A Practical Review of IEC Standards for Line Surge Arresters

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Keywords: LSA, EGLA, lightning protection, IEC standardization, verification test, application

1. IEC Standardization for Line Surge Arresters

Line surge arresters (LSA) using metal-oxide elements have been developed and used for lightning protection of overhead lines for more than 25 years. However, no dedicated standard for LSAs was available until IEC 60099-8: Metal-oxide surge arrester with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV, was published in 2011.

2. IEC 60099-8 for EGLAs

Large numbers of EGLAs have been in service successfully in Japan, contributing to significant improvement of lightning protection performance of overhead lines since the 1980s. Some of the basic requirements are unique and different from metal-oxide arresters without gap as stipulated in IEC 60099-4, ANSI/IEEE C 62.11, etc. They seem to compose the major background for IEC standardization.

An EGLA is constructed of a series varistor unit (SVU) containing metal-oxide resistor elements and external air gap without a parallel insulator, as shown in Fig. 1. The purpose for applying an EGLA is to improve the lightning performance of a line. Therefore the external series gap should spark over only due to fast-front overvoltages, and withstand power-frequency and slow-front overvoltages. The paper will summarize the unique requirements, and introduce related verification tests.

3. Revision of IEC 60099-5

Another aspect in IEC standardization of LSAs will be the revision of IEC 60099-5: Selection and application recommendations. The FDIS (Final Draft International Standard) of this standard, which will be voted on this year, contains newly established parts for LSAs. In the new IEC 60099-5, two types of LSA, i.e. EGLA and NGLA (non-gapped line surge arrester), will be introduced with each selection procedure. The paper will introduce the essence of LSAs, and will discuss necessary information about LSA application.

4. Outstanding Issues on LSA Testing

The unique verification tests for EGLAs stipulated in IEC 60099-8, such as standard lightning impulse sparkover test, follow current interruption test, and EGLA withstand test with failed SVU, are based on the Japanese practice. During discussion in the IEC maintenance team these test procedures were slightly modified for easier approach or more precise verification. The paper discusses the significance and remaining issues to be resolved. Some tests in IEC 60099-8 such as the lightning discharge capability test, short-circuit test, and bending test in mechanical load tests on the SVU are imported from IEC 60099-4 for metal-oxide gapless arresters. The paper refers to the significance and differences from the Japanese practice, and provides considerations for future discussion.

An LSA is regarded as a package product including mounting hardware and, in the case of NGLAs, lead wires and disconnector. That is, the mechanical soundness of the mounting structure against various dynamic loads on overhead lines should be verified even if the LSA has failed. The paper also considers additional requirements for testing the LSA package.

5. Conclusion

Through discussions such as above, the paper aims to provide a more practical understanding of utilizing IEC standards for LSA testing and field application.
Photographic Investigations on Lightning Impulse Discharge Phenomena in Soil

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Keywords: breakdown mechanism, electrical breakdown, streamer discharge, positive streamer, negative streamer, electron avalanche

Due to the non-transparency of soil, a lot of conventional methods for gas discharge are hard to apply, and taking photos of soil discharge under impulse using X-ray films becomes the most effective means. Analyzing the images of soil discharges under impulse conditions, the discharge processes and breakdown mechanisms of soil can be estimated.

The purpose of this paper is to study the lightning impulse performance of soil by using X-ray film imaging technology. A common electrode arrangement is used. The soil is put in the well grounded iron hemispherical container, the rod electrode connected to the impulse generator is inserted into the soil sample, and the X-ray film is arranged close to the high voltage electrode to catch the images of the soil ionization.

Through a large number of tests, we obtained some pictures of soil discharges under impulse voltage. Under negative impulses, due to differences of the soil property and the impulse voltage applied, the spark discharges of soil under negative impulse voltage are quite different with each other, there are three types of streamer discharges, which are shown in Fig. 1, and are quite similar to the streamer discharges in gas.

