Development of 145 kV Dry Air Insulated Dead Tank Vacuum Circuit-Breaker (VCB)

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Keywords Vacuum Circuit-Breaker (VCB), Vacuum Interrupter (VI), SF_6 Gas Circuit-Breaker (GCB), Global Warming Potential (GWP), Greenhouse Gases (GHG), Dry air insulation technology

Abstract

The purpose of this paper is to provide an overview on the development of World's first Vacuum Circuit-Breaker (VCB) for applications to transmission voltage of 145 kV. This design offers outstanding environmental characteristics because it performs current switching with vacuum interrupter and uses dry air for main-circuit insulation.

Elimination of the SF_6 (a greenhouse gas) has an environmental impact and its awarness has been increasing after Kyoto Protocol as one of six greenhouse gases, since 1997. Also, the US power utilities are closely following the regulations by California Air Resource Board (CARB) and Enviromental Protection Agency (EPA) to reduce to zero.

This VCB design is an important step forward to reach that goal. Meiden conducted and completed the required type tests required by the American National Standards Institute (ANSI), the International Electrotechnical Commission (IEC), and the Japanese Electrotechnical Committee (JEC). All test results were satisfactory.

1 Preface

Following the restrictions and regulations of environmental agencies for elimination of SF_6 gas with GWP of 25,200, Meiden developed a dry air insulated dead tank type Vacuum Circuit-Breaker (VCB) as a 72 kV class circuit breaker using dry air as insulating medium and vacuum interrupters for current switching. Since 2004, the reliability data shows an excellent performance of more than 2500 units in the field, worldwide.

Based on the same design principles of using Vacuum Interrupter (VI) for current switching and dry air as insulating medium there are released a variety of dry air insulated products in the past of 20 years, such as Cubicle type Gas Insulated Switchgears (C-GIS). This paper introduces the features of the 145 kV dry-air insulated VCB for the North American Market.

2 Ratings

Fig. 1 shows the world's first 145 kV VCB delivered to the customer, Table 1 shows the ratings of the 145 kV dry air insulated dead tank VCB, and Fig. 2 shows its construction.

Fig. 1 World's First 145 kV VCB Delivered to Customer

World's first 145 kV VCB delivered to customer is shown.

Table 1 Ratings of 145 kV Dry Air Insulated Dead Tank VCB

Ratings of this equipment are shown.

Items		Specifications
Rated voltage		145 kV
Rated continuous current		3150 A
Rated short-time withstand current		40 kA-3 s
Rated short-duration power-frequency withstand voltage		275 kV
Rated lightning impulse withstand voltage	Full Wave	T1/T2 = 1.2 μs/50 μs 650 kV
	Chopped Wave	T1/Tc = 1.2 μs/2.0 μs 838 kV
Rated gas pressure	High pressure chamber	0.9 MPa·G
	Low pressure chamber	0.16 MPa·G (including VI bellows)
Applicable standards		IEC 62271-100 IEEE/ANSI C37.09 JEC-2300

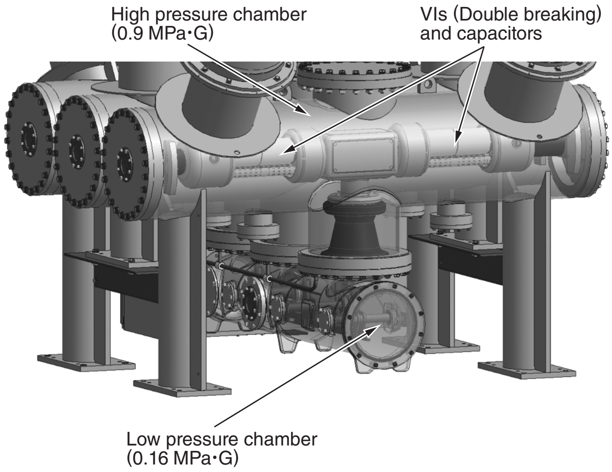


Fig. 2 Model Design of 145 kV VCB with Dual Pressure Systems

The model design of 145 kV VCB with dual pressure systems is shown.

3 Features

3.1 Application of High Pressure Resistant Vacuum Interrupter (VI)

Due to the dielectric withstand requirement the tanks have high-pressure dry air of 0.9 MPa-g, and VIs are required to withstand pressure difference. For this reason, the VIs need reinforcement of end flange. In addition, the bellows of the VIs are under separate low pressure at 0.16 MPa-g to prevent the bellows from being damaged by the pressure difference. Fig. 3 shows a dual pressure type structure of the VI.

