Development of Medium-voltage Switchgear for Reducing Environmental Impact and Space-saving

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*OVERVIEW: To make medium-voltage switchgear (52 kV or less) smaller and more robust, there has been a shift away from AISs and toward GISs that use SF_6 gas[*1]. However, the high global warming coefficient of SF_6 gas means it was designated as a greenhouse gas by the Kyoto Protocol (Kyoto Protocol to the United Nations Framework Convention on Climate Change) adopted at the Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change held in Kyoto in December 1997. Responding to this, Hitachi quickly embarked on the development of medium-voltage switchgear with the aim of eliminating use of SF_6 gas.*

INTRODUCTION

THE demands placed on electric power generation and distribution equipment are changing in response to the growing diversity of power generation and the need to reduce the load on the environment to create a sustainable society, with equipment also being made smaller, easier to maintain, and better able to cope with disasters. The distribution switchgear used to deliver electric power directly to users also needs to adapt to these diverse changes.

In developing medium-voltage switchgear to meet these needs, the key considerations are: (1) The development of alternative insulation techniques to sulfur hexafluoride (SF_6) gas by selecting the best mix of electrical insulators, (2) Making equipment smaller and providing it with multiple functions through greater use of vacuum technology, (3) Protection from internal arcs to prevent three-phase short circuit faults, (4) Save energy, improve maintenance, and enhance reliability by simplifying operating mechanisms and eliminating use of grease, and (5) Creation of added value, including services made possible by advances in protection, measurement, and diagnostic techniques.

This article describes the key technologies for medium-voltage switchgear and the outlook for the future.

KEY TECHNOLOGIES FOR MEDIUM-VOLTAGE SWITCHGEAR

Key technologies for medium-voltage switchgear include greaseless hybrid electromagnetic operating mechanisms that reduce the number of mechanical parts and eliminate the need for lubrication maintenance, multifunction vacuum interrupters that help make the devices smaller, wide-range current transformers (CTs), and diagnostic techniques for assessing the life of insulators. The following sections describe the features of these new technologies.

Greaseless Hybrid Electromagnetic Mechanism

This mechanism uses a hybrid magnet (combining a permanent magnet and electromagnet) and proprietary Hitachi technologies to achieve a number of benefits. These include: (1) Eliminating approximately 85% of mechanical parts[*2], (2) Reducing the energy needed to operate the mechanism by approximately 80%[*2], and (3) Using a greaseless mechanism to eliminate the need for regular lubrication (see Fig. 1).

Multifunction Vacuum Interrupter Technology

To reduce the device size, Hitachi utilized its vacuum technologies built up over many years to develop a vacuum interrupter that: (1) Halves the contact force required by the terminals[*2], and (2) Combines the functions of a circuit breaker and disconnecting switch (see Fig. 2).

Wide-range CT and Multi-relay

The wide-range CT incorporates a multi-relay intelligent control unit (ICU) that has functions

*1 Sulfur hexafluoride (SF_6) gas: A gas with excellent electrical insulation and arc extinction properties but with a global warming coefficient 23,900 times that of carbon dioxide (CO_2). As a result there is a need to manage and reduce release of the gas into the atmosphere.
*2 Compared to the previous Hitachi model.

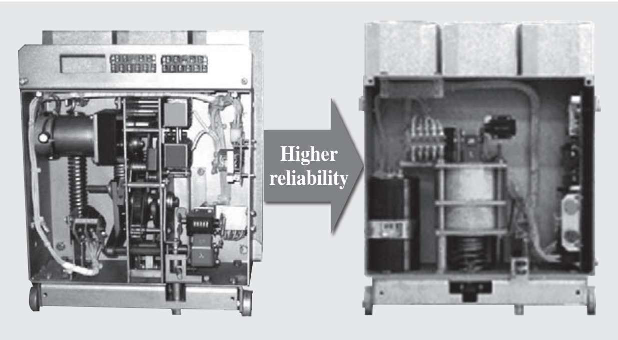


Fig. 1—Advances in VCB Operating Mechanisms.
To improve the reliability of the mechanisms used to operate vacuum circuit breakers (VCBs), the spring mechanisms used in the past, which had many mechanical parts, have been replaced with hybrid electromagnetic mechanisms that have few parts.

