Factory and Field Tests of Controlled Switching in Accordance with IEC62271-302 Standard

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1. Introduction

In controlled switching, where a circuit-breaker is switched in the optimum phase to minimize switching surge, it is important to predict precisely the variations in the operating time of the circuit-breaker with respect to the ambient temperature, control voltage, operating pressure, and number of times of operation.

CIGRE has investigated the operating conditions of phase control of actual systems and proposed type test items and testing procedures required for controlled switching systems (CSSs).(1) Based on the proposal, a test standard IEC62271-302 has been prepared, and a new standard document will be published in the near future.

This paper discusses the type test items and testing procedures specified in the International Standard IEC62271-302 and also introduces the operating characteristics of circuit-breakers tested in accordance with the standard and the testing of combined CSSs.

2. Type Tests

Table 1 shows the type test items and test contents required for the circuit-breakers used in the CSSs specified in IEC62271-302. For this standard, the following test items are added to the tests conforming to the conventional International Standard for High-Voltage Alternating-Current Circuit-Breaker IEC62271-100:

- Mechanical characteristics test to evaluate the operating time with respect to specific operating conditions of circuit-breakers
- Electrical characteristics test to evaluate the variations in dielectric strength at the moment when the circuit-breaker is opened and when it is closed
- Controlled switching test to open and close a CSS, which consists of a circuit-breaker, a controlled switching unit, and a sensor, in a particular phase.

2.1 Mechanical characteristics test

The operating time of a circuit-breaker changes not only in accordance with such operating conditions as ambient temperature, control voltage, and operating pressure but also with total number of times of operation and idle time (time interval between the last operation and the next operation). This is why the standard specifies a test to evaluate the dependency of the variations on the operating conditions and the total number of times of operation.

The operating mechanism of a circuit-breaker is such that the plunger is excited according to the switching command to disengage the ratch mechanism and release the hydraulic pressure or spring energy for

Table 1 Type tests for circuit-breakers tested with dedicated controller

Type Tests item		Test procedure
Mechanical tests	Measurement of mechanical scatter	100 opening and 100 closing operations at rated control voltage, rated gas density, rated drive pressure
	Impact of temperature	10 opening and 10 closing operations at each ambient temperature (between -10°C and 40°C in not more then 15°C steps
	Impact of control voltage	10 opening and 10 closing operations at each voltage level (minimum, nominal, maximum, additional level)
	Impact of stored energy level	10 opening and 10 closing operations at each stored energy level (between its maximun and minimum value in not less then 5 equal steps)
	Impact of idle time	5 operating cycles (close and open) at each idle period (1, 2, 4, 8, 16, 32, 64, 168 hour)
Electrical tests	Determination of RDDS Determination of RRDS	Tests shall be performed with the circuit-breaker in new condition and also following pre-conditioning of three opening operations with arcing time as for T60 (same current as test duty T60) Delay the close impulse by 15 electrical degrees and perform a further 4 making operations Test voltage = 1.5 x rated voltage/$\sqrt{3}$ Test current for RDDS = <400A, Test current for RRDS = 315A
Controlled switching tests	Controlled closing type test	20 closing operations at voltage zero (with the circuit-breaker in new condition and pre-conditioned circuit-breaker) Test voltage = 1.5 x rated voltage/$\sqrt{3}$, Test current $\geq$10A
	Capacitive current switching test	Controlled opening with setting intended to minimise re-strike probability Controlled closing at voltage peak
	Test duty T100a	Controlled closing at voltage zero

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driving the main contact in the interrupting chamber of the circuit-breaker. The operating characteristics of the plunger which releases the ratch mechanism depend on the control voltage, which changes the coil current, and the ambient temperature, which influences the coil resistance. In addition, the switching characteristics of a circuit-breaker, which consists of many mechanical sliding parts, depend on the ambient temperature which changes the lubrication on the sliding surface or the coefficient of friction and the total number of operations and operating time in the past. Furthermore, in the case of hydraulic operation or pneumatic operation, the hydraulic pressure or pneumatic pressure also influences the operating characteristics.

