Paper

Characterized Discharge Current Waveforms of Metal Oxide Surge Arresters on 77 kV Power Systems

Iwao Miyachi* Honorary Member
Masayuki Yoda* Member
Toshiaki Ueda** Member
Kazuto Kanehara* Member

The behaviors of metal oxide surge arresters installed at substation terminal, generally without spark gaps are well-known by the excellent performances of automatic fault clearance and of reliable overvoltage protection of substation apparatus. As the result of four-year research experiences on the 77 kV operating power systems including observed substations T and F halfway between the protection terminals, authors have proved the characterized discharge current of those arresters can be divided into three types of waveforms such as instantaneous heavy pulse, low level lingering continuance and medium continued damping oscillation. The negative lightning discharge with subsequent multiple strokes against de-energized power lines may be the distinct and frequent causes of damping current oscillation of surge arresters. Moreover, the negative discharge current on the sound phase has been encountered not a little in the case of related double-line-to-ground fault. In this paper, the combination of those parameters is clearly expressed through several representing figures of arrester current waveforms together with those of corresponding voltage of surge fronts and 60 Hz voltage transients if available.

Keywords: metal oxide surge arrester, discharge current, characterized waveform, 77 kV system, multiple lightning stroke.

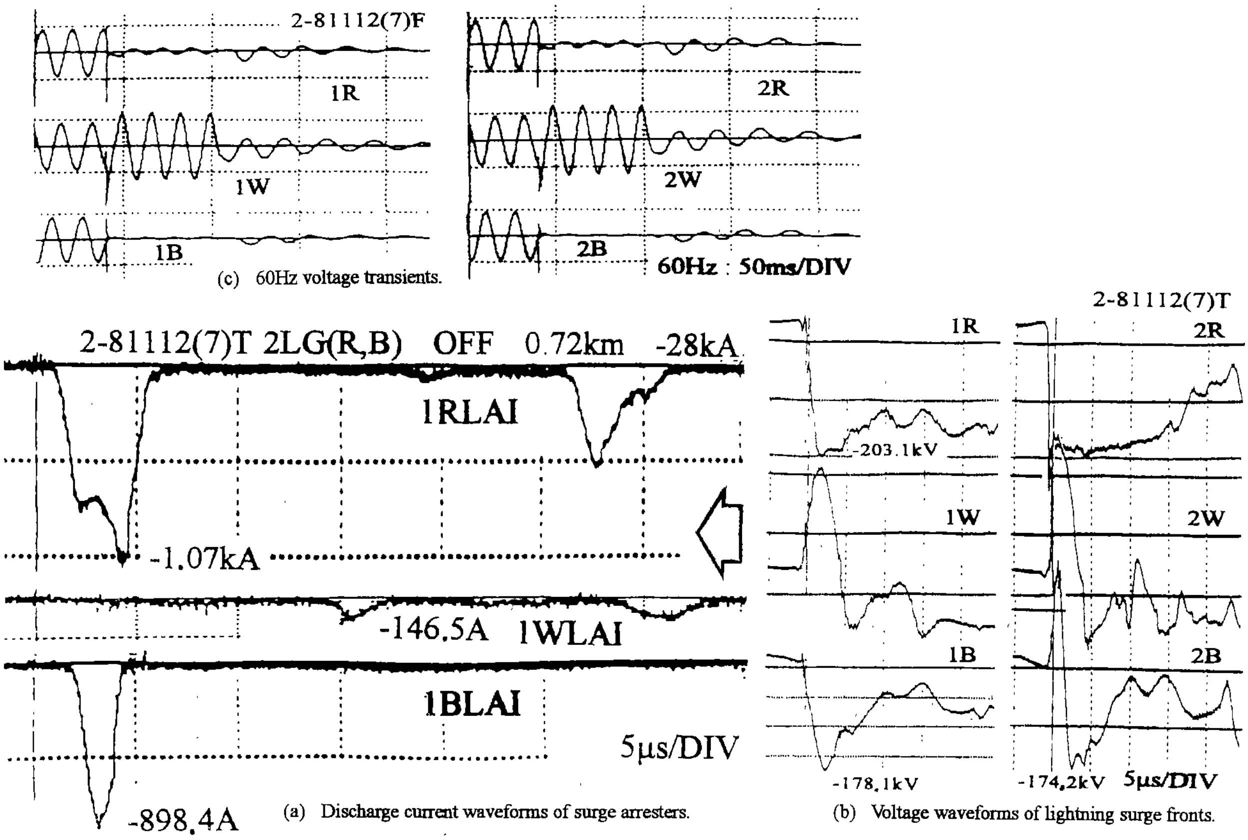
1. Introduction

The substations T and F are situated, with 10.13 km power-line distance apart from each other, on one of the most terribly lightning-exposed regions in the south of mountainous Gifu prefecture, central Japan. Among the numerous field data obtained through summertime experiments ranging from June 1990 to August 1993, discharge currents of high performance metal oxide surge arresters are analyzed in detail, and are revealed to have three distinguished types of waveforms characterized by sharp pulse, low level lingering continuance and evident damping oscillation. The phenomena are rather exaggerated while