# Surge Arresters Operation at Opening of No-load 500kV Transmission Line

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**Abstract—High performance Metal-Oxide surge arrester (SA) with low protective level has been applied to a Gas Insulated Switchgear (GIS) substation. Some surge arresters in a newly commenced 500kV full-GIS substation operated frequently although there was no lightning during operation.**

**This paper describes that temporary overvoltage, when a circuit breaker opens a no-load transmission line, causes SA frequent operation. Electro-Magnetic Transients Program (EMTP) simulation reveals the occurrence process of this phenomenon.**

**In order to confirm the validity of the simulation, we measured discharge current of the SA in the 500kV full-GIS substation. As a result, the measured waveform is almost equal to the simulated one. Thus, the occurrence process and the simulation result are applicable to this phenomenon.**

**Keywords: Temporary Overvoltage, Surge Arrester, Transmission Line, Switching Surge, EMTP (Electro-Magnetic transients program)**

## I. Introduction

The lightning impulse protective level (V10kA) of surge arrester (SA) made of Metal-Oxide used to be 1,220kV in a conventional 500kV substation. Now, the high performance SA which reduce V10kA by about 30% (V10kA = 870kV) is used. For this reason, the discharge inception voltage of the high performance SA also decreases. [1] [2] [3]

In recent years, the high performance SA with low protective level is applied to a Gas Insulated Switchgear (GIS) substation because such SA makes it possible to install the low Lightning Impulse Withstand Voltage (LIWV) equipment which leads to cost reduction. Some surge arresters in a newly commenced 500kV full-GIS substation operated frequently although there was no lightning during operation.

This paper describes that temporary overvoltage, when a circuit breaker (CB) opens a no-load transmission line, causes SA frequent operation. Discharge current of the SA measured in the 500kV substation and Electro-Magnetic Transients Program (EMTP) simulation reveal the occurrence process of this phenomenon.

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## II. Simulation of Temporary Overvoltage

### *A. Simulation model*

No-load parallel transmission lines model is shown in Fig. 1. Phase configuration of transmission line and Tower size are shown in Fig. 2. Simulation data is shown in Table 1.

EMTP analyzes the voltage fluctuation when the one-side is opened.

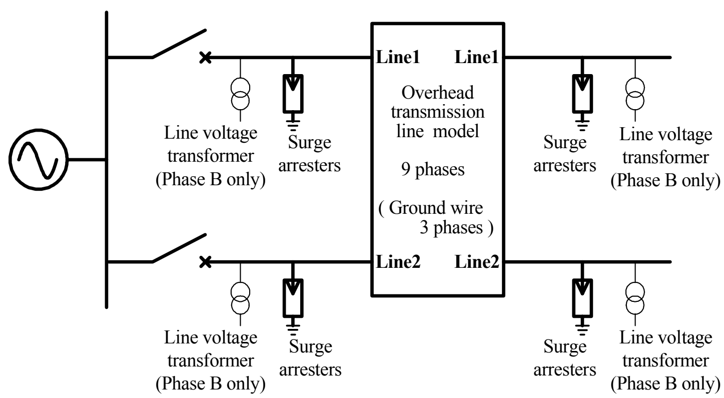


Fig. 1. No-load transmission line analysis model.

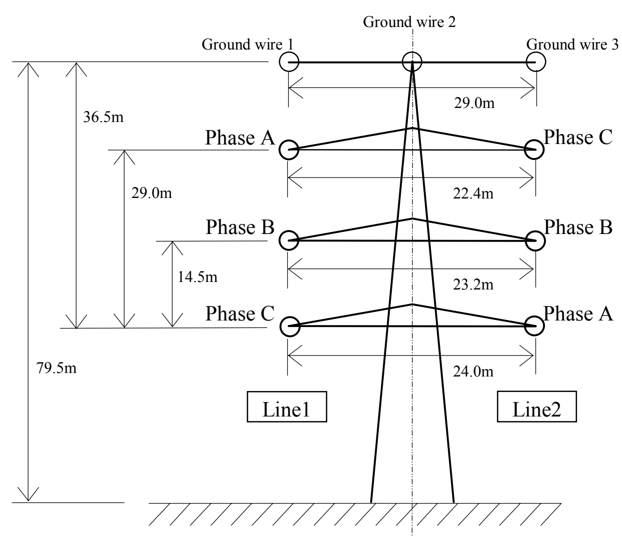


Fig. 2. Phase configuration of transmission line and Tower size.

