Focused Shadowgraphy in the Heating Volume of a High-Voltage Gas Circuit Breaker

Roger Wiget, Fredrik Lundqvist, and Nils T. Basse

***Abstract*—The gas or plasma flow in the heating volume is central for the interruption performance of a circuit breaker (CB). This flow is visualized in a real breaker for the first time. Transparent parts were added to the breaker to use the focused shadowgraphy technique. Several experiments show the flow and distribution of the hot gas in the heating volume. The results can be used for further analysis of the gas/plasma flow in a CB.**

***Index Terms*—Gas circuit breaker, gas flow visualization, Gladstone–Dale relation, high-speed camera, shadowgraphy.**

HIGH-VOLTAGE (HV) gas circuit breakers (CBs) are needed to control and protect electrical power transmission grids. The current is interrupted by a complex extinguishing process in a gaseous medium [1]. When the CB opens, an arc ignites between the arcing contacts situated in the middle of the breaker. This area is surrounded by the nozzle, which conducts the flow. The arc energy is used to build up pressure in a volume at the outlet of the nozzle. This so-called heating volume is one of the most crucial parts for the performance of a CB. The hot gas from the arcing zone, consisting of a vaporized nozzle material [2] and a fill gas (usually SF_6), flows through the heating channel to the heating volume. As the current approaches zero crossing, the gas flow reverses direction. Usually, the gas flow process is not visible. This issue was already discussed in previous studies [3], [4], in which they used the shadowgraphy method as well. Nevertheless, it has never been tried to visualize the flow in a real CB. The previous studies were done with simpler models.

In this paper, a real HV gas CB is used to examine the flow. The test object needed to fulfill certain requirements. It was to function almost like a normal HV gas CB, but the parts of the heating volume had to be built with transparent rectangular parts to let the light pass straight through. In addition, all parts have to withstand high-pressure buildup and hot gas waves. The production of hydrofluoric acid (HF) during an arc interruption in SF_6 is also a problem. Therefore, no normal glass is used. A test device based on an existing HV gas CB is constructed. The parts around the heating volume are changed to a combination of polymethylmethacrylate (PMMA) and aluminum parts. To model the original round form of the heating volume by keeping rectangular surfaces, steps are added to the PMMA. Windows are also added to a gas-insulated switchgear tank (length of about 2000 mm) enclosing the breaker.

The focused shadowgraphy method [5] is used to visualize the gas flow inside the heating volume. This technique relies on the fact that the refraction index of a gas depends on the density (Gladstone–Dale relation). The light source is a 20-mW He–Ne laser that has a wavelength of 632.8 nm. The laser beam is expanded by a microscope objective, deflected by a mirror, and made parallel by a Fresnel lens. The beam, with a diameter of about 200 mm, crosses the tank and the test object, which moves during the opening operation. The beam is deflected due to the flow inside the heating volume. On the other side of the tank, the beam is focused using a second Fresnel lens and filtered with various optical filters to remove scattered light. The results are recorded with a complementary metal–oxide–semiconductor camera. The camera used is a Phantom V7.3, sampling 34 188 frames per second (29.25 μs between frames) with an exposure time of 1 μs. The resolution is 320 (width) $\times$ 232 (height) pixels.

The test breaker is connected to an oscillation circuit consisting of a capacitor bank (34 mF), loaded between 0.4 and 1.8 kV, an inductance (250 μH), a resistor (414 $\mu\Omega$), and two auxiliary breakers. One auxiliary breaker is used to close the circuit, and the other is used to interrupt the current if the test object fails. Seventy-eight shots are conducted with different gases and filling pressures in the tank.

Fig. 1 shows the gas flow into the heating volume; a frame is shown every 0.7 ms. This example is a shot with two current half-waves, which have peaks of 16.2 and 10.6 kA. The tank is filled with 3-bar SF_6. The time stamps in Fig. 1 are relative to the final current zero crossing. This shot has an arcing time of about 15.0 ms. Therefore, the contact separation is after the peak of the first half-wave, and the flow from the first half-wave into the heating volume is almost invisible. The horizontal lines are from the steps in the PMMA, and the round ones are from the imperfection of the Fresnel lenses. The middle is blocked by a metal part.

