etz publication translated by ABB

VDE VERLAG

Operating mechanism and switching technology

Vacuum interrupters and embedded poles for medium voltage

Burkhard Fenski • Harald Fink • Thorsten Fugel • Dietmar Gentsch • Till Rümenapp

Vacuum switching technology is nowadays the dominant switching principle in medium voltage. Innovative developments are leading to a continuously increasing market growth, based on the fundamental advantages such as reliability, availability, compactness and, last but not least, the environmental friendliness of the vacuum as a switching medium.

Circuit-breakers have the function in the closed condition of conducting operating and short-circuit currents. They must also be capable of connecting and disconnecting these currents, and, in the open condition after interrupting the current, isolating different potentials from each other.

Various technologies have been used in recent decades to secure the functionalities described above. Interruption of a current is always associated with the formation of an arc between the switching contacts, irrespective of which quenching medium surrounds those contacts. These media include gases, for instance air or SF_6, and liquids such as oil.

While compressed air circuit-breakers and minimum-oil circuit-breakers are practically no longer used in new and retrofitted medium voltage installations and the proportion of SF_6 circuit-breakers is constantly dropping, the number of vacuum circuit-breakers is significantly rising. **Figure 1** shows the development in shares of the various technologies installed from 1980 to 2010.

A vacuum circuit-breaker is a three-phase device, with main components consisting of a mechanical or magnetic operating mechanism and the three pole parts. The current interrupting devices, the vacuum interrupters, are located in the pole parts (**Figure 2**).

ABB [1] commenced manufacture of the first vacuum interrupters in the early 1980s. By the mid-1990s, annual production had reached around 30,000 units, and that level has risen almost ten times today in response to strong demand from the market. ABB is therefore now the world's largest manufacturer, with over 1.5 million vacuum interrupters installed [2].

At the same time, development activities (including cooperation with research institutes and universities) have continuously been intensified, new modelling and simulation methods introduced, and innovative manufacturing and testing strategies implemented. One special example is the market launch of embedded poles, in which the vacuum interrupters are directly enclosed in the insulating material, an epoxy resin moulding, in a special manufacturing process. In conjunction with the maintenance-free vacuum interrupters, this solution provides high dielectric insulation strength for service in a wide range of ambient con-

