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new techniques for medium voltage SF6 circuit breaker

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introduction

There are various methods of breaking electrical arcs in the HV range, as opposed to LV, where magnetic blowout in air is the only possibility and EHV where the SF6 puffer technique is used by the majority of manufacturers.
No matter which technique is employed, a circuit breaker is always a device with separating contacts. Furthermore, the breaking medium is always gaseous and very hot:

- mainly hydrogen for oil-break devices,
- nitrogen and oxygen for magnetic air-break devices,
- various metallic vapours for vacuum devices,
- fluorine and its compounds for SF6 devices.

In this lecture consider SF6 technique only.

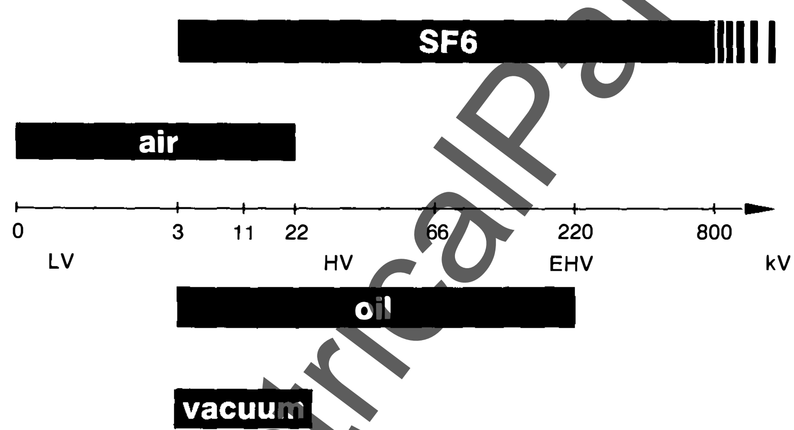


fig. 1. SF6, Air, Oil, Vacuum

Note : a conference, based on this article has been given during the 4th Conference on Electric Power Supply Industry (C.E.P.S.I.) 22-26 november 1982.

1. why SF6?

SF6 gas was at first used in switchgear because of its highly superior dielectric properties with respect to air. Its important arc interruption properties were discovered later and can be summarized as:

- its higher capacity for evacuating the heat created during arcing,
- its decomposition is a perfectly reversible phenomenon and without wear.

During the short decomposition period, it produces fluorine, which is highly electronegative and thus capable of capturing the free electrons found between the contacts of the circuit breaker, which are mainly responsible for the electrical conduction of the gaseous medium.

In the vicinity of the current zero point, the arc is cooled chiefly by radial conduction. This good conduction from the centre of the arc towards the exterior is explained in the curve. On this curve a very pronounced thermal conductivity peak around 2100 °K may be observed. The arc is confined to a small diameter where it is still conductive and it is surrounded by a ring of cooler gas which does not conduct the electric current but does conduct heat very well.

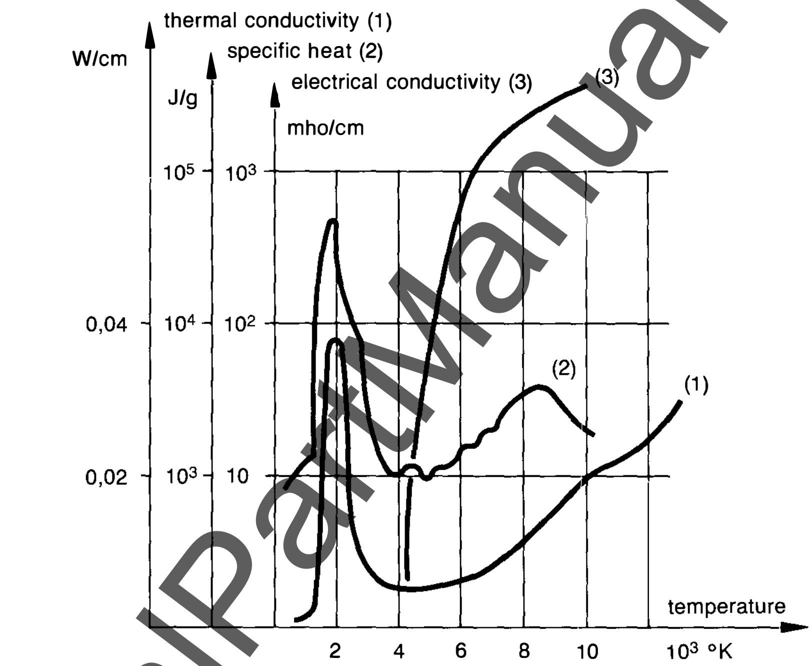


fig. 2. thermal conductivity - specific heat - electrical conductivity

2. the SF6 puffer type C.B.

