Paper

Corona Discharge Current and Ambient Electric Field Intensity on the Arm Ends of an EHV Transmission Tower During a Winter Thunderstorm

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This paper analyzes the distribution of the corona discharge current distribution and the ambient electric field intensity on an EHV transmission tower during a thunderstorm. In the measurement of corona discharge current from the arm ends of a tower at Mt. Okushishiku in 1996 and again in 1998, unexpected phenomena were observed in the corona current and the charge distribution. The different polarities of the corona discharge current were intermittently measured at the different arm ends of a transmission tower. Through these measurements, the initiation field intensity of the corona discharge current and the field intensity on the top of the tower were observed for the first time.

Keywords: corona discharge, space charge, electric field intensity, EHV transmission tower, winter thunderstorm

1. Introduction

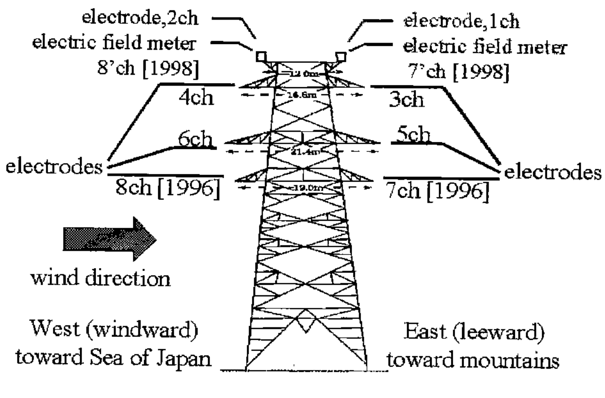
It is commonly known that during a thunderstorm, corona discharge is initiated from the tip of tall structures and/or tall trees, and then the resultant space charge decreases the intensity of the ambient electrostatic field[1]-[9]. By implication, it may be possible to control lightning strikes by their space charges. The measurement of corona discharge current was carried out in 1996 and 1998 at a 60m-high test transmission tower (owned by the Hokuriku Electric Power Co. Inc.) on the top of Mt. Okushishiku, in Ishikawa, during experiments involving rocket-triggered lightning[10]. The electrodes creating the corona discharge current were equipped at all arm ends of the tower except on the ground wire side, and two electric field meters were placed on the top of the tower to measure the ambient field. The members of the experiment analyzed and discussed the data obtained from the various sources and, in so doing, discovered an anomaly in the corona discharge current. The present paper will examine the measurements and analysis of distribution of corona discharge current on the tower.

2. Experiments

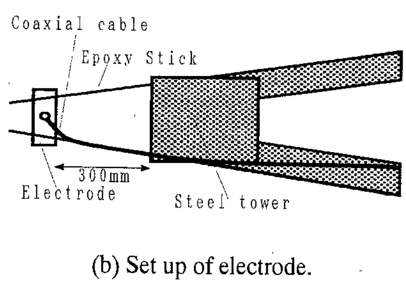
2.1 Arrangement of measurement equipments

Fig. 1 shows the set up of the measurement equipment. Fig. 1(a) represents the structure of the transmission tower located about 950m above sea level, and Fig. 1(b) represents the aluminum plate electrode used to obtain the corona discharge current. The electrode's dimensions were 250×100×10mm. The electrode was insulated with glass epoxy sticks fixed to the arm end of the tower. The separation was 300mm. The four electrodes at the west side (toward Sea of Japan) were named Channels 2, 4, 6, and 8 (i.e., even-numbered channels), and the electrodes at the east side were named Channels 1, 3, 5, and 7 (i.e., odd-numbered channels), respectively.

In 1996, only the measurement of the corona discharge current was made on the eight electrodes on the top-level, the second-level, the third level, and the fourth-level arm ends of the tower, respectively. In 1998, however, measurements were performed on both the corona discharge current and the electric field intensity. In stead of measuring corona discharge current on the fourth level arms, two electric field meters were located on the top level arms named 7' and 8' channels.



