Paper

Experimental Considerations for the Dielectric Characteristics of Inhomogeneous High Temperature SF_6 Gas in a Gas Circuit Breaker

Member Toshiyuki Uchii (Toshiba Corporation)
Non-member Koichi Iwata (Toshiba Corporation)
Member Hiromichi Kawano (Toshiba Corporation)
Member Tetsuya Nakamoto (Toshiba Corporation)
Member Katsumi Suzuki (Toshiba Corporation)

The purpose of the present paper is to show the dielectric characteristics of inhomogeneous hot SF_6 gas in a dead-tank-type gas circuit breaker (GCB) experimentally. High-temperature and low-density SF_6 gas generated during a heavy current interruption is distributed inhomogeneously in the grounded tank, and can strongly threaten the dielectric capability of the GCB. Few studies, however, have been carried out on the dielectric characteristics of the inhomogeneous hot gas. Using small gap discharges, the hot gas behavior of a GCB model, having breakdown or no breakdown occurring, was investigated. As a result, it was found that there was little or no effect on breakdown voltages of the cool gas in the breakdown paths. This suggests that the breakdown voltage of inhomogeneous hot gas could be obtained as the applied voltage at which the electrical field strength equals E_{crit} of local hot gas at the concerned location.

Keywords: gas circuit breaker, dielectric breakdown, hot gas, inhomogeneousness, dielectric capability, small gap

1. Introduction

In a large-capacity gas circuit breaker (GCB), the current is interrupted by blowing SF_6 gas onto the conductive arc plasma generated between arcing contacts. The SF_6 gas blown onto the high-temperature arc then turns into a low-density hot gas, and is passed through an exhaust tube to a grounded tank. The dielectric capability of the hot gas is much lower than that of unheated gas. Thus, the behavior of the hot gas can strongly threaten the dielectric capability between the grounded tank and the high-voltage interrupting chamber of the GCB.(1)(2)(3) Recently, GCB units have been made increasingly compact, and the decrease in the dielectric capability due to hot gas has become an important engineering problem in the development of equipment.

The hot gas emitted from the exhaust tube disperses in the tank as shown in Fig. 1. Here, the high-temperature gas is distributed around the exhaust tube whose electrical field is raised by a transient recovery voltage applied, and low-temperature gas near the tank which is at the ground potential. In other words, gas in the entire space becomes non-homogeneous in terms of temperature and density. Extensive studies have been carried out on the dielectric characteristics of normal-temperature and homogeneous SF_6 gas, while little has been explained about how dielectric characteristics are determined in a space that has temperature and density distributed non-homogeneously.

Using a dead-tank-type GCB model having breakdowns or no breakdown occurring, a hot gas measurement test was carried out to investigate the dielectric characteristics of non-homogeneous hot gas in a GCB experimentally.

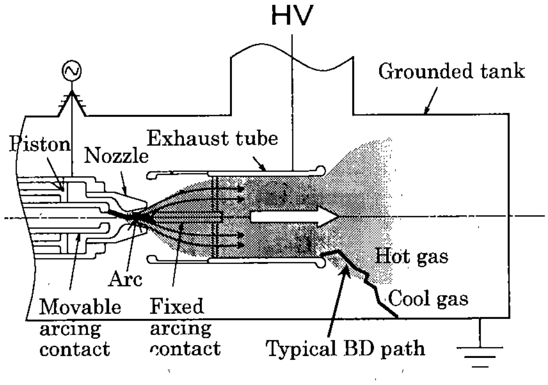


Fig. 1 Breakdown due to inhomogeneous hot gas in a GCB.

