Analysis on the Maintainability of Smart Meter Software for Full Lifetime

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Abstract: With the deepening of Internet concept and electricity marketization reform, more requirements are put forward for metering equipment, and the scale and complexity of software also increase. The new generation of intelligent electricity meters meet the IR46 standard and adopt the multi-core modular design scheme, which also puts forward higher requirements for the maintainability of software. This paper starts from the key control points of the whole life cycle of intelligent electricity meters and combines the characteristics of software testing, so as to analyze and evaluate the maintainability of the software. Firstly, the factors that influence the maintainability of watt-hour meter products are analyzed, and the software key data is considered from the perspective of software development and design. Then, the index system of the maintainability of the intelligent software is established, and the key points of the maintainability test and the weight of each index are analyzed in combination with the testing technology of the intelligent meter software and the analytic hierarchy process.

1. Introduce

With the rapid development of smart grids, more and more requirements are put forward for the functional design of software, in addition to basic metering, display, and communication functions, it must also meet demand metering, multiple tariffs, tariff tariffs, tiered tariffs. The complexity of the software function requirements such as prepayment, pull-close control and other functions will inevitably lead to the increasing complexity of the software design process of the electric energy meter and the increasing size of the software code. There are also more and more problems to be considered when designing the software framework. If the design process is not considered comprehensively, if the meter has not undergone rigorous software testing and verification after the meter design is completed, or even if the verification plan is not fully considered after the test and verification, this will lead to the entry of the energy meter into the market It has some potential design flaws, and it eventually broke out after a long period of operation in the complicated site[1].

The maintainability of the software is the ease with which the software can be modified to meet user requirements or to correct the detected defects. It mainly includes two aspects: the first aspect evaluates how easy it is to implement the maintenance and modification of the system; the other aspect is the ability of the software to adapt to the external environment for repair. As an embedded software, smart meter software has special failure judgment criteria, and requires high maintainability testing. Based on the entire life cycle of smart meters, this paper analyzes and sorts out the important factors
affecting maintainability and embedded testing methods, and then establishes a software maintainability index system using AHP to obtain the index weight of each element. It finds out the key data of smart meter software in the whole life cycle, and improves the ideas for improving maintainability and reducing operation and maintenance costs.

2. Full life cycle analysis of smart meter

2.1. Full life cycle business links

In the "Internet +" application environment and conditions, the entire business process of metering equipment is divided into different stages and different links according to the upstream and downstream relationship of the business. The whole life cycle process mainly includes eight links, namely R&D and design, material procurement, manufacturing, delivery from the factory, acceptance inspection, warehousing and distribution, installation and operation, dismantling and scrapping.

In these business links, the life characteristics of the metering equipment are different, and the business logic, constraint relationships, information transmission and progression modes between different links are different. The business link of the whole life of the metering equipment is shown in Figure 1.

![Figure 1: Business links throughout the life of metering equipment](image)

As shown in the figure above, the whole life business link of measurement equipment includes eight links. The business processes of the first four links are completed in the manufacturing enterprises of power metering equipment. The vital characteristics of the equipment are mainly related indicators such as R&D, design and manufacturing. Relevant information is circulated in the relevant systems within the manufacturing enterprise along with the production process of the product. The business process of the last four links is completed by the power company that is the application and maintenance company of power equipment. The vital characteristics of the equipment are mainly related indicators in the use, acceptance and use process. This information is transferred between different business systems as the business progresses[2].

2.2. Key points in the life cycle of smart meters

Based on the theory of the whole life cycle, this paper comprehensively considers the key data of the eight stages of the smart meter in the whole cycle, and obtains the following analysis.

1. The R&D and design link is mainly the process of outputting a complete production plan including the design plan through the confirmation of product requirements, related software and hardware design, process and equipment confirmation, prototype generation and testing.

2. Material procurement is mainly to complete the business process of material demand identification, supplier selection, sample quality monitoring, procurement and contract management, etc., to provide reliable materials for product manufacturing.

3. The manufacturing flow link is mainly to complete the manufacturing of equipment according to the manufacturing process and manufacturing standards. Through periodic verification and daily spot inspection of production equipment and testing equipment (instruments, measuring tools), to ensure that the equipment and instruments are operating under normal conditions.

