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Study of Post-Arc Plasma Behavior in an AC Circuit Breaker

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Abstract

In the search to obtain a better understanding of switching arc phenomena in the current interruption, our attention has been focused on the study of arc plasma behavior in the alternative current circuit breaker. In this paper a comparison between interruption capability of sulfur hexafluoride (SF_6) and nitrogen (N_2) ballast arcs are made and we present physical aspects and characteristics of arc plasma specially plateau variation of the post-arc current near the interruption limit that have been investigated in experimental measurements with a gas mixture of sulfur hexafluoride (SF_6) and nitrogen (N_2).

Keywords:

circuit breaker, post-arc current, sulfur hexafluoride and nitrogen, transient recovery voltage, rise of recovery voltage

1. Introduction

When interrupting an alternating current, an electrical arc is initiated between the contacts of a breaker. The different basic limits exist which determine the breaking capacity of a circuit-breaker that they have many industrial applications [1].

The study of arc in a circuit- breaker enables us better understanding of the main parameters which successful breaking depends on. If arc cooling to be sufficiently enough, the electrical conductivity in inter-electrode space will become so slight that the current will tend towards zero, even when the applied voltage is considerable [2].

Immediately after current zero, the transient recovery voltage (TRV) drives a post-arc current through the remains of the decaying arc plasma resulting in a heating effect. The energy balance between this heating and cooling effects either results in a: decay of the plasma and an interruption of the current, or in a reheating of the gas to a well-conducting arc column, which is termed "thermal reignition" [3]. Measuring the current form close to zero is a very helpful diagnosis and in this paper we present results of arc behavior according to use of a particular device that has been developed for this reason before [4].

2. Device Principal and Experimentation

As a requirement, a device that its mechanical principle is based on Eddy current effect and insert a high value shunt in series with the circuit-breaker has been developed and was used for measuring current according a new method. The shunt does not disturb the circuit, because its insertion is just in the vicinity of zero current for a short period at the time chosen for measurement (when the current approaches zero). This duration is adjustable, can varies and be controlled by a very accurate electronic unit during the breaking period.

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This unit operation is linked with zero current.

Immediately after zero is reached, the shunt is shorted again and will be out of the circuit and in the event of a failure to break, the full current wave will not flow through it [5]. The device also has been tested on a rotating arc gas circuit-breaker.

In order to study the behavior of a gas mixture of SF_6 and N_2 as an interrupting gas a series of experiment was carried out using a rotating arc circuit breaked, and the peak voltage and current were 4 kV/11 kA, respectively. Measuring of current by high value shunt in series with the power circuit of the above characteristics was done and typical recorded results are shown in Figs. 1–3 [6]. For comparison results of pure SF_6 and N_2 is added.

3. Physical Aspects and Discussion

SF_6 and N_2 are the two most commonly used working gas ballast arcs in high voltage circuit breaker. Since experiments in this field are difficult and costly matter, usually mixture of SF_6 and N_2 is used. Successful current interruption in N_2 is illustrated in Fig. 1. The post-arc current with its amplitude (> 4 Amps.) is clearly apparent and finally reaches to zero (after ~ 15 μsec).

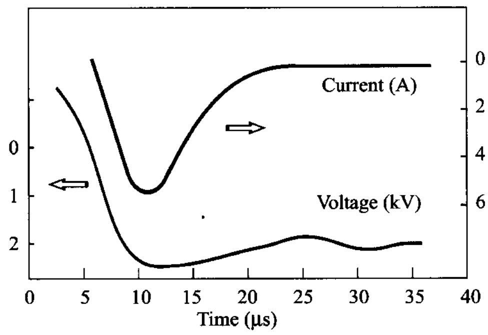

Fig. 1 Interruption in N_2. $P = 4$ bars

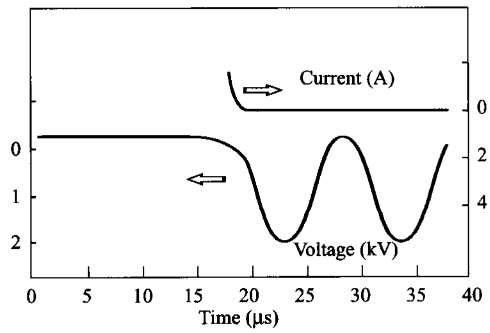

Fig. 2 Interruption in SF_6. $P = 2$ bars.

