Japan ÆPower Systems Review®

Vol.4

AUGUST 2011

HFMJÆPS Japan AE Power Systems Corporation

Japan
ÆPower Systems Review®

Vol.4
AUGUST 2011

Toward the New Development

Kunihiko HIDAKA
Professor, Doctor of Engineering
Department of Electrical Engineering and Information Systems
The University of Tokyo

First of all, I would like to congratulate Japan AE Power Systems Corporation on the 10th anniversary of its establishment. Ten years can bring a lot of changes, and indeed, significant changes have occurred in the past decade in the electric power field too. These changes include a slowdown in power demand growth, increasing awareness of environment in advanced countries, and surging demand for power in developing countries. A decade ago already feels like the distant past. I would like to express my respect to Japan AE Power Systems for its running a steady business on the solid foundation in this fast-changing environment.

The record shows that the first lecture on high voltage engineering, which is my major research field, was given in the University of Tokyo in 1912 by Professor Shutaro Ho, who is famous for the Ho-Thevenin theorem, as part of alternating current theory. This is the 99th anniversary of that first lecture. The year 2011, the 10th anniversary of Japan AE Power Systems and the 99th anniversary (Hakuju celebration according to Japanese tradition) of the first lecture, is therefore a major celebratory year for me.

I started writing the above preface when the Great East Japan Earthquake struck on March 11, followed by the calamity at the Fukushima Daiichi Nuclear Power Plant and the planned power outages due to insufficient electric power. I would like to express my heartfelt condolences and sympathies to the victims of the disaster, and I believe that all of us who have survived the disaster should make every effort to rebuild Japan with the full use of our own abilities.

We can learn many things from this catastrophic earthquake and nuclear accident. First of all, it is important to reconsider how we view systems. Substation equipment engineers tend to focus on improving the efficiency and reliability of the equipment they specialize in, namely transformers, switchgear, lightning arresters, etc. However, I think it is essential to overview the efficiency and reliability of the entire system including power generation, power transmission/distribution, status monitoring, and control systems, to which substation equipment is connected, and to consider how each equipment can help improve the system as a whole. Of course, one approach is to optimize the entire system by optimizing each device. The accident in Fukushima Daiichi Nuclear Power Plant, however, revealed that damage in a certain weak part of a system, if there is any, causes damage in an entire system, even if the accident itself is unpredictable. The insulation coordination, which is exactly what we regard as system concept, has been well-known in the field of electrical insulation. It is necessary to reconstruct the concept of reliability coordination in the entire power supply.

The second point we should study is the autonomous-decentralized recovery function. Society requires a mechanism to ensure self-sustained recovery or self-restoration in the event of a trouble or failure in the system whatever cause it may be. In addition, engineers are required to develop a number of technologies including securing the minimum quantities of independent power supplies and developing remote-control robots that can work in the environments where humans cannot.

The third task that is becoming increasingly apparent is to modularize equipment components not only to speed up recovery work but also to make the equipment easier to be transported and installed, and to streamline the maintenance. It is therefore worth reviewing the modularization of equipment and devices.

I would like to encourage you to overcome all these challenges and develop new technologies, to promote worldwide disaster-resistant substation equipment, and to achieve international standardization just as the 1,100 kV (UHV) transmission system which originated in Japan has become the IEC standard.

Individuals working in the electric power field should be aware that electricity is essential for security, just like air and water. Without it, our lives could be threatened: life-sustaining equipment could not work, for example. Society requires us to focus on our work with this mission in mind while balancing reliability with economic efficiency.

I expect Japan AE Power Systems to grow by overcoming these great challenges at the turning point of its 10th anniversary, to develop technologies in future decades to gain public trust, and to pave the way toward the 22nd century.

Greetings from the President

Junichi OISHI
President and Director
Japan AE Power Systems Corporation

Since the establishment of Japan AE Power Systems Corporation in July 2001, we have supported energy lifelines as an energy solutions company with a vision of the future. Upon this 10th anniversary of the company, I would like to thank our customers, shareholders, employees and their families, partner companies, and local communities for their support over the decade.

The global economy in 2010 suffered sluggish demand as economic measures by various governments lost steam and as emerging countries took measures to cool their overheating economies. Furthermore, the strong yen and paralyzed various economic activities following the catastrophic Great East Japan Earthquake in March 2011 pushed the Japanese economy to the brink. Despite the damage suffered by some of our factories, we are fulfilling the requests from our customers to inspect and repair damage to the equipment that we have delivered, in order to rebuild the power infrastructure in Eastern Japan.

Under such circumstances, we have delivered our substation equipment, substations for power plants, photovoltaic power generation demonstration plants, 1100kV 63kA gas insulated switchgear, 800kV gas circuit breakers, and 800kV transformers/reactors to many customers in the Middle East, China, Asia, North America, and Africa. Domestically, we have delivered a wide range of equipment including substation equipment for trunk systems and transmission/distribution systems for buildings and factories. In addition, we enhanced the overhauling of our delivered products as preventive maintenance, and focused on releasing environment-friendly tank-type vacuum circuit breakers, cubicle-type gas insulated switchgear, silicone oil-immersed transformers, and palm oil-immersed transformers.

To be a sustainable corporation, it is essential to continuously develop new business fields and next-generation products. We will continue providing our customers with products and services satisfying various needs, including the creation of smart grids for power systems, development of environment-friendly and disaster-prevention products, and downsizing of UHV shunt reactors, capitalizing on our wealth of manufacturing expertise.

Lastly, under the slogan of "Toward a true global company," we have created a midterm plan for the five years from 2011, "Next-10," and will continue focusing on developing reliable products and solutions as a supplier of critical power transmission and distribution infrastructure. This fourth edition of *Japan AE Power Systems Review* introduces some of our key technical developments and the latest topics.

We look forward to your continuous support.

Future Prospects of Japan AE Power Systems

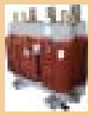
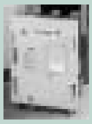
1 A decade of Japan AE Power Systems Corporation

Japan AE Power Systems Corporation was established on July 1, 2001 through the merger of the power transmission and distribution sector of Hitachi, Ltd., Fuji Electric Co., Ltd., and Meidensha Corporation. At that time, Japan was still suffering from post-bubble economic stagnation, and the heavy electrical machinery industry was facing an increasingly competitive environment with suppressed public investment, declining power demand, and successive electricity deregulation. We therefore focused on eliminating and consolidating overlapping products resulting from the three-way merger and developing new products, to satisfy increasing demand for higher economic efficiency, functionality, and reliability of transmission and distribution equipment.

Amid the increasing calls for creating a low-carbon society to counter environmental issues such as global warming, we have been improving our power system stabilizing techniques for power transmission and distribution equipment to handle increasing use of renewable power sources such as photovoltaic and wind power generation. We have also focused on ensuring that aging equipment continues to run smoothly.

Table 1 shows the major systems/products we

[Table 1] Major Deliveries and Developments in the Past 10 Years

Item	FY2000	FY2001	FY2002	FY2003	FY2004
History	Preparations for Establishment Signed comprehensive business collboration agreement, by Hitachi, Fuji & Meidensha (2001/1)	Manufacturing started (2001/10〜) AE Power Systems established (2001/7)	Opened Singapore Rep. Office & Shanghai Rep. Office (2002/4) Business succession (2002/10)	First new recruits join AE Power Systems (2003/4) Opened Shanghai Rep. Office (2004/1) Opened Middle East Rep. Office (2003/5)	Established AE-Asia (2004/9) AE-HVB(USA) aquired from Hitachi (2005/3) AE America established (2004/4)
Turn-Key Projects	Singapore 230/66kV SS turn-key project	Abu Dhabi 230/33kV SS turn-key project			
Transformer	USA Transformers for IPPs Chugoku Electric Power 500kV 1000MVA Site-assembly TR 	 Tokyo Electrci Power 281.25(525)kV 1060MVA TR	Silicon liquid immersed TR sales starts	Tohoku Electric Power 275kV phase-shifting TR	Hybrid cast resin TR with noise reducers, sales starts 
High Voltage Switchgear	Taiwan 170kV GIS	Singapore 230kV GIS Hong Kong 145kV GIS	J-Power EPDC 300kV GIS USA 362kV GIS	Egypt 550kV GCB	Shandong AE 550kV GCS Hokuriku Electric Power 550kV GIS with Polymar Bushings Tohoku Electric Powe 266kV Polymar Type Lightning Arrester
Medium Voltage Switchgear	 Grease-less general purpose VCB, sales starts		Okinawa Electric Power 72kV Vacuum featured GIS(VFS) 24kV Dry-air C-GIS 145kV Single break VCB, introduced at IEEE Asia Conference		Chugoku Electric Power 72kV Dry-air VCB General purpose 7.2kV electro-magnetic operated VCB sales starts

have delivered to domestic and overseas users as well as new products developed in the past decade.

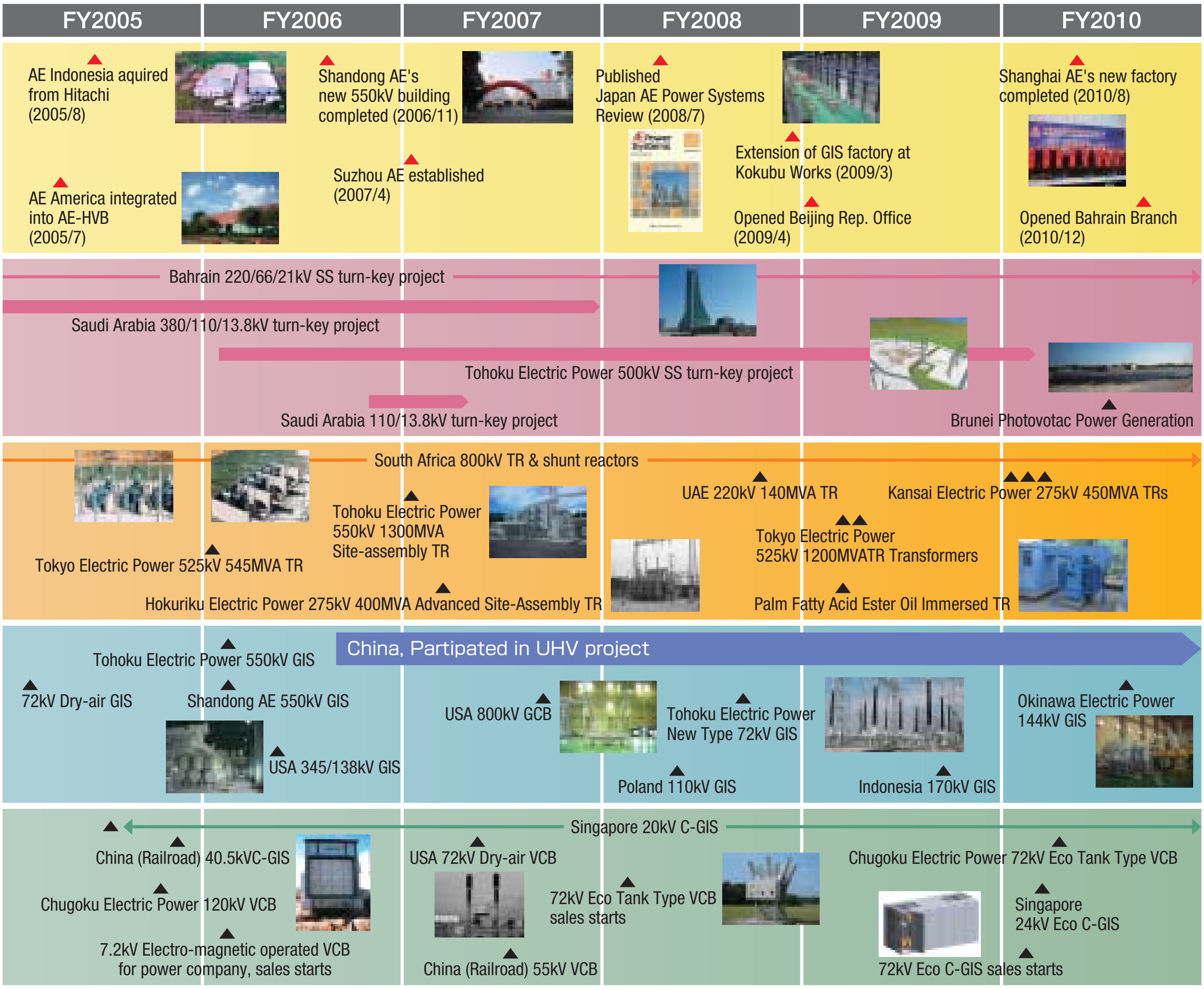
1.1 Measures for power transmission trunk systems[1]

One major role of Japan AE Power Systems is to develop and supply highly reliable large-capacity equipment for trunk systems. Domestically, we deliver high-reliability 500kV transformers with reduced transportation weight and lower total cost to power utilities throughout Japan. Meanwhile, overseas we delivered 1,100kV hybrid-type gas insulated switchgear (H-GIS) in 2009 in cooperation with the New Northeast Electric Group High Voltage Switchgear Co., Ltd., our partner in China, marking the world's first UHV transmission project, and the delivered H-GIS is now in commercial operation. We have also delivered a large number of 765kV transformers and shunt reactors to ESKOM, a state-owned utility in South Africa.

1.2 Power quality and system stabilization

Renewable energies, such as wind and photovoltaic power, are increasingly being connected to power systems, causing concern about their effect on power quality. To reduce adverse impacts, we have developed phase-shifting transformers and variable-capacity shunt reactors to control power flow.

▲Denotes shipments, deliveries and developments, unless otherwise noted ●Denotes deliveries before establishment of AE Power Systems



1.3 Environmental and disaster-preventive measures

With switchgear, we have minimized the emissions of SF_6 gas, which is a greenhouse gas subject to regulations, to help reduce global warming, and have developed cubicle type switchgear that does not use SF_6 gas (dry-air insulated C-GIS)(2), environmentally-friendly VCB(3), etc.

We have also developed transformers using biodegradable vegetable oil (palm fatty acid ester fluid) instead of mineral oil, and expanded their applications, and have developed top-runner cast resin transformers(4).

Meanwhile, as disaster-prevention measures, we have developed transformers using low-flammability, low-viscosity silicone fluid, along with bushings using a composite insulator having much higher seismic resistance, and are selling such products up to 500kV-class.

1.4 Analyses, diagnoses, and measures for aging equipment

We have been developing advanced analytical techniques, including a hot gas analysis method for analyzing the interrupting current within switchgear, and a three-dimensional analysis program combining a fluid and magnetic field for accurately simulating the complicated static electrification phenomena in transformers. These techniques are ideal for analyzing equipment during operation.

To meet the need for advanced analytical techniques to ensure the reliability of aging equipment, we have developed the frequency resonance analysis (FRA)(5) method, ultra-high-frequency (UHF) insulation diagnosis method for GIS(6), and VCB vacuum level diagnosis method, in addition to the conventional dissolved gas analysis method. We have also adopted a neural network system (a mathematical approach)

[Fig. 1] Worldwide Network (as of Mar. 2011) to precisely assess the remaining life of transformers.

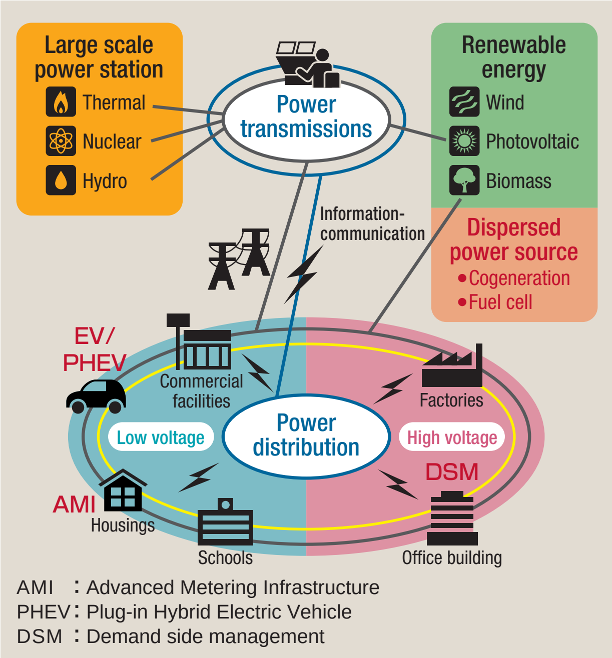
Meanwhile, to cope with the increased demand for replacing aging equipment, we have improved our techniques for assembling transformers on site, as well as for updating and extending the life of GIS.

1.5 Global development

In contrast to the lost two decades of economic stagnation in Japan, investment in developing countries such as China, India, and the Gulf countries in the Middle East as well as in resource-rich countries such as Brazil and Australia have boomed in the past decade. Japan AE Power Systems has therefore been setting up production and sales hubs since its establishment to build a global company. As shown in Fig.1, we operate a four-region system (covering the Middle East, China, Southeast Asia, and the U.S.), and our efforts are beginning to bear fruit. We have established offices in Beijing and Shanghai and have expanded production hubs in China. As described previously, in the UHV transmission project in China, the 1,100kV GISs we have delivered are now operating successfully. We have also sold many GISs and transformers to the Gulf countries in the Middle East, and look forward to the success of our Bahrain Branch, which was set up recently following the Dubai Branch. In the U.S., where demand for replacing many aging equipment will increase, sales of environmentally-friendly equipment such as SF_6 dry-air insulated VCB will expand, supported by continuous orders for 800kV GCB. Thus, we foresee global growth. Future challenges include building a more secure global system integrating India and South America.

2 Future prospects

With the growing environmental awareness, the production, consumption, and distribution of energy are changing worldwide. The most notable global trend in the distribution of electric power is the "smart grid," which is defined as an "electric grid for optimized bi-directional power transmission and distribution backed by information transmission technologies." Meanwhile, the globalization of information and communication technologies is also advancing rapidly thanks to the spread of the Internet. With regard to substation equipment, efforts are being made to ensure that Japanese standards such as JEC are consistent with the IEC standards, and international standardization is now in progress. Japan AE Power Systems develops equipment that complies with international standards including smart grids.



[Fig. 2] Concept of Smart Grid

2.1 Technology for 500kV to 1,100kV trunk systems (next-generation power network)

The 500kV systems installed in the 1970s in Japan will be updated in the next 5 to 10 years, and the new equipment must offer even higher reliability. In addition, the demand for switchgear having a rated interrupting current of 80kA, instead of the conventional 63kA, might increase due to the establishment of system grids and the connection of renewable energy to the grids. Regarding the power network, major technical innovations are expected in the future; one challenge is to reduce transmission loss and raise efficiency by establishing UHV power transmission networks[7]. Accordingly, transmission and distribution equipment needs to be improved to cope with the increasing use of UHV networks. Another challenge is technological improvement in high-voltage DC (HVDC) power transmission, which is ideal for long-distance power transmission. We are committed to developing and improving these technologies to satisfy global needs.

