IOP Conference Series: Earth and Environmental Science

Influence of the Test Current on Dynamic Resistance Measurements of SF_6 Circuit Breakers

To cite this article: Yufeng Lu *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **310** 042006

Influence of the Test Current on Dynamic Resistance Measurements of SF_6 Circuit Breakers

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Abstract. In order to study the influence of the test current on the dynamic resistance measurement of the SF_6 circuit breaker with different erosion degrees, simulated erosion experiment was carried on 126 kV SF_6 circuit breaker. The result shows, that the higher the test current is, the smaller the resistance of arcing contact when the circuit breaker is of any degree of erosion, but there is always no obvious link between the arcing contact travel and the test current. In addition, the dispersion of the test results decreases with the increase of the test current. However, when the erosion of the circuit breaker is very serious, the dispersion of results will be great regardless of the value of the test current. Therefore, considering the influence of test current on contact resistance, in order to obtain actualarcing contact resistance and to reduce the dispersion of test results considering the influence of test current on contact resistance, the larger dynamic resistance test current should be chosen as much as possible, and the dynamic resistance test must be carried on many times when contact erosion is extremely serious, so that the state of arcing contact can be obtained according to the distribution of test results.

1. Introduction

In order to obtain the state of the arc contact without disassembling the arc quenching chamber of circuit breaker, a dynamic resistance test method was proposed. In order to eliminate the inductance effect between contacts, direct current should be selected for dynamic resistance testing [1-2]. The contact state of contacts is not consistent under different test currents, which will affect the dynamic resistance test results. The dynamic resistance test current not less than 100A can reduce the relative noise level. The literature finds that the rated speed action circuit breaker can obtain the resistance of main and arc contacts from the dynamic resistance curve only when the test current reaches 700A. It is found in reference [3] that the dynamic resistance value decreases with the increase of test current without erosion, and the resistance value is not affected by the test current after serious erosion. There are not many kinds of circuit breakers with different erosion degrees in both papers.

The SF_6 circuit breakers in the actual power grid are in various erosion degrees. Based on the above research, the simulated erosion experiment of 126kV SF_6 circuit breaker was carried out. The dynamic resistance test of SF_6 circuit breakers with 13 different erosion degrees was carried out, which can almost represent all erosion degrees of SF_6 circuit breakers in the power grid. The dynamic resistance curve of the circuit breaker was obtained by the test, and the influence of the test current on the arc contact resistance and the contact travel value of the circuit breaker with different erosion degrees were analyzed. In this paper, in order to study the dispersion of the measurement results under different test currents, the correlation of dynamic resistance curve measured many times under the same current was analyzed, and the standard deviation of arc contact resistance value was analyzed. The test results provide a reference for SF_6 circuit breaker to diagnose electrical life by dynamic resistance test.

2. Simulated erosion experiment and dynamic resistance test

2.1. Experiment circuit

In order to study the influence of test current on dynamic resistance test of circuit breakers with different erosion degrees, the simulated erosion experiment was carried out on 126kV SF_6 circuit breaker. The process of breaking the fault current directly by the circuit breaker can be divided into high current phase, interaction phase, and high voltage phase. The high current and high voltage do not appear on the arc gap at the same time, and the erosion of the circuit breaker contacts mainly occurs in arcing period of high current.Therefore, only the high current was applied to circuit breaker for interupting experiment to simulate the erosion process of contacts. The simulated erosion experiment circuit is shown in Figure 1.

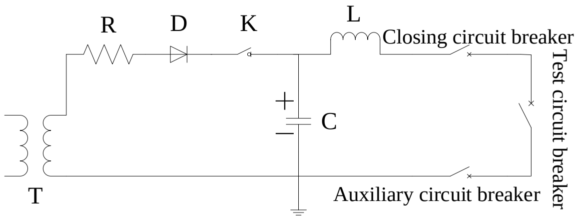

Figure 1. Simulated erosion experiment circuit.

In the figure, *C* was the capacitor bank, *L* was the inductor, the left side of the capacitor bank was the charging circuit of the capacitor, and the *LC* constituted the single-frequency oscillation circuit, which provided power frequency high current for the simulated erosion experiment. The circuit parameters are shown in Table 1.