the system being de-energized than normally operated. Actually, the substation T is usually fed by circuit no.1 and the substation F by circuit no.2 of 77 kV double circuit halfway between the protection terminals. Therefore, the apparatus such as transformers and arresters are always left connected to power lines even if they are de-energized. Distinct three types of arrester current waveforms are equally obtained both in the fault-related and de-energized conditions. The independent pulse current or eventually following another one is usually included within a short period of 5 μs each and lingering small current tends to continue more than 40 μs. The characteristic damping current oscillation can be classified as the phenomenon comprised within a time interval of 25 μs. The characterized discharge current waveforms of the surge arrester on phase R of circuit no.1, for example, is represented by 1RLAI and so forth with the same scale for all the figures except Fig. 4. They are accompanied with two different sorts of diagrams corresponding to line-to-ground voltages, 1R etc., the one for the related surge front and the other for the overall 60 Hz transients. Each figure is headed, as far as possible, by the date number notation, observed substation, type of back flashover with included phase symbols, the ending fact, fault distance and estimated original lightning current intensity. The 3-phase conductors R, W and B are installed on the transmission tower in the order of decreasing height, and also B and W are equipped with instrument capacitor at substation T and F respectively. All the arrester current and surge voltage waveforms were obtained by specially designed GIS-type measuring devices through electro-optical system of extra-high resolution with allotted sampling period of 20 ns at substation T, and 50 ns at substation F. The referred 60 Hz voltage transients at substation F were measured by 20 μs sampling period for a range of 400 ms [1].

* Department of Electrical Engineering, Aichi Institute of Technology
1247, Yakchigusa, Yakusa-cho, Toyota 470-0392
** Research and Development Division, Chubu Electric Power
20-1, Kitasekiyama, Odaka-cho, Midori-ku, Nagoya 459-8522