(a) Structure of the tower.



(b) Set up of electrode.

Fig. 1. Set up of measurement equipments.

2.2 Recording System The corona current was guided to the ground through a 70m-long coaxial cable and was detected with a resister of 10kΩ. The output voltage of the corona current and that of the electric field meter were digitized with the sampling frequency of 1Hz and recorded in a memory card with 256kB capacity. This memory capacity covered three days of continuous measurement. The zener diode was connected to a 10kΩ resistor to limit the over-voltage to no more than ±5V.

3. Measurements

3.1 Measurements in 1996 Fig. 2 shows typical corona discharge current measured in 1996 (15 Nov. 1996, 6:15 a.m. to 9:00 a.m.). The maximum value of the current was -227μA on 2ch at 8:40 a.m. All the trends of the current in the odd-numbered channels were similar, and the same thing could be observed in the even-numbered channels. On the other hand, when comparing the current between the odd-numbered and the even-numbered ones with the same height, for example, their polarities between 7:45 a.m. through 8:00 a.m. were opposite.

The wind speed on the ground was 0~5m/s, and the direction was WE, and the direction of the thunderstorm was also WE according to radar observations from Komatsu. Here the even-numbered channels were located on the windward side, and the odd-numbered ones were on the leeward. In the rocket-triggered lightning experiment, the lightning discharge channel with multiple strikes was photographed, allowing us to observe that the width of the channel was almost the same along the length from the ground to the top of the rocket wire. This suggested that the wind speed distribution and direction were almost the same in between.

From 6:00 a.m. to 6:50 a.m. on the second channel the current of more than +55μA indicated not the net value but the saturated value because of the lost protection that followed the breakdown of the zener diode.

3.2 Measurements in 1998 Fig. 3 shows typical corona discharge current (10 Nov. 98, 2:00 a.m. to 5:00 a.m.). The first through the fourth channels were the current, and the eighth prime (8'ch) channel was the output of one the two electric field meters. The other three channels were out of operation except for the figures shown. The largest current measured was -258μA on the second channel around 4:15 a.m. At 2:35 a.m., the first channel had recorded the maximum of +80μA, however, there was no current measurement on the other three channels. By contrast, at 2:20 a.m., the first channel had recorded no current measurement, but the other three active channels had an output of corona discharge currents. Except for these two cases (at 2:35 and 2:20), the corona currents were always output on the first four channels.

