240 kV Tank-Type Vacuum Circuit Breaker (VCB)

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Abstract

Vacuum circuit breakers (VCBs) do not use sulfur hexafluoride (SF_6) gas as an arc extinguishing medium for current interruption. Because the arc generated during current interruption is extinguished in a vacuum, no decomposition gases are produced. Furthermore, the arc energy generated during current interruption is small, resulting in less electrode wear, making them suitable for frequent interruptions. Due to these features, their application to high-voltage circuit breakers is progressing.

Based on the above background, our company has developed a 240 kV tank-type VCB. To achieve 240 kV insulation and interruption performance, this product employs a double-break series vacuum interrupter (VI) system. In addition, to achieve 2-cycle breaking, the tripping mechanism of the actuator has been made faster. While this would normally require an increase in control power capacity, by equipping the circuit breaker's control circuit with a current compensation device (capacitor power supply), the 240 kV tank-type VCB eliminates the need to increase the control power capacity.

1 Preface

Our company has been producing vacuum circuit breakers (VCBs) using vacuum technology since the 1960s, accumulating a large number of supply records at home and abroad. VCBs contribute significantly to reducing life cycle costs due to their ease of maintenance and the absence of decomposition gas generation during interruption. To expand the application range of VCBs, our company has been a pioneer in increasing the voltage of VCBs. In recent years, in 2013, we commercialized the world's first 168/204 kV tank-type VCB[(1)].

As the tank-type gas circuit breakers (GCBs) we supplied to 240 kV railway substations reached the end of their lifespan, we developed a 240 kV tank-type VCB based on the technology cultivated with the previously developed 168/204 kV tank-type VCB, which significantly reduces sulfur hexafluoride (SF_6) gas, a greenhouse gas, compared to GCBs. This paper introduces its structure and features.

2 Structure and Features

Table 1 shows the specifications of the 240 kV tank-type VCB, and Fig. 1 shows the internal structure.

2.1 Adoption of a Dual Pressure Type

To ensure 240 kV ground-to-ground insulation performance, it is necessary to increase the sealing pressure of the SF_6 gas, which is the insulating medium. However, with a vacuum interrupter (VI), increasing the pressure in the bellows section increases the VI's self-closing force, thus increasing the operating energy required for interruption. Furthermore, a special external-pressure type bellows that can withstand even higher pressures must be used.

To solve these problems, this device employs a dual pressure type that separates the gas sections of the live section and the bellows section. This reduces the pressure difference in the VI bellows section, allowing the use of general-purpose bellows and preventing an increase in operating energy by reducing the self-closing force. Fig. 2 shows a comparison of VIs using general-purpose bellows and external-pressure bellows.

2.2 Double-break Series VI System

To ensure inter-electrode insulation and inter-

Table 1 240 kV Tank Type VCB Unit Specifications

The main specifications of the 240 kV tank type VCB unit are shown.

Item	Specifications
Model	Vacuum circuit breakers (VCB)
Insulation medium	SF_6 gas
Interruption method	VI inline 2-point cut, there is a shared capacitor
Rated voltage	240 kV
Lightning impulse withstand voltage	900 kV, peak
Power frequency withstand voltage	395 kV
Rated frequency	50/60 Hz
Rated current	2000 A
Rated short-time withstand current	31.5 kA-2 s
Rated interruption time	2-cycle
Rated control voltage	DC100 V
Rated car operation voltage	DC100 V
Car operation method	Electric power charger・spring input・spring cutoff
Rated gas pressure	High pressure chamber: 0.4 MPa･G Low pressure chamber: 0.16 MPa･G (at 20℃)
Elevations	1000 m or less
Ambient temperature	−20～40℃
Installation environment	Outdoors
Applicable standard	JEC2300 (2020) JRCS301-1I-EG15E, JEAG-5003

