COMPARISON OF SF_6-FREE LOAD-BREAK SWITCHING PRINCIPLES

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ABSTRACT

This paper presents different principles of MV load-break switches with a specific SF_6 gas-alternative: All switching principles presented in this paper are using natural gases (main components of ambient air, e.g. N_2, CO_2 and O_2) as insulating and/or arc quenching medium. For comparison of these principles, an assessment in terms of technical, economic and user-related operating aspects is given.

INTRODUCTION

Medium-voltage (MV) load-break switches are today widely used in SF_6-insulated MV switchgear in power distribution systems with rated voltages up to 40.5 kV and a rated load current usually up to 630 A. These load-break switches are designed and tested according to dedicated standards (e.g. IEC 62271-103) and use SF_6 for dielectric and arc extinguishing purposes. However, SF_6 is a greenhouse gas with a Global Warming Potential (GWP) of 23,500 and therefore an intense search for gas alternatives for both purposes – insulating and switching – has been started many years ago. Some applications with SF_6 alternatives have been published recently (see e.g. [1] - [5]).
Natural gases – meaning gases with main components of ambient air, i.e. for example N_2, CO_2 and O_2 – have no Ozone Depletion Potential (ODP = 0) and a very low Global Warming Potential (GWP $\leq$ 1). Furthermore, they are non-toxic, non-flammable and show high gas stability. Due to its low boiling point no additional means to avoid liquefaction / deposition are necessary, even for extremely cold climates down to -50°C. Compared to SF_6 no additional precautions related to gas handling are required and the end-of-life handling cost are relatively low, as gas recycling is not necessary. But natural gases have a lower dielectric strength and lower arc quenching capability compared to SF_6. To compensate this drawback – while keeping the overall switchgear size and functionality – new load-break switch principles for use with natural gases are to be developed.

In order to demonstrate the applicability of natural gases for MV load-break switches, four switching principles are compared in this paper:
#1) Vacuum interrupter in the main current path of the switch
#2) Vacuum interrupter in the auxiliary path of the switch
#3) Rotating arc
#4) Puffer type

These principles are described in the following section of this paper and are evaluated in terms of its:
- Current breaking capability
- Technical complexity
- Cost
- Overall space requirements
- Degree of industrialization
- Operating philosophy

LOAD-BREAK SWITCHING PRINCIPLES

Vacuum interrupter in the main current path of the switch (Principle #1)

This principle consists of a vacuum interrupter (VI) applied in the main current path of the switch, for making all currents up to the rated short-circuit making current and for breaking all required currents. It fulfills the requirements of the dedicated standards (e.g. IEC 62271-103). The switch uses natural gases as surrounding insulating medium in a closed gas compartment. In order to fulfill the disconnecting / earthing requirements a separate disconnector / make-proof earthing switch is necessary and therefore embedded in this switching principle, as illustrated in figure 1.

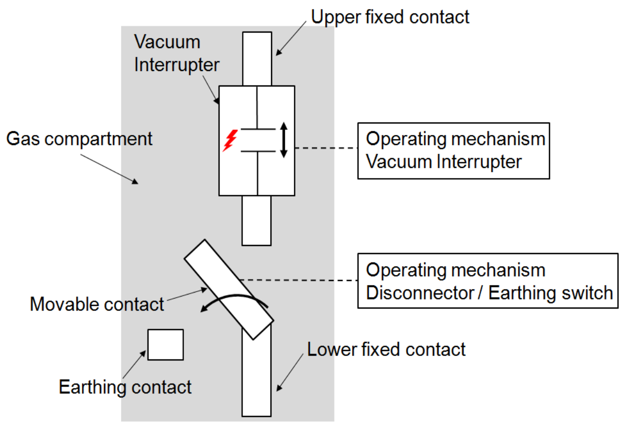

Figure 1: Illustration of the principle “Vacuum interrupter in the main current path of the switch”

Due to the VI as the main switching element the switch is capable to break usual load currents (e.g. 630 A). This switching principle is an option also in the application switch-fuse combination being capable to interrupt take over currents up to 2,000 A. A specific and precise timing is not required. The VI has substantially improved properties in terms of current capacity regarding temperature rise, short-time withstand currents and short-circuit making currents.

Instead of a switch-fuse combination a regular circuit-breaker can be used; however, this solution is significantly more expensive and shows no current limiting characteristics.

The translational movement of the switching contact of the VI might result in an increased effort for the transmission of operating forces and movements in a gas-tight switching compartment, as well for the design of the drive mechanism. Increased operating power, stay open forces and a specific adapted drive for the VI mechanism are needed. Thus, the complexity and the cost are high. The space requirements for this solution are relatively high, as they are similar to regular circuit breakers with an integrated disconnector / earthing switch.

The components of this switching principle are state-of-the-art and produced in a high quantity nowadays, resulting in a high degree of industrialization.

Due to the separate but interlocked operation of the VI and the disconnector / make-proof earthing switch the operation philosophy differs significantly from most today's load-break switch applications.

