Paper

Surge Voltages Induced in Secondary Circuits of 275 kV Full GIS

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The study of surge voltage levels induced in low voltage control or monitoring circuits by lightning surges is very important for the rational design of those circuits in substations. To investigate the induction levels in those circuits, we carried out full-scale lightning impulse tests in a new 275 kV full GIS substation. The obtained data clarified that the induced surge levels are under the testing levels of related standards. We analyzed the surge waveforms in the Potential Transformer (PT) secondary circuit by EMTP. The analysis indicated that induced surge levels are almost decided by the ratio of winding and the overvoltage level in a main circuit.

Keywords: lightning surge, 275 kV full GIS substation, control circuit, monitoring circuit

1. Introduction

In recent years, application of electronic control or monitoring devices to substations has advanced. In relation with this progress, rational design techniques of these devices against surges induced in low-voltage circuits are expected furthermore. Lightning surge is one of main sources of induced surges. Up to now, several lightning tests were carried out in actual substations [(1)~(3)]. However, these tests were mainly performed for the purpose of examining the insulation performance of main apparatus. Some tests were performed for low voltage circuit, but most of them were low voltage tests. Consequently, these tests did not obtain sufficient knowledge relating to the surge levels in control or monitoring circuits induced when a surge arrester actually operated near the control or monitoring system.

Full scale lightning impulse tests were carried out in order to grasp the characteristic of the surge levels induced in control or monitoring circuits when a surge arrester operated in 275 kV GIS substation [(4)]. The tests were carried out before the commercial operation. Applying lightning surge voltage of about 500 kV to the power line, a surge arrester was operated. Then induced voltages in control and monitoring circuits were measured. Moreover, tests injecting lightning surge current to the dead-end tower top or the telecommunication tower top, which are considered to be the probable paths of the lightning surge propagation into substation, were also carried out. In these tests induced surge voltages in control and monitoring circuit were also measured.

Using the obtained results, the induced surge levels and the test voltages of related standards were compared. Furthermore, the induced surges in PT secondary circuits were analyzed by the EMTP. The results of this analysis showed that the induced surges in PT secondary circuit hardly exceed the testing level of related standards. This paper reports the details of these results.

2. Test Method

2.1 Lightning Impulse Applying Method

Tests were carried out in a 275/77 kV full GIS substation. The outline of the substation is shown in Table 1. An impulse generator (IG) was installed at about 180 m apart from the substation.

The output of IG was applied to (1) a power line, (2) a dead-end tower, or (3) a telecommunication tower. Each applying method is as follows.

(1) Power line test: In order to grasp the surge voltages induced in low voltage circuits when lightning impulses were applied upon a 275 kV-GIS main circuit, the voltage of about 500 kV was applied to a power line of the bushing top from IG. Standard lightning impulse voltages were applied upon a power line in which a PT is installed. Figure 2.1 shows structure of GIS main circuit to which lightning impulse voltages were applied. A circuit breaker (CB) and a disconnecting switch (DS) were open so that no surge had any effect on buses and transformers.

(2) Dead-end tower test: In order to grasp the induced voltages in the low-voltage circuit in the substation when lightning currents were infused directly or through grounding wire to dead-end tower, lightning impulse currents of about 390 A were injected to dead-end tower top. The waveform was 0.9/68 μs as shown in Fig. 2.

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Table 1. Outline of substation

Site	275/77kV all GIS substation Area : 10,800m^2 (275kV yard: about 90x65m, 77kV yard: about 25x150m)
Grounding grid	Grounding resistance: 0.24Ω (only grounding mesh)
275kV apparatus	3 phase encapsulated GIS, LIWV:1,050kV surge-arrester restriction voltage: 660kV or less (at 10kA)
275kV power line	500kV specification 2 lines (three grounding wires). All wires were grounded at No.5 tower.
Main transformer	275/77kV-250MVAx2set, 275kV: Direct connection (gas-oil Bg), 77 kV:CV cable connection
77kV apparatus	3 phases encapsulated GIS
77kV power line	4 lines (four grounding wires: first tower two grounding wires). Line conductors are detached by jumpers..
Main building	Steel frame concrete (2 stories), Area 19x19m, height 10.4m
Telecommunication tower	Installed on main building. Height:66.1m (include main building height)

