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POTENTIAL OF MULTILAYER COATING FOR GAS INSULATED CABLE DIELECTRIC WITHSTAND IMPROVEMENT

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ABSTRACT

Gas Insulated Lines (GIL) are widely used for linking gas insulated substations (GIS) to overhead lines or to power transformers.
The possibility of improving the GIL dielectric withstand by applying a multi-layers coating on the conductors surface, in order to reduce the GIL size, is investigated. Tests are thus done with SF_6 gas, as it is widely used in GIL, and a silicone based multi-layers coating. N_2 gas is also investigated since it is considered as one of the possible SF_6 substitutes in a greenhouse effect viewpoint.
A dielectric withstand improvement is noted under negative Lightning Impulse voltage in accordance with the literature. Advanced tests may be carried out on the gas/coating interface, the voltage wave form, presence of particles, moisture, etc.

KEYWORDS

Dielectric withstand, SF_6 substitutes, N_2, coated electrode.

INTRODUCTION

Gas insulated lines (GIL) are widely used for linking gas insulated substations (GIS) to overhead lines or to power transformers. Because they are versatile by design, they can easily be installed in different configurations (horizontally, vertically or at inclined positions, in overhead and ground level). They can also be installed in underground tunnels eliminating thus the need for unsightly overhead lines for both short and long distances. When installed on the outskirts of towns, cities or large industrial sites such as factories, power stations, airports, etc., the environmental horizon is preserved while the effective delivery of high voltage power up to 800 kV to users can be provided [1-3].
But a major drawback of this technology is that in case of failure, repairing operation can be difficult and long. Therefore, important work is conduct in the technical community to improve the reliability of GIL, and especially the dielectric behaviour which is one of the major cause of failure [8, 9].
Actually GIL often use sulphur hexafluoride gas (SF_6) as insulating gas, but, since SF_6 is identified in the Kyoto protocol as one of the potential greenhouse gases, many works have been launched to find possible alternatives. One of the best candidates from a Global Warming Potential (GWP) viewpoint is the nitrogen gas (N_2).
Unfortunately, this gas has a low dielectric withstand compared to SF_6, so mixtures of 90 to 95% of N_2 with 5 to 10% SF_6 can also be found in that technology.
In the following, we focus on the possibility of improving the dielectric withstand of a GIL by applying a multi-layers coating on the conductors. Indeed, it is now well known that the dielectric withstand of a gas insulated system is reduced by field-emitted electrons at the conductors [4-7].

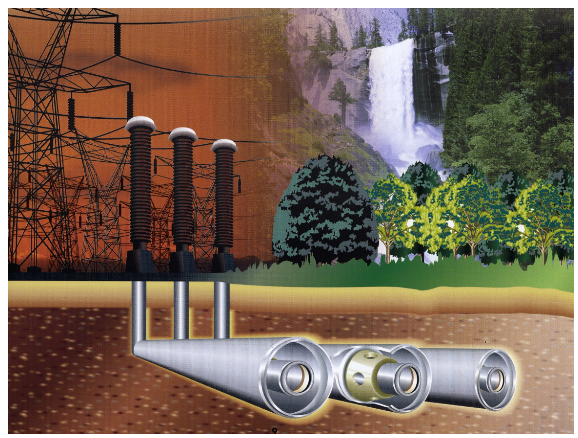

Figure 1: Example of underground GIL.

This dielectric withstand improvement would then allow to improve the reliability and/or will allow to reduce the GIL dimensions, especially in the case of N_2.

For that purpose, the investigation is carried out on a GIL-based system, with SF_6 and N_2 gases.
The first part of the study is dedicated to a comparison of the SF_6 and N_2 dielectric withstand without coating under negative Lightning Impulse (LI) voltage. Then, the influence of a silicone based multilayer coating on the dielectric withstand of a GIL-like system insulated by the two gases is investigated.

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EXPERIMENTAL SET-UP AND PROCEDURE

Experimental set-up

The experiments have been performed on a test mock-up easy to handle. The electrodes profile has been optimized to control the electrical field distribution in the insulating zone using FLUX2D finite elements calculation software (figures 2 and 3). The electrodes made of aluminum were then enclosed in a vessel filled with a gas to be tested. The gases used were 99.99% pure N_2 and 99.95% pure commercial SF_6.