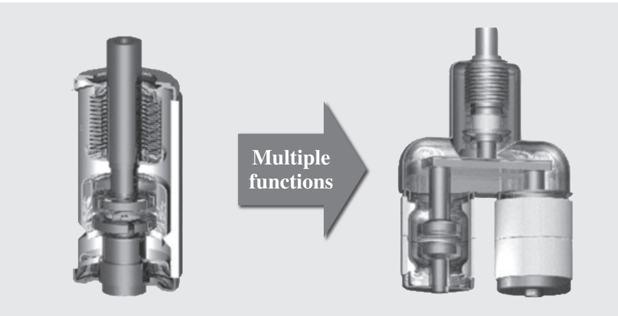


Fig. 2—Combination of Multiple Functions in Vacuum Interrupter.
Switchgear is made smaller and lighter by using vacuum interrupters for both circuit breaker and disconnecting switch functions, rather than as single-function devices as in the past.

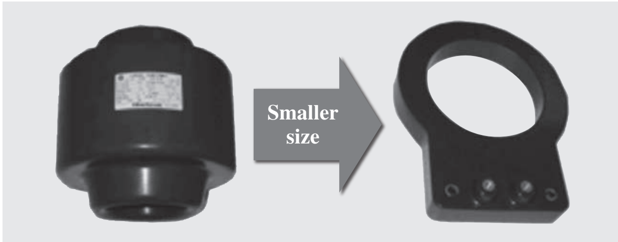


Fig. 3—Wide-range CT.
Wide-range current transformers (CTs) designed for smaller size and lighter weight have become available. These incorporate Hitachi multi-relays to significantly expand the scope of protection compared to previous models.

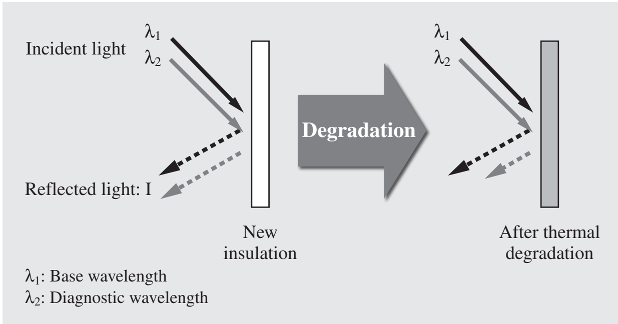


Fig. 4—Principle of Operation of Dual-wavelength Optical Diagnostic Technique.
This proprietary dual-wavelength technique was devised by the Hitachi Laboratory. It provides a non-contact method for assessing insulation degradation.

including protection, control, measurement, and communications, and that provides accurate detection over a wide range. The features of the CT are as follows (see Fig. 3).
(1) Approximately 80% smaller by volume and weight[*2] to help make panels smaller.
(2) Does not require replacement or tap changes when load capacity changes.
(3) Equipment can be selected prior to finalizing load capacity.

Dual-wavelength Optical Technique for Assessing Remaining Insulator Life

Hitachi Research Laboratory of Hitachi, Ltd. has demonstrated the ability of this technique to assess deterioration in insulators based on the following principles (see Fig. 4).
(1) Some of the light shined on organic material is absorbed, and the intensity of reflected light differs depending on the material and the wavelength.
(2) While the intensity of reflected light varies depending on variations in the surface condition of the material and the intensity of incident light, the proportion of absorbed light remains constant.
(3) The amount of absorbed light varies depending on thermal degradation and other changes in the chemical structure.

Fig. 5 shows how these principles can be used to assess the condition of a cable. Hitachi is expanding the scope of application of this technique by building up a database of material degradation.

PRODUCTS INCORPORATING KEY TECHNOLOGIES

The following sections describe medium-voltage switchgear products that utilize these key technologies.

