgment are studied respectively. Based on the theory of generating test cases of equivalent classes, the process of identifying and generating test cases of equivalent classes is given, and the process of simplifying test cases of equivalent classes based on decision table driving method is given. Finally, the factorial test design method and the method of generating test cases are compared by taking several different types of electric energy meters from different manufacturers as examples. The situation and test efficiency verify its effectiveness.

1. Introduction
With the improvement of the level of smart grid informationization, smart electric energy meters and metering terminal and other electronic devices are widely used in the power grid. In the long-term information acquisition and transmission work, the reliability defects of electronic equipment in many aspects such as function, communication, interface, software and so on will gradually expose under the interference or limit conditions such as electromagnetic interference in the field[1].

At present, there are no mature technical specifications and applications in the software reliability evaluation and detection methods of electric energy meters in China Southern Power Grid Corporation. There are some common laboratory performance tests, such as basic electric energy errors and daily timing errors. There is a lack of perfect testing schemes and effective testing means for software reliability. Based on the theory of equivalence class, this paper studies the design of reliability test cases for electric energy meters, and applies the equivalence class method and decision table driving method to the generation and optimization of test cases. The method in this paper can provide guidance for the design of software reliability test cases for power equipment and the functional verification of reliability test devices, and provide verification means.

2. Software Reliability Testing Content of Electric Energy Meters
According to statistics, typical faults of electric energy meters mainly include data boundary condition, limit condition, fault-tolerance, interface fault, storage anomaly, etc. Common reliability testing
methods of electric energy meters software include boundary value analysis method, equivalent class method, limit pressure testing method, etc.

The reliability test items of electric energy meters can be divided into three categories according to the manifestation of defects, namely fault tolerance, limit and consistency test, as shown in Table 1.

Table 1. Examples of Reliability Testing Items for Electric Energy Meters

| Sequence Number | Test Item Type       | Common Test Items                                                      |
|-----------------|----------------------|-----------------------------------------------------------------------|
| 1               | Conformance class testing | Conformance Testing of Communication Protocol                         |
|                 |                      | Full ergodic test of pull-in and Power-Preserving States               |
|                 |                      | Reading Data Consistency Test                                         |
|                 |                      | Measurement Test of Limit Load and Full Rate Switching                |
|                 |                      | Test of Limit Load, Full Rate and Maximum Demand for Outage           |
|                 | Limit class testing  | Limit Load, Power Outage and Time Sudden Freezing Test                |
|                 |                      | Communication Limit and Baud Rate Redundancy                          |
|                 |                      | Instantaneous Data Limit Range Measurement and Testing                |
| 3               | Fault-tolerant testing  | Fault Tolerance and Interference Transfer Test on Settlement Date     |
|                 |                      | Clock Carry, Boundary Timing, Fault Tolerant Testing                  |
|                 |                      | Time Rate Priority and Parameter Fault Tolerance Testing              |

2.1 Fault-tolerant Reliability Test

1) Test content

Fault-tolerant reliability testing of electric energy meters mainly tests whether the values of data items exceed the set range or the data types do not conform to the actual rules when the parameters are set, and whether shielding measures are provided for invalid or illegal operation. The common test method is invalid equivalence class method. Equivalent classes are subsets of an input domain. In this subset, each input data is equivalent to uncovering abnormal problems in software, and it is assumed that testing representative values in an equivalent class is equivalent to testing other values of this class. The valid equivalence class can be used to verify whether the program achieves the function and performance specified in the technical specification, while the invalid equivalence class can verify whether the software can withstand the test of illegal data.

2) Examples of test case design

Taking the test project of fault tolerance and interference transfer on the settlement day as an example, according to the technical specification [2], the parameters of the settlement day in the electric energy meters are allowed to be set in the range of 1-28 days and 0-23 points.

3) Test scheme:

(1) Correct parameter testing, arbitrarily setting 1-28 days, 0-23 points, responding to the correct response frame, playback parameters and setting parameters are consistent;

(2) Monthly fault-tolerance, daily fault-tolerance, whole-point fault-tolerance test, such as setting up 13 months, the meter should respond to the error response frame, and the playback parameters remain unchanged;

(3) System fault tolerance, such as setting 0 A, 0 B and other hexadecimal values, the meter should respond to the error response frame, and the playback parameters remain unchanged.

