# Short-Circuit Testing Technologies for High-Voltage Vacuum Circuit-Breakers (VCB)

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**Abstract**

**High voltage circuit breakers include Gas Circuit-Breakers (GCBs) that use Sulfur hexafluoride ($SF_6$) gas and Vacuum Circuit -Breakers (VCBs) that use vacuum. GCBs cover ultra-high voltages up to 1000 kV class and are the mainstream Circuit Breakers (CBs) in power transmission systems.**

**VCBs are widely used, mainly for medium voltages. Dry air insulated VCBs that do not use $SF_6$ gas, a greenhouse gas, have also appeared, which is expected to further expand their application to high voltage power transmission systems.**

**In the evaluation test of high voltage circuit breakers, the test methods described in the standards are mainly intended for GCBs. In some cases, the GCB-based test method may not be possible to deal with phenomena unique to VCBs. Our high power testing laboratory, however, is able to cope because it was specially designed for VCB testing.**

## 1 Preface

In many countries, there are plans to gradually restrict or phase out the use of Circuit Breakers (CBs) that use Sulfur hexafluoride ($SF_6$), a greenhouse gas. Vacuum Circuit-Breakers (VCBs) are expected to be an alternative technology, and the development of VCBs with higher voltages and larger capacities is accelerating.

In this paper, we introduce examples of arc extension tests, synthetic making tests, and the four-parameter method as test technologies for high-voltage VCBs.

## 2 Arc Extension Test

When direct testing is difficult due to the limits of equipment capacity, the breaking performance is verified by a synthetic test. In this event, the breaking performance is verified by a current zero synthetic equivalent test as it is necessary to verify a long arcing time beyond the current zero point. In general, a non-oscillating waveform current is superimposed just before the first current zero point after contact parting of the CB, forcing the current to flow for the next half cycle as well. This method is called arc extension. It is an effective method for verifying Gas Circuit-Breakers (GCBs). In the case of VCBs, the success rate of arc extension[(1)-(3)] is low because the superimposed current is interrupted by the excellent high-frequency current extinguishing ability. Arc extension becomes particularly difficult as the breaking current becomes smaller.

In order to solve these problems, our testing laboratory has proposed an arc extension method[(4)(5)] that superimposes a current that combines an oscillating and non-oscillating waveform.

Fig. 1 shows the arc extension circuit, and Fig. 2 shows the current waveforms flowing through

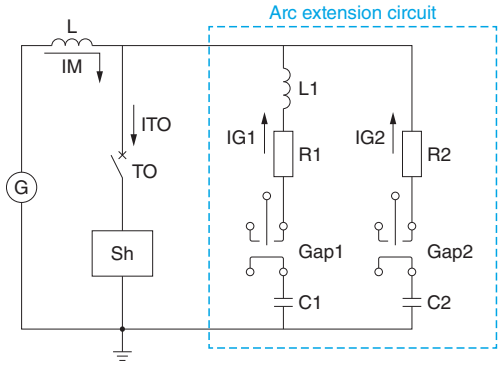


**Fig. 1 Arc Extension Circuit**

A diagram of the arc extension circuit is shown. This circuit is needed for the synthetic test on VCBs.

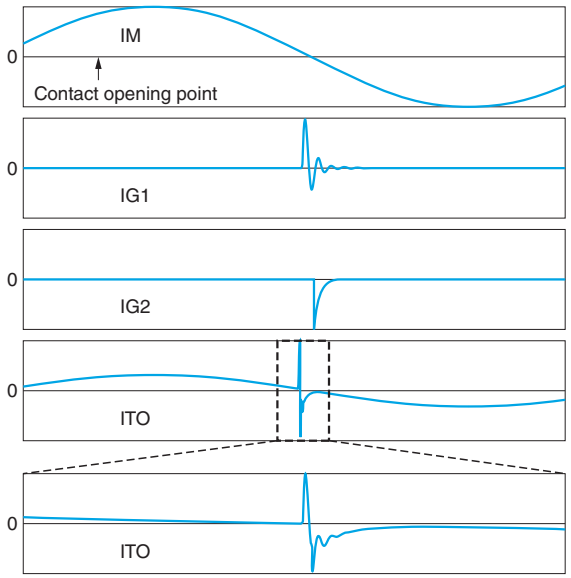


**Fig. 2** Waveforms at Time of Arc Extension

The timing to trigger the current of IG1 and the IG2 to the IM and the resultant phenomenon are shown.

