NEW APPROACH TO PREDICT SHORT-LINE-FAULT INTERRUPTION PERFORMANCE IN HIGH VOLTAGE CIRCUIT BREAKER

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ABSTRACT

It is discussed for the feasibility of performance prediction of Short-line-fault (SLF) interruption using the combined simulation of computational fluid dynamics (CFD) analysis and the circuit analysis with mathematical arc models.
The mathematical arc model of serially connected 3 arc model is able to reproduce the interruption performance of SLF when arc parameters are set so that the calculated result agree with the measurement for the amplitude and the period of extinction peak.
The extinction peak for every type of GCB exists at around 100A under the condition of 63kA-50Hz-90% SLF interruption. If the extinction peak at around 100A could be obtained by CFD analysis, therefore, the interruption performance of SLF will be predicted using the circuit analysis with mathematical arc models. This means that it is not necessary to calculate the arc discharge of tiny current under several tens of amperes by the CFD analysis in order to evaluate the SLF performance.

1. INTRODUCTION

Gas circuit breakers (GCBs) filled with SF_6 gas have been used for high voltage power transmission systems, due to their excellent dielectric characteristic and arc extinguishing ability. The development of GCBs has been conducted by using computational fluid dynamics (CFD) analyses. Such analyses help researchers and designers predict the current interruption performance, which is expected to decrease in time and cost of GCB development. However, it is difficult to calculate the success or failure of current interruption performance directly by CFD analyses, because the tiny residual current around current zero should be simulated in detail.
There is a circuit analysis using mathematical arc model in order to predict the short-line-fault (SLF) interruption performance. The simulation with the mathematical arc model, however, requires some arc parameters which derived from the configuration of GCB and interrupting conditions. In general, the arc parameters are set so that the measurement of interrupting test and circuit analysis agree on the arc voltage waveforms. Therefore, the circuit analysis with the arc model cannot predict the interruption performance of GCB which the interrupting test has not conducted with.
In this study, we discuss the feasibility of performance prediction of the SLF interruption using the combined simulation of CFD analysis and circuit analysis with mathematical arc model.

2. PERFORMANCE PREDICTION USING MATHEMATICAL ARC MODEL

Following equations show the arc models which are proposed by Cassie [1] and Mayr [2].

Cassie model

$$\frac{1}{g}\left(\frac{dg}{dt}\right)=\frac{1}{\theta_c}\left(\frac{v^2}{v_0^2}-1\right) \qquad \dots (1)$$

Mayr model

$$\frac{1}{g}\left(\frac{dg}{dt}\right)=\frac{1}{\theta_m}\left(\frac{vi}{P}-1\right) \qquad \dots (2)$$

where g is the arc conductance, v is the arc voltage, i is the current, θ_c is the Cassie model arc time constant, v_0 is the arc voltage in a large current period, θ_m is the Mayr model arc time constant and P is the Mayr model arc power loss.

The Cassie model can simulate an arc in a large current period and the Mayr model can simulate an arc around current zero. In general, arc parameters of θ_c, v_0, θ_m and P are set so that the measurement of interrupting test and circuit analysis agree on the arc voltage waveforms.

Figure 1 shows the measurement results of arc voltage and current for the 300kV double flow type model gas circuit breaker. The measurement conditions are the interruption current of 63kA-50Hz–90% under various arcing times. The current and arc voltage are measured using a Rogowski coil and a voltage divider installed near the model GCB. Figure 2 shows an example of the waveform resulting from calculation using the serially connected 2 arc model analysis which is the combination of the Cassie model and the Mayr model. The analytical condition is the case-C of Fig. 1. The arc parameters of arc models are set so that the measured and calculated arc voltages are identical [3].

