EXPERIMENTAL STUDY ON CONCURRENT FLASHOVER PHENOMENA OF TWO PARALLEL LONG AIR GAPS

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ABSTRACT

The concurrent flashover characteristics of two parallel long air gaps are investigated. The gap lengths of the two gaps are the same and are set as 502, 798 or 1200 mm. The wave shape of applied voltage is the short-tail lightning impulse. The voltage between the two gaps and the currents flowing through grounding electrodes are measured using a resistive voltage divider and current transformers, respectively. The development processes of leaders are recorded using the image converter camera IMACON468 (Hadland Corp.).

1. INTRODUCTION

To protect an insulator string against lightning, arcing horns are installed on each phase of electric power transmission towers. When lightning strikes the top of a transmission tower, the potential of the transmission tower increases in a very short time because of the surge impedance and negative voltage reflection at the tower foot. Flashover of the arcing horn becomes an earth ground of an electric power line and leads to faulty electricity transmission.

The calculation methods of the breakdown characteristics of the single long air gap were developed to predict the flashover voltage and time of an arcing horn [1, 2]. However, in real situations, several arcing horns are placed on the same transmission tower, and the discharge processes of one arcing horn affect the others. Indeed, a concurrent flashover of arcing horns was observed at the Okushishiku test transmission line [3]. From the industrial viewpoint, it is desired to reveal the concurrent flashover phenomena and to develop a new method of calculating the concurrent flashover probabilities of long air gaps. In this study, the concurrent flashover phenomena of two parallel long air gaps are investigated. The gap lengths of
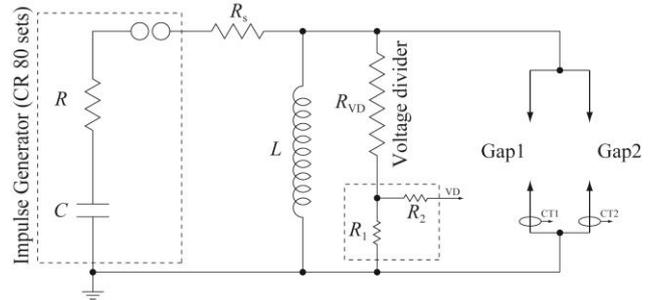

Fig. 1 Test circuit

Table 1 Circuit constant of test circuits and front and tail time length of generated voltage without test gaps.

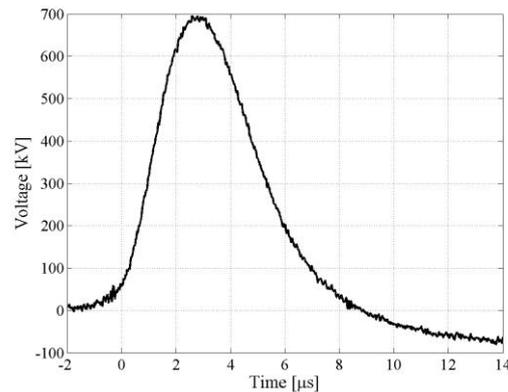| # of CR sets of I.G.	R_s [Ω]	L [mH]	R_{VD} [kΩ]	ΔT_{front} [μs]	ΔT_{tail} [μs]
80	600	2.8	15.88	2.3	5.1
40	600	2.8	91.10	1.4	4.4
20	400	1.2	91.07	1.4	3.3

Fig. 2 Output voltage of the CR 80 sets impulse generator without test gaps. Origin of time is the virtual zero time.

the two gaps are the same and are set as 502, 798 or 1200 mm. 502 and 798 mm are the minimum and maximum gap lengths of the arcing horns of 77 kV transmission lines, respectively. On the other hand, 1200 mm corresponds to the gap length of the arcing horns of 154 kV transmission lines.
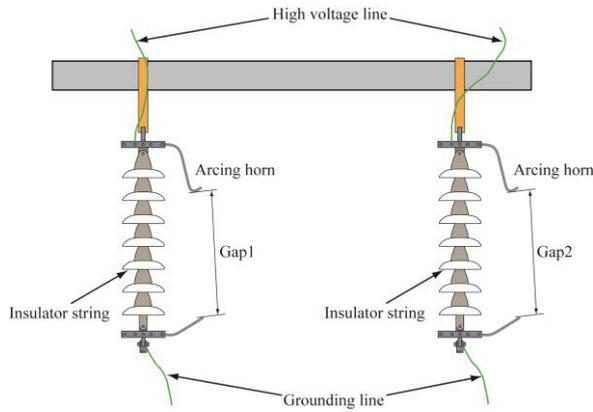
Fig. 3 Configuration of two parallel long air gaps, Gap1 and Gap2.