Adaptive compensation, which compensates the average operating time through comparison between the actual operating time for about the 10 most recent operations and the predicted time, has been proved effective for evaluating the variations in the operating characteristics due to wear or the like of the sliding parts as a result of repeated switching of the circuit-breaker.(2)

On the other hand, the operating characteristics that depend on the idle time of the circuit-breaker change with the time-varying lubrication characteristics of the sliding surface and the air bubbles generated in the hydraulic circuit of the hydraulic-operating mechanism. The air bubbles generated in the low-pressure hydraulic circuit in the open condition are compressed when the oil is subjected to the transition to a high-pressure condition at the beginning of a closing stroke, thus causing a delay in the propagation of pressure to the piston. With the operating mechanisms subject to an operational delay depending on the idle time, the delay becomes conspicuous several hours after the beginning of the idle time, and it has been observed that the delay usually tends to saturate at about a maximum of 3 ms before reaching 100 hours.(2)

In controlled switching, the next operating time is compensated by predicting variations in the operating time with respect to the idle time on the basis of the respective condition values measured immediately before the switching operation or the previous operation, with the variations in the operating time under each operating state (state quantity) obtained from the mechanical characteristics tests memorized in the program of the controlled switching unit as the function of one or two state quantities.

2.2 Electrical characteristics test

The withstand voltage between the contacts of a circuit-breaker decreases with a decrease of the contact gap during the closing stroke. The making instant is when the voltage across the circuit-breaker exceeds the dielectric withstand between the gaps and its deviation results from a mechanical variation of the closing time and the pre-strike behavior characterized by Rate of Decay of Dielectric Strength (RDDS). On the other hand, the withstand voltage between the contacts increases with an increase of the contact gap during the opening stroke. The circuit breaker can interrupt an inductive current successfully and avoid re-ignition when the dielectric withstand between the gaps after interruption always exceeds a transient recovery voltage across the circuit-breaker. The characteristic of Rate of Recovery of Dielectric Strength (RRDS) is defined by an interruption test of a small inductive current.

The gradual wear of contact and nozzle may affect these RDDS and RRDS characteristics and therefore the RDDS measurement is required to evaluate it with the circuit-breaker in new condition as well as in wear condition following a pre-conditioning of the circuit breaker (after three interruptions with arcing times as for T60 similarly for a capacitive current switching for C2 class circuit-breaker).

2.3 Controlled switching test with circuit-breaker, sensor, and controlled switching unit combined

To verify the soundness of CSSs that combine a circuit-breaker (GCB), a sensor, and a controlled switching unit, a test in which a GCB is closed or controlled to break at a specified voltage or phase angle is required. For the target closing phase angle of controlled closing, the closing voltage is confirmed by executing controlled closing phase operation up to 20 times at zero-voltage and at a voltage wave crest point.

3. Results of Typical Type Tests

3.1 Mechanical characteristics test

(1) Dependence of operating time on operating conditions

Figure 1 shows the results of evaluating closing time measured on a 145 kV spring-operated GCB by changing the control voltage and ambient temperature. Two types of closing time were measured. One type of the time ("ratch release time") refers to the time from coil current initiation to ratch release moment and the other type of the time ("contact operating time") refers to the time from the ratch release moment to contact touch moment by means of the operating mechanism. The measurements showed that the ratch release time depends on the control voltage and ambient temperature and that the contact operating time mainly depends on the ambient temperature. The small dependency of the control voltage on the contact operating time is attributed to the fact that the operation of the plunger does not influence the operation of the main contact of the circuit-breaker after the ratch is released. When the dependency of the variations in connection with this

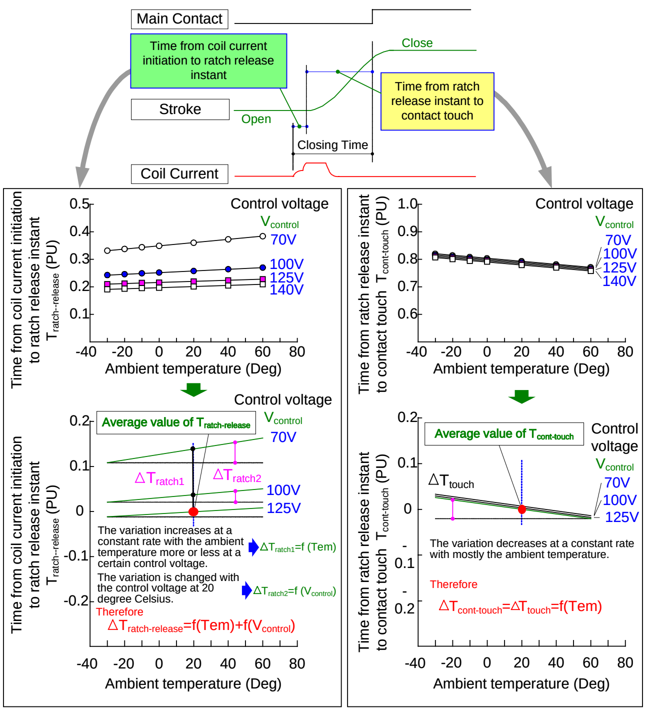

Fig.1 Closing time dependence on the external valuables and possibility of expressing independent functions with a single variable

definite reproducibility of idle-time dependency, by compensating the variation in closing time on the basis of the idle-time dependency.

