Measurement of Electric Conductivity of Hot Gas in a SF_6-circuit Breaker Interrupting Fault Currents

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The realization of a new measurement method to determine electric conductivity of hot SF_6-gas during interruption fault currents in an original self-blast circuit breaker is presented. The method is based on evaluation of phase shift between sinusoidal kHz-high voltage and current, applied on a sensor. This needs a kHz-resonance voltage generator and adapted sensors as a part of an electromagnetic shielded measurement system to determine time dependent electric conductivity with high resolution.

Keywords: SF_6-circuit breaker, hot gas flow, electric conductivity

1 INTRODUCTION

Sophisticated software is used for the simulation of arc plasma processes and the hot gas flow during the interruption of fault currents with SF_6-circuit breaker. The aim is to understand and to improve arc extinction process for a wide range of switching parameters. Important aspects are the movement, the velocity, the electric conductivity and the temperature of hot gas in the interruption unit. These evaluated values allow the estimation of the arc extinction process as well as the indication of re-ignitions. Hot gas flow simulation is very helpful to detect and to understand the mentioned processes. Furthermore measured data from a real switching process are useful to verify calculated values. The transient hot gas flow processes and the environment conditions in the interruption unit restrict the applicability of measuring principle. Only electrical or optical methods are applicable. Optical detection of emitted radiation of hot gas is difficult, especially in a time dependent hot gas flow. Here, the application of an electrical measurement method is presented, whereby the transient electrical conductivity of hot gas, which flows through a sensor, is determined.

2 MEASUREMENT SYSTEM

2.1 MEASURING PRINCIPLE

A plate-plate sensor is used, which is connected to a high-frequency high-voltage source. Based on the measured high-frequency high-voltage and the current through the sensor the transient electrical conductivity of the gas between the plates is calculated. The plate-plate electrodes can be described as a parallel connection of a capacitor and a resistor. For cold gas between the electrodes the resistor is neglected. While the gas temperature between the electrodes increases, the resistivity of the gas volume is rising and the phase shift between voltage and current decreases.

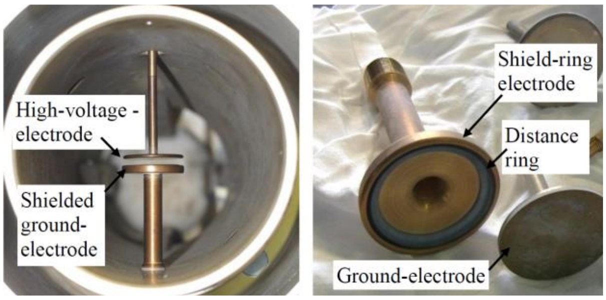

Fig.1: Sensor electrodes in the switching chamber

The sensor is positioned in the flow-out volume at a short distance behind the pin in a high-voltage SF_6- circuit-breaker pole (see Fig. 1, left). The measurement method was tested by using a stationary plasma and hot gas flow with specified temperature field [1]. Due to the use of a high-voltage with a kHz-frequency a sample rate of electrical conductivity nearly at 1 to10 µs is possible.

2.2 SENSOR GEOMETRY AND CURRENT MEASUREMENT

Applied high-frequency high-voltage causes power losses due to high electric field (ionisation, charging particles etc.) as well as current flow to all grounded components. Furthermore this current is influenced by the magnetic field of the interrupted kA- current. These effects are regarded by experimental tests before. The figure, the distance, the diameter and the position of electrodes were varied systematically. It becomes apparent that the ground electrode is encased by a shield-ring to minimize leakage current, see Fig. 2 and Fig. 1. Without shielded electrode the measured sensor current at the same applied voltage is twice as high. In Fig. 2 the left electrode is connected to the high-frequency high-voltage, the right electrode is grounded. The electrical equivalent circuit of the cross section of the circuit breaker, with the sensor and the equivalent circuit is shown in this picture.

