

A FEW ASPECTS ABOUT ESTABLISHING THE STATUS OF THE GAS INSULATION INSIDE HIGH VOLTAGE EQUIPMENT

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Abstract

SF₆ insulating installations are today the most performing technical solution applied to high voltage devices such as circuit-breakers and surge arresters. This gas is used due to a lot of excellent insulating properties. These properties are depending on many variables, one of them is electrodes' geometry and material. Capsulated SF₆ installations unlike open ones are submitted to various faults which are revealed only when all the equipment is completely or partially destroyed. This paper presents some aspects concerning fault location methods used in the diagnosis of capsulated SF₆ equipment (circuit breakers, surge arresters). These methods are applied in Romania and in other countries by both producers and users of this piece of equipment.

Key words: high voltage equipment, gas insulation

1. INTRODUCTION

Generally, in capsulated equipment each fault which appears is less visible than in open ones. Only when the entire compartment is open (and by doing that, it is totally or partially destroyed), all faults could be visible and located. In the case of insulation tests made by the producer or by the user of that equipment, each partial discharge have to be precisely located in order to reduce time or to reduce the costs of the maintenance.

Generally, when studying the dielectric breakthrough process, ideal electrode surfaces are taken in consideration. But many experimental results, different than theoretical ones, could be a consequence of microscopic asperities. These asperities are mostly undefined and could modify the dielectric breakthrough process by local increases of the electric field's intensity or by supplementary electrons emission which leads to an apparent dielectric rigidity decrease. In reality, only a few parameters are modified (the electric field, the initial electrons number). The individual asperities number will affect the dielectric rigidity empirically determined before.

We also notice all SF₆ equipment users' requests for having precise methods and test equipment adequate for continuous control of the insulation state [2], [3]. Such methods and test equipment will be presented in this paper.

2. FAULT LOCATION POSSIBILITIES INSIDE SF₆ CAPSULATED INSULATIONS

Insulation breakthrough appears as a consequence of an electrical discharge like a streamer or like an electrical arch. Breakthroughs during insulation test are most likely streamers and the others, appearing during long time service are electrical arches.

As we know, the appearance of the leader (as a preliminary phase of the breakthrough) is characterized by an intense light, heat, sound and ultrasound emission as well as SF₆ decomposition. These effects are normally limited to the fault area. Combined with these effects, an electromagnetic transitory phenomenon, consisting in traveling waves, over voltages or intense magnetic fields, occurs too.

Each fault location device has to be able to memorize that fault, which mostly has a very short period of time, until the fault (the state) is registered by the operator or by a dispatcher. After that, the record could be erased on demand or automatically.

Figure 1 shows the main effects produced by electrical breakthrough, which could be used for fault location. “S” means an effect used for spark faults and “A” an effect used for arch faults.

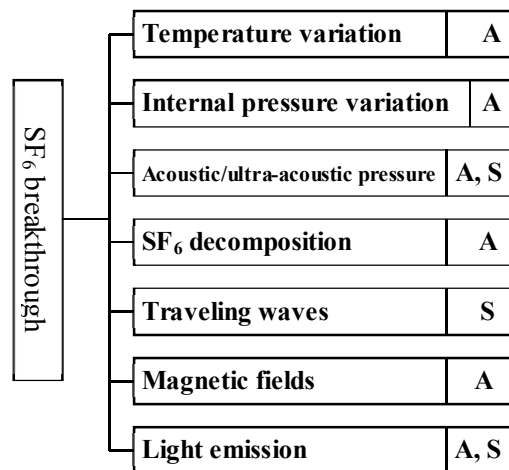


Figure 1. The effects of SF₆ breakthrough and their use for fault location

Fault location is based on the main effects of dielectric breakthrough and it could be:

- Fault location based on temperature increase is a function of the electric energy transformed in heat in the electrical arch canal. It could not be applied to insulation tests. But it could be used in detecting faults appearing in long service time by applying heat sensitive paint on capsulated devices.
- Pressure increase based fault location applied to separated capsules (with no gas exchange) is possible only in the case of an electrical arch.

Pressure variation is given by equation (1):

$$P = k I t / V \quad (1)$$

where I is the RMS value of the short-circuit current, t is the short-circuit time, V is the capsulated gas volume, and k is a constant depending on equipment' design. Pressure variation occurred in this case has the same order like gas pressure and it's bigger than temperature caused pressure variation. It could be measured by using a simple manometer.