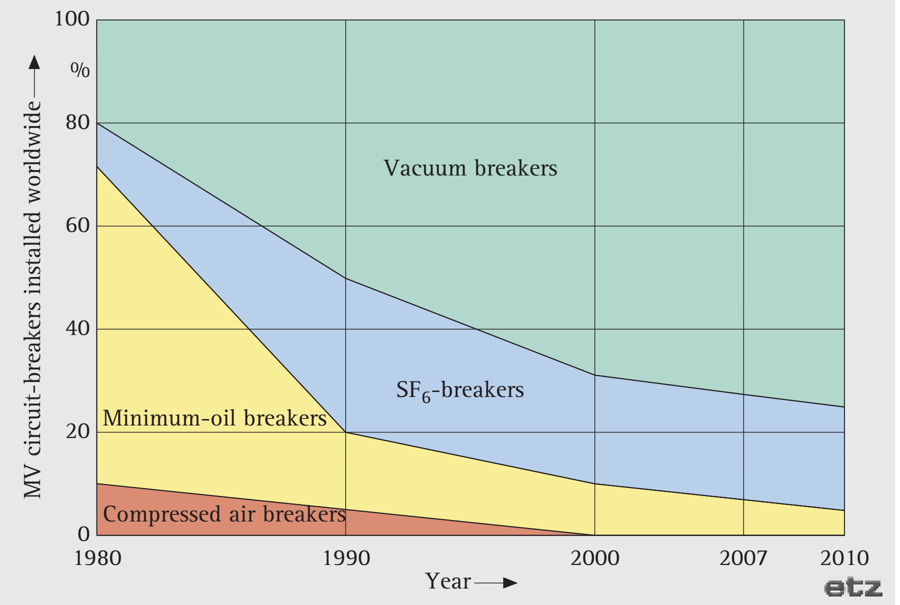

***Figure 1**. Shares of medium voltage circuit-breakers installed worldwide by switching medium*

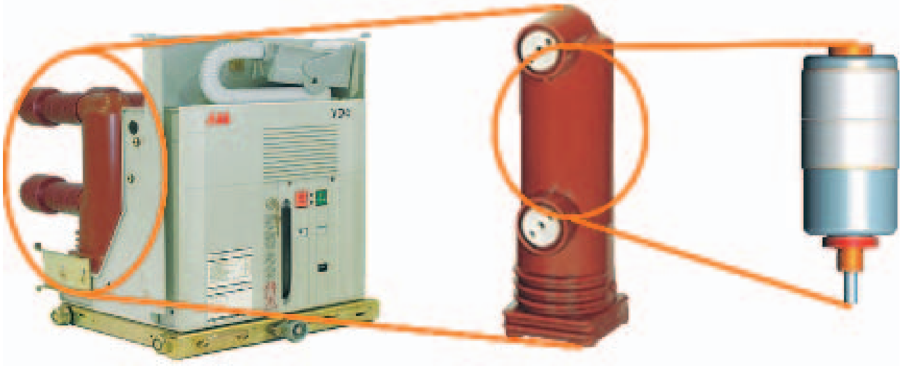

***Figure 2**. The vacuum interrupter (r) as the core component of the vacuum circuit-breaker (l)*

ditions, and has proved successful on the market, above all with the ABB vacuum circuit-breakers of types VD4 and VM1.

Vacuum interrupters and embedded poles as components are a promising solution for manufacturers of medium voltage switchgear. Using these components to construct vacuum switching devices, they can participate in the forward-looking vacuum technology simply and, most particularly, cost-effectively, and position forward-looking competitively on the market.

The core component: The vacuum interrupter

Successful production and marketing of vacuum interrupters requires optimum chamber design, modern process-controlled production facilities and a product portfolio tailored to suit the market with its broad range of different requirements.

Vacuum interrupters are predominantly used for rated voltages up to 40.5 kV and short-circuit breaking currents up to 80 kA. Together with perfect function at the selected ratings, the compactness of these components is especially decisive, as they determine the overall size of the whole switching device.

Figure 3 shows a cross-section of a modern vacuum interrupter. It consists of two switching contacts in copper-chromium composite material (CuCr), one of which is fixed and the other movable [3]. The contacts are located in a cylindrical casing which encloses an ultra-high vacuum (UHV) of $<10^{-7}$ hPa. The vacuum interrupter chamber consists of a ceramic insulator, a metal bellows on the moving contact side and a concentric shield to prevent the condensation of metal vapour on the inside of the ceramic material during an opening process.

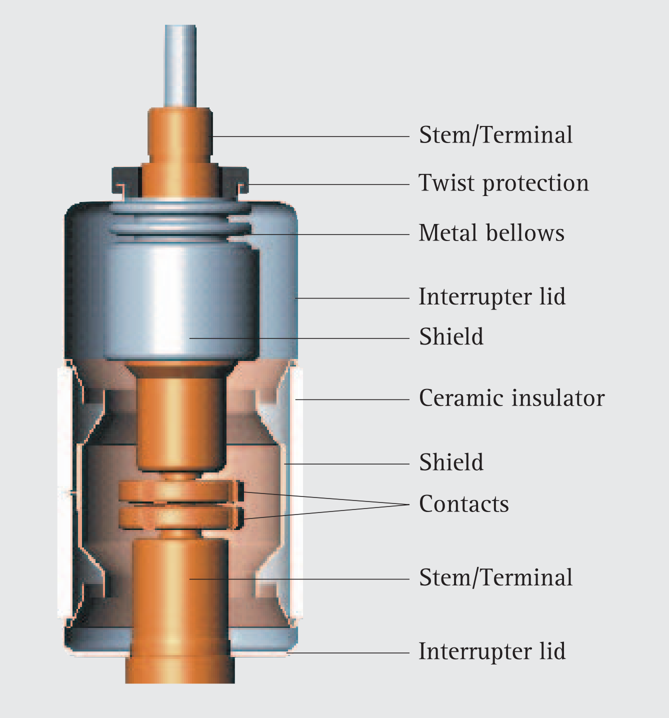

Figure 3. *Cross-sectional representation of a vacuum interrupter of type VG4. Rated data:* $U_r = 12$ *kV,* $I_r = 2\,500$ *A,* $I_{sc} = 25$ *kA; diameter: 90 mm*

As soon as the contacts in a vacuum interrupter are separated by the breaker's operating mechanism, a switching arc (metal vapour arc) begins to form, and is interrupted at the next current zero. A special contact geometry ensures that the arc is moved in the gap between the contacts and the energy the arc contains transmitted to the contacts and the shield (Figure 3, [4]).