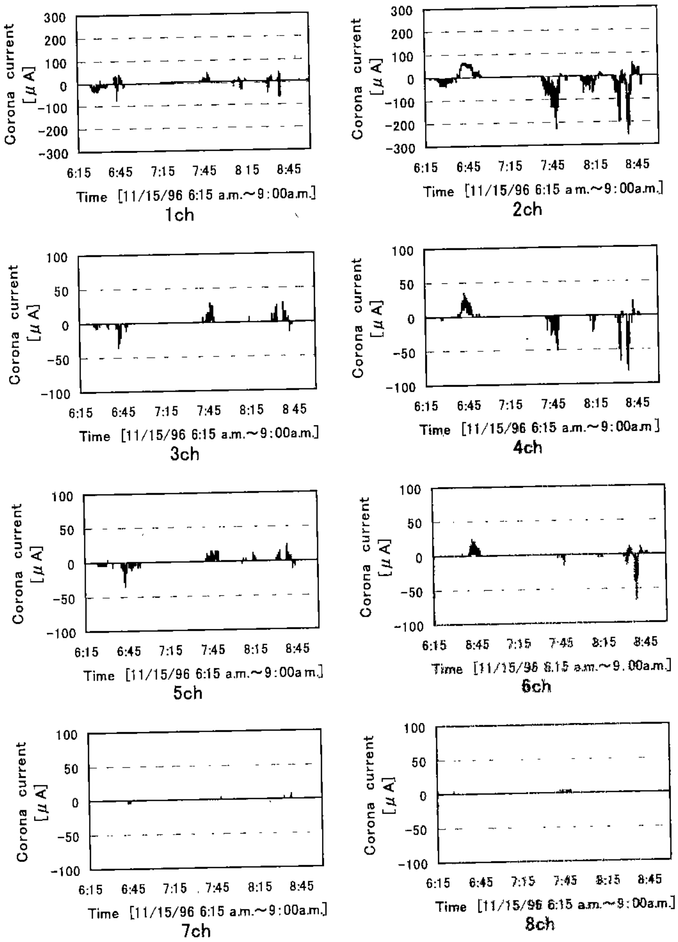


Fig. 2 Typical corona discharge current measured in1996.

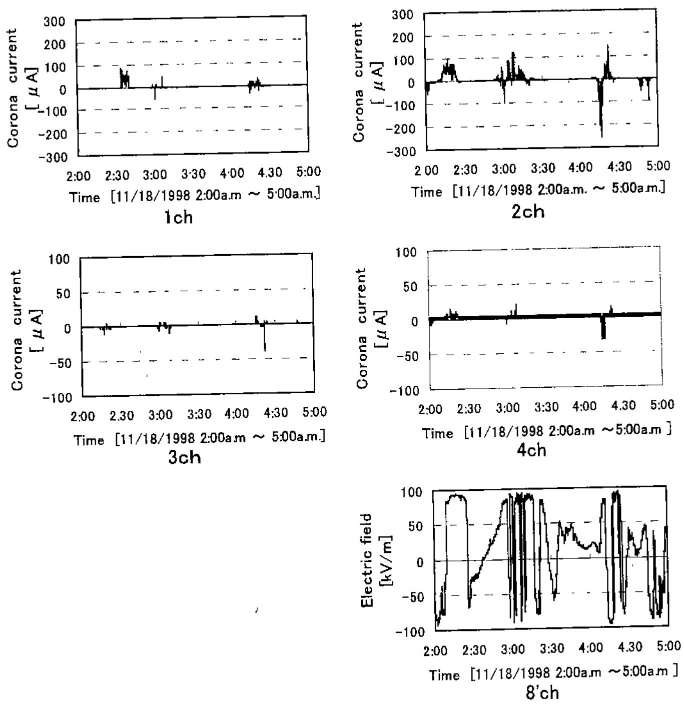


Fig.3. Typical corona discharge current and the electric field intensity measured in1998.

It should be noted that it was snowing during the time that the measurements were taken, increasing the frequency of lightning strikes.

4. Data Analysis

4.1 Height dependence of current Fig. 4 shows the corona discharge current characteristic for the different heights of the arms based on the data of Fig. 2. Fig. 4(a) shows the relation between the first channel (top) and the third channel (second level) and indicates that their ratio is 3:2. Fig. 4(b) shows the relation between the second and fourth channels and indicates that their ratio is 4:1. Fig. 4(c) shows the relation between the first and fifth channels and indicates that their ratio is 3:1. Fig. 4(d) shows the relation between the second and sixth channels and indicates that their ratio is 10:1. All of the trends of the corona discharge current between the upward and downward arms were the same: The values of the corona discharge current at the upward arms were from 1.5 to 10.0 times larger than those at the downward arms.

Fig. 5(a) indicates the relation between the first and third channels corresponding to the current in Fig. 3. The current ratio between the first and third channels is 2:1. Fig. 5(b) shows the relation between the second and fourth channels and indicates their ratio is 8:1. The polarities of the corona current are the same in Fig. 5(b). In the Fig. 5(a), however, the different polarities often appeared as dots marked in the second and fourth quadrants. This means that the different polarities appeared between different heights on same side arms.