Hybrid (Electromagnetic Mechanism) VCB

Hitachi developed the vacuum circuit breaker (VCB) for the Japanese market in 2003 with the aims of minimizing maintenance, reducing the energy required to operate the circuit breaker, and ensuring reliable long-term use. It is now expanding its product

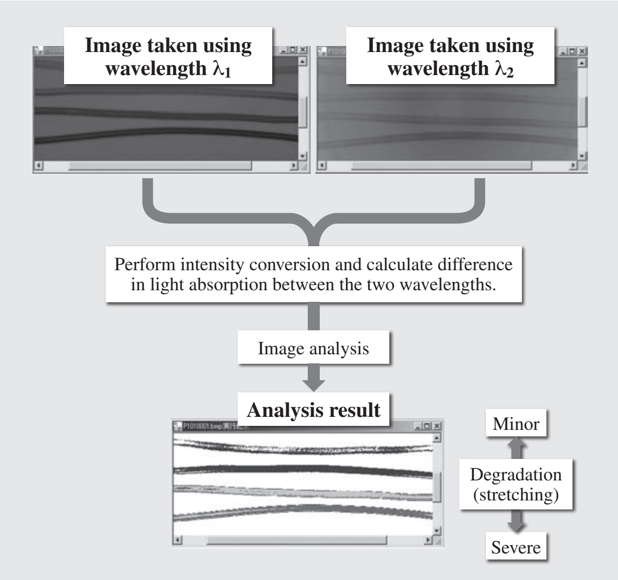


Fig. 5—Use of Dual-wavelength Optical Technique to Assess Cable Degradation.
The technique is used to assess degradation of electric cables.

range to include models for overseas markets (see Fig. 6). The features of this VCB include a hybrid electromagnetic operating mechanism, bearings that use solid lubricant, and a stainless steel shaft.

Fig. 7 shows a 12-kV hybrid VCB for the Chinese market undergoing certification testing at a test laboratory in Xi'an, China.

Switchgear with Solid Busbar Insulation

An issue with the air-insulated switchgear (AIS) used in the past has been how to prevent surface degradation of insulators and the breakdown of insulation for exposed live components due to factors such as condensation or other contamination, and infiltration by vermin or rainwater. The following two practices are adopted to resolve this issue (see Fig. 8).
(1) Use of moldings made of a solid insulator for main busbars and cable ducts, and coating the surface with an earthing layer.
(2) Housing the VCB in a sealed chamber protected by a gas-permeable coating.

To make maintenance and inspection easier, the hybrid VCB also incorporates a broader range of protection, including a drawer-mounted zero phase-sequence current transformer (ZCT), wide-range CT, and lightning arrester (see Fig. 9).

24-kV C-VIS

In 2006, Hitachi developed a cubicle-type vacuum insulated switchgear (C-VIS) based on a new concept

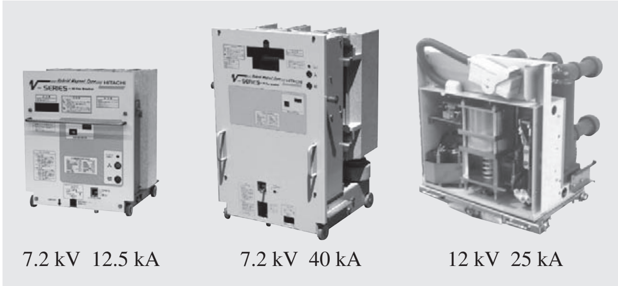


Fig. 6—Hybrid VCBs.
These VCBs with a hybrid electromagnetic operating mechanism have earned a strong reputation in the Japanese market. Hitachi has now started to sell them in overseas markets.

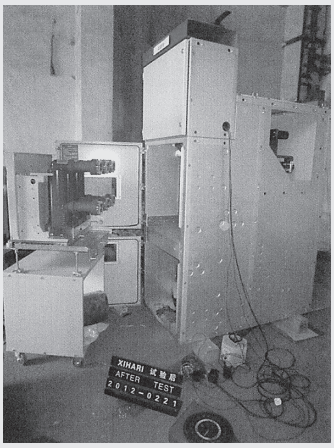


Fig. 7—Certification Testing of 12-kV Hybrid VCB for the Chinese Market.
After testing, the supplied VCB was inspected to ensure it had no problems.