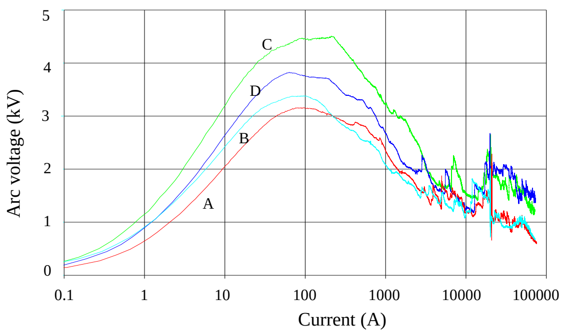

Fig. 1 Relation between arc voltage and current for the 300 kV double flow type GCB (63kA-50Hz-90%) A: failure, B, C and D: success

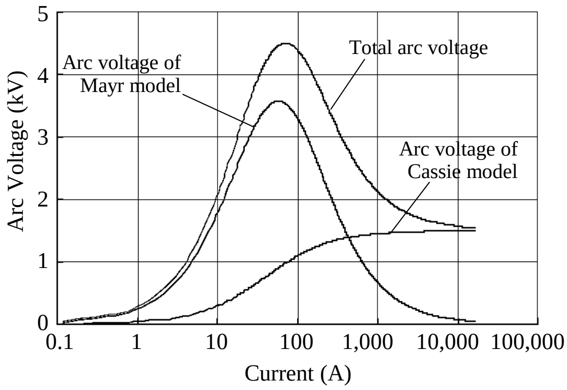

Fig. 2 Example of waveform resulting from calculation in the case-C of Fig. 1 : interruption failure (θ_c=2.5μs, v_0=1.5V, θ_m=1.6μs and P=950kW)

It can be found from Fig. 1 and 2 that there is no significant difference between the measured and the calculated arc voltages around the extinction peak. However, the decay process of measured and calculated arc voltages from the extinction peak to the current zero differs from each other. In spite of successful for the interruption test in the case-C of Fig. 1, the current interruption of calculation in Fig. 2 failed.

If the arc time constant of Cassie model is reduced, the decay process of calculated arc voltage from extinction peak to current zero corresponds to the measured arc voltage. The interruption success or failure, however, does not agree with the result of measurement [3]. This indicates that the arc of GCB cannot be simulated using one Cassie model and one Mayr model connected serially during the period from the extinction peak to the current zero.

Authors [3, 4] proposed to connect 3 arc models (Cassie model and two types of Mayr model) in series in order to reproduce the phenomena around current zero in detail. Two types of Mayr model have different arc parameters. One is used as a model for simulating around extinction peak of arc voltage, which is defined as Mayr model-1. The other is used as a model for simulating just around the current zero, which is defined as Mayr model-2.

Figure 3 depicts the waveform obtained from the calculation of serially connected 3 arc model analysis. The analytical condition is the case-C of Fig. 1. Not only around extinction peak near 100 A, but also the decay process of calculation from extinction peak to current zero come close to the measured value. Furthermore, the success of interruption test in the case-C of Fig. 1 can be reproduced by the serially connected 3 arc model analysis. Then, the arc time constant of Mayr model-2 is set to 10 % of that of Mayr model-1, and the arc power loss of Mayr model-2 is set to 2 % of that of Mayr moel-1 so that the measured and calculated arc voltages from the extinction peak to the current zero are identical.

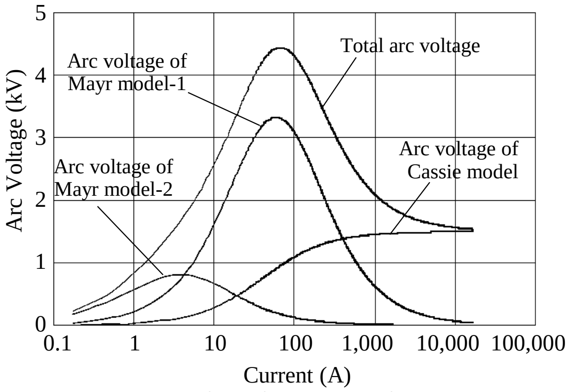

Fig. 3 Example of waveform resulting from calculation in the case-C of Fig. 1: interruption success (θ_c=2.5μs, v_0=1.5kV, Mayr-1: θ_{m1}=1.6μs, $P1$=950kW and Mayr-2: θ_{m2}=0.16μs(10% of θ_{m1}), $P2$=13.6kW(2% of $P1$))

Figure 4 shows a comparison of interruption successful or failure between the measurement and calculated results under the condition in Fig. 1. These results are expressed in terms of the relationship between the arcing time and the extinction peak of arc voltage. Success or failure of every interruption tests can be reproduced by the serially connected 3 arc model analysis.