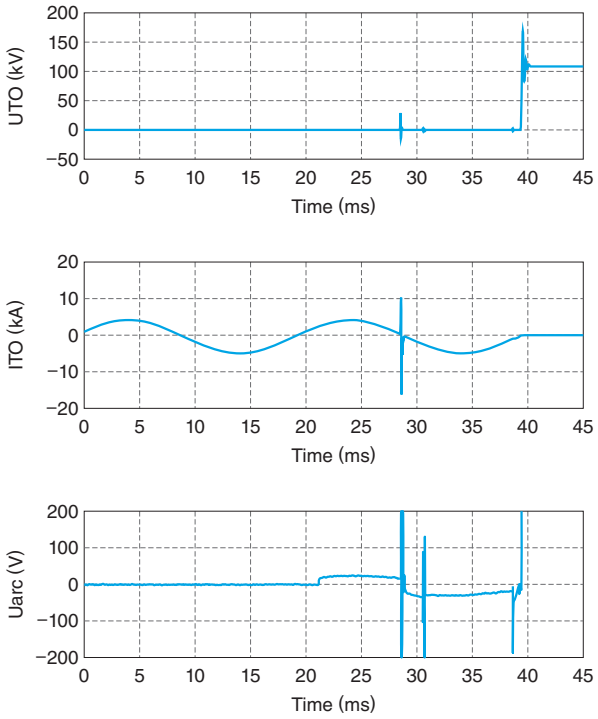


**Fig. 3** Synthetic Test Waveforms of VCB with Arc Extension Applied

The result of the verification of an arc extension time for T10 by a VCB is shown.

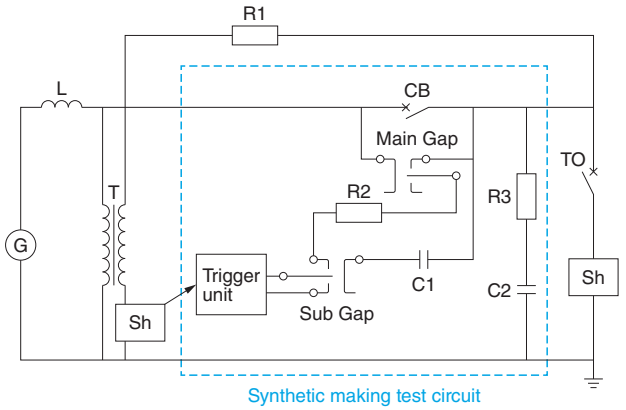


**Fig. 4** Synthetic Making Test Circuit

A diagram of the synthetic making test circuit is shown. This circuit is needed when the synthetic test is carried out for the CB.

each path. First, capacitors C1 and C2 are charged. The main current (IM) is passed from the generator (G) through the reactor (L) to the Test Object (TO). After contact parting of the CB, Gap1 is triggered just before the first current zero point. The LC oscillating current (IG1) is superimposed on the main current. IG1 is a high-frequency current that exceeds the breaking capacity of the VCB, so that the current passes through the zero point without breaking. Next, Gap2 is triggered and the CR non-oscillating current (IG2) is superimposed. The breaking current (ITO), which is the composite of IM, IG1, and IG2, is prevented from reaching the zero point.

The feature of the circuit is that energy is injected in a concentrated manner just before the current zero point. In addition, to increase the success rate of the arc extension, it is necessary to increase the peak value and frequency of the IG1. The circuit is installed close to the TO to minimize the inductance of the path.

Fig. 3 shows the synthetic test waveforms of the VCB with the arc extension applied. This is the result of verifying a long arcing time of 10% (T10) of the rated breaking current using a VCB rated at 84 kV-31.5 kA. The current value at T10 is small, making an arc extension particularly difficult.

For the ITO, it is 3.2 kA. We focused on the arc voltage (Uarc). The first current zero point is reached at an arcing time of 7.3 ms, and the arc is extended and broken in a total of 18.3 ms. For the TO, the arc is extended without being broken in the first half cycle, and the composite test is successful.

## 3 Synthetic Making Test

IEC standards require that the making shall be performed near the peak of the voltage waveform to verify the making current.

Fig. 4 shows a synthetic making test circuit constructed with reference to IEC 62271-101. First,

the C1 is charged. A supply voltage that meets the standard is applied from G to the TO via a Transformer (T) so that closing operation is performed by the TO.A pre-arc occurs before the electrodes physically make contact. When the current is detected by the Sh attached to T, the trigger device is activated. When the sub gap is triggered, the charge of the C1 triggers the main gap through the resistor (R2). This causes a large current to flow from G through L to the TO.

The feature of the circuit is that it is triggered with high energy with a high steepness, causing the main gap to operate at a high speed. Here, in the case of a VCB, the high-frequency current may be interrupted at the moment of pre-arc generation. C2 and R3 are installed to prevent the zero point from passing. Carbon graphite with a high melting point was used for the main gap to allow a large current to flow. To minimize wear, a CB was placed in parallel with the main gap. The current was diverted to the CB after it started to flow.

**Fig. 5** shows the test waveform when the synthetic making test was applied. This is the result of a synthetic making test with a rated breaking current of 31.5 kA using a VCB rated above 84 kV. The UTO was 91.3 kV and the making current ITO was 51.2 kA. The delay time from the occurrence of pre-arcing to the flow of large current was reduced to 100 $\mu$s or less. The TO was able to withstand the pre-arcing and the synthetic making test was successful.