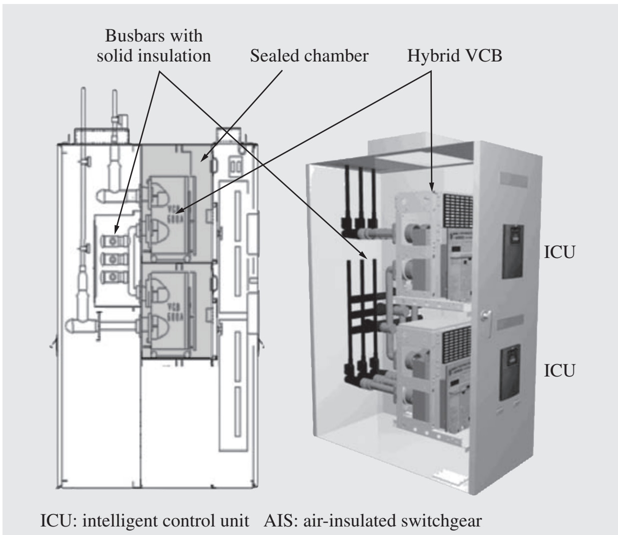
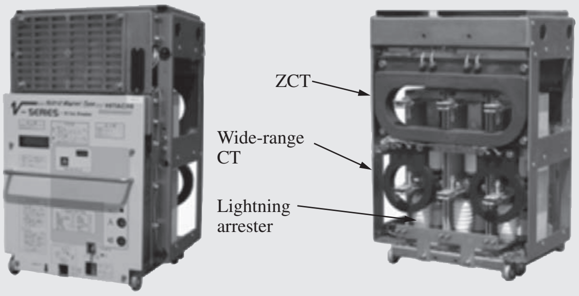


Fig. 8—Layout of 7.2-kV Panel with Solid Busbar Insulation.
The solid busbar insulation and use of a sealed chamber to house the VCB overcome the problems associated with previous AISs.



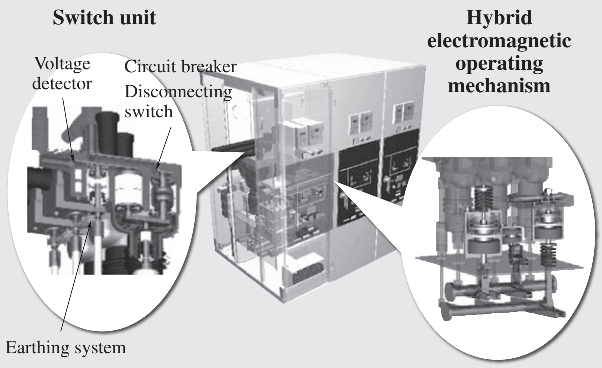
ZCT: zero phase-sequence current transformer
CT: current transformer

Fig. 9—Overview of All-in-one Hybrid VCB.
Maintenance is facilitated by fitting the CT and lightning arrester in the drawer-mounted hybrid VCB so that they can be pulled out for inspection along with the VCB.

Conventional AIS (integrated three-phase housing): Three-phase short-circuit test

C-VIS (separate phase housing): Single-line earth fault test

Fig. 11—Internal Arc Testing of Switchgear.
Use of a design in which the phases are kept separate significantly reduced the consequences of internal arc accidents.



C-VIS: cubicle-type vacuum-insulated switchgear

Fig. 10—Overview of 24-kV C-VIS.
Hitachi has developed a switchgear based on a new concept that combines a hybrid electromagnetic operating mechanism with a multifunction vacuum interrupter. In addition to existing markets, Hitachi has also started supplying these for use in harsh environments such as in tropical regions and at sea.

Parameter	Specification
VT rating	110 V
CT rating	Wide-range 1 A
Temperature range	0 – 40°C
Power supply	DC100/110 V
Dimensions	210 × 300 × 100 mm (W × H × D)
Weight	1.5 kg

VT: voltage transformer

Fig. 12—ICU Photograph and Specifications.
Use of the multifunction multi-relay helps make switchgear smaller by integrating the wide-range CT.

that uses neither dry air nor SF_6 gas (a designated greenhouse gas), and has been supplying these in Japan and elsewhere (see Fig. 10). These products have separate moldings for each phase for components such as the multifunction vacuum interrupter and vacuum leak/voltage detector, together with an earthing layer coating for the switch unit and a greaseless hybrid electromagnetic operating mechanism. Combining the ease-of-use of AISs with the small size and reliability of gas-insulated switchgear (GIS), this switchgear also has a potential market for use in harsh environments such as in tropical regions and at sea.