The closing circuit breaker was responsible for conducting the circuit and putting the experiment current into operation. The test circuit breaker should break at the second half wave of current to simulate the erision process of circuit breaker contact. The auxiliary circuit breaker would break protectively after the test circuit breaker had been opened. The operation time and sequence of three circuit breakers in the circuit were controlled by the signal control board.

Table 1. Parameters of simulated erosion experiment circuit.

Parameter	Test value
Inductance/ mH	0.60
Capacitance/ mF	16.80
Charging voltage/ kV	1.65
Current/ kA	20
Frequency/ Hz	50
Duration of current/ ms	100

The test circuit breaker type was LW36-126 with rated short circuit breaking current of 40 kA and rated breaking times of 22. In this paper, the breaking current was selected 20 kA. According to the conversion relationship between breaking current and allowable breaking times, the test circuit breaker can break 20 kA power frequency current 70 times. In order to ensure the safety of the experiment, 48 times of simulated arosion were carried out on the test circuit breaker.

The dynamic resistance of circuit breaker was tested after simulated erision experiment. Dynamic resistance was measured by four-wire method, measurement of small resistance with large DC current. The basic principle was to add DC current at both ends of the circuit breaker. The contact resistance between the static and moving contacts could be obtained by measuring the voltage drop produced by the current on the contacts during the breaking and closing process. The dynamic resistance test mainly obtained the circuit resistance change curve during the breaking and closing process of the circuit breaker [4]. The measurement of dynamic resistance with four-wire method is shown in Figure 2.

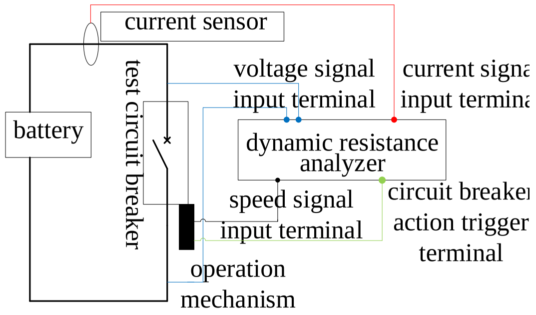

Figure 2. Dynamic resistance test circuit.

The battery was connected to the two ends of test circuit breaker. During the test, the dynamic resistance analyzer sent out a signal (green line). The test circuit breaker performs the opening and closing action. The circuit is short-circuited instantaneously when closing, and the battery added DC current to the two ends of the circuit breaker. To avoid the long-time short circuit of battery, the time interval between closing and opening trigger signal was 250ms. The DB8016 dynamic resistance analyzer collected and collated the break voltage (blue line), current (red line) and action speed signal (black line) during the breaking and closing process, as well as outputing the curve of dynamic resistance and contact travel during the breaking and closing process of circuit breaker. The dynamic resistance measurement range was 10-1000μΩ with resolution of 0.1μΩ. The contact travel range was 0-300 mm with resolution of 1mm.

2.2. Experiment procedure

A total of 48 simulated erosion experiments were carried out on the test circuit breaker, and dynamic resistance tests were performed after every 4 simulated erosion experiments. A total of 13 erosion degrees were simulated. Three DC test currents of 0.5kA, 0.7kA and 1.4kA were selected for dynamic resistance test, and each current was tested five times.The complete test flow is shown in Figure 3.

