Recent Technical Trends of Vacuum Circuit-Breakers (VCBs)

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Abstract

Since the early era of the wider acceptance of Vacuum Circuit-Breakers (VCBs) in the 1960s, we have consistently continued its own development of VCBs as a core product of current breaking technologies. In the 1970s, we were one of the earliest companies to realize higher system voltages for the VCBs. We successfully produced an 84kV single-break VCB and a 168kV double-break VCB. Following the advent of new electrode materials (Cu-Cr type) and the development of the axial magnetic field electrodes with outstanding current breaking capabilities in the 1980s and the adoption of ceramic insulating envelopes in the latter half of the 1990s, we achieved the compact design of Vacuum Interrupters (VIs) and increased VI capacities. After that, we successfully realized the reduction of overall VCB unit size. In 2000 and thereafter, we have made efforts to manufacture eco-friendly switchgears without using SF_6 gas, which is a greenhouse gas. We also intend to develop our own technologies and products meeting the requirements of our customers, such as the reduction of life cycle cost.

1 Preface

The Vacuum Circuit-Breaker (VCB) has some unique features such as compactness, low operating force, easy maintenance, and the capability of multiple switching operations. It is therefore, widely used in power grids where VCBs are mainly adopted. In addition to the aforementioned features, the VCB application range has recently been extended because this product does not use any greenhouse gas such as SF_6 and higher system voltages and larger capacities are available. Recent technical trends for VCBs reveal four features itemized below (**Fig. 1**):

(1) Extension of VCB voltages and capacities (up to 204kV class)
(2) Creation of eco-friendly circuit breakers (freedom from SF_6 gas)
(3) Trends to reduce Life Cycle Costs (LCCs)
(4) New application of VCB features

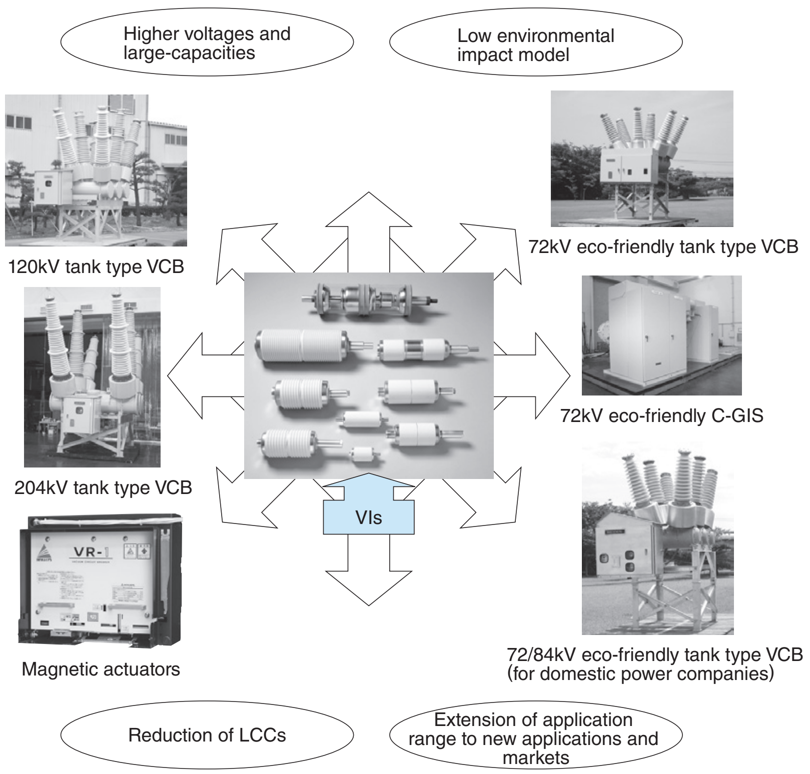

Fig. 1 Recent VCB Technologies and Trends of Products

The application range of VCBs is extending because of their features of high-voltage VIs, advanced compact-design technology, low environmental impact, and reduction of LCCs.