## B. Simulation Result at Opening Transmission Line

Figure 3 shows the simulation waveform of Line1 voltage at opening Line1. Figure 4 shows the simulation waveform of Line2 voltage at opening Line2.

The simulation waveforms of Fig. 3 and Fig. 4 reveal that the voltage waveforms differ with the first interrupted phase and with the lines.

In Fig.4-(b), the absolute maximum peak voltage is 627kV in phase A.

## C. Occurrence Process of Temporary Overvoltage

From the simulation result, the occurrence process of the temporary overvoltage can be described as below.

1. When the CB interrupts each phase, alternating-current peak voltage remains on each phase as residual voltage. This is because only charging current flows on the no-load transmission line.
2. The residual voltage of the interrupted phase(s) fluctuates because of electrostatic induction from the non-interrupted phase(s).

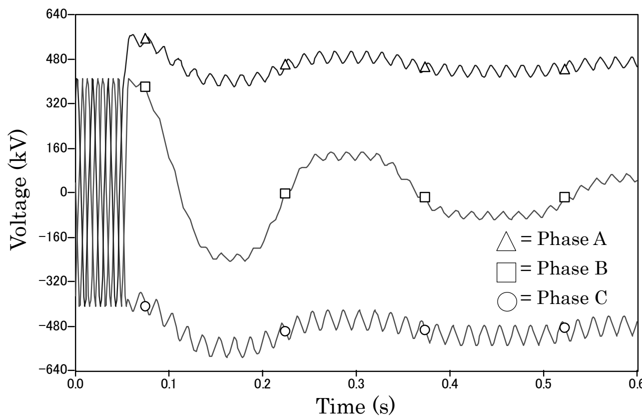


Fig. 3-(a). The first interrupted phase is A.

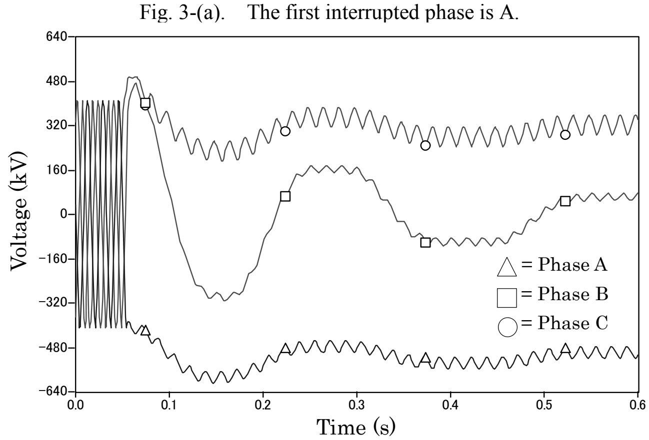


Fig. 3-(b). The first interrupted phase is B.

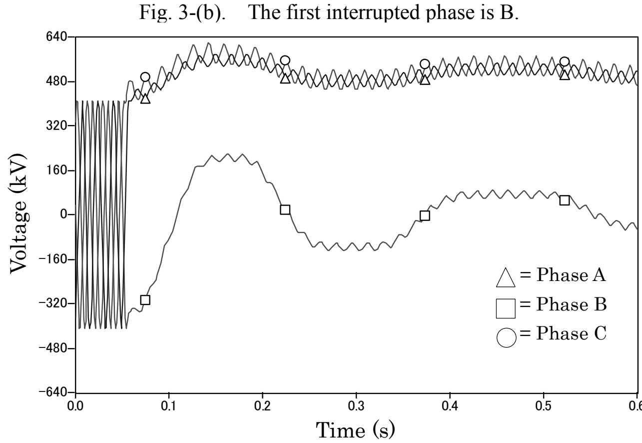


Fig. 3-(c). The first interrupted phase is C.

Fig. 3. Simulation waveforms of Line1 voltage.