2. Pulse Current Discharge

A double-line-to-ground fault only 0.72 km distant

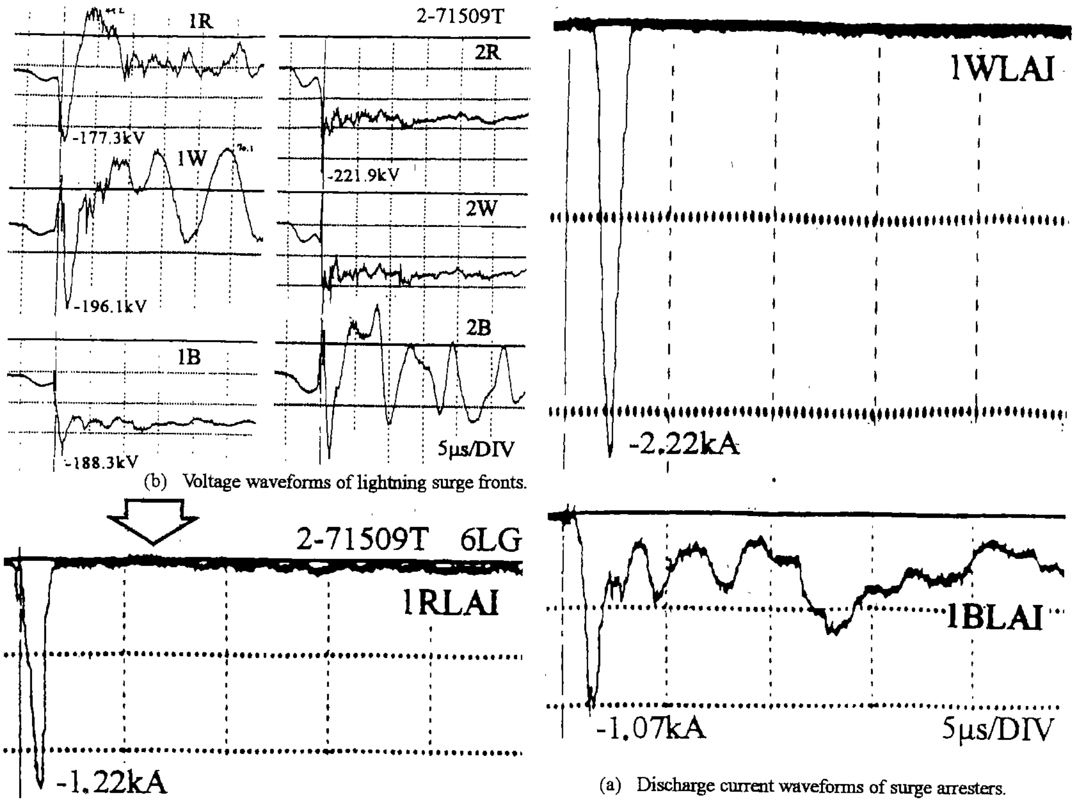


(c) 60Hz voltage transients.

(a) Discharge current waveforms of surge arresters.

(b) Voltage waveforms of lightning surge fronts.

Fig. 1. Fault-related pulse current discharge of metal oxide surge arresters (T)



(b) Voltage waveforms of lightning surge fronts.

(a) Discharge current waveforms of surge arresters.

Fig. 2. Pulse current discharge of metal oxide surge arresters while de-energized (T)

from substation T by the lightning flash of −28 kA results in the appearance of pulse type current discharge on the surge arresters at the terminal of circuit no.1, 1RLAI and 1BLAI, as shown in Fig. 1. The most positive instantaneous phase voltage R and the second most B are quite likely to cause flashover for the lightning attack of negative polarity as mentioned before [2]. More precisely, we can discriminate the first group (1R, 1B and 2R) and the second (2B) from the surge front diagram. After keeping sound condition for several cycles on phases 1 W and 2 W, the system has been perfectly shut down as shown by the figures of 60 Hz voltage transients. Here, we can point out the lightning current flow 1WLAI on the sound phase when the induced surge voltage happens to exceed the negative threshold of the arrester. Including the following second pulse of 1RLAI, all the pulse current flows are observed during the instantaneous surge voltage swing beyond this value of about −150 kV. This may not be the case for the surge voltage front 2R at the dead-end terminal with supposed current flow duration of about 15 μs.

Under the de-energized system condition brought about just after the clearance of lightning fault, power line conductors are momentarily free from the fixed voltage supply and are exposed to the subsequent multiple lightning strokes. Starting from the severe negative shift to about −50 kV on all of the six conductors, a sharp pulse discharge current 1WLAI of −2.22 kA at substation T has been detected together with 1RLAI of −1.22 kA as indicated in Fig. 2. On the contrary, the conductors 1B, 2R and 2 W are characterized by the continued longer intervention of arrester exceeding 30 μs as depicted through the surge front diagram. It is worth notice that the same event 2-71509 observed at substation F is classified, later in Fig. 4, as an example of lingering small current discharge. The fault distance is unknown and the more extended analyses should be widely carried out.