The developments of the streamers in soil were explained by using the gas discharge theory. Besides, the similarity between the phenomena in soil and in gas effectively supports the electrical breakdown mechanism of soil under impulse, that is, soil breakdown under impulse is mainly caused by the avalanches of the gaps between soil particles.

An image under the rod-plane electrode arrangement was shown in Fig. 2. It can be seen that there were many tiny and isolated white points in the discharge region, showing an obvious phenomenon of discontinuous ionization. The bottom figure in Fig. 2 was the partial zoom of the circle region, it could be seen more clearly that around soil particles, discontinuous ionization occurred, every branched discharge pattern seems to be formed around a soil particle.

With an ideal soil structure of several particles, the electric field under a fixed voltage can be calculated, and the regions sensitive for ionization under high electric field can be found. From analysis, we can conclude this discontinuous ionization phenomenon in soil is formed due to the non-uniformities of soil dielectric properties and the shapes and sizes of air apertures, this also support the soil ionization is caused by the electrical breakdown mechanism.

According to the causes of discharges, there are two mechanisms of soil breakdown, electrical breakdown and thermal breakdown, but from previous literatures supporting the thermal breakdown, the time duration of thermal breakdown was often a long delay, which reached hundreds or even thousands microsecond, while the process of the lightning impulse is shorter than one hundred of microsecond, the thermal process would be difficultly formed in such a short time duration.

If we consider the electrical breakdown, all of these phenomena from experiments can be well explained. From the detailed discussion in the paper, a possible conclusion can be drawn that soil breakdown under impulse is mainly caused by the electrical breakdown of the air among the soil particles.

In conclusions, due to differences of the soil property and the impulse voltage applied, there are three types of discharges, positive streamers, negative streamers, and negative feathers and positive retrograde streamers, which are quite similar to the streamer discharges in gas and can be explained by the gas discharge theory. The observed discontinuous ionization phenomenon in the soil around the grounding electrode was formed due to the non-uniformities of soil dielectric properties and the shapes and sizes of air apertures.
Wave Propagation Characteristics on a Pipe-Type Cable in Particular Reference to the Proximity Effect

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Keywords: impedance, frequency response, pipe-type cable, proximity effect, EMTP, FDTD

This paper investigates the proximity effect on the surge propagation on a pipe-type cable as a function of the eccentricity of the inner conductor against the pipe inner surface.

Figure 1 shows the frequency response of the coaxial mode impedance $z_c$ with various separation distance $d$, i.e. the degree of the eccentricity of the inner conductor against the center of the pipe. It is observed that the resistance increases as frequency increases due to the well-known skin effect. The resistance also increases as the eccentricity $d/r_p$ of the inner conductor increase, especially in a high frequency region. The increase of the resistance is somehow proportional to the distance from the pipe center. On the contrary, the inductance decrease as the eccentricity increases. This phenomenon is caused by the eccentricity of the inner conductor, and it is called "proximity effect".

Figure 2 shows EMTP simulation results, (a) $V_1$ and (b) $I_1$ at the sending end when a voltage with the amplitude 100 V and the rise time $T_f = 15$ ns is applied in the case of the lead wire inductance $L_0 = 0.5 \mu$H. The effect of the eccentricity is very clear in the simulation results in Fig. 1. For example, the first peak voltage for $d/r_p = 0.9$ (Case 1) is 50 V, while that for $d/r_p \leq 0.5$ is about 70 V, which is greater by 1.4 times. This corresponds to the greater surge impedance for $d/r_p < 0.5$. The current for $d/r_p = 0.9$ becomes greater by about 1.7 times than that for $d/r_p \leq 0.5$ correspondingly.

Figure 3 shows an FDTD simulation result of $V_1$, which satisfactorily agrees with the simulation result in Fig. 2(a), and the effect of the eccentricity is clearly observed.

Based on the investigations, the following remarks are obtained.

