Switching Performance of Weakly Cooled Arcs

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Understanding the response of a low current and weakly cooled arc in subsonic axial flows is important to effectively control the switching in medium voltage switchgear. We have looked into the effect of blowing overpressure on the switching behaviour of an arc in air for conditions relevant to load break switches. The transient recovery voltage was chosen according to the active load break test duty.

Keywords: low current arcs, subsonic flows, low blowing, load break switches

1 INTRODUCTION

Free burning and weakly cooled arcs are found in a wide variety of switchgear ranging from high voltage gas insulated switchgears (GIS) to medium voltage ring main units, such as, disconnectors, fast acting earthing switches, and load break switches. Understanding the physics of interruption of such weakly blown arcs is very important for the safe functioning of such devices. Many articles about the physics of interruption in high voltage circuit breakers, where current of a few 10 kA to 100s of kA are typical, can be found in the literature (see Ref. [1] and references therein). Recently Jonsson et al. have published some work that looked into the domain of weakly cooled arcs within the framework of load break switches (LBS) [2-3]. They describe in detail the current and voltage stresses seen by LBS in operation. Their experiments aim at finding switching conditions for LBS of different ratings using air at 1 bar as filling gas. In Ref. [4] Jonsson et al. determined the minimum overpressure needed to interrupt current in the range of 300-900 A. In this work we follow a complementary approach and determined the current that is interrupted at a given overpressure. Here, we focus on the transition region from unblown to blown conditions; i.e., we varied the applied overpressure in a range of 0 to 110 mbar, while Jonsson et al. varied the overpressure in a range of 50 mbar to 1 bar. Applied TRVs are similar to those required for active load break switching [5]. The rate of rise of recovery voltage (RRRV) varied between 15-60 V/µs depending on the current (described in detail in section 2.1). Air at 1.3 bar filling pressure is used.

These results may find relevance for those switching applications where low currents are involved and minimal cooling is desired. Since air is used as an arcing medium one could assess the capabilities of air as a possible alternative to SF_6 in some selected switching domains. Aside from this, this may also open a discussion aimed at a better understanding of the physics of interruption in the weakly blown subsonic domain, an area where little is currently known.

2 EXPERIMENTAL METHOD

The experimental setup is designed in a way that several parameters (blowing pressure, travel, working gas) can be varied independently.

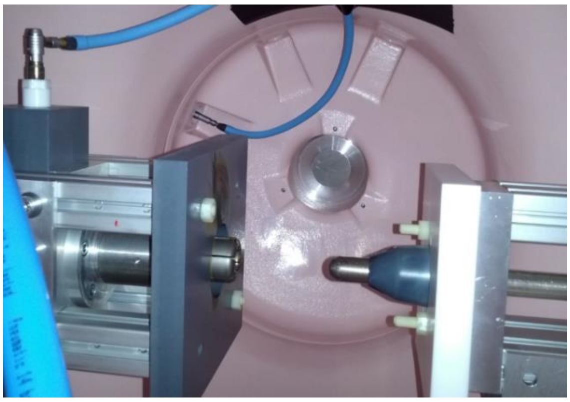

Fig. 1: Plug and tulip assembled into the test object

The entire contact system is enclosed in standard 420 kV GIS components [6]. The main part of the mechanical drive is a pneumatic cylinder that allows variation of the travel speed in a range from 0.6 m/s to 10 m/s. For our experiments the speed was fixed to 5 m/s at contact separation. We used this velocity as the opening speed in real LBS is around this value. The total stroke is limited to 140 mm. The contact system is taken from a high voltage circuit breaker; the plug and the tulip are depicted in Fig. ***1***. One flange is equipped with a Quartz window in order to gain direct optical access to the arcing zone (plug-tulip contact region). A high speed camera with a maximum frame rate of 14000 fps is used to capture videos of the arcing zone during current interruption.