4.2 Polarity difference of current The characteristics of the current between the even numbered channels and the odd ones in 1996 (15 Nov. 96, 6:15 a.m. to 9:00 a.m.) are found in Fig. 6. Fig. 6(a) shows the relation between the first and second channels. The dots are distributed mainly in the forth quadrant, indicating the opposite polarity between the two channels. Fig. 6(b) and Fig. 6(c) show the relations between the third and fourth channels and between the fifth and sixth channels, respectively. In these two figures, the dots are concentrated almost entirely in the second and fourth quadrants. In other words, the polarity difference of the current appeared during nearly all of the experiment period. Fig. 7 show the corresponding plots taken in 1998 (18 Nov. 98, 2:00 a.m. to 5:00a.m.). The dots are scattered in the four quadrants as shown in Fig. 7(a). In Fig. 7(b), the dots are distributed in the 2nd and 4th quadrants.

Fig. 8 and Fig. 9 show the computed percentage of the opposite polarity of the current for the total time of current output in each electrode pair in 1996 and 1998, respectively. The two graphs and the total time periods produce an average value, indicating that the appearance percentages of the opposite polarity are roughly 60% for the arm end on the top of the tower, 100% for the arm end on the second level, and 100% for the third arm end, respectively. The percentages are between 12% and 60% for the top, and between 60% and 100% for the second top in Fig. 9. The appearance of the opposite polarity of the lower arm is comparatively greater than that of the top one.

4.3. Charge of corona discharge current Charge can be considered as the time integration of the corona current. In Tables 1 and 2, the total charge and its contents are listed, and each time period corresponds to each measurement period. In Table 1, the total charge on all eight arms registered 204.0mC from 6:00 a.m. to 8:00 a.m. More than 80% of the charge, however, was concentrated on the two top arms, and the percentage of the remaining 20% was on the lower arms. From Table 1 and 2, it can be concluded that roughly 80% of charge was emitted from the top arms of the tower.

4.4 Characteristic between corona discharge current and field intensity The relation between the corona discharge current and the electric field intensity is shown in Fig. 10. Fig. 10(a) and Fig. 10(b) indicate the relations between the corona discharge current on the second channel and the electric field intensity on the eighth prime channel (8'ch), as well as the relation between the current on the first channel and the electric field on the eighth prime channel, respectively. The distance between the electrode on the second channel and the electric field meter was 2m, and the distance between the first channel and the electric field meter was 10m, as shown in Fig. 1(a). As shown in Fig. 10(a), the corona current started to flow at the field of 65kV/m and increased to 100μA at 100kV/m. The output of the electric field was saturated at 100kV/m. On the other hand, Fig. 10(b) indicates the different relation without the simple curve.

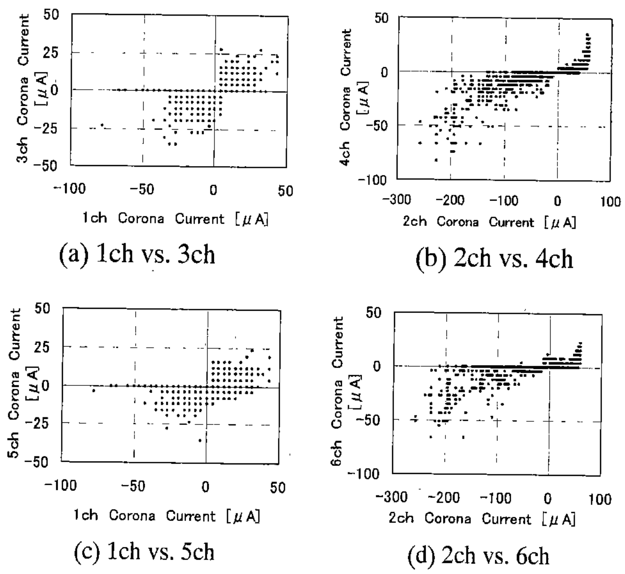
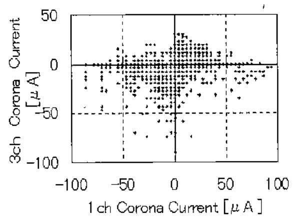
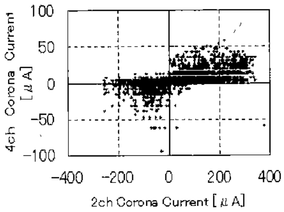


Fig. 4. Corona discharge current characteristic for the different heights of the arms based on the data of Fig. 2.