2.2 Technologies for ensuring highly reliable, high quality, stable networks

As total power generation increases worldwide, there is a growing need for more stable power supply. In today's advanced information society, stabilization of voltage and frequency is a critical issue, and so we are continually developing high-reliability equipment.

With the increasing use of renewable energy, the power flow in networks may change even further, so we will continue to provide high-quality phase-shifting transformers (PST)[8] to control power flows. A fault current limiting system will also be introduced in future.

2.3 Low-carbon/environment-friendly technologies

Mineral oil has long been used as a cooling-insulation medium for transformers, and is expected to continue being used. To reduce environmental impact and prevent disasters, we have developed products using substitute insulating liquids such as silicone oil and ester oil tailored to each application. With high-voltage/large-capacity switchgear, SF_6 gas will likely continue to be used due to its superior current interrupting characteristics. However, the use of SF_6 gas, a powerful greenhouse gas, must be minimized by making equipment smaller, eliminating natural leakage by developing and improving sealing technologies, and minimizing gas leakage during maintenance and inspections. The use of SF_6 gas could be minimized by improving the interrupting/insulating characteristics of VCB to the same level as SF_6 gas by achieving higher voltage and performance using dry air, which is generally used as an insulating medium, combined with solid insulation. As a future technology, semiconductor circuit breakers may be used for transmission systems thanks to the advancement of power semiconductor technology, and the combination with current limiting equipment might allow them to become key devices for future power networks. We are also working on this new technology.

2.4 Analytical technologies

Analyses for judging the success or failure of current interruption are necessary for switchgear. In the future, the breakers manufactured according to specifications determined by advanced analyses will be subject to type tests only to check their performance, and their development tests will be minimized. In addition, since the need for stable power supply will surely grow with the introduction of smart grids, more detailed system reliability analyses will be required.

2.5 Measures for maintaining aging equipment

Some countries such as the U.S. are updating their power transmission and distribution equipment and introducing IT for power networks, as manifested by the Green New Deal policy of the Obama Administration. In Japan also, power transmission and distribution equipment must be updated using new technologies complying with global standards. Technologies for total and partial updating (updating the interrupting unit of circuit breakers only and replacing degraded parts and frequently operated parts, for example) are expected to improve. The existing time-based maintenance (TBM)[9] is likely to gradually shift to condition-based maintenance (CBM)[10] or reliability-centered maintenance (RCM)[11]. We are therefore improving our diagnostic/monitoring technologies to reliably extend the life of equipment.

2.6 New materials

The use of newly developed insulating materials (such as alternative insulation fluids and heat-resistant solid materials) for transformers will increase for preserving the environment and extending the service life of equipment in line with social demand. Regarding switchgear, it is necessary to study new insulating media consisting of single or mixed gas from a broader perspective.

To improve the electrical performance of VCB, contact materials must be studied. Cu-Cr sintered material(12) is mainly used at present, and studies have shown that if the Cu-Cr surface is heated or cooled rapidly by vacuum arc, which occurs during conditioning, the molten texture on the surface significantly affects the electrical performance. Contact materials superior to Cu-Cr sintered material must be developed by studying the molten texture.

3 Conclusion

We will continue providing high-reliability, high-efficiency power distribution equipment for stable power supply worldwide, capitalizing on our experience of the past decade.

(1) Trunk system :
Major transmission system for power distribution of 275kV or higher

(2) Dry-air insulated C-GIS :
Cubicle type switchgear using dry air for insulation

(3) Environmentally-friendly VCB :
VCB using dry air for insulation

(4) Top-runner cast resin transformer :
Energy-saving transformer conforming to the government guideline

(5) FRA diagnosis :
Diagnosis based on frequency resonance analyses

(6) UHF analysis :
Diagnosis based on foreign-matter detection using ultra-high frequency of 300 MHz to 3 GHz

(7) UHV :
Ultra high voltage (between 1,000kV to 1,500kV)

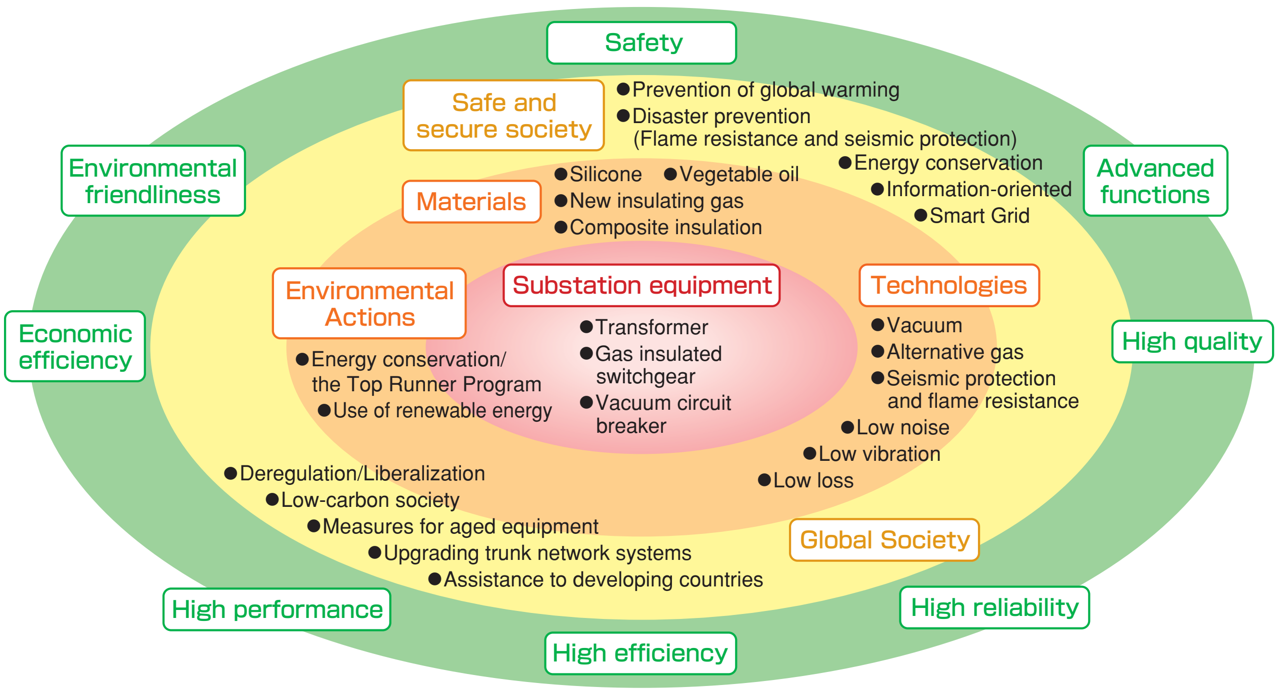
(8) PST :
Phase-shifting transformer

(9) TBM :
Time-based maintenance (maintenance of specified items at fixed intervals)

(10) CBM :
Condition-based maintenance (maintenance to be conducted based on equipment condition)

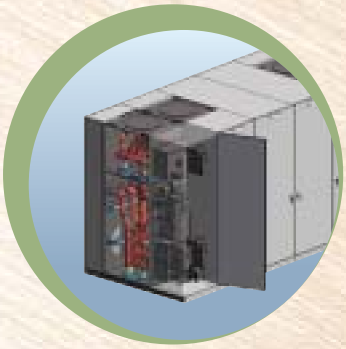
(11) RCM :
Reliability-based maintenance (maintenance focusing on serious abnormalities affecting equipment functions)

(12) Cr-Cu sintering material :
Metallic material obtained by sintering chromium and copper powder



[Fig. 3] Current circumstances surrounding substation equipment

HIGHLIGHTS



275kV Transformers delivered to Kansai Electric Power Co., Inc.

450MVA transformer for Higashi-Osaka substation

The aging transformers of Kansai Electric Power Co., Inc. have been steadily updated, with Japan AE Power Systems successively delivering 275kV transformers to the company's Minami-Himeji, Shin-Kakogawa, and Higashi-Osaka substations.

- Minami-Himeji substation:
  3-phase 275kV 300MVA 1unit
- Shin-Kakogawa substation:
  Special 3-phase 275kV 200MVA 1unit
- Higashi-Osaka substation:
  Special 3-phase 275kV 450MVA 1unit

We have delivered many 275kV transformers to Kansai Electric, and replaced aging transformers with more reliable units using the latest technologies.

Factory test of 300MVA transformer for Minami-Himeji substation

In the improved transformers, the bushing on the 275kV side penetrates the housing horizontally to reduce installation area (Minami-Himeji substation), and noise has been reduced by adopting a large-capacity aluminum compact cooler in addition to steel insulating walls (Shin-Kakogawa and Higashi-Osaka substations). The unit for Higashi-Osaka substation, in particular, satisfies the nation's first 50dB low-noise specifications.

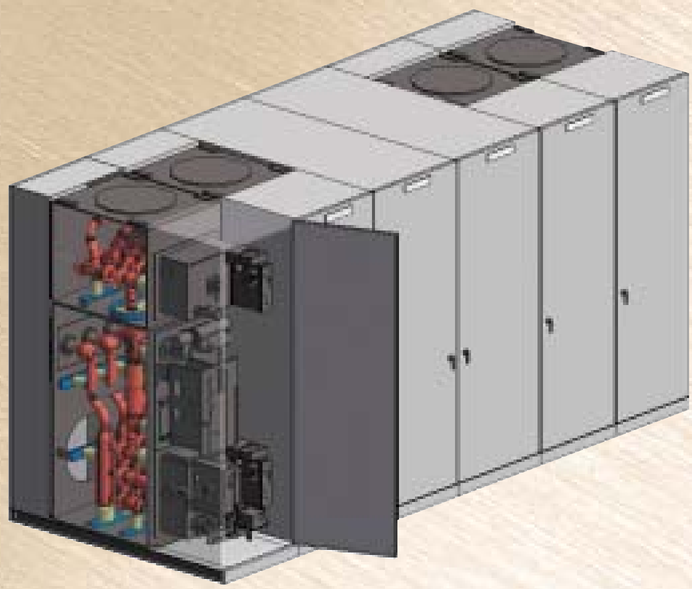
In addition, the efficiency of the design, manufacture, and processing of transformers having different specifications has been improved by the following:

- Automatic drafting of drawings based on standardized core structure
- Reduction in the number of man-hours based on improved core and winding structures
- Standardization and sharing based on test production and structural review

These transformers have been successively delivered to each site after carefully coordinating the schedule of manufacturing processes, delivery, transportation, and on-site assembly work.

We will continue updating aging equipment more efficiently and rationally to enhance the reliability of our products.

Commercialization of 72kV Cubicle-type Dry Air Insulated Switchgear



72kV cubicle-type dry air insulated switchgear

SF_6 gas is generally used as an insulating/arc-quenching medium for switchgear. However, since its global warming potential is 23,900 times higher than that of CO_2, its use must be minimized.

Japan AE Power Systems has been developing switchgear using a vacuum interrupter (VI) for the interrupting part and dry air as an insulating medium. The newly-developed 72kV cubicle-type dry air insulating switchgear is summarized below.

Since the dielectric strength of dry air is less than one third of that of SF_6 gas, equivalent insulating performance was attained by adopting partial hybrid insulation technology based on insulating sheathing of high electrical field regions while minimizing the pressure increase. Furthermore, a VI based on the axial magnetic field electrode method, which provides high insulating performance, was used for the interrupting part. By optimizing the electric field distribution and intensifying the axial magnetic strength, sufficient insulating and interrupting characteristics were achieved, and the outer diameter of the VI was decreased to 88% of the conventional model. The product is thus almost the same size as the existing SF_6 gas insulation type.

In addition, a self-diagnostic device for monitoring the operating time and partial discharge of the interrupting part as well as the loss of vacuum of VI has been developed and made available as an option to improve reliability through constant supervision and minimize inspection items, thus reducing maintenance cost.

Units for overhead line connection and direct transformer connection as well as molded insulation type CT and EVT housing the switchgear within a tank were developed to create a C-GIS satisfying various customer needs such as for use in various circuit configurations and more compact equipment.

We will continue to develop environment-friendly equipment.

Rating and specifications

Rated voltage	72kV
Rated current	800/1200A
Rated short time current	25/31.5kA-2s
Rated lightning impulse withstand voltage	350kV
Rated air pressure	0.16MPa·G

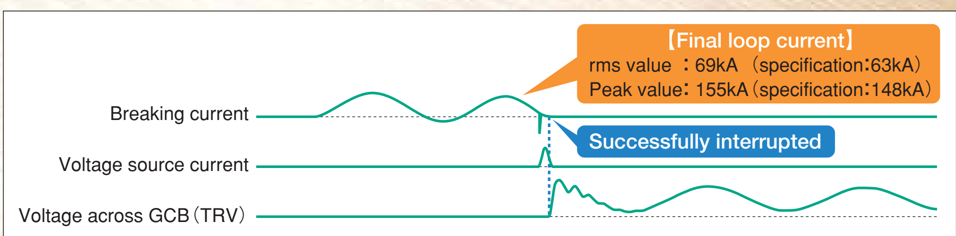
Type Test of Breaking Performance of 1100 kV 63 kA Gas Circuit Breaker

T100a full-pole test configuration in XIHARI

To fulfill the demands in overseas market, Japan AE Power Systems started the development of 1,100kV 63kA gas circuit breaker (GCB) for gas insulated switchgear (GIS) in late 2009. In the verification tests at high power laboratory of Japan AE Power Systems, the GCB was confirmed to have enough interrupting performance for various duties for the upgrading of breaking current specification from 50kA to 63kA. In addition, in China, the series capacitors will be installed in UHV transmission systems, in order to improve the efficiency of electric power transmission of 1,000kV (UHV) systems. However, in case of the grounding faults in UHV transmission systems with series capacitors, the voltage higher than switching impulse withstand voltage is applied across GCB as transient recovery voltage after current interruption. Therefore, the change in breaking current and the very high transient recovery voltage are added as new specifications for 1,100kV GCB. The type tests of 1,100kV 63kA GIS-CB, including the above new two duties, were carried out from the end of August, 2010, at Xi'an High Voltage Apparatus Research Institute (XIHARI), a third party testing laboratory in China, in cooperation with New Northeast Electric Group Ultra High Voltage Equipment Co., Ltd.

In XIHARI, firstly, the tests for duties of capacitive current switching, out-of-phase, grounding fault in system with series capacitors, T100a and T100s were performed and completed within about one month, in very short period of time. In these duties, in case of T100a and T100s, GCB must interrupt very high current of 63kA. Especially in the case of T100a, the breaking current contains large d.c. component with large decay time of 120 ms, therefore T100a is very severe breaking duty for GCB. In the actual test, the UHV-GCB interrupted the current with peak value of final loop of breaking current of 155kA, that is much higher than rated peak value of 148kA, and the 1,100kV GCB was proved to have enough breaking capability. The other tests were successfully completed as well as the above tests, including the electrical endurance (E2) test that specifies 16 times interruption of 63kA without maintenance. In XIHARI, the developed 1,100kV GCB interrupted 20 times for this duty.

The 1,100kV 63kA GCB will be delivered to Nanyang switching station at Henan Province in China, as one of the expansion construction projects of UHV-AC pilot transmission system. And the application of the UHV-CB to 63kA transmission systems, planned to be constructed in China, is expected.



Waveforms of T100a (major loop) breaking test

Completion of Corp600 project for ESKOM of South Africa

In South Africa, there is an urgent need to build a power grid for supplying power from many large coal-fired thermal power plants located to the east of Johannesburg to the southern region including Cape Town, and a 765kV transmission system must be set up as soon as possible to serve as a major trunk system.

Japan AE Power Systems has completed on-site installation of six 765kV 666.7MVA single-phase transformers and twelve 765kV 133.3Mvar single-phase reactors for the Corp600 project of ESKOM, the national power company of South Africa. Bids were submitted in March 2006 for the turnkey contract to collectively undertake the manufacture, transportation, installation, and testing of equipment. Our high technical expertise embodied in our products delivered over 20 years since the days of Fuji Electric, one of the predecessors of Japan AE Power Systems, was evaluated highly and led to the winning of the order.

Local South African companies performed on-site transportation, installation, and testing, and thanks to close coordination between the local staff and our instructors and the two-group system for working on transformers and reactors separately, the project was successfully completed as scheduled. The following equipment has finally been installed:

1) Zeus substation

①2000/3MVA 765/400/33kV transformers: 3 units (1 bank)

② 400/3MVar 765/3kV shunt reactor: 3 units (1 bank)

2) Perseus substation

①2000/3MVA 765/400/33kV transformers: 3 units (1 bank)

②400/3MVar 765/3kV shunt reactors: 9 units (3 banks)

With the completion of the project, the cumulative total of delivered transformers now stands at 26 and reactors at 39, raising our share of 765kV equipment to over 70%.

ESKOM plans to expand the 765kV transmission systems, and we will continue supplying our products to the company.

● Mounting 800kV bushing

● Before cable connection

Introduction of 36kV and 72/84kV Environment-friendly VCB

Japan AE Power Systems has developed a 72/84kV environment-friendly vacuum circuit breaker (VCB) using dry air instead of SF_6 gas, which is a greenhouse gas, as an insulating medium.

This SF_6 gasless VCB has a lower lifecycle cost because it is lighter thanks to the use of aluminum for major parts such as tanks, has lighter transport current loss, and does not require repair painting.

We started delivering the VCB to overseas users in 2007, and to domestic users in 2008. Approximately 100 units in total have been delivered to North American and Australian users and 70 units to domestic users, and they are all currently in operation in various fields including general, railway and power industries.

72/84kV environment-friendly VCB

In response to increasing environmental awareness, users are studying the feasibility of shifting from conventional VCB using SF_6 gas to environment-friendly VCB.

The environment-friendly VCB, which has already attained a high reputation because of its high specifications and performance, will be delivered to environment-conscious overseas countries and the domestic market.

Furthermore, as a new model of the environment-friendly VCB series, the 36kV VCB, which also uses dry air similar to the 72/84kV VCB, was developed in 2010.

36kV environment-friendly VCB

The first unit of this 36kV VCB will be delivered to Australia in the summer of 2011.

We will make the 36kV VCB into a series like the 72/84kV VCB to strengthen the lineup and help reduce environmental impact.