The first generation of SF6 C.B., was the puffer type, as an extrapolation of the technology which was already well known in E.H.V.

Today, in the field of MV applications, the technology has performed a separate evolution. An example of this evolution concerns the tightness of the bottles. They are small and sealed for life. But the interrupting process by puffer piston is always the same.

3. puffer type breaking in SF6

This technique has already been presented in many circumstances and is now well known. The movement of the moving parts simultaneously causes the compression of a small volume of gas behind the puffer piston. The gas compressed in this way remains captive during the first third of the piston stroke and only begins to escape between the arcing contacts at the moment they separate. This precompression time results in a pressure difference without delay, i.e. a flow of gas by forced convection.
During the arcing period the arc is cooled by convection in that a certain quantity of hot gas is replaced by cold gas. This is not a surface phenomenon; the cold gas is brought in perpendicularly to the direction of flow to promote the mixing of hot gas and cold gas.

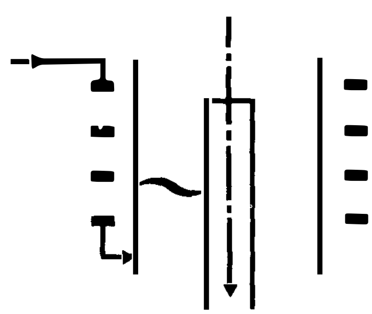
The tubular contacts facilitate the rapid flow of hot gases and cause instability of the arc root, preventing wear on the arcing contacts.
The puffer technique is remarkably effective, as it is sufficient to inject only a small quantity of gas between the contacts.
At high current values, the arc may occupy the whole of the available space blocking the flow of gas. Indeed, the mass flow in the arc is very low compared with the flow of cold gas around the arc, as the gas density is low at the temperature of the arc. This is what is known as the "clogging" effect. The total mass flow at the nozzle throat is thus low when instantaneous current values are high, but it rises very quickly as soon as the current falls, and shortly before current zero it is greater than that which would occur on opening without current.

The clogging effect is beneficial for two reasons:

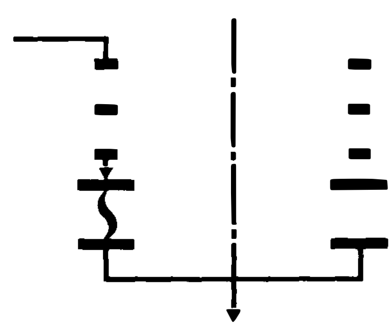
- when the circuit breaker opens on a high current it keeps a larger amount of gas in reserve than when it interrupts lower currents. It does not act "blindly" whatever the current; it is better prepared for the passage through current zero in heavy currents, and it avoids brusquely interrupting low currents, as the mass flow on non-load is modest,
- interruption of a heavy current causes braking in the opening movement. This braking limits the distance between contacts, that is, the length of the arc and thus the energy dissipated in the arc. It is therefore important to stress that the arc is relatively short, in the order of 15 mm for a 12 kV, 24 kV, or 36 kV equipment that is, smaller than the contact diameter.

4. rotating arc in SF6

To cool the arc, it must be thoroughly mixed with the cold gas i.e. there must be relative movement between the arc and the cold gas. In the puffer breaking process the arc is stationary and the cold gas moves. In the arc rotation process, it is the arc that moves within a larger volume of cold gas under the effect of electromagnetic forces.
These forces result from the action of the magnetic field created by a blowout coil located in series on the circuit and the current that flows through the arc between the contacts.
This blowout technique offers a great variety of schemes. The magnetic field exists near the turns, inside and outside the coil. We decided to locate the arc under the coil rather than inside in order to start the rotation of the 2 arc roots quickly; the rings on which the arc roots move are of approximately the same size. The dimensions may be optimized using automatic field plotting techniques. This optimization makes possible the use of relatively low pressures (2.5 bars).