3. Lingering Small Current Discharge

Some hundreds of amperes lasting more than 40 μs can be recognized at substation F through Fig. 3 where the 2LG (R, B) fault followed by total shut down took place with the most negative phase W keeping momentary sound. Here, the surge arresters are solely installed on the common bus bars fed by circuit no.2 and no protective device is equipped at the dead-end terminal of circuit no.1. After the initial phase-to-phase interference from the grounded phases 2R and 2B, the sound phase 2 W tends to shift negative so as to cause the comparatively lingering current flow 2WLAI evidently recognized in the figure by delayed starting of some 5 μs. As the arrester current waveforms 1RLAI, 1WLAI and 1BLAI measured at substation terminal T for the same event are considered to belong to the same category; the original lightning surge voltage might have been the lingering nature.

An extremely long lasting period of small arrester current flow extending over 130 μs has been found at substation F as shown in Fig. 4. This is the counterpart of pulse current flow at substation T for the same event on de-energized system already studied in Fig. 2. With the initial negative voltage shift of about −70 kV on all of the six conductors at F terminal, the characterized

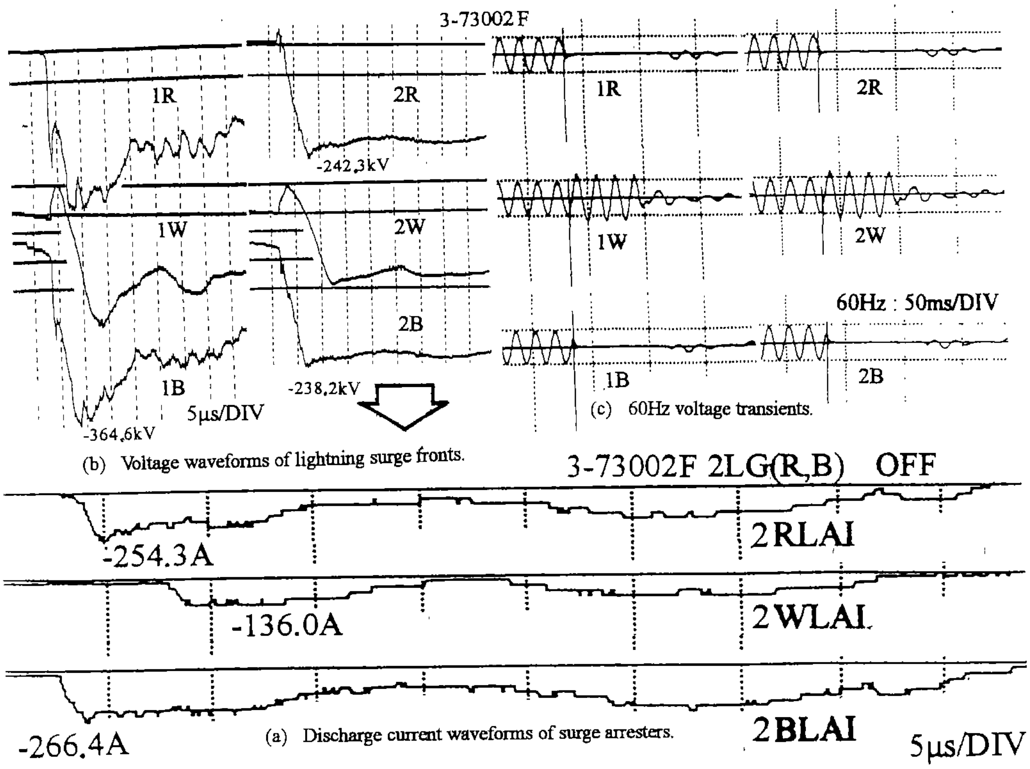
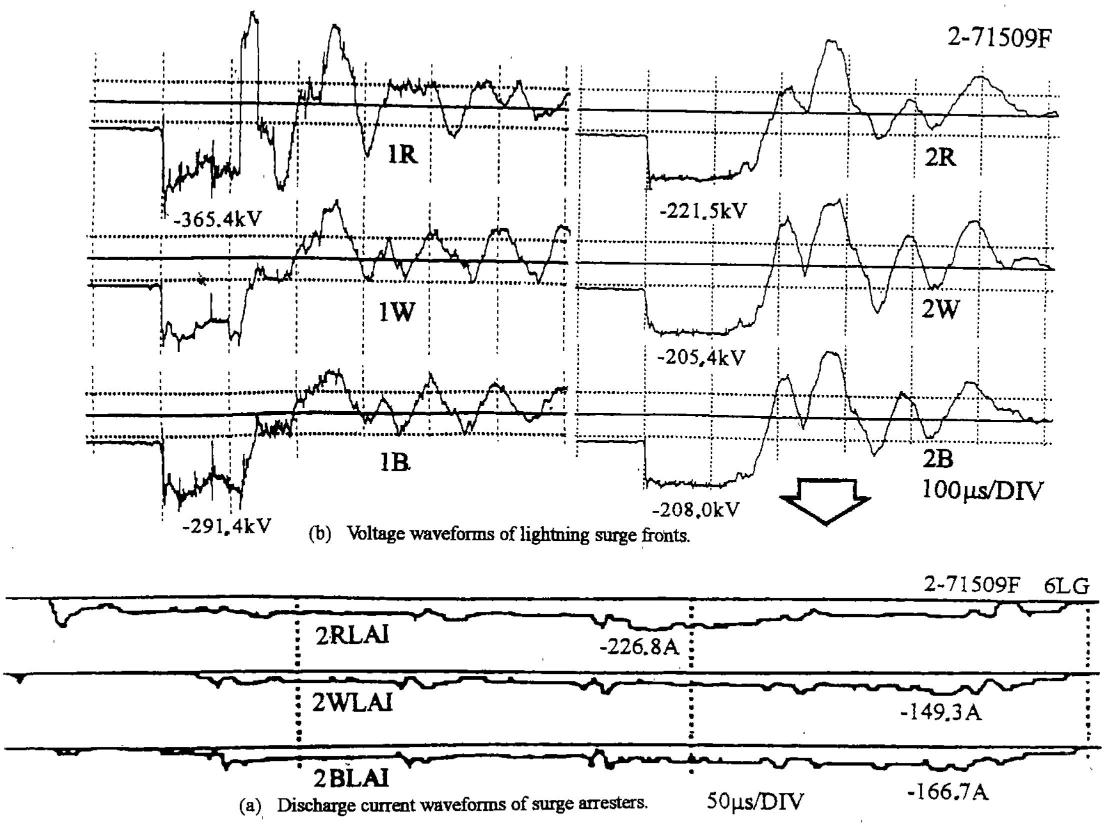


