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Study on Influential Factors of ATSE Transfer Time Based on Orthogonal Polynomial Curve-Fitting

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Abstract. Study on transfer time of Automatic transfer switching equipment (ATSE) has been an important part in the process of switch design and development. Starting from analysis of the electrical operational performance test of ATSE, relationship of all key time parameters during its transfer cycle are researched. Then, the circuit and the test method that can satisfy the requirement of the test are designed, and tests on various types of ATSE are completed. Finally, orthogonal polynomial curve-fitting method is introduced, suitable polynomial for fitting analysis on the test data is explored, key factors influencing the transfer time is discovered, and hidden relationship between each other is found, which provide guidance for designing more stable ATSE and carrying out better electrical performance test.

1. Introduction

With the development of smart grid, reliability requirements for power system are higher and higher. Especially important places such as hospital system, military installation etc., where do not allow power outage, even several cycles of voltage sags may result in great loss [1, 2]. Once main power appears failure, load circuit needs quickly switch to the alternative one. ATSE provides possibility to meet this need, which can transfer fast between different supplies under preset instructions and ensure power supply reliability [3]. Therefore, studies of transfer time and reliability of ATSE has become a focus in its industry.

The existing research methods include simulation analysis, optimization of controller and communication mode etc. Counterforce characteristics of ATSE under different air gaps are obtained by ADAMS software, and compared with engineering mechanics method, feasibility of the dynamics simulation method is verified [4]; ADAMS software is used to analyze influential factors of ATSE transfer time, spring stiffness and motor speed are found to be the most sensitive factor [5]; ATSE with PLC control system is proposed and designed, and its effectiveness used as an independent system is verified [6]; Communication protocol is utilized to replace traditional signals to control transfer of ATSE from different angles, effectiveness of this method is verified by experiments [7, 8]. Unlike these, this paper starts from study of actual electrical performance test of ATSE, and reveals factors influencing transfer time of ATSE through analyzing mass test data, which guide the design and development of this switch.

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2. The performance test of ATSE

Standard IEC 60947-6-1 provides specific methods for study of ATSE transfer time, which is the electrical operational performance test. The test requires ATSE can well make and break test current under a given voltage, current and power factor. An operating cycle consists of making and breaking the test current on both the main and the alternative supply contacts as Fig.1 shows. The cycle begins from off-position, then ATSE transfers to main position; when main power is failure, it automatically transfers to the alternative one; when main power becomes normal, it returns to main one.

In Fig.1, O is off position; Ⅰ is normal position; Ⅱ is alternative position; T_1 is time when position Ⅰ is closed; T_2 is time when controller gives action instructions; T_3 is time when moving contact starts to leave; T_4 is time when arc is extinguished, T_5 is time when position Ⅱ is closed. Therefore, assuming that delay time is zero, combined with Fig.1, it can be obtained: (1) transfer time: $T_o=T_5-T_2$; (2) off-time: $T_f= T_5- T_4$; (3) normal time: $T_n= T_2- T_1$; (4) making time: $T_m=T_4-T_1$.

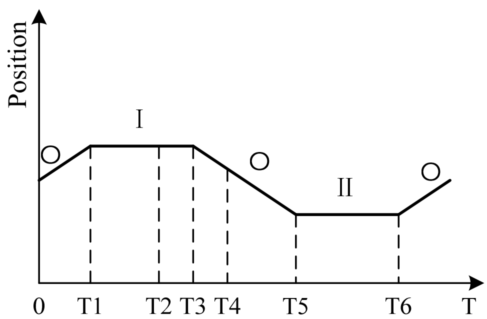

Figure 1. An operating cycle

In conclusion, without delay time, the relationship between T_o, T_f, T_n and T_m is available as follows:

$$T_o=T_m-T_n+T_f \tag{1}$$

The off-time is an intrinsic characteristic of ATSE products, and always has a relatively fixed value. According to Eq.1, to obtain the shortest transfer time T_o, maybe reducing making time T_m and increasing normal time T_n can realize.

3. Design of the performance test

The performance test needs a test system which can provide the prospective current as the standard requires. Therefore, design of the test system circuit is shown in Fig.2. It can be seen from Fig.2, going through high-voltage switch QS, QHV and impact transformer TM, high-voltage transforms to low-voltage. Then ATSE sample D is connected between breaker QF and load Z, and the performance test of ATSE can be carried out. In addition, fusible element F and current-limiting resistor R connecting with erection fixture of sample D make up the fault current detecting circuit. TA is rogowski coil, TV is voltage sensor. Operations of all these equipments and data acquisition are completed in the central control center.

