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Investigation on the current-zero characteristic of vacuum circuit breakers

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ABSTRACT

The current-zero characteristic of vacuum circuit breakers (VCBs) has an important influence on the dynamic dielectric recovery and the success of the breaking test. In the paper, the characteristic of the post-arc current, post-arc charge and the post-arc conductance at current-zero is researched to obtain the influence of the arc memory on the current-zero characteristic and the post-arc characteristic. Based on the synthetic test circuit, the test plat of the current-zero characteristic is set up and the test VCB is a transparency vacuum interrupter in order to observe the development and extinguishing process of the vacuum arc by the high speed CMOS camera. The distribution law of post-arc characteristic is gained by measuring and processing the post-arc current. The relationship between the post arc charge and the final position of last cathode spot is investigated. The current-zero characteristic of VCBs supply the base for controlling vacuum arc, improving the breaking capacity, which maybe also useful to VCBs with multi-break.

1. Introduction

The VCB is widely used in the medium voltage because of the superior extinguishing ability and the high dielectric recovery strength. However, it is difficult to extend VCBs to high voltage level be limited by the saturation effect which is that the breakdown voltage increases slower even remains unchanged with the increase of the vacuum gap [1]. The current-zero characteristic of VCBs is a key factor to improve the breaking capacity and voltage distribution of multi-break VCBs [2,3].

The current zero characteristic mainly includes the residual plasma in current-zero, the temperature distribution of the anode surface and the post-arc characteristic which is composed of the post-arc current, post-arc conductance and the post-arc charge. There have been a lot of researches on current-zero characteristic. The post-arc sheath growth model is always used to analyze the dynamic dielectric recovery strength as shown in Fig. 1 [4]. At current zero, the residual plasma is composed of ions and electrons, which is electroneutral. The ions continue to move towards the anode because of their inertia while the electrons can adapt their speed immediately as the electric field is applied. As shown in the Fig. 1, the electrons reduce their speed to zero and then reverse the direction while the transient recovery voltage (*TRV*) is almost zero in this phase. In the second phase, the electrons move towards the new anode and leave an ionic space charge sheath behind. The *TRV* is mainly applied across the sheath. At the third phase, the electrical current drops because that all the electrons have been absorbed by the new anode and the ions current caused by the *TRV* can be negligible [5,6]. The sheath expansion is simulated by a 1D hybrid model of the non-equilibrium post-arc plasma and cathode sheath coupled with a direct simulation Monte Carlo method [7]. The 2d3v model of sheath expansion is established the post-arc decay process [8]. The influence of the electron density and ion temperature on the sheath expansion is investigated by the particle in cell (PIC) simulation [9]. In all of the above simulation, the initial residual plasma and temperature, which is influenced by the arc memory, is set a certain value. The arc memory is the effect of the vacuum arc (including arcing time, arc current, plasma density and temperature) on the current zero characteristic such as the residual plasma, surface temperature of the electrodes, post-arc resistance and the dielectric recovery strength. So the relationship between the arc memory and the current-zero characteristic is needed to be further researched. In the experimental aspect, the distribution of the electron density is gained by the Langmuir probes [10]. The residual plasma is measured by the retarding field analyzer (RFA). The post-

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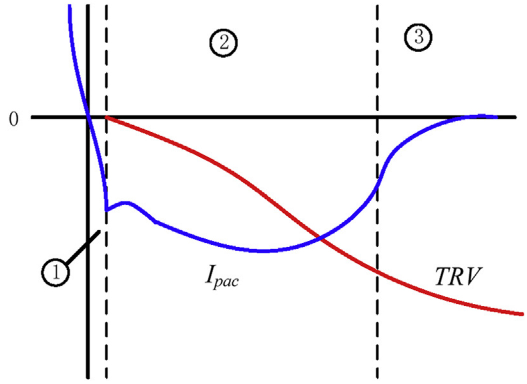

Fig. 1. The post-arc current in VCBs.

arc charge is varied from 9 to 31 μC [11]. The decay process of the anode surface temperature is also researched to gain the optimal magnetic control. The post-arc characteristic such as the post-arc current and charge is always used to indicate the breaking capability of VCBs [12,13].

In conclusion, there are a lot of researches on the current-zero characteristic in previous works. However, there are little researches on the relationship between the arc memory and the current-zero characteristic and the influence of the current-zero characteristic on the post-arc characteristic. In this paper, the test plat is set up to investigate the distribution of the post-arc characteristic by processing the post-arc current. The arc photos are observed by the high speed CMOS camera to analyze the arc memory to the current-zero characteristic such as the post-arc charge. The influence of the final position of the last cathode spot on the post-arc characteristic is obtained.