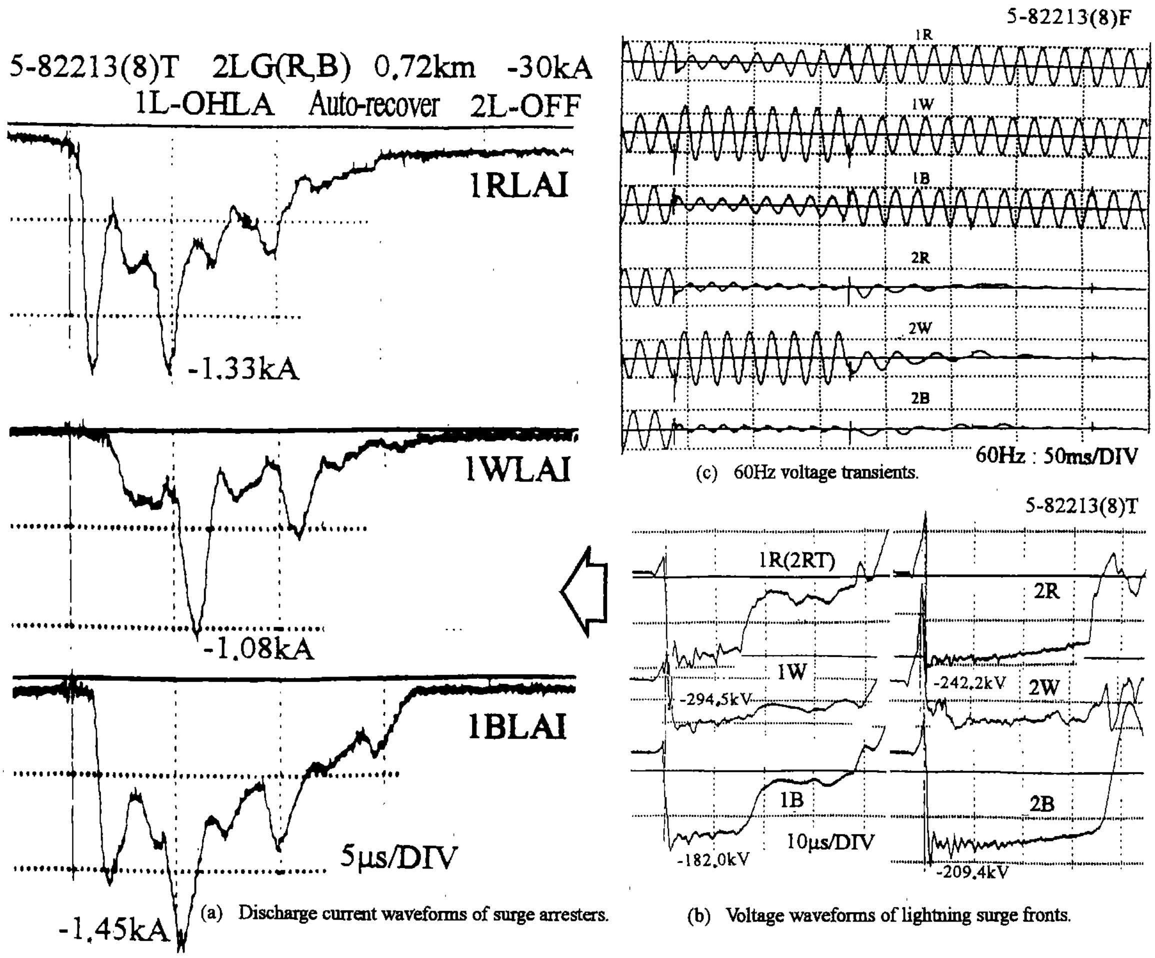
Fig. 3. Fault-related lingering small current discharge of metal oxide surge arresters (F)



(b) Voltage waveforms of lightning surge fronts.

(a) Discharge current waveforms of surge arresters.

Fig. 4. Lingering small current discharge of metal oxide surge arresters while de-energized (F)