scheme 1: arc located radially inside the coil



scheme 2: arc located axially under the coil (Fluarc circuit breakers and Rollarc contactors)

fig. 3. rotating arc technique

The speed of rotation of the arc has been measured. It varies with the intensity of the current to be interrupted and can reach the speed of sound in the gas for the highest currents.
When short-circuit currents are interrupted, the speed slightly before the current zero is high enough to keep the arc in rotation. The field is out of phase with the current and the product of the two is still significant.
On the other hand, the speed is very low just before the current zero when small current are interrupted. This is the reason for the smooth breaking made possible by this technique and the absence of switching surges.
Consider HV motor applications. This quality is especially important for low output motors and is provided by the following Merlin Gerin devices:

- Rollarc contactor,
- low range Fluarc FG1 circuit breaker.

These equipments use the rotating arc breaking technique exclusively, without any auxiliary puffer type device. The result is a simple and reliable device with a great many advantages thanks to the rotating arc technique.

	during arcing period	**just before current zero**
high currents	**very high (speed of sound)**	**high**
low currents	**high**	**low**

fig. 4. speed of arc rotation in the magnetic field

5. the behaviour when breaking small currents

The breaking of a small inductive current without producing harmful voltage surges is a quality reserved for certain breaking techniques.
Magnetic breaking in air or SF6 offers a perfect solution to this problem.
The electromagnetic forces applied to the arc to move it and cool it are proportional to the square of the current to be interrupted. These forces are therefore very low for small currents which results in a "soft" break without harmful voltage surges.

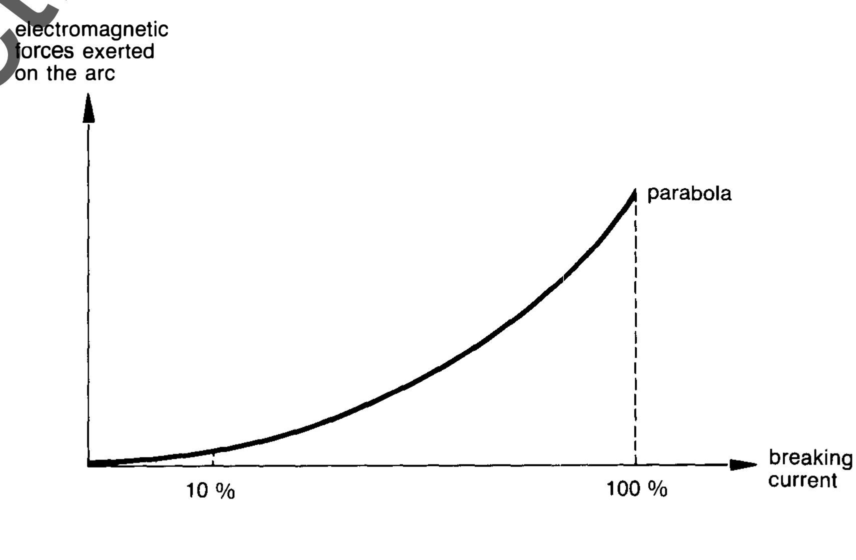


fig. 5. smooth breaking by arc rotation

An SF6 puffer type circuit breaker can arrive at the same result if the deionization effect obtained by the injection of gas between the contacts is moderate. Merlin Gerin succeeded in this with its Fluarc circuit breaker by making maximum use of the natural expansion of the hot gases from the region near the contacts towards colder regions of the device. This convection movement made it feasible to limit as far as possible the forced convection effect via the piston.