Table 2 50% Flashover voltage.

Gap length [mm]	Polarity	50% Flashover voltage V_{50} [kV]
502	Positive	432.6
502	Negative	- 433.7
798	Positive	645.6
798	Negative	-661.3
1200	Positive	857.9
1200	Negative	-846.9

Fig. 4 V-t characteristics.
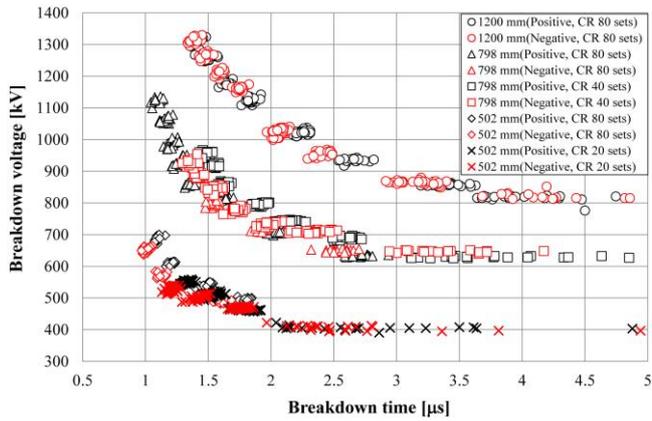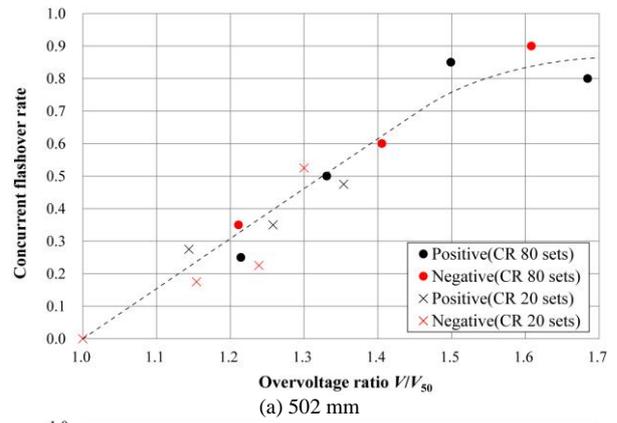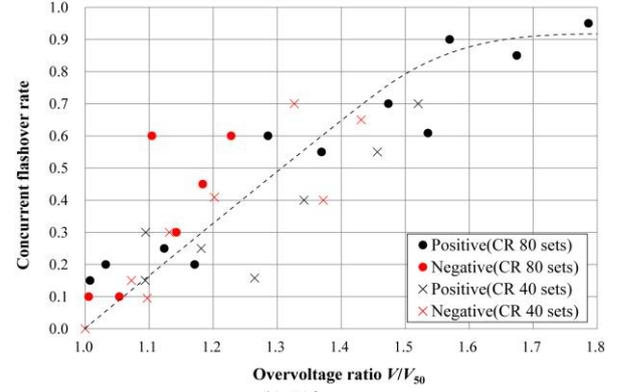

(a) 502 mm

(b) 798 mm

(c) 1200 mm

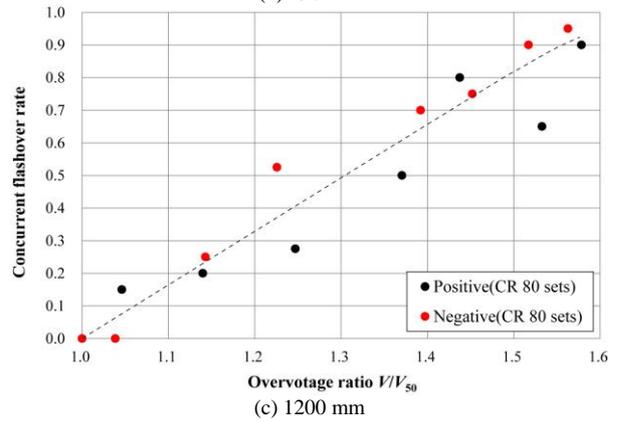Fig. 5 Concurrent flashover rates.