- Fault location based on acoustic waves caused by the incident is possible both in case of sparks and electrical arch. Although it is difficult to separate sounds of an electrical arch fault from sounds of an electrical arch which appears on normal commutation.
- Gas analysis based fault location, on each compartment of the capsulated device is a cheap technical solution. A minimum amount of gas from the verified compartment is released by a valve in a glass tube containing a basic solution. In presence of acid decomposition residues, the solution is neutralized and changes color. For the whole capsulated device, this process could take a few hours, so its use is limited.

- Traveling waves based fault location can be used only for a short amount of sections, only in specialized labs, because each impedance variation causes reflections and refractions which could complicate the process.
- Magnetic field based fault location is used when an internal breakthrough, followed by an electrical arch, occurs. This phenomenon produces a strong magnetic field which could be measured only on the exterior surface of the aluminum shield, as we notice on Figure 2. The experimental results [3] shown a radial component of the magnetic induction of about 3 mT for a fault current of 1 kA. This kind of magnetic fields could be measured by magnetic sensors placed on an adhesive tape fixes around the envelope. This deposit has to look like a heavy magnetic material and the distance between two separate tapes has to be at least 120 – 150 mm [3].

The flexible magnetic sensors, (named from 1 to 8 in Figure 2) are initially de-magnetized and in normally service state of the equipment and their magnetic status is not affected by the current crossing the envelope. The reading of the measurements is done by using a flux-meter. I_k is the short-circuit current and B_r is the radial magnetic induction.

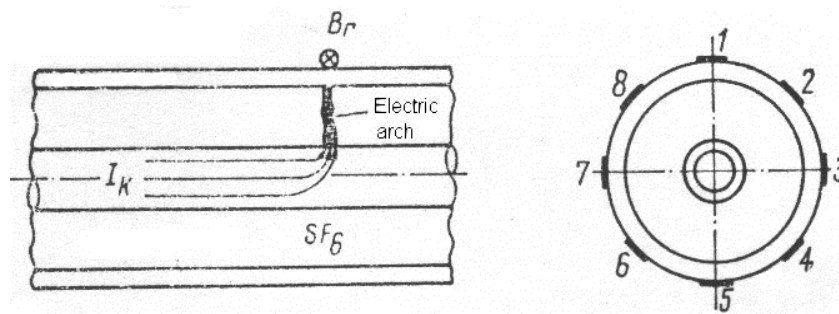


Figure 2. Magnetic field based fault location method applied to a capsulated bar system

- Light emission fault location allows detection of both sparks and electrical arch. Experiments shown that breakthroughs in SF_6 made light emissions in a specter between 330 and 655 nm [2]. We can also notice a weak continuous red specter and a spectral maximum between 330 and 470 nm (ultra-violet and blue). If every section of the capsulated device contains an optical sensor, each of them must be extremely sensitive, due to the geometry of that section (curves, angles, insulations, different layer).

As we notice in Figure 3a, the light open angle of that device must be as large as possible due to its exocentric position. Light emission diodes, and photo-transistors are placed as sensors and the light is received by passing trough Plexiglas windows. The detection block may be realized, as we notice in Figure 3b, by using an integrated light sensor. This block contains also a pre-amplifier followed by a comparator block which gives de sensitivity limit of this device. The turn-off of that comparator acts an execution circuit which maintains the information for a local or remote control. In order to avoid any electromagnetic interferences caused by fault short-circuit currents, detectors' electric supply is made by using batteries, the whole device being made inside an electromagnetic shield.

In Figure 3 a:

- 1 are the optical sensors;
- 2 are the tight insulating elements;
- 3 is a middle insulating element.

In Figure 3 b, (which is the schema of the optical sensor):

- 1 is a threaded connection;
- 2 is a transparent section;
- 3 is a photo-diode (or a photo-transistor);
- 4 is a pre-amplifier;
- 5 is a comparator;
- 6 is a relay;
- 7 is a battery;
- 8 a signal output gate;
- 9 is an electromagnetic shield.

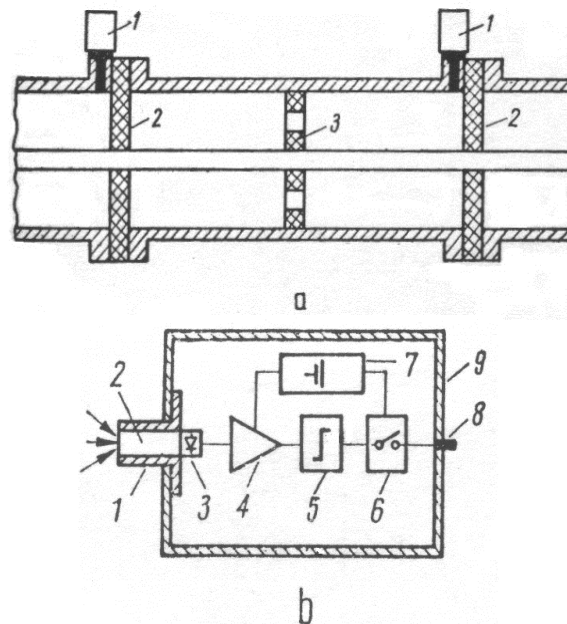


Figure 3. Light emission based fault location method applied to a capsulated SF₆ compartment