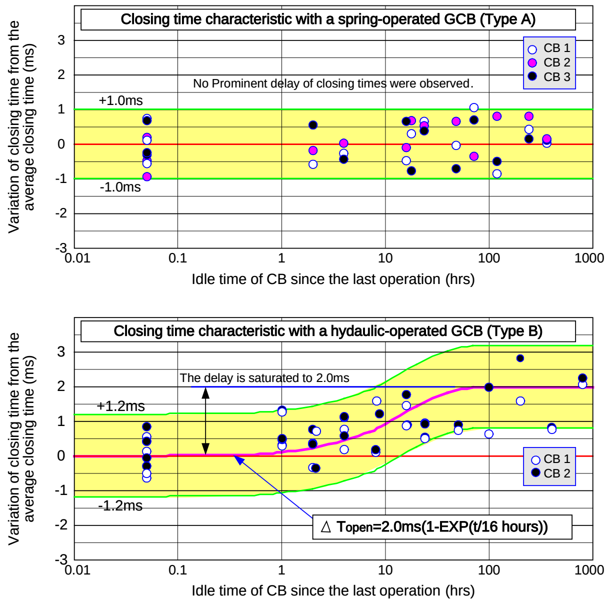

Fig.2 Idle time dependence of the circuit breakers with spring operating mechanisms and a conventional hydraulic operating mechanism

ratch release time on ambient temperature appears to be almost the same with different control voltage levels, the variation in closing time can be approached as the sum of independent functions of ambient temperature and control voltage.

In the case of hydraulic-operated GCBs, the ratch release time depends on the control voltage and ambient temperature, while the contact operating time depends on the operating pressure and ambient temperature. Likewise, when the dependency of the variations in connection with this ratch release time on ambient temperature appears to be almost the same with different control voltage levels and the dependency of the variation in connection with the contact operating time on ambient temperature appears to be the same with different operation pressure levels, the variation in closing time can be approached as the sum of independent functions of ambient temperature, control voltage, and operating pressure.

(2) Dependency of total number of times of operation on operating time

Figure 2 shows the results of measuring the dependency of the closing time of 300 kV hydraulic-operated GCB and 145 kV spring-operated GCB on idling time.[2] With the hydraulic-operated GCB, the air bubbles generated in the low-pressure hydraulic circuit resulted in an operation delay several hours after the beginning of the idle time, and the variation saturated at about 2 ms after 100 hours of idle time. High-accuracy controlled closing is possible with GCBs, which have

On the other hand, with the spring-operated GCB, the variation in closing time depending on the idle time is comparatively limited. Especially, this spring-operated mechanism uses a lubricating chemical coating instead of grease for the lubrication of major sliding parts, which results in outstanding characteristics with almost no operational delay before reaching 1,000 hours of idle time.

Figure 3 shows the results of evaluating the variation in the average closing time obtained by converting the closing time values measured during multiple operating tests to the normal operating conditions. The average closing time varies as the number of operations increases. However, since the variation remains within a certain range of scatter, the accuracy of predicting the operating time can be enhanced by compensating the closing time on the basis of the total number of times of operation in the past.[3]

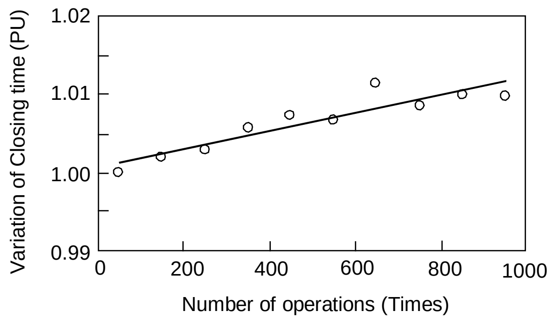

Fig.3 Typical drifts of the closing times measured without adaptive control of controller

3.2 Electrical characteristics test

Figure 4 shows a typical measurement of pre-strike characteristics plotted with a cycle of power frequency. The measurements consist of three series of tests with an EHV GCB in new condition and also following pre-conditioning of three and six opening operations (current interruptions) with the medium arcing time as for T60. The RDDS was obtained by the measurement of the pre-strike voltage and the pre-arcing times for different closing instants (electrical phase angles from 0 to 360 degrees) at the rated voltage.