The internal structure adjusted to suit the prevailing switching capacity and the use of special materials are the preconditions for reliable and robust function of the vacuum interrupter. With the use of a vacuum as the switching medium, relatively small contact gaps of around only 8 mm to 14 mm are sufficient, with a corresponding beneficial effect on the cost-effectiveness of the operating mechanism.

Together with a large number of potential breaking operations on the full rated short-circuit breaking current, other parameters such as mechanical service life also place demands on the quality of vacuum interrupter production and testing. In order reliably to achieve a service life of 30 years of more ("Sealed for Life"), extremely stringent quality requirements have to be applied to every individual soldered joint, some of which are between different materials, to maintain the ultra-high vacuum (**Figure 4**, [5]).

As a result, production in clean room conditions and the necessary routine testing of the dielectric properties and internal pressure of vacuum interrupters are characteristic features of interrupters of the highest quality. These demands can only be met by process-monitored series production, supported by a strictly im-

Dr.-Ing. ***Burkhard Fenski*** *(41) has been Head of Product Management for Switchgear and Components at ABB AG Calor Emag Mittelspannungsprodukte in Ratingen/Germany since 2003. Following his degree studies in electrical engineering at the Technical University of Braunschweig/Germany and doctorate in the field of vacuum switching technology at the university's Institute of Electrical Power Systems, he joined the company in 1997 as a development engineer in the vacuum interrupter department.*
E-mail: burkhard.fenski@de.abb.com

Dr.-Ing. ***Harald Fink*** *(52), VDE, has been Head of Development at ABB AG Calor Emag Mittelspannungsprodukte in Ratingen/Germany since 1991. He studied electrical engineering at the Technical University of Dresden/Germany and took his doctorate in the field of vacuum circuit-breakers at the university's Institute of High Current and High Voltage Engineering.*
E-mail: harald.fink@de.abb.com

Dr.-Ing. ***Thorsten Fugel*** *(34) has been Product Manager for Switchgear and Components at ABB AG Calor Emag Mittelspannungsprodukte in Ratingen/Germany since 2003, and Global Product Manager responsible for vacuum interrupters, embedded poles, load break switches and fuses since the end of 2006. He studied electrical engineering at the Technical University of Braunschweig/Germany, then gaining his doctorate in the field of vacuum circuit-breakers at the High Voltage Engineering Department of the Technical University of Darmstadt/Germany.*
E-mail: thorsten.fugel@de.abb.com

Dr.-Ing. ***Dietmar Gentsch*** *(40) has been Head of Development for Vacuum Interrupters at ABB AG Calor Emag Mittelspannungsprodukte in Ratingen/Germany since 2005. He studied mechanical engineering at the Technical University of Hanover/Germany and took his doctorate in electrical engineering at the Technical University of Braunschweig's Institute of High Voltage Engineering and Electrical Power Systems.*
E-mail: dietmar.gentsch@de.abb.com

Dr.-Ing. ***Till Rümenapp*** *(35) has been Head of Development for Switching Devices at ABB AG Calor Emag Mittelspannungsprodukte in Ratingen/Germany since 2005. He studied electrical engineering at the University of Dortmund/Germany and gained his doctorate at the Institute of High Voltage Engineering and Electrical Systems there.*
E-mail: till.ruemenapp@de.abb.com

plemented Quality and Environmental Management System to DIN EN ISO 9001:2000-12 [6] and DIN EN ISO 14001:2005-06 [7].

ABB supplies a broad range of latest generation vacuum interrupters whose compact design and versatility in use satisfy the requirements of the market in full (**Figure 5**). They can be combined with other platform technologies such as embedding, and are thus suitable for service in a broader spectrum of applications.

Series VG for vacuum circuit-breakers covers applications with rated voltages U_r in the range of 12 kV to 40.5 kV and is suitable for rated currents I_r of up to 4 000 A and rated short-circuit breaking currents I_{sc} of up to 63 kA. Even the 63 kA vacuum interrupter variant is extremely compact in design, with a diameter of only 142 mm and a length of 224 mm. All the vacuum interrupters of this series fulfil the highest mechanical, electrical and capacitive switching requirements M2, E2 and C2 to IEC 62271-100:2006-10 [8] and DIN EN 62271-100 (**VDE 0671-100**):2004-04.

The vacuum interrupters of the VS series are designed for contactors and switch-disconnectors in the rated voltage range from 3.6 kV to 24 kV and for up to 1 000 000 mechanical switching operations (contactor applications) or 15 000 mechanical switching operations (switch-disconnector applications). The vacuum interrupters comply with requirements AC-1, AC-2, AC-3 and AC-4 to IEC 60470:2000-05 [9] and DIN EN 60470 (**VDE 0670-501**): 2002-01.