2.1 TEST CIRCUIT

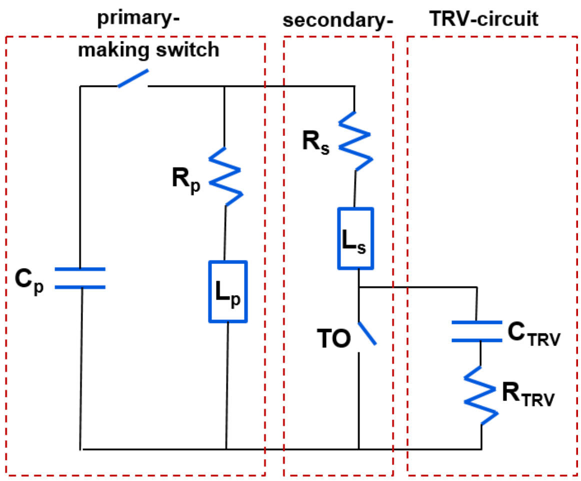

Fig. 2: Test circuit

The test circuit is shown in Fig. ***2***. The circuit can be split into three parts: primary, secondary and TRV circuit as is shown in Fig. ***2***. The primary circuit is optimized for low damping by using coils with low ohmic losses (large conductor cross section) and tuned to a frequency of ~50 Hz. The test object is located in the secondary circuit, where the current is limited by a high inductance choke (L_s=10-100 mH). Because $L_s >> L_p$ only a small fraction of the current is bypassed through the secondary circuit so that the damping rate is mostly determined by the primary circuit and there is only a minor change of the frequency. L_s is chosen in a way that the desired current in the secondary circuit is reached for a charging voltage of the capacitor bank C_p in the range of 3-4 kV. This is done to minimize the arc circuit interaction. The TRV is generated by the TRV circuit parallel to the test object (TO). The dimensions of the circuit elements are compiled in Table 1. In this test circuit, the circuit impedance (Z) at CZ is constant for defined circuit parameters. Z is defined as $Z_{cz} = \frac{du/dt_{CZ}}{di/dt_{CZ}}$. Since $\frac{di}{dt}$ at CZ depends upon the peak value of current, the slope of TRV ($\frac{du}{dt}$) changes with the current.

Table 1: Circuit element

Circuit element	Values
C_p	7 mF, charged up to 4.0 kV
L_p, R_p	1.66 mH; 15.5 mΩ
R_s	0.1 - 1 Ω
C_{TRV}, R_{TRV}	2 µF; 0.1 – 2 kΩ
F	50 Hz

2.2 BLOWING CIRCUIT

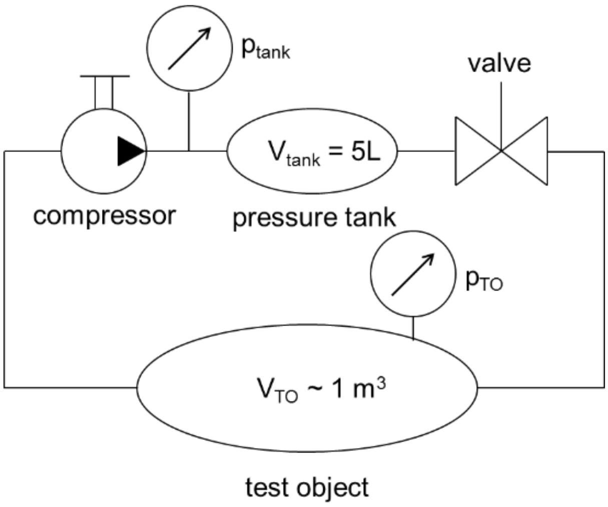

Fig. 3: Sketch of the blowing circuit

We used a closed gas handling system so that for multiple interruption tests the amount of gas and the gas pressure within the test object remains constant. A sketch of the gas handling system is shown in Figure 3. A compressor charges the pressure tank to the desired overpressure. The volume of the pressure tank is V_{tank}=5 l and the pressure (P_{tank}) is monitored by a pressure sensor. When the valve is triggered, the pressurized gas is suddenly released through the tulip into the test object. The temporally resolved pressure measurement in the tank was then used to calculate the mass and volume flow rate and blowing speed.

2.3 TIMING

The pneumatic drive of the contact system, the making switch of the electrical circuit, and the valve of the gas handling system were computer controlled and could be triggered independently. For the present tests the trigger delays were set in a way that the blowing was started first and a flow was established before an arc was drawn between the contacts. The current was injected just before contact separation so that the arcing time is in the range of t_{arc}=8 – 10 ms. In Fig. ***4*** current, voltage, travel, and tank pressure are shown for a representative shot. In this case, the current was interrupted after the first half wave and the blowing pressure is almost constant during the entire arcing time.

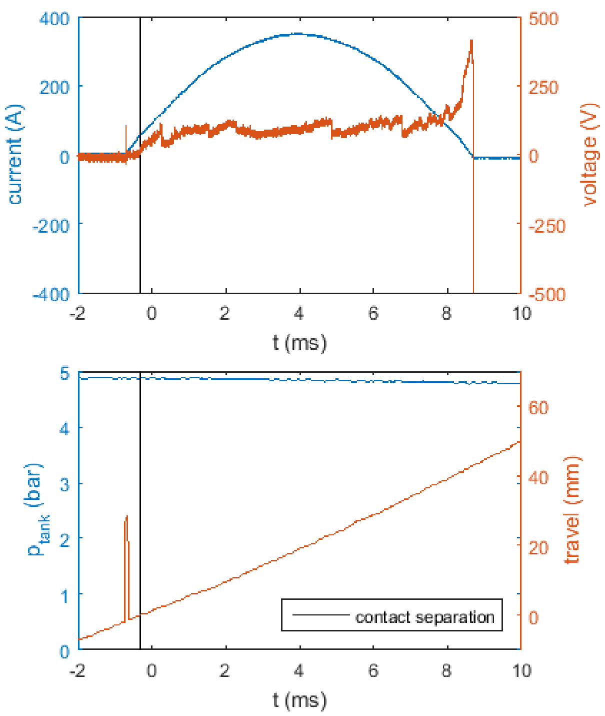

Fig. 4: The top panel shows the current and the arc voltage versus time; the bottom panel shows the travel and the tank pressure versus time