(1) The conductor impedance is significantly affected by the eccentricity when it is large. The resistance increases and the inductance decreases as the eccentricity increases. The effect of the eccentricity is more pronounced in a high frequency region.

(2) The conductor characteristic impedance and the propagation velocity decrease as the eccentricity increases proportionally to the decrease of the inductance. The attenuation constant increases proportionally to the increase of the resistance as the eccentricity increases. The difference of the characteristic impedance and the attenuation constant are more noticeable in a high frequency region, while that of the propagation velocity becomes more noticeable when the frequency becomes lower.

(3) Corresponding to the above, a transient voltage becomes smaller and a transient current becomes greater as the eccentricity becomes larger. It should be noted that the lead wire inductance comparable to the inductance of a conductor and the rise time of an applied voltage affect a transient voltage and currents very significantly when a tested conductor is short, and thus it becomes not easy to discuss the effect of the proximity from a measured results of a transient response.

(4) FDTD simulation results satisfactorily agree with the EMTP simulation results, and show clearly the effect of the eccentricity during a transient. Thus, the significance of the eccentricity, i.e. the proximity effect on the transient has been confirmed also by an FDTD simulation.

Fig. 1. Frequency characteristic of coaxial mode impedance $z_c$

(a) Resistance $R$
Case 1: $d = 4.5$ cm, Case 2: $4.0$ cm, Case 3: $2.5$ cm, Case 4: $1.25$ cm,
Case 5: $0$, $r_p = 5$ cm
Fig. 2. Simulation results for $T_f = 15$ ns and $L_0 = 0.5 \mu$H

(b) Inductance $L$

Fig. 3. FDTD simulation result $V_1$ corresponding to Fig. 2(a)
Case Studies of Recent Lightning Troubles in Traction Power Supply System

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Keywords: traction power supply, catenaries system, silicon rectifier, lightning trouble, traction substation

In Japan, DC1.5 kV traction power supply system has been adopted for high density electric railway transportation system in central part of Japan, mainly in Honshu that is the main island of Japan. AC20 kV, on the other hand, has been applied in regional area mainly in three islands, Hokkaido, Shikoku and Kyusyu and AC25 kV is used for high speed railway called Shinkansen, respectively. Figure 1 shows the voltage level map of electric railway in Japan.

In DC1.5 kV system, it is possible to reduce insulation level compared to AC traction power supply system and appropriate to be used in city area. The peculiarity of DC power supply is, however, its difficulty to detect ground fault caused mainly by lighting as the ground fault current is much smaller than regular load current and the concept of three phase imbalance is not able to be utilized to detect the ground fault. So that, such a ground fault trouble sometimes results in a critical transport disorder such as a breaking of contact wire above the railroad tracks. In this paper, the examples of lightning troubles in DC1.5 kV traction power supply system such as overhead catenaries system and substation system are shown and the tendency of the trouble is described. Figure 1 shows the breaking procedure of the pair of feeder messenger wires by the arc caused by lightning estimated based on the remained broken wires and its burnout conditions.

As an example of lightning trouble in catenary system, the wire breaking trouble caused by lightning near Ogikubo station on August 5th, 2008 is explained in detail in this paper. In this trouble, a pair of feeder-messenger wires is broken by continuing D.C. grounding fault current caused by lightning and flashover at support point. According to the remained broken wires, the process of the wires breaking is estimated in detail in this paper.

As an example of lightning trouble in traction substation, the silicon rectifier trouble caused by lightning at Sakaori substation on July 25th, 2010 is explained in detail in the this paper. In this trouble, silicon rectifier was severely burnt and a part of switchboard for machine control was also electrically broken. The grounding fault detection relay was also broken. The outlines of the damages of silicon rectifier and ground fault detection relay were described in detail. Figure 2 shows the estimated process of fault progression in this trouble.