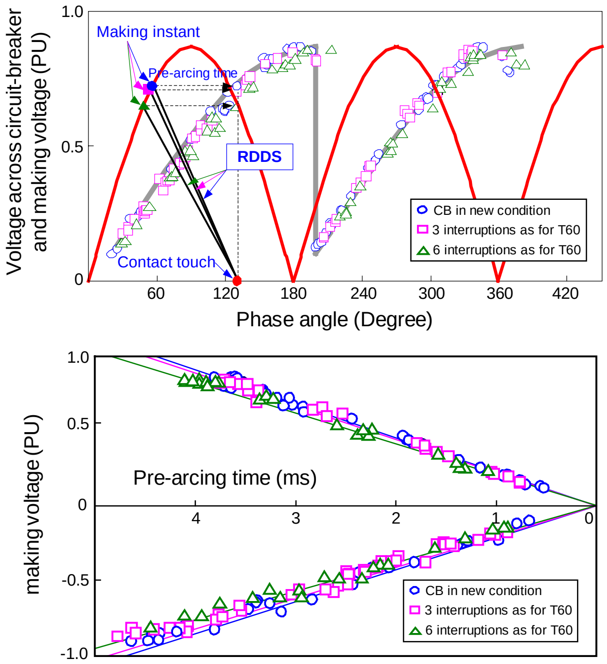

Fig.4 RDDS measurement with EHV GCB

According to the measurement results, the RDDS characteristic after the current equivalent to 60% of the rated breaking current is interrupted six times changes by up to 10% compared to the level of a new circuit-breaker. However, the characteristic after the current equivalent to 60% of the rated breaking current specified in the standard is interrupted three times shows a decrease of about 2%.

3.3 Controlled closing Test

Figure 5 shows the distribution of the closing instants for voltage zero target using 145 kV circuit breaker. The optimum close target for voltage zero are determined using the measured RDDS and the mechanical scatter. The distribution of making voltages was evaluated from the data measured by controller. The results of closing instants show a normal distribution around the target closing instant of 13 electrical degrees for 145 kV with a small standard deviation less than 0.3 ms. The maximum making voltage is 0.35-0.38 PU. The scatter of making voltage can be explained within the voltage deviations corresponding to mechanical scatter within ±1 ms around the target instant.

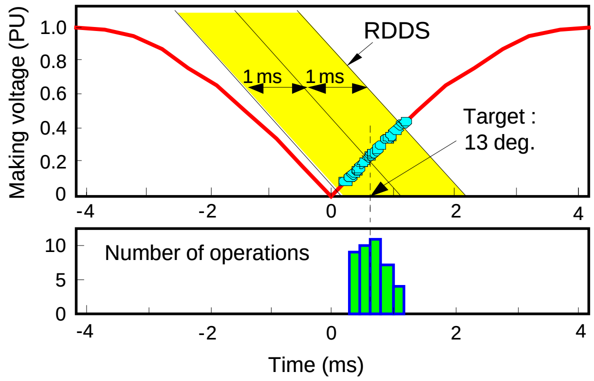

Fig.5 Distribution of making voltages and closing instants

4. Conclusions

Tests on the mechanical characteristics and electrical characteristics of circuit-breakers, which are very important for determining the optimum switching target of controlled switching, were evaluated in accordance with the type test procedures in compliance with IEC62271-302. As a result, the authors have confirmed that the controlled switching systems evaluated in accordance with the standard requirements can perform controlled switching at desired phase angles by the operation compensation function based on the operating characteristic data.

References

(1) CIGRE Working Group 13.07., "Controlled Switching of HVDC circuit breakers", ELECTRA No. 197, August 2001

(2) H. Ito, et al., "Factory and Field Testing of Controlled Switching Systems and Their Service Experience", CIGRE A3-114 (2004)

(3) H. Tsutada, et al., "Development of Synchronous Switching Controller for Gas Circuit Breakers", Trans. IEE of Japan, Vol. 121-B, No. 7, pp. 822-829 (2001)