Field Experience with Controlled Switching System Applied in Reactor and Capacitor Switching

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1. Introduction

This paper presents a method to easily determine close or open targets based on electrical characteristics such as rate of decay of dielectric strength (RDDS) and mechanical characteristics such as scattering of operating time of circuit breakers. The validity of the method is verified based on the results of energization and de-energization of an actual circuit breaker system. This paper also introduces the excellent operating performance of a controlled switching system, including its compensation function for breaker operating characteristics, based on the records of actual long-term breaker operation as it was applied to capacitor banks and shunt reactors.

2. Setting of Energization Target (1)

The target point for energization can be directly determined from an energization test at a system voltage, with the breaker closing phase as a parameter, when the making voltage reaches its highest or lowest level. However, execution of multiple energization tests at real voltages may not be possible in certain cases, for example, the additional application of controlled switching function to an existing circuit breaker.

On the other hand, if the mechanical scatter and RDDS of the circuit breaker are known, the target point can be calculated as a function of these parameters. Figure 1 shows a conceptual representation of the relationship between the target point, mechanical scatter, and RDDS of the circuit breaker. For example, the target point for which the making voltage is set at the lowest level is given as a point that minimizes the largest making voltage in the distribution. Figure 2 shows the relationship between the mechanical scatter and target point in a case where RDDS is a parameter and the target is to minimize the making voltage. It is indicated that the target point approaches the zero voltage instant as RDDS increases and mechanical scatter decreases.

3. Application to Switching of VAR Compensation Equipment

When energizing phase-modifying equipment such as capacitor banks or shunt reactors with iron cores, a large inrush current is generated and causes problems such as increased wear of circuit breaker contacts and disturbance in system voltage. On the other hand, when de-energizing shunt reactors, re-ignition is generated, usually within short arcing times, and causes problems such as high re-ignition overvoltage and increased wear of circuit breaker contacts, etc. Even though re-strike free is required to prevent voltage escalation in de-energization of capacitor banks, it is a heavy task for circuit breakers that are required to perform numerous number of switching. As an effective and economical solution for such problems, the controlled switching system has become widely recognized and is increasingly employed.(2)

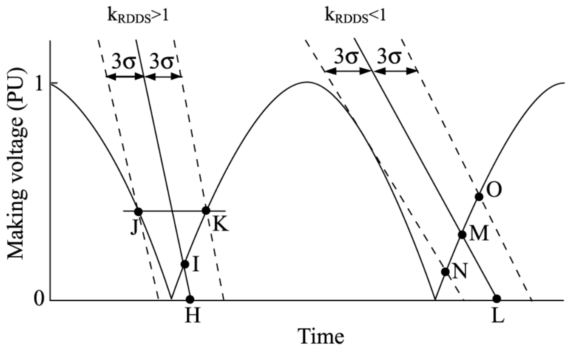

Fig. 1 Conceptual representation of target point for energization (Target: minimizing making voltage)