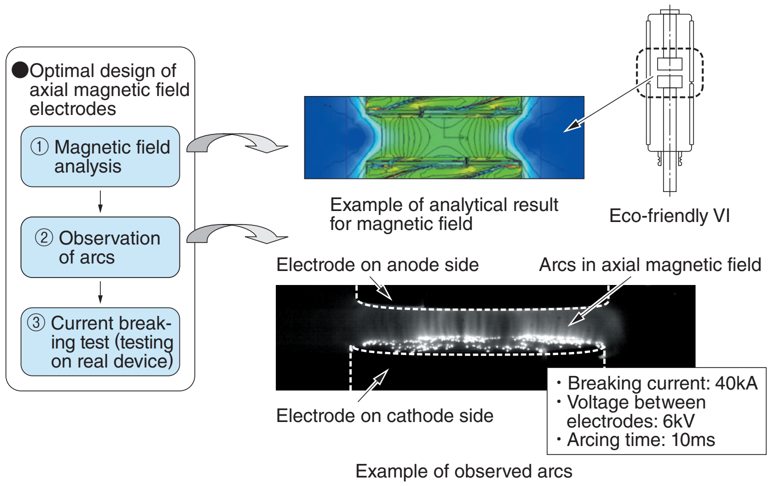

Fig. 2 Example of Magnetic Field Analysis for Axial Magnetic Field Electrodes and Observed Arcs

Thanks to advanced analytical and observing techniques, a large capacity and compact design were realized.

and extension of application range for the market

This paper outlines the aforementioned four features and introduces technical trends in the future.

2 Technical Trends of VCB

2.1 Technical Trends for Higher Voltages and Larger Capacities

2.1.1 Expansion of Current Breaking Capacities

The expansion of current breaking capacities was realized as a result of the progress of electrode materials and development of axial magnetic field electrodes. At the time of current interruption, the axial magnetic field electrode offers a feature in which the generated arcs are uniformly spread over the electrode surface. Compared with the radial magnetic field electrode where electromagnetic force is used to rotate arcs to interrupt, arc-breaking energy is therefore extremely small. The axial magnetic field electrode is suitable for multiple occurrences of current breaking. Fig. 2 shows the analytical result of a magnetic field for the axial magnetic field electrode and an example of the behavior of the observed arcs. Recently, there has been remarkable progress of technologies in regard to 3-dimensional electromagnetic field strength analysis and high-speed video. These techniques are very useful for grasping a relationship between vertical magnetic field intensity and the behavior of arcs. Based on such a progress of analytical and observing technologies, the interrupting part has been greatly improved for downsizing and expansion of capacities.

2.1.2 Expansion of Current-Carrying Capacities

Since the inside of the interrupter is kept under the vacuum, internal heat dissipation is based mainly on heat conduction. Compared with a Gas Circuit-Breaker (GCB), it is difficult to expect the effect of heat dissipation due to convection heat loss. It was therefore believed disadvantageous for the VCB to increase current-carrying capacities. Recently, however, there is a new method of VI construction where heat is dissipated via conductors neighboring the interrupting part and an aluminum tank where the tank itself does not generate any eddy current losses. As a result, the 72/84kV tank type VCBs became applicable to a 36kV class Cubicle type Gas-Insulated Switchgear (C-GIS) for currents up to 3000A.

2.1.3 Acquisition of Higher System Voltages

In order to improve withstand-voltage performance, it is important to grasp some physical properties of electrode materials such as Cu-Cr alloy used in the vacuum valve and a shielding material like stainless steel by observing their behavior of insulation breakdown in a high electrical field under the vacuum. It is also important to investigate phenomena of electrostatic charges in the ceramic insulating envelope in a high electrical field. According to recent research, a great progress can be recognized in this field[(1)(2)]. Since the mechanism of insulation breakdown under vacuum is different from that of insulation medium located in gases, it is necessary to optimize the effect of conditioning for the metallic material used, in addition to having consideration for electrical field distribution. The effect of conditioning is a characteristic of insulation breakdown under vacuum such that the breakdown voltage is raised by repeating discharges. This characteristic depends on types of metallic materials and electrical field distribution. Fig. 3 shows a potential distribution observed inside the 72kV class interrupter. Characteristics of conditioning are effectively utilized and an optimal combination of materials and shapes is adopted. By taking this approach, improvement of withstand-voltage performance and downsizing have been attained.

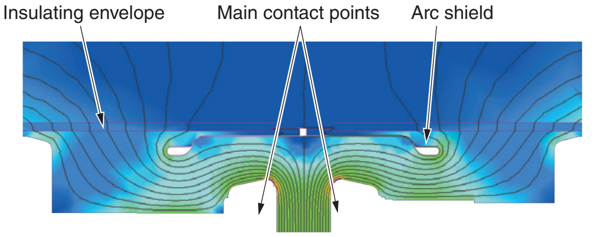

Fig. 3 Example of Electrical Field Analysis on Interrupting Part (Electric Potential Distribution)

This analysis is intended for the optimal design of main contact points in each interrupting part, electrical field around arc shields, and electrode materials to be used.

