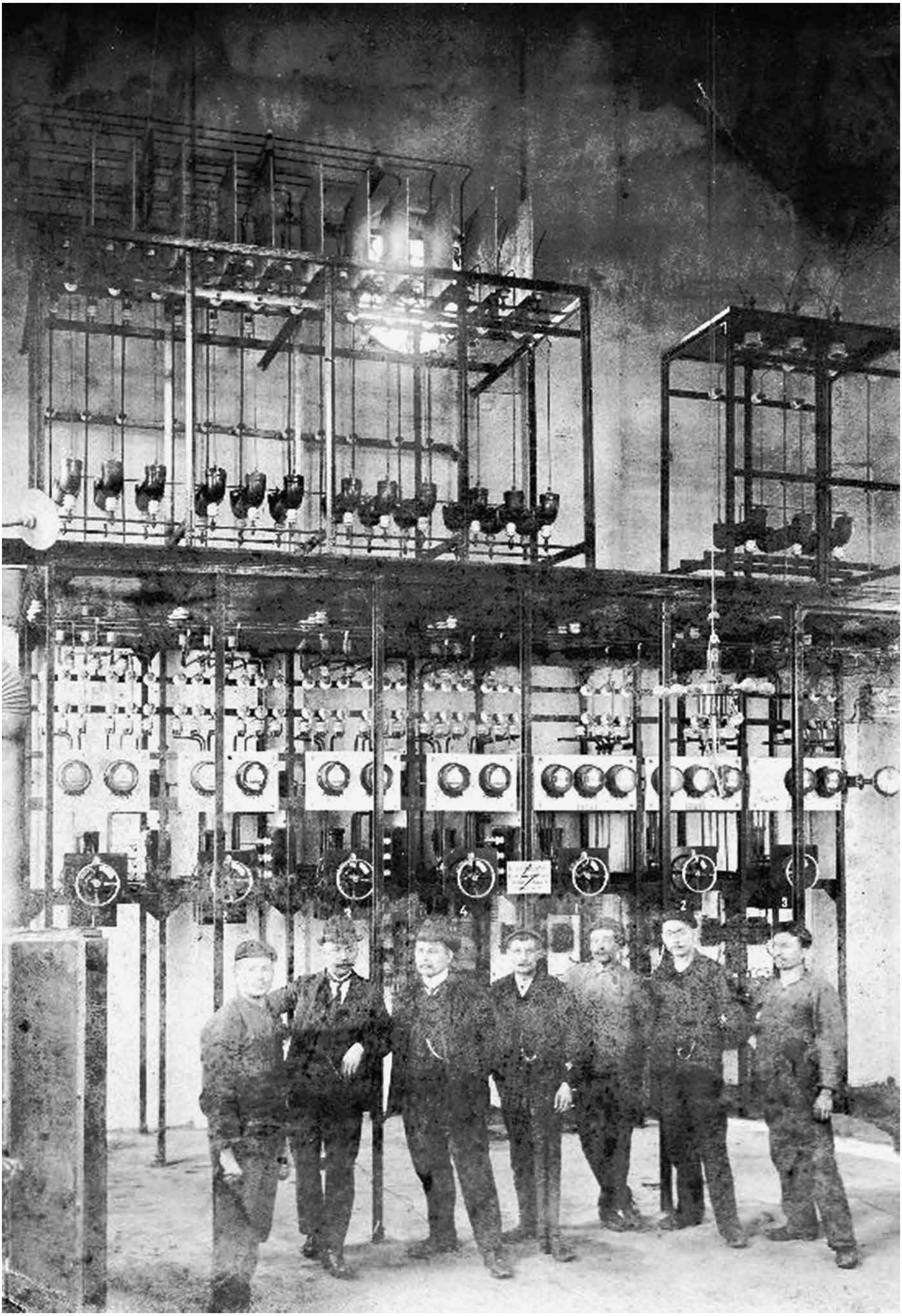


Distribution evolution

Medium-voltage distribution technology is a key part of the power network

GERHARD SALGE – It is well over a century since the so-called Current Wars that pitted Edison's established direct current (DC) distribution technology against the new alternating current (AC) approach championed by, among others, Westinghouse (later to be part of the ABB family). Initially, DC was the standard method of medium-voltage (MV) power distribution in the United States but, as time went on, AC technology caught up with and then overtook DC: Workable AC motors were developed; AC transmission lines were shown to be much more efficient; and AC transformers were invented that allowed simple voltage step-up and step-down – the Achilles heel of DC. In the 120 years since the ousting of DC, AC technology has evolved to such an extent that today's MV distribution network would be unrecognizable to the early pioneers: Numerous sophisticated technologies are now employed for current conduction, electrical insulation, switching operations, protection, control and interruption. The modern MV distribution product provider must be master of all these.

Title picture
ABB has over a century of experience in MV distribution technology. The photo shows ABB (then Brown Boveri) MV switchgear from the 1920s.

Though DC technology is experiencing a resurgence in specific applications like data centers, AC is now the weapon of choice for distributing electrical power. The last remnants of DC hung on until the middle of the last century – the New Yorker Hotel, for example, converted fully to AC only in the late 1960s. (Ironically, it was in this very hotel that the AC pioneer Nikola Tesla spent the last years of his life.)

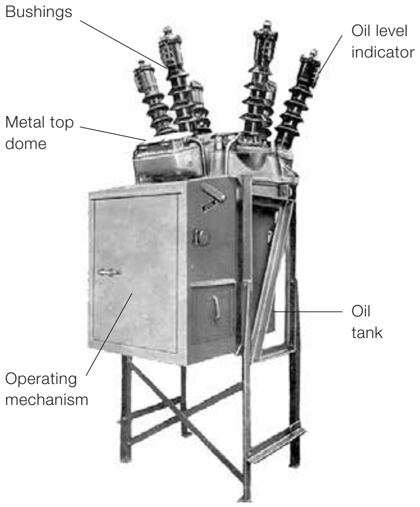