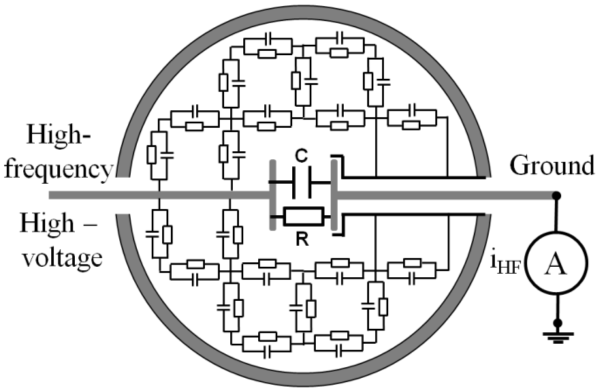

Fig.2: Sensor and interruption unit environment: electrical equivalent circuit

The relation between applied voltage, measured current, frequency and the sensor capacity given by

$$I_{HF} = 2 \cdot \pi \cdot f \cdot U_{HF} \cdot C$$

is to verify. It allows detection of minimal changes of sensor geometry before or after tests, mainly caused by transient high forces and or mechanic vibrations. The high frequency of the voltage U_{HF} leads to a relatively high current I_{HF}, so that current changes are detected with high sensitivity. Using a 50Hz-high-voltage source is impossible. The measuring line from ground-electrode to the high resolution current transformer (Pearson principle, 10mV/1mA) as well as the current transformer itself is shielded. Comparison between the calculated current I_{HF} and the measured capacitive current results a maximal derivation in the range of 1%.

2.3 VOLTAGE MEASUREMENT

The measurement of high-frequency high-voltage to ground is realized directly above the coaxial high voltage bushing witch leads the kHz-voltage into the interruption unit, see Fig.3. It was the aim to minimize the capacitive load of the voltage divider, to measure voltage signals with a high resolution, to prevent partial discharges as well as capacitive heating of solid materials due to the medium-frequency electric field. Due to the positions of the divider the influence of the magnetic field caused by the interrupted current is minimized.

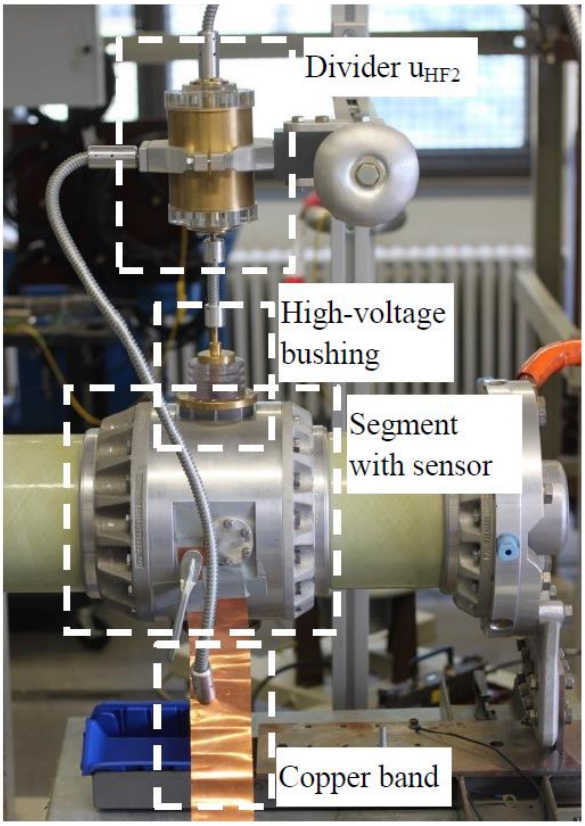

Fig.3: Specified SF_6 voltage divider and shielded Pearson Monitor (current transformer)

2.4 HIGH-FREQUENCY HIGH VOLTAGE GENERATOR

The high-frequency high-voltage generator, with maximum voltage amplitude of 70kV and frequency in the range of 1kHz to 50kHz is an elementary component of the measurement system.

The function of the high-frequency high-voltage generator is based on the resonance principle, and is described in [2].

The resonance principle offers the following advantages:

- constant sinusoidal output voltage (required for the complex calculation),

- enough power for the required current and voltage,
- power, necessary for a high resolution of the sensor current,
- automatic limitation of the current in the case of shorted electrodes due to leaving resonance point.

