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# Research on the overload protection reliability of moulded case circuit-breakers and its test device*

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**Abstract:** This paper analyzed the reliability and put forward the reliability index of overload protection for moulded case circuit breaker. The success rate was adopted as its reliability index of overload protection. Based on the reliability index and the reliability level, the reliability examination plan was analyzed and a test device for the overload protection of moulded case circuit-breaker was developed. In the reliability test of overload protection, two power sources were used, which reduced the time of conversion and regulation between two different test currents in the overload protection test, which made the characteristic test more accurate. The test device was designed on the base of a Windows system, which made its operation simple and friendly.

**Key words:** Moulded case circuit breakers, Overload protection, Reliability, Test device
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## INTRODUCTION

Low-voltage apparatus is a kind of electrical devices which functions as switch, control, protection, detection, display and alarm in the low-voltage distribution system and control system. Circuit breaker is an important device of low-voltage apparatuses, which is used in low-voltage distribution circuit, motor or other electrical devices, and it takes in charge of make-on, carrying and breaking current in normal or abnormal conditions such as short circuit. With the development of the national economy, the moulded case circuit-breaker with better performance and higher quality has higher demanding now and its reliability becomes a more and more important issue (Lu, 1996, Zhu *et al.*, 2000). For the repairable apparatus, the reliability is separated into two different aspects of dependability and security. The reliability can be improved by carrying routine maintenance or by including built-in monitoring and self-checking facilities during the design stages. A Markov model is used to examine the features of the repairable apparatus (Billinton *et al.*, 2002). In order to identify age-related degradation in the various breaker subcomponents, the breaker is mechanically cycled by the power-operated mechanism. The suggestions were provided to alleviate the age-related degradation that could occur as a result of normal closing and opening of the breaker contacts during the breaker's service life (Subudhi, 1992).

Overload protection is one of the important functions of the moulded case circuit-breaker. The reliability of overload protection is an important index. In this paper, the reliability was analyzed, the reliability index of overload protection was put forward and the test device was developed. The device, with a simple and friendly Windows based operation system, can carry out the reliability test of overload protection.

## RELIABILITY INDEX AND RELIABILITY LEVEL OF OVERLOAD PROTECTION OF MOULDED CASE CIRCUIT-BREAKER

The following are the specifications of the

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moulded case circuit-breaker.

First, in normal load condition, the breaker should not mis-break to ensure that the electrical device and distribution circuit run normally.

Second, in overload condition, the breaker must not destruct the electrical device and distribution circuit. It means the breaker should not break the circuit to guarantee the continuous running of the electric device and distribution circuit during the short overload period, but should break the circuit to avoid the destruction of the electrical device and distribution circuit if the overload duration is over prescribed time.

Compared with the control relays and contactors which are operated frequently, the moulded case circuit-breaker has much more different characteristics. It is necessary to adopt the reliability examination method of the protected apparatus as the reliability examination method of the moulded case circuit-breaker.

The success rate is the probability of the product accomplishing the specified function under the specified conditions or the probability of success in the test under specified conditions. Either refuse-breaking or mis-breaking represents the breaker does not accomplish the specified function (Lu, 1996; Li *et al.*, 1997; Luo *et al.*, 1999). So the success rate is adopted as the reliability examination index of moulded case circuit-breaker.

For the overload protection of moulded case circuit-breaker, five levels of success rate are set according to the minimum success rate $R_{\min}$. The levels and the value of the minimum success rate are shown in Table 1.

**Table 1 The level and minimum success rate of moulded case circuit breakers**

| Name of success rate | $R_{\min}$ |
|---|---|
| Level A | 0.98 |
| Level B | 0.96 |
| Level C | 0.94 |
| Level D | 0.92 |
| Level E | 0.90 |

## METHOD OF THE RELIABILITY TEST OF MOULDED CASE CIRCUIT-BREAKER

In practical work, we often put forward the reliability for the moulded case circuit breaker and then examine whether the success rate reaches the requirement. To have a clear picture of a test, we should have an examination plan ready in advance, which refers to the sampling test of success rate. The relationship between the acceptance probability of success rate, $L(R)$, and the success rate, $R$, is shown in Fig.1.