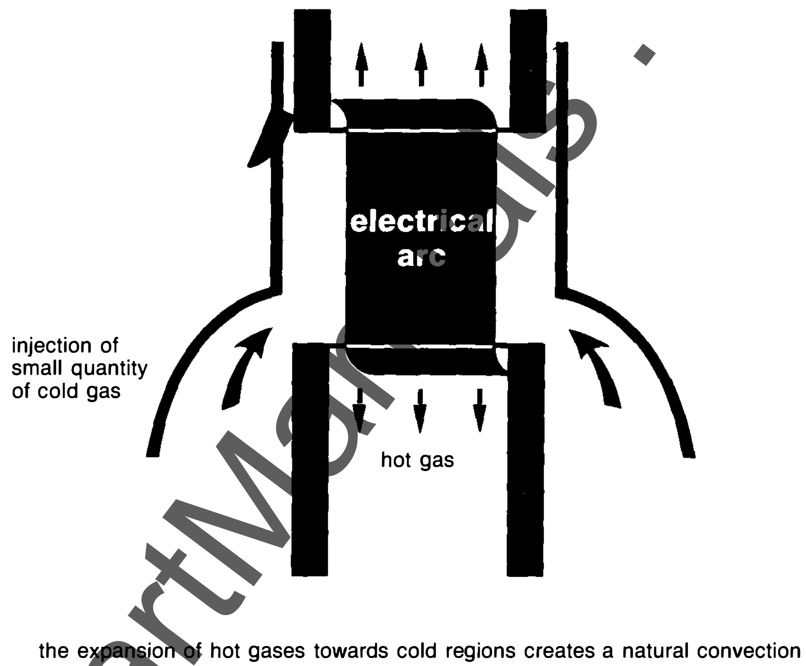


fig. 6. smooth breaking by puffer technique

6. the technology of SF6 ' C.B.

Up to 1982 the Fluarcs were all puffer type. Since 1982 the new type with rotating arc in SF6 in manufactured.
All these types have insulating tanks, in order to decrease the dielectric stresses of the bushings, internally and at the surface.
The sealing of the enclosures is also a common point to the different C.B. This important point is developped in the following paragraph.
The main contacts are located concentrically and, more recently, in a separate volume.

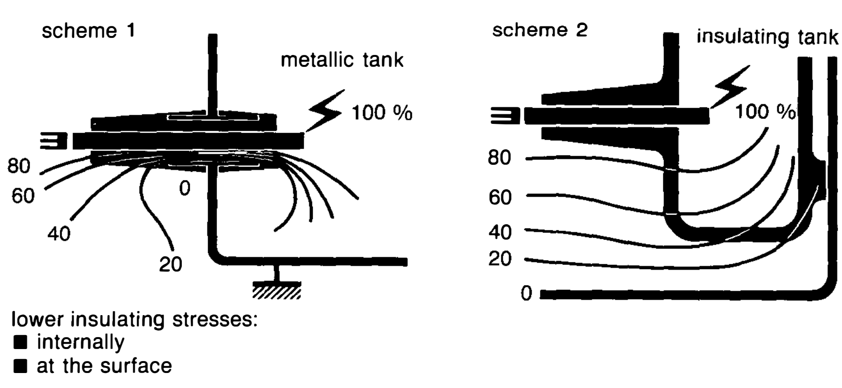


fig. 7. bushings

At 12 and 17,5 kV, the Fluarc FG are of a typical design with a very short main circuit entirely segregated from the breaking circuit. The disconnection of the main circuit takes place at the beginning of the opening by means of self-compensated and self-wiping blades.
The Fluarc FG1 uses arc rotating and the FG2 uses the puffer technique:
■ in the Fluarc FG1, the auxiliary blade located at the end of the main blades carries out be transfer of the current towards the breaking circuit. The arc is inserted between the 2 fixed rings. The upper ring is under the coil and the lower one is directly opposite it. The two rings are closed together since the dielectric withstand between two large diameter rings is very high. The arc is therefore short and it releases only a moderate amount of energy. The enclosure is of the triple pole design and is made up of two moulded resin half-shells.
■ in the Fluarc FG2, the main circuit is of modular design in order to handle different current ratings of 630, 1250 and 2500A. The breaking circuit is the same for the different current ratings. The design uses the active parts of the Fluarc FB.
The Fluarc FB's are mainly suited to the high and of the voltage range (36 kV) and the Fluarc FG's to lower voltages.
The Rollarc contactor is a high performance rotating arc device. It is in fact a small circuit breaker with a very high mechanical endurance.
Its design is a different combination of the various devices described above. Its main contacts are located concentrically. The layout of the coil and the arcing-rings is similar to the Fluarc FG1 except that the lower ring is mobile.
The function of a contactor is a delicate one. The frequency of the operations and the many types of a circuits lead to a very high probability that the most severe cases will be encountered. In answer to these stiff demands, we have chosen a technology that offers the following advantages:
■ a very high breaking capacity (10 kA at 7.2 kV)
■ a very low overvoltage level.
These two qualities are rarely found in a single contactor. The high breaking capacity provides a high degree of reliability in the contactor-fuse combination. The contactor delay can be reduced to zero even for the highest rated fuses. Blown fuses are therefore very rare and occur only for true short-circuits, a feature which avoids interruptions in service. The absence of switching voltage surges eliminates worries concerning the circuit, the length of the cables, etc... Surge limiting devices are unnecessary.