4) Test flow

Figure 1 shows the process of parameter setting and fault tolerance test on the settlement day. First, let the meter run under the rated working condition and log in to the test master station. Then the master station sends the command of parameter setting on the settlement day to the meter through Ethernet or RS-232, such as setting the settlement time of monthly frozen electricity quantity. Then read the data item and monitor the message returned by the terminal. When setting parameters is legal, after reading the data item, the test terminal should return the updated parameters. When setting parameters is illegal, the test terminal should return the original parameters and not accept the newly set parameters.
2.2 Limit Class Testing
1) Test contents and methods
   The common form of limit reliability test of electric energy meters is pressure test, that is, using the methods of error inference and boundary value analysis to analyze the abnormal problems in the limit state of each functional item required by technical specifications of electric power equipment, list all possible abnormal or prone to failure, and simulate each of them. In the limit state, and in the endurance state beyond the normal functional strength, observe whether the equipment software can work properly.

2) Examples of test case design
   The technical specifications of China Southern Power Grid require that the meter can store at least the total energy of the first 12 months or the first 12 (settlement) reading cycles, and the data transfer demarcation time is 24:00 on the last day of each month (at the beginning of the month)[2]. In order to verify the reliability of the transfer, it is necessary to carry out the transfer measurement of the limit voltage on the settlement day, as well as in the case of large data processing and interference.

2.3 Conformance Class Testing
1) Test contents and methods
   The reliability testing of electric energy meters software consistency mainly includes the verification of communication protocol and data consistency. The purpose is to eliminate the differences in understanding of communication protocol between different manufacturers and to ensure that the data stored in electric energy meters are consistent with the actual data collected. The commonly used test method is the effective equivalence class method.

2) Examples of test case design
   Taking the data block reading conformance test as an example, according to the technical specifications [2], the frame reading data items of the electric energy meters should be consistent with the corresponding data block reading and the actual data. For example, the current A, B and C three-phase data of the electric energy meters read by the main station in a single frame mode should be identical with the A, B and C three-phase data of the electric energy meters voltage data block read by the data block mode respectively.

3. Application of Decision Table Driven Method in Case Design Optimization
   With the attention of power grid companies to the reliability of electric energy meters software, the requirement of fault tolerance, limit processing ability and anti-interference ability of electric energy meters software increases gradually. Add to the technical specifications. The key to the reliability test
of electric energy meters is whether the designed test case can accurately judge the various functional requirements of the electric energy meters and avoid functional defects and judgment errors. At the same time, the test cases should represent and cover all kinds of legal and illegal input data, i.e. valid equivalence class and invalid equivalence class. The number of detection cases formed by a large number of equivalent class permutations and combinations will increase dramatically, which makes the test time unbearable. Therefore, how to balance the test efficiency and test coverage in the design of detection cases is a difficult task. To this end, this paper combines the equivalence class partition method and the decision table driving method to realize the design of software reliability test case of electric energy meters [3].

Detection cases based on equivalence classes are usually generated by multi-factor factorial test design method. The main processes are: (1) comprehensive analysis of technical requirements of technical specifications for power equipment, extraction of test factors, and formation of equivalence class table; (2) combination of typical scenarios of effective and ineffective equivalence classes to form detection cases; (3) repetition of steps; (2) until The test case can traverse the equivalent class table.

4. Case Analysis
This example comes from the fault tolerance and interference transfer test items of the watt-hour meter settlement day in Section 2.1, saving electric energy meters settlement day as an example. Based on equivalence class theory and three-factor factorial design method[3], the input domain equivalence classes and initial decision tables can be determined by technical requirements[2], as shown in Tables 2 and 3.
Table 2 Equivalent Classes Extracted from Input Conditions.