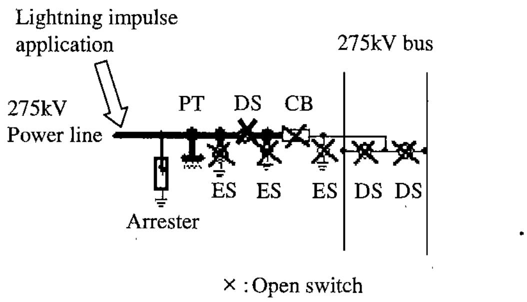


Fig. 1. Structure of GIS main circuit (power-line test)

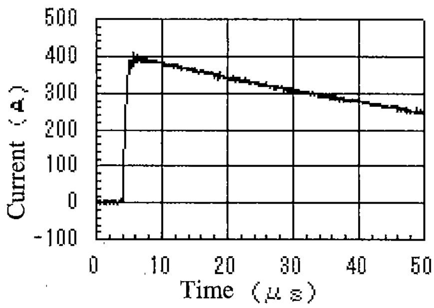


Fig. 2. Injection current waveform to the dead-end tower

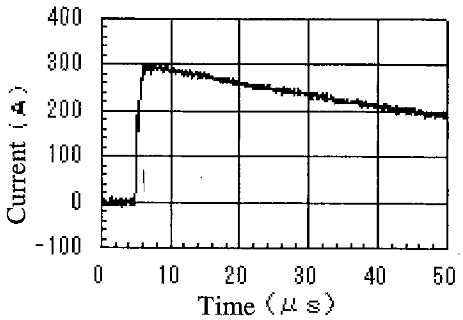


Fig. 3. Injection current waveform to the telecommunication tower

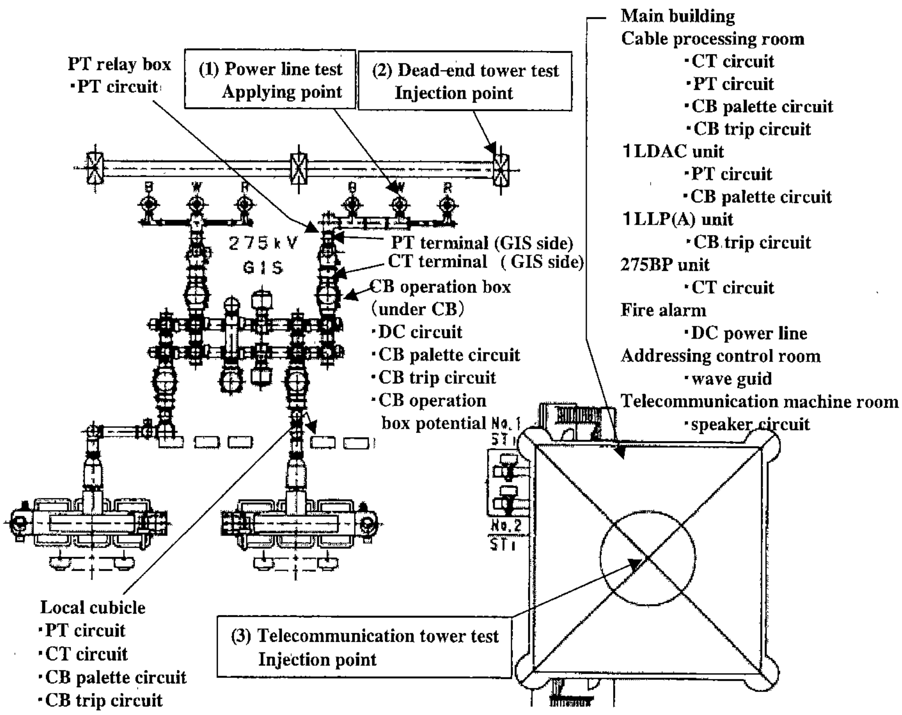


Fig. 4. Lightning impulse voltage/current injection points and measuring points

(3) Telecommunication tower test: In order to grasp the voltages induced in low voltage circuits and low voltage devices in a main building when a lightning stroke strikes the telecommunication tower, lightning impulse currents were injected to telecommunication tower top. In this test, the currents were about 300 A. The waveform was 1.0/72 μs as shown in Fig. 3.

2.2 Measurement Measuring points are shown in Fig. 4. Control and monitoring circuits, secondary circuit of PT, secondary circuit of CT, CB palette circuit, and CB trip circuit were selected. The potential of CB operation box was also measured as a reference. Moreover, in the telecommunication tower test, potentials of the wave guide, DC power supply circuit of the fire alarm, a broadcast control board and the speaker circuit of a communication devices room inside main building were also measured.

The applied voltages of IG were measured with voltage divider. Injected current and the discharge current of a surge arrester were measured by using high frequency CTs. All measured signals were converted to optical signals and transmitted through optical fibers to digital oscilloscopes.