800kV Gas Circuit Breakers for the U.S. Market

Japan AE Power Systems was the first Japanese manufacturer to enter the North American 800kV substation equipment market, delivering 800kV dead tank type gas circuit breakers (GCB) to American Electric Power Company, Inc. (AEP), one of the biggest U.S. power companies operating the largest 765kV electric power network. These GCB's, having passed the rigorous tests including a withstand voltage test, transient recovery voltage test, and post-interruption withstand voltage test, were recognized for their high reliability backed by the closing method using pre-inserted resistors, which is one of the features of the 800kV GCB of Japan AE Power Systems. The first unit started to be operated in 2008, and we received a total of 10 orders for the GCB's that year. Furthermore, at the end of 2009, AEP established Transco, a wholly owned subsidiary of AEP in charge of investing in its new transmission networks and updating existing facilities. The establishment of Transco reflects AEP's policy of strengthening the 765kV power networks. We were awarded 17 units in total from AEP for fiscal 2010, and these are now being delivered in turn.

Installation of GCB at substation

Shop test

The GCB features two of the latest 420kV interrupting units connected in series. By standardizing these units such as the interrupting part and hydraulic operating mechanism, parts can be shared with other equipment of different rated voltage. A bilaterally symmetrical two-block structure was adopted, and the parts within a tank were made into a unit structure. Each unit can be pre-assembled, which minimizes the assembly work within the tank. Furthermore, by minimizing the height of the GCB, containerized transportation is possible unlike for the UHV-class GCB, thus facilitating ocean and land transportation.

AEP plans to strengthen the 765kV networks connecting various states. We will focus on delivering as many 800kV GCB's as possible to enhance the reliability proven by those currently in operation.

New Technologies & Products

Assessment of Degradation Indicators for
Oil-immersed Transformers during Overload Operations

Inspection of Secular Degradation of
Ultra-high-voltage Circuit Breaker by Accelerated Degradation Test

Improvement of 72kV-class Vacuum
Interrupters and Vacuum Circuit Breakers

Arc and Hot Gas Flow Simulation to
Evaluate Interruption Performance for Gas Circuit Breakers

Assessment of Degradation Indicators for Oil-immersed Transformers during Overload Operations

Hideyuki MIYAHARA | Katsunori MIYAGI | Etsuo OE

Electric power suppliers independently define the upper limit of capacity and operating time of transformers to be operated under overload depending on the estimated life loss of transformers. However, the relation between overload operating conditions and life loss of transformers has not been fully determined. In this research, the effect of differences in overload operating conditions on degradation diagnostic assessment was studied using various overload patterns, for the same estimated life loss of winding insulating paper, to minimize the risk of overload operation of transformers. It was found that the conventional degradation diagnostic method is valid provided that overload operation is performed according to the existing guideline for transformer operation.

1 Introduction

The power flow of power transmission and distribution equipment under normal conditions is determined with the rated capacity of the equipment regarded as the upper limit, taking into consideration the permitted overload capacity for the failure of a single unit in parallel facilities. Transformers can be continuously operated at their rating within the rated capacity. In case of a failure, a temporary increase in the temperature of the transformer winding is permitted to ensure operation for a limited period of time within the overload capacity of transformers[1]. Meanwhile, the life of transformers depends on the mechanical strength of the winding insulating paper. Winding temperature during operation and operating time are two major factors that affect the degradation of insulating materials. Electric power suppliers set the upper limit of capacity and operating time under overload conditions based on the degree of loss of life of transformers to allow overload operation. However, the relation between the overload operating conditions and the life of transformers has not been fully determined.

Based on the overload pattern of a transformer for a distribution substation[2], the effect of differences in overload operation status on the degradation diagnostic assessment (mean degree of polymerization and furfural, and production of CO_2+CO) was studied using various overload patterns (short-time overload, long-time overload, etc.) for the same estimated life loss of winding insulating paper. The results are summarized below.

2 Life loss and overload patterns of transformers

2.1 Normal life and overload operation

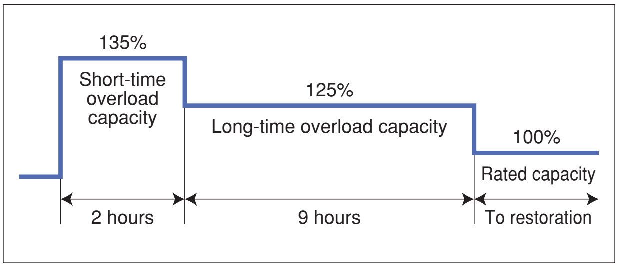
The Japanese transformer standard (JEC-2200) stipulates the following conditions to ensure a normal life of approximately 30 years[3]:

(i) Ambient temperature of 25˚C
(ii) Continuous operation at the rated load
(iii) Hottest-spot temperature of 95˚C

Meanwhile, a report on the guideline for operating oil-immersed transformers recommends the following restrictions for overload operations of transformers[4]:

(i) Overload capacity not exceeding 150%
(ii) Hottest-spot temperature of winding not exceeding 150˚C
(iii) Maximum oil temperature not exceeding 100˚C

Electric power suppliers define overload operating procedures separately for short-time and long-time overload capacities, with slight differences between the suppliers. Fig. 1 illustrates a typical overload operation pattern of a transformer in a power distribution substation[2]. Various overload patterns consisting of short-time and long-time overload capacities must be studied for a possible failure of parallel facilities of the substation.



[Fig. 1]
Typical overload pattern of a distribution transformer [2]

2.2 Concept of life loss

The thermal degradation of insulating materials is generally calculated by Arrhenius' equation. Within the heating temperature range from 80˚C to 150˚C, degradation of mechanical strength of insulating materials is approximated by Montsinger's equation, and the life Y of insulating materials is given by[4]

$$Y = a \cdot e^{-b\theta} \quad \cdots\cdots (1)$$

where, a is a constant, θ is temperature (˚C), and b is an index indicating the thermal durability of insulating materials.

Assuming the normal life of a transformer under continuous operation at the temperature of 95˚C as Y_0, the life loss V after the operation of h hours at the overload temperature of θ˚C (>95˚C) can be calculated by

$$V = \frac{h}{Y} = \frac{1}{Y_0} \cdot \frac{h}{(Y/Y_0)} = \frac{h}{Y_0} \cdot e^{b(\theta-95)} \quad \cdots\cdots (2)$$

Meanwhile, the life loss V when the overload temperature θ changes with time (θ = f(t)) is given by[4]

$$V = \frac{1}{Y_0} \int \frac{dt}{(Y/Y_0)} = \frac{1}{Y_0} \int e^{b(\theta-95)} dt$$
$$= k \int e^{b\theta} dt \quad \cdots\cdots (3)$$

where, k is a constant and b is 0.1155 (thermal durability of kraft insulating paper).

The life loss per overload operation of typical transformers is defined as approximately 1% to 5% (with normal life loss for one year regarded as 100%).

2.3 Assumption of overload patterns

As a basic overload pattern for a day (24 hours), the following case was assumed: overload duration: two hours, hottest-spot winding temperature: 152˚C, normal load duration: 22 hours, and winding temperature: fixed at 95˚C. In addition, four more overload patterns were assumed, reflecting actual overload operations. Table 1 summarizes the relation between overload duration and temperature for each overload pattern. These five patterns were determined so that the life loss of insulating paper for each overload pattern obtained by equation (3) remained the same.

[Table 1] Loading time per day (one cycle)

Overload pattern	Overload duration	Normal load duration
①Short-time overload	2 hours at 152℃	22 hours at 95℃
②Long-time overload	8 hours at 138℃	16 hours at 95℃
③Two-stage (short-and long-time)	8 hours at 141 to 132℃	16 hours at 95℃
④Continuous overload	24 hours at 127℃	—
⑤High-temperature overload	1 hour at 161℃	23 hours at 95℃

3 Samples and testing method

3.1 Samples for heating test

Insulating oil, kraft paper and a copper wire were placed in a glass ampoule, and then nitrogen gas was injected into the ampoule to degrade the samples by heating in the sealed state (Table 2). The moisture content of the kraft paper was adjusted to 2% (at 20˚C), with the moisture control value and the moisture content of the insulating paper of aging transformers taken into consideration.

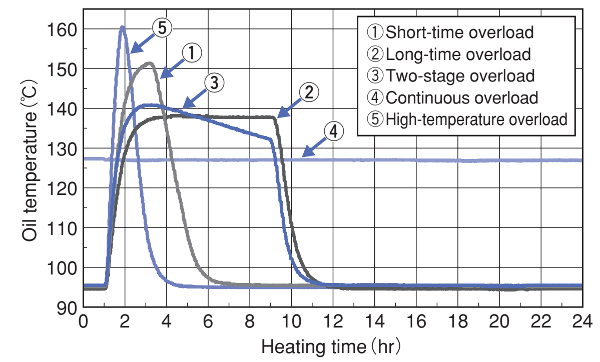
[Table 2] Samples used for the test

Sample	Quantity
Mineral oil	217.5g (250ml)
Kraft paper	7.5g (75μm×20mm×200mm)
Copper wire	6.3g (ϕ1mm×130mm×7)

3.2 Heating degradation test method

The glass ampoule containing samples was placed in a thermostatic oven and heated in five patterns for degradation in 20-, 40- and 60-day cycles. Oil temperature was measured by a thermocouple inserted into the glass ampoule and the obtained data was recorded by a data logger once a minute, and the life loss for a day was calculated by equation (3). The overload temperature setting conditions of the thermostatic oven and the overload duration were fine-tuned to make the measured life loss for each overload pattern the same. The difference between the life loss of each overload pattern and that of the short-time overload pattern (reference) was controlled to be within 5%. Fig.2 shows the oil-temperature curve of each load pattern for a day (one cycle).

After the test was conducted in the given heating cycles, the mean degree of polymerization (DP) of each kraft paper was measured, and CO_2+CO in the gas phase of each sample, furfural (2-FAL) and CO_2+CO in oil, and 2-FAL and CO_2+CO in insulating paper were analyzed to calculate the entire quantities of 2-FAL and CO_2+CO.



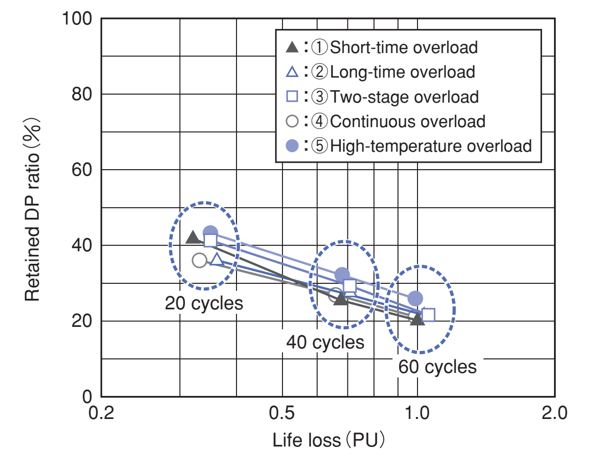
[Fig. 2]
Measured oil temperature waveform of each load pattern

4 Test results and consideration

There are various methods of diagnosing the degradation of transformers, including measuring the DP value, which is closely related to tensile force, of winding insulating paper taken from a transformer, and analyzing the quantity of degradation indicators (2-FAL, CO_2+CO) within insulating oil.

4.1 Degradation characteristics of measured life loss

Degradation of each sample subjected to 20-, 40- and 60-cycle continuous heating was analyzed. Fig. 3 illustrates the retained DP ratio characteristics. The horizontal axis represents the measured life loss ratio for the short-time overload pattern ① after 60 cycles (see Table 3). As shown in Fig. 3, the retained DP ratio decreases linearly with increase of heating cycles. The difference in retained DP ratio of insulating paper for each load pattern falls within the ±5% range, which is comparable with the difference in directly measured life loss (±5%).



[Fig. 3] Heating cycle characteristics of retained DP

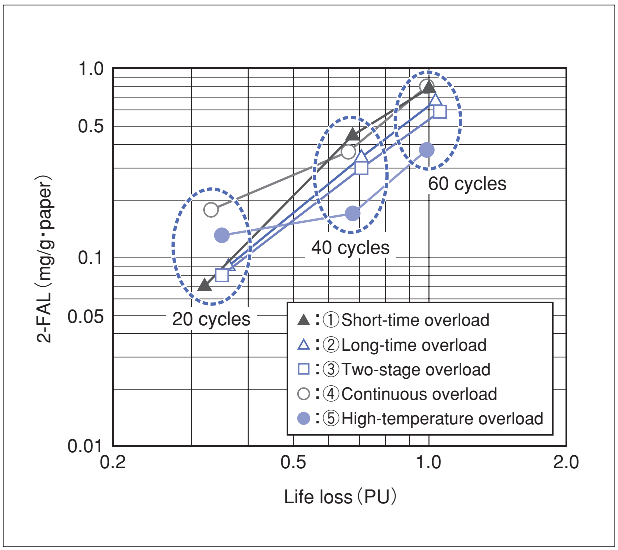
[Table 3]
Measurement of life loss ratio for each overload pattern

Overload pattern	Life loss ratio		
	20 cycles	40 cycles	60 cycles
①Short-time overload	0.32	0.68	1.00
②Long-time overload	0.36	0.71	1.03
③Two-stage overload	0.35	0.71	1.06
④Continuous overload	0.33	0.66	0.99
⑤High-temperature overload	0.35	0.68	0.99

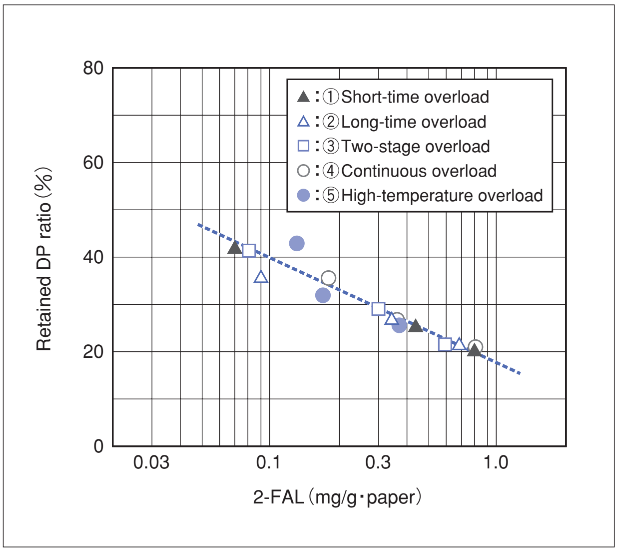
Note: With reference to the 60-cycle short-time overload pattern as 1.00.

Fig. 4 illustrates the production characteristics of 2-FAL, a degradation indicator. Although a big difference was found with 20 cycles, the patterns almost coincided with 40 and 60 cycles except for the high-temperature overload pattern ⑤. Meanwhile, as shown in Fig. 5, the CO_2+CO degradation indicator production characteristics tended to coincide except for the high-temperature overload pattern ⑤.

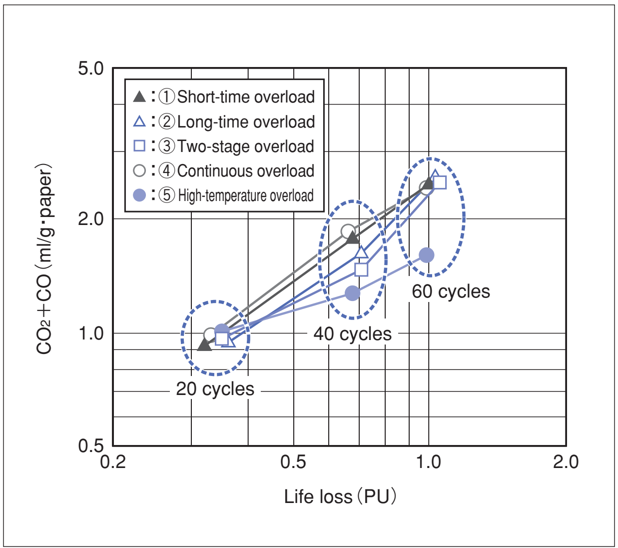
These results indicate that the degree of degradation of insulating paper is relatively low with the sharp high-temperature overload pattern, because the moisture content in the insulating paper is as high as



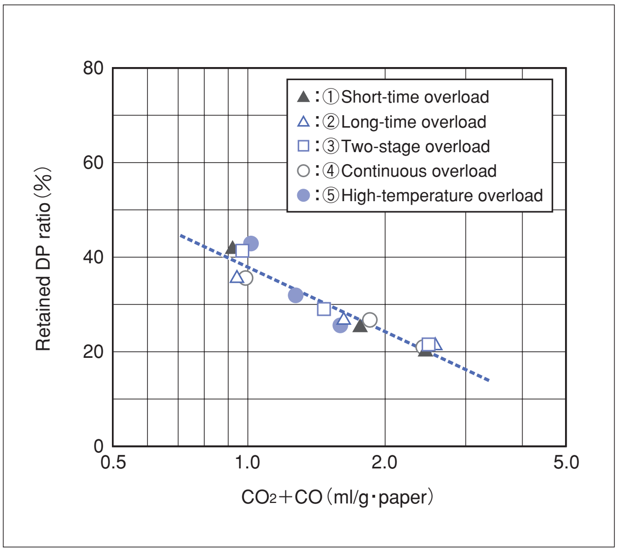
[Fig. 4] 2-FAL production heating cycle characteristics



[Fig. 6] Relation between 2-FAL and retained DP



[Fig. 5] CO_2+CO production heating cycle characteristics



[Fig. 7] Relation between CO_2+CO and retained DP

2%, causing air bubbles to form in the moisture of the insulating paper if the temperature quickly rises to approximately 160˚C thus decreasing the moisture content of the paper[5].

4.2 Evaluation of retained DP ratio and the quantity of degradation indicators

Fig. 6 illustrates the relation between the generated quantity of 2-FAL and retained DP obtained by the heating test, and Fig. 7 illustrates the relation between the generated quantity of CO_2+CO and the retained DP. Both figures exhibit good correlation between each degradation indicator and the retained DP. From these figures, the quantity of degradation indicator equivalent to the danger level DP250 (retained DP of 25%) of the insulating paper is approximately 0.5 mg/g･paper for 2-FAL, and 2 ml/g･paper for CO_2+CO. Meanwhile, a test report on heat degradation characteristics insulating paper within oil by constant-temperature heating[6] indicates that the total quantity of 2-FAL equivalent to DP250 is 0.4 to 0.5 mg/g･paper, whereas that of CO_2+CO is 2.0 to 2.5 ml/g･paper, which are comparable with the values obtained by this research. Thus, overload operation of transformers was found to have little effect on the analysis of degradation indicators in oil, and consequently the conventional degradation diagnostic method is considered to be applicable.

