2019 International Symposium on Lightning Protection (XV SIPDA), São Paulo, Brazil, 30th September – 4th October 2019.

New gas discharge tubes for AC protection : Influence of gas and size on electrical characteristics

Yves Gannac, Cong Duc Pham, Geoffrey Chanard, Vincent Crévenat
RD Department, CITEL
Reims, France
yves.gannac@citel.fr

Wang Hui
RD Department, CITEL
Shanghai, China

Christian Macanda, Henri Guichard
CITEL
Sèvres, France

***Abstract* - The paper presents the influence of different manufacturing parameters on electrical characteristics for a new generation of metal-ceramic gas discharge tubes (GDT). These new components are named GSG: Gas filled Spark Gap. This paper is checking the correlation between the manufacturing parameters (the nature of the gas filling the GDT and the size) and the electrical characteristics (the breakdown voltage - static and dynamic – and the endurance of GDT on surge current according to standard impulses, especially in high energy) in an attempt to understand how to design a GSG withstanding some value of current peak in 10/350 µs test current wave shape.**

Keywords—gas filled spark gap; high current impulse; surge protective device; electrical proprerties

I. INTRODUCTION

Electrical discharges in the gas are well studied phenomena since the beginning of 19th century [1]. At that time, the aim was to have a better understanding of the electric spark in the ionized gas.

Today, this field of physics has some application in electrical engineering like high power switches and surge protection devices like gas discharge tube (GDT).

Overvoltages in electrical networks cause damages of electrical devices. Since there are more and more electrical devices, these damages could have serious financial and technical consequences such as insurance costs increases, network failure…

Different components are used in surge protection devices (SPD). The commons one are GDT, air spark gap, varistor and clamping diode. Each one has his own advantages and disadvantages.

GDT has a very high insulating resistance (> $10^9\Omega$) and low residual voltage (< 30V) in conduction state with a high current capability for its small dimensions. Unlike air spark gap, there is no hot gas exhaust to the outside and unlike varistor there is no risk of explosion due to an increase of temperature during impulse. The main disadvantage of GDT is a bad extinction capability on AC power line with high follow currents.

During the last years some studies [2-4] have tried to explore different parts of the behaviour of GDT such as voltage breakdown and impulses' withstand.

As the GDT are deeply involved in surge protection for telecom lines and data lines, a new type of gas filled components is required for AC surge protection. These new components must provide higher impulse discharge capability and better follow current extinction than the regular one. In order to show the difference, these components are named "Gas filled Spark Gap" (GSG).

The GSG will be used in AC surge protection diagram in association with specific metal-oxide varistor (MOV) to improve extinction capability: this association is generally available under the name "VG technology".

II. SAMPLES DESCRIPTION

Two different technologies could be used for GDT: metal-glass or metal-ceramic technology. In the former one, the insulating spare part is made in glass. In the latter one, this part is made with an isolated ceramic (manufactured in Al_2O_3). From a manufacturing point of view, metal-glass technology is more complicate. Having a hermetically closed GDT needs to have perfect raw materials, very good knowledge and controlled process. And even in that case, we need to be sure that there is no leakage few years later. For this reason, GSG component are based on metal-ceramic technology.

In the present study, the type of GSG is made with an insulator ceramic between two copper electrodes assembled on a cap made in steel (Fig. 1 and Fig.2). For all the samples, the thickness of copper is about 2.0mm; the thickness of the GSG is about 8.0mm. By construction, the distance between the two copper electrodes is about 0.8mm.