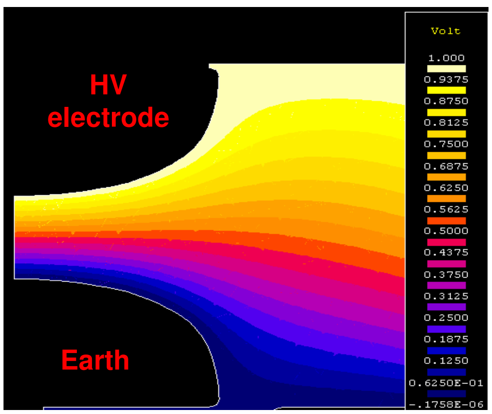

Figure 2 : Dielectric calculation.

Before each test, the electrodes and the vessel were cleaned with ethanol, a molecular sieve was put inside to limit moisture apparition and a vacuum below 10 Pa was made. The pressure during the tests was 0.4 MPa absolute. The electrodes roughness was 1.6 µm and the applied voltage was a standard negative Lightning Impulse (LI-) i.e 1.20 µs/50 µs.

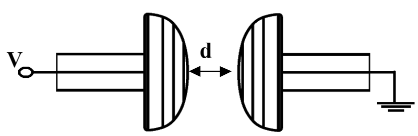

Figure 3 : Test electrodes.

The silicone multi-layer coating is composed by a first 0.1 mm thick semi-conducting layer (in black on the figure 4) applied on the electrode (in grey), a second 0.5 mm thick non-linear conductivity layer (in white) and a third 1.5 mm thick insulating layer (in bue). The coated samples were obtained by a molding and heating (up to 160°C) process.

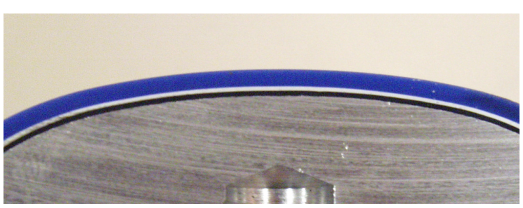

Figure 4 : Multilayer coating cross section view.

For tests with uncoated electrodes, the distance (*d*) between the electrodes was 10, 12 and 14 mm involving a calculated field utilization factor (ratio between the maximum and the mean electrical fields in the gap) of respectively 0.89, 0.87 and 0.84.
During dielectric tests with coatings, several electrode configurations have been tested. The multi-layer coating was first applied to the HV electrode (configuration 1), then to the earthed electrode (configuration 2) and finally to both electrodes (configuration 3). The gas gap was kept equal to 10mm in each configuration.

Experimental procedure

The experimental procedure is represented in figure 5.

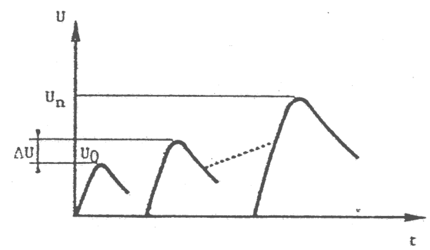

Figure 5 : Experimental procedure.

For each couple of electrodes, the first applied voltage (U_0) corresponds to the tested gas theoretical 50% dielectric strength. The voltage was then increased by step of 10 kV (ΔU) until breakdown (U_n) with 1 minute between two shots. Once the breakdown obtained, the couple of electrodes was changed and the operation was repeated. For each gas gap, six tests were done (with new electrodes set).

RESULTS

Dielectric comparison of N_2 and SF_6 with uncoated electrodes

The figure 6 shows the dielectric strength average values calculated from the results obtained for SF_6 (lozenge) and N_2 (triangle), according to the experimental procedure described above. The dispersion of the results is also indicated in the form of two σ (standards deviation) bars.

It can be seen in figure 6 that, as envisaged, SF_6 dielectric withstand is about 2.25 times higher than N_2 one.

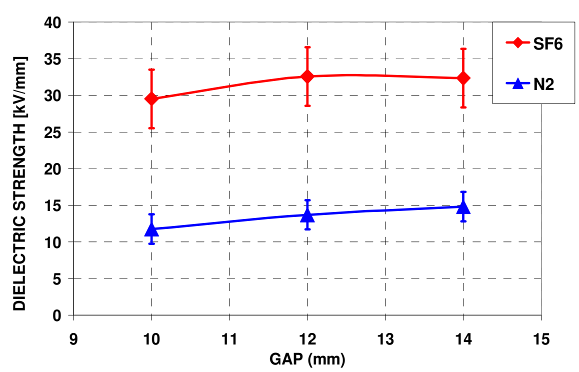

Figure 6 : Dielectric strength of SF_6 and N_2 at LI-voltage.