With the realization last century of the first high-voltage AC transmission lines, today's familiar power network began to emerge. In the vicinity of the user, the voltage is stepped down (transformed) from the high voltages produced by the generators to medium-voltage levels (1 kV to 52 kV). Large industrial users may consume power directly at these levels; households require further stepping-down to a few hundred volts.

For it to be reliable and safe, a modern AC MV distribution network relies on multiple technologies. These cover aspects such as current conduction, electrical insulation, switching operations, and protection, control and interruption capabilities during any type of network failure. This entails the use of:
– Switching elements for normal situations and any type of fault condition.
– Protection and control equipment to supervise the network and trigger appropriate switching elements in normal and fault situations.
– Measurement equipment for voltage and current.
– Switchgear for safe incorporation of all switching, protection, control and measurement equipment.

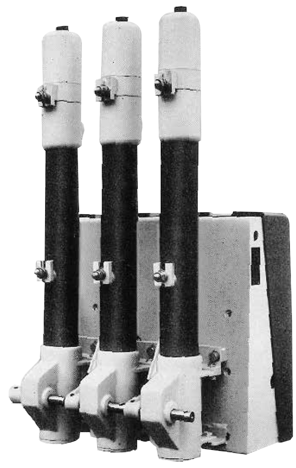
In the 120 years since the ousting of DC, AC technology has evolved to such an extent that today's MV distribution network would be unrecognizable to the early pioneers.

Gas-insulated switchgear using SF_6 was introduced to the market in the early 1980s by ABB as a three-phase design.

1 Bulk oil circuit breaker



2 Calor Emag minimum oil CB OD4 for 20 kV (1976)



Switchgear history and development

The first installations of MV-like switchgear are mentioned in the literature in 1900. In the beginning, designs were very simple and focused purely on technical functionality; safety requirements and footprint were of little interest ➔ title picture.

With growing operational experience, switchgear design and optimization parameters changed significantly. For instance, electrically live parts (at MV potential) were encapsulated in steel to shield operators from live parts and hazards arising from equipment faults. This evolved into today's standard arc-resistant switchgear. In a further significant step forward, porcelain (later epoxy) insulators were brought into play.