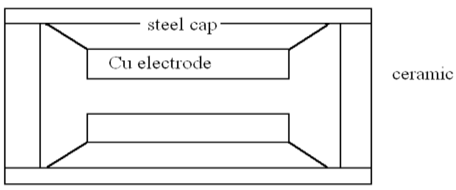

Fig. 1. GSG with ceramic body

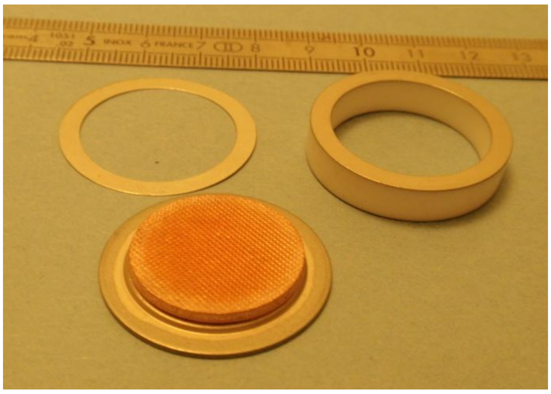

Fig. 2. Raw materials for GSG

A special powder is putted on the top of each electrode. The aim of this powder is to decrease the electron work of copper (around 4.6eV) to help the breakdown voltage.

During manufacturing, the GSG is filled with a gas. Normally, manufacturers used rare gases.

The aim of this study is to check the influence of two parameters on electrical characteristics of the GSG:

- The nature of the gas [4]. For it, GSG are filled with four different types of gases according to table I. Nature of the gas is the only one parameter checked, so each GSG is filled with the same pressure of gas, 300mB at room temperature.

Table I: Gases used for this study.

Type of gas
Argon
Argon – 5% Hydrogen
Argon – 10% Hydrogen
Argon – 20% Hydrogen

- The size of the gas tube (Fig. 3). For this study, the diameter of the outside is directly proportional to the diameter of the copper electrode, table II

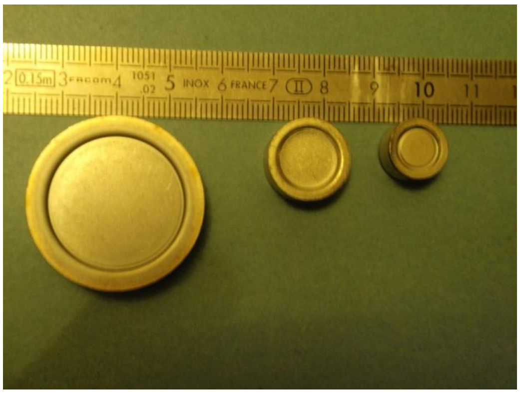

Fig. 3. Samples' sizes for the study

Table II: Sizes of GSG and ratio between outside diameter and copper electrode diameter.

Outside diameter	**Cu electrode diameter**	**Ratio**
12 mm	8.0	0.67
16 mm	11.1	0.69
32 mm	23.4	0.73

III. THEORETICAL BACKGROUND

The electrical breakdown of a gas can occur when enough ionizing collisions take place between electrons and a neutral background gas. It is a transition from a non-self-sustained to a steady self-sustained current in the Townsend discharge. The first Townsend coefficient α is the probability that an electron ionizes a gas neutral by collision per unit length of path, can be expressed by [5]:

$$\alpha = Ap\exp\left(\frac{-Bp}{E}\right) \quad (1)$$

where p and E represent the pressure and electrical field, respectively. The constants A and B are properties of the gas.

The Townsend secondary coefficient, γ, is number of electrons released from cathode per incident positive ion. The value of γ depends on cathode material and gas type, as well as on the ratio E/p. The breakdown condition is:

$$\alpha d = \ln\left(1 + \frac{1}{\gamma}\right) \quad (2)$$

where d is the inter-electrode distance.

In planar geometry, $V_B = Ed$, combining (1) and (2),

$$V_B = \frac{Bpd}{C + \ln(pd)} \text{ avec } C = \ln\left(\frac{A}{\ln\left(1+\frac{1}{\gamma}\right)}\right) \quad (3)$$

Equation (3) is Paschen's law implying that U_B depends only on pd.

However, an additional and independent influence of the electrode dimensions on the breakdown voltage has been observed by Lisovskiy et al. [6-7]. A modified formulation of the Paschen's law for the low-pressure dc discharge was obtained: $V_B = f(pd,d/R)$ where R is radius of the discharge tube; i.e. V_B depends on pd and on the ratio d/R.