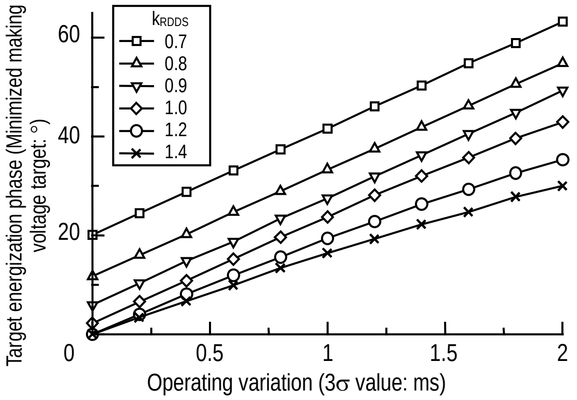

Fig. 2 Relationship between RDDS and target point for energization

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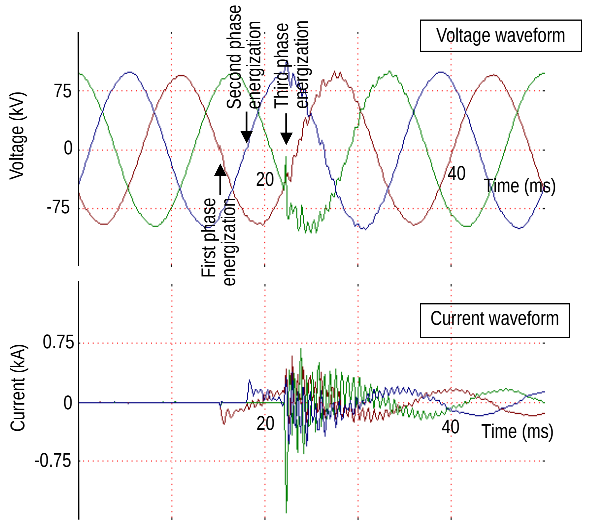
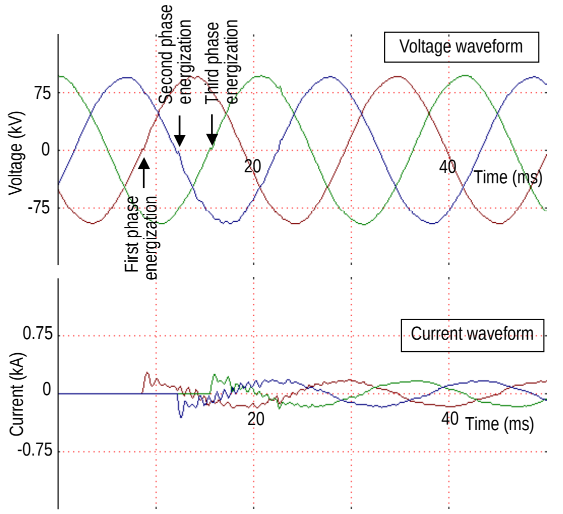
3.1 Example of application to switching capacitor banks

Figure 3 shows the results of the commissioning test conducted on-site where a controlled switching system was applied to 121 kV capacitor banks. In the first energization as shown in (a), energization of the third phase was delayed due to a tolerance of RDDS, resulting in the generation of an inrush current of about 7 PU. However, with the adaptive control effect of the controlled switching system, each phase was energized at zero voltage in the case of the tenth energization as shown in (b).



(a) First operation



(b) Tenth operation

Fig. 3 Voltage and current waveforms during capacitor bank energization

In the case of the controlled switching system used here, the tolerance of electrical characteristics of the circuit breaker mentioned above can be compensated by adaptive control[3] based on the operating history, since the energization time, which is the controlled result, is directly measured from the initiation of the main circuit current.

Figure 4 shows the distribution of making voltages in the actual operation over a period of about six months and the distribution of closing phases. The upper half of the figure shows the distribution of making voltages, and the lower half shows the distribution of mechanical closing instants. Distribution of closing instants is extremely limited; distribution centers on "16°", which is the close target. The maximum value of making voltage stands at about 0.35 PU, which is slightly lower than the estimated value of 0.4 PU based on mechanical scatter and RDDS. This is probably due to the actual mechanical scatter, which was lower than the results of the verification test at the factory.

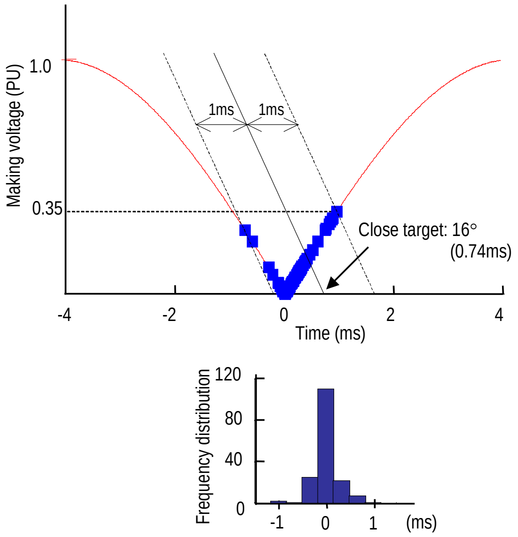


Fig. 4 Distribution of making voltages and closing instants

3.2 Application to switching of shunt reactors[4]

Figure 5 shows the voltage and current waveforms of controlled closing in the energization of a shunt reactor. We had confirmed that a maximum 3.0 PU of inrush current was generated in the energization of the shunt reactor without controlled closing. This figure, however, indicates that almost no inrush current resulted from controlled closing.

