Progress of Vacuum Interrupter (VI) and Recent Technical Trends

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Abstract

Vacuum Interrupters (VIs) used for Meiden Vacuum Circuit- Breakers (VCBs) have been sourced internally since they began to be manufactured at Meiden under technical license from General Electric (GE) in 1967. Since the start of manufacturing, we energetically worked on various R&D programs. The research topics cover the independent development of electrodes, realizing higher VI voltages and larger capacities, and vacuum chambers made of ceramics. We developed and delivered, releasing and supplying a variety of VI products. Up until now, the total number of VI units manufactured has exceeded two million units. In addition, sales from individual VI units supply (not in the form of circuit breakers) have recently increased. Presently, more than 200 types of product lineups are meeting the requirements of our customers.

1 Preface

Fig. 1 shows the internal construction (for the M30 Series) of recent 7.2kV Vacuum Interrupters (VIs). The VI is composed mainly of moving-side and fixed-side rods, the tips of which are attached respectively with the electrodes and arc shields, and the moving-side bellows, all items are assembled in a vacuum chamber where the insulating envelope and the metallic flange are joined together. The bellows is a component that can make a telescopic motion while vacuum tightness is maintained. It is used for electrode switching inside the vacuum chamber. There is no dramatic change in overall configuration from original VI versions, but great progress has been made in terms of both size and performance.

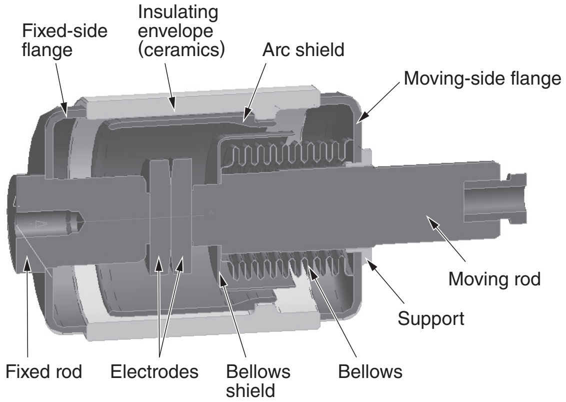

Fig. 1 VI Internal Construction (M30 Series)

A pair of electrodes, bellows, shields, and other constitutive parts is accommodated in a vacuum chamber consisting of an insulating envelope and metallic flanges.

Fig. 2 shows the transition of Meiden VIs. In 1967, we started production of VIs under technical license from GE. In 1969, we established a VI factory at Meiden Numazu Works in Numazu City, Shizuoka Prefecture, Japan in order to start a serial production. At the same time, a short-circuit testing laboratory was newly founded in Meiden Numazu Works to build an independent development organization. For the development of VIs, production was started from the rated voltage 3.6kV model. Currently, we succeeded in increasing the rated voltage capacity up to 145kV. In addition, a variety of product lineups have been developed. The total number of VI units manufactured up to the present has exceeded two million units. There have been many technical changes: from glass to ceramics for vacuum chambers, from copper-bismuth to copper-chromium for electrode materials, from two-segment coil shape to cup or twin helical shape for axial magnetic field electrode construction, and to a one-part spiral shape for radial magnetic field electrode construction.

This paper introduces the technical transition of VIs and recent technical trends.