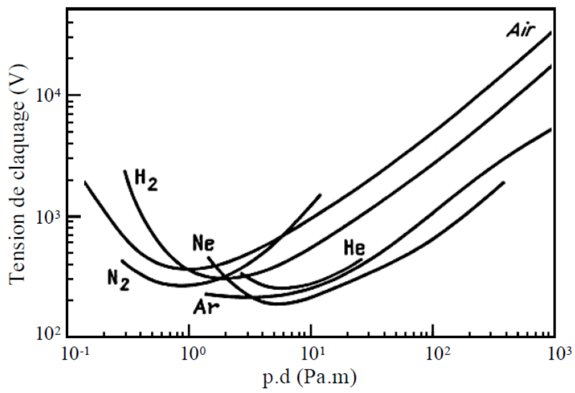

Fig. 4. Paschen curves, showing the breakdown voltage (VB), as function of pd for different gases [8]

In Fig. 4, Paschen curves for different gases were showed. The values of V_B are deeply dependant of the nature of the gas. A small variation in the composition of the gas could made high variation in value of V_B. Another important point is that these values are measured with increasing slowly (about 100V/s) the value of the voltage. With fast increases of voltage, the breakdown voltage is increasing. The dynamic breakdown voltage voltage is measured with a voltage increasing about 1kV/µs.

IV. TEST EQUIPMENTS

GSG operation principle is based on electrical breakdown in insulating gases. When the voltage, applied between the two electrodes of GSG, is enough high, a discharge appears between the two electrodes. This voltage, called DC sparkover voltage (V_s) [9]. We measured two kinds of characteristics, one using non-destructive methods (static and dynamic spark over voltage), the other one destructive method (10/350 µs test current wave shape).

A. Non-destructive methods

The test to measure *Vs* (DC) is relatively simple. An increasing voltage is applied to the GSG. The voltage's speed is around 100V/s. We measure the current through the GSG and when the value is higher than few mA, it means when the GSG is becoming non-insulating, we detect the sparkover voltage.

For measuring dynamic sparkover voltage (U_{imp}), we use a 1,2/50 µs generator with a voltage charge of 6kV. We measure the voltage to terminals of GSG.

B. Destructive method

The generator "G100K" (Fig. 5) used for this test delivers double-exponential waveforms in accordance with the requirements of IEC 62305-1 standard [9]. The system generates both 8/20 µs and 10/350 µs test current wave shape with surge current from 3 to 100kA. An AC network could be added to the impulse in order to follow the requirements of IEC 61643-1 standard [10].

Fig. 5. Surge generator: G100K

V. RESULTS

A. DC Sparkover Voltage

We measure *Vs* for each sample; it means 3 different sizes and 4 gases inside the cell.

The increasing of *Vs* (around 250V) is important with a small amount (5%) of H_2 (Fig. 6). With more quantities of H_2 (10 to 20%), the increase is not so high (50V).

There is influence of the size of the GSG on V_S. The increase of *R* leads to the increase of V_S. This agrees with the deviations from Paschen's law ($U_B = f(pd,d/R)$).

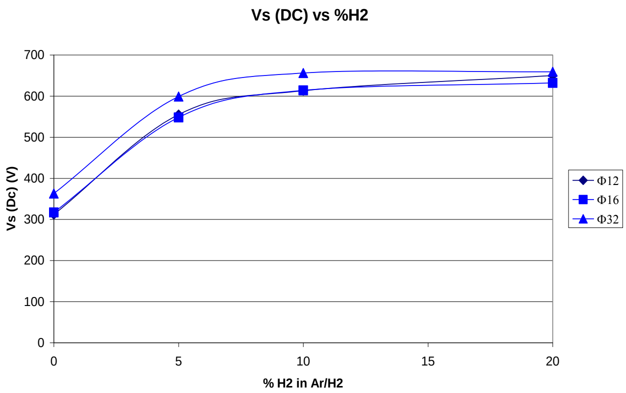

Fig. 6. DC sparkover voltage (VS) as a function of percentage of hydrogen in argon-hydrogen mixtures for three values of outside diameter

B. Impulse Sparkover Voltage (U_{imp})

Measurements are made on all the samples. To avoid a bias in measurements due to the different values of V_S, we calculate the value of U_{imp}/V_S (Fig. 7).