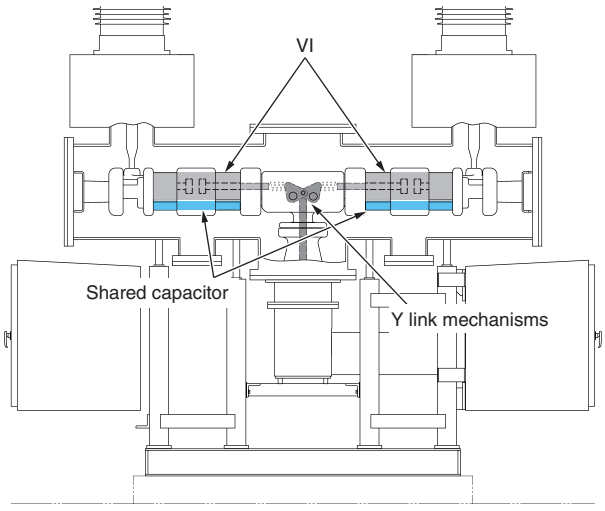
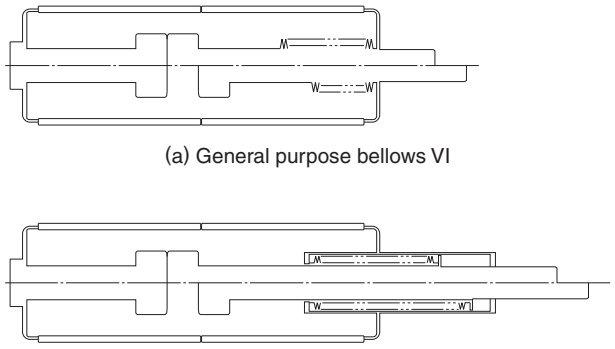


Fig. 1 Internal Structure

The internal structure of a 240 kV tank type VCB unit is shown. VIs are arranged on the left and right, and each VI is provided with grading capacitors in parallel. There is a Y-shaped link mechanisms between VIs, and the VI contact is opened or closed and closed by raising and lowering the insulation rod.

ruption performance at 240 kV, a double-break series VI system was adopted, where each one of

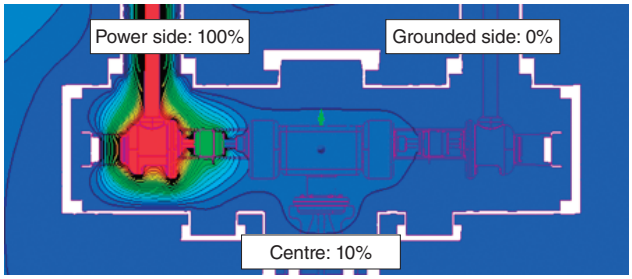


(a) General purpose bellows VI

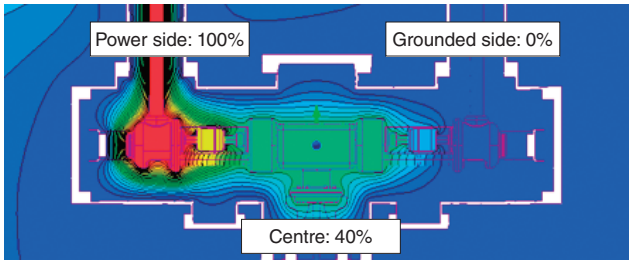
(b) External pressure bellows VI

Fig. 2 VI Comparison Using General Purpose Bellows and External Pressure Bellows

VI employing general bellows for (a) and VI adopting external pressure bellows for (b) are shown. By adopting general purpose bellows, not only can autism be reduced, but VI can also be designed to be compact.



(a) No grading capacitors



(b) There is a grading capacitors

Fig. 3 Grading Capacitors Electric Field Analysis Results

The voltage sharing ratio is improved by installing a grading capacitors.

high-voltage vacuum interrupters (VIs) is positioned on the left and right sides (two (2) points) in series. In tank-type VCB with a double-break series VI system, the tank is grounded, which reduces insulation and interruption performance due to the uneven voltage distribution at the power supply side interruption point.

To solve this problem, a voltage-sharing capacitor was placed in parallel with each of the above-mentioned VIs. Fig. 3 shows the results of the voltage-sharing capacitor field analysis. It can

be seen that the voltage distribution improved from 9:1 to 6:4 by installing the capacitor.

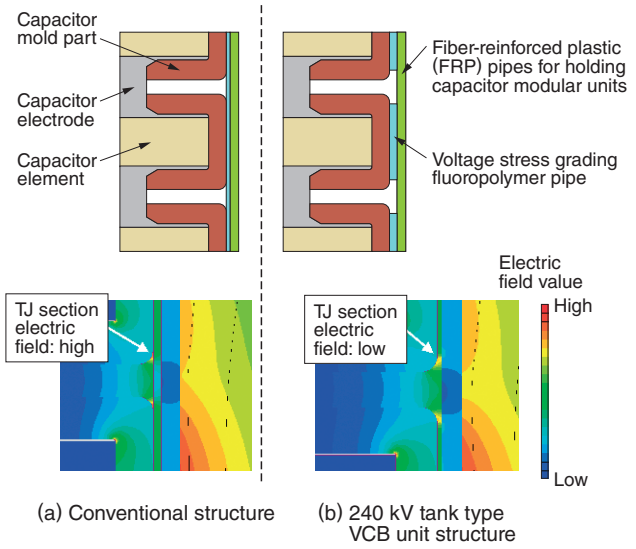


Fig. 4 **Capacitor Modular Units Electric Field Analysis Results**

By providing a fluorine resin pipe on the outer periphery surface of the capacitor resin, the electric field value of the TJ part was reduced.