5 Conclusion

To manage the risk of overload operation of transformers, the effect of differences in overload operating conditions on the degradation diagnostic evaluation was examined. The results showed that the difference in overload operating conditions of transformers has little effect on the analysis of degradation indicators in oil, and that the conventional degradation diagnostic method is applicable. We will establish a method of assessing the degradation of insulating materials of aging transformers.

This research was commissioned by Chubu Electric Power Co., Inc.

References

[1] Electric Power System Council of Japan, The Rules of ESCJ (2010)

[2] Chubu Electric Power Co., Inc., Power Transmission and Distribution Facilities Expansion Guideline (2009)

[3] The Institute of Electrical Engineers in Japan, "Transformer," Japanese Electrotechnical Committee standard JEC-2200 (1995)

[4] Transformer Reliability Study Committee, "Operation Guideline for Oil-immersed Transformers," The Institute of Electrical Engineers in Japan technical report (Part I), No. 143 (1986)

[5] T. Masuyama, K. Miyagi, Y. Yagihashi, T. Saito, "Characteristics of generation of air bubbles in oil of mobile transformer winding model," Academic conference in 2005 of the power/energy department convention of the Institute of Electrical Engineers in Japan, 367 (2005)

[6] H. Sakai, N. Daikuhara, Y. Ishioka, S. Isaka, "Heat degradation characteristics of insulating paper for transformers," Collection of abstracts for the workshop of the 21st insulating oil subcommittee of the Japan Petroleum Institute, pp. 50–53 (2001)

Authors

Hideyuki MIYAHIRA
Design Department
Medium Power Transformer Business Unit
Transformer Business Division
Member of the Institute of Electrical Engineers of Japan

Katsunori MIYAGI
Manager
Research & Development Management Department
Research & Development Division
Doctor of Engineering
Senior member of the Institute of Electrical Engineers of Japan

Etsuo OE
Design Department
Medium Power Transformer Business Unit
Transformer Business Division

Inspection of Secular Degradation of Ultra-high-voltage Circuit Breaker by Accelerated Degradation Test

Shunichi ISHIZEKI

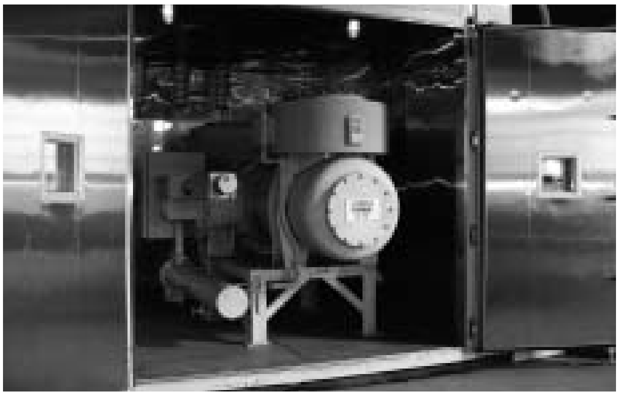
Gas circuit breakers (GCB) installed during the period when power demand was escalating are aging, causing concern about degradation and failures due to repeated operations.
Samples were taken from the three phases of a 35-year-old 240kV double-break GCB that had been operated in the field. The red phase was disassembled immediately, the white phase was disassembled after a constant-temperature accelerated degradation test (equivalent to 50 years), and the blue phase was disassembled after a 2,000-times continuous switching test to examine how degradation progresses due to aging and repeated switching operations. The results were as follows.

1 Introduction

There is concern about possible troubles with aging gas circuit breakers (GCB) due to secular degradation and repeated switching operations. To analyze the degradation status, the three phases (red, white, and blue) of a 35-year-old GCB were disassembled immediately, after a constant-temperature accelerated degradation test (equivalent to 50 years), and after a 2,000-times continuous switching test, respectively.

2 Inspected GCB and inspection method

Table 1 lists the specifications, age, and number of times of breaking operations of the GCB inspected. As additional load tests, the white phase was subjected to a constant-temperature accelerated degradation test (Fig. 1), and a 2,000-times continuous switching test was conducted on the blue phase.



[Fig. 1]
White phase under constant-temperature accelerated degradation test

[Table 1] Inspected GCB

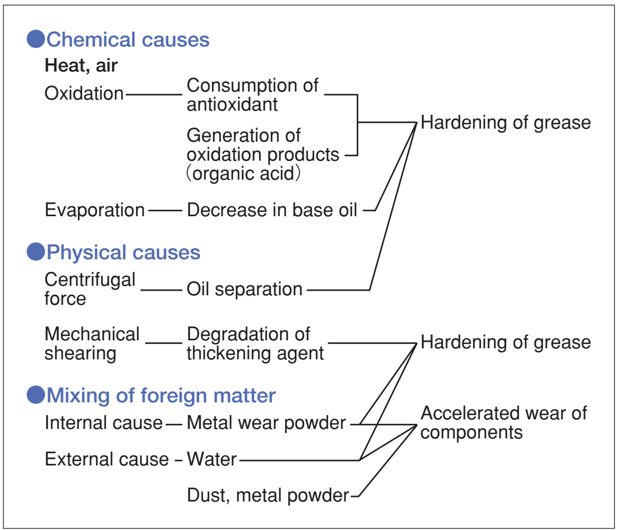
Equipment	Pneumatically-operated GCB		
Type	OFPTB-200-40L, PAR		
Rated voltage	240kV		
Rated current	2,000A		
Year of manufacture	1973		
Age	35 years old		
Application	For power transmission line		
Number of breaking operations at removal	Red phase: 568, White phase: 566, Blue phase: 568		
Details of additional load test	Red phase	White phase	Blue phase
	Disassembled immediately	Disassembled after an accelerated degradation test	Disassembled after a 2,000-times continuous switching test

3 Inspection result

3.1 Grease

Grease is used in various places of GCB driving units for lubrication and to maintain air-tightness. Grease is applied to the energized sliding contacts to ensure smooth movement and prevent wear of the silver plating of the contacts. It is also applied to the shaft seals of the main lever, for example, to ensure that rotation starts smoothly and to prevent gas leakage into the atmosphere.

As shown in Fig. 2, the causes of degradation of grease include chemical causes, physical causes, and mixing of foreign matter, and symptoms of degradation include hardening, softening, and accelerated wear of components.

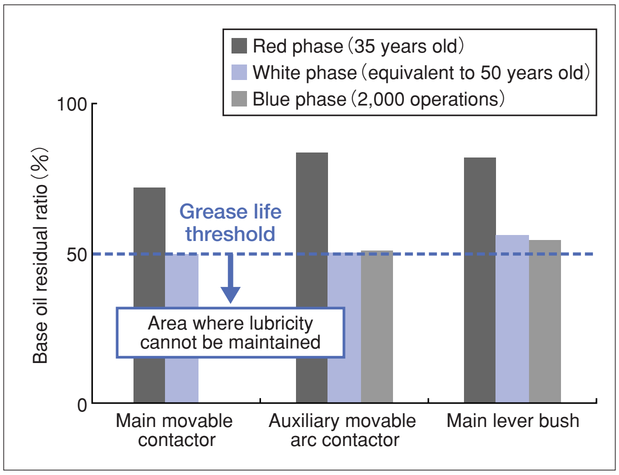


[Fig. 2] Symptoms of degradation of grease

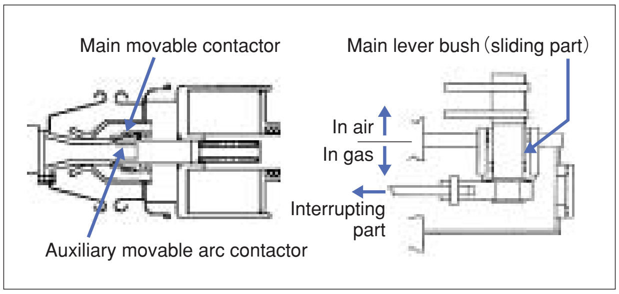
Fig. 3 illustrates the base oil residual ratio of the grease taken from three positions (white and blue phases: collected after the additional load tests), and Fig. 4 illustrates the positions from which the grease was collected. Lubricating performance cannot be maintained if the base oil residual ratio decreases to 40 to 60%. Grease is therefore assumed to have reached the end of its service life when the base oil residual ratio reaches the threshold of 50%.

The base oil residual ratio of the white phase, which had undergone an accelerated degradation test equivalent to 50 years, and of the blue phase, which had undergone a 2,000-times switching test, was found to have decreased to around 50%, causing concern about an increase in contact resistance and stiffening of operation of the main lever resulting from continuous use of the grease.

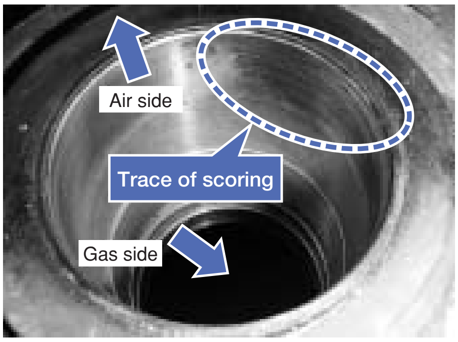
Fig. 5 is a photo showing the scoring found within the main lever bush of the blue phase disassembled after the continuous switching test.



[Fig. 3] Base oil residual ratio of each part



[Fig. 4] Positions from which grease was collected



[Fig. 5] Scoring within the main lever bush

Although no abnormality was found in the switching characteristics, scoring was found on a part of the internal face of the bush. If the GCB were to be operated many times in such conditions where the base oil residual ratio is near the threshold, gas leakage or stiffening of operation may result.

3.2 O-ring/packing

The compression set rate and hardness of O-rings and packings used in parts that had never been disassembled or replaced for inspection since installation were measured.

The thickness of the O-ring was measured at four positions on its circumference, namely the four points of intersection of the circumference of the O-ring and two straight lines crossing perpendicular to each other at the center of the O-ring, approximately 30 minutes after the sample was taken.

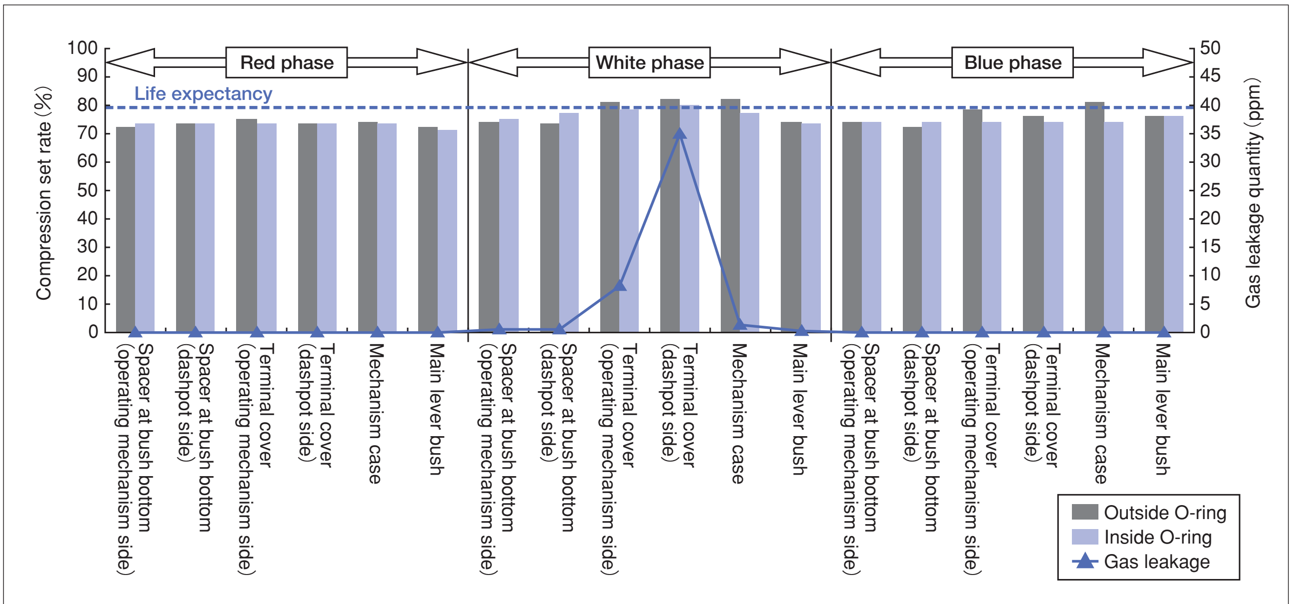
It has been reported that the risk of gas leakage increases dramatically if aging progresses and the compression set rate reaches 80%, which is therefore defined as the threshold value of the life of O-rings. Table 2 summarizes the results of the compression set rate and hardness tests conducted. A comparison of the average compression set rate of the outer O-rings of the three phases showed that the value of the red and blue phases was 45.9%, whereas that of the white phase, which had been subjected to accelerated degradation, was 63.4%. Meanwhile, the average value of the internal O-rings of the red and blue phases was 35.5%, whereas that of the white phase was 52.6%.

The compression set rate and hardness of the outer O-rings were higher than those of the inner O-rings probably because the outer O-rings are susceptible to rusting due to contact with the atmosphere and rainwater, causing faster degradation.

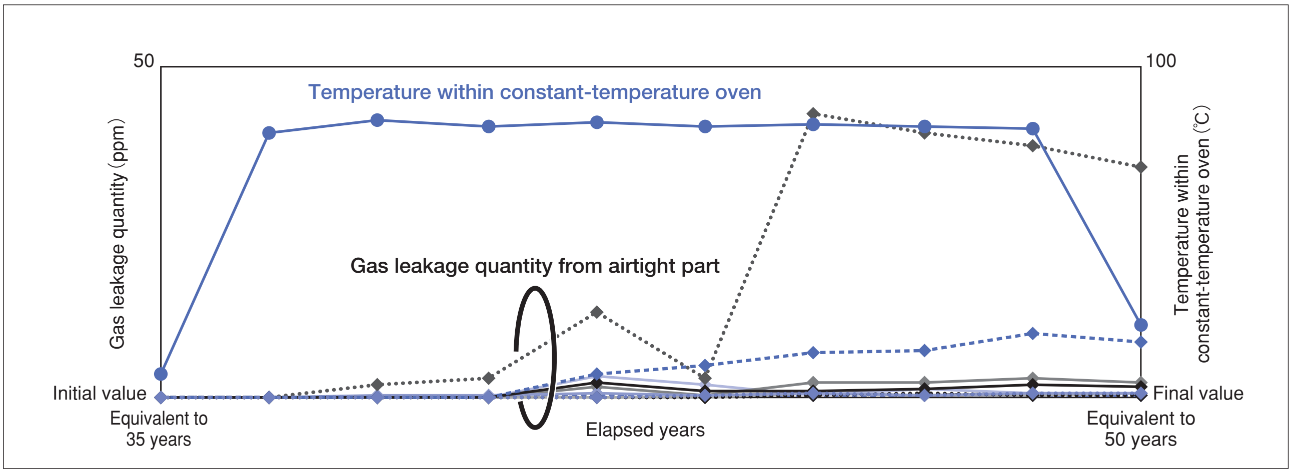
Fig. 6 shows the relation between the compression set rate and gas leakage quantity. It was found that the compression set rate of the red and blue phases was approximately the same, and no leakage was found. However, the white phase, which had undergone the accelerated degradation test, demonstrated a much higher compression set rate. From the gas leakage quantity in the accelerated degradation test shown in Fig. 7, the leakage was confirmed to have started when degradation progressed to the level equivalent to 38 years of operation, and leakage was eventually found at all the airtight positions.

[Table 2] Compression set rate and hardness measurements

No.	Position	Compression set rate		Hardness		Gas leakage	Note
		Min. ~ Max.	Average	Min. ~ Max.	Average		
1	Fixed part in gas (outside), Red and blue phases	23.6~75.0 (%)	45.9	66.0~81.0	73.0	Without	
2	Fixed part in gas (inside), Red and blue phases	27.0~74.0	35.5	67.0~82.0	68.3	Without	
3	Sliding part in gas, Red and blue phases	50.6~55.3	52.7	71.0~76.0	73.8	Without	
4	Fixed part in gas (outside), White phase	30.0~77.1	63.4	66.0~87.0	77.6	With	After accelerated degradation test
5	Fixed part in gas (inside), White phase	39.0~76.4	52.6	74.0~84.0	69.6	With	
6	Sliding part in gas, White phase	49.4~50.6	50.0	73.0~74.0	73.5	With	



[Fig. 6] Relation between compression set rate and gas leakage quantity

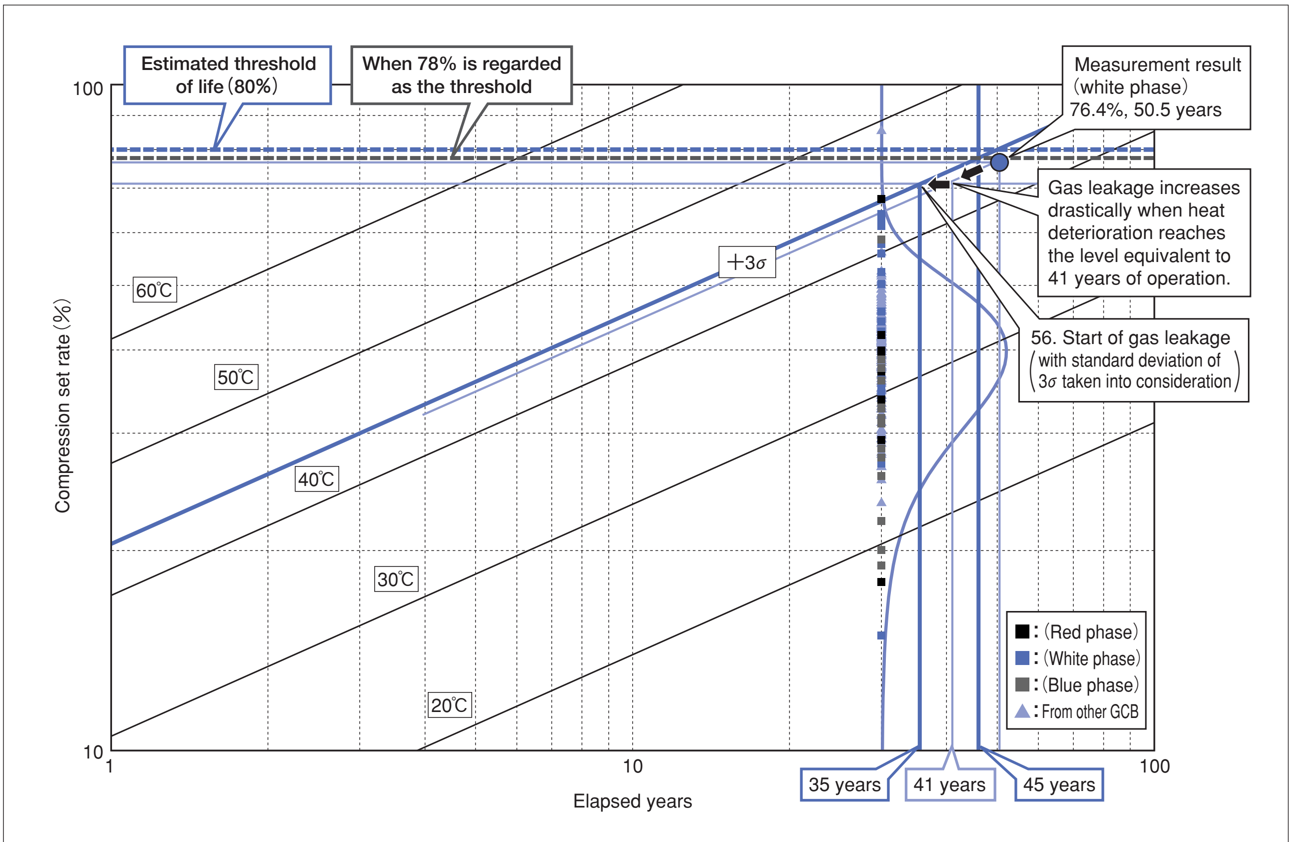


[Fig. 7] Gas leakage quantity in accelerated degradation test

It was also confirmed that after the accelerated degradation test, gas leakage continued even at room temperature.