3. Results

3.1 Voltage and Current of Surge Arrester

Figure 5 shows a main circuit voltage waveform (measured at the bushing part) and surge arrester discharge current waveform measured simultaneously. The duration of a surge arrester operation was about 10 microseconds. The relation between the voltage waveform and the current waveform is well in agreement with the voltage-current (V–I) characteristic of a surge arrester. In the voltage waveform, the reflection from the grounded end of power line appeared at 17 microseconds after the initiation of this waveform. This is well in agreement with the roundtrip time from dead-end tower to the 5th tower (about 2400 m) at the propagation speed (300 m/microsecond).

3.2 Low Voltage Control and Monitoring Circuit Among the surges induced in low-voltage control and monitoring circuit, only the surges of PT secondary circuit in power line test contained comparatively low frequency component around 25 kHz. The induced surge voltage waveforms of PT secondary circuit in other 2 tests and the waveforms of other low voltage circuits in all 3 cases were dominated by relatively high frequency component around 200 kHz. The high frequency dominant waveforms were almost same oscillatory waveforms.

Figure 6 shows examples of measured PT secondary

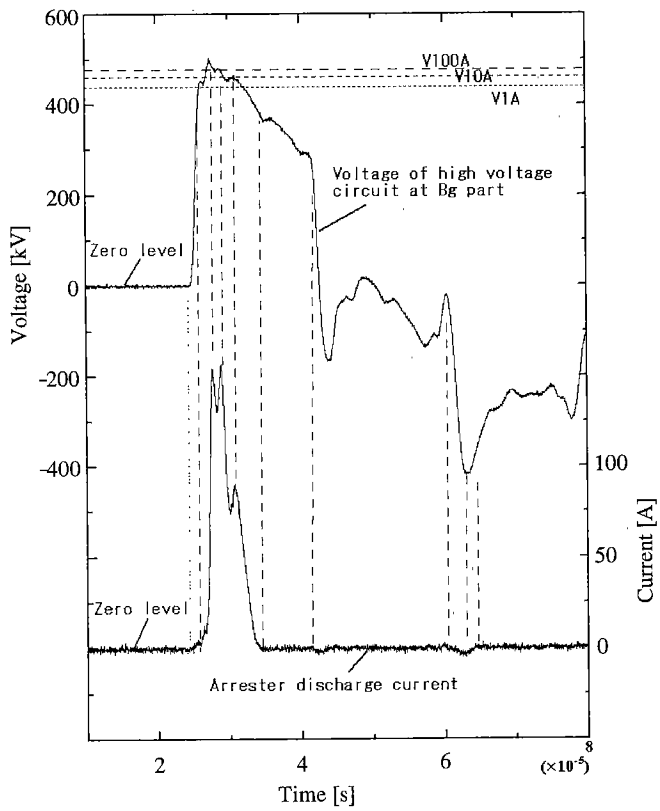


Fig. 5. Voltage of high voltage circuit and arrester discharge current (power line test)