We hope, the detail investigations of such sever lightning troubles will contribute to enhance reliability of traction power supply system in the future.
Study on Lightning Overvoltage Generated on Power Distribution Lines with Telecommunication Cables

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Keywords: lightning protection design, distribution line, telecommunication cable, lightning overvoltage analysis

1. Introduction
Due to the progress of information-oriented societies, telecommunication cables are often installed on concrete poles along with power distribution lines. When a lightning stroke hits a concrete pole equipped with an overhead ground wire and a telecommunication cable, the lightning current is split into the three paths: the concrete pole, the overhead ground wire, and the telecommunication cable.

In this paper, we clarified the effect of the telecommunication cable on reducing the voltages across the phase-wire insulators from the both sides of an actual-scale distribution line test and EMTP (Electro-Magnetic Transients Program) analysis.

2. Main Results
At first, we experimentally clarified the effect of the telecommunication cable to reduce the voltages across the phase-wire insulators by using an actual-scale test distribution line. Figure 1 shows the experimental result of the maximum insulator voltage. When a telecommunication cable was installed, the insulator voltage decreased, particularly when the overhead ground wire (GW) was not installed.

Fig. 1. Effects of the telecommunication cable with respect to the maximum insulator voltage

Next, we proposed a model of the telecommunication cable for the lightning overvoltage analysis. Figure 2 shows the comparison of the measured and calculated insulator voltage waveform. The calculated results using the proposed model agree well with the measurement results. Thus, the simulation model proposed in this paper is effective for of lightning overvoltage analysis in distribution lines. Using this model, we analytically examine the lightning performance of a distribution line equipped with a telecommunication cable against a direct lightning stroke to a concrete pole. Figure 3 shows the calculated minimum two-phase flashover (FO) current. Similarly to the experimental results, the two-phase FO current is increased by the installation of a telecommunication cable, particularly when a GW is not equipped.

By considering the existence of a telecommunication cable installed on a distribution concrete pole, the lightning overvoltage behavior on the power distribution lines is estimated accurately.

Fig. 2. Comparison between the calculated waveforms and the measured ones

Fig. 3. Calculated minimum crest values of the 2-phase flashover current. (Lightning current waveform: 1/70 μs)
Study of Lightning Hazard Evaluation for Low Voltage Distribution Systems

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Keywords: lightning hazard, low voltage distribution line, telecommunication line, household electrical appliances, lightning

1. Introduction
Recently, lightning damage rate of household electrical appliances has increased to about two times as compared with that of 20 years ago. So establishment of lightning protection design of household electrical appliances has been an important subject with progress of a highly informative society. As examining lightning protection design of household electrical appliances, the individual measure for power equipment, communication equipment, and household electrical appliances is insufficient. And it is important to evaluate and examine these synthetically as one circuit (low voltage distribution system). Moreover, it is difficult to propose a unified lightning protection design of low voltage distribution system because there are many parameters related to lightning protection design. So it is effective to apply the lightning hazard evaluation in order to study the effective and efficient lightning protection design for low voltage distribution system. This report describes the results of the lightning hazard evaluation for low voltage distribution system based on experiments.

2. Lightning Hazard Evaluation Method
Figure 1 shows the flowchart of lightning hazard evaluation method. First, peak value of lightning current is extracted at the Monte Carlo simulation. Next, lightning shielding theory of geometric modeling electricity applies to extracted lightning current. As a result, the lightning striking frequencies to a concrete pole and a home antenna are calculated. The lightning hazard amount (H) is defined to multiplied by these lightning striking frequencies and divert ratio of lightning current that flows to household electrical appliances, as in Eq. (1).

\[ H = \left( \sum_{k=1}^{K} I_1(k) \times B_1 \frac{N}{M} \times \frac{A}{S} \right) \times K + N \times M \times A \times \frac{1}{S} \]  