Past field data and relevant data on the compression set rate of the O-rings of the GCB were compiled and plotted on a normal distribution after conversion into degradation after 30 years. Fig. 8 shows the result of the statistical analysis of the compression set rate obtained.

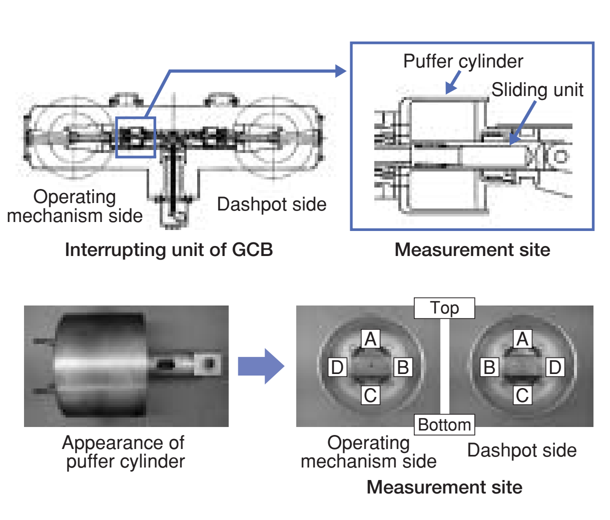
In the accelerated degradation test of the white phase, the gas leakage started to increase dramatically when the degradation reached the level equivalent to 41 years of operation. The life of O-rings was assessed based on this result, and gas leakage was assumed to have started when 35 years have elapsed (Fig. 8), with standard deviation 3σ taken into consideration. Meanwhile, the threshold of life expressed in terms of compression set rate or gas leakage ranges between 78% and 86%. If 78% is



[Fig. 8] Statistical analysis result of compression set rate (inside O-rings) adopted as the threshold, O-rings reach the end of their life after 45 years. From the above, the expected life of O-rings is estimated to be 35 to 45 years.

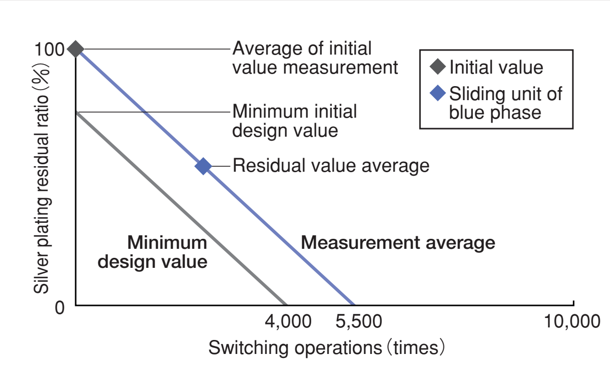
3.3 Silver plating

As a result of measuring the plating thickness of the puffer cylinder, the wear of the plating of the blue phase, which had undergone the 2,000-times continuous switching test, was confirmed to be higher than that of two other phases.



[Fig. 9] Measurement site of silver plating of puffer cylinder

The silver plating thickness of the puffer cylinder of the blue phase after the continuous switching test was measured, and the relation between the number of switching operations of the GCB and the wear of the silver plating was determined. It was found that the base material might be exposed due to wear after approximately 5,500 operations, assuming that the volume of wear of the silver plating per operation is the same.



[Fig. 10] Estimated life of silver plating of puffer cylinder

4 Consideration

Major degraded parts found by the inspection are summarized below.

[Table 3] Major degraded parts found by the inspection

No.	Item	Possible trouble
1	Grease in gas Grease of major lever (Degradation of grease)	Progress of sliding wear, generation of metallic foreign matter, deviation from switching characteristics control value, stiffening, heating/melting/ground fault due to improperly closed circuit
2	Gas sealing parts (Degradation of O-rings and packing, formation of rust on sealing surface)	Gas leakage
3	Silver plating (Exposure of base material due to wear)	Internal ground fault and improper conduction due to generation of foreign matter

The life of a GCB is determined by environmental conditions, operating years involving degradation of insulating materials, and resistance against mechanical wear, fatigue, and deviation. By repairing or replacing degraded parts, the GCB can be used continuously. However, if the GCB has been operated numerous times and can no longer satisfy its functions, it must be replaced, timing of which must be determined based on the number of times of operation. Japan AE Power Systems recommends replacing an aging GCB when it has been operated approximately 10,000 times.

Regarding an aging GCB that has been operated infrequently, major degraded parts must be replaced for continuous use. Repair of degraded parts includes removing rust and associated repair, re-greasing, and replacing the O-rings and bush. When grease has degraded and re-greasing becomes necessary, the auxiliary movable contactor, main movable contactor, and link pins can be disassembled, cleaned, and re-greased relatively easily through hand holes, but the puffer piston power collector and bush of the main lever, for example, need substantial disassembly work. In addition, repair of rusted parts and replacement of O-rings involve substantial disassembly work of the terminal cover, mechanical case, and main lever.

It is therefore necessary to determine the replacement timing, taking into consideration not only the maintenance period (supply of parts and dispatch of engineers) but also the economic efficiency including future maintenance cost (lifecycle cost).

5 Summary

5.1 Maintenance of parts inspected for degradation

The parts inspected for degradation this time by the continuous switching test and the new approach of subjecting the 35-year-old GCB to accelerated degradation, such as grease, O-rings, and silver plating, should be maintained, taking the following into consideration.

①Severe rusting was found on the surface of the gas-sealing flange, the rusting had progressed to the outer groove of the O-ring, and a part of the internal groove also was beginning to rust. Since degradation of caulking on the flange may result in entry of rainwater and rusting, periodic waterproofing measures by caulking must be taken.

②The estimated service life of O-rings used for the fixing part in gas (on the inside perimeter) is 35 to 45 years. Since it is hard to disassemble the terminal cover, mechanism case, main lever, etc. at site, it is important to monitor the trend of gas pressure.

③Regarding the silver plating of the conducted sliding contactor, the base material was found to have been exposed only at the edge of the main movable contactor, and no wear of silver plating was found on other regions. However, the base oil residual ratio of grease was found to have decreased to near the limit of use.

In addition, the base oil residual ratio of the grease for the power collector of the puffer piston, link pins in gas, and the main lever bush was also found to have decreased to near the limit of use. If the GCB were to continue to be operated as it is, the silver plating would be lost, contact resistance would increase, and improper circuit closing would occur due to stiffening of operation, resulting in heating/melting/ground fault. Grease must therefore be reapplied. However, re-greasing the power collector of the puffer piston, link pins in gas, and main lever bush is difficult to do on site because major disassembly is needed to take out the interrupting unit. It is therefore necessary to measure the resistance of the major circuit and monitor the trend of switching operations.

5.2 Replacement timing of the GCB inspected for degradation and temporary maintenance to be performed until the replacement

Based on the results of this inspection, the replacement intervals of the relevant GCB was determined to be 35 to 45 years.

The following maintenance must be performed until replacement: ①periodic inspections of essential items must be conducted, ②degraded parts must be replaced before the end of their expected service life, and ③facility improvement plans proposed must be implemented without fail.

6 Conclusion

It is important to determine when to replace old GCBs and what maintenance work needs to be done until replacement. Our new study on accelerating the degradation of an already-aging GCB conducted this time produced highly accurate data on the limit of use of O-rings and other parts, which is a major factor determining the service life of a GCB. We will continue to accumulate data by inspecting the degradation of parts affecting the life of GCBs, and reflect the results on facility replacement and maintenance measures.

Authors

Shunichi ISHIZEKI
Design Department
High Voltage Switchgear Business Division

Improvement of 72kV-class Vacuum Interrupters and Vacuum Circuit Breakers

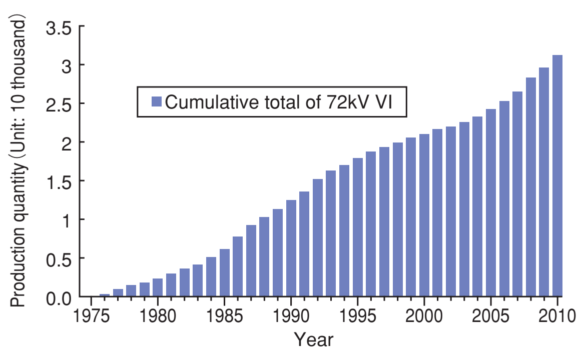
Hideki KOMATSU | Hitoshi SAITO | Masayuki SAKAKI

Vacuum interrupters (VI) of 72kV or higher are classified as high-voltage equipment and cannot be manufactured simply by increasing the scale of small medium-voltage VI in various phases including design, manufacturing, and applications. Japan AE Power Systems has been manufacturing vacuum circuit breakers (VCB) for power transmission and distribution systems for over 30 years since successfully developing the 72kV-class VI. We have a strong and unique lineup of high-voltage VCB. This paper describes the improvement in performance, history of downsizing, increase in interrupting capacity, and the progress of design and manufacturing techniques that made such improvements possible.

1 Introduction

72kV-class vacuum interrupters (VI) were commercialized in Japan in the late 1960s, and efforts have long been made to increase their voltage range. Meidensha Corporation, one of the predecessors of Japan AE Power Systems, succeeded in developing the world's first 72kV-class VI in 1973, and has since focused on improving the performance, decreasing the size, and increasing the interrupting capacity of the high-voltage VI. Fig. 1 shows the cumulative total of 72kV-class VI we have manufactured.

In the 1980s and later, insulating and interrupting performance were greatly improved thanks to the introduction of numerical analyses of electrical fields/structures and design methods such as arc observation.



[Fig. 1] Cumulative total of 72kV-class VI manufactured

In the 1990s, thanks to the adoption of axial magnetic field electrodes suitable for large interrupting capacity and the use of new materials for electrodes and insulating envelopes, the 72kV-class VI was made significantly smaller, and operating mechanisms were also reduced in size and operating force.

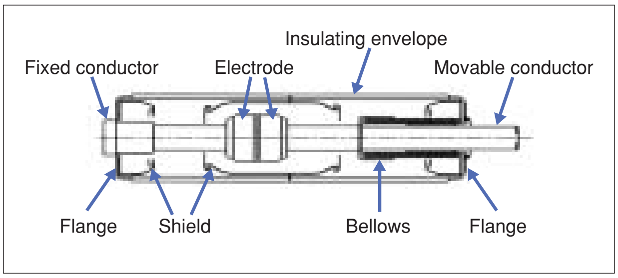
From 2000, high-pressure dry-air insulated VCB was developed to eliminate the use of SF_6 gas, and these have attracted attention both in Japan and abroad as environmentally-friendly circuit breakers.

This paper focuses on our 72kV-class VI, describing the progress of VI during the past three decades, the associated designing and manufacturing techniques, and the history of VCB.

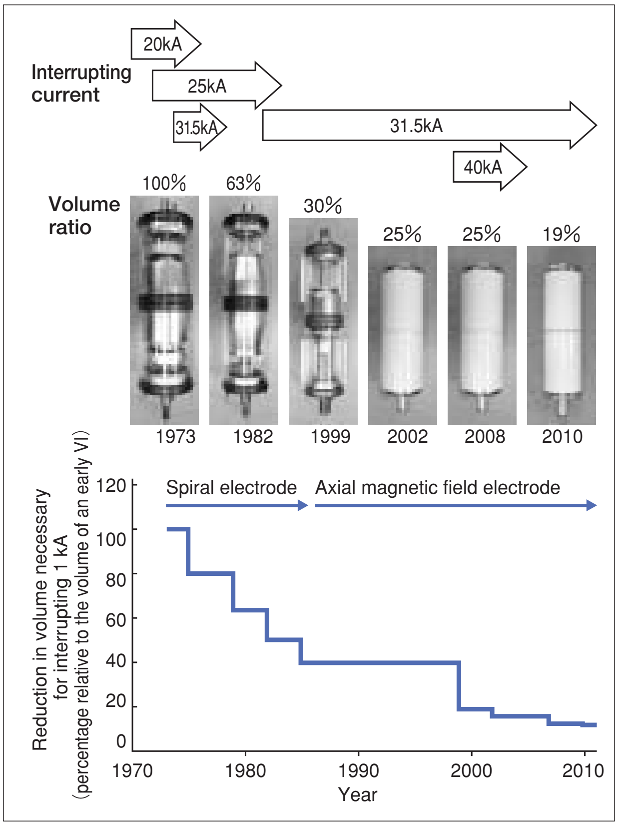
2 History of VI technologies

2.1 Downsizing and increase in interrupting capacity

Fig. 2 illustrates the internal structure of the latest 72kV-class VI. A VI is a vacuum vessel, in which metal flanges are connected to an insulating envelope, housing electrodes at the end of fixed and movable conductors respectively, bellows on the movable side, shields for magnetic field relaxation, etc. Although the basic structure does not differ much from that of the early VI, the size has been minimized and performance improved significantly. Fig. 3 shows the change in size of the 72kV-class VI and interrupting capacity along with the volume of VI necessary for interrupting unit current. Compared with the early VI, the volume of VI necessary for interrupting the same magnitude of current has been reduced to 1/8 thanks largely to advances in design technologies, as described in the next section. Furthermore, with the change from the glass insulating envelopes used for early VI to ceramic



[Fig. 2] VI internal structure



[Fig. 3]
Change of 72kV class VI
(relation between interrupting current and volume)

envelopes, production efficiency was improved dramatically, thus tripling the total production volume of 72kV-class VI during the past decade.

2.2 Design/application technology

Designs based on numerical analysis of electromagnetic fields and structures started in the late 1970s. Initially, due to the limited performance of computers at that time, the studies were limited to axially symmetrical three-dimensional structures. Today, thanks to faster analyses on powerful computers using sophisticated software, actual electrodes can be simulated in detail by general three-dimensional magnetic field analysis, thus improving the accuracy of design.

In addition, thanks to powerful high-speed videos and advanced technologies for measuring high-frequency currents, information can be fed back quickly to the design and so development work has speeded up significantly.

Fig. 4 summarizes the analysis and measurement techniques adopted for each design technique.

(1) Insulation design

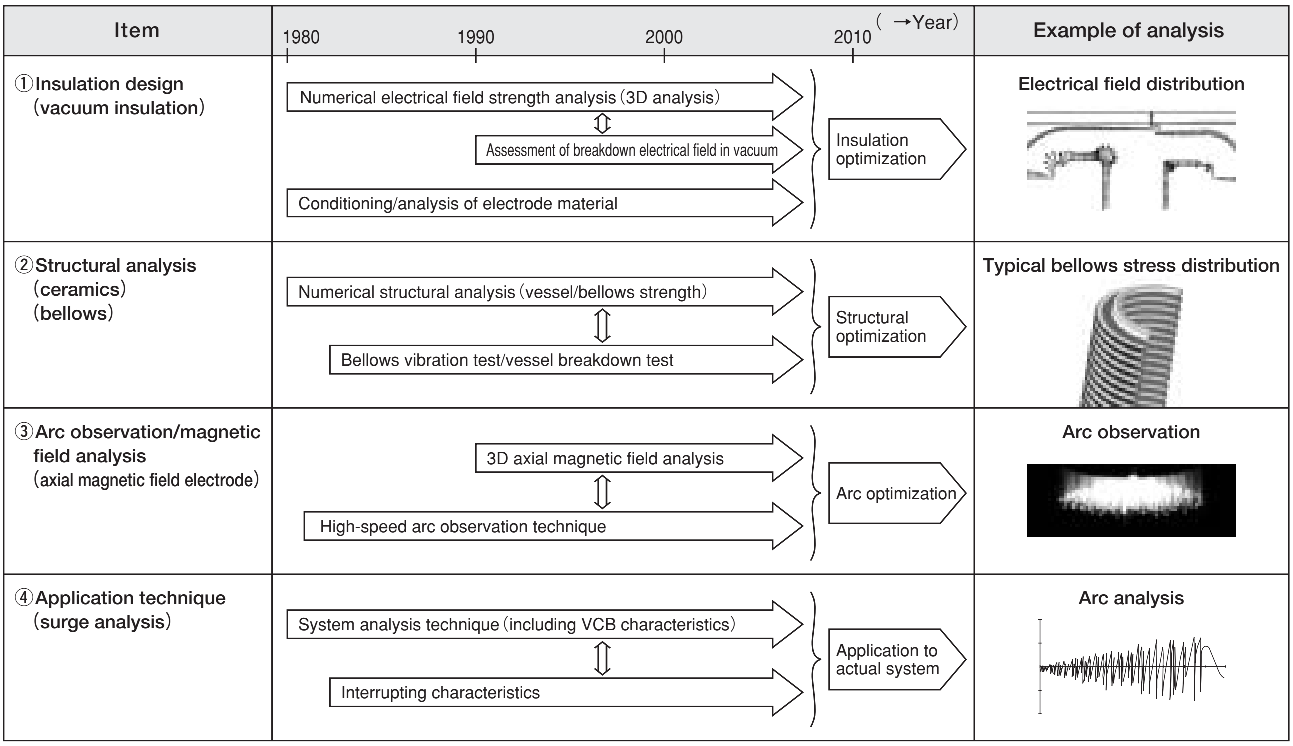
In the 1980s, quantitative assessment of the breakdown electrical field and conditioning effect (the effect of improving the withstand voltage by eliminating weak points such as minute protrusions through discharge between electrodes) of various materials in a vacuum was performed as well as electrical field analyses, and the breakdown mechanism was also studied[1]. The shapes of the shield and electrodes within VI were thus optimized, which facilitated downsizing of VI.