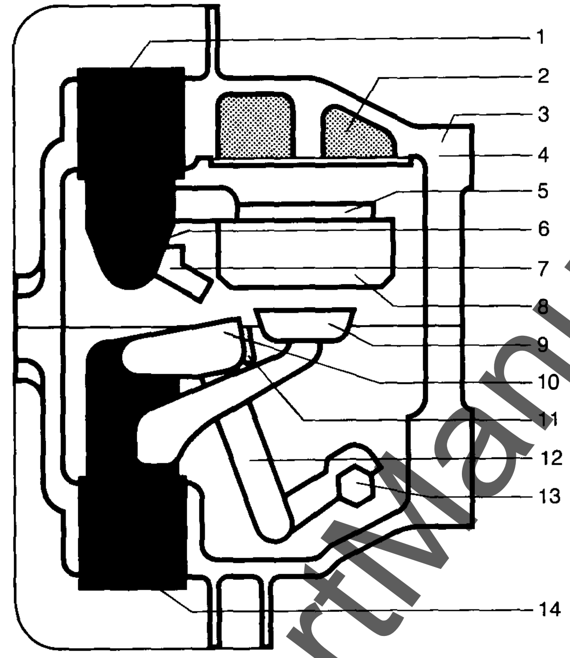


fig. 8. FG1 - pole unit

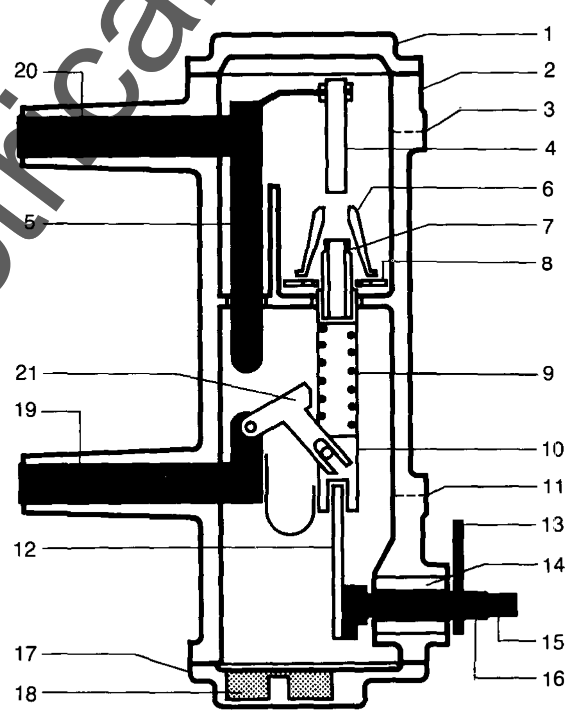


fig. 9. FG2 - pole unit

7. sealing of SF6 enclosures

A high level of sealing is one of the important factors in the design of long service life devices.
The problem is however easier to solve than for EHV breakers. These devices are designed as factory-built subassemblies which are assembled at the time of final erection. Controls are made locally at each point in the assemblage. The high number of assemblies makes monitoring by means of pressure switches a necessity. With careful manufacturing, SF6 needs to be added after 5 years.
In HV, the devices are much smaller in size. Each pole is a complete unit and is closed off by one or two covers bolted and bonded to the enclosure (FG2, FB). Adhesive bonding has been put to the test in aeronautic engineering and is now a well developed technology. With the FG1, the enclosure is made up of two parts assembled with a gasket. It can be seen that already at the design level, all possible precautions have been taken to ensure a good seal. After assembly, the poles are individually tested. Their small size makes it possible to place them in a small closed volume for one day followed by a measurement of the gas concentration. The leak value is the ratio between the measured mass of the gas and the test time, it must not be superior to a specified value which would lead to atmospheric pressure only after 3 centuries.
Another interesting point is the technology used in making the current bushings and the means of transmitting the movement into the enclosures.
The current bushings are inserted in the enclosure and have a relatively long interface with it. Mechanical stresses are better absorbed by the enclosure and the adherence between the bushing and the enclosure is guaranteed all around the bushing. Static sealing therefore poses no great problem.
Dynamic sealing requires however an original solution. There are two possibilities:
- ■ metallic bellow, transmitting the movement by translation,
- ■ a rotating shaft.

The first alternative has already been used in vacuum enclosures. It is especially of interest when the stroke is low, corresponding to the lowest voltages. Elastomers cannot be used in making the bellows due to their low but everpresent permeability.

Type I	Type II	Type III	
expressed in % per day	1 to 3 per year	< 1 % per year	Leackage rate
continuous refilling	regular refilling	filled for life	time years
0	3	10	30

fig. 10. sealing: definitions and specifications

Type I	Type II	Type III
■ 2-pressure compressed air circuit breaker ■ 2-pressure SF6 circuit breaker	■ 1-pressure SF6 circuit breaker HV and EHV ■ metal-clad compartment	■ SF6 1-pressure HV indoor circuit breaker, factory sealed and inspected e.g. Fluarc ■ vacuum enclosure circuit breaker

fig. 11. examples of each type

We started building our line of SF6 circuit breakers with the first solution which was known, then we chose the second solution because of its wider field of application. Today, nearly all our circuit breakers use a rotating shaft mechanism.