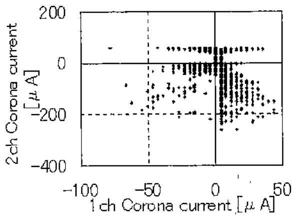


(a) 1ch vs. 3ch.

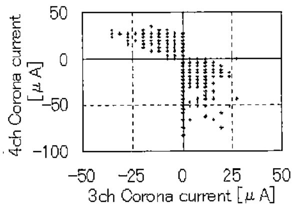


(b) 2ch vs. 4ch.

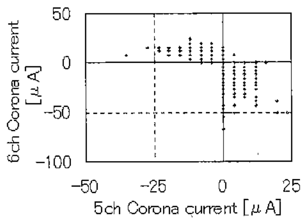
Fig. 5. Corona discharge current characteristic for the different heights of the arms based on the data of Fig. 3.



(a) Top.

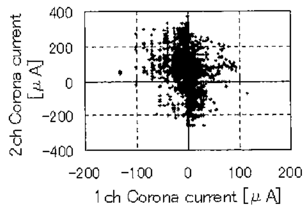


(b) Second level.

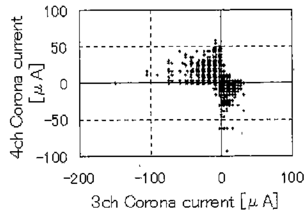


(c) Third level.

Fig. 6. Relations between corona discharge current on odd-numbered channel and even-numbered channel, based on the data measured in 1996.



(a) Top.



(b) Second level.

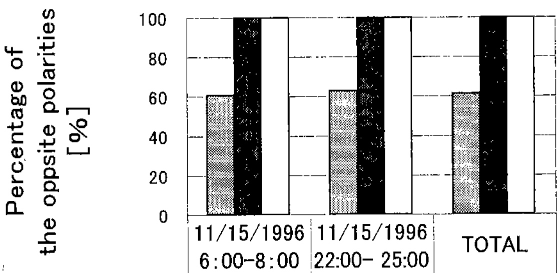
Fig. 7. Relations between corona discharge current on odd-numbered channel and even-numbered channel, based on the data measured in 1998.

Table 1. Percentage of charge initiated on each arm ends, computed by all of the data obtained in 1996.

Period	11/15/1996 6:00-8:00	11/15/1996 22:00-25:00	TOTAL
Top arms [%]	86.8	66.4	72.4
Second level [%]	5.7	16.2	13.1
Third level [%]	7.4	17.4	14.4
Fourth level [%]	0.1	0.0	0.1
Charge [mC]	204.0	482.1	686.1

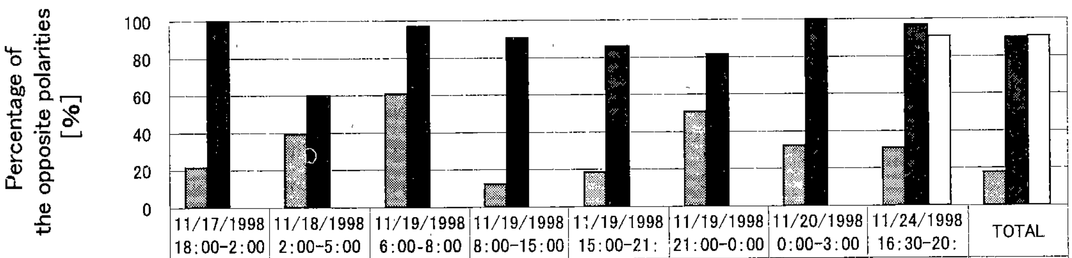
Table 2. Percentage of charge initiated on each arm ends, computed by all of the data obtained in 1998.