2. EXPERIMENTAL METHODS

Figure 1 shows the schematic of the test circuit used in the experiment. The impulse generator is a Marx-type circuit and consists of 80 sets of capacitances (C) and resistances (R). In this experiment, to decrease the output voltage of the impulse generator, 40 or 20 CR sets out of 80 are used appropriately. In the circuit, R_s is the adjustment resistance and R_{VD} is the resistive voltage divider. R_1 and R_2 ($<< R_{DV}$) are detection resistances for the voltage measurement. The configuration of the impulse generator is the same for generating the lightning impulse voltage except that an inductor L is used for generating the short-tail lightning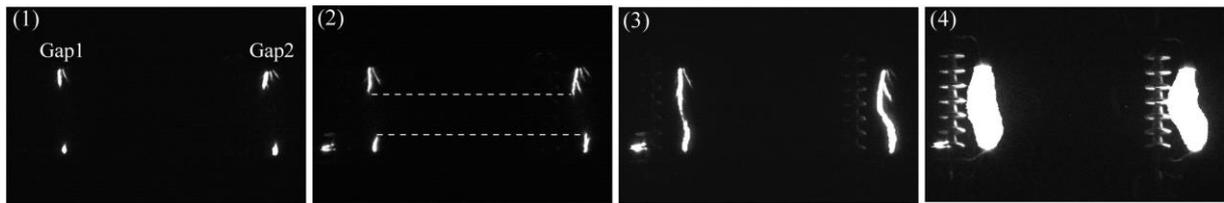 impulse voltage. The generated voltage is applied to two parallel long air gaps, Gap1 and Gap2. Currents flowing through Gap1 and Gap2 are measured using current transformers CT1 and CT2, respectively. Table 1 shows circuit constants, the front length ΔT_{front} and the tail length ΔT_{tail} of the generated voltage without test gaps. Figure 2 shows an example of the output voltage of the impulse generator using 80 CR sets without test gaps.

Figure 3 shows the configuration of two parallel long air gaps. The gaps consist of arcing horns and insulators. The leader development process, which is the preliminary phenomenon of flashover, is recorded using an image converter camera IMACON468 (Hadland Corp.).

(a) Voltage   (b) Current   (c) Current (expanded)   (d) still image
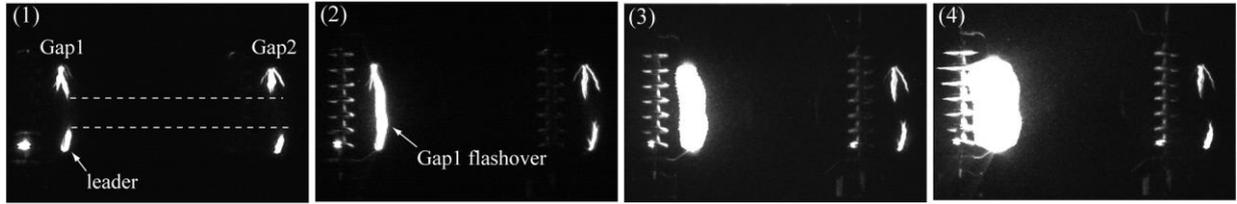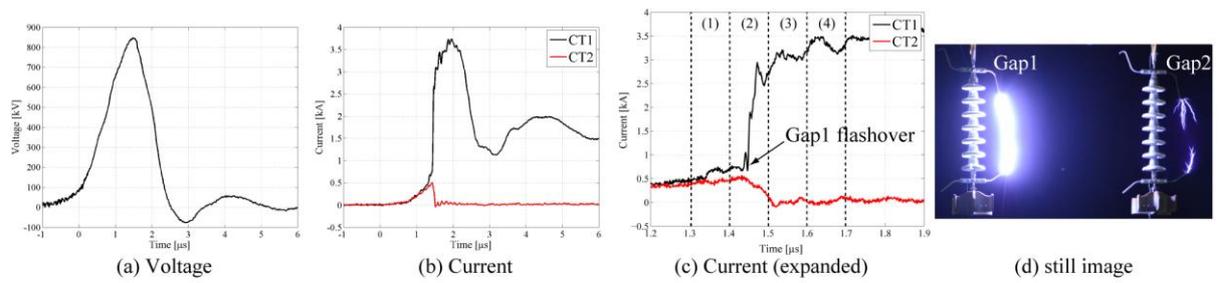
(e) IMACON468