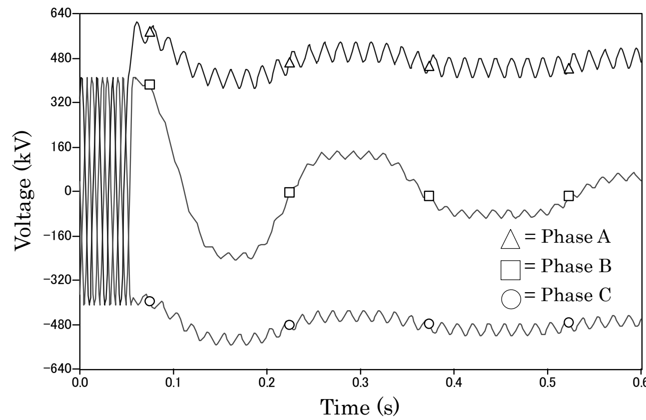


Fig. 4-(a). The first interrupted phase is A.

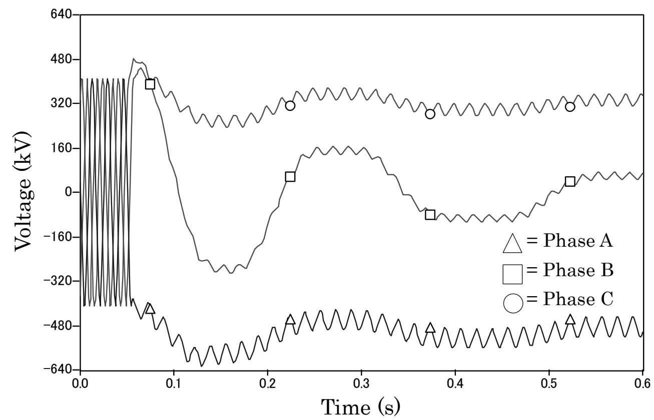


Fig. 4-(b). The first interrupted phase is B.

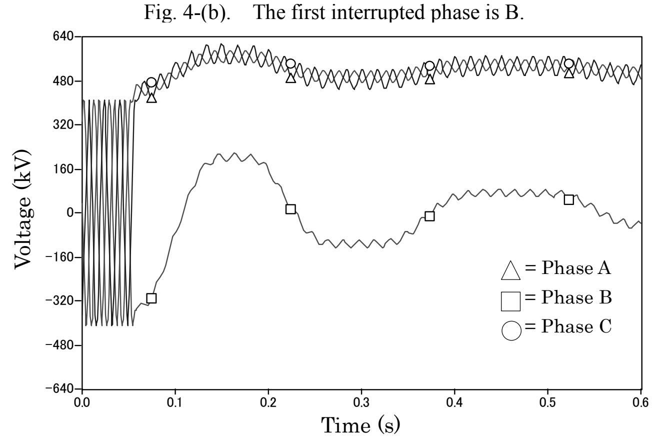


Fig. 4-(c). The first interrupted phase is C.

Fig. 4. Simulation waveforms of Line2 voltage.

TABLE 1. SIMULATION DATA

| | | Data |
|---|---|---|
| Simulation program | | EMTP (ATP) |
| Overhead transmission line, Ground wire | | Multi phase model |
| Distance of transmission line | | 33.4 km |
| Power line | The number of phases | 6 |
| | SKIN | 0.364 |
| | RESIS | 0.024 Ω/km |
| | DIAM | 4.62 cm |
| | SEPAR | 60cm |
| | NBUND | 3 |
| Ground wire 1, Ground wire 3 | The number of phases | 2 |
| | SKIN | 0.354 |
| | RESIS | 0.165 Ω/km |
| | DIAM | 2.05 cm |
| | NBUND | 1 |
| Ground wire 2 | The number of phase | 1 |
| | SKIN | 0.394 |
| | RESIS | 0.163 Ω/km |
| | DIAM | 2.05 cm |
| | NBUND | 1 |
| Line voltage transformer ratings [JEC-1201-1996] [4] | | Primary voltage = 550/√3 kV<br>Secondary voltage = 110 - 110/√3 V<br>Output = 50 VA<br>Class = 3P<br>LIWV = 1425 kV |
| GIS surge arrester ratings [JEC-2372-1995] [2] | | Rated Voltage = 420kV<br>V10kA = 870kV |
| Source (Phase sequence) | | AC500kV, 3 $\phi$ , 60Hz<br>(A-B-C) |

The simulation waveform at the moment of the CB interrupting is shown in Fig. 5. Figure 5 is the waveform in the case that is the time of a horizontal axis expanded in Fig. 3-(a).

On the one hand, Phase A is much influenced by the electrostatic induction from Phase B, because Phase A is near to Phase B in Fig. 2. Therefore, Phase A voltage rises from the residual voltage with the electrostatic induction from non-interrupted Phase B.