(2) Structural analysis

VI vessels and bellows are required to withstand the differential pressure between the internal vacuum and high external gas pressure, impact at the time of switching operation, and the heating that occurs during normal operations. By applying numerical analysis to such requirements, the structure and reliability can be optimized.

(3) Arc observation/magnetic field analysis

Regarding the axial magnetic field electrodes ideal for interrupting large currents, by performing



[Fig. 4] Progress of VI design and application techniques

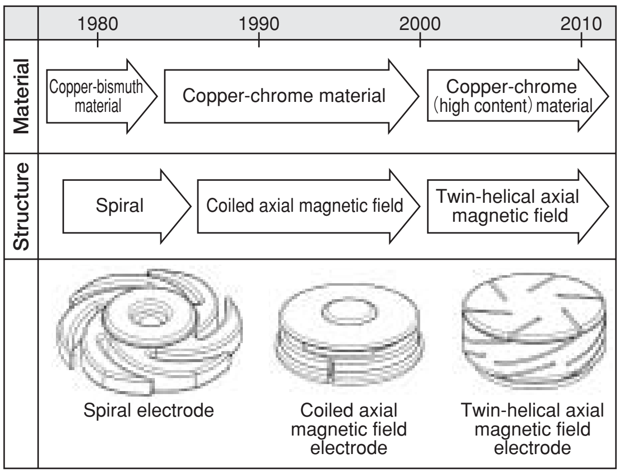
high-speed and high-resolution arc observation and checking the results against magnetic field analysis, the relation between the arc conditions and magnetic field distribution or large-current interrupting performance was clarified, which led to the improvement in interrupting performance and development efficiency[2].

(4) Application techniques

When the application of high-voltage VCB to capacitor banks and reactors was studied for the first time, there was concern about the generation of switching surges such as chopping and generation of arcs. However, thanks to system analyses including the interrupting characteristics of VCB, it became possible to determine the surge voltage generated in each circuit at the time of switching of VCB[3], and the conditions for application to phase-modifying equipment were clarified. The use of improved electrode materials has expanded the applicable range of VCB, and by using specially designed switchgear, it is now possible to apply the VCB to capacitor banks of up to 60MVA and reactors ranging from 10 to 100MVA.

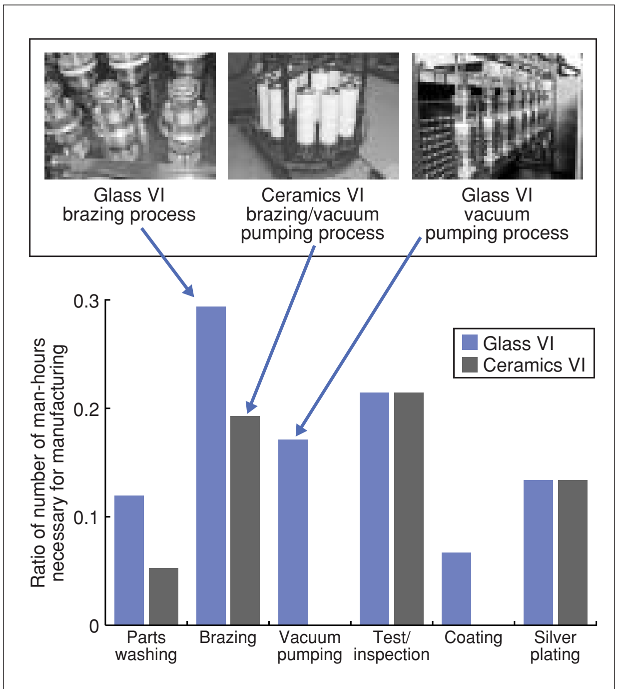
2.3 Advancement of electrode materials/structures and manufacturing technologies

The recent improvements in performance, downsizing, and cost reduction of 72kV-class VI were made possible largely by improved materials and manufacturing technologies. Fig. 5 summarizes the transition of electrode materials and structures. The first 72kV-class VI developed in 1973 had a electrodes with spiral structure contact portion made of copper-bismuth alloy. In 1982, copper-chrome alloy, which has superior interrupting performance,



[Fig. 5] History of electrode technology started to be used. Performance was then significantly improved by adopting the axial magnetic field method. The early axial magnetic field structure, in which energized conductors were arranged in the circumferential direction, is called the coiled type. The twin helical type developed in 2001 uses a cylindrical conductor having angled slits to generate an energizing path for magnetic field generation, and offers improved magnetic field generation and energizing performance. In addition, by using a copper-chrome alloy having high chrome content for the contact portion, its interrupting performance and withstand voltage have also improved significantly.

One of the manufacturing innovations that helped to reduce the cost was the adoption of ceramic insulating envelopes in 2002. Fig. 6 illustrates the ratio of the number of man-hours necessary for manufacturing by type of insulating material. Since the conventional glass material cannot withstand the brazing temperature of parts, the brazing process must be separated from the vacuum pumping process. By using ceramic, which has good heat resistance, vacuum pumping can be performed simultaneously with the brazing process, thus reducing the man-hours necessary for manufacturing one VI by more than 40%.



[Fig. 6]
Ratio of number of man-hours necessary for manufacturing by type of insulation envelope material

3 Progress of VI and transition of switchgear and VCB

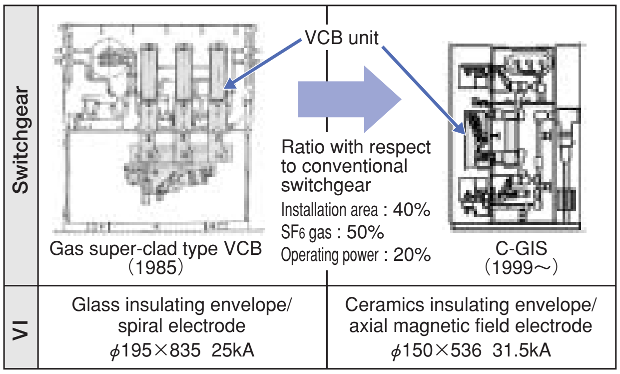
3.1 Switchgear

The switchgear adopting a VCB for an interrupting unit and integrating a disconnecting switch, earthing switch, lightning arrester, etc. was studied around the same time as the development of the first-generation 72kV-class VI, and in 1974, an oil-insulated super-clad type VCB was commercialized.

To satisfy the demand for downsizing, improved economic efficiency, and noncombustibility, the transition from insulation oil to SF_6 gas was promoted, and in 1985, a smaller 72/84-kV gas super-clad type featuring the second-generation ϕ 195-mm VI was developed.

More compact panel cubicle-type gas insulated switchgear (C-GIS) was commercialized in 1999. Glass VI was used at first, and ceramic VI was used for the first time in 2002. Improved interrupting performance as well as downsized VI ensured the reduction in gap length and higher opening speed, enabling significant downsizing of VCB including the operating mechanism, hence the switchgear installation area was more than halved (Fig. 7).

Thanks to VI downsizing and generation changes, to date we have delivered more than 1,500 units (VCB units) to power companies and industrial consumers.



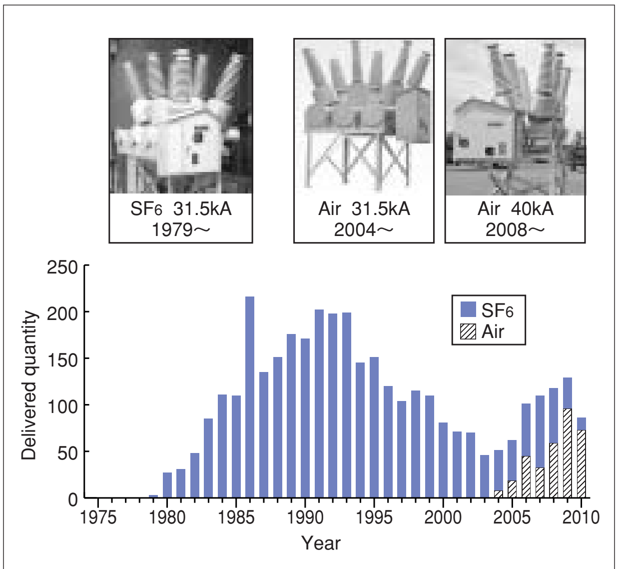
[Fig. 7] Downsizing in 72kV-class gas insulated switchgear

3.2 VCB

The world's first 72kV-class porcelain type VCB was commercialized in 1975, and some of the VCBs were sold overseas. Domestically, after the 1978 Miyagi earthquake in Japan, the demand for highly seismic-resistant VCB increased, and in 1979, a highly seismic-resistant tank-type VCB was developed. After type approval was granted by power companies, the tank-type VCB became the mainstream in Japan.

In the 2000s, the use of ceramic VI enabled VCBs to be used in a high-pressure gas atmosphere, and we succeeded in using high-pressure dry air, instead of SF_6 gas, which is a greenhouse gas. We then commercialized in 2004 the world's first 72kV-class dry air insulated VCB, which is also attracting attention in other countries because SF_6 gas recovery is unnecessary.

We have delivered over 3,500 units of tank-type VCBs to railway companies, etc. (Fig. 8), thus supporting the use of oilless circuit breakers, saving energy for maintenance, and helping to eliminate SF_6 gas.



[Fig. 8] Delivery record of 72kV-class tank-type VCB

4 Future outlook

Vacuum interrupters have been evolving thanks to the progress of design, material and production technologies. Their performance has been improved by advances in simulation techniques such as magnetic field analysis, adoption of new materials for electrodes and insulating envelopes, and improved arc observation techniques. We have delivered more than 5,000 units of 72kV-class VCB units to many users. We will focus on further reducing the size and enhancing the performance of 100kV-class VI to expand the market.

References

[1] K. Miyazaki et al., "Dielectric breakdown characteristics of Cu-Cr electrodes in non-uniform electric field in vacuum," Discharge Study Group, 2002, ED-02-157

[2] Y. Matsui et al., "Observation of arc of axial magnetic field electrodes in large-current region," Institute of Electrical Engineers of Japan, Class B Convention, 2008, No. P42

[3] Y. Matsui, "Re-ignition surge phenomenon of vacuum circuit breakers," Meiden Review, 1989, Issue 206, No. 3

Authors

Hideki KOMATSU
Design Department
Medium Voltage Switchgear Business Division

Hitoshi SAITO
Development Department
Senior Engineer
Medium Voltage Switchgear Business Division
Doctor of Engineering
Member of the Institute of Electrical Engineers of Japan

Masayuki SAKAKI
Senior Chief Engineer
Member of the Institute of Electrical Engineers of Japan

Arc and Hot Gas Flow Simulation to Evaluate Interruption Performance for Gas Circuit Breakers

Masanori TSUKUSHI | Hajime URAI | Makoto KOIZUMI

Various analysis techniques have been applied to the design and development of gas circuit breakers to reduce their size and enhance performance and reliability. It is particularly important to evaluate current interruption, which is accompanied by arcing, but it has been difficult to develop interruption simulations including an arc plasma model. We have developed an accurate hot gas flow analysis program in which the arcing phenomenon is precisely simulated by taking the spatial distribution of arc electrical conductivity into account. This paper outlines the hot gas flow and arc analysis procedures. The calculated results show good agreement with the measurement results of basic experiments. The program was used to calculate the dielectric recovery characteristic inside the nozzle of an actual gas circuit breaker.

1 Introduction

In high-voltage gas circuit breakers, a high-speed flow of SF_6 gas is formed inside a nozzle and blasted at the arc in order to interrupt the fault current. This gas flow in the nozzle is closely related to the interruption performance of the breaker. We are developing a gas flow simulation tool to calculate the interruption performance and improve its accuracy.

Various highly accurate flow simulations including advanced arc simulations have been developed[1]. Analysis of the arc includes electric field analysis of the spatial distribution of electrical conductivity in the arc, and radiation-absorption of arc light which results in ablation of the nozzle material.

This paper starts by describing the computational fluid and arc dynamic analysis technique we developed to evaluate the interruption performance of gas circuit breakers. Then, the validity of the analysis model is verified by comparison with the measurements of basic experiments of ablation with a testing tube and small circuit breaker. Finally, the dielectric recovery characteristic is calculated for an actual circuit breaker just after clearing the current at the zero crossing point of the fault current.

2 Analysis method for compressible fluid

The basic equations for a compressible fluid are shown in Fig. 1. These equations are solved with the Constrained Interpolation Profile (CIP) method[2] and CIP-Combined Unified Procedure (C-CUP) method[2], which can treat a compressible fluid and an incompressible object in a unified manner. These methods can model an SF_6 gas space and both fixed and moving parts of a circuit breaker without complex procedures and can simulate the puffer compression action in interruption motion. The profile of puffer pressure calculated for the small research circuit

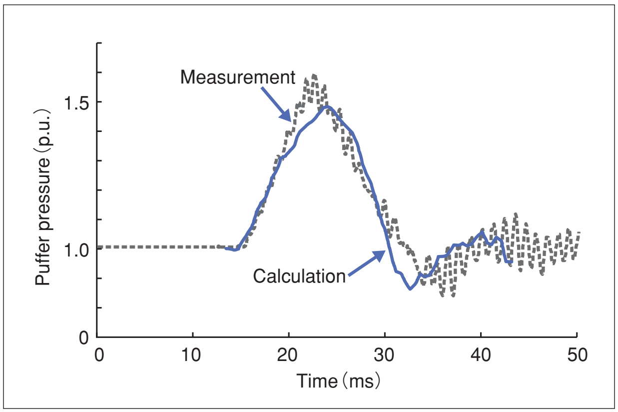
Mass : $$\frac{\partial \rho}{\partial t} + (u \cdot \nabla)\rho = -\rho \nabla \cdot u + s \quad (1)$$

Momentum : $$\frac{\partial u}{\partial t} + (u \cdot \nabla) u = -\nabla p/\rho + F/\rho \quad (2)$$

Energy : $$\frac{\partial e}{\partial t} + (u \cdot \nabla) e = Q - (p+e) \nabla \cdot u \quad (3)$$

ρ: gas density, p: pressure, e: internal energy per unit volume, u: velocity, F: volume force, s: source term of mass, Q: source term for heat input and loss

[Fig. 1] Basic equations for fluid analysis



[Fig. 2] Pressure buildup in a puffer chamber

breaker is shown in Fig. 2 in comparison with an experimental result. The pressure rise is accurately calculated by the puffer compression model.

3 Analysis method for ablation arc

The arc simulation model consists of electric field and radiation field calculations, using the basic equations shown in Fig. 3[1]. To solve the electric field, the spatial distribution of arc electric conductivity is taken into account, and current density and arc voltage are calculated using equation (4). Joule heating of the arc is calculated from the current density and arc voltage across electrodes. The radiation field calculation, which is approximated by diffusion equation (5)[4], is solved to calculate the spatial distribution of radiation intensity. The radiation intensity corresponds to the energy loss of the arc. The source term for heat and loss of energy equation (1) are given by the heating and radiation loss of arc analysis.

The heating and radiation loss are substituted into the conservation of energy equation (1) as a source term for heat input and loss.

The insulation nozzle surrounding arcing contacts absorbs radiation power on its surface and so the nozzle material ablates. In order to simulate the arc precisely, the ablation of nozzle material must be modeled. Assuming that the ablated mass is proportional to the radiation power absorbed by the nozzle material, the gas density and internal energy increase as a function of the intensity of radiation on the nozzle surface.

4 Validity verification of arc analysis method

4.1 Calculation for ablation arc measurement with a testing tube

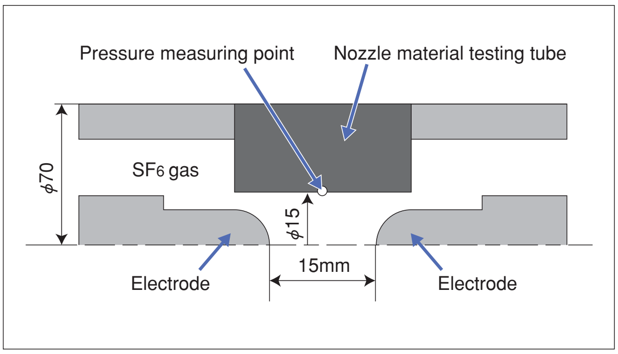
In order to verify the validity of the arc analysis method, the arc simulation was carried out for the same configuration as the ablation measurement with a testing tube made of the nozzle material. A schematic diagram of the arc generation part and testing tube for ablation measurement is shown in Fig. 4. The tube diameter was 15 mm, the arcing electrode diameter was 10 mm, and the gap between the electrodes was 15 mm. SF_6 gas was filled to a pressure of 0.3 MPa. In the experiment, the arc was ignited using a thin copper wire. An AC current at 50 Hz was provided by an LC resonance circuit and its peak value was 15 kA. Fig. 5 and 6 compare the calculated arc voltage across the electrodes and the pressure with the measured results at the center of the tube. A good match was obtained between the measurement and simulation by taking nozzle ablation into account.