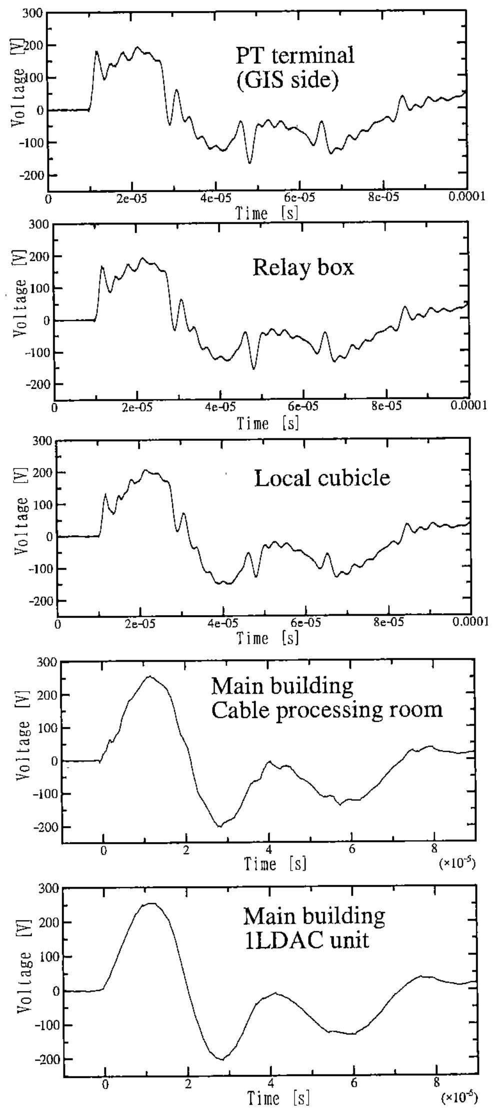


Fig. 6. Voltage waveform in the PT secondary circuit (power line test)

circuit voltage waveforms. They were obtained in power line test. They contain fundamental frequency component of 25 kHz and superimposed frequency component of 200 kHz. They show the appearance that superimposed 200 kHz component is decreasing as it goes to the terminals inside of a main building. This is considered as the effect of the capacitors attached in the 1LDAC (Data Acquisition and Control) unit for serge suppression.

Examples of PT secondary circuit voltage waveforms in telecommunication tower test are shown in Fig. 7. In these waveforms, frequency component around 200 kHz is dominant and frequency components lower than this are rarely contained.

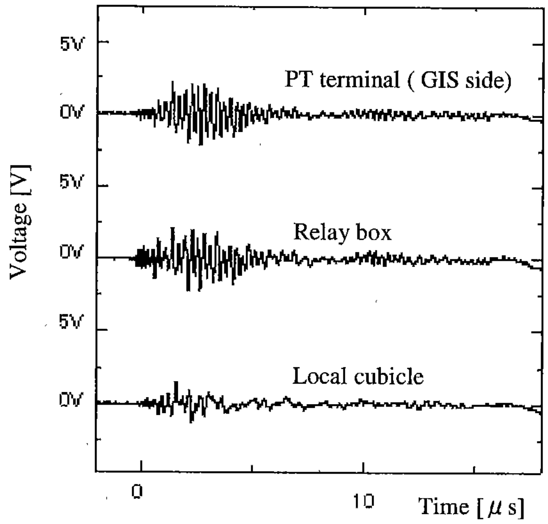


Fig. 7. Voltage waveform in the PT secondary circuit (telecommunication tower test)

In dead-end tower test, this feature was same. In low voltage circuits except PT secondary circuit, the dominant frequency component was around 200 kHz in any test cases. In order to compare with related standards, measured induced voltages were converted proportionately as follows.