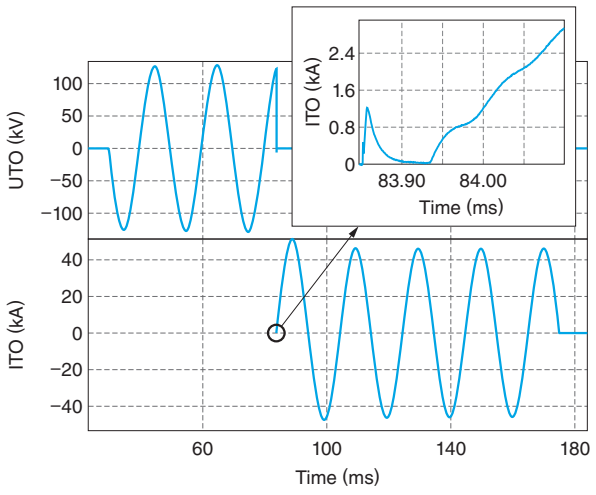


**Fig. 5** Test Waveforms when Synthetic Making Test was Applied

The result of the verification of the pre-arcing effect is shown. This verification is performed when a peak voltage is applied with the use of a VCB.

## 4 4-Parameter Method for TRV

There are two types of TRV application in the interruption test: single-frequency 2-parameter method and multi-frequency 4-parameter method. The standard recommends the 4-parameter method for short-circuit tests of CBs rated over 84 kV. We have traditionally applied the simple 2-parameter method to CBs rated over 84 kV. This is because VCBs have good insulation recovery characteristics, so there is little difference in performance between the 2-parameter method and the 4-parameter method. As the number of opportunities to test CBs rated over 84 kV has increased, however, we decided to introduce the more optimal 4-parameter method.

**Fig. 6** shows the 4-parameter method circuit. First, the C3 is charged. A breaking current that meets the standard is applied from G to the TO. The TO is opened, and the Gap is triggered at any timing. When the TO interrupts the current consisting of L3 and C3, the charge remaining in C3 moves to R1, C1, and L2, C2. The composite waveform at this point becomes a multi-frequency wave, and the four-parameter waveform is completed.

**Fig. 7** shows the TRV waveforms of the test duty T100s when a VCB rated over 84 kV is used as a TO. The test was performed with an appropriate waveform that satisfied the standard value.

In the case of a VCB, the arc voltage is low and close to that of an ideal CB. The inherent TRV of the test circuit and the measured TRV during the interruption test are almost the same. Therefore, we do not use an analyzer or other method. As shown in **Fig. 7**, we performed tests to show that the measured waveform exceeds the standard value.

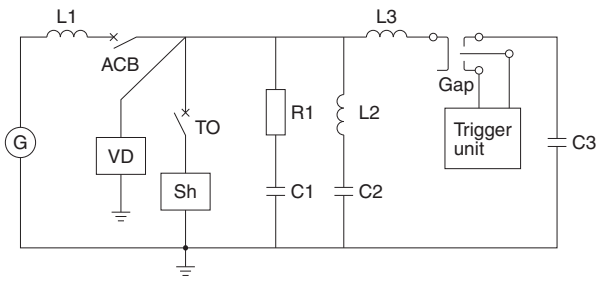


**Fig. 6** 4-Parameter Method Circuit

The voltage source circuit (TRV of 4-parameter method) is shown for the CB synthetic testing, exceeding the rating of 84 kV.

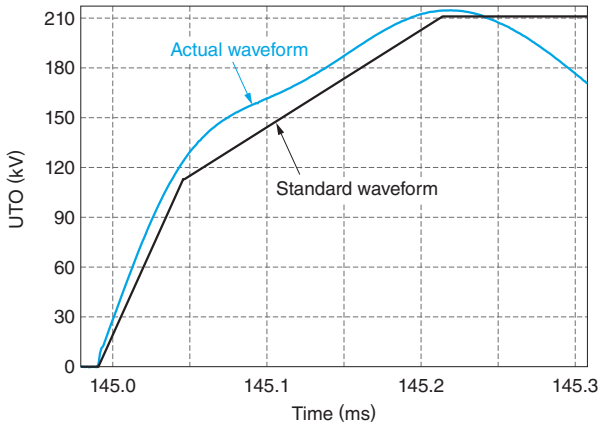


**Fig. 7** **TRV Waveforms where 4-Parameter Method is Applied**

Multiple-frequency TRV waveforms for T100 s by a VCB are shown.

## 5 Postscript

We have introduced examples of arc extension tests, synthetic making tests, and the four-parameter method, test technologies for high-voltage VCBs.

Expectations for VCBs are rising because the VCBs do not use $SF_6$ gas. As we develop high-voltage and large-capacity VCBs in the future, we will face an unexperienced level of technical challenges. It is important to simultaneously improve and develop interruption test processes and technologies.

・All product and company names mentioned in this paper are the trademarks and/or service marks of their respective owners.

**《References》**

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