Fig. 6 Observation result of one side flashover.

(a) Voltage   (b) Current   (c) Current (expanded)   (d) still image
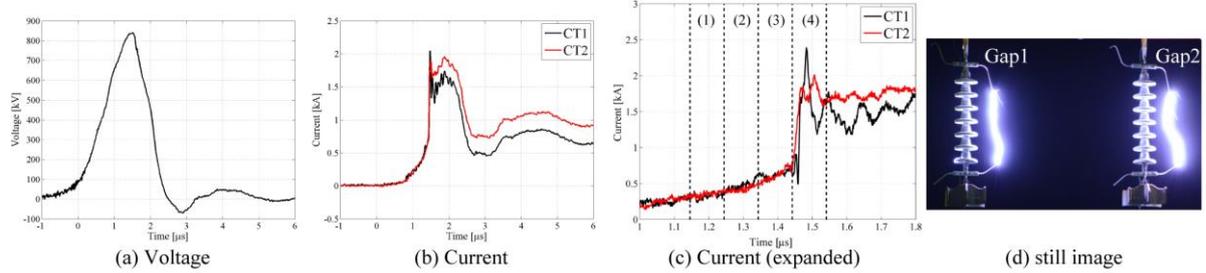
(e) IMACON468

Fig. 7 Observation result of concurrent flashover. Gap1 and Gap2 simultaneously flashover.

3. EXPERIMENTAL RESULTS

3.1 50% breakdown voltage and *V-t* characteristics

Table 2 shows the 50% breakdown voltage V_{50} of each gap length for both polarities. V_{50} is obtained by the up-down method and corrected with humidity and atmospheric pressure. V_{50} is approximately proportional to gap length and rarely dependent on polarity. Figure 4 shows V-t characteristics. For the long-breakdown-time region (> 2–3 μs), the breakdown voltage is almost constant because the tail length of the applied voltage is very small. Even with the same gap length and polarity, V-t curves slightly vary according to the configuration of the test circuits.

3.2 Concurrent flashover rate (probability)

Figure 5 shows the concurrent flashover rates of each gap length. To obtain the concurrent flashover rate, 20 or more voltages are applied to air gaps. The concurrent flashover rate is the number obtained by dividing the concurrent flashover times by the total flashover times (the sum of one-side flashover and concurrent flashover). The concurrent flashover rates are rarely dependent on the gap length and polarity. The concurrent flashover does not occur at V/V_{50} = 0 and reaches 80% at V/V_{50} = 1.5. The concurrent flashover rate is proportional to the overvoltage ratio from V/V_{50} = 0 to 1.5, and is saturated to about 90% over V/V_{50} = 1.5. The overvoltage ratio, in which the concurrent flashover rate reaches 100%, could not be obtained because of the maximum charging voltage restriction of the impulse generator.

These concurrent flashover rates are considerably different from the 3 m rod-rod air gaps [4]. In that electrode configuration, the concurrent flashover rate reaches 100% at V/V50 = 1.15.