2.2 Manufacturing Techniques for Eco-Friendly Switchgear

2.2.1 Background of Development and Trends

Since SF_6 gas was designated as a greenhouse gas, the use of SF_6 gas has been strictly controlled and the introduction of a gas reduction goal has been promoted. As a result, development of equipment free from SF_6 gas has been greatly anticipated. Against such a technical background, VCB has been adopted for the current interrupting part after 2000 and we have developed an eco-friendly VCB switchgear where inner insulation gas is replaced by an SF_6 substitutive gas like air. Since insulation performance of air is inferior to that of SF_6 gas, inner gas pressure is raised; in addition, a specific approach is adopted in order to use a synthetic insulation that is a combination of solid insulation materials. In 2000, we developed the 24kV C-GIS and in 2003, 72/84kV single-unit VCB(3) was developed. In 2009, the 72kV C-GIS with a low gas pressure was developed(4). In either case, dry air is used as an insulation gas.

2.2.2 Composite Insulation System

Since the VCB uses no SF_6 gas for current interruption, it becomes a circuit breaker completely free from SF_6 gas if dry air is used as an insulation gas. However, insulation performance of dry air is about 1/3 that of SF_6 gas if the same pressure is maintained. Therefore, in order to keep the same equipment size as conventional equipment, the internal gas pressure is usually raised. If insulation performance is still insufficient, highly electrified parts on the conductor surface are generally treated by an insulation coating or covered. This technique is of a composite insulation to be established with the use of solid insulation materials producing high insulation performance. **Fig. 4** shows an image of composite insulation.

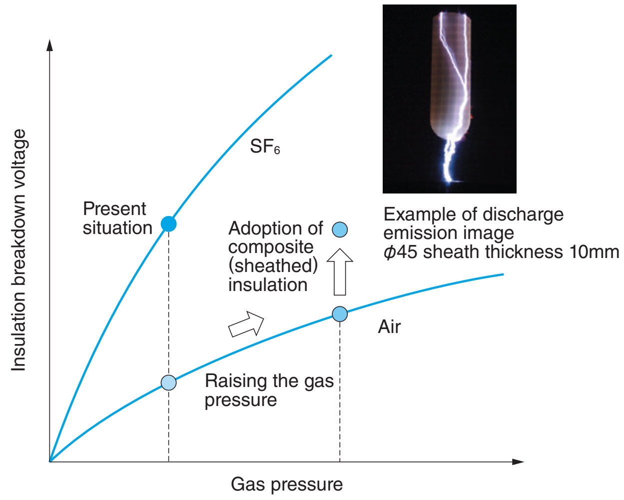

Fig. 4 Image of Composite Insulation

The electrical field can be relieved by covering the part where the electrical field is concentrated.

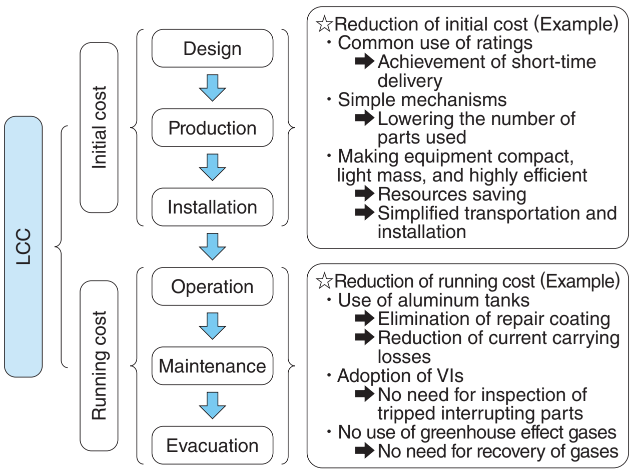

Fig. 5 LCC Reduction

In addition to the reduction of initial cost, running cost is also required to be reduced.