Vacuum interrupter in the auxiliary path of the switch (Principle #2)

This principle, as illustrated in figure 2, uses a 3-position load-break switch, consisting of a make-proof disconnector, a make-proof earthing switch and a VI in the auxiliary path of the switch as an arc extinguishing device, which is actuated by a single operating mechanism.

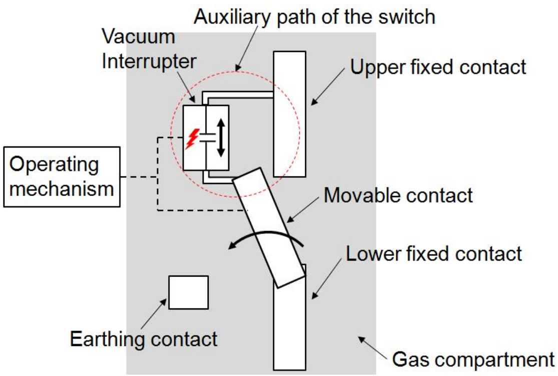

Figure 2: Illustration of the principle "Vacuum interrupter in the auxiliary path of the switch"

The switch uses natural gases as surrounding insulating medium in a closed gas compartment.The advantage of this system is the integrated isolating distance, which is fulfilled in compliance with the applicable standards. The VI in the auxiliary path of the switch performs all switching tasks for the specified load currents. Due to the VI's high interruption capability this switch is capable breaking usual load currents (e.g. 630 A) as well as take over currents up to 2,000 A in switch-fuse combinations. The VI does not need to carry the short-time withstand current and does not need short-circuit making capability since making operations are performed by the make-proof disconnector and the make-proof earthing switch, respectively. Adversely of this principle is, that the mechanical actuation requires a specific and precise timing, leading to a high technical complexity of this switching principle.

Due to the electrical characteristics mentioned above an optimized VI allows a relative compact switch design. Thus the overall space requirements are low, and due to the compactness this solution is regarded as cost-effective.

A serial manufacturing process of such an optimized VI is not known yet. Therefore, the degree of industrialization is relatively low.

The operation of the switch is the same as known from already existing SF_6 load-break switches. The mechanism establishes the well-known three positions ON-OFF-EARTHED, and – for safe operation – two operating shafts (one shaft for the OFF-ON operation and another shaft for the OFF-EARTHED operation) can be realized.

Rotating arc (Principle #3)

This principle consists of a device generating a magnetic field to rotate the arc on a circular surface and finally to quench the arc, as illustrated in figure 3.

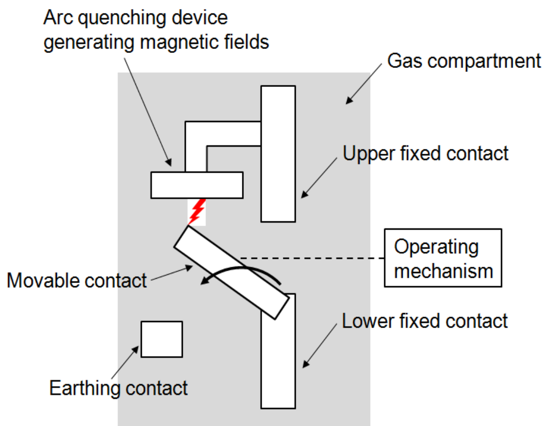

Figure 3: Illustration of the principle "Rotating arc"

During the breaking operation an arc is firstly initiated between the movable contact and the upper fixed contact. During the further movement of the movable contact the root of the arc commutates from the upper fixed contact to the circular surface of the arc quenching device. Thus the rotation of the arc is initiated. This basic principle can

be found in several existing SF_6 load-break switches. These existing SF_6 load-break switches show reliable and well performing current interruption capability.
The principle shown in figure 3 includes a disconnector and an earthing switch, which are make-proof for short-circuit currents. The design of the switch is relatively simple: Beside the arc quenching device initiating the arc rotation – realized by e.g. a coil or a permanent magnet – in total three fixed contacts (earthing contact, upper and lower fixed contact) and a movable contact are necessary. Therefore, the technical complexity is regarded as low.
During breaking tests with natural gases, using today existing arc quenching devices, we found a similar behaviour of the arc regarding commutation and rotation compared to SF_6. However, the interruption capability is relatively low: The maximum breaking current reaches approximately 200 A @ 3.5 kV with natural gases, compared to 800 A @ 24 kV with SF_6. Based on this result no further investigations related to the breaking capability of the principle "rotating arc" are carried out, because basically this principle is assumed not supplying a sufficient cooling effect on the arc column to interrupt at least 630 A @ 24 kV. Therefore, evaluation in terms of cost and overall space requirements is not given.
From today's perspective all parts of the switching principle shown in figure 3 are quite common in existing load-break switches since many years. These parts are also optimized in terms of production processes and are manufactured in high quantities per year. Therefore, the degree of industrialization is regarded as high.
The operation of the switch is quite the same as known from already existing SF_6 switches. As in principle #2 the three positions ON-OFF-EARTHED are established with just one operating mechanism, and for safe operation two operating shafts (one shaft for the OFF-ON operation and another shaft for the OFF-EARTHED operation) can be realized.