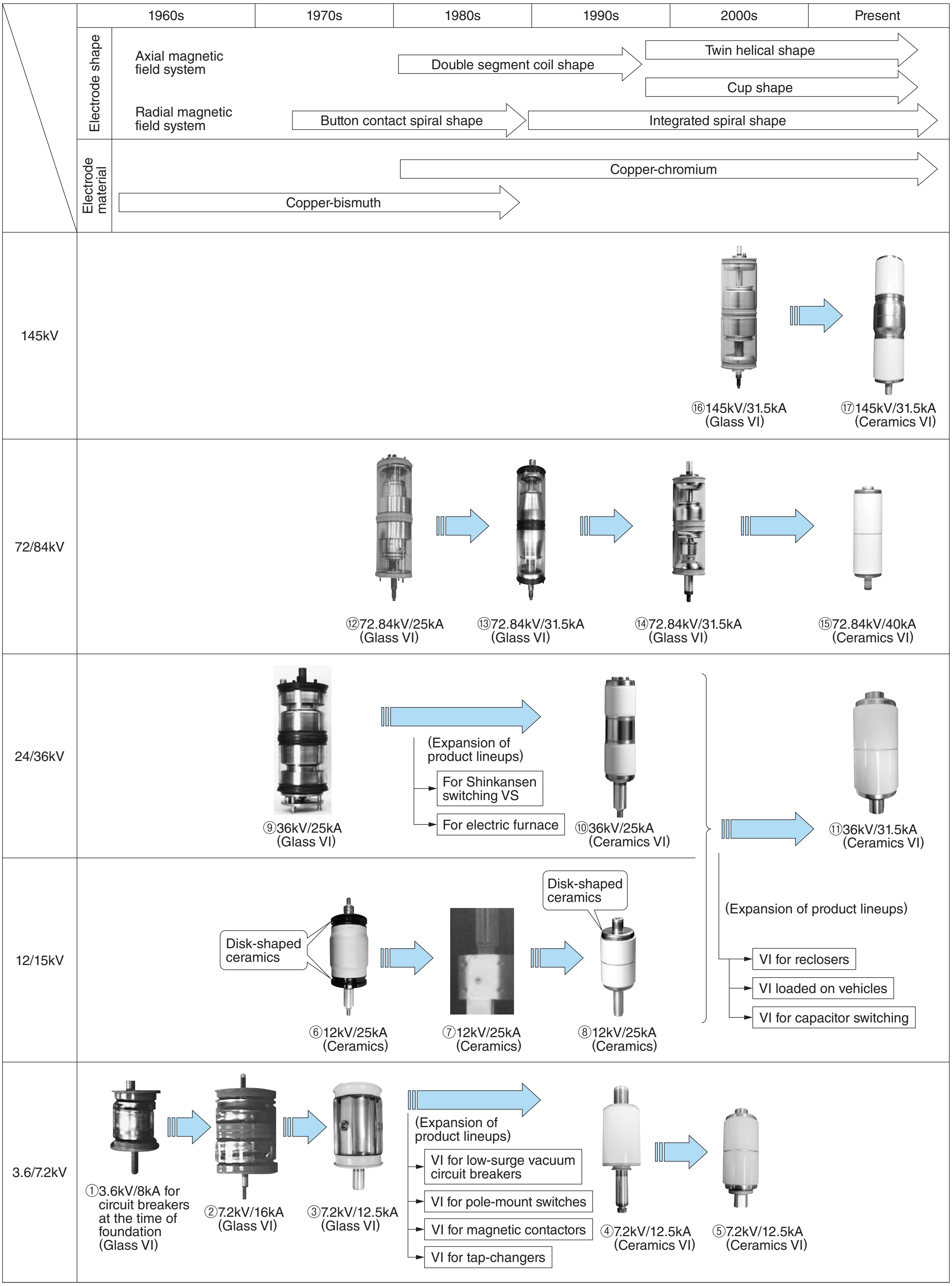

Fig. 2 **Transition of VIs**

We met the requirements of higher voltage VIs and various product lineups.

2 Technical Transition of VIs

The technical transition of VIs is described below for each constitutive element.

2.1 Vacuum Chamber

The vacuum chamber is composed of insulation and metallic materials. These parts must be brazed so that a high vacuum degree of 10^{-4}Pa or below can be maintained. At the initial stage of VI manufacturing, the VI insulation material was glass. Vacuum sealing was performed with the use of a metallic material called Kovar that has the same coefficient of thermal expansion as that of glass so that this metal can be embedded in glass successfully. **Fig. 3** shows the construction of VI vacuum sealing. Practically, however, glass cannot withstand any brazing temperature for the parts located inside the VI. For this reason, the manufacturing process line of glass VIs had to be divided into the brazing process and the evacuation process.