The rotating shaft is polished and lip joints are located on both sides of a small volume of oil which ensures continuous lubrication and which are liquid seals. The joints each have an internal spring which permanently applies the seal lip to the shaft. This patented system is highly reliable and offers a solution for very diverse cases (e.g. both for infrequent and very frequent circuit breaker operation). Tests were carried out with frequencies of 1 to 100,000 operations without modification of the resisting torque and of course no changes in the seal.
As a final point, the poles of the SF6 circuit breakers are filled for life in the factory. No periodic refilling is necessary. This corresponds to the new IEC definitions which are presently being prepared. A working group of international experts published the IEC Document 17A Secretariat 209 (December 81) which definies the construction classifications:
- ■ type 1: Systems requiring continuous refilling.
E.g. 2-pressure SF6 and compressed air circuit breakers.
- ■ type 2: Systems requiring regular refilling.
E.g. 1-pressure SF6 circuit breakers and metal-clad switchgear compartments.
- ■ type 3: Sealed systems; designed, manufactured and inspected so as to eliminate all later maintenance.
E.g. Vacuum and certain SF6 circuit breakers.

Note: in this third category, only indoor circuit breakers completely factory assembled and tested and with a small number of parts can normally be considered as sealed, and for less than 72.5 kV.
The manufacturer of a SF6 circuit breaker has the choice between the second and the third type of sealing level. If he chooses the second type, regular pressure measurement must be made. If he chooses the third type, pressure measurement is possible but not obligatory thanks to the corresponding design and factory tests.
Merlin Gerin chose the third type in order to reduce the constraints for the user.

8. conclusions

The best field for the arc rotating type is the medium caracteristics of the circuit breakers:

- the electromagnetic forces applied to the blowing coil are moderate. The number of turns is approximatively the same than the one in a SF6 contactor; so, the breaking of small currents is possible with a short arcing time,
- the level of voltage surges is the lowest one with the magnetic blowing. For example the small MV motors can be switched.

For the puffer type, the best field is the highest caracteristics:

- the natural effect of expansion is beneficient when interrupting heavy currents. The design of the arcing contacts allows the effect of self-expansion with an economy of energy for the mecanism.
- the stroke of the arcing contacts is the single parameter to adapt to the voltage. It is possible to obtain a homogeneous range for different voltage ratings.

Finally, the puffer type and rotating arc Fluarcs are a complete range of circuit breakers in KV and KA.