Here, 
- \( H \): Lightning hazard amount of household electrical appliances. \([\text{kA/\text{House \times Year}}]\)
- \( I_1(k) \): Lightning current when lightning struck to a concrete pole. \([\text{kA}]\)
- \( B_1 \): Divert ratio of lightning current that flows into household electrical appliances, when lightning struck to concrete pole.
- \( K \): Lightning striking frequency to the concrete pole. \([\text{Number}]\)
- \( I_2(n) \): Lightning current when lightning struck to home antenna. \([\text{kA}]\)
- \( B_2 \): Divert ratio of lightning current that flows into household electrical appliances, when lightning struck to home antenna.
- \( N \): Lightning striking frequency to home antenna. \([\text{Number}]\)
- \( M \): Total frequency of lightning hit. \([\text{Number}]\)
- \( A \): Lightning striking density to the ground \([\text{Number/\text{km}^2 \times \text{Year}}]\)
- \( S \): Number of concrete poles per unit area \([\text{Number/\text{km}^2}]\)

3. Example of the Result of Lightning Hazard Evaluation
Figure 2 shows an example of the result of lightning hazard evaluation. This figure is the result of the calculation of the lightning hazard amount by the parameter of distance between home antenna and concrete pole, height of home antenna, and the grounding method of household electrical appliances. The lightning hazard amount of household electrical appliances becomes large, when grounding method of household electrical appliances is individual grounding or the height of home antenna is high. However, the lightning hazard amount is not affected by the distance between home antenna and concrete pole.
Analysis of Lightning Current at Home Electric Appliance in Case of Stroke to Concrete Pole

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Keywords: lightning, distribution line, SPD (surge protective device), concrete pole

1. Introduction
With the advent of highly advanced information-oriented society, the ITC appliances, vulnerable to the lightning surge, come to be widely used, and these appliances are reported to be frequently damaged by lightning. In this paper, the authors verified the lightning surge on an indoor distribution line calculated by the VSTL (Virtual Surge Test Laboratory) by comparison with the measurements obtained in the model house. Then, the critical current resulting in the damage of the SPDs is estimated in the case of the direct strokes to the concrete pole.

2. Verification of Calculation
In the analysis, the authors calculate the current and the voltage at the electric appliance by the VSTL, developed at the CRIEPI (Central Research Institute of Electric Power Industry), where the FDTD method is adopted.

In designing the protection measures, it is useful to classify the electric appliances to four categories, namely (I) the appliances connected to the power line only, (II) the grounded appliances, (III) the appliances with the antenna line and (IV) the appliances connected to the telecommunication line. The measurement is made in the model house where the appliance (I) to (IV) is connected to the indoor distribution line individually. Table 1 shows the accuracy of the calculated parameters, namely peak values, the front duration, and the time to half value of the peak of the current waveforms flowing into appliances (I) to (IV) for various current injection points. The accuracy of the calculated parameters is less than 6%. This demonstrates the validity of the calculated results through the VSTL.

3. Estimated Damage Rate
Figure 1 shows the schematic drawing of the analysis and Figure 2 shows the critical return-stroke current resulting in the damage of the SPD when the stroke hits the top of the concrete pole and the electric power is supplied from the transformer at pole No.1 to one customer where the appliance (I) to (IV) are connected together to the indoor distribution line. The varistor of the appliance (IV) is first damaged. The length of the low-voltage distribution line little influences the critical return-stroke current due to the existence of the overhead ground wire. With the increase of the distance to the struck pole from the pole No.1, the critical return-stroke current increases in a step-like manner: the critical current increases dependent on the number of the surge arresters on the path from the struck pole to the pole No.1 where the service wires are connected.

The probability of the direct stroke to the 1 km-long line, having the peaks of higher than 50 kA is about 0.21 times/year when the current distribution obtained by Berger et al. are used for the area with the lightning flash density of 3 flashes/km². If the length of the low-voltage line is 200 m, the frequency of direct strokes to the poles with the low-voltage line is 0.04 times/year. The electric appliances are reported to be damaged by the lightning current on the AC line at the rate of 0.006 times/year. With the increase of the load and/or the number of the customer supplied from the same low-voltage line, the critical return-stroke current increases. If the critical return-stroke current is 130 kA, the estimated rate agrees with the observed rate. This corresponds to the case that the load is 2.4 times of the assumed load. Taking account of this condition, the estimated rate reasonably agrees with the observed rate.