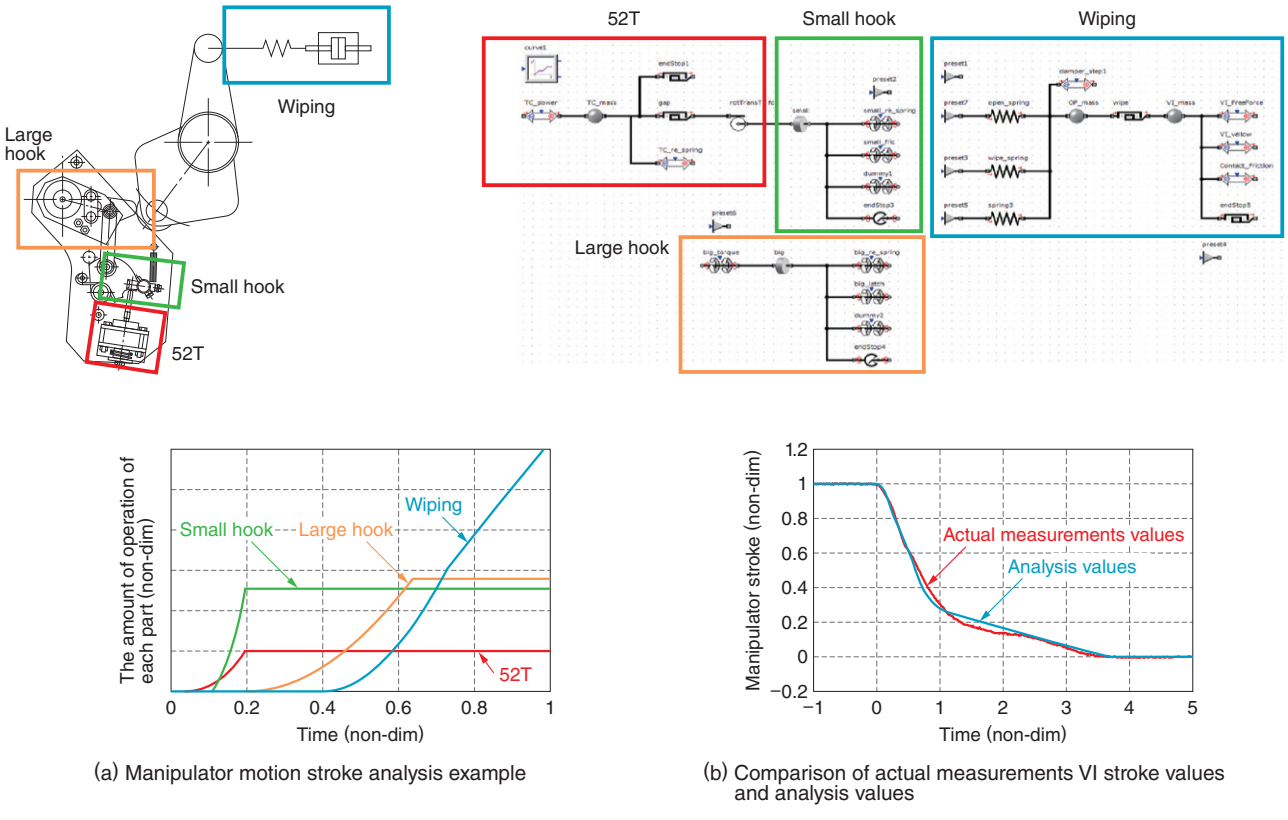
2.3 Capacitor Unit Field Mitigation Structure

The aforementioned voltage-sharing capacitor is a method also used in 168/204 kV tank-type VCBs, but the 240 kV tank-type VCB has a higher voltage applied than conventional systems. Therefore, a higher electric field is generated in the capacitor unit section than in conventional systems, and partial discharge occurred in the triple junction (TJ) section.

To solve this problem, a fluororesin pipe was provided on the outer surface of the capacitor element to lower the field value at the TJ section and prevent partial discharge. Fig. 4 shows the electric field analysis results for the capacitor section.