Electric field : $\nabla\cdot(\sigma\nabla\phi) = 0$ (4)

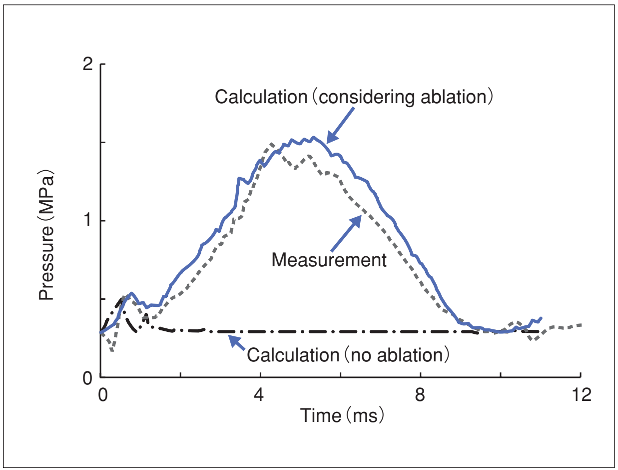
Radiation field : $\nabla^2 U/3k_r = k_p U - 4k_p\sigma_s T^4$ (5)

σ : electrical conductivity, ϕ : electrical potential,
U : radiation intensity, T : gas temperature,
k_p : absorption coefficient, k_r : inverse of energy diffusion coefficient,
σ_s : Stefan-Boltzmann constant

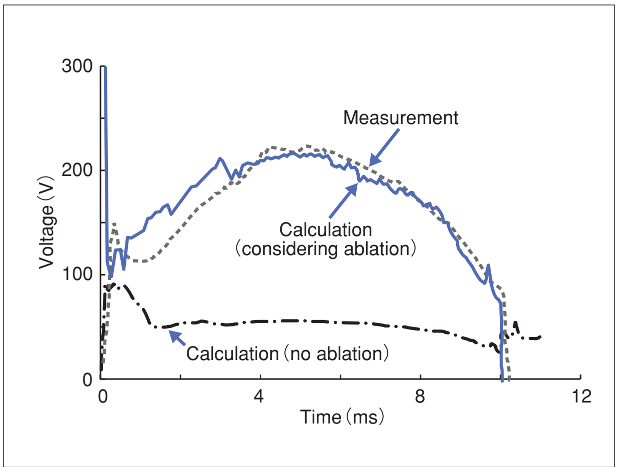
[Fig. 3] Basic equations for arc analysis



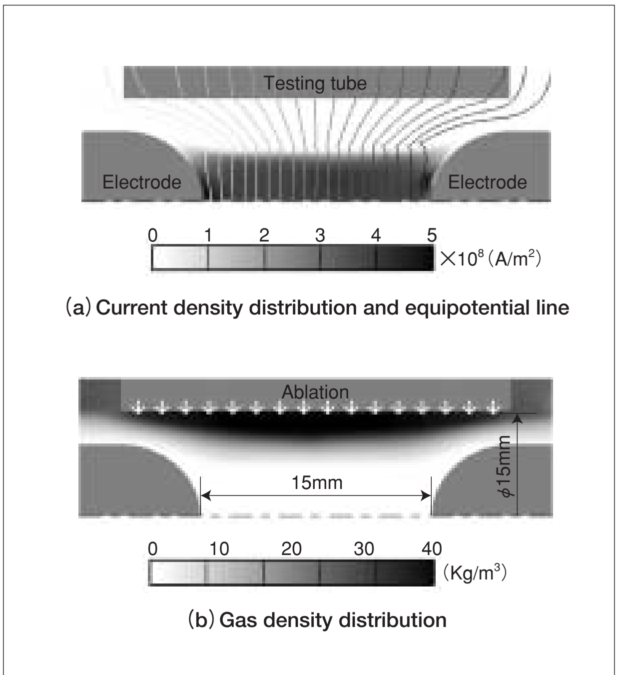
[Fig. 4] Experimental setup of ablation measurement



[Fig. 5] Time variation of pressure in the testing tube



[Fig. 6] Time variation of voltage between electrodes



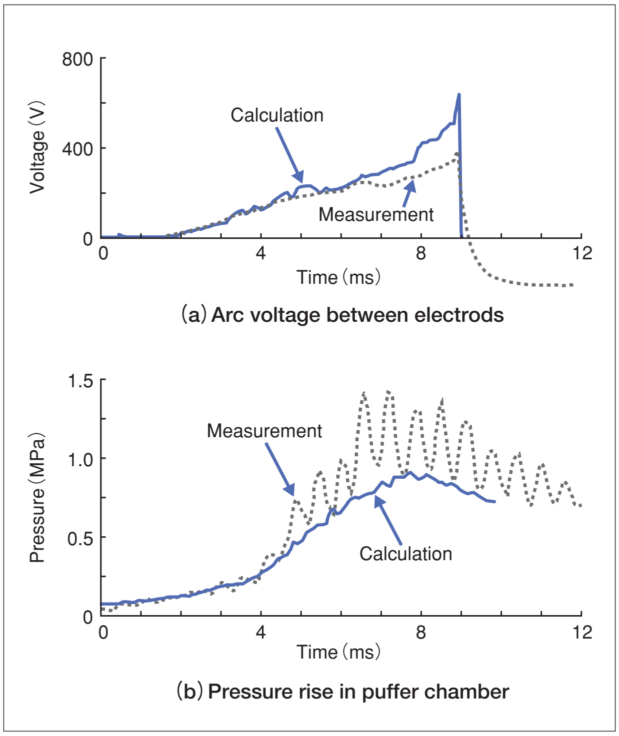
[Fig. 7]
Spatial distributions of current density and gas density

The spatial distributions of current density and gas density at 4.5 ms from arc initiation are shown in Fig. 7. The gas density near the tube wall becomes high because of nozzle ablation and the high-density gas surrounds the arc area in the conducting state. Therefore, the ablation gas maintains a high pressure in the arc and squeezes the arc into a small conducting area to make the arc voltage high.

Fig. 5 shows simulation results of the spatial distributions of current density and gas density at 4.5 ms from arc ignition.

4.2 Calculation for small experimental circuit breaker

The test calculation was carried out for a small experimental circuit breaker. The voltage across the electrodes and the pressure rise in the puffer chamber for a peak interruption current of 10 kA at 50 Hz and arc duration of 7.2 ms are compared with the measurement result in Fig. 8. The calculated and measured profiles of the arc voltage and the puffer pressure rise closely match, confirming that the interruption arc characteristics can be calculated properly.



[Fig. 8]
Calculation results of voltage across electrodes and pressure rise in puffer chamber

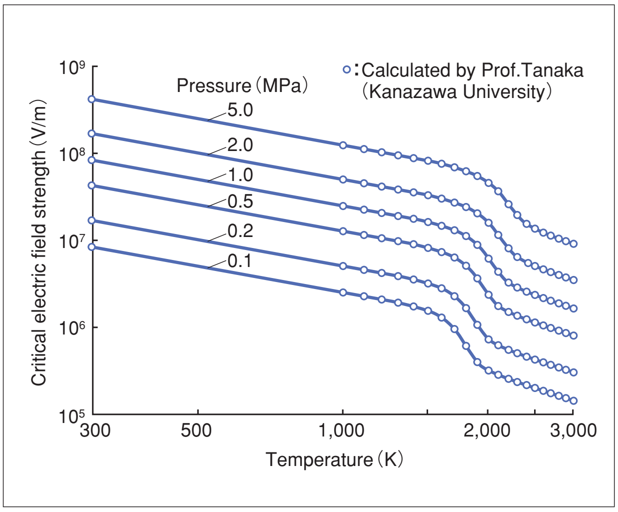
5 Evaluation of weak point for dielectric breakdown just after current interruption

In the interrupting process of a high-voltage circuit breaker, a Transient Recovery Voltage (TRV) is applied between contacts just after clearing the current at the zero crossing point of the fault current. The circuit breaker is required to have a higher dielectric strength in the transient recovery phase than the TRV. The dielectric strength depends on both the electric field strength and the state of the SF_6 gas on local conditions such as pressure, density, and temperature. The weak points that may act as a start point for dielectric breakdown can be calculated from the local dielectric strength.

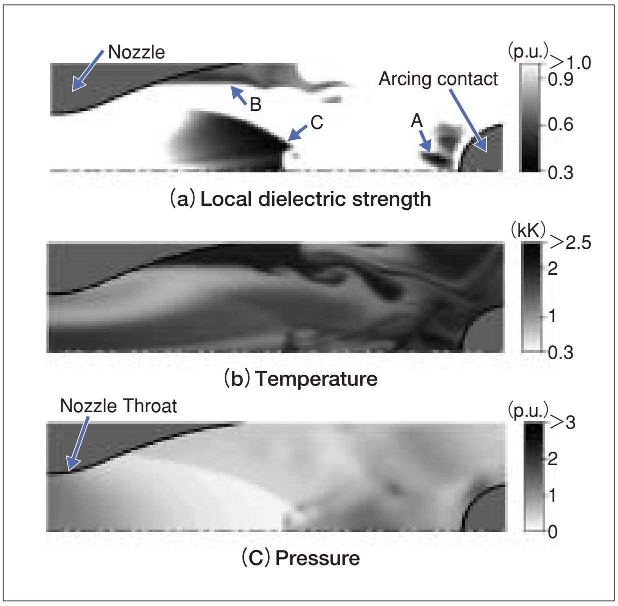
The critical electric field strength of hot SF_6 gas is used to calculate local dielectric strength. The critical electric field is defined as the electric field in which the ionization coefficient is equal to the electron attachment coefficient. The critical electric field data calculated by Prof. Tanaka of Kanazawa University are shown in Fig. 9. The calculation is based on the two-term approximation solution of the Boltzmann equation considering the equilibrium composition of hot SF_6 gas[5].

Simulation results are shown in Fig. 10 for 80 kA asymmetric current interruption and 17.8 ms arcing time in a puffer-type circuit breaker at 100 μs just after current interruption. There are three weak points where the local dielectric strengths are low. The causes of the low dielectric strength are the high-temperature gas that remains near the tip of the arcing contact (point A) and the wall of the nozzle (point B), as well as the lower pressure at the center of the nozzle expanding zone (point C) in which the gas is accelerated.

Sufficient interrupting capability was preliminarily surveyed from the simulation result that the dielectric strength at points A and B where the hot gas stagnates becomes only as low as that at point C where the gas temperature is low. From the actual interruption test in a high-power laboratory, the interrupting capability was verified and the circuit breaker successfully interrupted the 80 kA Breaker Terminal Fault (BTF) duty.



[Fig. 9]
Dependence of critical electric field strength on gas temperature



[Fig. 10]
Spatial distribution of pressure, temperature, and breakdown voltage in vicinity of fixed arcing contact at 100 μs after the zero current point

6 Summary

A computer fluid dynamic simulation tool for designing high-voltage circuit breakers has been developed. The compressible fluid equations are solved with the CIP and C-CUP methods. An arc simulation model that considers nozzle ablation caused by absorption of arc radiation was proposed and its validity was demonstrated in a tube arc experiment with a small research circuit breaker.

Simulation results for the local dielectric strength for large current interruption in high-voltage circuit breakers were discussed. Three weak points that could become start points of dielectric breakdown were found.

Regarding application to simulation of the interrupting phenomenon for actual circuit breakers, the analysis method identifies the local dielectric weak points in the dielectric recovery phase just after the zero current point. The simulation tool helps to clarify the interrupting phenomenon in the nozzle and to improve the design of the nozzle.

We thank Prof. Yasunori Tanaka of Kanazawa University for his valuable assistance with calculating the critical electric field strength in SF_6 gas at high temperature.

References

[1] Makoto Koizumi, et al., "Development of Highly Accurate Analysis Method for Compressible Fluid Considering Radiation and Ablation," IEEJ Trans PE. vol. B-127, no. 9, 2007, pp. 1002–1008. (in Japanese)

[2] Tadashi Yabe, et al.. "The Constrained Interpolation Profile Method for Multiphase Analysis," J. Comp. Phys. vol. 169, 2001, pp. 556–593.

[3] Hajime Urai, et al., "The Influence of Inlet Convergence Angle of Puffer Type Circuit Breaker on Arc Extinction Capability (Experimental Results for SF_6 Gas)," 2007 National Convention Record I.E.E. Japan, 6-238, 2007. (in Japanese)

[4] J J Lowke, "Radiative Energy Transfer in Circuit Breaker Arcs. Current Interruption in High-Voltage Networks," K Ragaller (ed.), Plenum Press, New York, 1978, pp. 299–372.

[5] Yasunori Tanaka, "Influence of copper vapor contamination on dielectric properties of hot air in temperature range of 300-3500 K at atmospheric pressure," IEEE Trans. Dielectrics and Electrical Insulation. vol. 12, no. 3, 2005, pp. 504–512

Authors

Masanori TSUKUSHI
Research & Development Management Department
Research & Development Division
Doctor of Engineering
Member of the Institute of Electrical Engineers of Japan

Hajime URAI
Hitachi Ltd., Hitachi Research Laboratory
Senior Researcher
Doctor of Engineering
Member of the Institute of Electrical Engineers of Japan

Makoto KOIZUMI
Hitachi Ltd., Hitachi Research Laboratory
Doctor of Engineering
Member of the Institute of Electrical Engineers of Japan,
the Japan Society of Mechanical Engineers and the Japan Society for Industrial and Applied Mathematics

Life Assessment of Thermally Upgraded Kraft Paper in Mineral Oil by Accelerated Aging Test

Katsunori MIYAGI

1 Introduction

A guideline for the design, application and operation of transformers using high-temperature insulating materials has recently been established as an IEC standard for achieving a low-carbon, environmentally-friendly society. Japan AE Power Systems has been examining heat deterioration characteristics within oil of thermally upgraded kraft paper (TUK) (Tomoegawa Paper Co., Ltd., nitrogen content: 2.2%), a type of heat-resistant insulating paper[1]. TUK is made of a chemically-treated cellulose-based material. The results of the study of TUK life assessment are summarized below.

2 Life estimation

2.1 Method of estimating life

The life of insulating paper used for transformer windings is generally considered to end when the average degree of polymerization (DP) of the cellulose in the paper falls to 450. The Arrehenius model is used for predicting life by an accelerated aging test. Using the percentage of retention, 45%, of the DP of insulating paper as the criterion for life assessment, a life prediction chart was created by an Arrehenius plot of the heating time and heating temperature to find when the criterion is reached. Note, however, that the data obtained at each heating temperature was subjected to a linear approximation depending on the test conditions (heating time and heating temperature) to estimate the lifetime at retained DP of 45%.

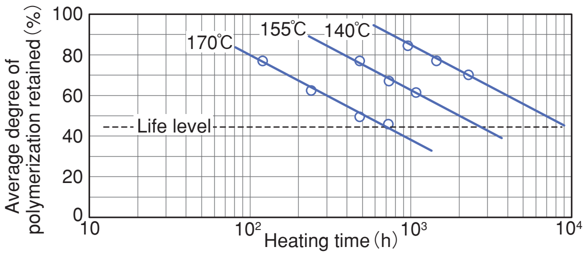
2.2 Results of life prediction

Data on TUK[1] and that on general kraft paper[2] were used for life assessment. Fig. 1 and 2 illustrate the change with time of retained DP of the two types of paper, respectively. The lifetime (at retained DP of 45%) was estimated by linear approximation.

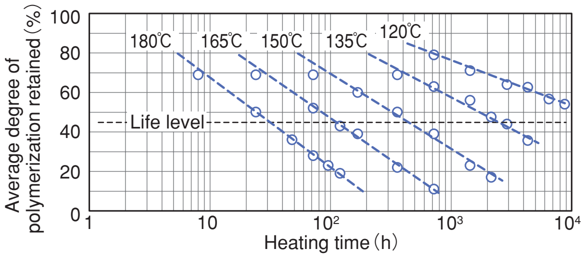
Fig. 3 illustrates the results of the Arrehenius plot conducted based on the relation between lifetime and heating temperature obtained by this method. The horizontal axis represents both temperature t (˚C) and 1/T (= t + 273). The chart indicates that TUK can be used continuously at approximately 109˚C to ensure the life of 30 years, whereas general kraft paper must be used at 98˚C.

3 Conclusion

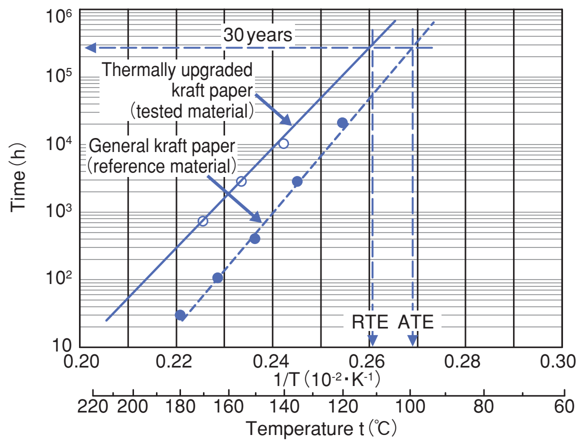
Life assessment recommended by the Electric Technology Research Association in Japan was conducted based on the data obtained by the accelerated aging test of TUK in mineral oil. The obtained results indicate that the heat performance of TUK is higher than that of general kraft paper by approximately 10˚C, assuming continuous rated operation for 30 years.



[Fig. 1] Change with time of thermally upgraded kraft paper



[Fig. 2] Change with time of general kraft paper



[Fig. 3] Life assessment by Arrehenius plotting (based on retained DP of 45%)

Reference

[1] N. Yamagata et al., "Diagnosis of Thermal Degradation for Thermally Upgraded Paper in Mineral Oil," CMD 2008, pp. 1000-1004 (2008)

[2] Sakai et al., "Thermal Degradation Characteristics of Insulating Paper for Transformers," Abstracts of the 21st Insulating Oil Committee Workshop of the Japan Petroleum Institute, pp. 50-53 (2001)

Research study report

Technology to Increase the Operating Speed of Spring-operated Mechanisms for Circuit Breakers

Kenichi OKUBO

1 Introduction

To drive gas circuit breakers (GCB) of 204kV or higher, operating mechanisms using high-pressure air or hydraulic pressure have been used. However, spring-operated mechanisms, which are easy to maintain, are now increasingly being used. In Japan, GCBs of 3-cycle interrupting time is applied for 168kV or and 2-cycle interrupting time for 204kV. Therefore speed of the operating mechanism must be increased to use it for GCB of 204kV or higher.

2 Problems in increasing the speed

Fig. 1 illustrates the structure of a spring-operated mechanism. The tripping control mechanism related to the tripping operation consists of a solenoid and three levers.

Fig. 2 illustrates the time division from the moment of giving a tripping command to the opening of the GCB. Period *t1* is from the moment of a tripping command to the breaking of engagement between the tripping trigger and the intermediate lever, *t2* is the duration until the interrupting spring is actuated, and *t3* is the period up to the opening of the GCB. With a 3-cycle GCB, the ratio *t1*:*t2*:*t3* is 0.6:0.15:0.25, assuming that the opening time is 1. It is therefore essential to decrease *t1*, the operating time of the solenoid, to increase the operating speed of the GCB.

3 Details of study on increasing the speed

Fig. 3 illustrates the structure of a solenoid. To increase the speed of the solenoid, the following parameters were examined.

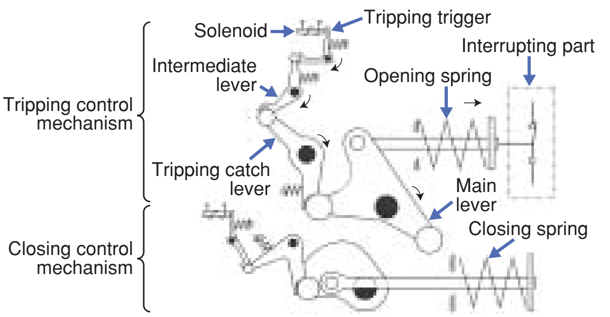
(A) Core material: Silicon steel, which is hardly affected by eddy currents and allows magnetic flux to pass through easily, is used to ensure high-speed response.

(B) Coil turns: By using a roller bearing for the sliding part of the tripping mechanism, thus reducing the load on the solenoid, coil turns can be decreased to reduce the startup time of coil current.

