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INFLUENCE OF THE FILLING GAS MIXTURE ON THE INTERRUPTION CAPABILITY OF MEDIUM VOLTAGE LOAD BREAK SWITCHES

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Abstract. In today's medium voltage switchgear SF_6 is commonly used as insulating and arc quenching medium. Because of its high potential impact on the environment a substitution with an environmentally friendly alternative is pursued. In this paper the influence of the mixing ratio of carbon dioxide nitrogen mixtures as filling gas on the interruption capability in medium voltage load break switches is investigated. The interruption capability is regarded by means of the thermal interruption performance as well as the dielectric recovery of a model load break switch. The model load break switch allows an axial arc blowing with variable pressure and uses an exchangeable nozzle system.

Keywords: load break switch, alternative gas, thermal interruption capability, dielectric recovery.

1. Introduction

In the medium voltage (MV) secondary distribution a large number of load break switches (LBS) is installed to interrupt load currents up to 1250 A and as disconnector switches. Most of them are installed in ring main units (RMU) connecting the low voltage grid to the MV grid. Because of the limited space in urban areas, they are often designed as metal clad gas insulated switchgear (GIS). Sulphur hexafluoride (SF_6) with its superior insulating and arc quenching performance is the state of art filling gas for GIS. However, with a Global Warming Potential (GWP) of 23500 it is the most potent greenhouse gas known and therefore listed in the Kyoto protocol as one of the gases to be reduced [1, 2]. Possible substitutes for SF_6 should have a low GWP and no Ozone Depletion Potential (ODP). They must have a sufficient dielectric strength to insulate occurring voltage stress and a good arc quenching capability to guarantee current interruption. To ensure a safe operation over the complete service life the gas should be stable under the influence of an arc and not produce conducting byproducts [1]. For the use in MV switchgear different gas mixtures of atmospheric gases like carbon dioxide (CO_2) and nitrogen (N_2) with and without fluorinated gases are discussed [1, 3–5].

The arc quenching capability of a gas can be evaluated by means of the arcing time constant. The lower arcing time constant of CO_2 indicates a better thermal interruption capability compared to N_2 (see Table 1) [3]. By using CO_2-N_2 mixtures the impulse withstand voltage can be increased compared to pure N_2 and pure CO_2 [4, 6]. Both gases have no or a low GWP and no ODP (see Table 1). Investigations showed that CO_2 can produce conducting byproducts when interrupting large currents in the range of tens of kA [3].

Property	SF_6	CO_2	N_2.
GWP	23500	1	0
Dielectric strength [%]	100	37	40
Arcing time [µs]	0.8	1.5 – 15	210 – 220

Table 1. Properties of SF_6, CO_2 and N_2 [1, 9]

N_2 has a lower permeation rate than CO_2 [7], which makes the enclosure design easier. By using a CO_2-N_2 mixture, the advantages of both gases can be combined. Therefore, in this paper the influence of the mixing ratio of CO_2-N_2 mixtures on the interruption capability of a MV LBS is investigated. Some of the experimental results have been shown in [8] and are used for comparison in this work.

2. Methodology

The interruption process in LBS can be divided into a thermal and a dielectric phase [10]. To evaluate the influence of the filing gas mixture on both phases separately two different test methods are used, which are desribed shortly in the following. A detailed explanation can be found in [5] and [8].

2.1. Thermal Interruption Capability

In this paper, the thermal interruption capability is quantified by the critical current steepness di/dt_{crit}. For the determination a synthetic test circuit is used. The test circuit provides one half oscillation of a sinusoidal current with a value of $I_{RMS} = 630$ A and a frequency of $f_1 = 50$ Hz. Shortly before the current reaches its natural CZ an injection current in the range