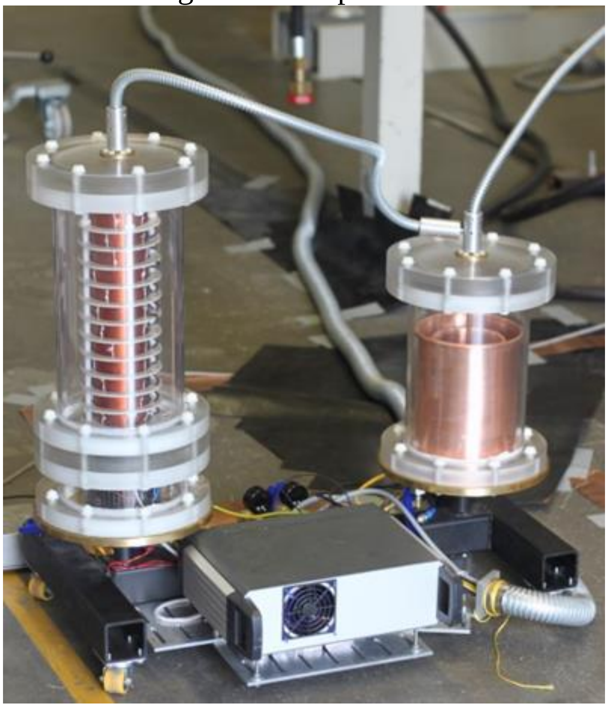

Fig.4: High-frequency high-voltage generator

The electromagnetic compatibility of the generator was improved especially by magnetic field of a conducted 40kA current over the closed contact system of the circuit breaker. So the influence of the magnetic field was nearly completely avoided due to appropriate arrangement of the measurement connections and measuring devices and by shielding.

2.5 TEST SETUP

Fig. 5 gives an overview of the whole test setup and the modified SF_6- selfblast circuit breaker as well. The distance between the horizontal positioning circuit breaker pol, the kHz-high-voltage-generator and signal transducer is caused by the influence of the magnetic field of interrupted fault current. For transmission of measurement signals to the optic-electric transducer the bypass-technique is applied. Further the measurement system has an own low-impedance ground (copper band), which is separated from the ground pole of the circuit breaker.

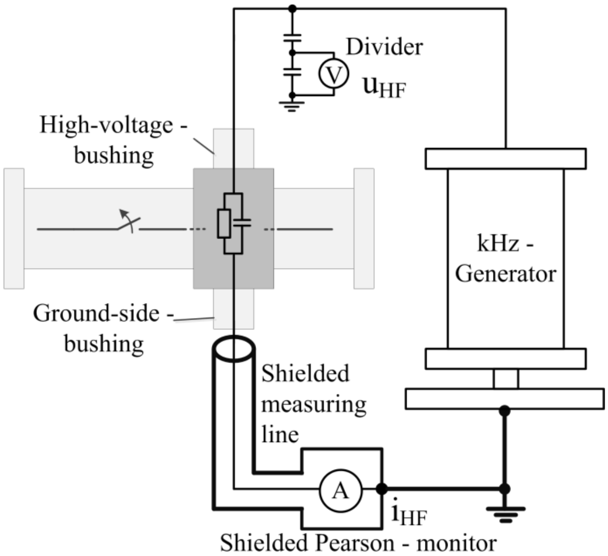

Fig.5: Measurement arrangement and the modified original SF_6- circuit breaker

For positioning and isolating sensor electrodes an adapter with isolators is constructed as a part of the gas tube. Gas flow simulations were done to optimize position of sensor electrodes concerning interaction between gas flow and electrodes.
The interrupted current up to 40kA was realized by a Weil-Dobke circuit.

3 TEST RESULTS

First fault current interruption tests have had the aim to improve the shielding, to find out limits of conductivity measurement and at last to get confidence to the measuring principle and the experimental setup.
Fig. 6 shows an exemplary diagram of measured signals and the calculated electrical conductivity. In this example, the contact separation takes place at t = 0. At a time of t ≈ 16ms the sensor registers hot gas or more specifically, an increase in the electrical conductivity. At the time t ≈ 17.5ms a large increase in the electrical conductivity took place.
From Fig. 6 becomes clear that with the presented measuring principle a time-resolved measurement of the electrical conductivity of the gas in the real SF_6-circuit breaker is possible. The interrupted current and switching angle have been varied systematically. Fault currents up to 40kA were switched. Thus, the potential field of application of the measurement method and the sensor could be determined. In the course of investigations it became clear

that contamination of the sensor after a few switching tests does not affect the function of the measuring arrangement. Fig.7 show an example of polluted sensor plates after a few switching tests.