2. Hot gas measuring test

<2.1. GCB model> The test was done using a dead-tank-type GCB model provided with the puffer interrupting chamber shown in Fig. 1. The tank is filled with SF_6 gas at an absolute pressure of 0.6 MPa. Prior to hot gas measurement, the dielectric capability to the grounded tank of the GCB model was investigated through synthetic interrupting tests. In the synthetic interrupting tests, a transient recovery voltage (TRV) as shown in Fig. 2 was applied to the fixed part of the interrupting chamber including the exhaust tube after a current interruption at a current zero point. Here, the peak of TRV is defined as 1 pu (V). Table 1 summarizes the results of the synthetic interrupting tests. In Case-1, injected with an arc energy of 369 kJ, the GCB model withstood the TRV, showing no breakdown. In Case-2, injected with an arc energy of 668 kJ, the GCB model showed breakdown at TRV of 0.85 pu 333μs after a current interruption.

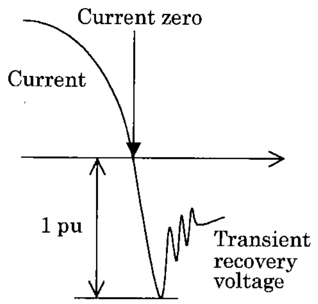


Fig. 2 A schematic of a transient recovery voltage(TRV).

Table. 1. Result of the synthetic interrupting test with TRV.

	Arcing time	Arc energy	Result
Case-1	16.5 ms	369 kJ	NO BREAKDOWN
Case-2	25.2 ms	668 kJ	BREAKDOWN at TRV 0.85 pu

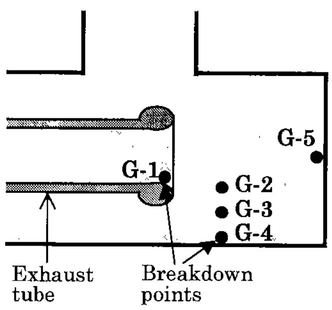


Fig. 3 Locations of the five small gaps(G-1 through G-5) for measuring the hot gas.

<2.2. Experimental setup> To investigate the state of hot gas in the GCB model during a current interruption, five small gaps were set up near the exhaust tube as shown in Fig. 3. This enabled the breakdown voltages of local hot gas at each small gap to be measured (details explained in 2.3). Gap 1 (G-1) was at the interior of the end of the exhaust tube, and G-2, G-3 and G-4 were arrayed linearly in the tank space. G-5 was at the center of the tank end-face. G-1 and G-4 were exactly at the points at which the breakdown had occurred in Case-2 of the synthetic interrupting test. The locations of actual breakdowns were presumed from the melt scars.

<2.3. Hot gas measurement with small gaps>
As shown in Fig. 4, a CR charging/discharging circuit was connected to each small gap to continue discharging at the gap. C_1, C_2, R_1 and R_2 were adjusted so that the charging and discharging time constants of the capacitor C_2 were 100 μs and 1 μs respectively. Fig. 5 shows a schematic of the gap sparking waveform. It is interpreted that the envelopes of the gap sparking waveforms, shown by a broken line, represent hourly variations in the breakdown voltage of local hot gas at each small gap (which is defined as BDV_{gas} in this paper).

To avoid the disturbing the hot gas flows, the size of the gaps was minimized. The gap length was adjusted to 0.2 mm. A preliminary test proved that the small gaps nearly had uniform electric field characteristics.(1)

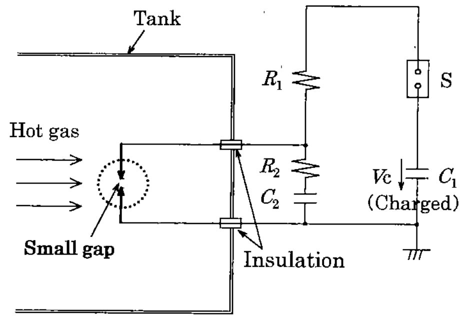


Fig. 4 The CR charging/discharging circuit for the continual small gap discharging.

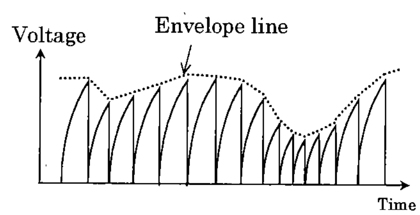


Fig. 5 A schematic of a sparking waveform. The envelope represents hourly variations in the breakdown voltage of local hot gas (BDV_{gas}) at each small gap.