Around the mid-1970s, ceramics began to be used as an insulation material, thus making it possible to carry out both brazing and evacuation at the same time. The metallic material for the ceramics VI used at that time was such that a surface joint was produced between the disk-shaped Kovar and the edge surface of cylindrical ceramics (the same Kovar as that used for glass VIs). The brazing strength, however, was not enough so the application range was limited to production of small-capacity VIs for 7.2kV.

Around the 1980s, we developed a VI whose the tip of a cylindrical copper material was brazed. Copper has a different coefficient of thermal expansion as that of ceramics. There are, however, some preferable advantages: (1) copper becomes flexible

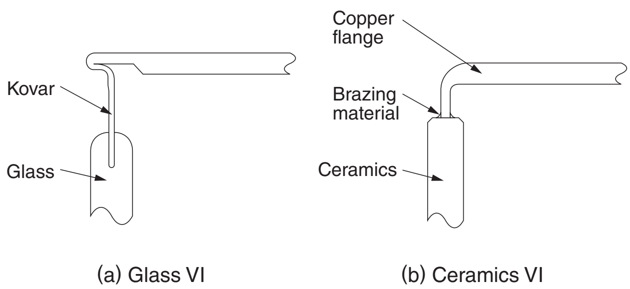

Fig. 3 Construction of VI Vacuum Sealing

Kovar, having a similar coefficient of linear expansion, is adopted for glass VIs while copper flanges are used for ceramics VIs.

after the processes of brazing and annealing and (2) mechanical strength can be intensified if the wall thickness of the cylindrical material is made thin in order to relieve stresses generated after brazing. Around the same period, we developed a 12kV VI which adopted disk-shaped ceramics. In 1990, 24kV general-purpose circuit breakers began to adopt this type VI using where disk-shaped ceramics. Around 1995 and thereafter, copper cup press-fabricated flanges and general-purpose brazing began to be used for the purposes of cost reduction and improvement of mass production stability. At present, most VIs up to 145kV use this vessel.

2.2 Electrode Materials

At the beginning of 1969, copper-bismuth alloy was used for the VI contact points. Copper-bismuth contact points offer such a feature that bismuth distributed over the grain boundary lowers tensile strength of the base material to relieve fusion occurring around the contact point.

In the 1980s, development of copper-chromium electrode materials was promoted worldwide. We also promoted its own development and in 1984, this material began to be adopted for the contact points for high-voltage and capacitor switching. Advantages of this copper-chromium electrode material are that it assures outstanding withstand voltage performance and current breaking performance, and that current chopping phenomena, being a disadvantage of vacuum, can be suppressed. In this connection, this type of material is presently adopted as an electrode material for vacuum circuit breakers.

Around the 2000s, magnetic actuator VCBs were frequently used worldwide. Compared with conventional spring-actuation type, this magnetic actuation consumes less operating energy. We, therefore, developed a new electrode material to balance this feature.

Thanks to the improvement of chromium powder for an electrode material and the use of a small amount of additives, the contact welding force has been reduced by approximately 35% compared with conventional copper-chromium electrodes. In combination with copper arc shields, a new type of copper-chromium spiral electrode has improved its current breaking performance by 25%. **Fig. 4** shows a comparison of current breaking performance and **Fig. 5** shows a comparison of separating forces.

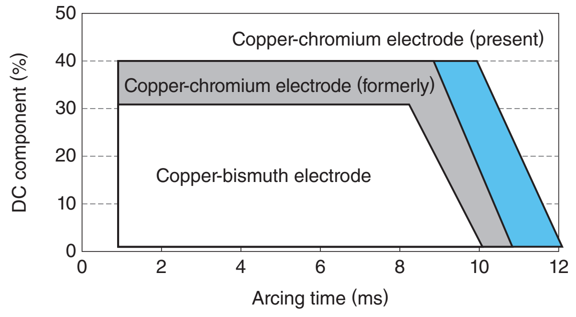

Fig. 4 **Comparison of Current Breaking Performance**

Along with the improvement of electrode materials, the breaking-enabled arcing time and current values have been increased and current breaking performance is improved.