It should be noted that only arc time constant and arc power loss of Mayr model-1 are adjusted in order to match the amplitude and period of extinction peak of arc voltage in every case. The arc voltage in large current period v_0, the arc time constant of Cassie model θ_c and the ratio of arc parameters of Mayr model-2 to parameters of Mayr model-1 are set as a constant value in every case.

If the amplitude and period of extinction peak are obtained, the whole waveform of arc voltage is not needed in order to predict the interruption performance using the serially connected 3 arc model analysis.

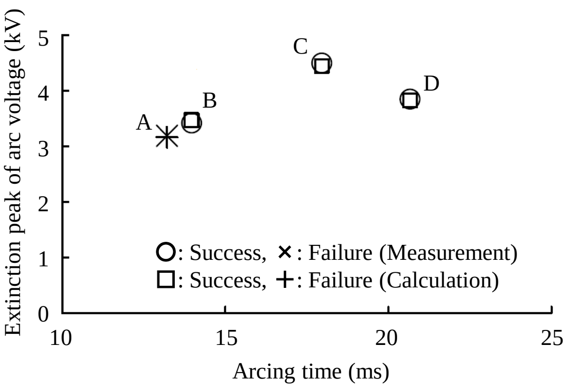

Fig. 4 Comparison of extinction peak between measurement and calculated results for 300 kV double flow type GCB (63kA-50Hz-90% SLF interruption)

3. ARC TIME CONSTANT AND ARC POWER LOSS OF MAYR MODEL

It is important for the calculation of SLF interruption that arc parameters of Mayr model are decided, because the Mayr model simulates the arc around current zero.

Figure 5 shows the arc time constant of Mayr model by the calculation[4] from measured voltage-current waveforms for the 300 kV double flow type GCB and 550 kV hybrid puffer type GCB. The arc time constant just before current zero at several amperes is around 0.1 to 0.2μs, which corresponds to the arc time constant of Mayr model-2 in Fig. 3. It is reasonable that the arc time constant of Mayr model-2 is set to 10 % of that of Mayr model-1. Furthermore, arc time constants from the extinction peak around 100 A to the just before current zero at several amperes are almost the same for both type of GCB.

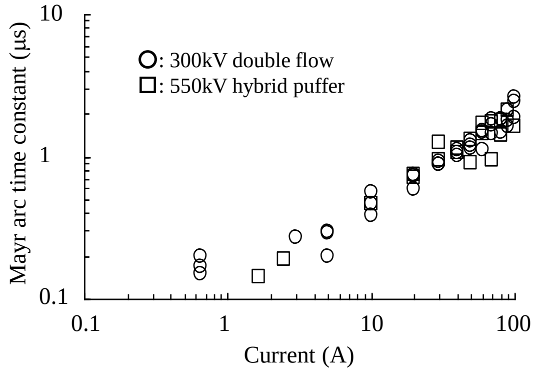

Fig. 5 Arc time constant of Mayr model for 300kV double flow type GCB, and 550kV hybrid puffer type GCB (63kA-50Hz-90%).

Figure 6 shows the measurement results of arc voltage and current for the 550kV hybrid puffer type model gas circuit breaker, and Figure 7 illustrates the measurement results for the 300kV tandem puffer type model gas circuit breaker. The measurement conditions are the interruption current of 63kA-50Hz–90% under various arcing times. It can be found from Fig. 6 and 7, arc voltages under the condition of every arcing time and every type of GCB become highest at the current of around 100 A under the condition of 63kA-50Hz-90%. These results correspond to the results of 300 kV double flow type model GCB in Fig. 1.