The hot gas or plasma, still emitting light, flows into the heating volume with a high velocity from −7.4 ms until about −4.6 ms. Then, the wavefront stops, and the cloud starts to diffuse slowly into the whole heating volume. The distance where the wavefront stops depends on the energy in the arc. This was shown by the analysis of different shots. The outflow from the heating volume back to the arcing zone is not visible, because the burnt-off nozzle material deflects the laser beam.

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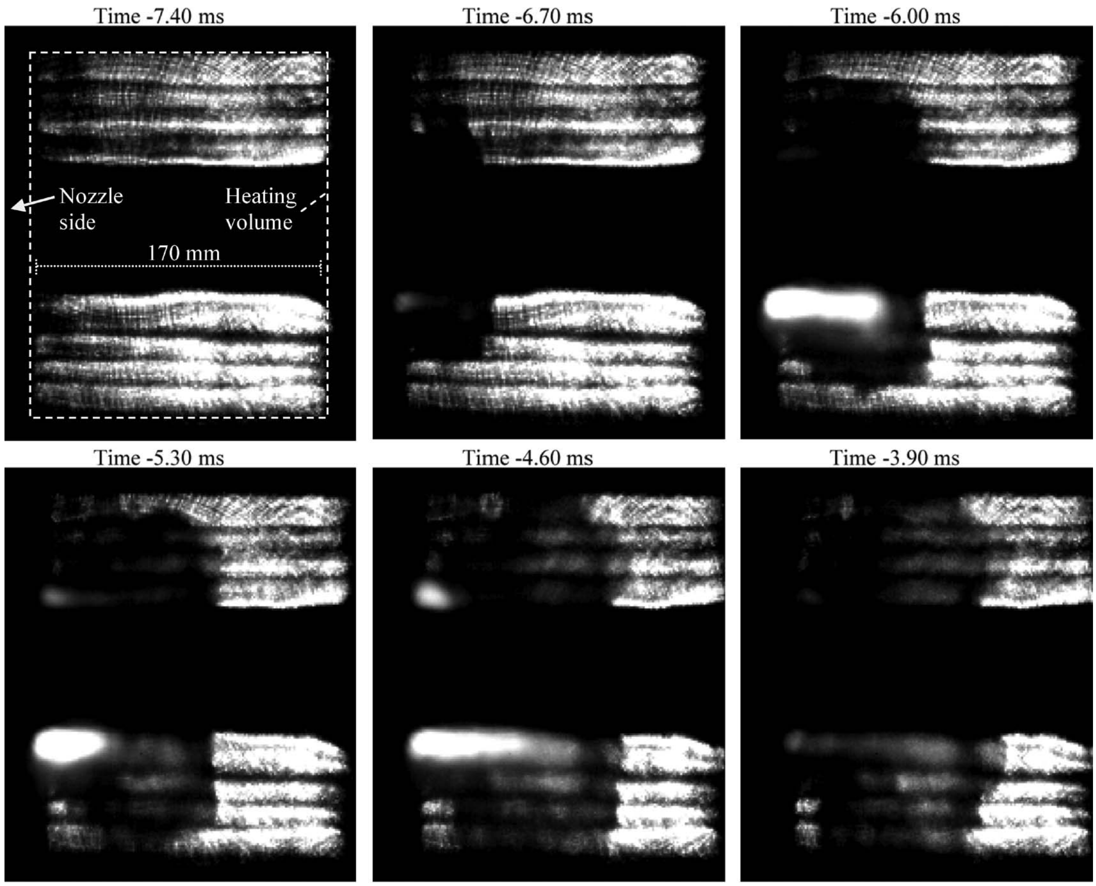

Fig. 1. Flow in the heating volume of an HV gas CB measured using the shadowgraphy method.

In conclusion, the focused shadowgraphy method has been demonstrated for the first time in a real HV gas CB. The thick PMMA parts with steps and the movement of the breaker make it challenging to achieve focused images. The images can be used, for example, to compare the experiments with computational fluid dynamics simulations.

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