2. Test configuration

As shown in Fig. 2, the test plat of current-zero characteristic in synthetic circuit is composed of the synthetic test circuit, measuring equipment, the test VCB and the high speed CMOS camera. The maximum capacity of the synthetic test circuit is 110kV/50 kA. The current source consists of L_i and C_i while the voltage source is composed of C_v and L_v. The closing circuit breaker CB is used to introduce the main current while the triggered switch G is used to introduce the high *TRV*. The post-arc current measure equipment is composed of *VI*, R_{sh}, *SG* and CT_1, which is designed and verified in our previous researches [14,15].$P_{t1,}$ is used to measure the *TRV* while CT_2 is Rogowski Coil which is used to measure the main current. The VCB is drove by the permanent magnet actuator (PMA) and the vacuum interrupter is transparent in order to observe the development of the vacuum arc by the high speed CMOS camera.

The post arc current is measured by the PACME which is composed of the VCB, protective gap *SG*, the shunt resistor R_{sh} and CT_1. As shown in Fig. 3, the VCB is composed of the upper terminal, transparent vacuum interrupter with observing window, the lower terminal, the insulating rod, the PMA and the controller. The detailed parameters can be found in our precious researches [31]. The breaking current is 20 kA while the rated voltage is 10 kV. The high-precision current sensors CT_1 is Tektronix current probe TCP202 whose measuring range, bandwidth and precision is 50 A, 50 MHz and 1% respectively. The resistance of the shunt resistor is 448 mΩ and the maximum current of the shunt resistor is about 30.84 A.

The post-arc current is measured and the vacuum arc photos are observed when the test condition is shown in Table 1. The post-arc conductance and charge can be gained by the formula (1) and (2). The transparent vacuum interrupter is 10kV/20 kA and the contacts are in AMF configuration. The main current is varied from 0 to 15 kA while the *TRV* is 0–22 kV. When the main current and the *TRV* is 10 kA and 22 kV respectively, the influence of the arcing time on the post-arc characteristic can be gained. In the condition that the main current and the arcing time are 22 kV and 5 ms respectively, the influence of the main current magnitude on the post-arc characteristic can be obtained. The entire above test is repeatedly conducted in order to gain the distribution law of post-arc characteristic in different condition.

$$G_t = \frac{i_{pac}}{U_{TRV}} \tag{1}$$

$$Q_{pac} = \int_0^t i_{pac}\mathrm{d}t \tag{2}$$

3. Experimental result and analysis

3.1. Post-arc characteristic

In the condition that the main current and the *TRV* are 10 kA and 18 kV respectively, the interrupting test is shown in Fig. 4. The *du/dt* of the *TRV* is 4.5 kV/μs. The period of the half sine-wave is about

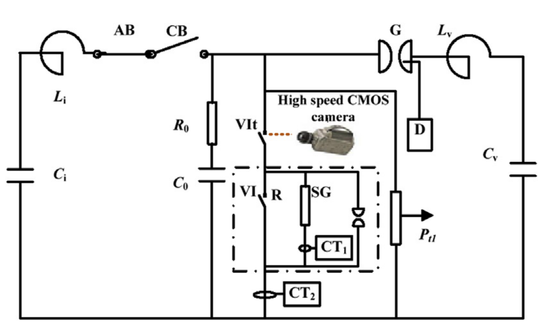

Fig. 2. The test plat of current-zero characteristic in synthetic test circuit.

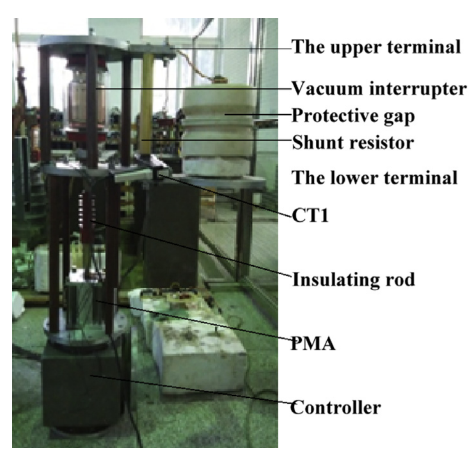

Fig. 3. Prototype of the novel post-arc current measurement equipment (PACME).