2.4 High-Speed Tripping Mechanism

The tripping time of a circuit breaker with a rated voltage of 240 kV is specified as 2-cycle in the JEC-2300 standard. To achieve this, the mechanism was modeled and a one-dimensional simulation-based mechanism analysis was performed. Fig. 5 shows an example of the mechanism analysis. Spring characteristics, load, lever ratio, mass, etc., were simulated using physical element models, and the operating characteristics of the mechanism



(a) Manipulator motion stroke analysis example

(b) Comparison of actual measurements VI stroke values and analysis values

Fig. 5 **Mechanisms Analysis Examples**

An example of Mechanisms analysis is shown. We obtained almost the same characteristic results as the analysis results and the actual machine characteristic.

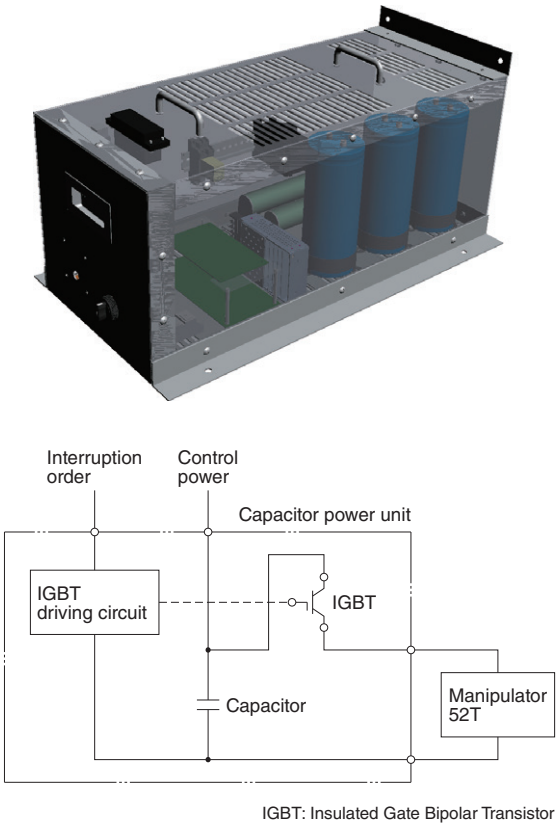


Fig. 6 **Capacitor Power Unit Device External Appearance and Schematic Diagram**

The capacitor is charged from a control power source during standby. When a interruption command is received and the IGBT driving circuit operates, the IGBT is turned on, removed from the capacitor, and current is supplied to the coils.

were examined using each element as a parameter. The tripping time is the time from when the tripping command is received, the tripping coil (52T) operates, the latch of the small hook is released, followed by the engagement of the large hook being disengaged, the pressure spring is released, and the VI contacts open, interrupting the current. The time it takes for the internal contact to open and interrupt the current is determined by VI, so we investigated ways to shorten the time from operation until the contact opens (opening time). To shorten the time required for the pressure spring to release, we minimized the spring's compression (wipe). However, reducing the wipe lowers the interruption speed and makes it impossible to maintain interruption performance. We set a balance between the pressure force and wipe to achieve the shortest possible operating time while maintaining the required opening speed. Furthermore, to speed up the operation of the large hook, we increased the operating torque of the large hook. However, this increases the latch load of the small hook and the time until the latch is released. To reduce the latch load and shorten the operating time, we adopted a lightweight and responsive latch mechanism. In this way, we improved responsiveness by balancing these conflicting elements.

Furthermore, to shorten the time from when the 52T receives a command until the small hook latch is released, the coil characteristics were determined based on the coil turn count, the mass of the movable part, and the coil dimensions, using a two-dimensional magnetic field transient analysis of the parameters.

2.5 Current Compensation Unit (Capacitor-based Power Supply)

With the increased speed of the 52T, a control current of 100 A is required in three phases. Therefore, in existing upgrade projects, additional work such as power supply re-selection and control cable reinforcement is necessary.

To solve this, a capacitor-based power supply was installed in the control circuit inside the circuit breaker. By charging the capacitor from the control power supply in standby mode and supplying current from the capacitor power supply during tripping operation, the need to increase the capacity of the control power supply was eliminated. **Fig. 6** shows the appearance and schematic diagram of the capacitor-based power supply unit.

3 Postscript

A 240 kV tank-type VCB with 2-cycle breaking capability, the world's highest voltage, was developed.

We intend to utilize the one-dimensional structural analysis and switching characteristic analysis methods cultivated in this 2-cycle breaking technology development in future VCB development.

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

《**Reference**》

(1) Kiyohito Katsumata, Mitsuyasu Shiozaki, and Kazuhiro Nagatake: "Commercialization of 120-204 kV Tank-Type Vacuum Circuit Breakers (VCBs)", Meiden Jiho No.340, 2013/No.3, pp.44-47