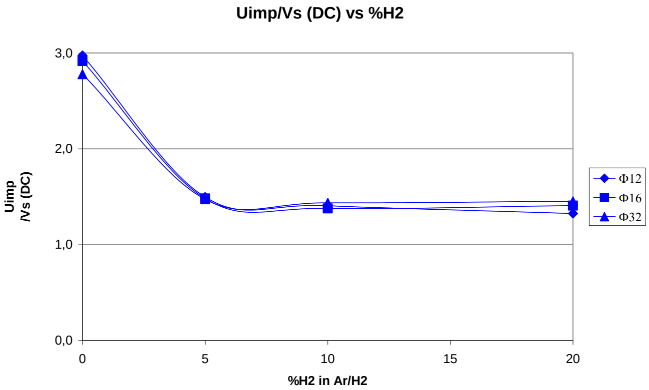

Fig. 7. Ratio of U_{imp}/V_S as a function of percentage of hydrogen in argon-hydrogen mixtures for three values of outside diameter

For these measurements, the size of the GSG has no influence. The main modification in the ratio is due to the presence of H_2 in Ar/H_2 mixtures. Without H_2, U_{imp} is about 3 times higher than V_S. If we add a small percentage of H_2, the ratio is decreasing to around 1.4. This ratio doesn't change with 10 and 20% of H_2.

Having a low ratio is very important. In normal use, the GSG has to be insulating, it means to have a high DC sparkover voltage. But the GSG needs to have a fast answer to an impulse, it means to have a as low as possible dynamic sparkover voltage.

C. 10/350 µs test current wave shape (I_{peak})

For these measurements, we have applied 10/350 test current wave shape. We have increased peak currents by 10kA steps and checked the DC sparkover voltage until GSG reaches short-circuited state. Even if this test process doesn't fulfill standard, the aim is to have a quick idea of which current could be withstand by the GSG (I_{peak}).

The basic data (Fig. 8) show:

- 10/350 µs withstand decreases when the diameter of the copper electrodes decreases
- 10/350 µs withstand depends of the gas inside the GSG. The best withstand is for low percentages of H_2. The optimum value seems to be between 5% and 10% of H_2 in Ar.

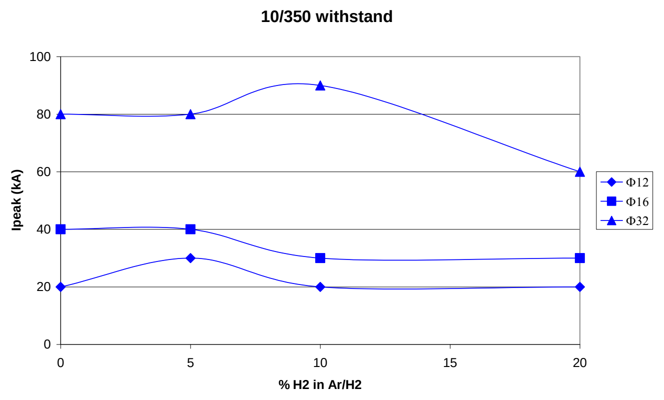

Fig. 8. 10/350 µs withstand (I_{peak}) as a function of percentage of hydrogen in argon-hydrogen mixtures for three values of outside diameter

As observed above, the 10/350 µs withstand seems dependant of the Cu electrode's diameter. We calculated the ratio 10/350 µs to Cu electrode's diameter for all the samples (Fig. 9).