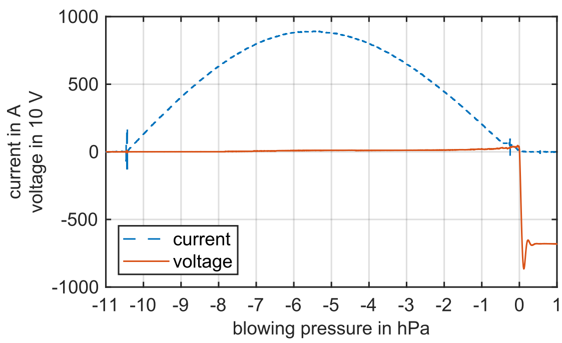

Figure 1. Voltage and current measurement of a succesfull interruption

of a few ten amps and a frequency of $f_2 \approx 1000\,\mathrm{Hz}$ is superimposed on the test current. Using this superposition method, the current steepness in the model switch at CZ can be varied independently of the test current amplitude. After successful current interruption, a recovery voltage rises across the open contacts (see figure 1). To ensure a conservative test the rate of rise of the recovery voltage (RRRV) is chosen to create a RRRV corresponding to 1.2 times the RRRV of a standardized test for $I_N = 630\,\mathrm{A}$ at $U_N = 24\,\mathrm{kV}$ and $f = 50\,\mathrm{Hz}$. This results in an RRRV of approximately $\mathrm{d}u/\mathrm{d}t \approx 75\,\mathrm{V/\mu s}$ at a current steepness of $\mathrm{d}i/\mathrm{d}t = 0.28\,\mathrm{A/\mu s}$ at CZ. At the beginning of a test series a low $\mathrm{d}i/\mathrm{d}t$ is chosen and five successful interruption tests are performed. Afterwards the $\mathrm{d}i/\mathrm{d}t$ is increased and another five interruptions are performed. This procedure is repeated until all five interruptions for one level of $\mathrm{d}i/\mathrm{d}t$ fail. The critical current steepness is determined as the mean value of the current steepness of the lowest failed test and the current steepness of the next lower successful test.

2.2. Dielectric Recovery

The dielectric recovery of the model switch is determined with the test method and circuit described in [8]. Firstly, the model switch is stressed with a half oscillation of a current with a value of $I_{RMS} = 630\,\mathrm{A}$ like in figure 1. Following the CZ a steep impulse voltage is applied after a short delay time. The impulse voltage has a maximum peak of 80 kV. The rise time (10 % to 90 % of the peak voltage) is 1 µs. The delay time is varied in a range of $t_{delay} = 10\,\mathrm{\mu s}$ to 300 µs after CZ to get a time resolved breakdown voltage after current zero. For each delay time a minimum of four breakdown tests is performed. In the resulting diagram each marker indicates the mean breakdown voltage of at least four measurements in a time frame of maximum 10 µs. The error bars indicate the maximum and minimum of the measured breakdown voltages in that time frame.

2.3. Test Setup and Procedure

The experiments presented in this paper are performed using a model switch with an axial blowing of the arc through a polymer nozzle shown in figure 2. It is build in a closed test vessel with a volume of $V = 153\,\mathrm{l}$. The mixing ratio is given by the volume fraction of N_2. An absolute filling pressure of $p = 1800\,\mathrm{hPa}$ is used in all experiments. The model switch consists of a tulip-pin contact system made from tungsten-copper (80/20). The contact diameter is $d_c = 10\,\mathrm{mm}$. The used polymer nozzle is made from Polytetrafluorethylen (PTFE) and has a nozzle throat diameter of $d_n = 11\,\mathrm{mm}$ and a throat length of $l_n = 24\,\mathrm{mm}$. This configuration was identified as suitable in previous works [5, 8]. The blowing through the tulip contact is realized by an external pressure vessel, which is filled with the same gas mixture as the test vessel. The opening of a magnetic valve initiates the blowing. The blowing pressure is measured upstream of the nozzle and gives the total pressure drop across tulip contact and nozzle. It is varied in a range from $p_B = 100\,\mathrm{hPa}$ to 770 hPa. A pneumatic piston drive is used to operate the model switch with an average opening speed of $v_{mean} = 5\,\mathrm{m/s}$. Since in the used test circuit only current interruption in the first CZ can be tested and previous investigations showed that the interruption capability increases when the pin contact is outside of the nozzle at CZ [11] all experiments are conducted with an arcing time of $t_{Arc} \geq 7\,\mathrm{ms}$.

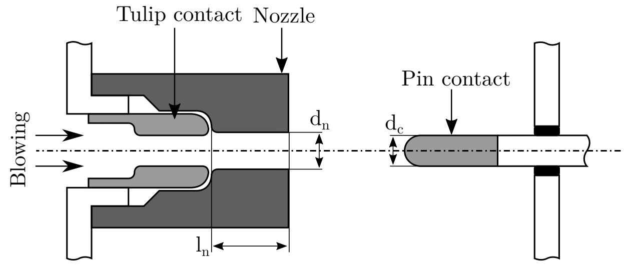

Figure 2. Section of the model load break switch [5]

3. Results

3.1. Thermal Interruption Capability

The critical current steepness for different CO_2-N_2 mixtures in dependence of the blowing pressure and the N_2 content is shown in figure 3. The lines connecting the data points are only drawn for better visualization. The used test circuit can create a current steepness of maximum $\mathrm{d}i/\mathrm{d}t_{max} = 1\,\mathrm{A/\mu s}$. Therefore, the critical current steepness for the mixture with 20 % N_2 content can only be determined for blowing pressures $p_B \leq 550\,\mathrm{hPa}$ and for pure CO_2 only for $p_B \leq 330\,\mathrm{hPa}$. For the measurement series with pure N_2 the thermal interruption capability at a blowing pressure of $p_B = 100\,\mathrm{hPa}$ is so low that no critical current steepness could be determined.