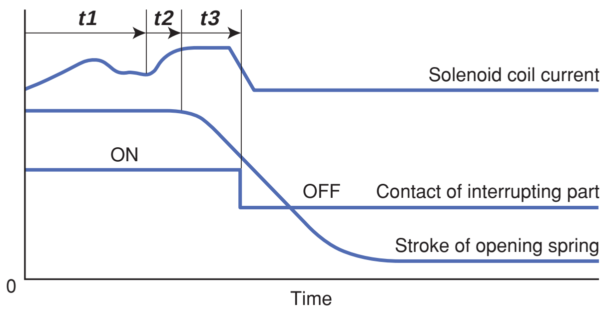
(C) Plunger stroke: Governor gain of the tripping coil is increased to minimize the stroke.

(D) Core shape: Reduced coil capacity in (B) decreases the core height and magnetic path length.

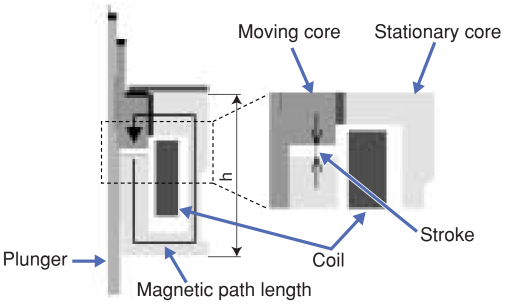
The coupled analysis of plunger operation and moving magnetic field conducted on the above parameters confirmed that *t1* could be shortened by 65%. It was also confirmed that of all the items studied, reducing the stroke was most effective for reducing *t1*. In addition, *t2* and *t3* were shortened by reducing the weight of parts and improving mechanisms, and as a result a spring-operated driving mechanism that satisfies 2-cycle interrupting specifications was developed.



[Fig. 1] Structure of spring-operated mechanism



[Fig. 2] Definition of time division



[Fig. 3] Structure of solenoid

Reference

H. Hashimoto et al., "Speed-up Technology for Ultra-high-voltage Large-capacity GCB," Collection of papers for the national convention of the Institute of Electrical Engineers of Japan, No. 6-223, pp. 376-377

Study of Surface Conditions of Cu-Cr Electrode for Vacuum Interrupters

Hiromasa SATO Yoshihiko MATSUI Yasushi NODA

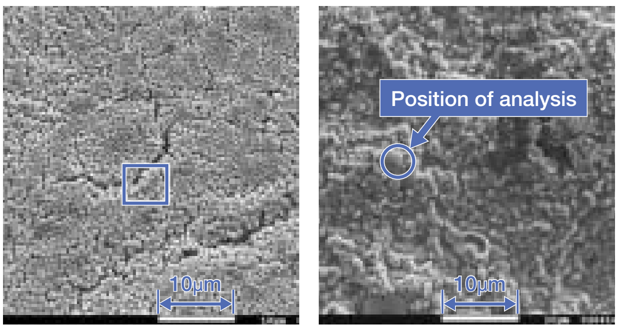
1 Introduction

Gas circuit breakers (GCB), which use SF_6 gas as an arc-quenching medium, have been used mainly as high-voltage power circuit breakers. In line with the increasing attention on techniques to reduce environmental load in recent years, efforts are being made to achieve vacuum circuit breakers (VCB) of higher voltage and larger capacity using a vacuum as an arc-quenching medium to reduce the amount of SF_6 gas, which has high global warming potential. To assess the effect of the magnitude of interrupting current on the surface state of electrodes, the surface conditions of the copper-chromium (Cu-Cr) electrode materials used for high-voltage VCB were examined.

2 Analytical survey

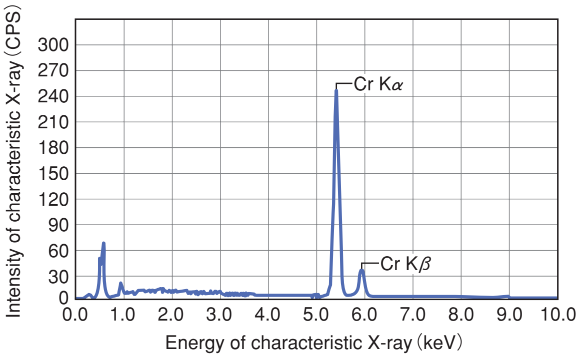
It is known that the surface conditions of Cu-Cr electrodes after an interrupting test vary depending on the polarity, namely the melting on the anode side is severe. Arc observation also indicates that in some cases, the anode melts more severely in a region where the interrupting current is large. After an interrupting test, an anode melted layer was examined using a scanning electron microscope and energy dispersive X-ray spectrometer. A current of 5kA was selected for mild melting of the anode, and 20kA to 40kA for severe melting.

The surface of the anode after the interruption of a 5kA current as shown in Fig. 1(a) reveals a fine particulate state of 1 μm or smaller. Meanwhile, on the surface examined after the interruption of 40kA as shown in Fig. 1(b), scattered particles of various sizes were found, with the largest being approximately 5 μm. Component analysis showed that the particles were Cr (Fig. 2).



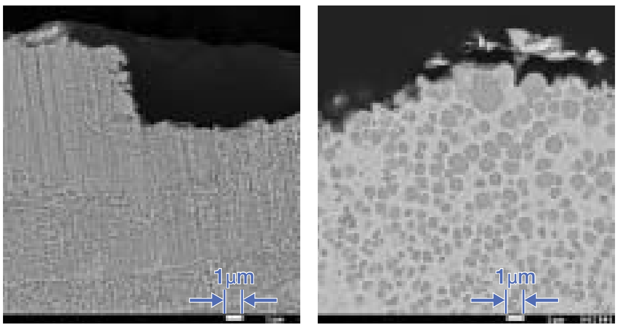
(a) After the interruption of 5kA (b) After the interruption of 40kA

[Fig. 1] Surface of anode after current interruption



[Fig. 2] Component analysis of large particles (Fig. 1 (b))

Fig. 3 shows the cross-sectional area of the melted layer examined. Fig. 3(a) shows the cross-sectional area of the melted layer after the interruption of 5kA. The Cr particles within Cu were fine and uniform. With the interrupting current of 20kA, larger Cr particles were found to be scattered similar to the surface. The difference in the conditions of the melted layer by current value is due to the difference in cooling rate due to different melting depths.



(a) After the interruption of 5kA (b) After the interruption of 20kA

[Fig. 3] Cross-sectional area of the melted layer after the current interruption

3 Conclusion

The conditions of the melted layer varied between the current region where the effect on the anode was small and the region where the effect was large. In the latter, larger Cr particles were found to be scattered within Cu. We will improve the performance of VI by clarifying the relation between the surface conditions and current interrupting performance.

TOPICS

1 Degradation Diagnosis of Large-capacity Transformers

High accuracy is required in diagnosing the degradation of aging power transmission and distribution equipment. To present optimum maintenance and replacement plans for aging transformers to our users, Japan AE Power Systems has been developing high-accuracy degradation and residual life diagnostic methods. In collaboration with Electric Power Development Co., Ltd., we examined the degree of degradation of various materials, including the degree of polymerization of insulating paper, taking the opportunity of replacing the approximately 40-year-old 265MVA transformer. The results matched the residual life estimated in advance. We will continue to gather data to improve the accuracy of our degradation diagnostic technology.


Hoisting the winding of an aged transformer

2 Lightning Arresters

Japan AE Power Systems has a wide range of lightning arresters conforming to major international standards including IEEE, IEC and JEC. We have many voltage classes, including 22kV to 1,100kV for tank-type lightning arresters used for gas insulated switchgear (GIS), 3.3kV to 550kV for the porcelain bushing type used for gas circuit breakers and 66kV to 300kV for polymer insulator type lightning arresters. A high withstand voltage zinc-oxide element having a voltage per unit thickness twice as high as that of the conventional model is used for tank type arresters to reduce the size of the product. We have a good selection and supply record of delivering lightning arresters, including those for DC power transmission lines, AC/DC converters, generator protection, and railway feeders. We can also provide lightning arresters and absorbers for special applications.

Tank type lightning arrester for 550kV GIS

266kV polymer insulator type lightning arrester

3 New Production Line of Environment-friendly VCB

The Numazu Works of Japan AE Power Systems set up a new production line for environment-friendly vacuum circuit breakers (VCB) using dry air instead of the conventional SF_6 gas. To build this new, more efficient production line, we thoroughly analyzed the problems of the existing lines, changed the line shape to minimize its length, introduced exclusive assembly facilities, enhanced the testing facilities, and then created three more such lines. This investment in facilities has increased the maximum production capacity of the environment-friendly VCB to 480 units/year. The product is starting to be delivered to environment-conscious countries including the U.S. and Australia, as well as the domestic market.

Environment-friendly VCB production line

Topics

4 Medium-size Transformers for the Ministry of Electricity in Iraq

Japan AE Power Systems has delivered more than one hundred sets of 25MVA- to 90MVA-class 132kV transformers for power transmission to the Ministry of Electricity in Iraq through Meidensha Corporation* since 2004 to supply power to the areas of the country that are being rebuilt. Due to the difficulty of sending our instructors for field assembly, we trained engineers of the Ministry of Electricity at the factories on how to maintain quality after field assembly. We will continue playing an important role in the reconstruction of Iraq together with Meidensha Corporation.

132kV mobile substation

* Japan AE Power Systems supplied products to Meidensha Corporation.

5 AE Green Factory: Minimizing the Environmental Load

Japan AE Power Systems makes utmost effort to improve its business processes by creating an appropriate company-wide organization, and aims to turn the company into the “AE Green Factory” with the minimum environmental load. We have set numerical five-year reduction targets for energy consumption, CO_2 emissions, and the quantities of waste and toxic chemical substances. Our activities include examining energy consumption as a contractor designated by the revised Energy Saving Act* in cooperation with experienced external company, in order to rationalize consumption by reducing the operating loss of their combustion-type steam boilers.

Checking the combustion status of the boiler

* Revised Energy Saving Act :
“Act on Temporary Measures for Promotion of Rational Uses of Energy and Recycled Resources in Business Activities” enforced in April 2010

6 24kV Cubicle-Type Gas Insulated Switchgear for Singapore

Japan AE Power System started delivering 24kV cubicle-type gas insulated switchgear (C-GIS) conforming to the new IEC standard in 2005. This C-GIS is a competitive product achieved by sharing and simplifying parts. We have been successively supplying the product to Singapore, with approximately 6,500 sets sold (including scheduled ones). Furthermore, a number of environment-friendly 24kV dry air-insulated C-GISs, which we started to supply in 2010, are used as major equipment for power distribution facilities in Singapore.

24kV dry air-insulated C-GIS

7 362kV Gas Circuit Breaker for the U.S. Market

HVB AE Power Systems, an affiliated company of the Japan AE Power System group in the U.S., is providing 72.5kV to 800kV gas insulated circuit breakers (GCB) to power utilities all over the U.S. In particular, over one hundred 362kV GCBs were delivered in 2010 because of their high performance and reliability. We are currently delivering both conventional pneumatically-operated and hydraulically-operated models at the request of our users, but aim to accelerate the transfer to the hydraulically-operated GCB which offers improved performance and economic efficiency, thus expanding the use of 362V GCB in the U.S. market.

362kV dead tank type gas circuit breaker

Topics

8

Leading Supplier in Bahrain

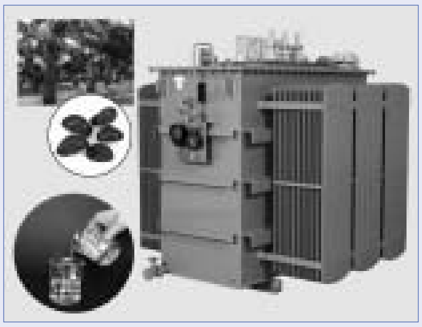
The Kingdom of Bahrain is an island nation located in the Arabian Bay, and is about the size of Singapore Island. Japan AE Power Systems has been delivering various substation equipment such as gas-insulated switchgear and transformers to many of its 220kV and 66kV substations, which are the main power network systems of the nation, since the 1980s. We have being supplying a number of our products for power infrastructure and industry, including those for the aluminum smelting and steel industries, which are the major industries of the nation and on a par with petroleum refining, and for urban development by private developers and industrial complex development. Thus, we cover the entire power distribution field and are a key supplier with a strong presence.

Urban development in Manama, the capital of Bahrain

9

Secondary Use of Palm Fatty Acid Ester Insulating Oil

Japan AE Power Systems has developed palm fatty acid ester (PFAE) insulating oil as an alternative insulating medium for transformers instead of mineral oil, and is currently studying how to use waste PFAE oil effectively in cooperation with the Kanazawa Institute of Technology. Waste mineral oil is generally treated by combustion at present, but since PFAE oil is low-viscosity plant-based oil, secondary use as diesel fuel might be possible, and so we are currently investigating the feasibility of this approach. If PFAE could be used as a fuel for diesel engines in various fields, CO_2 emissions would be reduced significantly, thus helping to create a recycling-based society.



Transformer using PFAE oil

Affiliated company in China

New plant inaugurated in August 2010

Shanghai AE Power Changcheng Switchgear Corporation

Shanghai AE Power Changcheng Switchgear Corporation is a Japan-China joint venture established in 2004 with Tianshui Changcheng Switchgear Factory, our Chinese partner, as a production center for medium-voltage switchgear in China. We mainly manufacture 40.5kV cubicle-type gas insulated switchgear (C-GIS) and 55kV vacuum circuit breakers (VCB) in this new plant constructed in the North Jiading Industrial District located 40km northwest of Shanghai, and sell them in the Chinese market. Our landmark first delivery, a 45.5kV C-GIS, is currently being used as substation equipment for the Qinghai line, a highland railway connecting Lhasa in the Tibetan Autonomous Region to Xining in Qinhai Province at an altitude as high as 3,000m. We have already provided a number of products in the six years since establishment and the joint venture is growing steadily.

The Jiading District where our company is located is a satellite city of Shanghai, which is growing at an astonishing pace. The Shanghai International Circuit is nearby, where the Chinese F1 Grand Prix is held every year. We started operation in 2004, but in 2006, we were suddenly ordered by the government of Shanghai to evacuate to make way for an urban development plan. Along with many neighboring foreign firms that had set up there at around the same time, we were required to move and started operation in the new plant in August 2010. After this unexpected move, we increased the production capacity of our C-GIS and VCB by 20%, and created a new production line for the 72kV environment-friendly VCB. Approximately 50 local employees are currently manufacturing and selling products, working together with staff dispatched from Japan including myself; we put top priority on product quality. Our products are mainly used for the electric power, steel, metallurgical, petrochemical, and chemical industries as well as for railways and subways. With the growing environmental awareness, the demand for products for wind power generation has recently been increasing. Products for railroads in particular will be in great demand because both passenger lines and coal transportation lines are being rapidly constructed throughout the nation. We will continue to help improve the electric power infrastructure in developing China.

Yoshiaki UCHIDA (President)

Environment-friendly VCB : Vacuum circuit breaker using dry air


New plant inauguration ceremony


40.5kV C-GIS for Qinghai line

Corporate data

▼ **Address**
North Jiading Industrial District, Shanghai

▼ **Year of foundation**
2004

▼ **Capital**
US$4.5 million (as of the end of fiscal 2010)

▼ **Businesses**
Manufacture, sale, and after-sale service of medium-voltage switchgear

Worldwide Network

Japan

Head Office
9-1, Shibaura 3-chome,
Minato-ku, Tokyo 108-0023, Japan
Tel +81-3-5439-3010


Tokyo（Head Office）

Plants in Japan

Kokubu works
(Hitachi city,
Ibaraki-Prefecture)

Chiba works
(Ichihara city,
Chiba-Prefecture)

Numazu works
(Numazu city,
Shizuoka-Prefecture)


Kokubu works


Chiba works


Numazu works

Worldwide

Branches & Representative Office

Singapore Branch
7 Tampines Grande #03-02
Hitachi Square
Singapore 528736

Dubai Branch
Room No. 606, Building No.6WA
Dubai Airport Free Zone Authority(DAFZA)
Dubai, U.A.E.

Bahrain Branch
Office No. 71, Building 892
Road 3618, Block 436
Seef District, Manama
Kingdom of Bahrain

Beijing Representative Office
Room No. 1505, Beijing Fortune Building
5 Dong San Huan Bei-Lu,
Chao Yang District,
Beijing 100004, P.R.C.

Shanghai Representative Office
Room No. 1701 Rui Jin Building,
205 Maoming Nan-Lu,
Shanghai 200020, P.R.C.

Taiwan Branch
3F No. 801 Chung Cheng Road, Chung Ho City,
Taipei Hsien, Taiwan

Affliated Companies

HVB AE Power Systems, Inc.
7250 McGinnis Ferry Road
Suwanee, GA 30024, U.S.A.

Japan AE Power Systems Asia Pte. Ltd.
7 Tampines Grande #03-02
Hitachi Square
Singapore 528736

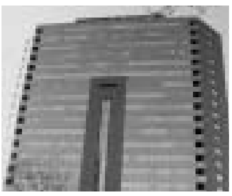
P.T. Japan AE Power Systems Indonesia
EJIP Industrial Park Plot 8E, Cikarang Selatan,
Bekasi 17550, Indonesia

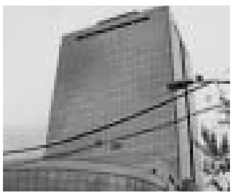
AE Power Metal Engineering Sdn. Bhd.
Lot 6, Peringkat 3, Kawasan Perindustrian Alor Gajah 78000
Melaka, Malaysia

CET AE Power (Shandong) High-Voltage Switchgear Co., Ltd.
Luneng Industrial Park Changqing,
Jinan, Shandong Prov. 250300, P.R.C.

Shanghai AE Power Changcheng Switchgear Corporation
No.885, Xing Rong Road, North Jiading Industrial Zone,
Shanghai 201807, P.R.C.

AE Power (Suzhou) EHV Switchgear Corporation
No. 458 Chao-Hong Road,
Suzhou New District, Jiangsu 215129, P.R.C.


Beijing


Shanghai


Singapore


Dubai


Bahrain

Japan AE Power Systems Review®
Vol.4
Printed on: July 22,2011　Published on: August 1,2011

Editor and Publisher
Koichi HARASHIMA

Published by
Japan AE Power Systems Corporation
9-1, Shibaura 3-chome,
Minato-ku, Tokyo 108-0023, Japan

Phone
+81-3-5439-3010

Printed by
Dai Nippon Printing Co., Ltd.

WWW.jaeps.com

Japan AE Power Systems Corporation
< Head Office > 9-1, Shibaura 3-chome, Minato-ku, Tokyo 108-0023, Japan