Experimental investigation of interrupting capacity of low voltage circuit breaker

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Abstract. The experimental results of the circuit breaker interrupting capacity are presented in the article. The scheme of the experimental workbench and diagnostic methods are described. The study was performed using high-speed shooting methods. The high-speed shooting results and diagrams for different modes are presented. The analysis of the arc divider geometry influence on the extinguishing process for different modes and power factor is completed. A parametric study of the influence of the power factor, the interrupting current magnitude and the moment of switching on the extinction of the electric arc in the circuit breaker is also performed. The influence of the arc chute geometry on the formation of a new arc attachment point is shown in the article. The test was carried out on the basis of a specially developed prototype of a low-voltage circuit breaker (AC). The obtained results can be used when designing a low-voltage circuit breaker (AC).

1. Introduction

An initial analysis of the power system energy security leads to the identification of two main types of protective devices: circuit breakers and fuses. Unlike fuses, which must be replaced after each operation, circuit breakers have the ability to re-enable, which makes these devices a more attractive option. The protective functions of the circuit breaker are aimed at preventing damage to the electrical circuit from overload currents or short circuits [1-3].

Due to the importance of low-voltage circuit breakers in the power system, the question of the design method of contact and current-carrying systems, as well as an arc suppression system, is one of the most pressing issues in the field of development of electrical devices.

The basis of modern technical solutions was laid by the Russian electrical engineer, physicist, and constructor Mikhail Osipovich Dolivo-Dobrovolsky (1862-1919) back in 1912, which is confirmed by patents No. 266745 and No. 272742 [4]. Two main types of designs of the arcing chamber of a circuit breaker have found application in practice (see Figure 1).

All other things being equal, the circuit in Figure 1a allows you to get a shorter arc burning time than the circuit in Figure 1b, however, the second version of the arcing system provides uniform arc entry into all gaps between the plates. The second type of the arc suppression system design is used in the vast majority of modern low-voltage circuit breakers [5-8].
Figure 1. Types of magnetic blast systems design.

A prototype of a low-voltage circuit breaker was developed with various arc divider geometries (see Figure 2) in order to study the influence of the arc divider design on the breaking capacity.

Figure 2. Designs of investigated arc chutes

2. Experimental facility
A schematic diagram for the study of the circuit breaker interrupting capacity is shown in Figure 3. Automatic shutdown is synchronized with high-speed shooting. The current was measured using the Rogowski coil [9]. The circuit breaker was connected on a test bench (see Figure 3) between the phase and neutral wires to realize a single-phase short circuit. The activation of the circuit breaker is implemented using a pneumatic actuator. The control of the pneumatic actuator is synchronized with the network for the possibility of switching at different points in time relative to the beginning of the sinusoidal voltage period. The blocks of inductance and resistance allow you to adjust the power factor and the value of the switched current [10-11]. The prototype of the low-voltage circuit breaker is designed with specialized viewing windows for high-speed shooting (see Figure 4).

Figure 3. Schematic diagram of the experimental installation
3. Results and Discussion
Experimental studies were performed for three types of arc divider design with short-circuit current values of 4kA, 10kA, 16kA, 19kA and 26kA, in addition, an investigation was made of the arc quenching process dependence on the switching moment with a delay of 3ms, 5ms and 7ms from the beginning of the sinusoidal short-circuit current period.

The time dependencies for the three types of the arc divider designs for the moment of switching at 5ms and short-circuit current value of 10kA are shown in Figure 5.

![Figure 4. Windows for high-speed shooting](image)

**Figure 4.** Windows for high-speed shooting

![Figure 5.](image)

**Figure 5.** The results of experimental studies at Ishc = 10kA and t = 5ms.
Frames with the high-speed camera, synchronized with current and voltage waveforms, for the experiment with short-circuit current value of 19kA are shown in Figures 6-10 (current scale: 100kA/V; voltage scale: 1.1kV/V; time scale: 30000 frames per second).

**Figure 6.** The results of experimental studies at Ishc = 19kA and t$_{\text{start}}$ = 5ms for chutes type 1 (frame 4617)

**Figure 7.** The results of experimental studies at Ishc = 19kA and t$_{\text{start}}$ = 5ms for chutes type 1 (frame 4686)

**Figure 8.** The results of experimental studies at Ishc = 19kA and t$_{\text{start}}$ = 5ms for chutes type 1
Figure 9. The results of experimental studies at $I_{shc} = 19kA$ and $t_{\text{start}} = 5ms$ for chutes type 1

Figure 10. The results of experimental studies at $I_{shc} = 19kA$ and $t_{\text{start}} = 5ms$ for chutes type 1

Figure 11. The results of experimental studies at $I_{shc} = 19kA$ and $t_{\text{start}} = 5ms$ for chutes type 1
The initial state is shown in Figure 6. You can see the formation of a new arc attachment point and arc shunting process from Figure 7 to Figure 8 and from Figure 9 to Figure 10. The end of the arc extinguishing process is shown in Figure 11.

4. Conclusion
An experimental study of the interrupting capacity of the low-voltage circuit breaker has been performed. The study was performed using high-speed shooting methods. The analysis of the arc divider design influences the arc extinguishing process. A parametric study of the power factor influence, the magnitude of the switched current influence and the moment of switching influence on the extinction of the electric arc in the arc quenching system of the circuit breaker was also performed.

As a result of experimental studies, it was found that the third type of the arc divider (see Figure 2) does not extinguish at short-circuit currents of 10 kA and higher. At small values of the short-circuit current (up to 19 kA), the arc quenching process more efficiently occurred when using the second type of the arc divider (see Figure 2), the value of the released heat power during arcing in the case of the second type of arc divider is much smaller than that of the first type.

Interrupting capacity of the circuit breaker is significantly reduced with a decrease in the power factor value. Interrupting capacity of the circuit breaker decreases with an increase in the switching delay time, while switching the circuit breaker in the second half of the half-cycle of a sinusoidal short-circuit current, there is no extinguishing in the first current zero.

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