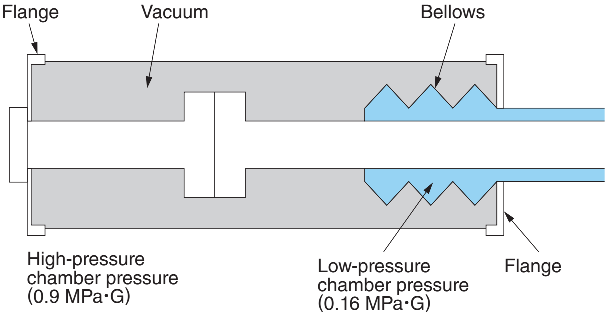


Fig. 3 Dual Pressure Type Structure of VI

The vacuum in the VI is hermetically sealed by bellows, which allocate the vacuum from the dry air of the low pressure chamber (0.16 MPa·G) for protection and to avoid that the dry air of high pressure chamber is not exerted directly to the bellows.

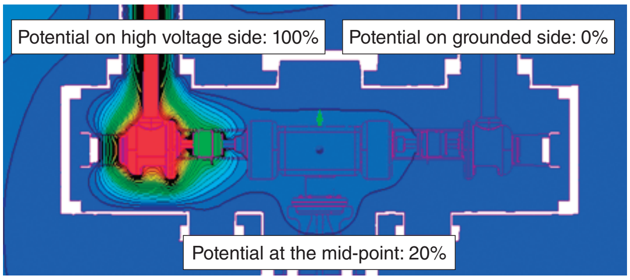
3.2 Dry Air Insulation under High Pressure

The electric field of insulation breakdown under high pressure of dry air tends to be saturated and it is easily affected by the surface roughness of the conductor. Such conductor surface leads to a dielectric breakdown. In this design, we acquired information about the insulation breakdown characteristics by conducting a basic experiment under high pressure. The obtained data was adopted for the design of the insulating parts of the assemblies and the interrupter reliability was assured.

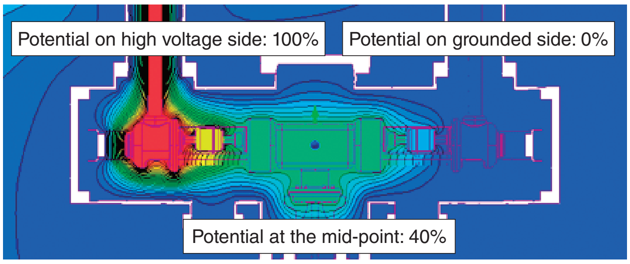
3.3 Double-Break VI System

To satisfy the IEEE standard requirement of Chopped Wave Withstand Voltage the interrupter is designed as double-break VI of 72.5 kV system, connected in series. This double-breaks interrupter is assembled in a grounded dead tank type VCB. Due to such configuration we needed to secure the equal distribution of the Transient Recovery Voltage (TRV) during the switching. The unbalanced voltage between of two VIs could be mitigated by implementating of grading capacitors connected in parallel with VIs.

The capacitance value of grading capacitors is determined by using the simulations of the 3D Finite Element Method (FEM). Fig. 4 shows a potential distribution in two cases: with or without grading capacitors. Since the 3D FEM makes it possible to take complicated shapes into consideration, an optimal capacitance could be defined at the designing process.



(a) Without capacitor



(b) With capacitor

Fig. 4 **Example of Potential Distribution with or without Grading Capacitors**

The grading capacitor improves the voltage distribution between the two VIs. The capacitance value is determined by using potential analysis FEM.

Table 2 **Major Type Test Items**

Major type test items for the 145 kV VCB are shown.

Type test items	Contents of testing
Short-circuit current breaking test	Terminal fault current breaking test, Short line fault test, Out-of-phase making and breaking test, Capacitive current switching test, Double-earth fault test, Transformer-limited fault test
Short-time current withstand test	Current 40 kA for 3 s, Peak current 104 kA
Lightning impulse withstand voltage test	Full Wave ± 650 kV Chopped Wave ± 838 kV
Continuous current test	Contact part 65 K or below for 3150 A carrying Connection part 75 K or below
Power-frequency withstand voltage test	AC275 kV-1 min
Low temperature test	Operation check under −50℃ environment
Mechanical endurance test	Switching operations for 10,000 times

4 Verification Test

A series of type tests such as mechanical endurance test, dielectric withstand voltage tests, and a short-circuit current breaking tests, were carried out for this VCB in accordance with the respective standards of ANSI, IEC, and JEC. All requirements passed. Table 2 shows major type test items.