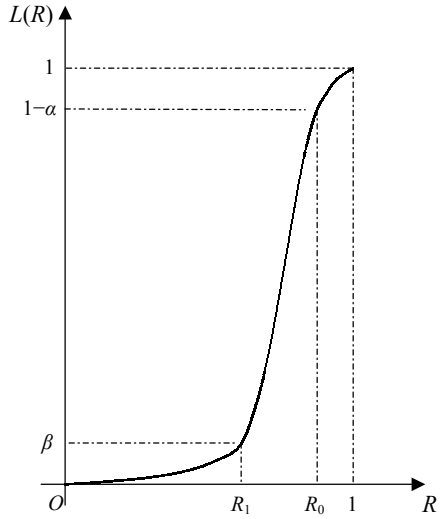


**Fig.1 The OC curve of the sample plan of success rate**

From Fig.1 we know:

$$\begin{cases} L(R_0) = 1-\alpha, \\ L(R_1) = \beta, \end{cases} \tag{1}$$

where $R_0$ is the acceptable success rate, $R_1$ is the unacceptable success rate, $\alpha$ is the producer's risk rate, and $\beta$ is the user's risk rate.

The sample plan, which is determined by parameters $R_0$, $R_1$, $\alpha$ and $\beta$, is a four parameters sample plan. The sample plan, which is determined only by parameters $R_1$ and $\beta$, is a two parameters sample plan. The four parameters sample plan is determined by Eq.(2):

$$\begin{cases} \sum_{k=0}^{A_c} C_n^r R_0^{n-k} (1-R_0)^k = 1-\alpha, \\ \sum_{k=0}^{A_c} C_n^r R_1^{n-k} (1-R_1)^k = \beta. \end{cases} \tag{2}$$

where $A_c$ is the number of acceptance, $n$ is the total

number of samples or the total times of tests.

The two parameters sample plan is determined by Eq.(3):

$$\sum_{k=0}^{A_c} C_n^r R_1^{n-k}(1-R_1)^k = \beta . \quad (3)$$

Since there are two unknown numbers in Eq.(3), it has infinite sample plans. Commonly we firstly decide the value of $A_c$, and then figure out the number of samples or the total times of test.

The sampling method of success rate, which adopts four parameters, can determine the compliance test plan of success rate. However, the minimum success rate of products cannot be below a certain value when the levels of success rate are determined. So the examination plan determined by four parameters is not suitable for the compliance test plan of success rate. The sample plan determined by two parameters, $R_{min}$, $\beta$, can denote the purpose of examining the levels of success rate. The plan guarantees the minimum success rate. The compliance test plan of success rate can be determined by Eq.(4):

$$1-\sum_{k=0}^{A_c} C_n^r R_{min}^{n-k}(1-R_{min})^k = 1-\beta, \quad (4)$$

where $1-\beta$, confidence, generally is 0.9.

The sample plan determined by Eq.(4) is shown in Table 2.

**Table 2 Sample compliance test plan of success rate ($\beta$=0.1)**

| Levels of success rate | Accumulation times | | | | | |
|---|---|---|---|---|---|---|
| | $A_c$=0 | 1 | 2 | 3 | 4 | 5 |
| Level A | 114 | 194 | 265 | 333 | 398 | 462 |
| Level B | 57 | 96 | 132 | 166 | 198 | 230 |
| Level C | 38 | 64 | 88 | 110 | 132 | 153 |
| Level D | 28 | 48 | 65 | 82 | 98 | 114 |
| Level E | 22 | 38 | 52 | 65 | 78 | 91 |

## METHOD OF THE RELIABILITY TEST OF MOULDED CASE CIRCUIT-BREAKER AND THE TEST DEVICE

### Method of the reliability test of moulded case circuit-breaker and the major functions of the test device

Based on the characteristics of the overload protection, we classify the overload protection tests into the following three groups:

(1) The cold state test. The overload characteristic test begins when the breakers are in the cold state.

(2) The hot state test. The overload characteristic test begins when the breakers are in the hot state.

(3) The returnable characteristic test, which is testing the returnable characteristic of the moulded case circuit-breaker.

In the reliability test of moulded case circuit-break, the test in different overload should be done. Based on the above method, all kinds of reliability tests can be accomplished conveniently. According to the test procedure, we classify the tests into test section and test cycle. One test cycle includes one or more test sections and one test section includes two test currents. The two test currents can be generated by different power sources and one of the test currents can be set zero. In the reliability test, the number of sections in the test cycle and the value of test currents in the test section are determined by the reliability examination of circuit-breaker and the number of the test cycles is determined by the reliability level and the examination plan.