2.3 Trends toward LCC Reduction

In order to eliminate the use of greenhouse effect gases, a demand for eco-friendly features has increased recently. In addition, there is a current social need for the establishment of a recycling society for the conservation of the global environment. There are growing social demands aiming at lowering the environmental impact from a product life cycle (an overall cycle including design, manufacture, installation, operation, maintenance, and scrapping) in consideration of 3Rs・LS, i.e. Reduce, Reuse, Recycle, Long-use, and Separable. Some examples of recent LCC, shown in **Fig. 5**, are introduced below, intended particularly for the reduction of running cost.

2.3.1 High-Efficiency Magnetic Actuator Mechanism (Easy Maintenance)

Since 2004, we have developed VCBs of a solenoid operating system with permanent magnet latch mechanisms. These VCBs offer a feature of extremely simplified operating mechanisms where no complicated gears and a mechanical latch part are accommodated. In this type of VCB, a plunger joined with an operating shaft and a fixed shaft bush are positioned in the center, and a ring-state permanent magnet, closing and tripping coils, and a middle shaft bush are incorporated in the case. An opening spring is installed at the top. **Fig. 6** shows the structure of magnetic actuator mechanisms (in closed state) and the result of a holding force analysis. The number of all parts used is 18 and this figure suggests a remarkable curtailment of parts, compared with any conventional spring operating system where about 50 parts are used. In addition, oilless bearings are used on the sliding parts of the operating shaft and the plunger so that the adoption of such a grease-less feature can facilitate easy maintenance. The newly developed magnetic actuator mechanism reduces the peak value of operating current down to less than 50% compared with conventional equipment and eliminates power-assist electrolytic capacitors that require periodic replacement services. This magnetic actuator mechanism has been developed based on recent growth of permanent magnet materials, advanced analytical technologies for the behavior of transient magnetic field, and compound mechanical analysis. We will continue to promote development of products of medium-voltage class (24kV).

2.3.2 Life of Interrupting Part for 10,000 Operations (No Need for Internal Inspection)

For the electrode configuration of the interrupting part, we have adopted an axial magnetic field electrode system that can greatly reduce arc-borne damage caused at the time of current switching. When this system is used, the capability of frequent current switching is remarkably increased. In a state of ordinary operation, therefore, the interrupting part of VCB does not require any internal inspection, thus reducing overall maintenance cost.

2.3.3 Use of Aluminum for the Tank (Low Loss and Reduced Maintenance Cost)

The 72/84kV eco-friendly tank type VCBs do not use any greenhouse effect gases and are designed for positive reduction of LCC. While conventional tank type VCBs have used steel materials for their tanks, aluminum materials are used for the eco-friendly tank type VCBs. **Fig. 7** shows the resultant effect with the use of aluminum materials. In the case of aluminum tank, there are some attractive features such as reduction of overall equipment weight, no need for repair coating (rustproof coating), and reduction of eddy current losses that results in reduction of current carrying losses. These features result in the reduction of expenses for transportation, installation, foundation work, and maintenance (coating). In addition, power transmission and distribution loss factors can be reduced[5].

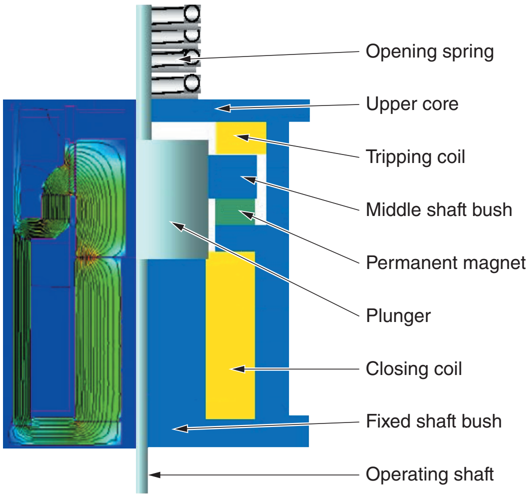

Fig. 6 **Structure of Magnetic Actuator Mechanisms (in Closed State) and Result of Holding Force Analysis**

The left part shows the distribution of a magnetic flux. According to the result of analysis, reduction of operating current is carried out.