(1) The results of power-line test were converted to the value in the case that surge arrester discharge current was 10 kA,

(2) The results of dead-end tower test were converted to the value in the case that the injected current was 100 kA,

(3) The results of telecommunication tower test were converted to the value in the case that the injected current was 100 kA.

The result in each measuring point is shown in Fig. 8. The voltage levels for the withstand tests of a control circuit in JEC, IEC, and the Japanese Electric Utilities' Standard (JEUS) are also shown in Fig. 8. As shown in this figure, converted induced surge levels are lower than two thirds of the minimum value of the test voltage level among the standards. From this result, it is considered that related standards have sufficient level to confirm the insulation reliability of a low-voltage circuit against the surges induced by lightning.

4. Analysis

In order to investigate the mechanism which affects the level of induced voltage in power line test, EMTP (ATP version) analyses were carried out. The outline of the model for EMTP analyses is shown in Table 2.

Analyzed main circuit voltage waveform at bushing

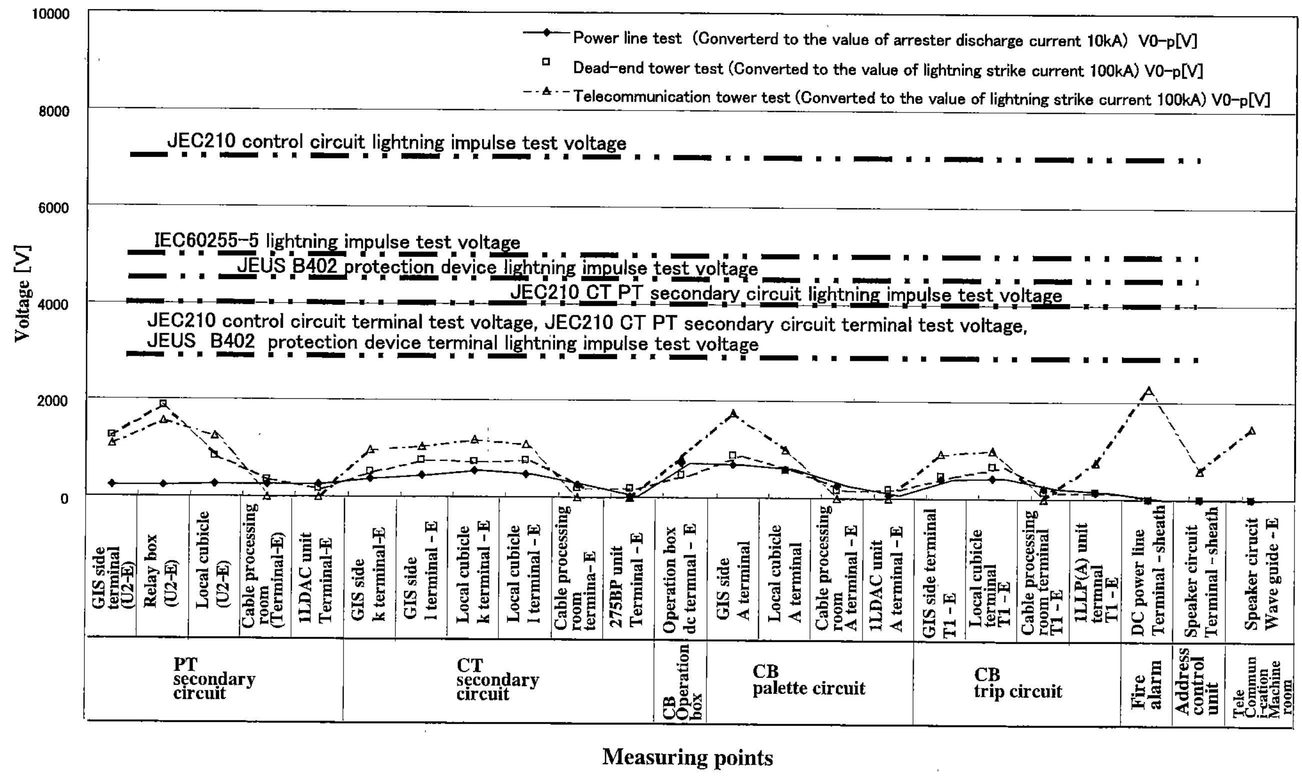


Fig. 8. Induced surge voltage and testing voltage levels of relating standards

Table 2. Outline of EMTP model

Apparatus	Items	Value
GIB	Surge impedance (Ω) propagation speed (m/microsecond) attenuation resistance (Ω/m)	Output of CABLE CONSTANTS
Surge arrester	Type 92	Restriction voltage 600kV (at 10kA)
Line from IG	Serge impedance (omega) propagation speed (m/μs) attenuation resistance (Ω/m)	600 300 0
Others	Standard values (Lightning proof design guidebook) Power lines : simulate five towers of 275kV line, grounded at the fifth tower. Tower: 4-story tower model	

Table 3. Types and length of the PT secondary cables

Division	Type	Length
PT - relay terminal	CVVS-5.5sqX4C	5m
Relay terminal - local board	CVVS-5.5sqX4C	24m
Local board - cable processing room	CVVS-8sqX2C	84m
Cable processing room -relay unit	CVV-8sqX2C	41m

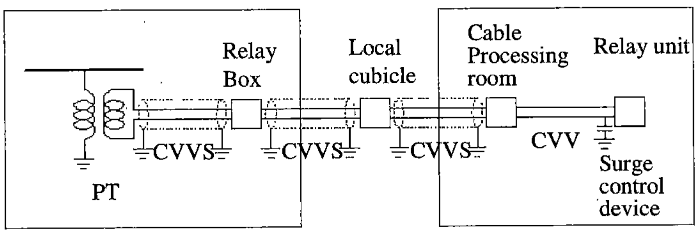


Fig. 9. PT secondary circuit

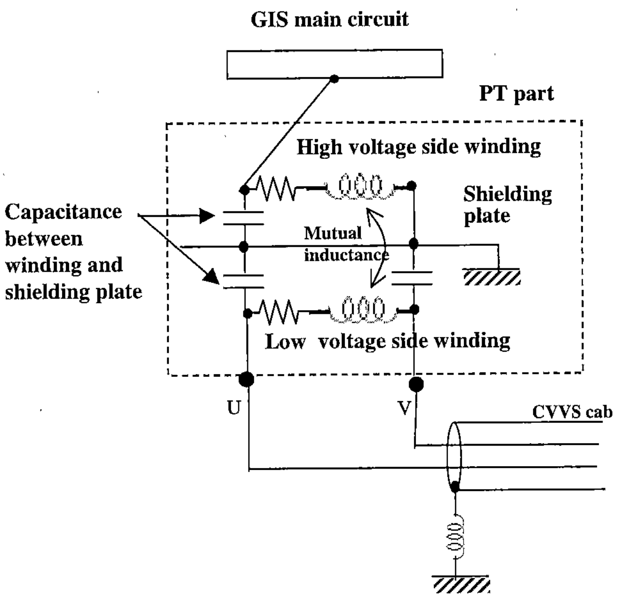
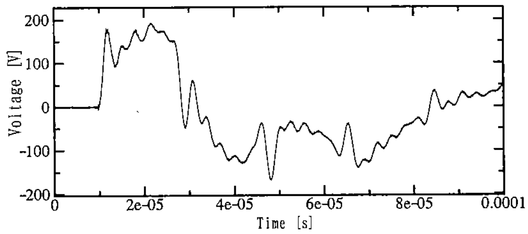
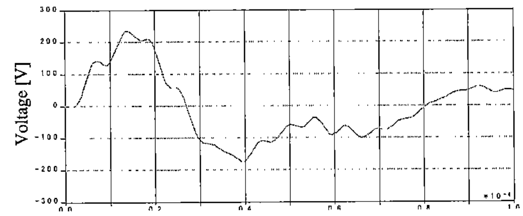