The sparking energy of the gaps was very little, and also the fresh gas flow was continuously supplied to the gap spaces. Thus, it was presumed that any lingering effect of a discharge in the gap could be neglected, although the gap length was as short as 0.2 mm. In the sparking waveforms at the inception of discharge in a no load test without hot gas supplied, no signs of sparking voltage variations due to discharges was observed.

The hot gas measuring tests using small gaps consisted only of current interruptions equivalent to those in Case-1 and Case-2 shown in Table 1, without TRV.

3. Results of hot gas measuring test

Figs. 6 and 7 show the measured results of (a)current, (b)arc power, and (c) through (g) BDV_{gas} at each small gap, in Case-1 and Case-2 respectively. The time of contact separation is represented as t=0 ms. The values of (c) through (g) are normalized – BDV_{gas}, about 10.3 kV, of the gap under normal conditions (normal temperature, absolute pressure 0.6 MPa) as 100.

Fig. 6 (c) and Fig. 7 (c) show zones having a lower BDV_{gas} due to a high-temperature and low-density gas

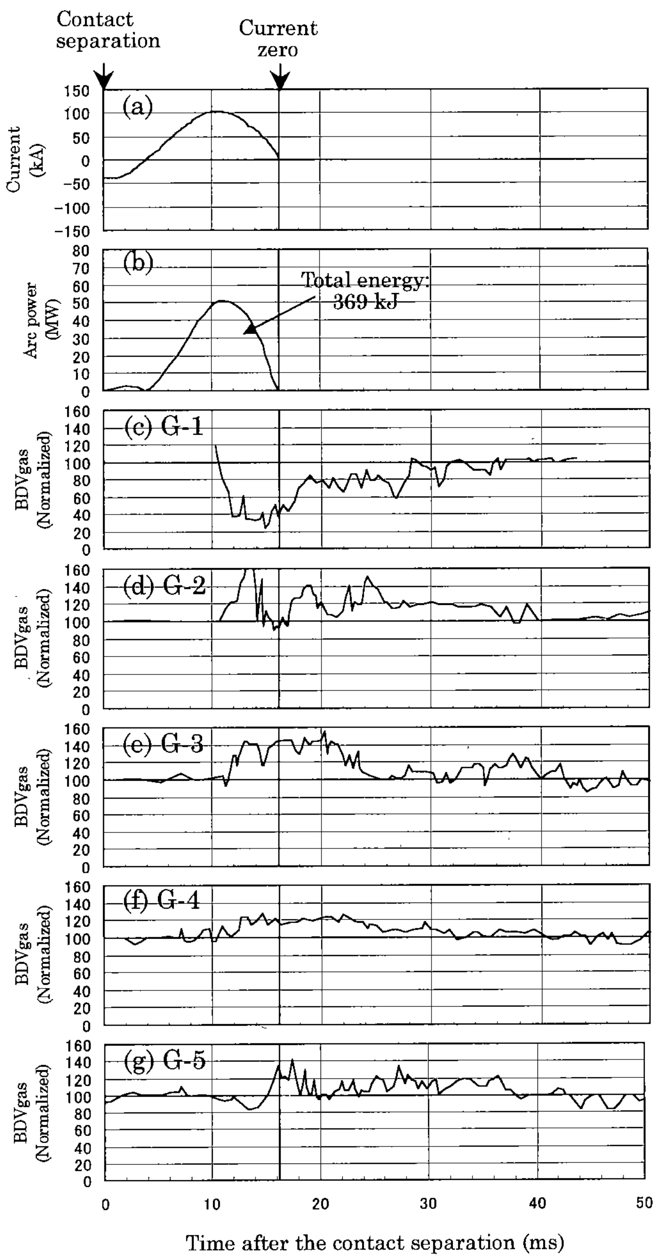


Fig. 6 The Results of hot gas measurements in Case-1 (no breakdown case).