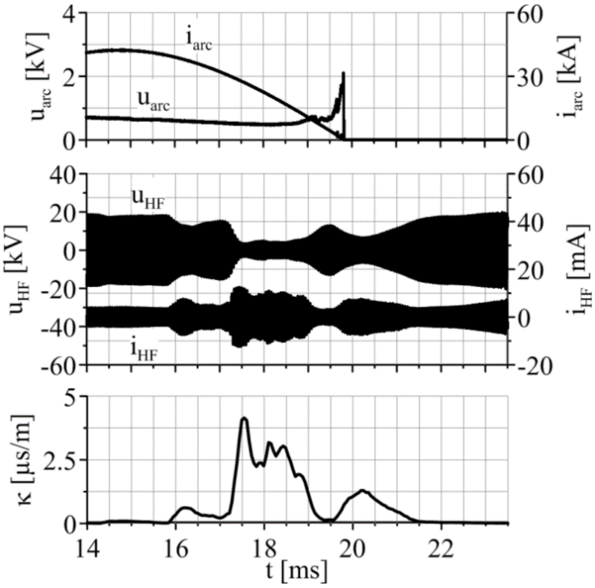

Fig.6: Example of measured signals and the calculated electrical conductivity

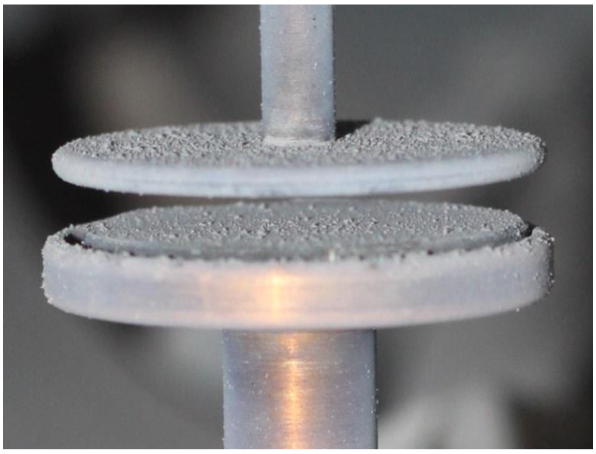

Fig.7: Polluted sensor after a few switching tests

The repetition of tests at the same circuit parameters shows a good reproducibility of the measured time curve of the electrical conductivity (see Fig.8). From the time-resolved conductivity measurements information about the time of gas flow, the speed and the temperature decrease can be derived. The repetition of tests at the same circuit parameters shows a good reproducibility of the measured time curve of the electrical conductivity (see Fig.8). From the time-resolved conductivity measurements information about the time of gas flow, the speed and the temperature decrease can be derived.

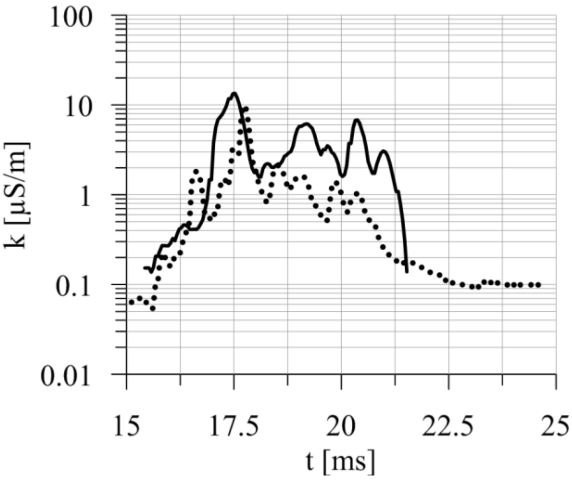

Fig.8: Determined electrical conductivity from two measurements with the same circuit parameters

4 CONCLUSIONS

Realization of a new measurement principle to determine time dependent electric conductivity of hot gas flow in original SF_6- circuit breaker is only possible due to a combination of the kind of generating, measuring and post processing electric signals. Experimental experiences with the influence of the magnetic field of an interrupted current up to 40kA to the measurement system were made to prevent coupling by optimized shielding of the measurement arrangement.

With the measurement of electric conductivity of hot gas the verification of CFD-simulation data as well as better understanding of arc extinction process is possible. Here the derived time dependent electric conductivity from the sensor behind the pin is presented. The derived values are in the range from 0,1 up to 12µS/m. Interpretation of the time-resolved conductivity measurements allow a view about the velocity of hot gas and the development of gas temperature at the position of the sensor. Further an indication of re-ignitions is possible.

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