Period	11/17/1998 18:00-2:00	11/18/1998 2:00-5:00	11/19/1998 6:00-8:00
Top arms [%]	99.2	85.0	91.6
Second level [%]	0.8	15.0	8.4
Charge [mC]	126.4	113.6	224.6
Period	11/19/1998 8:00-15:00	11/19/1998 15:00-21:00	11/19/1998 21:00-0:00
Top arms [%]	76.3	73.0	96.4
Second level [%]	23.7	27.0	3.6
Charge [mC]	891.0	759.8	218.4
Period	11/20/1998 0:00-3:00	11/24/1998 16:30-20:00	TOTAL
Top arms [%]	94.3	95.7	82.7
Second level [%]	5.7	4.3	17.3
Charge [mC]	196.3	264.9	2795.1



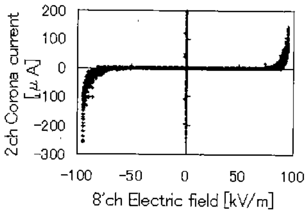
	11/15/1996 6:00-8:00	11/15/1996 22:00- 25:00	TOTAL
▨ Top [%]	60.5	62.8	61.4
■ Second level [%]	100.0	99.9	99.9
□ Third level [%]	99.7	99.9	99.9

Fig. 8. Percentage of the opposite polarities of corona discharge current between west and east of the tower in 1996.

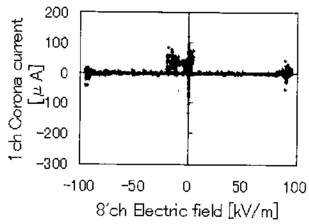


	11/17/1998 18:00-2:00	11/18/1998 2:00-5:00	11/19/1998 6:00-8:00	11/19/1998 8:00-15:00	11/19/1998 15:00-21:	11/19/1998 21:00-0:00	11/20/1998 0:00-3:00	11/24/1998 16:30-20:	TOTAL
▨ Top [%]	21.7	39.6	61.0	12.4	18.5	50.9	32.1	30.6	17.7
■ Second level [%]	100.0	59.7	97.2	91.0	86.1	81.3	100.0	96.7	89.6
□ Third level [%]								90.5	90.5

Fig. 9. Percentage of the opposite polarities of corona current between west and east of the tower in 1998.



(a) Relation between 2 and 8'ch.



(b) Relation between 1 and 8'ch.

Fig. 10. Relations between corona discharge current and electric field intensity.

This suggests that the polarities of the current of the first channel and the electric field were different in most cases. Kawasaki, et al. measured the electric field of 100kV/m at the top of a 50 m tower and observed that the field there was 100 times larger than that on the ground[11].

5. Discussions

It is usually understood that the polarity of the space charge on the ground is opposite to that of a thunderstorm. Therefore, it can be safely assumed that the polarities of the current emitted from each arm end of the transmission tower should be the same. In these measurements, however, the positive and negative polarities of the current were simultaneously observed on the different arm ends. This finding suggests that the polarities of the electric field intensity around each arm end were not the same, i.e., the polarities of the electric field at the west side of the tower arm was opposite to that at the east side.