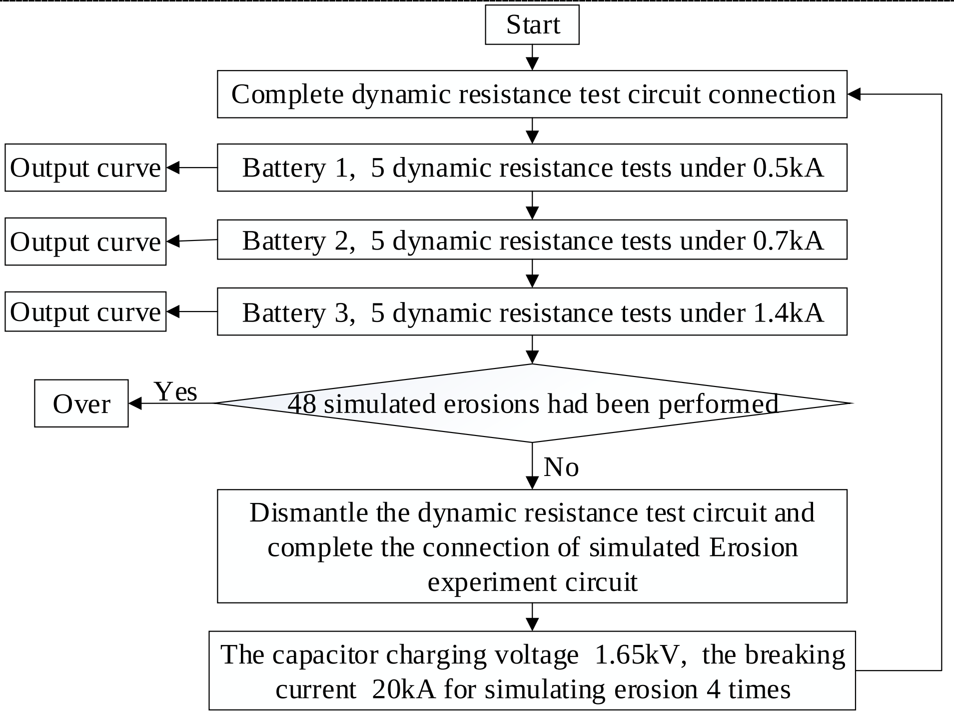

Figure 3. Process of simulated erosion experiment and dynamic resistance test.

3. Dynamic resistance test results

3.1. Standard dynamic resistance curve

The dynamic resistance analyzer outputted the curve of dynamic resistance and contact travel of the contact during the opening and closing process of the circuit breaker. In this paper, only the dynamic curve of the opening process was selected for analysis. The standard curve is shown in Figure 4. The dynamic resistance curve can be divided into two parts, the main contact part and the arcing contact part. There was a significant separation point between the two parts, which was caused by the sudden change of contact resistance when the circuit current was transferred from the main contact to the arcing contact.

The arcing contact was most severely eroded by arc during the breaking process of circuit breakers. The contact travel was too short and the critical breakdown voltage would be significantly reduced [8]. The arc may not be transferred to the arcing contact during the breaking process, resulting in breaking failure or even explosion. Excessive contact surface wear would also reduce the current breaking capability of the circuit breaker and affect the insulation performance of the arc quenching chamber. The contact state of contact surface was the main reason affecting the electrical life of circuit breaker. As the number of breaking short circuit current increasing, the contact surface would be eroded and the contact resistance would be greatly increased. At this time, the circuit breaker was prone to cause a significant temperature rise during the operation, causing the contact temperature to rise above the design limit. In this paper, only the main parameters that characterized the erosion degree of arc contact, the arcing contact resistance and contact travel, were extracted from the dynamic resistance curve for analysis. The average resistance of arcing contact part was arcing contact resistance, and the arcing contact travel was the sum of contact travel in main contact part and arcing contact part in dynamic resistance curve.

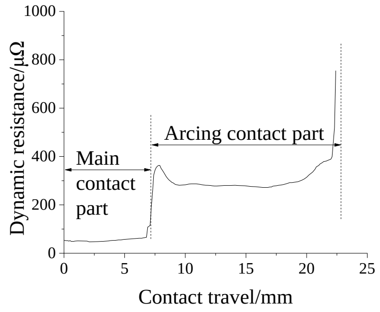

Figure 4. Contact resistance curve as a function of contact travel.

3.2. Arcing contact resistance

In this test, five dynamic resistance tests were carried out respectively under DC currents of 0.5kA, 0.7kA and 1.4kA. The measured values of arcing contact resistance were extracted from the dynamic resistance curve, and the average values of the five test results under each test current were obtained. The arcing contact resistance value during the entire simulated erosion experiment was counted, and the result is shown in Fingure 5.

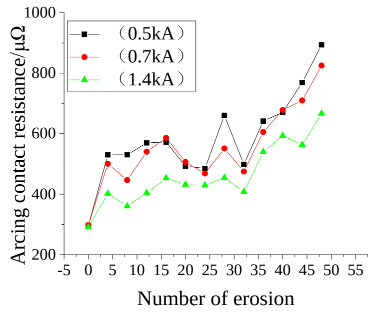

Figure 5. Average arcing contact resistance of simulated erosion test process.