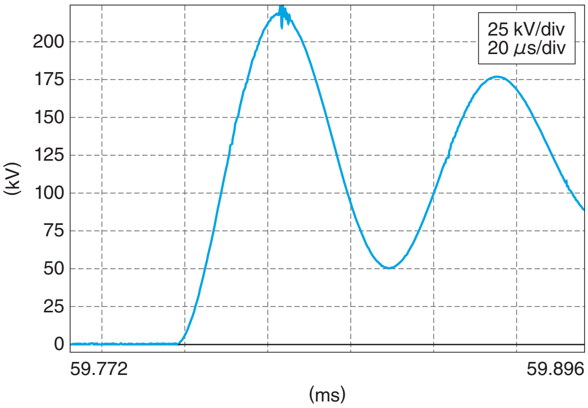


Fig. 5 **Waveform of Transient Recovery Voltage Observed during Transformer-Limited Fault Tests**

The waveform of TRV is observed during transformer-limited fault tests. The waveform verifies that the circuit breaker withstood the Fast TRV, which is typical for this test duty. This test was conducted as a half breaker test with a single VI unit.

4.1 Short Circuit Current Interruption Tests

The most important duties for a circuit breaker are the fault current interruption in the event of a failure occurring in a power system. This VCB has undergone the short-circuit current interruption tests stipulated by the relevant standard and satisfied the requirement of each current braking test duties. Due to the high rate of the transient recovery voltage specified by the ANSI Standard, this VCB underwent a series of most rigorous transformer-limited fault tests for circuit breakers and satisfied the requirements. Fig. 5 shows a waveform of a transient recovery voltage observed during transformer-limited fault tests and Fig. 6 shows a view of the prototype VCB conducting a short-circuit current interruption test.

4.2 Short-Time Current Withstand Test

This test was carried out under the conditions of a current at 40 kA for 3 seconds and a peak current at 104 kA. At all contacts and connection, no arcing and fusion could be perceived and there was no change in the resistance value of the main circuit before or after the testing. These results confirmed that a good breaking performance was maintained.

4.3 Dielectric Withstand Voltage Test

To examine the duty of 145 kV class circuit breakers, the rated short duration power frequency withstand voltage test was carried out at 275 kV. The lightning impulse full-wave withstand voltage

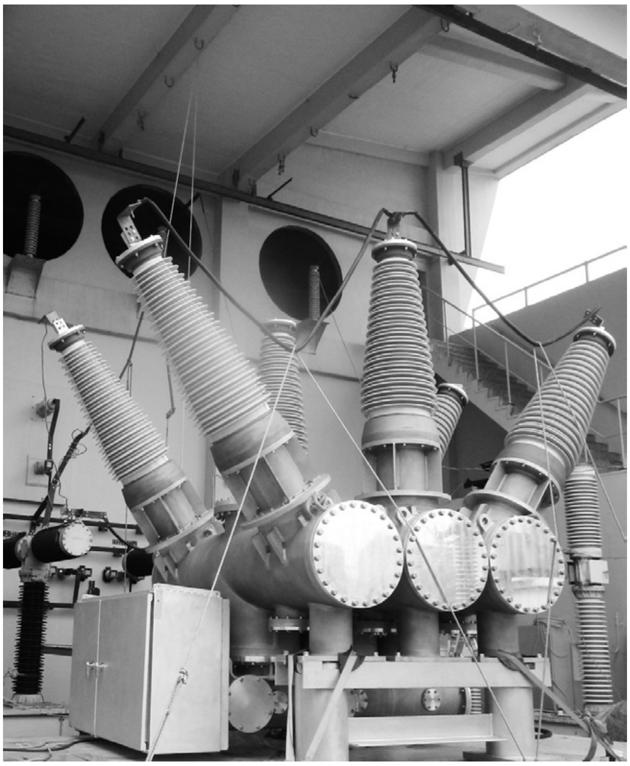


Fig. 6 View of Prototype VCB Conducting Short-Circuit Current Interruption Test

A view of a short-circuit current interruption test exerted on the circuit breaker is shown.

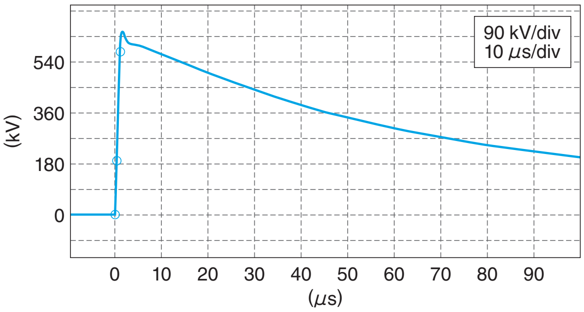


Fig. 7 Lightning Impulse Waveform at 650 kV

The lightning impulse withstand voltage test was carried out to verify that the circuit breaker withstands 650 kV specified by the relevant standard.

test was also conducted at 650 kV and the results confirmed that that the insulation requirement was satisfied. Fig. 7 shows a lightning impulse waveform at 650 kV. In the case of the chopped wave lightning impulse withstand voltage test performed under the conditions of a rising time of 1.2 μs, a crest height value of 838 kV, and a chopping time of 2 μs, favorable result was also obtained. Fig. 8 shows a impulse waveform of 838 kV chopped wave impulse voltage.