Fig. 10. Model of PT

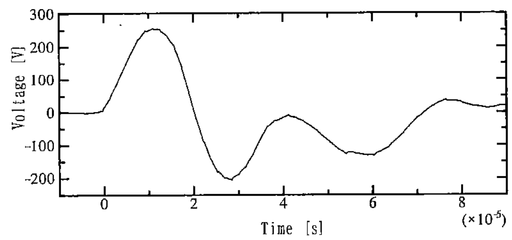


(a) Measured waveform

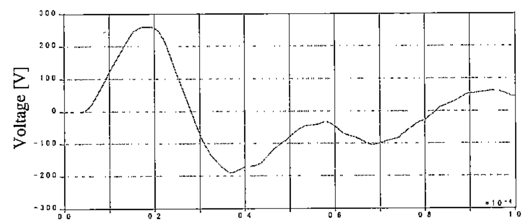


(b) Analyzed waveform

Fig. 11. PT secondary circuit voltage (GIS side terminal)



(a) Measured waveform



(b) Analyzed waveform

Fig. 12. PT secondary circuit voltage (relay unit terminal)

part and arrester discharge current waveforms coincided well with measured waveforms.

In the measured results, only the results of PT secondary circuit in power line test contained relatively lower frequency component around 25 kHz. On this circuit, EMTP analysis was performed and generation mechanism was examined. The kind and length of a control line cable in PT secondary circuit are shown in Table 3. The circuit constants of a control line cable were obtained using Cable Constants.

Figure 9 shows the composition of PT secondary circuit. PT was modeled by 2 windings with mutual inductance. Figure 10 shows this model. The self-inductance and the mutual-inductance were computed from the dimensions of high-voltage side winding and low-voltage side winding, and the capacitances between windings and a shielding plate were also taken into consideration. This model can simulate the frequency characteristics of the PT in which frequency components under 200 kHz transfer secondary circuits by almost winding ratio.

This model was incorporated in the EMTP equivalent circuit of power line test. The measured waveform and analyzed waveforms of the PT secondary circuit at GIS side terminal are shown in Fig. 11(a) and (b). Figure 12(a) and (b) show measured and analyzed waveforms of PT secondary circuit at relay unit terminal. Levels and basic frequency of measured and analyzed waveforms are well coincided with each other.

This shows that the surge voltages generated in the main circuit by lightning stroke transfer to the secondary circuit of this type of PT by the winding ratio. This indicates that the surge voltages induced in PT secondary circuit due to lightning strike do not reach to the level which poses a problem if the overvoltages in the main circuit are appropriately controlled by surge arresters.

5. Conclusion

In the 275 kV GIS substation before commercial operation, full scale lightning surge tests were performed. The purpose was to grasp the induced voltage level in the low-voltage circuit.

From these results, it turned out that test voltage levels of related standards are in a higher level than the induced voltage levels. The standards are considered to have sufficient levels to secure the insulation reliability of low-voltage circuits of the substation in this voltage class.

Furthermore, induced voltages in PT secondary circuit were analyzed. From the analysis, the frequency components up to about several 100 kHz were found to transfer to a secondary low-voltage circuit from a high-voltage circuit by the factor corresponding to the winding ratio of the PT. This indicates that, when the main circuit voltages are controlled appropriately by surge arresters, the voltages induced in PT secondary circuit are considered not to exceed the level which poses a problem to the low-voltage circuit.

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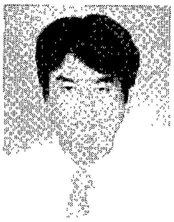

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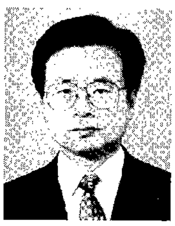

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