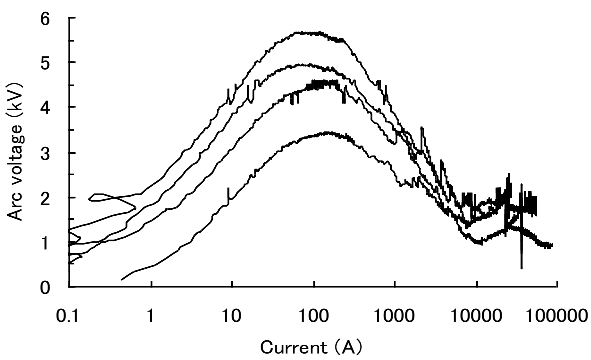

Fig. 6 Relation between arc voltage and current for the 550 kV hybrid puffer type GCB (63kA-50Hz-90%)

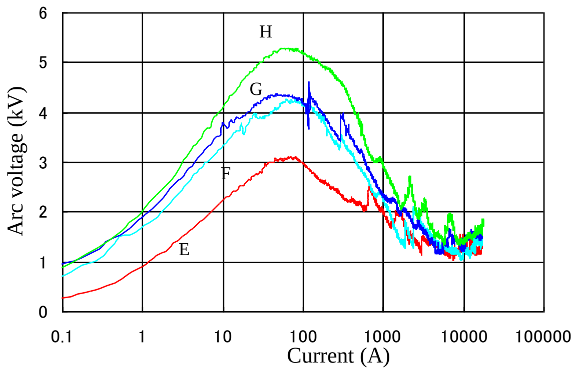

Fig. 7 Relation between arc voltage and current for the 300 kV tandem puffer type GCB (63kA-50Hz-90%)

Table 1 shows arc time constants using the serially connected 3 arc model analysis for the performance prediction in various types of GCB. The arc time constant of Mayr model-1 becomes the same value for every type of GCB, because the period of extinction peak exists at almost the same time in every types of GCB. It will depend on the condition of interruption current.

The arc time constant of Mayr model-2 can be decided as a constant without relying on the types of GCB.

It is required that the arc power loss of Mayr model-1 is adjusted in order to match the amplitude of extinction peak. The ratio of arc power loss of Mayr model-2, however, can be set to 2 % of Mayr model-1 under conditions of every type of GCB (300kV double flow, 300kV tandem puffer and 550kV hybrid puffer). The ratio of parameters of Mayr model-2 will depend on the gas properties.

Table 1 Arc time constants for various type of GCBs

	Cassie	Mayr-1	Mayr-2
300kV double flow	2.5 μs	1.6 μs	0.16 μs (10% of Mayr-1)
550kV hybrid puffer	1.95 μs	1.6 μs	0.16 μs (10% of Mayr-1)
300kV tandem puffer	1.5 μs	1.6 μs	0.16 μs (10% of Mayr-1)

If the period and amplitude of extinction peak around 100 A can be calculated by using the CFD analysis, the interruption performance of SLF can be predicted by the analysis of serially connected 3 arc model. This means it is not necessary to calculate the arc discharge of tiny current under several tens of amperes by CFD analysis.

4. CONCLUSIONS

It was examined for the feasibility of performance prediction of SLF interruption using the combined simulation of CFD and circuit analysis with mathematical arc models.

Serially connected 3 arc model analysis is able to reproduce the interruption performance of SLF when the arc parameters are set so that the calculated result agree with the measurement for the amplitude and the period of extinction peak.

The extinction peak for every type of GCB exists at around 100A under the condition of 63kA-50Hz-90% SLF interruption. If the extinction peak at around 100A could be obtained by CFD analysis, the interruption performance of SLF will be predicted using the circuit analysis with mathematical arc models. This means that it is not necessary to calculate the arc discharge of tiny current under several tens of amperes by the CFD analysis in order to evaluate the SLF performance.

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