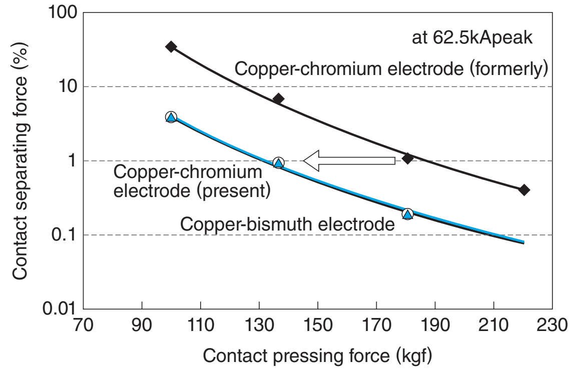

Fig. 5 **Comparison of Separating Force**

The addition of a slight amount of element to copper-chromium electrodes has reduced the contact welding force by approximately 35%.

2.3 Electrode Construction

Fig. 6 shows a transition of electrode construction for Meiden VIs. Electrode construction is classified into two types. For medium-voltage classes of 36kV or below, electrodes of transverse magnetic field system is used. For high-voltage classes of 72kV or above, those of axial magnetic field system is used. For electrodes of transverse magnetic field system applied to medium-voltage classes or lower, arcs generated at the time of current breaking are driven and dispersed in the direction of the arc shield around the electrode so that arcs are finally quenched. At an early stage of VI production, a double-domain button-contact spiral construction was adopted where copper-bismuth alloy was placed on the copper material in a spiral shape. In the 1980s, we succeeded in the development of electrodes in single-domain spiral construction with copper-chromium alloy. After that, remarkable downsizing of electrodes and VI outer diameter became possible. Simultaneously, the near net shape forming method

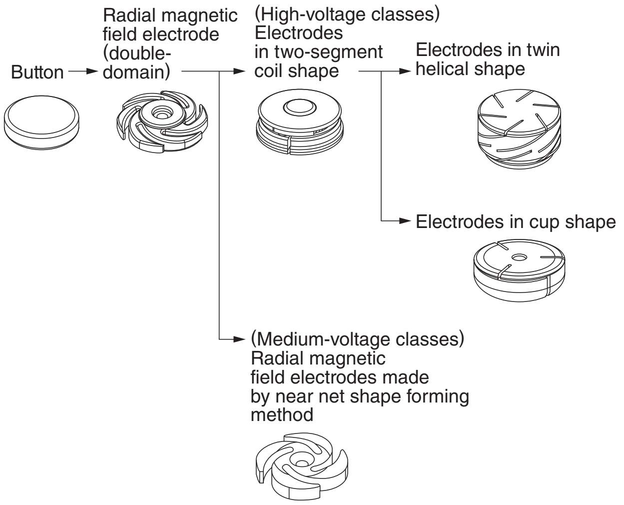

Fig. 6 **Transition of Electrode Construction for Meiden VIs**

For medium-voltage classes, radial magnetic field electrodes by near net shape forming method are adopted. For high-voltage classes, axial magnetic field electrodes in twin helical shape are used.

was established, thus improving the productivity remarkably. In 1986, these electrodes began to be applied to general-purpose circuit breakers of our VJ Series.

For high-voltage classes, electrodes of the transverse magnetic field system for 72kV were developed. This was the first such achievement in the world. The outer diameter was ϕ240mm and the breaking capability was 20kA. After, in 1982, materials were changed and a new VI was developed with an outer diameter of ϕ190mm and a breaking capability of 25kA. It was hard, however, for the spiral construction to ensure enough insulation and further downsizing and expansion of current interruption of capacities were difficult to attain. In addition, it was difficult to apply this type of VI to phase compensation facilities where high withstand voltage characteristics are required, such as capacitor switching. As such, we began to develop the electrodes in the axial magnetic field system. The axial magnetic field electrode is composed of the coil section where the magnetic field is generated by the effect of current carried and the contact section where arcs are quenched. Electrons and ions in arcs generated in the contact section at the time of current interruption are spirally driven by the magnetic field in axial direction generated by coils. This is a feature of this electrode that arcs are dispersed and quenched within the range of electrode diameter.