One aspect that has changed little is the insulation gas: Today, the majority of switchgear worldwide is still air-insulated. However, gas-insulated switchgear (GIS) using SF_6 (sulfur hexafluoride) was introduced to the market in the early 1980s by ABB as a three-phase design and by Siemens as single-phase design. The three-phase approach is more compact than the single-phase concept and this state-of-the art technology is now used by the majority of producers worldwide.

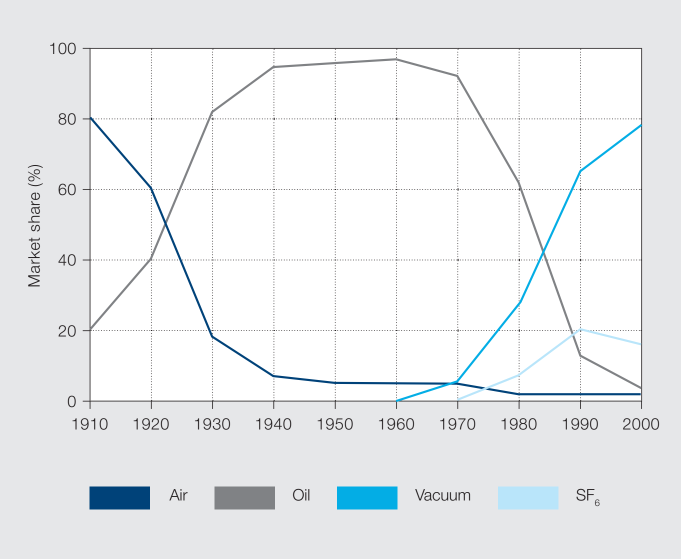
The latest, and today's dominant, MV interruption technology is based on vacuum techniques.

Today's air-insulated switchgear (AIS) and GIS are highly optimized with respect to functionality, operator safety, reliability and footprint. The choice between AIS and GIS depends on a customer's specific requirements.

MV switching equipment

In the beginning, the preferred MV current interruption technology was based on the air-blast technique. Air-blast circuit breakers (CBs) used either axially or radially blown air streams to deform and cool or stretch, and thus quench, the arc. In a further enhancement, arc chutes were used to split the arc up in order to increase the arc voltage and make it easier to extinguish. This type of breaker needed air compression up to 100 bar and the associated compressors, high-pressure containers, fast valves and pipes.

In a second technology step, oil breakers started to be used in MV applications. The first generation of these – bulk oil breakers – consisted of a steel tank filled with oil from which the arc was drawn and interrupted between two simple contacts ➔ 1. These devices had very limited interruption capabilities (approximately 15 kV and 200 A) and high explosion risk. As a next step, 3 Vacuum interrupter development



4 ABB vacuum circuit breakers

4a Circuit breaker VD4 for indoor applications

4b Circuit breaker OVB-VBF for outdoor applications

tubes were placed around the interrupter contacts, thus helping to shape the oil flow. With this development, higher currents (up to 50 kA) could be interrupted. As a side effect, the amount of oil within the breaker was significantly reduced and thus was born the minimum oil breaker, which was used until the 1970s with great success → 2.

The next technology generation of MV circuit breakers was based on SF_6. After the first SF_6 circuit breaker patent was filed by Westinghouse in 1951 it took approximately 10 more years for the first breakers to enter the market. The interrupting technology started with two voluminous pressure systems requiring a gas reservoir at high pressure, similar to air-blast breakers. Then puffer breakers followed (around 1970) where the operating mechanism produced the high SF_6 pressure during opening via a moving piston. Finally, in the 1980s, the self-blast breaker was introduced, where the blast pressure was extracted from the energy of the arc itself, making the operating mechanism much more efficient.

The latest, and today's dominant, MV interruption technology is based on vacuum techniques → 3–4. To make this approach possible, multiple constituent technologies, namely Al_2O_3 ceramics, oxygen-free copper, appropriate clean-room manufacturing, advanced brazing technologies and copper-chromium contact technology had to reach mature industrial status. In 1982, ABB introduced an interrupter, called VC1 (24 kV/25 kA), that used this technology. The production technology developed rapidly from manual welding of flanges and evacuation of the vacuum tube by diffusion pumps and pinch-off, to one-shot brazing technique in a high-temperature furnace evacuated by turbo-molecular pumps. Today, ABB uses spiral-shape contact technology to make devices with short-circuit ratings of up to 63 kA.