Puffer type (Principle #4)

This principle has a combined isolating distance and contact gap, as illustrated in figure 4.

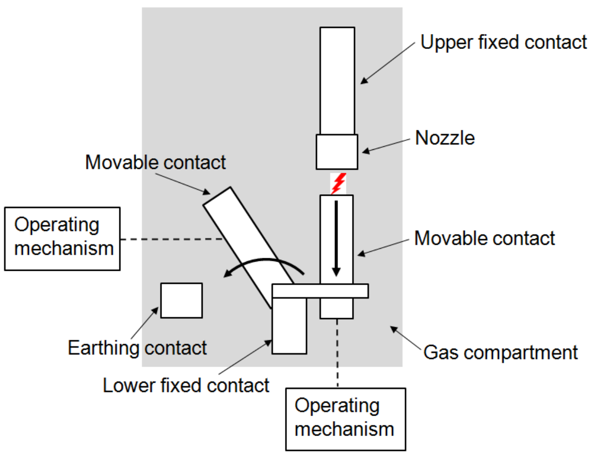

Figure 4: Illustration of the principle "Puffer type"

In this design, the filling gas does not only act as an insulating medium but is also responsible for extinguishing the switching arc. Consequently, additional measures to realize a sufficient arc cooling have to be introduced. This can be achieved by an axial blowing of the arc with cold gas from a puffer volume by introducing a polymer nozzle close to the arc to use the effect of polymer ablation or a combination of both ([6] - [8]).
An example for the realization of the earthing function by a separate rotating movable contact is given in figure 4 as well. Alternatively, the operating mechanism of the earthing switch can be integrated in the mechanism of the load-break switch.
The mechanical movement of the switch can be linear, rotatory or a combination of the two.
Previous work on a puffer type load-break switch with a combination of axial blowing and polymer nozzle shows, that especially the blowing pressure across the contact and nozzle system has an influence on the interruption capability. Furthermore, the diameter and length of the nozzle throat show an impact on the extinguishing performance. With an optimized nozzle and contact design as well as a sufficient blowing of the arc in the range of a few hundred hPa, thermal interruption capabilities as high as 630 A @ 24 kV are possible, using alternative gas mixtures to SF_6 [8]. Dielectric failure is usually less of a concern in axially blown load-break switch designs [6].
The piston in the puffer volume and the moving contact is usually actuated by the same operating mechanism.
This system requires a careful and complex selection of the ambient (gas) medium because of its simultaneous use as an arc extinguishing and insulating medium. A wide range of properties have to be taken into account, including its:

- Arc extinguishing behaviour
- Dielectric performance
- Deposits after arcing
- Regeneration capacity

The design of this load-break switch requires an increased design effort e.g. by the introduction of insulating barriers for phase separation. This leads to a relative high technical complexity.
An advantage of this system is the simultaneous provision of an isolating distance and contact gap within one switching device during its breaking operation. This fulfils all the safety requirements as indicated in the relevant standards and allows a compact switch design. Because of its overall compactness this solution is regarded as cost-effective.
A serial manufacturing process of the switch components using natural gases is not known yet; therefore the degree of industrialization is low. In case of a combined operating mechanism for the earthing switch and the load-break switch the operation principle of the switch is similar to already existing SF_6 load-break switches.

CONCLUSIONS

In this paper different MV load-break switch principles using natural gases are described. These principles were evaluated in terms of technical, economic and operating criteria. The result of this evaluation is summarized as given in table 1.

Table 1: Evaluation result of presented load-break switch principles

Criterion	Principle			
	#1	#2	#3	#4
Breaking capability	high	high	low	medium
Technical complexity	high	high	low	high
Cost	high	low	not evaluated	low
Overall space require-ments	high	low	not evaluated	low
Degree of industriali-zation	high	low	high	low
Operating philosophy	medium	simple	simple	simple

Although principle #1 (vacuum interrupter in the main current path of the switch) shows a high breaking capability and has a high degree of industrialization, there are several drawbacks (e.g. technical complexity, cost, overall space requirement), so that this principle is not regarded as a favoured one.
Because of its low current breaking capability principle #3 (rotating arc) is not an alternative solution for load-break switching using natural gases.
Principle #4 (puffer type) has positive effects on cost and overall space requirements, but shows a high technical complexity. But due to its sufficient breaking capability, this principle is regarded as a possible solution.
In spite of the high technical complexity for principle #2 (vacuum interrupter in the auxiliary current path of the switch), this principle shows many advantages (e.g. high breaking capability, low cost, low overall space requirements, simple and well-known operation philosophy) and thus looks as a viable solution for a load-break switch using natural gases.

ACKNOWLEDGMENT

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