Apart from the requirements of medium voltage networks, operated differently throughout the world, the vacuum interrupters from the portfolio outlined above also fulfil the requirements for railways and further special applications.

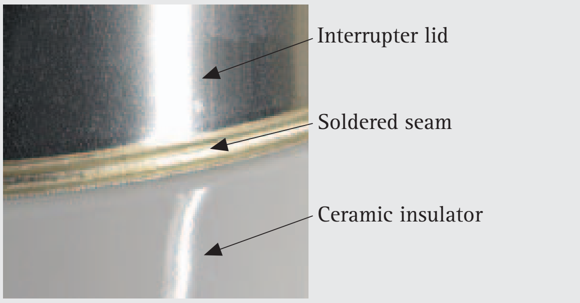

Figure 4. *Detailed view of a soldered seam between a stainless steel chamber lid and a ceramic insulator*

Figure 5. *Overview of vacuum interrupters of series VG and VS. Left: Series VG embedded in silicone. Top centre: Series VG for circuit-breaker applications. Bottom right: Series VS for contactor and switch-disconnector applications*

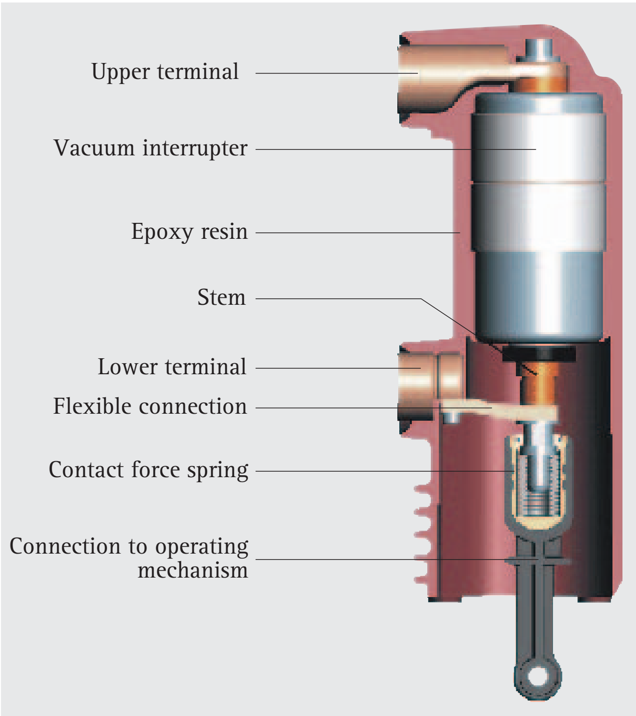

Figure 6. *Cross-sectional representation of embedded pole type P1, vacuum interrupter type VG4 with rated data U_r =12 kV, I_r =1 250 A, I_{sc} =25 kA*

The innovation: Embedded poles

One major advantage of the vacuum interrupters is their extremely high internal dielectric strength resulting from the UHV, which requires no checking whatsoever throughout the service life of the interrupter. The external dielectric strength is however limited by the insulation capacity of the air, and therefore also requires compensation for adverse ambient conditions such as soiling of the surface or extreme condensation.

One method of increasing the external dielectric strength of the vacuum interrupters is to embed the chamber in a solid material (e. g. silicone or epoxy resin moulding compound). In such cases, the vacuum interrupter is additionally well protected against external mechanical influences such as impacts.

In the case of poles manufactured in column form, the assembled poles, the vacuum interrupters are bolted to their terminal connections inside an insulating tube of epoxy resin. With embedding technology (**Figure 6**), however, the maintenance-free vacuum interrupters are directly cast in epoxy resin by the automatic pressure gel (APG) process to produce a form-fit pole. As a result, the vacuum interrupters and the epoxy resin enclosures can be manufactured with the smallest possible number of bolted connections. This ensures freedom from maintenance for the embedded poles, and facilitates especially compact and robust design.

The main advantages of embedded poles are high dielectric strength without additional external compensation in air, usability in an extremely wide range of climatic conditions, and good protection of the vacuum interrupter from dust, mechanical impacts and moisture. Furthermore, the greatly reduced number of individual parts required allows significantly increased production reliability to be achieved with shortened production times. With the introduction of the embedded poles, a modern Manufacturing Execution System

(MES) was also installed, in which all important information such as the process and material parameters for each individual embedded pole are stored and made available for detailed evaluation at a later date.