For the breakers without auto open-close operation, the test mode is set as manual mode. In the manual mode, when a section is over, the next section will not start until the operator enters the instruction.

The major functions of the overload protection reliability test device of moulded case circuit-breaker are shown below:

(1) The user can set parameters through its man-machine interface;

(2) Three test samples can be tested simultaneously;

(3) The test device can monitor the test procedure and regulate the test current automatically;

(4) The device can accomplish the whole test automatically including the overload test with 1.05Ie, the overload test with 1.3Ie and the returnable overload characteristic test with 3.0Ie or other current;

(5) The device can record the test results automatically and print the test data.

### Hardware design of the test device

1. Circuit of computer control

The operation of the test device is controlled by computer. Its principle diagram is shown in Fig.2.

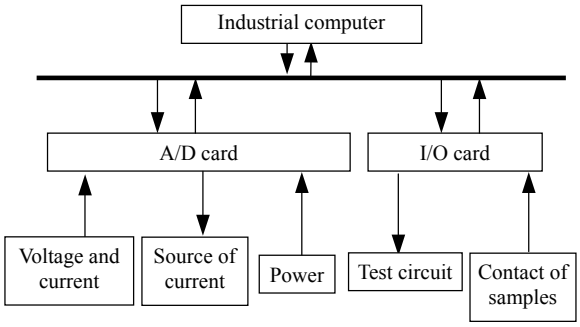


**Fig.2 The circuit diagram of computer control**

Two sets of power sources are available with the output currents of 0~250 A and 0~750 A respectively. The power sources are used in the test of overload protection characteristic and the test of overload protection reliability. The overload test with 1.3Ie should be done in the hot state. That means the overload test with 1.05Ie should be done first and the test samples do not open, then the overload test with 1.3Ie will be followed. By using the two power sources, the time of conversion and regulation between two different test currents is reduced. This makes the characteristic test more accurate. Meanwhile the returnable overload characteristic test with 3.0Ie can be done.

Because the test current circuit is interrupted after the moulded case circuit-breaker opens, in normal condition one set of power source can only be used for testing one sample. However, the test of overload protection characteristic takes about 2 to 4 h so it will take a very long time to complete a test, which includes several test samples. In order to accelerate the test and obtain more reliability test data, we designed the test device, which tests several samples simultaneously. The method is connecting several samples in series and doing the test at the same time. When a sample opens, the circuit connects to the balance circuit and the test of other samples continues. The resistance of the balance circuit is similar to the internal resistance of the sample. The computer is used to stabilize the current automatically to minimize the current variation and shorten the variation time duration. Our test circuit can handle three samples at the same time and even more after extension. It resolves the experimental error resulting from the current interruption and variation, because it is not at the same time that the samples open.

2. Circuit of current regulation

The rated current of moulded case circuit-breaker varies from 10 A to 225 A so the variation of the current is large in the overload protection test. In order to ensure the accuracy of control and examination, we classify the currents into four ranges according to the magnitude of currents. Those are 0 to 25 A, 0 to 75 A, 0 to 250 A, 0 to 750 A. The circuit of current regulation is shown in Fig.3.

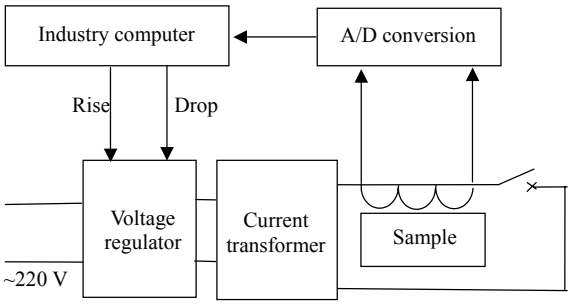


**Fig.3 The circuit of current regulation**

The circuit of current regulation is composed of 22 contactors and 20 solid-state relays. Two of the contactors are used to switch the current source circuit, which is used in the overload tests with 1.05Ie, 1.3Ie and 3.0Ie. Twelve of the contactors are used to switch the balance circuit. Four of the contactors are used to select the current inductors. The others are used for the auxiliary control. It can test one to three samples simultaneously.

3. Detect circuit of the contactor of breaker

The major function of the detect circuit is judging the status of the auxiliary contactor and the main contactor of moulded case circuit-breaker. That means to judge the status of moulded case circuit-breakers in the test current. The circuit sends the signal to the industrial computer through photoelectric isolation.