(a) Voltage   (b) Current   (c) Current (expanded)   (d) still image
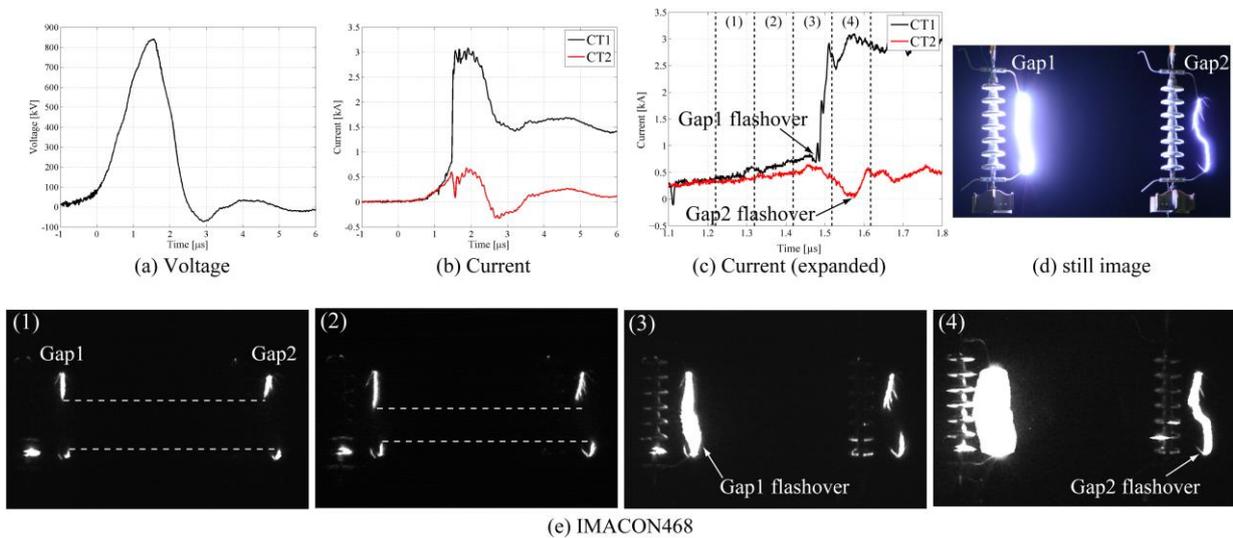
(e) IMACON468

Fig. 8 Observation result of concurrent flashover. Gap1 and Gap2 flashover with 100 ns time lag.

3.3 Observation of breakdown process using the image converter camera

Figures 6—8 show the discharge processes recorded with IMACON468. In each figure, (a) to (e) show applied voltage, currents, expanded currents at flashover point, still image and IMACON468 images, respectively. Four frames can be taken with IMACON468, and in this study, each exposure time frame is fixed to 100 ns. Time periods (1) – (4) divided by the dotted lines in (c) correspond to exposure times of frames (1) — (4) of IMACON468 shown in (e).

In figure 6, an observation result of one-side flashover is shown. In frame (1), the leader development occurs on both gaps, and the leader length and current of Gap1 are larger than those of Gap2. In frame (2), the leader of Gap1 bridges between the gap and the Gap1 flashovers. The current of Gap1 rapidly increases and the voltage between gaps starts to decrease. In frames (3) and (4), the leader of Gap2 does not propagate anymore, and the current of Gap2 decreases to zero. In figure 7, an observation result of no time lag concurrent flashover of gaps is shown. In frames (1) and (2), the propagation lengths and currents of both gaps are the same. In the end of frame (3), both gaps flashover and currents rapidly increase. Currents and light emission of arcs of both gaps are similar. In figure 8, an observation result of concurrent flashover with a 100 ns time lag of gaps is shown. In frame (2), the leader propagation length and current of Gap1 are larger than those of Gap2 and Gap1 flashover in frame (3). The process up to this point is the same as the case of the one-side flashover. In frame (4), the current of Gap2 increases again after it decreases once and Gap2 flashovers.

From these observation results, it is considered that the dispersion of the leader developments affects the concurrent flashover probabilities. The concurrent flashover, in which the time lag is longer than 100 ns, is not observed in this experiment.

4. CONCLUSION

Concurrent flashover phenomena of two parallel long air gaps are investigated for 502, 798 and 1200 mm. Concurrent flashover rates are dependent on the overvoltage rate. Flashover processes can be classified into three types: one-side flashover and concurrent flashover with and without time lag.

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