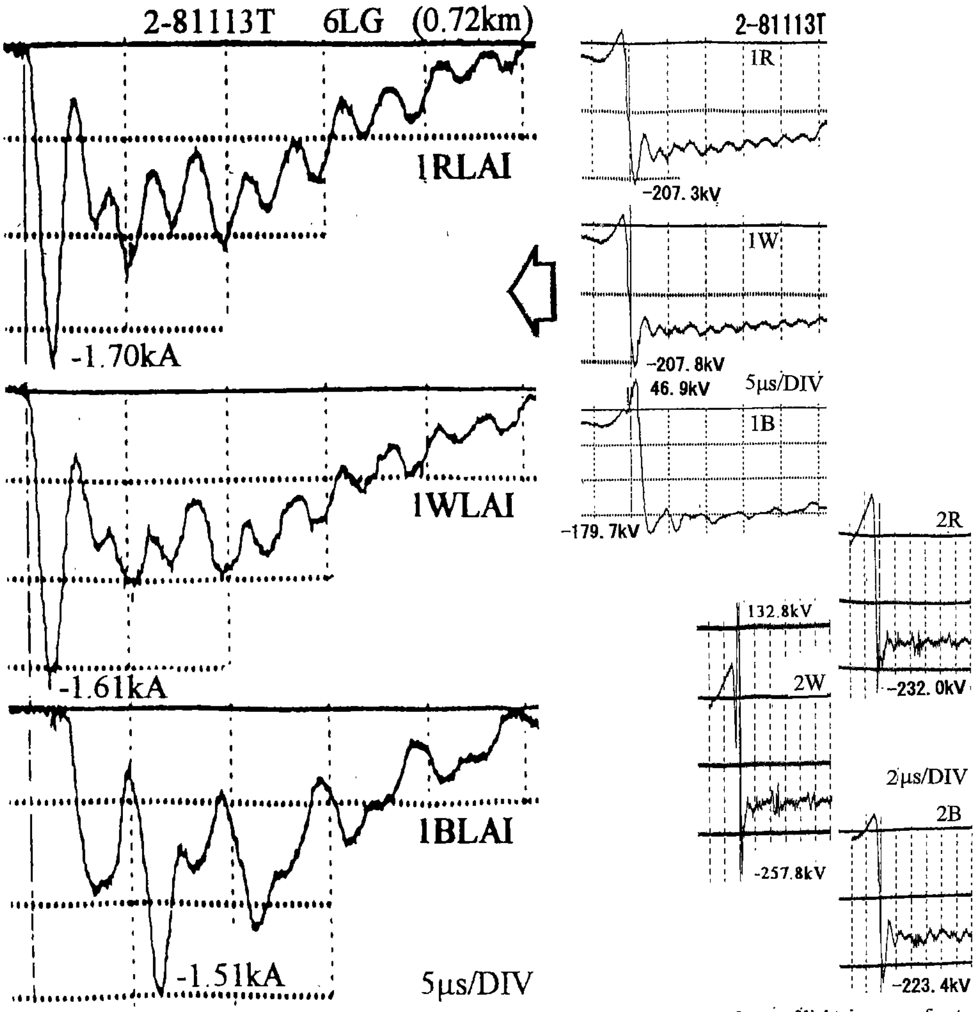


(c) 60Hz voltage transients.

(a) Discharge current waveforms of surge arresters.

(b) Voltage waveforms of lightning surge fronts.

Fig. 5. Fault-related oscillatory current discharge of metal oxide surge arresters (T)



(a) Discharge current waveforms of surge arresters. (b) Voltage waveforms of lightning surge fronts.

Fig. 6. Oscillatory current discharge of metal oxide surge arresters while de-energized (T)

lingering small current flow may be supposed to be derived from the long distant traveling of surge voltage front in contrast to the case of pulse current flow within a short range.

4. Oscillatory Current Discharge

Fig. 5 denotes the distinct oscillatory current flow on all phases of circuit no.1, 1RLAI, 1WLAI and 1BLAI, at substation T through a double-line-to-ground fault 2LG (R, B), originated by the 0.72 km distant lightning discharge of current intensity −30 kA. The arrester current flow on sound phase can be commonly found in this case too. The fault on circuit no.1 is cleared up in the discharge course of 15 μs by the effect of external gap type line arresters OHLA alternatively installed on this circuit, and the other circuit is finally shut down as recognized from the accompanied diagram of 60 Hz voltage transients. A half of the arrester operating period of circuit no.1 compared with circuit no.2 is supposed probably because of the reduced surge voltages through the OHLA intervention in series. The time interval between adjacent current peaks of 4.8 μs during the damping stage after initial transient is clearly corresponding to the shuttle distance of traveling waves equal to $0.72 \times 2 = 1.44$ km.