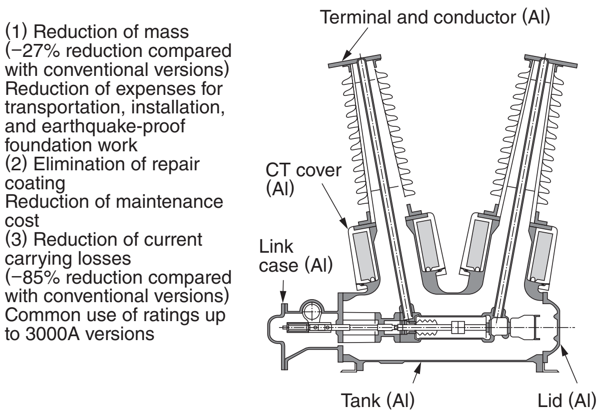

Fig. 7 **Resultant Effect with the Use of Aluminum Materials**

This diagram shows a cross-sectional view of a 72/84kV eco-friendly tank type VCB. The tank and case are made entirely of aluminum materials.

2.4 Extended Applications

Taking a variety of VCB features, the application range has expanded. Some examples are shown below.

2.4.1 Mobile Substation Facilities

Triggered by the Great East Japan Earthquake, the significance of power-related infrastructures has been recognized again. In this connection, demand for mobile substation equipment is increasing for societal recovery after disasters. Since the VCB is compact and light-mass equipment and insulating gas (SF_6) used inside is kept at a low pressure, there is no need for any gas treatment in the site at the destination. We are always ready to ship a variety of equipment such as a mobile substation that is a combination of a VCB and a transformer and single VCB unit that can be moved. Fig. 8 shows a 72/84kV mobile transformer with a VCB (20t truck).

2.4.2 Application to Railways and Phase Modifying Switchgear

Since the VCB functions as a switchgear with maintenance-free interrupters where 10,000 switching operations of load currents are assured, it is widely applied to railway systems and used as a phase modifying switchgear where frequent switching duty is required. In particular in regard to railway use VCBs, they were designed and developed for frequent load current switching more than 30 years ago and their reliable performance has been highly evaluated since then. Recently, construction and extension of railway infrastructures are actively promoted both in Japan and overseas such as China. As such, this type of VCB is widely applied to frequent switching operations. As one of applications for frequent switching, it is applied to phase modifying facilities of reactor or capacitor banks. Based on the result of analysis on systems inclusive of current breaking characteristics of VCBs, it has been possible to grasp surge voltages at the time of VCB switching. It is therefore now possible to define conditions for application to phase modifying facilities. In addition, VCB application range has been extended resulting from improvement of electrode materials. Where an appropriative VCB is used, it is applicable to a maximum of 60MVA capacitor bank or 10 to 100MVA reactors.

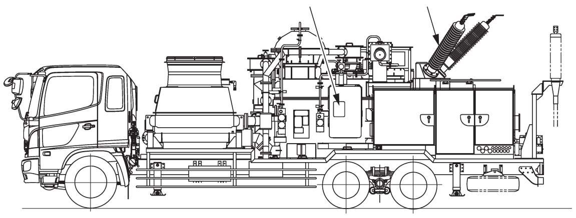

Fig. 8 **72/84kV Mobile Transformer with a VCB (20t Truck)**

As a result of compact design and reduction of mass, a 72/84kV VCB has been modified to permit loading on a truck.

3 Future Trends and Challenges

There is a growing hope that VCB will be the only high-voltage and large-capacity circuit breaker that does not use SF_6 for an arc-extinction medium. In order to realize higher voltages and larger capacities in the future, it is necessary to lower the cost in comparison with GCB and improve the current carrying capability under the vacuum. VCBs for eco-friendly equipment will become mainstream where dry air is used as insulation substitutive for SF_6 gas. For system voltages of 72kV or below, application of these VCBs will continue to further increase. As ideas for energy saving and LCC reduction are increased, demand for diagnostic functions is considered to increase toward the goal of Condition-Based Maintenance (CBM) shifting from Time-Based Maintenance (TBM). The demands also call for the improvement of maintainability such as greaseless performance. In regard to magnetic actuators, it is essential to lower the operating current. Mainly for low-voltage classes, application of solenoid operating systems with magnetic latch mechanisms is anticipated to increase in the future.

4 Postscript

For information about recent VCB technologies and related products, this paper introduced our activities to realize higher system voltages and VCB capacities, reduce environmental loads and LCC, and expand the application range. Presently, the aggregated number of our major products of VCBs of 72kV class has amounted to approximately 6000 units. This figure suggests that our products are widely used by many customers both in Japan and overseas. In terms of eco-friendly features and reduction of LCC, the VCB is a product that meets such requirements of contemporary society. We intend to expand the application range in the future for high-voltage VCBs of 120-168kV classes while we make every effort in realizing further compact design and higher performance.

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

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