2.4 PRESSURE DROP ACROSS THE NOZZLE

During the tests, blowing pressure is adjusted by the tank pressure and the flow is limited by the valve because it has the smallest cross sectional area along the flow path. Thus, the valve and the tulip can be seen as a "pressure divider" that strongly reduces the pressure drop across the nozzle. The pressure difference between the tank and the test device is a few bar; the desired pressure difference at the tulip is a few tens of mbar. While the pressure drop across the tulip is the quantity of interest that can be used to assess the performance of the blowing topology, it is difficult to measure it in the present setup. For this reason, a simplified blowing circuit simulation was set up using the Dymola programming environment [7]; it was based on the actual volumes and cross sectional areas for flows. In this way, the tank pressure, which was measured and could easily be adjusted, can be related to the pressure drop across the nozzle/tulip, as is shown in Fig. ***5***.

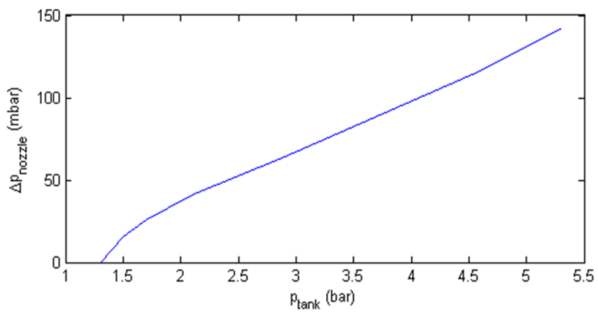

Fig. 5: Pressure drop across the nozzle as a function of upstream pressure in the tank

3 RESULTS AND DISCUSSION

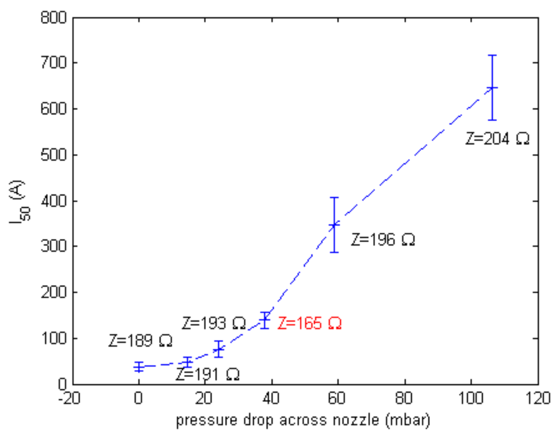

Fig. 6: Current level (r.m.s) for 50% interruption probability versus pressure drop across the nozzle; for comparison, the circuit impedance is written next to the data points

The up and down method [8] was used to determine the current (I_{50}) at which holds and fails occur with 50% probability. For each set of parameters we performed a sequence of about 40 interruption tests in order to get a good estimate of the 50% probability level for one particular configuration.

Fig. 7: Arc drifts away from the axis due to increased blowing; arrow shows the axis where maximum blowing occurs

We measured the 50% interruption level in synthetic air for different blowing pressures, ranging from unblown conditions up to a pressure drop across the nozzle of 110 mbar for an opening speed of ca. 5 m/s at contact separation and a circuit impedance of Z ~ 190 **Ω**. For these parameters the gas flow is clearly in a subsonic regime and we do not expect the wind speed to exceed a Mach number of M=0.4. As is shown in Fig. *6*, the interruption performance increases monotonically with the blowing pressure and the additional cooling by the inflowing air clearly helps to improve the interruption performance. The error bars indicate the width of the distribution "$\boldsymbol{\sigma}$" as it was determined using the up and down method. Furthermore, the pressure drop across the nozzle is derived from the Dymola-based model, which might result in a systematic error in the blowing pressure of a few percent towards higher or lower values. The functional dependence of I_{50} on Δp does not follow a simple power law. Up to ~40 mbar the current level rises faster than linearly and for higher pressures the increase in interruption performance seems to slow down a bit. It is observed by the high speed camera that with increased blowing pressure the arc moves away from the axis where the maximum blowing occurs (Fig. *7*). Hence, for stronger blowing the cooling becomes less efficient. Since we have low current and relatively large sized tulip, we do not expect clogging. This is also evident from Fig. *7*. Hence we have not taken into account the reduction in area due to clogging, for the calculation of pressure drop across the nozzle in section 2.4.

4 CONCLUSION

In this article we described our experimental setup to measure the influence of blowing over pressure on the interruption of low current arcs. A full parametric scan was performed from free burning arcs to about 110 mbar of blowing pressure. It was found that the increase in blowing pressure leads to an increase in the current that can be interrupted. Aside from blowing pressure, there are various other factors that influence the interruption. Further tests are planned in future to obtain a better understanding of switching phenomena for low current arcs.

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