Table 1. Accuracy of calculated current parameters

<table>
<thead>
<tr>
<th>Injection point</th>
<th>Appliance</th>
<th>Peak value (%)</th>
<th>Front duration (%)</th>
<th>Time to half value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One phase wire of low-voltage distribution line (I.I)</td>
<td>I</td>
<td>1.8</td>
<td>3.8</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>0.3</td>
<td>2.5</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>4.5</td>
<td>5.9</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>1.0</td>
<td>3.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Three phase wires of low-voltage distribution line</td>
<td>II</td>
<td>0.5</td>
<td>4.8</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>5.4</td>
<td>3.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Fig. 1. Schematic drawing of analysis
Fig. 2. Critical return-stroke current
Assessment of the Lightning Performance of Compact Overhead Distribution Lines

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Keywords: lightning protection, overhead distribution lines, induced overvoltages, electromagnetic transients

This paper deals with the assessment of the lightning performance of medium voltage overhead distribution lines, carried out in the framework of a joint research project between AES Sul, the Federal University of Itajubá and the University of Bologna. A compact overhead line configuration is expected to be adopted in the near future by the Brazilian distribution company that serves a region characterized by high keraunic levels. The typical compact design is characterized by insulated covered conductors (without shield) and a close upper unenergized wire that has the main function of sustaining periodical spacers of the phase conductors. The specific configuration of the poles and the spacers adopted in this paper is shown in Fig. 1, with the upper wire located at 9.3 m above ground.

As the unenergized wire is periodically grounded, this paper presents the analysis of its effectiveness in reducing the overvoltages due to indirect lightning. Its contribution to the protection against direct lightning is disregarded as the insulation between the upper wire and covered conductors, around 215 kV that reduces to 95 kV in case of local damages of the insulation, is not considered sufficient.

The lightning performance analysis is based on a statistical procedure which applies the Monte Carlo method and the calculations of the indirect lightning induced voltages along the line are performed by using the LIOV-EMTP code. The lightning performance of the compact line is compared with the one calculated for a conventional line configuration usually adopted by the Brazilian power utility.

The procedure for the calculation of the lightning performance starts with the generation of a large number of events each characterized by the values of the lightning current parameters (amplitude and time to peak) and by the coordinates of the perspective stroke location at ground in the absence of the line, uniformly distributed in an area around the line large enough to include all the events that could cause induced voltages higher than the assumed minimum dangerous level. Such a dangerous level is the minimum voltage value considered in the abscissa of the graphs that represents the lightning performance of the line, i.e. the graph of the expected number of annual voltages exceeding the value in abscissa. The minimum voltage level is chosen lower than the expected insulation level of the line and of the connected components (in particular of the transformers).

The calculation performed for the case of compact configuration with the upper wire ungrounded along the line give results analogous to those obtained for the conventional configuration. The calculations with the upper wire grounded has been repeated for different values of the distance between succeeding wire groundings and for different values of the grounding resistance.

The paper shows and discusses the results obtained by assuming the presence of surge arresters installed along the line with compact configuration. The calculation takes into account the presence of a steady state voltage of the phase conductors.

The analysis shows that the compact configuration has some advantages with respect to the conventional one for the protection against indirect lightning events. These advantages are tangible provided that the upper wire is periodically grounded.

The paper shows the advantages of the presence of surge arresters located along the line of the compact line configuration examined. Their effectiveness is significant, although — as far as only lightning induced voltages are concerned — it could be considered as a secondary/additional protection mean with respect to the periodical groundings of the upper wire.
Deducing Locations and Charge Moment Changes of Lightning Discharges by ELF Network Observations in Japan

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Keywords: ELF transient, charge moment change, red sprite, thunderstorm activity

In this paper we derive, for the first time, the spatio-temporal distributions of energetic CG (cloud-to-ground) flashes around Japan with a charge moment change (CMC) information by using our new ELF network observations. To perform this study we set up a new permanent ELF observation station in Kagoshima Japan in addition to the existing station in Moshiri Hokkaido to establish the network observations of ELF transients. Then we deduce the detailed spatial lightning distribution together with the information of CMC around Japan and Asian region.