Might as well we take class PC and CB ATSE as the research objects. Class CB ATSE is generally derived from circuit breaker, which is driven by motor directly. Class PC ATSE is generally derived form isolating switch products, which is driven by excitation mechanism such as electromagnet. So the subsequent tests and researches will be completed under class PC and CB ATSE with different drives.

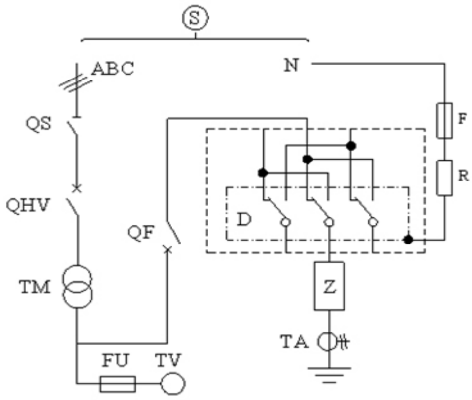

Figure 2. Schematic diagram of the test circuit

4. Analysis of the test data

Firstly we study the case of class PC ATSE. Its specification is: U_e=400V, I_e=250A, and utilization category is AC-33iB, which employs electromagnet as its drive. According to the method described above, tests are completed under the specified test parameters, and 6 groups of test data are randomly selected and shown in Table 1. In order to make test data have more representatives, deliberately not to control T_n during the test, just let it random variation. As Table 1 shows, fluctuating deviation of T_f is just 6ms, which can be regarded as a fixed value as described above; T_m and T_n seems to fluctuate irregularly, and T_o also fluctuates without any rules. But that is not the case, studies found that there is certain relationship between T_m and T_n. Suppose coefficient r=T_m / T_n, the r values of the test data can be obtained in the last column of Table 1. As you can see, r values are all greater than 1 and fluctuating small, but seemingly hiding some rules.

Table 1. Test data of class PC ATSE

No.	T_o/ms	T_m/ms	T_n/ms	T_f/ms	r
1	677	798	451	330	1.769
2	673	671	326	328	2.058
3	678	775	423	326	1.832
4	670	787	448	331	1.757
5	673	766	427	334	1.794
6	665	633	294	326	2.153

Assuming that there is an group of data (x_i, y_i) (i=1, 2, 3, …, n), which need to search the relationship between x and y, they can be realized by curve fitting. The method just requires the fitting curve can satisfy general characteristics of discrete points, and doesn't require it accurately through all points. Orthogonal curve fitting is a curve fitting method with high precision [9, 10], and its polynomial as Eq.2 shows.

$$\phi_m(x) = a_0\varphi_0(x) + a_1\varphi_1(x) + \cdots + a_m\varphi_m(x) = \sum_{k=0}^{m} a_k\varphi_k(x) \tag{2}$$

Where m is degree of fitting polynomial ($m \le n$-1); $\varphi_k(x)$ is orthogonal polynomial with highest power k which generates at the first k times; a_k is fitting coefficient, as Eq.3 shows.

$$a_k = \sum_{i=1}^{n} \omega_i y_i \varphi_k(x_i) \Big/ \sum_{i=1}^{n} \omega_i \varphi_k^2(x_i) \ (k=0,\ 1,\ 2,\ \ldots,\ m) \tag{3}$$

Where ω_i is the weight. In order to ensure effectiveness of the fitting, appropriate orthogonal polynomial will be selected to complete the fitting according to different application requirements.

Might as well take the data T_n in Table 1 as the abscissa and T_m as the ordinate, then orthogonal fitting is carried out. The curve is got as shown in figure 3 (a) and its fitting polynomial is got as follows:

$$T_m=1.02T_n+336.5 \tag{4}$$

As can be seen from Fig. 3 (a), these data are evenly distributed on both sides of the fitting curve, and the maximum deviation to the curve is just 8.01. T_m increases with the increase of T_n, which also showing a good linear relationship between them. All these indicate that it is a good fitting result, and also verify that there is surely direct proportion relationship under certain linear rule between T_m and T_n.