On the other hand, Phase A is not much influenced by the electrostatic induction from Phase C, because distance to Phase C is further than to Phase B, and because time from Phase A interruption to Phase C interruption is shorter than that from Phase A's to Phase B's.

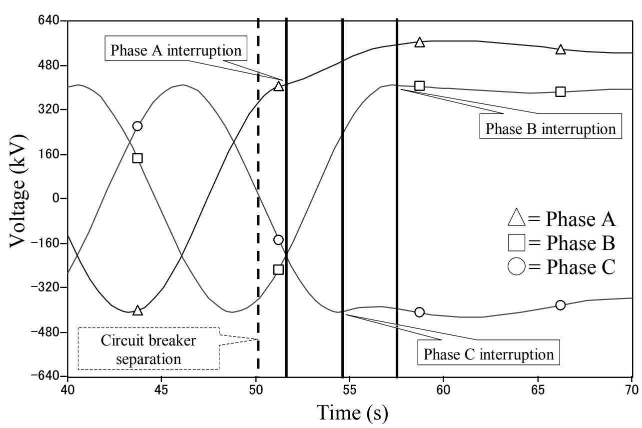


Fig. 5. Simulation waveform at the moment of the CB interrupting.

After the CB interrupts all the phases, the following phenomena continue.

3. Phase voltage vibrates with normal-frequency (60Hz) because of the electrostatic induction from the neighbor operating line (Line2).
4. In addition, Phase B voltage oscillates with low-frequency. A line voltage transformer (VT) is installed in Phase B only. This oscillation is caused by the coupling of the inductance of the VT which is saturated by the residual voltage and the capacitance of the transmission line. The voltages of Phase A and Phase C fluctuate slowly with the electrostatic induction from Phase B. The oscillation is attenuated with the passage of time.

The occurrence process of the temporary overvoltage on the transmission line described above is shown in Fig. 6.

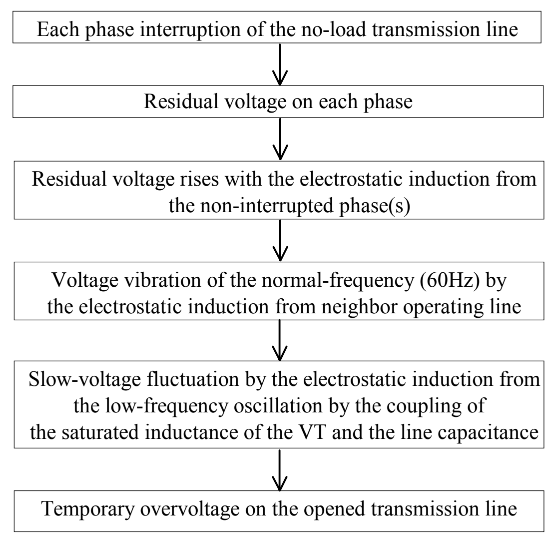


Fig. 6. Occurrence process of the temporary overvoltage.

The temporary overvoltage differs with the various factors such as the first interrupted phase, the line VT and the transmission line structure (e.g. the rating and the installation phase of the VT, the transmission line structure such as distance between wires, phase configuration, distance of transmission line, etc.).

## III. SURGE ARRESTER DISCHARGE WAVEFORM OF SIMULATION AND FIELD MEASUREMENT

### *A. Simulation waveform of SA discharge current*

Figure 7 shows the simulation waveform of Line1 voltage, when the first interrupted phase is C in Line1. The simulation waveform SA discharge current in phase C is shown in Fig. 8.

The simulation waveform in fig. 7 is reversed to be equal polarity to the measured waveform.

In Fig. 8, the SA in Phase C discharges four times.

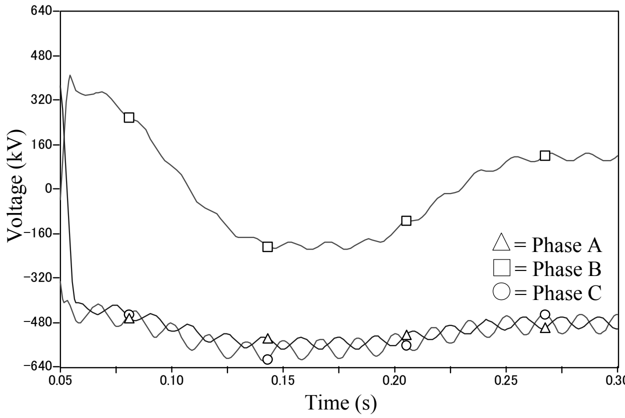

Fig.7. Simulation waveform of Line1 voltage (the first interrupted phase is C).