Figures 1(a) and (b) show the magnetic hodograms of an ELF transient simultaneously observed in the two field sites, MSR and TRU respectively. According to the hodograms from two separated field sites the location of the CG flash was obtained by the triangulation technique (Fig. 2). The determined CGF position of this transient is over the Pacific Ocean in the geographical coordinate system of 32.5°N and 147.7°E. Corresponding calculated CMC is −396 C·km (negative CG).

Figures 3(a) and (b) show the example of spatial distributions of CG flashes (March 25, 2011) for the positive and negative CG flashes respectively. The color of each dot (CG) stands for the amount of CMC with its polarity. Two active thunderstorm centers are clearly identified over the Pacific Ocean. Both positive and negative flashes have similar spatial distributions.

Figures 4(a) to (b) show the histograms indicating dependence of the CMC for the two well-known thunderstorm active regions around Japan. Both Figs. 4(a) and (b) indicate that the number of lightning events monotonically decreases with increasing CMC for both polarities but the total number detected by ELF transients for positive CG flashes is superior to that for negatives. Most importantly median value of the charge moment change from Pacific CG flashes is considerably larger than that of Sea of Japan for both polarities. The number of positive GC flashes is much larger than negatives over the Sea of Japan indicating typical nature of winter lightning in Hokuriku, whilst the number of positives and negatives are comparable for CG flashes over the Pacific Ocean. CMC between two regions can be due to the different meteorological conditions of thunderstorm activities (Pacific Ocean and Sea of Japan) during the early spring season. In future physical mechanisms of these differences will be investigated in detail.
Parameters Determination for a.c. Voltage and Current Waveforms Generated by IEC 61083-4 TDG

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Keywords: steady state a.c., short-term a.c., IEC 61083-4 TDG, FFT, base curve, digital recorder

IEC 61083-4 has been in draft stage since 2010. The publication comes with TDG (Test Data Generator) which generates simulated measured data in digital form for typical waveforms. Scientists participating in the compiling work of IEC 61083-4 should propose elegant waveform analysing algorithms before the final version of the publication is released in 2013 so that it can be made public that the reference parameter values and their margins to be shown in IEC 61083-4 are really reasonable for every given waveform. One of authors, among the committing members, believes to have found a couple of new algorithms for analysing TDG data and their details will be introduced in the paper in addition to the preliminary reports.

A short term a.c. current waveform is known to be described by the following equation in which the first term is called a.c. component and the second term d.c. component.

\[
f(t) = (I_1 e^{-t/\tau_{ac1}} + I_2 e^{-t/\tau_{ac2}} + I_3) \sin(2\pi f_0 t + \frac{\partial f}{\partial t} t - \Phi) + (I_1 + I_2 + I_3) \sin(\Phi) e^{-t/\tau_{dc}} \]

The proposed algorithm makes Eq. (1) to fit TDG digital data by adjusting parameters \( \tau, \tau_{ac1}, \tau_{ac2}, I_2, \tau_{dc}, I_3, \frac{\partial f}{\partial t}, \Phi \) using least square method. Once those parameters are determined, it is possible to compute a set of a.c. component, d.c. component and a combined value at the time when crest appears on every half cycle as IEC 61083-4 requires.

Every TDG short term a.c. waveform has been successfully processed by the software based on the proposed technique (see, Table 1). The calculated values are in good agreement with the theoretical one. The composed waveform using Eq. (1) and values in Table 1 as well as TDG raw data are plotted in the same figure (see, Fig. 1). It can easily be recognised that two curves look a single line and one cannot distinguish the difference.