3. PREDICTIVE BREAKTHROUGH DETECTION POSSIBILITIES

This problem is more difficult to solve than fault location due to the lack of information about it. One way to do this is by using the partial discharges.

Each partial discharge detector must have these properties:

- to not modify the existing capsulated insulation (eventually to be placed outside that device);
- to be as compact as possible;
- to not be affected by external discharges or electromagnetic noises and to resist to extreme internal ones.

Fault simulation in a capsulated insulation (having a nominal voltage of 77 kV) has lead to the results shown in Table 1. All the measurements were made by using an electrical fault detection equipment

type ERA3. We can notice that no matter the detection method involved, that one has to be able to detect partial discharges on a level from 10 to 20 pC.

Table 1- Partial discharges level and repetition frequency made by artificial faults in a 77 kV capsulated insulation

Simulated fault	Apparent charge pC	Frequency Hz
Imperfect contact on current way	10 000	1 000
Contour discharge for a border insulating element	11 000	600
Presence of foreign elements:		
Grains of Copper	40	-
M10 screw	600	100
Border insulating element enclosures	2800	80

Between all preventive fault detection methods taken in consideration, the optical and the acoustical method are mostly used. The ultra-acoustic method was successfully applied by the biggest Romanian high-voltage circuit-breaker manufacturer, Electroputere S.A. Craiova [2] to detect any free particle inside that equipment. This company is making some researches in order to design and manufacture an industrial testing equipment based on this method.

An original electrical preventive fault detection method is described in [1]. This method is designated for fault detection on conic insulators or disc insulators. These faults could appear as pollution with SF₆ decomposition residues.

As we notice on Figure 4 a, on one exterior surface of the insulating element 1 (made of resin) which sustains the main conductor 2, a conductive layer 3 was applied. This layer represents the electrode used to collect all the information about any possible faults in the insulating element. This information is then transmitted to the differential amplifier 4. On the other entry of that amplifier, a signal from the capacitive sensor made through the insulation 5 between the electrode 6 and the earth-connected metal envelope 7 is received.

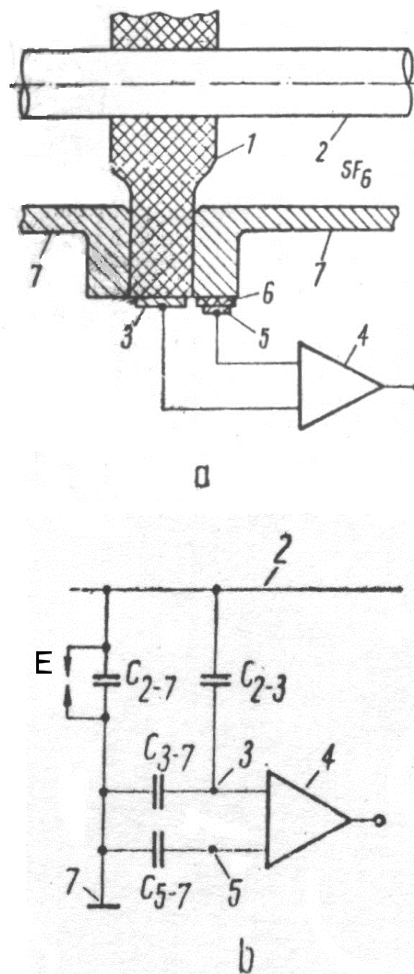


Figure 4. Partial discharges detection method applied to a capsulated SF₆ installation

This differential scheme assures a very high noise reduction as we observe in Figure 4 b. A 10 pC partial discharge could be easily detected using this equipment.

On this figure, E is a spark gap which simulate the partial discharges on the insulating element I .

C_{2-7} , C_{2-3} , C_{3-7} and C_{5-7} are the capacities existing between all these electrodes involved.