The critical current steepness increases with increasing blowing pressure and a decreasing N_2 content. Mixtures with a N_2 content of less than 80 % show an almost linear increase with increasing blowing pressure in the investigated range. Mixtures with a N_2 content

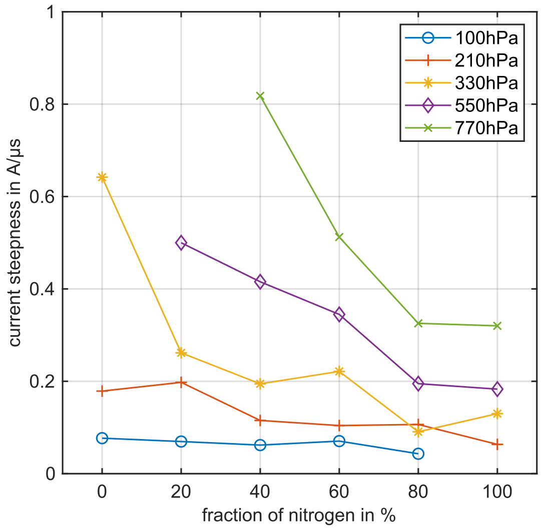

Figure 3. Critical current steepness depending on the fraction of N_2 for various blowing pressures

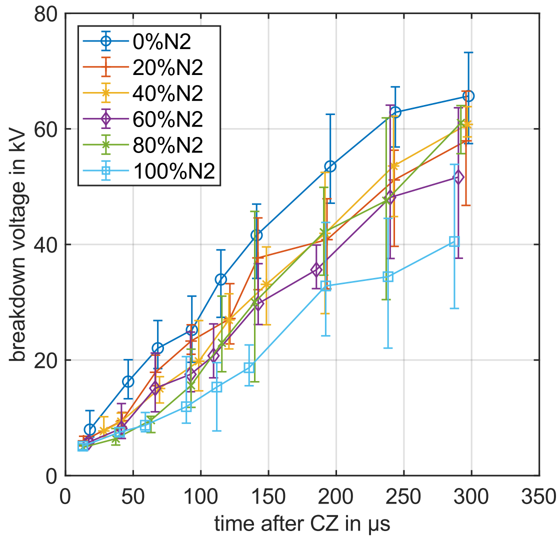

Figure 4. Dielectric Recovery of the model switch for various N_2-CO_2 mixtures at $p_B = 330\,\text{hPa}$

of 80 % and more show an exponential increase of the critical current steepness with increasing blowing pressure.

For low blowing pressures, the N_2 content has only a small effect on the critical current steepness. For a blowing pressure of $p_\text{B} = 770\,\text{hPa}$, a decreasing N_2 content leads to an exponential increase of the critical current steepness.

3.2. Dielectric Recovery

Figure 4 shows the time resolved breakdown voltages for different N_2 fractions at a blowing pressure of $p_\text{B} = 330\,\text{hPa}$. The differences between the different mixtures with N_2 contents of 20 % to 80 % are small and in the area of the measured scatter. With the use of pure CO_2, the model switch shows the fastest dielectric recovery. With pure N_2 the breakdown voltage at $t_\text{delay} \approx 300\,\mu\text{s}$ is less than 50 % of the one measured with pure CO_2.

The time resolved breakdown voltages for varying blowing pressures and a mixture of 40 % N_2 and 60 % CO_2 are shown in figure 5. With increasing blowing pressure the dielectric recovery becomes faster. At $p_\text{B} = 330\,\text{hPa}$ the breakdown voltage increases almost linearly in the investigated time frame. For a blowing pressure of $p_\text{B} = 550\,\text{hPa}$ the dielectric recovery rises in the first 200 µs after CZ and then stays at a value around $U_\text{BD} \approx 70\,\text{kV}$. For $p_\text{B} = 770\,\text{hPa}$ the breakdown voltage increases even faster in the first 150 µs after CZ and increases further until the end of the investigated time frame.