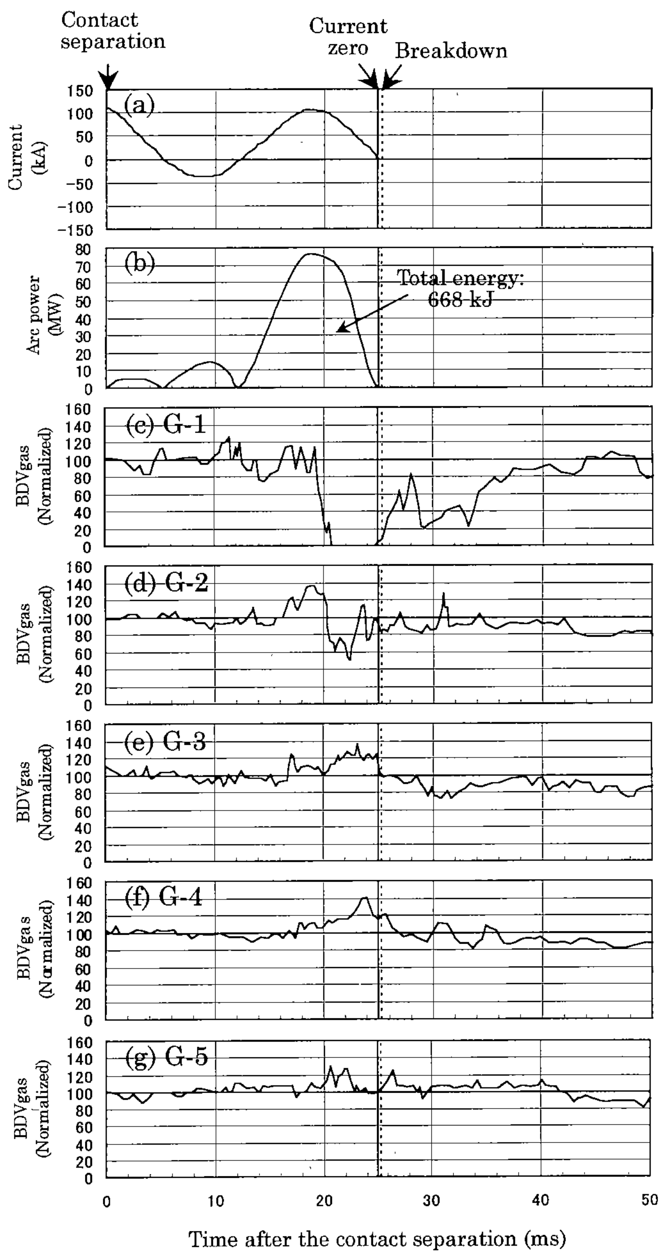


Fig. 7 The Results of hot gas measurements in Case-2 (breakdown case).

flow. These show that the hot gas produced by a large-current arc, forming a mass, passed through G-1. The total arc energy in Case-1 was as small as 369 kJ, thus BDV_{gas} at G-1 did not decrease much, at most to about 30% of normal temperature, as shown in Fig. 6 (c). On the other hand, in Case-2, having a total arc energy of 668 kJ, there was a zone with zero BDV_{gas} for about 4 ms before a current zero point, as shown in Fig. 7 (c). The gas in such a zone was so hot that SF_6 was thermally dissociated and ionized, becoming non-dielectric. The temperature in such processes is reported as above 2900 K by L. Rothhardt et al.[4] After the above non-dielectric zone, the dielectric capability of the hot gas gradually recovered. The dielectric capability recovered to about 6% of the value at normal temperature 333 μs after a current zero point having a breakdown in a synthetic interrupting test.

In both Figs. 6 and 7, decreases in BDV_{gas} due to the arrival of hot gas were detected only at G-1 located at the breakdown point of the exhaust tube. At G-2 through G-5, there were almost no decreases in BDV_{gas}, which were rather increased due to the compression of the cool gas.