Around 1985 and thereafter, axial magnetic field electrodes began to be used for 72/84kV

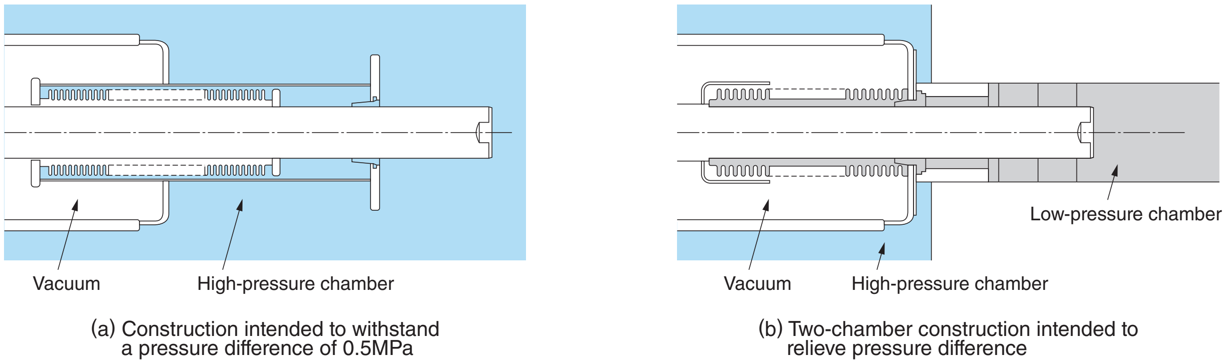

Fig. 7 Transition of Bellows

As a result of the change of insulation to highly pressurized dry air, a burden upon bellows was intensified; therefore, both materials and construction were reviewed.

capacitor bank switching with an outer diameter of ϕ190mm. In 1999, we succeeded in the development of 72/84kV VIs with an outer diameter of ϕ150mm. The most important factor of this success was that the distance to the arc shield could be reduced by making full use of withstanding voltage performance of the axial magnetic field electrodes. In addition, the inter-electrode stroke could be remarkably reduced to 2/3 that of the spiral construction and current breaking performance was raised from former 25kA to 31.5kA. For axial magnetic field electrodes, the shorter the inter-electrode stroke, the stronger the magnetic field to be generated. As a result, current breaking performance is improved. Since 2000, the development of the coil shape has been promoted further and we have created an electrode in a twin helical shape where the number of parts used in former coils has been decreased to 1/3. At the same time, the ohmic resistance of the coil section has been dramatically lowered and the current to be carried has been raised to a maximum of 3000A. This coil is produced by giving a slit to a cylindrical shape so that a current path can be formed to generate a magnetic field. Presently, a new type of electrode is available where the layout of the slit has been improved to obtain a more favorable magnetic field. As a result, current interruption is possible to a maximum of 72/84kV and 40kA with the same outer diameter of ϕ150mm.

2.4 Bellows

Since the initial stage of production in 1969, a stainless steel material with a high corrosion-proof property has been used to guarantee performance of vacuum tightness to be maintained for more than 20 years. Even for mechanical durability against multiple switching and long strokes, materials have been carefully selected and used according to applications.

In many cases recently, highly pressurized dry air began to be used as a VI ambient atmosphere. In some cases, the difference between VI inner and outer pressures may become 0.5MPa or greater. If such a differential pressure is directly exerted on the bellows, it may be distorted and its pleats (peaks and valleys) may be deformed. In such a case, its mechanical durability will be extremely reduced. Fig. 7 (a) and (b) show examples of countermeasures taken against high pressures. In (a), the inside of bellows is generally maintained at a high pressure and the outside under vacuum. On the contrary, however, the bellows interior is made to stay under vacuum and the exterior is maintained at a high pressure to avoid distortion of the bellows. By this approach, stresses on valleys possibly leading to fatigue failure can be relieved. In (b), the VI exterior is separated into two chambers. The ceramics section that is required to secure insulation is maintained at a high pressure and a low pressure is maintained in the bellows interior. In this manner, pressure exerted on the bellows was reduced.