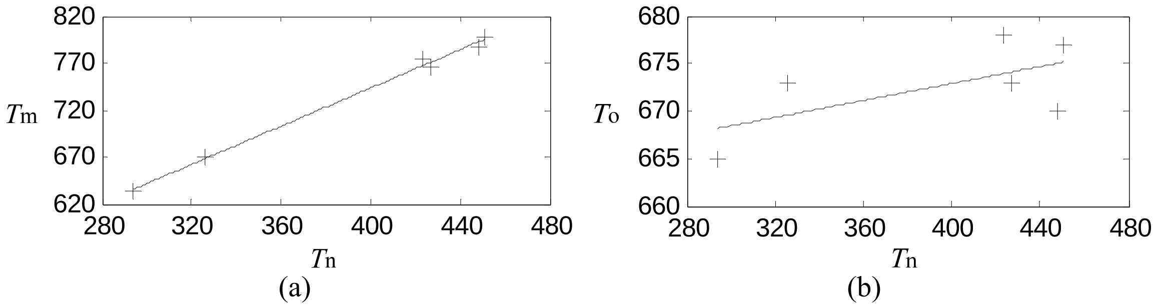

Figure 3. Orthogonal fitting results of class PC ATSE. (a) Result of T_m and T_n; (b) Result of T_o and T_n

Therefore, according to Eq.1, the relational equation of transfer time changes to Eq.5 as follow.

$$T_o=0.02T_n+336.5+T_f \tag{5}$$

If so, whether T_f maintains at a relatively stable level, T_o will change with the change of T_n. Following work will verify the doubt. Look at the fitting result between T_o and T_n, as shown in Fig.3(b). Linearity of the curve is better, T_o and T_n increases synchronously. The fitting polynomial is shown in Eq.6, compared with Eq.5, it is found that the slopes of them are almost similar. So there is indeed certain linear relationship between T_n and T_o.

$$T_o=0.04T_n+655 \tag{6}$$

This phenomenon is not an accident. The author obtains consistent results through large numbers of tests and their data analysis. Look at the results of class CB ATSE, as they are respectively shown in Table 2 and Fig.4. This ATSE employs capacitor running asynchronous motor as the drive, its specification is: U_e=400V, I_e=630A, and utilization category is also AC-33iB.

Table 2. Test data of class CB ATSE

No.	T_o/ms	T_m/ms	T_n/ms	T_f/ms
1	2204	1428	328	1110
2	2239	1561	425	1103
3	2169	1306	243	1104
4	2210	1366	260	1120
5	2175	1292	242	1119
6	2191	1310	245	1126

As you can see in Table 2, breaking time T_f is stable, and its fluctuation deviation is only 23ms. And in Fig.4, the fitting degree of this curve is better, which also shows a certain linear relationship between T_o and T_n. All these verify the reliability of above conclusion again.

Compared Table 1 with Table 2, it can be found transfer time of the class PC ATSE employing electromagnet drive significantly faster than the class CB ATSE employing motor drive. This is also not an accidental phenomenon under the support of large numbers of tests data.

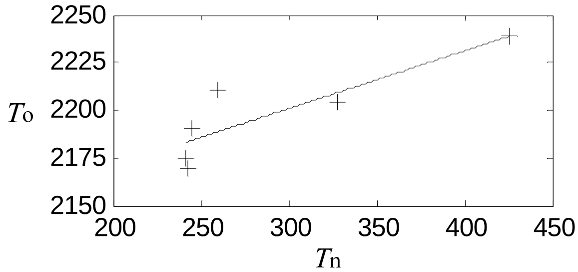

Figure 4. Orthogonal fitting results of class CB ATSE

In addition, it is discovered from large numbers of tests that T_n can not arbitrarily short, especially the class CB ATSE with longer T_f, otherwise there will be happening a situation that the drive receives the reverse action command before it is in place at certain direction. It is no doubt that it will superpose the time delaying to execute new instructions to the transfer time in the collected waveforms, and greatly extend the transfer time. So the best T_n is supposed to be at the moment when the drive of ATSE run in place.

5. Conclusion

This paper firstly studies the transferring action process of ATSE and the relationship of time related parameters appearing in the process. Then, test system with function of producing certain prospective testing current is designed and used to complete mass tests on ATSE with different categories. The test data show that the off-time is the intrinsic characteristics of ATSE, and generally has a stable value. Transfer time of ATSE employing electromagnet as its drive significantly faster than ATSE employing motor as its drive. Finally, after utilizing appropriate orthogonal polynomial to carry out curve-fitting analysis on the test data, it is found that normal time is the key factor influencing the transfer time of electrical operational performance test; there is a certain linear proportional relationship between them instead of the random fluctuation, and the best moment to obtain normal time is given.

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