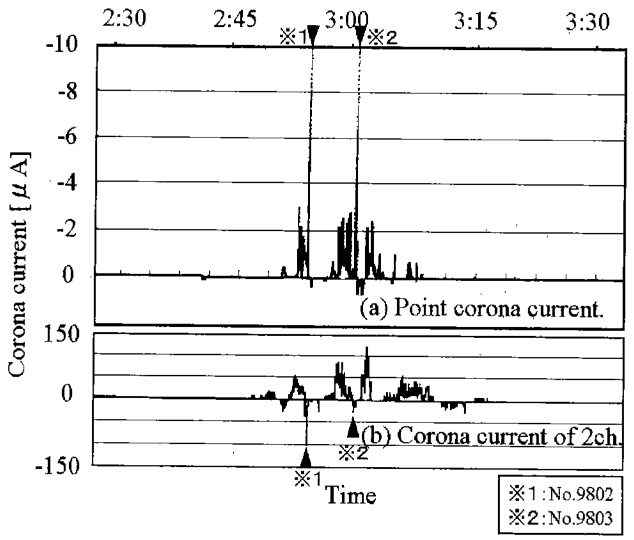


Fig. 11. Comparison of corona discharge current between on the tower and on the ground. [11 Nov. 98: 2:30 a.m. to 3:30 a.m.] No.9802 and No.9802 represent lightning strikes by rocket-triggered technique.

The central question here is why such polarity opposition occurred. It might be helpful to consider the matter from another angle. Fig. 11(a) represents a point corona current measured by a point electrode 5m from the ground, i.e., about 980m above sea level, and Fig. 11(b) represents the current of the top arm end (on the second channel) at the same time. The distance between them was 200m, and the point electrode was located leeward of the tower. In contrast to the mountain location of this experiment, H. Sakurano et al. observes a similar experiment on level plains in which two corona currents using point electrodes were measured with one electrode located windward, and another electrode located leeward, separated from each other by a distance of 2km. As a result, the time trend and polarities of the currents were almost the same, though time-lag occurred because of the movement of thundercloud[12]. In Fig. 11, however, the polarities of the corona current between Fig. 11(a) and Fig. 11(b) were opposite to each other.

Moreover, the corona current of the first channel was different from that in Fig. 11(a). This suggests that the electric field around the first-channel arm end and that around the ground level were strongly affected not only by the thundercloud above, but also by the locally surrounding floating space charge. In particular, the lower arm ends below the third channel and around the ground level leeward of the tower were strongly affected by the space charge. Such space charges flew from the windward arm ends to the leeward arm ends and produced the opposite polarity of the electric field to generate the corresponding polarity of corona discharge current. In theory, 10μC of point charge makes 100kV/m of electric field intensity at a distance of 1m from the charge center. It is not unreasonable, therefore, to state that such local space charges can be distributed sufficiently to create the opposite electric field, considering that the space charge emission of several tens or several hundreds of micro coulombs per second were emitted from the windward arm ends.

6. Conclusions

From two years' worth of measurement of corona discharge current and electric field intensity on an EHV transmission tower during winter thunderstorms, the following conclusions can be made.

1) The maximum corona discharge current recorded on the top of the tower was greater than 250μA. The comparatively large corona currents were observed on the windward arms.

2) During one thunderstorm, the charge for the total current from the tower was estimated to be roughly less than 1C. Around 80% of the total charge was measured at the top arm ends.

3) The corona discharge current started to occur when the electric field at the top of tower reached 65kV/m. On occasion,

the field intensity at the top of tower reached levels greater than 100kV/m.

4) The different polarities of the discharge current were frequently observed at both arm ends on the windward and leeward sides.

In this experiment, the measurement of the corona discharge current on the overhead ground wire was not performed. It makes the space charges distributed between the transmission towers. It is a future subject.

Acknowledgement

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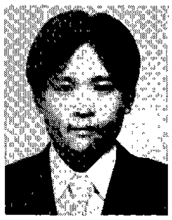

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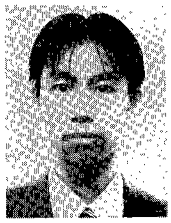

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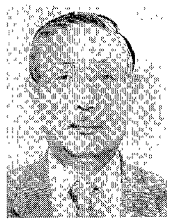

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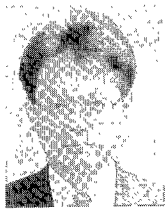

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