3 Recent Technical Trends

3.1 High-Voltage VI

Ahead of our competitions, we developed 145kV and 168kV double-break live tank VCBs in the 1970s. Since then, we have many track records at home and abroad. Against the technical background of improved performance of axial magnetic field electrodes, we succeeded in the development of 145kV single-break VIs in 2002 and the first

Fig. 8 145kV Single-Break Ceramics VI

For sections between contact points and between shields, as well as creepage distance over the ceramics surface, the balancing of insulation performance was optimized through electrical field computation.

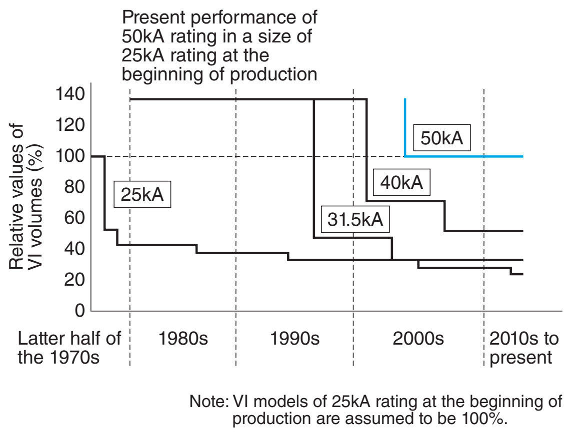

Fig. 9 More Compact Design for Medium-Voltage VIs (Transition of 12kV Class)

A ten-year level comparison was made among relative values of cubic size. In a size of 25kA rating in the 1980s, current interruption of 50kA is possible at present. (VI models of 25kA rating at the beginning of production are assumed to be 100%.)

product of live tank VCBs was delivered in 2010. In order to accelerate the market acceptance of high-voltage circuit-breakers to power transmission line networks, we tried to modify insulating envelopes of 145kV single-break VIs from conventional glass material to ceramics that is suitable for mass production and we came to a near-commercialization stage. Fig. 8 shows a 145kV single-break ceramics VI.

3.2 Medium-Voltage VI

For medium-voltage class VIs, the market scale is large and many customers are interested in these versions and make various requests. In order to meet such requirements from the market, we are making every effort in regard to a compact design, meeting various international standards requirements, and customizing for special applications.

Fig. 9 shows the transition of compact design for 12kV class VIs. In 1979, the company manufactured VIs in a unique shape. A glass VI was modified to using a disk-shaped ceramics material (Fig. 2) in order to secure the specified withstand voltage. After, in 1987, VIs began to be manufactured with the use of axial magnetic field electrodes of outer coil system. In these versions, cylindrical ceramics was adopted to produce copper cup press-fabricated flanges deriving from our unique expertise. After 1995, we focused on the simple component shapes and automation of VI manufacturing lines in order to cope with cost competition. For large-capacity classes of 40kA and 50kA as well as 25kA class, electrode materials and shapes were reviewed to realize a further compact design.

Fig. 10 shows the VIs for reclosers. In addition to circuit- breakers, we have a wide variety of product lineups of about 200 types or more, such as versions for switches (LBS, DS, VMC, etc.), and VIs for electric furnaces and for on-board application to railway vehicles. These products are exported to 24 nations.

Fig. 10 VIs for Reclosers

VIs for pole-mount reclosers to be exported are shown. These models conform to the specification of current breaking capability in continued operation. In addition to vacuum circuit breakers for substations, we manufacture a variety of VIs applicable to power distribution facilities such as reclosers.

4 Postscript

Drawing on many years of manufacturing experiences and engineering resources, we have unique VI product lineups covering a wide range of voltage classes from high-voltage power distribution systems to ultra-high-voltage power grids. We always seek fast and flexible responses to various requirements and requests from our customers at home and abroad. We will continue to work on the development of a compact design and high performance VIs and on the stable supply of VIs.

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

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