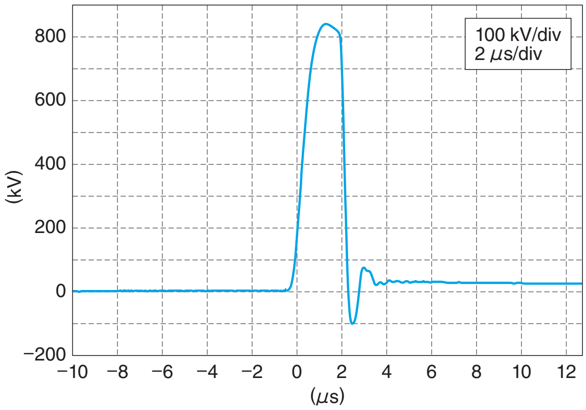


Fig. 8 Impulse Waveform of 838 kV Chopped Wave Impulse Voltage

The chopped wave impulse withstand voltage test stipulated by the ANSI Standard was carried out. It was verified that the VCB withstands exposure to 838 kV.

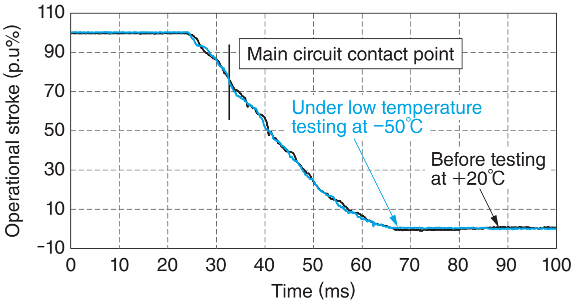


Fig. 9 Comparison of Switching Characteristics at Low Temperature Tests

The low temperature test was carried out and it was verified that the switching characteristics were kept equivalent to the testing conditions of both a regular temperature of +20℃ and a low temperature of −50℃.

4.4 Temperature Rise Test

Temperature rise tests were carried out at the rated current of 3150 A conforming to the relevant IEC Standard and 3000 A to the ANSI Standard. For the respective standards, the required temperature rise limits were satisfied. There was no change in the main-circuit resistance before or after the testing and we confirmed sufficient current carrying performance.

4.5 Low Temperature Test

Low temperature tests were carried out under the environment at −50℃. Even at −50℃, operating speed differences were minimal, and it was confirmed that the contact closing and opening speeds needed for short-circuit current interruption are assured. Fig. 9 shows comparison of switching characteristics at low temperature tests.

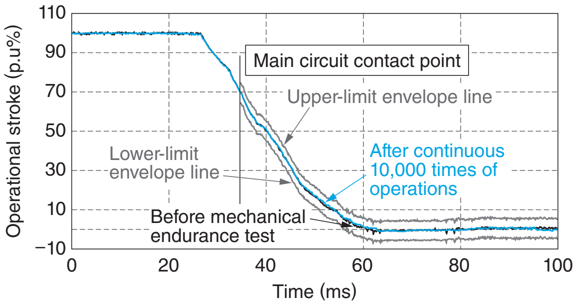


Fig. 10 145 kV VCB in Mechanical Endurance Tests

The mechanical endurance test was carried out at 10,000 times of operations. There was no difference between the before or after.

4.6 Mechanical Endurance Test

This VCB features the capability of multiple switching operations, which is an advantage for the VCB. The test object carried out the 10,000 times mechanical endurance test. Such a testing corresponds to the reliability class M2 according to IEC 62271-100:2017 and ANSI C37.09 for HV circuit breaker. There was no abrasion around the sliding part section and excellent conditions remained. In addition, since the VI did not leak, we confirmed that VI has sufficient tightness at high pressure. **Fig. 10** shows the 145 kV VCB in the mechanical endurance tests. Thus, there was no difference between the results before or after the test. We confirmed that it satisfied all mechanical endurance requirements.

5 Postscript

This paper introduced the 145 kV dry air insulated dead tank VCB newly commercialized for the North American Market. This VCB is a landmark product that contributes considerably to the prevention of climate change and a reduction of its environmental footprint. We responded to rising concerns of environmental issues worldwide.

Succeeding in our current endeavors, we will continue to develop products that utilize our dry air insulation technology to realize a more sustainable society.

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