4. Discussions

<4.1 Causes of breakdowns> The results above show that even in Case-2, in which breakdowns occurred, there was also adequate cool gas around the grounded tank. The aspect of BDV_{gas} at G-1 was the only difference between Case-1 and 2. At G-2 through G-5, there were almost no changes in the state of hot gas. Therefore the decisive factor was probably the BDV_{gas} at G-1 for the occurrence of breakdowns in Case-2.

Concentrating on hot gas at G-1, this paragraph deals with the causes of breakdowns occurring in the GCB model. Figs. 8 and 9 show the breakdown field strengths of the local hot gas (defined as E_{crit}) at G-1 near current zero points. These two figures correspond to Case-1 and 2 respectively. Because the small gaps are almost uniform electric field characteristics, E_{crit} was obtained by dividing BDV_{gas} by gap length. The figures also show the electric field at G-1 (E_{G1}) obtained from field calculations under the applied TRV in the synthetic test.

As shown in Fig. 8, E_{crit} in Case-1 was above 123 kV/cm, which is much higher than the peak value 42.4 kV/cm of E_{G1}. E_{crit} is also higher than electric field E_T at the tip of the exhaust tube shown in Fig. 10.

On the other hand, as shown in Fig. 9, E_{crit} in Case-2 at the time of the breakdown was 29.2 kV/cm, while E_{G1} at the same time was 35.9 kV/cm. Here, E_{G1} is higher than E_{crit}. This was probably the cause of the breakdown generated in Case-2. If the electrical field strength at the applied TRV is higher than E_{crit} at a location, a leader would start and cause a breakdown. To prevent breakdowns, electrical field strength values must be kept below E_{crit} as in Case-1.

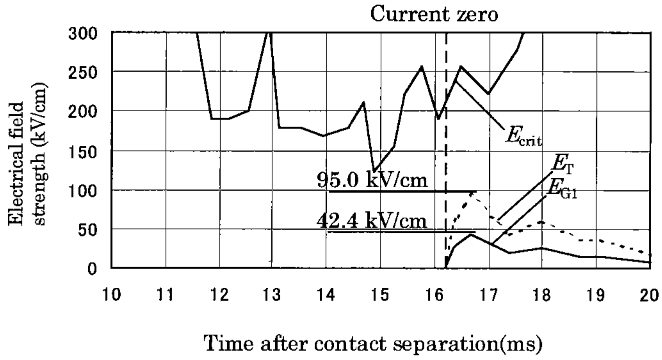


Fig. 8 Comparison between E_{crit} measured by the small gap G-1 and the calculated electrical field strength around the current zero in Case-1(no-breakdown case).

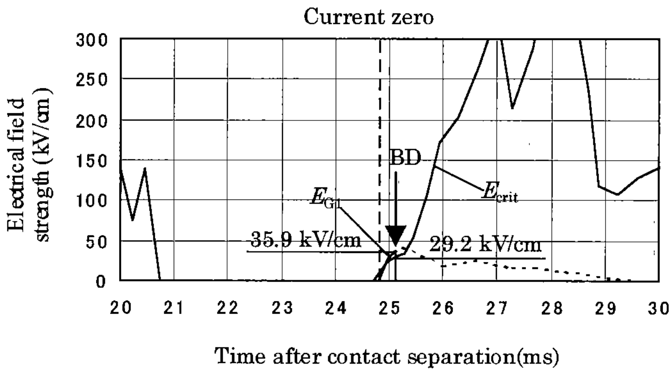


Fig. 9 Comparison between E_{crit} measured by G-1 and the calculated electrical field strength around the current zero in Case-2(breakdown case).

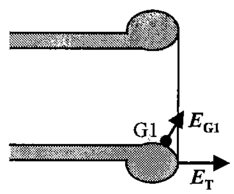


Fig. 10 The electrical field strength at G-1 (E_{G1}) and the tip of the exhaust tube (E_T).