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Dielectric withstand of N_2 and SF_6 with coated electrodes

The table 1 shows the breakdown voltage average values (V_{BD}) obtained for N_2 and SF_6 with coated electrodes.
The gas breakdown electrical field (E_{BDg}) is calculated in each case. This is achieved by considering a capacitive distribution of the electrical field in the tested system:

$$V_{BDg} = \frac{V_{BD}}{(1 + \frac{e}{d_g * \varepsilon_r})} \quad [1]$$

$$E_{BDg} = \frac{V_{BDg}}{d_g} \quad [2]$$

Where V_{BDg} is the gas breakdown voltage, e the total coating thickness in the system, ε_r the coating relative permittivity (equal to 3.6 for the tested silicone), d_g the gas gap and E_{BDg} the gas breakdown electrical field.

		Configuration		
Gas	Value	1	2	3
SF_6	V_{BD} (kV)	381	385.5	400.6
	σ (%)	4.2	9.8	3.9
	E_{BDg} (kV/mm)	36	36.5	36
N_2	V_{BD} (kV)	200	204.4	220.5
	σ (%)	14.1	9.8	7.6
	E_{BDg} (kV/mm)	18.9	19.3	19.8

Table 1 : Test results with coated electrodes.

- Configuration 1 : multilayer coating applied to the HV electrode ;
- Configuration 2 : multilayer coating applied to the earthed electrode ;
- Configuration 3 : multilayer coating applied to both electrodes.

To compare the results obtained in coated and uncoated electrodes configurations, one must consider the equivalent gas gap (d_g') in each configuration :

$$d_g' = d_g + \frac{e}{\varepsilon_r} \quad [3]$$

For coated electrodes configurations d_g' is equal to 10.55 mm in the configurations 1 and 2, and to 11.11 mm in the configuration 3. Therefore, the E_{BDg} values for uncoated electrodes configurations are calculated by extrapolation from the figure 5 for a gas gap of 10.55 and 11.11 mm (table 2).

	Gas gap d_g' (mm)	10.55	11.11
GAS	SF_6	30.4	30.8
	N_2	12.3	12.7

Table 2 : Extrapolated dielectric withstand of SF_6 & N_2 with uncoated electrodes for equivalent gas gap.

The figures 7, 8 and 9 show the effect of the coating on the dielectric withstand of N_2 and SF_6 for the configurations 1, 2 and 3 respectively.

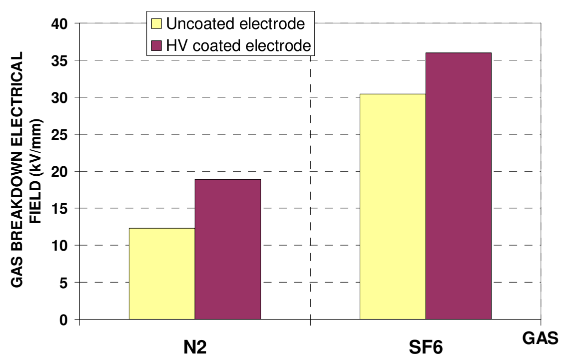

Figure 7 : Test results with HV coated electrode.

When the HV electrode is coated (figure 6), the gas breakdown electrical field is increased by about 53% in case of N_2 (i.e 38.9% taking account of σ of 14.1%) and 18% in case of SF_6 (i.e 13.8% taking account of σ).

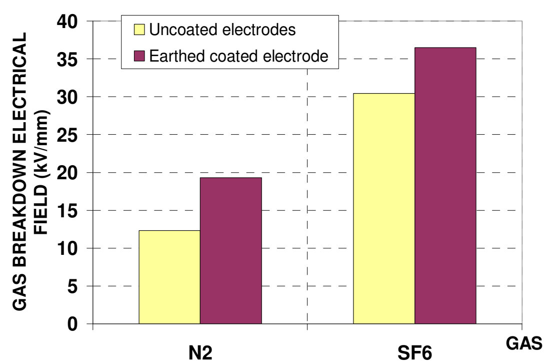

Figure 8 : Test results with earthed coated electrode.

When the multilayer coating is applied to the earthed electrode (figure 7), an increase of 57% and 20% (i.e 47.2% and 10.2% taking account of σ) was observed in case of respectively N_2 and SF_6.