4. The delivery link of the factory is to take monitoring and measurement activities in accordance with the requirements of the quality management system to identify and control
non-conforming products to prevent unintended delivery of non-conforming products and to ensure the eligibility of the factory meters.

(5) Acceptance test mainly completes the network access test and quality supervision of metering equipment, including three stages before bidding, before supply and after delivery.

(6) The business content of the warehousing and distribution link includes the warehousing and distribution business, reflecting the warehousing and distribution management system, warehouse storage management, distribution process management and other warehousing and distribution capabilities and quality status.

(7) The equipment installation and operation process refers to the installation, debugging, test and acceptance before commissioning, which mainly refers to the judgment of installation process and management, as well as the correct installation of power metering devices. The operation stage mainly includes patrol inspection, regular sampling inspection, quality supervision of fault instrument and replacement of measurement error.

(8) Equipment dismantling shall mainly manage the dismantling process of old electricity meters and sort out the dismantled electricity meters in accordance with relevant provisions.

3. Embedded software testing technology

Software testing in various industries, especially in mature industries, emphasizes the adoption of corresponding test analysis means to ensure software quality through each stage of the software life cycle, and the typical software life cycle is the corresponding test link from the development stage.

Tests are divided into static and dynamic tests, depending on whether the code is run. Static testing does not actually run the program under test, but uses reviews or typical static testing tools to look for possible software defects in documentation and code or to evaluate code, including code review, code walkthrough, and static analysis. Its testing features are not actually run code, can find defects in the code early, using tools to test efficiency, easy to standardize. Dynamic test is to actually run the program under test, input the corresponding test case, check the difference between the running result and the expected result, and determine whether the execution result meets the requirements, thus verifying the correctness, reliability and effectiveness of the program. It needs to establish a test environment, design test cases according to test quality characteristics, design input data and output processing, corresponding to the middle and late development test stage[3].

According to the depth of test technology, the test is divided into black box test, white box test and gray box test. Black box testing, also known as functional testing, data-driven testing, or based on the test specification, the test system as a black box, don't need to understand the interior of the object under test conditions, and rely on the specification of the function to design test cases, only check whether the program can properly receive input data and produce the correct output information. It is based on the user point of view, according to the requirements, from the software implementation of direct verification from the input and output point of view, high testing efficiency, testing easy automation, standardization. White box testing is also called structural testing or logically-driven testing, which aims to understand the internal structure of the program, design test cases according to the internal structure, and test all the logical paths of the program, so as to detect whether the internal action of the product is normally carried out in accordance with the design specification. White-box dynamic testing, testing the logical path of the software, requires a good understanding of the program interior to conduct moderately effective testing, including varying test coverage, and is a test of software adequacy. Grey box testing is a testing technique which is between white box testing and black box testing, based on the external performance of the program at the running time and combined with the internal logical structure of the program to design the use cases, execute the program and collect the execution information of the program path and the results of the external user interface. It not only focuses on the correctness of output and input, but also focuses on internal performance. However, such attention is not as detailed and complete as white box. It only judges the internal running state through some representational phenomena, events and signs, taking into account the client, specific system knowledge and operating environment[4].
4. Software maintainability index system based on the full life cycle

4.1. Establishment of maintainability index system

By analyzing the definition and connotation of maintainability, we know that there are three parts that are closely related to maintainability in the whole life cycle process. They are R&D and design links, manufacturing links, and installation and operation links.

R&D and design is the beginning of the life cycle of smart energy meters, and this link is also the basis for the quality of smart energy meters. The R&D and design process is mainly to output a complete production plan including the design plan through the confirmation of product requirements, related software and hardware design, process and equipment confirmation, prototype generation and testing. R&D design mainly includes five stages, namely product R&D requirements and technical solutions stage, product R&D planning stage, product development stage, product R&D verification stage, and product R&D release stage[5].

The manufacturing flow link is mainly to complete the manufacturing of equipment according to the manufacturing process and manufacturing standards. Through periodic verification and daily spot inspection of production equipment and testing equipment (instruments, measuring tools), to ensure that the equipment and instruments are operating under normal conditions. The environmental testing instruments and meters, such as thermometers and hygrometers, are also periodically verified to ensure that the material storage and production environment meet the production requirements of electric energy meters. Through measurement training for key positions personnel and obtaining relevant certificates, to ensure that key positions personnel carry out standardized operations. Manufacturing mainly includes two stages, namely PCBA section and finished product section.