In Fig. 2 recorded current and voltage for successful current interruption in SF_6 is shown. We can see that the both voltage and current reach zero simultaneously, and the circuit breaker performs the current interruption without any post-arc current. The test condition was to keep the opening phase angle the same in two cases. The reason for different interruption cases that were observed in Fig. 1 and Fig. 2 is due to different characteristics of these two gases. Molecular dissociation temperature is about ~ 7500 K for N_2 and ~ 2500 K for SF_6 and as long as an electric current goes through the plasma, the radial temperature profile peresents a plateau value around the dissociation temperature, dividing arc into a hot core and peripheral region having low thermal and electrical conductivities.

When the current reaches zero, the temperature profile become transformed as follows: rapid cooling of the central zone as long as the temperature is greater than dissociation temperature, followed by much slower cooling [7]. Relatively low dissociation temperature in SF_6 permits gas to conserve its time constant for a long time until complete disappearing. We can evaluate arc time constant by the below equation:

$$\frac{1}{\tau} = -\frac{1}{G} \cdot \frac{\mathrm{d}G}{\mathrm{d}t} \tag{1}$$

that τ is arc time constant and G is electrical conductance. In Fig. 1 post-arc current with relatively large amplitude (more than 4 Amps) is due to large arc time constant in N_2 and because of good thermal conductivity of gas (for high temperature equivalently some Amps) reaches zero. But successful interruption in SF_6 dose not permit measuring of a post-arc current, because of very low amplitude (low temperatures). Threrfore in a moment gas pass through from conductivity to non-conductivity. In case of SF_6 existence of a very low arc time constant in the vicinity of current zero can justify instant zero reaching of current.

Figure 3 shows a random behavior of gas mixture of SF_6 and N_2 [%75 and %25] that it may be the same as pure SF_6 (Fig. 3(a)) or causes successful interruption with an important post-arc current (Fig. 3(b)) or failure of interruption (Fig. 3(c)). The current curve in Fig. 3(b) shows a plateau variation that this behavior is not predicted by semi-empirical conductance methods. It must be noted that the post-arc current is due to recovery voltage applied to a medium having a residual conductance (the decaying plasma). The plateau in the post-arc current is related to closing rate of rise of recovery voltage (RRRV) to its maximum value (limit

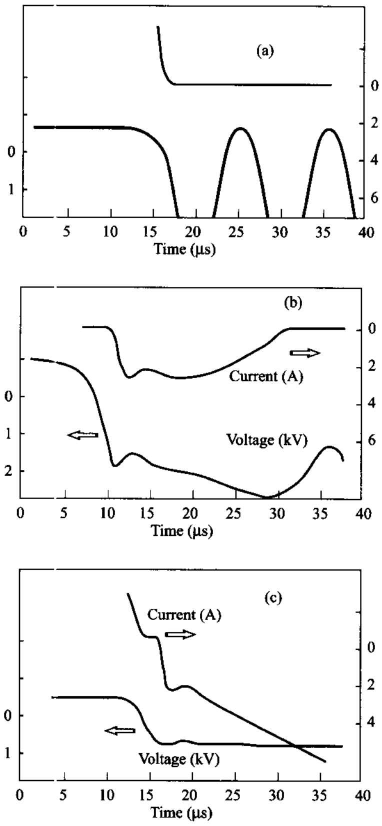

Fig. 3 Interruption in a mixture of SF_6 and N_2 gas (%75/%25). (a) Interruption without post-arc current, (b) Interruption with post-arc current and plateau variation. (c) Reignition. $P = 2$ bars N_2 and $P = 1$ bars SF_6, Circuit: 4 kV/11 kA.

RRRV). From Fig. 3(b) it also can be seen that the post arc current lasts for several tens of microseconds (~ 20 μsec) with a peak intensity of greater than 2 Amps. Where as in pure SF_6 this duration has been observed of the order of few microseconds [8] and in pure N_2 also of the order several tens of microseconds (~ 15 μsec Fig. 1).

These disagreements in behavior is due to differences in the cooling rates of the two gas, mainly due to turbulence. Turbulent mixing is a "necessary cooling mechanism" in order to understand the observed interruption behavior of SF_6 and N_2 gas in the our experimental works.

4. Conclusion

In this study recorded post-arc current measurement results have been illustrated and described. The amplitude and the duration of the post-zero current is greater for N_2 and gas mixture of SF_6 and N_2 than for pure SF_6. This is due to differences in the cooling rates of this two gases mainly due to turbulence. Also a plateau region in the case of gas mixture of SF_6 and N_2 was recorded. More longer plateau is equal to more probability of reignition or in other words such post-arc current inject an input energy that exceeds the energy loss by cooling mechanism. There is a competition between joule heating due to conduction, convection and turbulence.

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