While protection against internal arcing is a major issue for medium-voltage switchgear, these products are designed with safety in mind to prevent short circuits by using a configuration in which the phases are kept separated (see Fig. 11).

Wide-range CT and ICU (Multi-relay)

The ICU is designed for use with Hitachi's own wide-range CT, and has functions that include protection, measurement, control, communications, waveform recording, and operation (see Fig. 12). The ICUs can be used with two types of wide-range CTs: a 600-A model (40 A to 600 A) and a 1,200-A model (100 A to 1,200 A). Fig. 13 shows the performance compensation range of the 600-A model.

OUTLOOK FOR THE FUTURE

Hitachi plans to develop these key technologies further, and is working on research and development that includes: (1) Expanding its range of products that do not use SF_6 gas by making greater use of vacuum technologies and enhancing competitiveness, (2) Upgrading its primary and secondary distribution products for the global market, and (3) Strengthening its service business, including assessment of remaining insulation life.

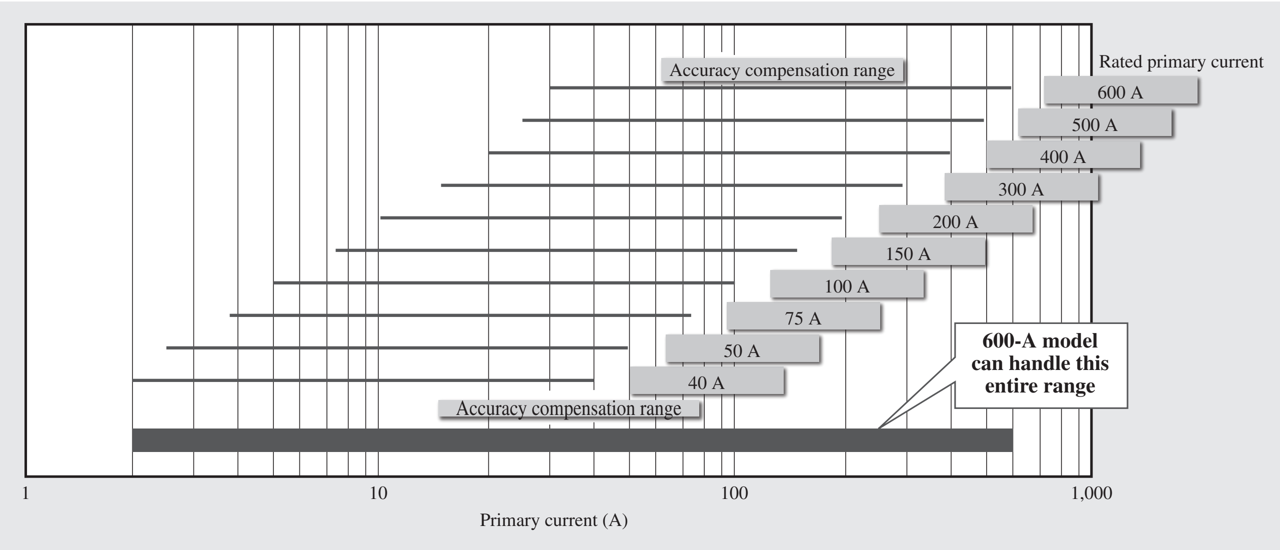


Fig. 13—Comparison of Current Compensation Ranges for Wide-range CT and Previous CT.
The wide-range CT has a wide performance compensation range, reducing the need to replace the CT to handle higher loads.

Construction of New Vacuum Interrupter Factory

The new factory will be adjoined to an assembly line for 72/84-kV switchgear and is scheduled to enter full production in 2014. Hitachi is establishing highly efficient production systems that utilize its research into production technology.

Product Range Expansion

To expand its range of products for the global market, Hitachi is adopting panels with solid busbar insulation for products intended for overseas markets. Fig. 14 shows the design concept for panels with solid busbar insulation (patent pending). Specifically, solid insulation has been utilized for busbars in Hitachi's existing AISs, with VCBs and earthing systems being housed in sealed chambers. Because of growing overseas demand for highly reliable high-end AIS models that provide this level of layout flexibility, Hitachi also sees potential for deploying this technology in the GIS market.