The installation and operation link has a direct effect on the functional operation of the smart energy meter, and is an important link that determines whether the product can achieve high-quality design effects. The maintenance of smart meters in daily operation directly affects the quality of the meters[6].

Based on the analysis of the characteristics related to maintainability in the three links, the maintainability index system of the smart meter software is obtained, as shown in Figure 2.

Figure 2. Maintainability Index System of Smart Meter Software

4.2. Weight coefficient calculation

In this paper, the analytic hierarchy process is used to determine the weights. This method is simple and practical, with higher reliability and less error. Specific steps are as follows:

1) Construct a judgment matrix. The judgment matrix is constructed from the level of the index system. The specific method is to analyze and compare the importance of all elements of this layer
corresponding to the elements of the previous layer, and give the judgment to form the judgment matrix.

(2) Consistency check and normalization process, use mathematical tools to find the maximum eigenvalue and corresponding eigenvector of each judgment matrix, and perform consistency check on each matrix.

(3) Obtain the weight coefficient of each index[7].

The analytic hierarchy process (AHP) was used to analyze the index system and the following judgment matrix was obtained, as shown in Table 1,2,3 and 4.

Table 1 U-A judgment matrix

| U | A1 | A2 | A3 |
|---|----|----|----|
| A1 | 1  | 2  | 3  |
| A2 | 1/2| 1  | 3  |
| A3 | 1/3| 1/3| 1  |

Table 2 A1-B judgment matrix

| A1 | B11 | B12 | B13 |
|----|-----|-----|-----|
| B11| 1   | 2   | 3   |
| B12| 1/2 | 1   | 2   |
| B13| 1/3 | 1/2 | 1   |

Table 3 A2-B judgment matrix

| A2 | B21 | B22 |
|----|-----|-----|
| B21| 1   | 1/3 |
| B22| 3   | 1   |

Table 4 A3-B judgment matrix

| A3 | B31 | B32 | B33 |
|----|-----|-----|-----|
| B31| 1   | 2   | 1/2 |
| B32| 1/2 | 1   | 2   |
| B33| 2   | 2   | 1   |

Through calculation, we can get the maximum eigenvalue and eigenvector of each judgment matrix, as shown below.

\[ W_1 = [0.3108, 0.1958, 0.4934]^T, \lambda_{max} = 3.0536; \]
\[ W_2 = [0.25, 0.75]^T, \lambda_{max} = 2; \]
\[ W_3 = [0.5396, 0.297, 0.1634]^T, \lambda_{max} = 3.0092; \]

Then consistency test is conducted on the judgment matrix of the maintainability index system of the smart electricity meter, and the weight coefficients of each element at the criterion layer and scheme layer are shown in Table 5 and Table 6.

Table 5 Weight of each element in the criterion layer

| Rule layer         | Criterion layer weight |
|--------------------|------------------------|
| R & D design link  | 0.5278                 |
| Manufacturing process | 0.3325               |
| Installation and operation | 0.1396         |

Table 6 Weight of each element in scheme layer

| Rule layer         | Scheme layer | Scheme layer weight |
|--------------------|--------------|---------------------|
| R & D design link  | Testability  | 0.5396              |
|                     | Portability  | 0.297               |
|                     | Modular      | 0.1634              |
| Manufacturing process | Material selection  | 0.25 |
|------------------------|---------------------|------|
|                        | Process flow        | 0.75 |
| Installation and operation | Failure analysis | 0.3108 |
|                        | Run spot checks     | 0.1958 |
|                        | Maintenance time    | 0.4934 |

Through the above analysis, the weight coefficient of each factor in the maintainability index system in the whole life cycle of the smart electricity meter can be obtained by combining with the scores of each index.

5. Conclusion
In this paper, the test points of embedded software are analyzed and summarized. Combining with the key data of the whole life cycle of electricity meters, the maintainability index system is established through analytic hierarchy process, and the weight coefficient and evaluation method of each element are given, which provides a theoretical basis for the maintenance work and has a very good practical value.

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