**Software design of the overload protection test**

1. Problems of software designing in windows system

(1) Real-time requirement

The construction of hardware provides the functions of device with necessary means and possibility but the implementation of the whole function and the reliable operation mainly depend on the software. The software of the overload protection characteristic test

device is developed by using Visual C++ 6.0 on Windows 2000 system. As an advanced language, the VC provides the interface commands that connect the hardware.

Unlike the common utility program in Windows, the realtime requirement is much higher for the overload protection characteristic test of moulded case circuit-breaker. The timing accuracy must be considered to meet the requirement. In order to guarantee the realtime control, the hardware delay and the software delay are adopted. The hardware delay is adopted when the delay time is short and the delay accuracy is high. Reversely the software delay is adopted when the delay time is long and the delay accuracy is not high.

(2) Single instance program running

In the Windows system, one program can run multiple times at the same time. In the overload protection reliability test of moulded case circuit-breaker, the data is acquired by interrupt mode, so it occupies the computer system's hardware and external hardware. The program will not run normally if the program is running repeatedly. In order to avoid mis-operation, the multiple instances running at the same time are banned.

(3) Modularized design

In order to make the operation more convenient, many functional designs are used in developing the software of the overload protection characteristic test. Some of these functions are similar so the software adopts modularized design. Thus not only repeatedly using of the module and software debugging is convenient but also the test runs more reliable. The software has good man-machine interaction interface and the operation of the test device is convenient.

2. The test software design

The software of the overload protection reliability test mainly includes four modules: test running, data display, data access and parameter setting.

The module of test running is the key part of software. It is in charge of the whole test running and data acquiring. It mainly includes the module of single test, the module of cycle test and the module of current regulating and stabilizing.

The data display is used to check the test results so the user can find out the test status of every sample.

In the module of data access, the test results can be saved in different location as other files for users' use later on. When a new test starts, the former test data should be saved. The former data file also can be loaded to the computer so that the user can view or print them.

The module of test parameter setting is used to change and set the test parameters. The user can change and set the test parameters according to the test parameters of different samples.

The interface of parameter setting is shown in Fig.4.

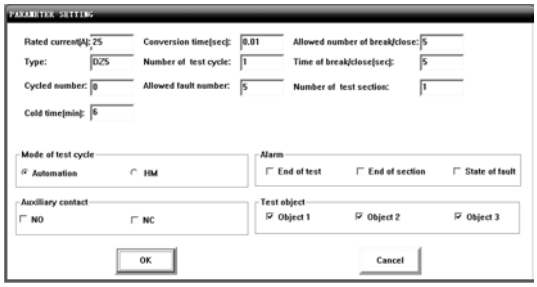


**Fig.4 Interface of parameter setting**

## CONCLUSION

In this paper we research the overload protection reliability of the moulded case circuit-breaker and develop the reliability test device. The conclusions are shown below:

(1) The reliability index is put forward.

We adopt the success rate as the reliability index of the overload protection of moulded case circuit-breaker. The mis-break and refuse-break can be examined by the success rate.

(2) The reliability level and examination plan of the overload protection is determined.

We classify the reliability level of the overload protection of the moulded case circuit-breaker into five levels A~E. The examination plan is determined by the two parameters sample plan.

(3) In order to make the test convenient, the overload protection tests are classified.

We classify the overload protection of moulded case circuit-breaker into three classes: the cold state test, the hot state test and the returnable characteristic test. For the first time the test is divided into test section and test cycle according to the different test procedure. One test cycle includes one or more test

sections. One test section includes two test currents. This makes the parameters setting orderly, the arrangement and operation of the test is much more convenient.

(4) The hardware of the overload protection reliability test is designed.

In the reliability test device of the overload protection, the current control and regulation are done by computer. The two power source with the output currents of 0~250 A and 0~750 A respectively is used in the test device. This minimizes the time of conversion and regulation between two different test currents, and makes the test results more accuracy.

(5) The reliability test software of the overload protection is programmed.

The reliability test software of the overload protection of moulded case circuit-breaker mainly includes such four modules as test running, data display, data access and parameter setting. The module of test running is the kernel of the software, which can do the overload protection test and the returnable characteristic test. The single instance running and real-time problems are resolved while the software is programmed.

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