Hitachi is also working on the development of C-VIS+, the next generation of C-VIS. It is also developing a new model that will be compatible at the wiring diagram level with existing cubicle-type GIS. The objective is to reduce device size by adopting a simple design while also keeping to the same concept as the 24-kV C-VIS (see Fig. 15).

Strengthening Service Business

Hitachi is establishing an electronic records system for existing installations in Japan so that it can advise on appropriate upgrade timings based on a database

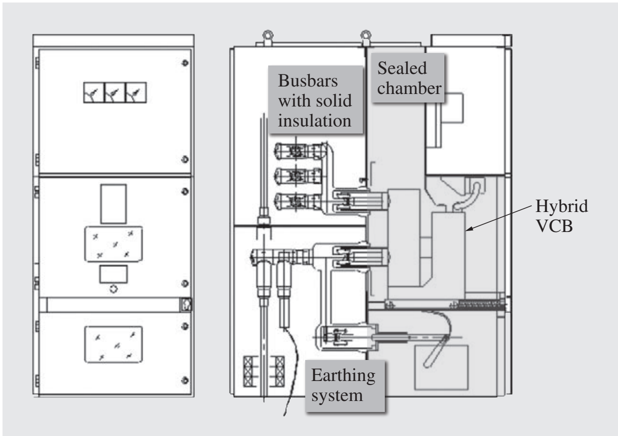


Fig. 14—Panel with Solid Busbar Insulation for Overseas Markets.
Hitachi sells panels with solid busbar insulation in the Japanese market and is now considering expanding into the high-end market overseas.

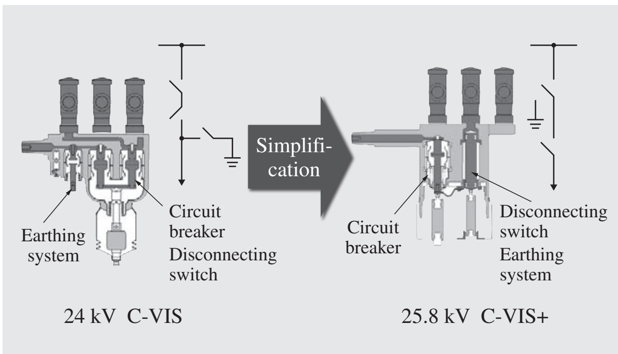


Fig. 15—Advances in Vacuum-insulated Switchgear.
Hitachi is developing the C-VIS+ to have an even simpler design than the C-VIS.

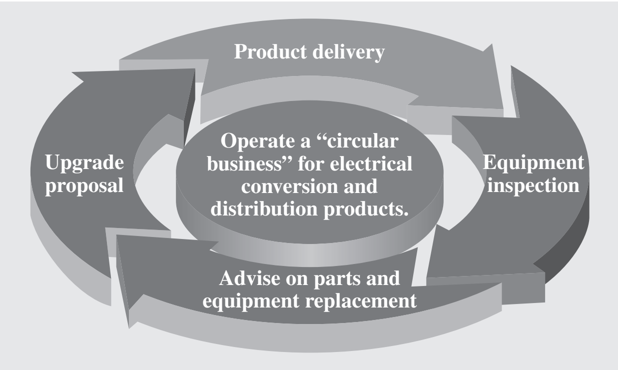


Fig. 16—Circular Business Concept.
To operate its "circular business" globally, Hitachi is establishing facilities around the world.

that includes the results of equipment inspections conducted voluntarily by Hitachi (see Fig. 16). Hitachi is establishing facilities around the world and is also working with partners to create added value for the more than 30,000 units supplied to overseas markets, including using services like this as a base to provide preventive measures against accidents and support for equipment upgrade planning.

CONCLUSIONS

Medium-voltage switchgear is essential for the maintenance of social infrastructure, with an important role in delivering electric power directly to end users. Use of the key technologies described in this article can meet the diverse requirements placed on electrical conversion and distribution equipment, which include reducing the impact on the environment and making the equipment smaller and easier to maintain.

REFERENCE

(1) T. Hae et al, "Features of cubicle type vacuum-insulated switchgear 'C-VIS'," CIRED 22nd International Conference on Electricity Distribution (Jun. 2013).

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