Under all erosion degrees of circuit breaker contacts, the arcing contact resistance decreased as the dynamic resistance test current increasing, $R_{0.5}>R_{0.7}>R_{1.4}$, which was related to the contact state of contacts getting better under high test current. Reference [5] pointed out that the arcing contact resistance of the non-eroded circuit breaker was 200~300μΩ. In this test, the three current test results were in accordance with the literature description when the contacts were not eroded. At 1.4kA, the arcing contact resistance showed a slow and steady increase trend. After 36 times of erosion, the arcing contact resistance increased significantly, indicating that the surface of the arc contact had been seriously damaged, and the resistance change conforms to the actual change process of contact state. When the test current was 0.5kA and 0.7kA, the arcing contact resistance deviated rapidly from the normal range after slight erosded, and changing dramatically during the whole test process. This reflected that the accuracy of the measurement results was not high when the test current was small. The actual state of the contacts does not match.

In the test, a few cases didn't meet $R_{0.5}>R_{0.7}>R_{1.4}$. At this time, the resistance measurement values were very close. It may be that the contact surface was not smooth or deformed after multiple simulated erosion, and the contact vibration caused the test results to appear. But this did not change the overall law of the influence of the test current on the dynamic resistance measurements. Regardless of the erosion degree of circuit breakers, ahigh current was selected for the dynamic resistance test, and the resistance measurement value was closer to the actual resistance of the contacts.

3.3. Arcing contact travel

The statistical results of the measured value of arcing contact travel during the whole simulated erosion experiment are shown in Figure 6.

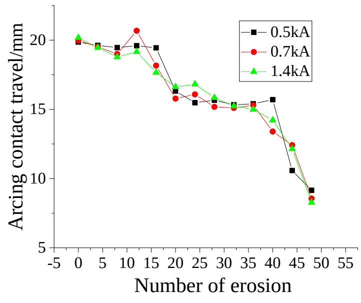

Figure 6. Arcing contact travel.

In Figure 6, the arcing contact travel decreased gradually with the increase of simulated erosion times, reflecting the erosion process of the arc on the length of the arcing contact. However, under three kinds of test currents, the measured values of arcing contact travel were basically the same as well as the trend of change. It can be seen that there is no obvious relationship between the arcing contact travel of circuit breaker and the current of the dynamic resistance test under any erosion degree.

4. Discussion

4.1. Correlation coefficient of dynamic resistance curve

In this test, five dynamic resistance measurements were performed under three kinds of test currents. In order to study the influence of test current on the test results, the correlation analysis of the dynamic resistance curves obtained from the five test tests under the same test current was carried out. The pearson correlation coefficient is a parameter indicating the correlation between the curves. The correlation coefficient ρ is between -1 and 1. When ρ>0.8, it is called height correlation. When ρ is closer to 1, the correlation between curves is stronger, and the dispersion degree of measurement results is lower. The statistical results of the correlation coefficients between the dynamic resistance curves obtained from the five tests under each test current are as follows:

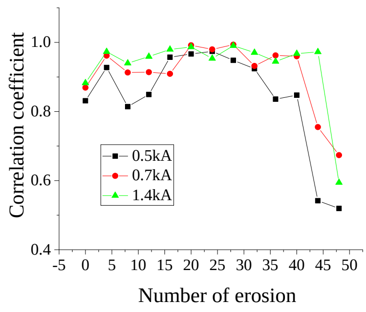

Figure 7. Correlation coefficient of dynamic resistance curve.

Figure 7 showed that the correlation coefficient increases with the increase of test current during the whole test process. When the test current was 1.4kA, the correlation coefficient curve was basically at the top, and the correlation coefficient was closest to 1. When the test current is 0.5 kA, the correlation coefficient is close to 0.8 (high correlated edge), indicating that the correlation between the dynamic resistance curves of multiple tests at 0.5kA was poor, and the measurement results were more scattered.

4.2. Standard deviation of contact resistance

It was found that the measured value of arcing contact resistance was greatly influenced by the measured current, so the dispersion degree of measured value of arcing contact resistance under each test current could be analyzed by the standard deviation. The standard deviation of arc contact resistance measured five times under three test currents during the whole test process was counted, as shown in Figure 8.

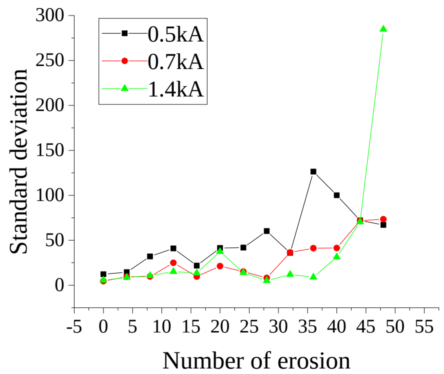

Figure 8. Standard deviation of arcing contact resistance.