The required values (crest value, etc) on each half cycle can analytically be evaluated using Eq. (1).

The significant advantage can be recognised in comparing the results of two waveforms, SHAC-A1 and SHAC-A5 in Table 1. Although the two TDG data are identical except digitised by different full-scale deflections (90% for SHAC-A1 and 30% for SHAC-A5), computed peak values are almost identical. The same fact is also confirmed at crest value in every half cycle.

-1500
-1000
0
500
1000
1500
2000
2500
0
0.2
0.4
0.6
0.8
1
1.2
Time (s)
Value (A)

Two curves are plotted.

Fig. 1. Given and computed waveforms, 16 bit resolution (SHAC-A7)

Table 1. Computed Waveform Parameters (16 bit resolution)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>( I_1 )</td>
<td>1.383</td>
<td>43.618</td>
<td>2.072</td>
<td>-200.005</td>
<td>200.925</td>
<td>652.077</td>
<td>320.000</td>
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<tr>
<td>( I_2 )</td>
<td>-1.383</td>
<td>37.834</td>
<td>0.002</td>
<td>-100.001</td>
<td>300.002</td>
<td>597.015</td>
<td>110.000</td>
</tr>
<tr>
<td>( I_3 )</td>
<td>999.999</td>
<td>918.548</td>
<td>997.926</td>
<td>1000.007</td>
<td>999.973</td>
<td>1250.009</td>
<td>1000.001</td>
</tr>
<tr>
<td>( \tau_{ac1} ) [ms]</td>
<td>-53.0156</td>
<td>large</td>
<td>large</td>
<td>400.070</td>
<td>400.078</td>
<td>400.127</td>
<td>399.944</td>
</tr>
<tr>
<td>( \tau_{ac2} ) [ms]</td>
<td>-53.0156</td>
<td>large</td>
<td>large</td>
<td>16.0007</td>
<td>16.0000</td>
<td>399.856</td>
<td>15.9996</td>
</tr>
<tr>
<td>( \tau_{dc} ) [ms]</td>
<td>45.0000</td>
<td>45.0000</td>
<td>45.0002</td>
<td>120.000</td>
<td>45.0001</td>
<td>80.0000</td>
<td>80.0000</td>
</tr>
<tr>
<td>( \theta^* )</td>
<td>89.9987</td>
<td>89.9991</td>
<td>90.0002</td>
<td>89.9946</td>
<td>89.9986</td>
<td>45.0000</td>
<td>44.9999</td>
</tr>
<tr>
<td>( \phi^* )</td>
<td>0.0020</td>
<td>0.0200</td>
<td>0.0020</td>
<td>0.0200</td>
<td>0.0020</td>
<td>0.0200</td>
<td>0.0020</td>
</tr>
<tr>
<td>( \eta^* )</td>
<td>0.19504</td>
<td>0.19504</td>
<td>0.19504</td>
<td>0.19474</td>
<td>0.19470</td>
<td>0.17792</td>
<td>1.06624</td>
</tr>
<tr>
<td>( C/A )</td>
<td>-0.00039</td>
<td>-0.00053</td>
<td>-100.001</td>
<td>-0.00031</td>
<td>-0.00013</td>
<td>-20.0000</td>
<td>0.00005</td>
</tr>
<tr>
<td>Peak [A]</td>
<td>1802.349</td>
<td>1802.349</td>
<td>1802.348</td>
<td>1395.496</td>
<td>2561.044</td>
<td>-3993.431</td>
<td>2364.458</td>
</tr>
<tr>
<td>( S )</td>
<td>8.5 \times 10^6</td>
<td>1.1 \times 10^7</td>
<td>8.0 \times 10^6</td>
<td>8.5 \times 10^6</td>
<td>8.5 \times 10^6</td>
<td>8.2 \times 10^6</td>
<td>8.9 \times 10^6</td>
</tr>
</tbody>
</table>

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