| Condition Number | Input Conditions                                                                 | NO. | Equivalent Classes |
|------------------|----------------------------------------------------------------------------------|-----|--------------------|
| 1                | Can the electric energy meters respond correctly when the parameters of the settlement day are set correctly? | 1   | satisfaction       |
|                  | Can the electric energy meters respond correctly to the abnormally set dates such as month, day and hour? | 2   | Dissatisfaction    |
| 2                | Can the electric energy meters respond correctly to the abnormal setting of the decimal number of settlement date parameters? | 3   | satisfaction       |
|                  | Can the electric energy meters respond correctly to the abnormal set of the decimal number of settlement date parameters? | 4   | Dissatisfaction    |
| 3                | Can the electric energy meters respond correctly to the abnormal set of the decimal number of settlement date parameters? | 5   | satisfaction       |
|                  | Can the electric energy meters respond correctly to the abnormal set of the decimal number of settlement date parameters? | 6   | Dissatisfaction    |

For example, Table 2, Equivalent Class 1 refers to any set of 1-28 days, 0-23 points, the electric energy meters can respond correctly, the playback parameters are consistent with the set parameters. Equivalent class 2 corresponds to a valid equivalence class when the condition is not satisfied; equivalence class 3 belongs to a valid equivalence class when the month, day and hour fault tolerance is set. If set for 13 months, the electric energy meters can respond to the error response frame, and the parameters of the energy meter copy back remain unchanged, it belongs to an invalid equivalence class; equivalence class 5 belongs to a referential fault tolerance class, such as setting “0A”, “0B” and other non-decimal values. The electric energy meters should respond to the error response frame, and the playback parameters remain unchanged, which belongs to the invalid equivalence class.

Table 3 Initial decision table

| No. | Condition pile | Action pile | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-----|----------------|-------------|---|---|---|---|---|---|---|---|
| 1   | Y              | PASS         | / | / | √ | / | / | / | / | / |
| 2   | N              | PASS         | / | / | / | / | / | / | / | / |
| 3   | Y              | PASS         | / | / | / | / | / | / | / | / |
| 4   | N              | PASS         | / | / | / | / | / | / | / | / |

According to the technical requirements, the equivalent classes of Table 2 are generated by factorial analysis, that is, Table 3. In Table 3, “Y” corresponds to the equivalent class number that meets the input criteria in Table 2, whereas “N” corresponds to the opposite. According to the decision table driving method in Section 3, the similar condition piles and the same action piles are merged. Table 3 is simplified to Table 4. For example, the test cases numbered 1, 5 and 6 in Table 3 correspond to the same condition piles 2 and have the same action piles. According to the merging principle of decision table driving method, the test cases numbered 2 as shown in Table 4 are merged. Where “/” denotes any conditional pile, i.e. “Y” or “N”.

From Table 4, we can get 1-4 detection cases covering all equivalent classes of Table 2, and simplify 8 cases to 4 cases. For example, when the parameters of the settlement day are set correctly, the electric energy meters can respond correctly. When the parameters of the settlement day are set abnormally in months, days and hours, the electric energy meters can respond correctly, but when the parameters of the settlement day are set abnormally in digits, the electric energy meters can not respond correctly. This situation accords with the condition pile in case 1 of Judgment Table 4, so that the function of the pile is unqualified according to the corresponding action pile.

Comparing Tables 3 and 4, it can be seen that the method in this paper simplifies the case set after factorial analysis generates the initial test case set, and then reduces the number of test cases on the basis of covering the equivalent class as full as possible. It can improve the test efficiency and achieve better results in the process of testing with more equivalent classes. For obvious.
Table 4  Simplified Detection Case Number

| Input condition Number | Number of test cases after simplification |
|------------------------|------------------------------------------|
|                        | 1  | 2  | 3  | 4  |                          |
| 1                      | Y  | /  | Y  | N  |                          |
| 2                      | Y  | N  | Y  | /  |                          |
| 3                      | N  | /  | Y  | /  |                          |
| Desired output         | Failure | Failure | Pass | Failure |
| Test Case Number in Coverage Table 3 | 7  | 1,5,6 | 3  | 4,6,8 |
| Equivalent Class Number in Covering Table 2 | 1,3,6 | 4  | 1,3,5 | 2  |

5. Concluding Remarks
Equivalence class theory and decision table driving method are applied to the design and verification of software reliability testing cases of electric energy meters. The test case of functional verification of the electric energy meters detection device shows that this method can improve the problem that it is difficult to fully cover the technical requirements in the design of the test case, optimize the scale of the test case and improve the test efficiency.

References
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