The standard deviations of arcing contact resistance values under three test currents during the whole test process were averaged, and the statistical results are shown in Table 2.

Table 2. Standard deviation of arcing contact resistance.

Test current	0.5	0.7	1.4
Standard deviation of arcing contact resistance	49.96	24.46	19.39

Figure 8 and Table 2 showed that the larger the test current when performing dynamic resistance measurement, the smaller the standard deviation of the arcing contact resistance obtained by multiple tests, $\sigma_{0.5}< \sigma_{0.7}< \sigma_{1.4}$. The standard deviation curve of high current test results was basically below that of low current test results. At 0.5kA, the standard deviation of arcing contact resistance was twice that of 0.7kA. It showed that the test results were highly dispersible when the test current was small.

When the number of erosion reached 36 times, the correlation coefficient between curves droped sharply, and the standard deviation of arcing contact resistance rised sharply. At this time, the contact of the circuit breaker had been severely eroded and deformed, and the mechanical vibration and other disturbances were serious. No matter what kind of test current was selected, the results of dynamic resistance test were highly dispersive. In this case, in order to obtain more clear contact status information of circuit breakers, no matter what kind of test current was adopted, a large number of dynamic resistance tests must be carried out to determine the state of arc contacts according to the distribution of test results.

4.3. The influence of test current on contact resistance

The larger the dynamic resistance test current is, the smaller the measured value of main and arcing contacts is. This is because the test current will affect the contact state between contacts. The mechanism is as follows. When two contacting conductors are electrified, the contact voltage drop occurs. At this time, the resistance between conductors is called contact resistance. For commonly used SF_6 circuit breakers, the contact resistance is mainly the shrinkage resistance [6], such as equation (1):

$$R_C = \frac{\rho \times \sqrt{\pi \times H}}{2 \times \sqrt{F_T}} \tag{1}$$

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Where ρ is the resistivity of the contact material, H is the hardness of the material, F_T is the contact pressure of contacts, R_C is the contact contact resistance. It can be seen from equation (1) that the contact resistance mainly depends on the contact pressure of the contacts. In reference [5], it is considered that the contact contact pressure is mainly the attraction between the contacts, which increases with the current increasing between the contacts, such as equation (2):

$$F_A \propto \frac{I_f^{\,2}}{d} \tag{1}$$

Where I_f is the current flowing through the contacts, d is the distance between the moving and static contact points.

According to equation (1) (2), when the test current is larger, the temperature of the contact peak will rise due to the greater contact pressure F_T, which will also soften the contact material and increase the elastic deformation. The peak conductive spot is elastically deformed to be flatter, and the contact resistance will decrease with the increase of the area of conductive spot [7]. From the point of view of contact vibration, the instability of measurement results caused by contact vibration will also be improved when the contact is more tightly contacted. In summary, the measured value of dynamic resistance under high current is closer to the actual contact resistance. When performing dynamic resistance test, high test current should be selected as much as possible, but the effective value of the test current should not be greater than the rated short circuit breaking current of circuit breaker.

5. Conclusion

In order to study the influence of the test current on the dynamic resistance test of circuit breakers with different erosion degrees, the simulated erosion experiment was carried out on the 126kV SF_6 circuit breaker. Three kinds of test currents were selected for dynamic resistance test under 13 different erosion degrees of the circuit breaker. The following conclusions ca be obtained:

(1) Regardless of the erosion degree of SF_6 circuit breaker, the greater the dynamic resistance test current, the smaller the measured arcing contact resistance, closer to the actual contact resistance and reflecting the true erosion of the contact. But the test current always has no significant impact on the measurement of the arc contact travel.

(2) When the SF_6 circuit breaker is in the same erosion degree, the dispersion degree of test results decreases with the increase of test current. Considering the influence of test current on contact resistance, large dynamic resistance test current should be selected as far as possible, but the effective value of test current should not be greater than the rated short circuit breaking current of circuit breaker.

(3) When the contact erosion of SF_6 circuit breaker is very serious, no matter what kind of test current is selected, the test results are dispersed. At this time, the test current should be as large as possible for dynamic resistance test, and a large number of dynamic resistance tests must be carried out to judge the state of arc contact according to the distribution of test results.

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