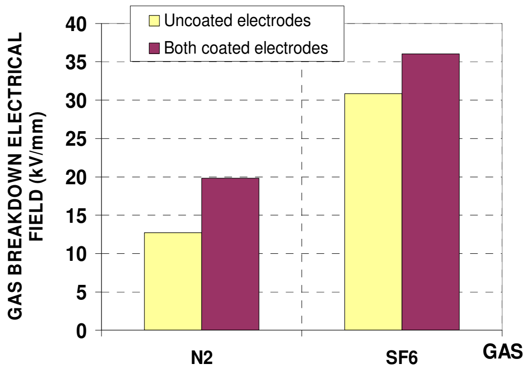

Figure 9 : Test results with both coated electrodes.

When both electrodes were coated (figure 8), the breakdown electrical field of the gas was increased by 56% and 17% (i.e 48.4% and 13.1% taking account of σ) in case of respectively N_2 and SF_6.

DISCUSSIONS

Applying the multi-layers coating on the electrodes increases the system dielectric withstand. This effect is more pronounced in the case of N_2 gas for which an improvement of up to 57% was found. These results are in accordance with data given in the literature (table 3).
For example, in [4], the influence of a 0.5 mm thick polyolefin film or a 0.03 thick polyvinylchloride (PVC) varnish coated electrodes on the dielectric withstand of a gas insulated system under LI voltage was investigated. Dielectric tests were done in a coaxial configuration (field utilization factor of 0.58) with SF_6 and N_2 under 1.5 MPa and 3.5 MPa (absolute) respectively. The best results were obtained when the inner electrode was coated by the polyolefin film and the outer electrode by the PVC varnish. The dielectric improvement reported is more than 32% and 27% in case of SF_6 and N_2 respectively compared to uncoated configuration.

In [5], the authors focused on the deviation between the measured dielectric withstand values and the Paschen's law values at high fields. Tests have been done on coaxial configuration (field utilization of 0.47) with SF_6, dry air and N_2 gases under LI and SI (Switching Impulse) voltages with a pressure of 0.2 MPa. The coating material was a 0.1 mm thick polyethylene (PE) applied to the inner electrode. The dielectric withstand improvement reported is 7.2% and 8.5% for SF_6 and dry air respectively under LI and 48.3% for N_2 under SI voltage.

In [6] too, tests have been done on a coaxial test mock-up (field utilization of 0.63) with SF_6 gas under 50 Hz power frequency (AC) voltage and a pressure of 0.35 and 0.7 MPa (absolute). The inner conductor was coated with a 0.2 mm thick epoxy film. The dielectric withstand improvement reported is 17%, 29% and 14% for 0.35 and 0.7 MPa respectively.

Finally, in [7], a bus bar of a GIS was used for tests under LI voltage with SF_6 gas at a pressure of 0.35 MPa. A 0.5-1 mm thick coating was applied to the insulator/bar screen where the electrical field is the highest. The dielectric withstand improvement reported is 25-30 % compared to the uncoated situation.

The conductors obviously play a significant role in the dielectric withstand of a gas insulated system. One explanation is a reduced field emission activity at the conductors. Indeed, without coating, electrons are emitted from the metal at surface irregularities because of local electrical field enhancement. Thus, applying coating reduces this irregularities effect.
An other explanation is the fixation of impurities at the interface coating/gas. Indeed, a practical GIL always contains free contamination particles which participate in the electrical breakdown. The application of a coating on the conductor's surface is though to reduce this phenomenon by preventing particles movement.

Reference	[4]	[5]	[6]	[7]
Tested system	Coaxial electrodes	Coaxial electrodes	Coaxial electrodes	GIS bus bar
Coating material	Polyolefin film and PVC varnish	PE varnish	Epoxy	Epoxy
Coated electrode	Inner electrode with film and outer electrode with varnish	Inner electrode	Inner electrode	HV insulator screen
Gas	SF_6 and N_2	N_2	SF_6	SF_6
Voltage	LI-	LI-	50Hz	LI-
Dielectric withstand improvement (%)	>32 (SF_6) / > 27 (N_2)	>48	>29	25-30

Table 3 : Bibliographic results.

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CONCLUSIONS

This paper shows that for LI voltages it is possible to increase the breakdown electrical field of a gas insulated cable with coated electrodes. In particular, it has been observed that the standard deviation is strongly reduced when covering both electrodes.

This phenomenon is either due to limiting the electron injection by trapping the injected charges in the insulating covering material, or either by fixing impurities in the interface gas-solid, or both phenomena together and these tests have demonstrated that the gas/coating interface plays a major role in the dielectric withstand of such systems.

However, additional test may be run with different voltage wave form in order to confirm these first results. In addition to that, the impact of other parameters such as presence of particles of contamination or the moisture may be investigated too. Then, the potential of such coating for GIL dielectric withstand improvement could be considered.

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