The new generation of ABB's UniGear switchgear (UniGear Digital) fully exploits IEC 61850 to bring more flexibility and value to the switchgear customer

Protection and control

ABB and its predecessors ASEA, BBC, Westinghouse, ITE and Strömberg have all played an important role in the evolution of MV protection and control technology over the past few decades by developing techniques to isolate malfunctioning units and minimize power outages. Early units were merely single-function electromechanical relays and solid-state (static) relays. Different construction types satisfied different electromechanical needs and the basic principles exploited were electromagnetic attraction, electromagnetic induction and solid-state electronics.

During the 1970s, significant hardware and software progress led to the first commercially available microprocessor-based relay (1979). The digital relays found on the market in the 1980s were relays with very basic functions, hybrid relays combining analog and digital techniques, and relays offering economical but barely adequate performance. Further progress led to multifunction relays in the late 1980s. This led to significantly enhanced network protection and control.

ABB took a leading role in the standardization work that paved the way for the following generations of relays. For example, the IEC 61850 standard, which represents the state-of-the-art for transmission and distribution relays, was developed and harmonized with major contributions from ABB. Subsequently, in 2007, the first ABB Relion relay for distribution applications capable of communicating in native IEC 61850 was launched → 5. Today, IEC 61850 ensures the future of relay communication and provides substantial advantages during switchgear design, installation and operation. The new generation of ABB's UniGear switchgear (UniGear Digital) fully exploits this technology to bring more flexibility and value to the switchgear customer → 6.

5 ABB Relion 615 series for protection and control

The relay has evolved from a simple protection device into an intelligent electronic device (IED) that is able to perform control, automation and communication functionalities. Associated software and hardware platforms are configurable via software and are integrated into distribution management systems (DMSs).

Measuring and sensing

The technology for measuring voltage and current has also undergone a revolution. The very first instrument transformers were just smaller versions of oil-paper-insulated power transformers, consisting of an iron core, primary and secondary windings, insulating oil and porcelain bushings. To get rid of the oil and to become more compact, cast resins have been used since the early 1960s. Over the decades, ABB and its predecessors contributed significantly to indoor as well as outdoor instrument transformer progress. Westinghouse and ABB brought aliphatic epoxy blends for indoor applications to the market. In 2005, ABB was the first manufacturer to introduce a hydrophobic cycloaliphatic epoxy for outdoor applications.

Today, the design and technology of the current or voltage measurement are highly dependent on the device that is connected and which additional functionalities the instrument transformer has to deliver. In this respect, sensors (sometimes also called electronic instrument transformers or low-power standalone sensors) are becoming more and more popular. Current measurement is usually based on the Rogowski principle, while voltage sensing can be either resistive or capacitive. Sensors can offer some significant technical advantages in terms of linearity, weight, safety (no ferroresonance) and space saving. In combination with the latest generation of IEDs, sensors offer a very interesting technological alternative, with additional value for the customer, to conventional instrument transformers.

Main features

Four main features characterize MV switchgear and substations: safety, reliability, environmental friendliness and intelligence. Technological advances are constantly improving operator safety – for example, ultrafast earthing switches (UFESs) working in combination with fast protection relays; ferroresonance-free sensors; optimized switchgear design that uses advanced simulation techniques; and new materials that have excellent flammability behavior. Optimized switchgear panel design also makes operation safer. Reliability is increased by high-performance circuit breakers and equipment that is produced in high-quality manufacturing processes. New materials are environmentally friendly and the latest IED design enables advanced protection, control, communication and equipment supervision functionality in combination with optimized human-machine interfaces. This *ABB Review Special Report* highlights numerous examples of the future of medium-voltage technology.

Gerhard Salge
ABB Power Products, Medium Voltage Products
Ratingen, Germany
gerhard.salge@de.abb.com

Reference

[1] Falkingham, G. Montillet (2004), "A History of Fifty Years of Vacuum Interrupter Development," retrieved from: http://www.vil.org.uk/USBPapers/VIDevelopment PESGM2004-000429.pdf (2014, January 1).