<4.2 Discussion on breakdown voltages> In Case-2, which had the breakdown between G-1 and G-4, there was a large volume of cool gas around G-4. This paragraph, therefore, discusses what effect the cool gas layer around G-4 has on the breakdown voltage of the GCB. Here, breakdown voltages in three cases (I), (II), and (III) shown in Fig. 11 are chosen. For the sake of simplicity, the exhaust tube with G-1 and the grounded tank with G-4 are drawn as a sphere electrode and a plate electrode respectively in the figure.

Case (II) corresponds to Case-2, which had a breakdown in the synthetic test. This represents a state with hot gas of E_{crit}=29.2 kV/cm at G-1, and cool gas with E_{crit}=516.6 kV/cm at G-4 – infomogeneous gas as a whole – as measured in the hot gas measuring test. The breakdown voltage here is the actual breakdown voltage in the synthetic test as shown in Table 1. Cases (I) and (III) are shown for comparison, representing states of hot and cool gases distributed homogeneously. Here, the breakdown voltages are calculated as applied voltages when E_{G1} equals E_{crit} at G-1.

When compared, the breakdown voltages in these cases have the relation shown at the bottom of Fig. 11. The values are percentages of the breakdown voltage in (II) taken as 100%. The value in (II) is between those in (I) and (III), which is a little higher than the breakdown voltage in (I) calculated from E_{crit} and E_{G1}. This might be due to the effects of the cool gas layer near the grounded tank. However, considering that <1> we have only one data of the actual breakdown voltage in (II), <2> the breakdown voltages in (I) and (III) are obtained by relatively simple means, <3> the breakdown voltage in (III) is more than 14 times higher than that in (II), the difference between (I) and (II) values could be interpreted as being not very significant. Thus, it is reasonable to recognize that there is very little or no effect of the cool gas layer on breakdown voltages. This suggests that the breakdown voltage of inhomogeneous hot gas could be obtained as the applied voltage at which the field strength equals E_{crit} of the local gas at the site concerned.

5. Conclusion

Using small gap discharging, the hot gas behavior of a GCB model, having breakdown or no breakdown occurring, was investigated. The results yielded the following findings:

(i) Even if there is a large volume of highly dielectric cool gas around the grounded tank, breakdowns do occur in the GCB model.

(ii) There was very little or no effect of the cool gas layer in the breakdown paths on breakdown voltage.

(iii) The actual breakdown voltage in the synthetic test was nearly the same as the applied voltage when E_{crit} at G-1 equaled E_{G1}, where E_{crit}: breakdown field strength of local hot gas, and E_{G1}: calculated field strength at G-1. This suggests that the breakdown voltage of inhomogeneous hot gas could be obtained as the applied voltage at which the electrical field strength equals E_{crit} of the local hot gas at the concerned location.

(Manuscript received on 11 January 2001, revised on 8 May 2001.)

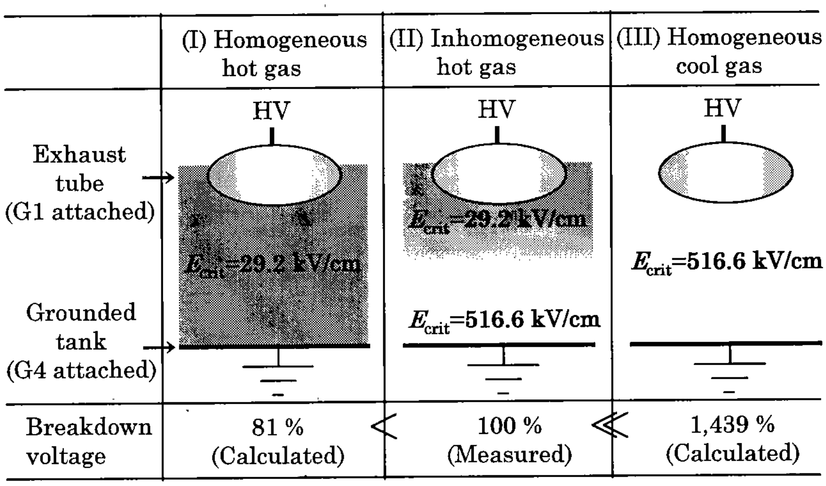


Fig. 11 Comparison with breakdown voltages in cases (I), (II), and (III). The exhaust tube fitted with G-1 and the grounded tank fitted with G-4 are drawn as a sphere electrode and a plane electrode respectively for the sake of simplicity.