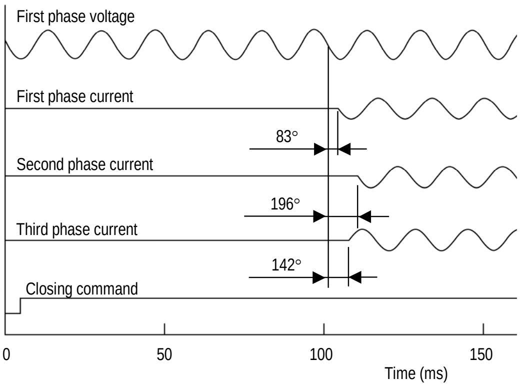


Fig. 5 Voltage and current waveforms of controlled closing in energization of shunt reactor (Controlled switching)

Figure 6 shows the voltage and current waveforms in de-energization of the load current of a shunt reactor. The current of each phase is de-energized from the first phase, third phase, to second phase in accordance with the phase rotation, and no high-frequency re-ignition current that indicates the generation of re-ignition is detected in the current waveforms. It is obvious that the GCB successfully completed de-energization without re-ignition.

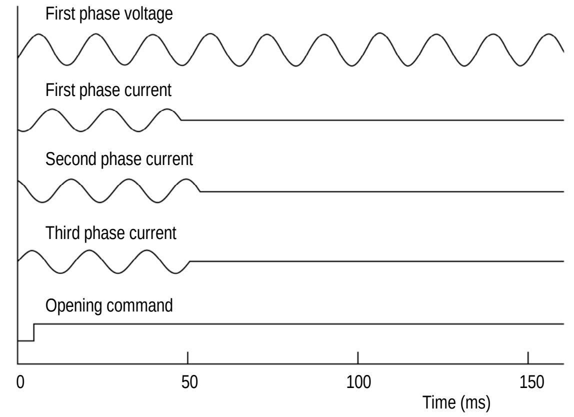


Fig. 6 Voltage and current waveforms in de-energization of shunt reactor (Controlled switching)

Figure 7 shows the distribution of making voltages in the actual operation over a period of about one year and the distribution of mechanical closing instants. The upper half of the figure shows the distribution of making voltages, and the lower half shows the distribution of closing instants.

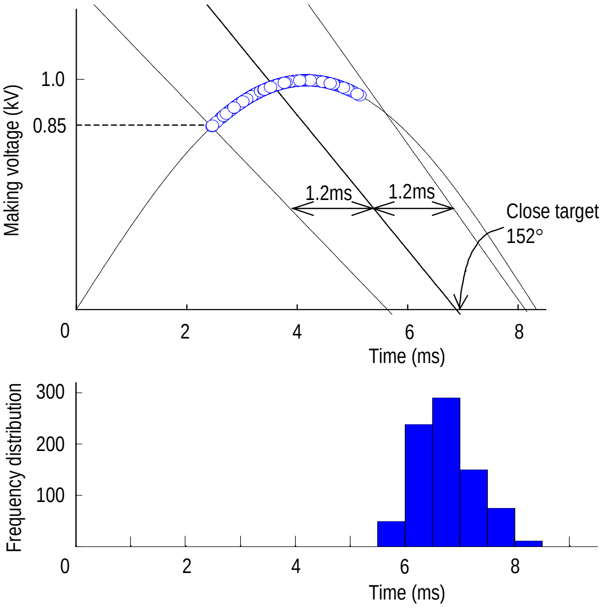


Fig. 7 Distribution of making voltages and closing instants

The mechanical closing instants distribution centers on "152°" after the voltage zero, in other words at about 7 ms, which is specified as the close target. All the control error were within ±1.2 ms, a sufficiently small distribution range that almost agrees with the value obtained in the verification test conducted at the factory.

The controlled switching system used for this purpose is provided with an alarm function set to start when the current continues in excess of 1/4 cycle of the estimated current de-energization time, which the function considers as generation of re-ignition. However, there was no alarm generated during the actual operation period; the controlled opening is also confirmed as functioning normally.

3.3 Evaluation of operating error in controlled switching

The validity of the operating characteristics verified at the factory was examined by evaluating the measurements of switching (opening/closing) time and the accuracy of controlled switching under the respective operating conditions of actual field operation over a period of about one year.

Figure 8 shows the ambient temperature in each closing operation. The ambient temperature varied from 4 to 33°C, for a width of about 30 K, and the maximum temperature gap between two adjacent closing times was 8 K. The variations in hydraulic oil pressure remain within a narrow range, from 31.5 to 32.5 MPa, which is the normal operating pressure range of the pump, and the control voltage remained at almost a fixed level due to stable power supply from the substation.