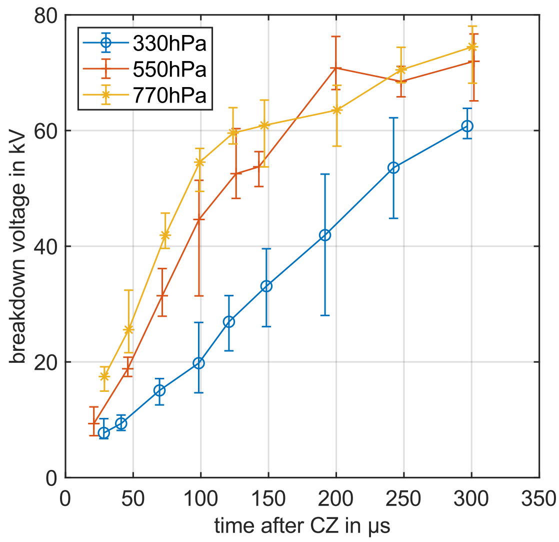

Figure 5. Dielectric Recovery of the model switch with mixture of 40 % N_2 and 60 % CO_2 for various blowing pressures

4. Discussion

4.1. Thermal Interruption Capability

At low blowing pressures, the N_2 content has only a small influence on the critical current steepness. It is assumed that through nozzle ablation a pressure rise inside the nozzle occurs, which leads to a clogging of the nozzle, resulting in an insufficient flow field. Additionally, this results in an unknown gas mixture in the nozzle where the N_2 content has a minor effect on the thermal interruption capability compared to high blowing pressure. At higher blowing pressure the flow field at CZ is stable and the N_2 content of the gas mixture has a greater influence on the thermal interruption capability. The higher interruption capability for lower N_2 contents results from the smaller arcing time constant of CO_2 (see Table 1). At comparable cooling, by axial blowing, the resistance of the switching gap rises faster for CO_2. This results in a faster limitation of the post arc current, which leads to a decreased heating and therefore to a decreased need for cooling. The authors assume that the significantly higher thermal conductivity of CO_2 compared with N_2 in the temperature range from 2000 K to 5000 K leads to the faster cooling of the gas in the switching gap. Combined with the limitation of the post arc current and therefore decreased post arc heating this results in the exponential increase in thermal interruption capability with an increasing CO_2 content.

4.2. Dielectric Recovery

The higher thermal conductivity of CO_2 leads to a faster cooling of the gas in the switching gap and therefore to a faster dielectric recovery in the first 300 µs after CZ. With an increased blowing pressure the cooling can also be intensified and a faster dielectric recovery is achieved. The faster dielectric recovery of switchgear using CO_2 in comparison to N_2 is also reported in literature [12].

In [4, 6] an increase in breakdown voltage of CO_2-N_2 mixtures compared with pure CO_2 and pure N_2 is identified. While in [4, 6] tests without prior stress through a switching arc were performed, this work investigates the breakdown voltage of the gases after current interruption. Therefore the gas is still hot when the breakdown voltage is determined. Hence, these results are not directly comparable to the cold gas breakdowns. The dielectric recovery of all tested gases and gas mixtures for $t_{delay} \geq 200\,\mu s$ is sufficient to withstand the recovery voltage at 24 kV load current interruption. For $t_{delay} < 200\,\mu s$ the dielectric recovery of mixtures with a low CO_2 content might lead to breakdowns in the first peak of the recovery voltage. The investigations on the influence of the blowing pressure show that in this time frame the dielectric recovery can be significantly accelerated by an increase of the blowing pressure. Since in the test method for determining the thermal interruption capability the recovery voltage is replicated until the first maximum of the recovery voltage, all configurations, which have a sufficient thermal interruption capability, will also have a sufficient dielectric strength in the critical time frame.

5. Conclusion

The thermal interruption capability and dielectric recovery of a model LBS is investigated for CO_2-N_2 mixtures. By increasing the content of CO_2 in a gas mixture with N_2, the thermal interruption capability can be improved compared to pure N_2. With a LBS using pure N_2 the required interruption capability of $\mathrm{d}i/\mathrm{d}t = 0.28\,\mathrm{A/\mu s}$ for a the interruption of a 630 A load current in the 24 kV voltage level is achieved with a blowing pressure of 770 hPa. When using pure CO_2 only a blowing pressure of 330 hPa is necessary. The dielectric recovery is also influenced positively by an addition of CO_2. From the presented investigations it can be expected that when a configuration has a sufficient thermal interruption capability the dielectric recovery will also be sufficient. In field application, the blowing pressure is generated by the compression of the filling gas in a puffer volume. Therefore, the choice of the gas mixture allows for an optimization of the needed drive.

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