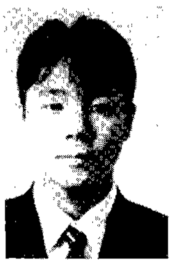
References

(1) T. Uchii, K. Miyazaki, T. Mori, K. Suzuki, K. Iwamoto, N. Kato: "Measurement of hot gas density distribution in SF6 gas circuit breaker," IEE of Japan High Voltage Switchgear Protection Session, SP-99-73, Jun 1999

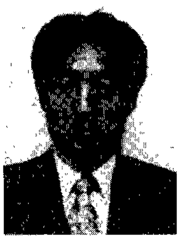
(2) Y. Hayashi, K. Suzuki, E. Haginomori, H. Toda, H. Ikeda: "On the hot gas exhaustion in the exhaust chamber of a gas circuit breaker after short-circuit current interruption," J. Phys. D: Appl.Phys., vol. 30, pp. 3123-3130, 1997

(3) G. J. Cliteur, Y. Hayashi, E. Haginomori, K. Suzuki: "Calculation of the uniform breakdown field strength of SF6 gas," IEEE Trans. on Dielectrics and Electrical Insulation, vol. 5, no. 6, pp. 843-849, 1998

(4) L. Rothhardt, J. Blaha : "Breakdown experiments in diluted SF6 at elevated temperatures," J. Phys. D: Appl. Phys. vol. 18, pp. L155-157, 1985



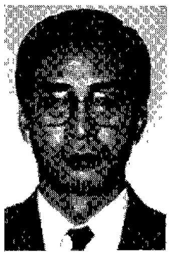
Toshiyuki Uchii was born on March 9, 1972. He received his B.S. degree in applied physics from Science University of Tokyo, and his M.S. degree in electrical engineering from Nagoya University, Japan. He joined Toshiba Corporation in 1997. He is presently a researcher of Power & Industrial Systems Research & Development Center, engaged in the development of large-capacity SF_6 gas circuit breakers. Mr. Uchii is a member of IEE of Japan and IEEE.



Koichi Iwata was born on May 2, 1968. He received his B.S. and M.S. degree in mechanical engineering from Waseda University, Japan. He joined Toshiba Corporation in 1993. He is presently an engineer of GCB design section, engaged in the development of large-capacity SF_6 gas circuit breakers and their hydraulically-operating mechanisms.

Hiromichi Kawano was born on March 7, 1961. He received his B.S. and M.S. degree in electrical engineering from Kyoto University, Japan. He joined Toshiba Corporation in 1985. He is presently a senior engineer of GCB design section, engaged in the development of large-capacity SF_6 gas circuit breakers and study on current interruption phenomena. Mr. Kawano is a member of IEE of Japan.

Tetsuya Nakamoto was born on February 4, 1957. He received his B.S. and M.S. degree in electrical engineering from Kyoto University, Japan. He joined Toshiba Corporation in 1981. He is presently a manager of High Power Technology Group, Power & Industrial Systems Research & Development Center, and engaged in the development of SF_6 gas circuit breakers and their testing technology. Mr. Nakamoto is a member of IEE of Japan.



Katsumi Suzuki was born on June 27, 1951. He received his B.S., M.S., and Ph.D degree in electrical engineering from Tokyo Electrical Engineering College, Japan. He joined Toshiba Corporation in 1978. He is presently a senior manager of Power & Industrial Systems Research & Development Center, and engaged in the development of gas insulated switchgears and their testing technology. Dr. Suzuki is a member of IEE of Japan and IEEE.