The oscillatory arrester current flow on de-energized system at substation T attacked about 32 seconds later than the case of Fig. 1 is shown in Fig. 6. As the arrester current intensities being almost the same order with those of Fig. 5, the lightning data may be estimated as well by the figures 0.72 km and −30 kA. The arrester current waveforms of the first two phases, 1RLAI and 1WLAI, are quite similar to each other and their oscillatory components are at an opposite polarity to that of the delayed phase, 1BLAI, as a whole. The delayed reason is probably based upon the lowest suspension height and connected instrument capacitor of the phase conductor B. The time interval of 4.8 μs between adjacent peaks can be also detected particularly on the arrester current waveform of delayed phase 1BLAI.

5. Summary

The discharge current of metal oxide surge arresters at 77 kV substation terminals T and F are studied through the continued four-year experimental research in summer. Three types of current waveforms such as instantaneous sharp pulse, low level lingering continuance and medium continued damping oscillation are discriminated. Those are represented by the figures obtained in the energized power line conditions as well as in the de-energized. Although the effect of combined original parameters including the distance from the faulty point shall be open to some more discussion carefully, a large number of the same types of discharge current waveforms have been found so as to be able to prove the pertinence of the proposed analyses. A negative current discharge on sound phase arrester in the case of 2LG fault has been discovered as the fairly common phenomenon during the power system protection against lightning discharge. This makes a striking contrast to the positive current discharge on the sound phase arresters in the case of probably nearby lightning attack to transmission equipments without line-to-ground fault.

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References

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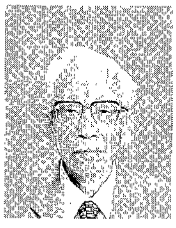
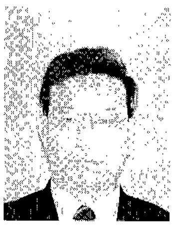
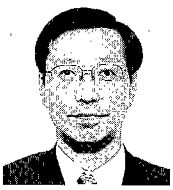


Iwao Miyachi (Honorary Member) was born in Kochi, Japan, on September 27, 1916. He was graduated from the University of Tokyo in 1940. He became a professor (1957) at Nagoya University, and professor emeritus (1980). In 1980, he became a professor at Aichi Institute of Technology and is presently a guest professor. He holds a D.Eng. degree. His research interests are switching surge and high power current interruption. He became director of the Institute of Electrical Engineers of Japan in 1977. He is a member of CIGRE distinguished and SEE (France).



Masayuki Yoda (Member) was born in Nagano, Japan, on March 18, 1948. Graduated from Nagoya University in 1970. He completed doctoral studies there in 1975 and became research associate in Engineering Division in 1975. He became a lecturer at Aichi Institute of Technology in 1976, an associate professor in 1979, and a professor in 1996. He was visiting researcher at MIT from 1984 to 1985. He holds a D.Eng. Degree. His research interests are electrical energy. He is a member of the Institute of Electrical Installation Engineers of Japan, IEEE, and the Institute of Engineers of Electrical Discharges in Japan.

Toshiaki Ueda (Member) was born in Shizuoka, Japan, on June 18, 1962. He received B.S. and M.S. degree in 1985 and 1987 from Tohoku University. He obtained Doctor's degree in 1998 from Nagoya University. He joined Chubu Electric power Co., in 1987. He has engaged in research on lightning surge analysis of power systems and substation equipment.



Kazuto Kanehara (Member) was born in Aichi, Japan, on December 8, 1959. He received B.S. and M.S. degree in 1982 and 1984 from Doshisha University. He joined Chubu Electric Power Co., in 1984. He engaged in research on transmission line and substation equipment.