4. THE INFLUENCE OF THE ELECTRODES' ROUGHNESS ON SF₆ DIELECTRIC BEHAVIOR

Generally, when studying the dielectric breakthrough process, ideal electrode surfaces are taken in consideration. But many experimental results, different than theoretical ones, could be a consequence of microscopic asperities. These asperities are mostly undefined and could modify the dielectric breakthrough process by local increases of the electric field's intensity or by supplementary electrons emission which leads to an apparent dielectric rigidity decrease. In reality, only a few parameters are modified (the electric field, the initial electrons number). The individual asperities number will affect the dielectric rigidity empirically determined before. We will present separately the influence of the asperities and the influence of electrodes' material on supplementary electrons emission.

The breakthrough fault could be stimulated when microscopic electrodes are present. The influence of the roughness of the electrodes must be taken in consideration after a massive maintenance operation when all contacts are cleaned, polished and covered.

On a technical electrode surface, depending on which treatment was applied on that surface, all asperities are distributed evenly (polished, sandblasted, cast) or periodically (turned, milled, planed) [1]. Even polished aluminum surfaces have roughness when looking on an electronic microscope. The maximum peak of that surface could be determined in a dielectric breakthrough. This microscopic fault, on a few square centimeters surface seems almost unidentifiable, because it could be detected only on a longitudinal palpation. That's why the maximum roughness R_{max} , taken from a standard profile is not representative for the entire electrode [2].

If measured values for the dielectric withstand-voltage are related to R_{max} , those results could heavily be used to other systems. It is more advantageous to describe the roughness of a certain electrode surface by using a standard well-defined method or (better) by using the medium roughness $\overline{R_t}$, measured from a roughness profile. A complete analysis is done when using both $\overline{R_t}$ and microscopic pictures taken from that profile. The electronic microscope pictures indicate even post-breakthrough geometrical variations of that superficial surface which normally don't affect the withstand-voltage, because simultaneously conductive deposits appear. The influence of electrode's roughness on the withstand-voltage could be easily and detailed studied by making measurements on aluminum electrodes characterized by a certain $\overline{R_t}$ combined with electronic microscope pictures.

As we know, when the medium roughness $\overline{R_t}$ increases, the dielectric rigidity E_{s063} decreases.

The relation between dielectric rigidity and gas pressure is given by (2):

$$E_{s063} = \left(\frac{E_{sT}}{p_{20}} \right)^* \cdot (10 \cdot p_{20})^C \quad (2)$$

This linear family is limited on top by the interior dielectric rigidity, line 1, E_{si} (considered only for ideal electrodes) and on bottom by the technical dielectric rigidity line 6, E_{st} , for not treated surfaces. All the surfaces considered are also represented by lines. Some values for those parameters are given in Table 2 [2]:

By using this relation between the dielectric rigidity and the medium roughness, a roughness factor, depending on pressure, could be determined, as shown in relation (2):

$$e_r = \frac{E_s}{E_{si}} = \frac{(E_{st} / p_{20})^*}{(E_{st} / p_{20})^*} p^{C-1} = f(\overline{R_t}) \leq 1 \quad (3)$$

These parameters are deductible from different other relations given in literature.

By knowing this roughness factor, for a given medium roughness $\overline{R_t}$, the requested dielectric rigidity could be easily determined:

$$E_s = e_r \cdot E_{si} \quad (4)$$

The withstand-voltage, for a given electrodes system is given by:

$$U_s = E_{si} \cdot e_r \cdot e_h \cdot \eta_F \cdot d \quad (5)$$

Where e_k is the curve coefficient, η_F is the homogeneity coefficient and d is the distance between the electrodes [3].

Table 2 - Dielectric rigidity values for different surface treatments

Line nr.	$\left(\frac{E_{sT}}{p_{20}}\right)^*$, in $\frac{kV}{mm \cdot MPa}$	Treatment	$\overline{R_t}$ [μm]
1	89	-	(0)
2	84	Polished	0,085
3	81	Pulled	0,550
4	78	Sandblasted	5,0
5	71	Striated	36,0
6	65	none	(300)

These relations could be used for any type of voltage.

5. CONCLUSIONS

Fault detection and location in capsulated SF₆ installations could be easily made on new pieces of equipment as well as on existing service ones.

Fault location optical devices have a large perspective for the next future, due to their simplicity. They are compact, easy to use and very high noise resistant and could be applied both for fault risk detection and effective fault detection.

Dielectric rigidity for SF₆ insulations depends on different factors. One of them is roughness. Generally, we can say that when the medium roughness increases, the dielectric rigidity decreases. The electrodes material's influence on dielectric behavior is interesting only for "smaller asperities". We noticed that for normal SF₆ insulations, no important electrode material influence was detected.

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