ABB started the market launch of the world's first embedded poles with the 12 kV components for low and medium switching capacities (I_{sc} up to 31.5 kA) in 1997. This led to a new trend for vacuum circuit-breakers in medium voltage engineering. With the continuous development of this technology, embedded poles are now available and established on the market for all indoor and outdoor applications with operating voltages U_r up to 40.5 kV and short-circuit breaking currents I_{sc} up to 50 kA (**Figure 7**). A new production record with almost 150 000 embedded poles in 2006 clearly illustrates this trend.

Together with the use of embedded pole technology for indoor applications, the development of a new epoxy resin system specially designed for outdoor applications made it possible to construct outdoor poles for even the most adverse environmental conditions and launch these on the market. The special properties of the new hydrophobic cycloaliphatic epoxy resin (HCEP) include its high UV resistance, impact strength and usability at temperatures down to –60 °C. The portfolio of outdoor embedded poles now comprises poles for circuit-breakers in outdoor installations for up to 12 kV and poles for outdoor reclosers with rated voltages U_r up to 38 kV with integrated current transformers.

Figure 7. *Variants of embedded poles for indoor (l) and outdoor (r) applications*

Prospects

Vacuum interrupters form the core of medium voltage circuit-breakers. Reliability in service, high quality materials and long life are demanded of these maintenance-free components.

Competent manufacturers are nowadays able to supply vacuum interrupters which cover all primary and secondary medium voltage applications in power supply. These include switching of loads in general, and of transformers, motors, generators, overhead lines, cables and even capacitors.

The highly compact vacuum interrupters of the latest generation developed by ABB can be deployed in these applications without any additional external insulation, or are encapsulated in an insulating material such as silicone or epoxy resin to optimize the external dielectric strength and protection against environmental effects.

The innovative modular embedded pole for use on vacuum circuit-breakers, with its compactness, robustness and freedom from maintenance, will in particular ensure rising market shares worldwide for vacuum circuit-breakers in medium voltage in future.

References

[1] ABB AG, Calor Emag Mittelspannungsprodukte, Ratingen: www.abb.com

[2] *Kaltenegger, K.; Salge, G.; Gentsch, D.*: Breaking to the front – Technological innovation in vacuum interrupters. ABB Review 92 (2005) no. 4, pp. 39–41 (ISSN 1013-3119)

[3] *Gentsch, D.*: Contact material for Vacuum Interrupters based on CuCr with a specific High Short Circuit Interruption Ability. pp. 437–442 in Proceedings of XXIIth International Symposia on Discharges and Electrical Insulation in Vacuum (ISDEIV), 25.9.–29.9.2006 in Matsue/Japan. Piscataway, New York/USA: IEEE, 2006

[4] *Gentsch, D.; Shang, W.*: High-speed observation of Arc Modes and Material Erosion on RMF- and AMF–Contact Electrodes. IEEE Trans. on Plasma Science 33 (2005) no. 5, pp. 1 605–1 610 (ISSN 0093-3813)

[5] *Renz, R.; Gentsch, D.; Fink, H.; Slade, P.; Schlaug, M.*: Vacuum Interrupters – Sealed for Life. In Proceedings 19th International Conference on Electricity Distribution (CIRED), 21.5.–24.5.2007 in Vienna/Austria (Paper submitted and accepted)

[6] Literaturstelle ändern in: DIN EN ISO 9001:2000-12 Quality management systems – Requirements. Berlin/Germany: Beuth

[7] DIN EN ISO 14001:2005-06 Environmental management systems – Requirements with guidance for use. Berlin/Germany:Beuth

[8] IEC 62271-100:2006-10 High-voltage switchgear and controlgear – Part 100: High-voltage alternating-current circuit-breakers. Geneva/Switzerland: Bureau Central de la Commission Electrotechnique Internationale (ISBN 2-8318-8798-4)

[9] IEC 60470:2000-05 High-voltage alternating current contactors and contactor-based motorstarters. Geneva/Switzerland: Bureau Central de la Commission Electrotechnique Internationale (ISBN 2-8318-5285-4)

ABB

ABB AG – Calor Emag Medium Voltage Products

Oberhausener Straße 33
40472 Ratingen, GERMANY

Petzower Straße 8
14542 Glindow, GERMANY

Phone: +49 2102 12-0, Fax: +49 2102 12-17 77
E-mail: powertech@de.abb.com
Internet: http//www.abb.de/mediumvoltage