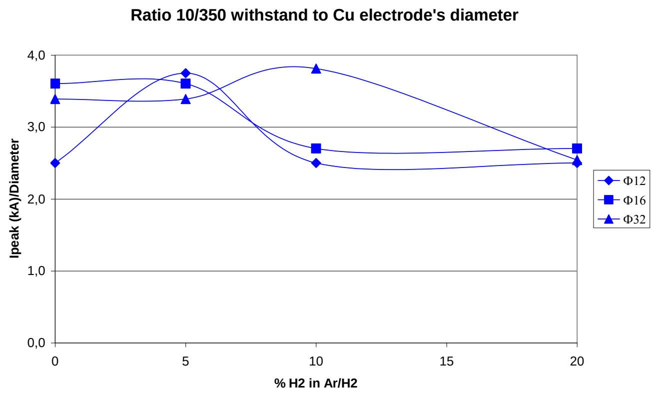

Fig. 9. Ratio of I_{peak}/Cu electrode's diameter as a function of percentage of hydrogen in argon-hydrogen mixtures for three values of outside diameter

Even if there were some discontinuities, a correlation appears:

- Lower than 5% of H_2, the ratio is about 3.5 kA/mm
- Higher than 10% of H_2, the ration is about 2.5kA/mm

As 10/350 µs withstanding is due to thermal destruction of Cu electrodes, the curves show that high percentages of H_2 have a bad effect on it.

VI. CONCLUSIONS

This study presents some important parameters in GSG's manufacturing and shows their influences on GSG's properties. Focusing on a ceramic-metal technology, we checked two parameters:

- the size of GSG
- the percentage of H_2 in Ar

We have determined that the size of GSG has no significant effect on sparkover voltage (DC or impulse). But size has a direct impact on 10/350 µs withstand. And, even if we know how complex and difficult it is to predict the behavior of GSG, we have determined a ratio between the size and 10/350 µs withstand.

Last point, we have determined the effect of H_2 in Ar for the filling gas. H_2 is improving the ratio U_{imp} to V_S. But high percentages of H_2 seems to cause important thermal damages to the Cu electrodes during a 10/350 µs test current wave shape.

Some characteristics of the GSG are not studied in this paper. For example the extinction capability of GSG is an important point. In further studies, we would like to check the influence of our manufacturing parameters on this characteristic.

VII. REFERENCES

[1] F.M. Penning, "Décharge électriques dans les gaz", Bibliothèque Technique Philips, 1958

[2] M. Edirisinghe, R. Montaño, V. Cooray "Response of Surge Protection Devices to Fast Current Impulses", Proc. Of 27th ICLP, Avignon, France, September 2004

[3] O. Diaz, V. Cooray, J.S. Schleimann-Jensen "Energy Dissipation in a New Flat Low Voltage Surge Protective Gas Discharge Tube", Proc. Of 30th ICLP, Cagliari, Italy, September 2010

[4] R. Rozman, A. Stagoj, "Operation of GDT with Metal Body Designed for High Current Surges", Proc. Of 30th ICLP, Cagliari, Italy, September 2010

[5] N. St. J. Braithwaite, "Introduction to gas discharges", Pasma Sources Sci. Technol. 9(2000) 517-527

[6] V. A. Lisovskiy, S. D. Yakovin and V. D. Yegorenkov, "Low-pressure gas breakdown in uniform dc electric field", J. Phys. D: Appl. Phys. 33 (2000) 2722-2730

[7] V. A. Lisovskiy, V. A. Koval and V. D. Yegorenkov, "Dc breakdown of low pressure gas in long tubes", Physics Letters A 375 (2011) 1986-1989

[8] M. Coulilaby, "Caractérisation des décharges électriques se propageant aux interfaces gaz/solides – Relation entre propriétés des matériaux et dimension fractale", Ph. D. Ecole Centrale de Lyon, July 2009

[9] IEC 62305-1 Standard

[10] IEC 61643-1 Standard