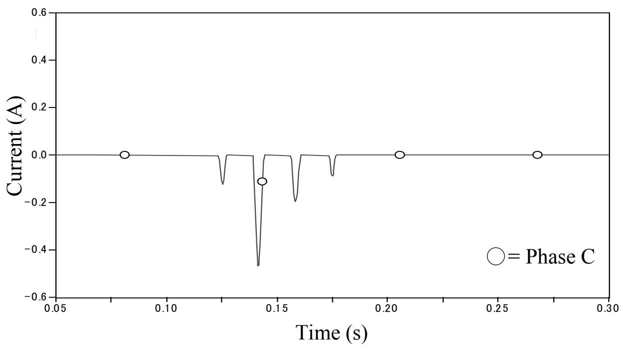

Fig. 8. Simulation waveform of Phase C SA discharge current (the first interrupted phase is C).

### *B. Field measurement of SA discharge current*

We measured the discharge current of the SA in the 500kV GIS substation where the SA had operated frequently.

The measurement object is the same transmission line modeled in the section II.

When Line1 was opened, SA in Phase C discharged four times. The measured discharge current waveform is shown in Fig. 9.

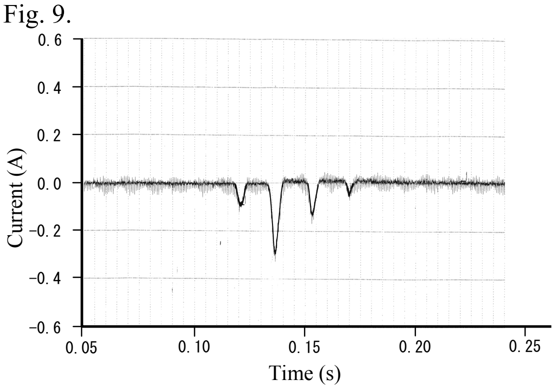

Fig. 9. Measured discharge current waveform of SA in Phase C.

In Fig. 9, Phase C SA discharges four times.

The measured waveform in Fig. 9 is almost identical to the simulated waveform in Fig. 8. Therefore, the simulation results are valid.

In the case of the newly commenced 500kV GIS substation, the discharge current of SA was small and the duration time was short. In addition, it was verified that SA were not degraded by such discharge current.

## IV. Conclusions

We revealed that the temporary overvoltage which happens at opening a no-load transmission line causes the frequent operation of the surge arresters in the new 500kV GIS substation. We conducted the simulation and the field measurement to confirm this phenomenon for the first time.

The temporary overvoltage takes place with the combination of the following four factors. The first is the residual voltage remaining after interruption. The Second is the residual voltage rising with the electrostatic induction from the non-interrupted phase(s). The third is the electrostatic induction from the neighbor operating line. The last is the electrostatic induction from the low-frequency oscillation that is caused by the coupling of the saturated inductance of the voltage transformer and the capacitance of the transmission line in the one phase.

As has been mentioned, the discharge aspect of surge arresters is changed by the various factors (e.g. the transmission line structure, the first interrupted phase, the line voltage transformer, etc.).

## V. References

[1] "Technical trend about adaptation technology and guide of metal-oxide surge arresters" IEE Japan Technical Report, No.966 (2004, June) (in Japanese)

[2] *Gas-insulated Metal-enclosed Surge Arresters*, Standard of The Japanese Electrotechnical Committee, JEC-2372 -1995 (in Japanese)

[3] *Metal Oxide Surge Arresters*, Standard of The Japanese Electrotechnical Committee, JEC-217-1984 (in Japanese)

[4] *Instrument Transformers for Protective Relays*, Standard of The Japanese Electrotechnical Committee, JEC-1201-1996 (in Japanese)

## VI. Biographies

**Satoshi Nomoto** was born in Nagano, Japan, in 1972. He received his Bachelor's degree in electrical engineering from Tokyo University of Agriculture and Technology, Japan, in 1995. He joined Chubu Electric Power Corporation Inc. in 1995. Presently, he is mainly engaged in the design of substations. He is a member of IEE Japan.

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