Figures 9 and 10 respectively show the variations in closing and opening time and the control errors during closing and opening operation. Both closing and opening time varied in accordance with the changes in operating conditions. However, the errors against the respective target were within ±1.2 ms in closing and within ±0.2 ms in opening, which verifies the relativity of operating conditions that were verified in the factory test and used in controlled switching and also the accuracy of the prediction for the closing and opening time based on the operating conditions.

Next, we examined the idle time characteristics in an actual application field. Figure 11 shows the relationship between the measurements of idle time and delay in closing time. Each point indicates the delay in closing time for the three phases in an actual application field, while the solid line indicates the idle time characteristics obtained in the factory test. The shortest and longest idle time during an actual operation period of about one year was 0.05 and 92 hours, respectively, and the delay in closing time is distributed within the range of ±1.2 PU centering on the value verified in the factory test.

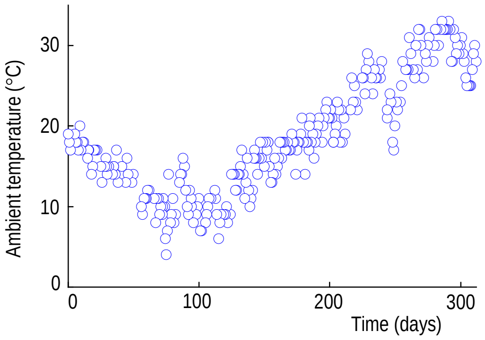


Fig. 8 Ambient temperatures during operation of circuit breaker

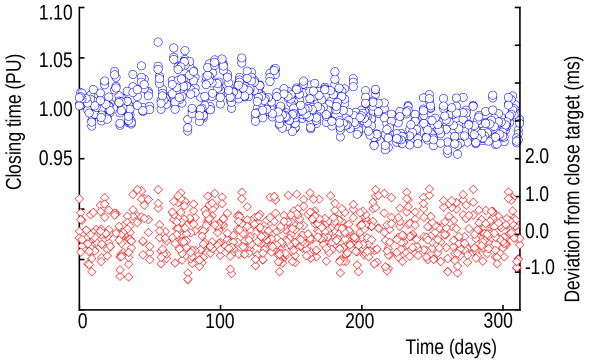


Fig. 9 Variation in closing time and deviation in closing target

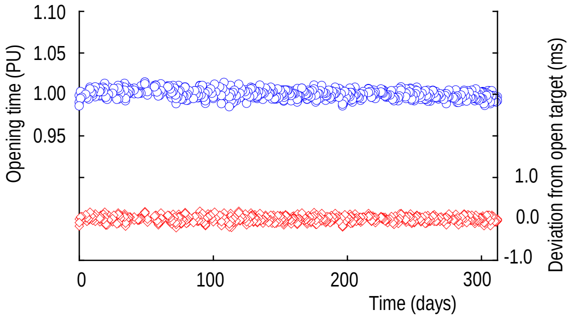


Fig. 10 Variation in opening time and deviation in opening target

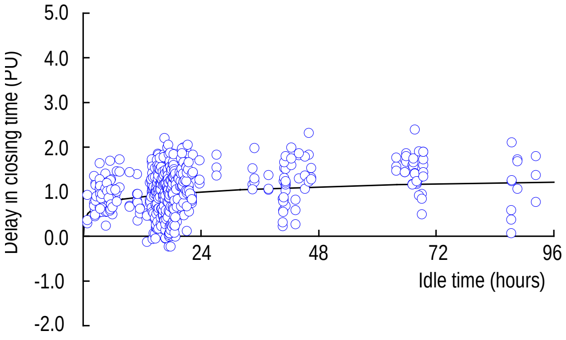


Fig. 11 Relationship between closing time and idle time in actual operation

4. Conclusion

This paper presented a method for setting the close and open targets in a controlled switching system based on the dielectric strength characteristics of circuit breakers and the mechanical operating variations obtained from no-load operation tests. In addition, it was confirmed, based on electromechanical switching operation in an actual system, that the application of controlled switching for capacitor banks and shunt reactors based on the close and open targets obtained from the method is effective for suppressing inrush current and preventing re-ignition.

Furthermore, it was confirmed, in connection with the variations in closing or opening time in response to the operating conditions, that the operating characteristics could be stably compensated over a long period by using the characteristics obtained from the factory test.

References

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(4) Kohyama, Ito, Asai, Hidaka, and Yonezawa: “Control of Switching Surge in Controlled Switching of Gas Circuit Breaker”, Transactions of the Institute of Electrical Engineers of Japan, Part B, Vol. 124-B, No. 2, pp. 267-273 (2004)