Development of Reference Impulse Measuring Systems and Investigation on Comparison Tests in Japan

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Abstract

The revised draft of IEC Publication 60 " High Voltage Test Techniques " introduced a new calibration system for impulse measurements. In order to corespond to this draft, development of reference measuring systems and investigation of comparison tests are being carried out in Japan. This paper is a preliminary report on the topic.

§1. Introduction

Impulse tests have occupied an important position in various high voltage and high current tests and the reliability of these test results depends on the test techniques, especially on the measuring techniques. Therefore, many researches have been carried out on impulse voltage and current measurements.
Furthermore, IEC standards publication 60-3 and 60-4, "High Voltage Test Techniques" , specifies the impulse measuring techniques in detail.
However, the present standards on the impulse measuring techniques were recognized to be incomplete and in sufficient by CIGRE 33.03 Working Group, "High Voltage Test Techniques." In 1990,A draft of Publication 60-3 and 60-4 were prepared by IEC Technical Committee 42. The draft introduced a new calibration system for impulse measurements as shown in Fig.1.

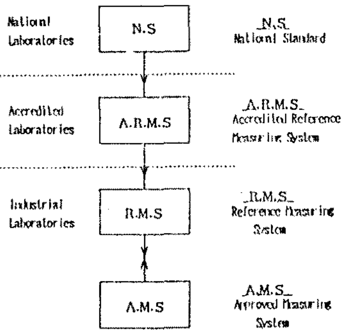


Fig.1. New Calibration System

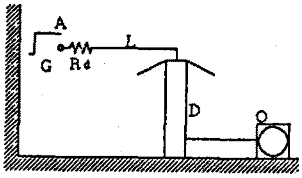
In this calibration system, measuring accuracy (peak value<±3%, time parameter<±10%) is maintained by a procedure of calibration against Reference Systems, traceable through Accredited Laboratory to National Standards, as in other industrial measurements. Since Japan has neither Accredited Laboratory nor Reference Measuring system, We believe that Japan should take all measurements to develop the new calbration System as soon as possible. In order to attain this, two technical Committees were recently organized in the Institute of Electrical Engineers of Japan. One of them is the Committee on improvement of impulse measuring accuracy (Chairman, Prof.M.Ishii, Tokyo University),the other is the committee on development of Reference Measuring System (Chairman, Prof. T.Harada). The former has been investigating on the comparison tests between the Reference Measuring System and the industrial measuring system. The latter has been developping the reference voltage dividers and the reference current shunts. This paper reports the present situation in Japan.

§2. Requirements for Reference Measuring System

In the revised draft of IEC 60-3 and 60-4, requirements for Reference Measuring Systems are specified for measurements of lightning,switching impulse voltages and impulse currents as follows:

1. Requirments for measuring accuracy
" A Reference Measuring System shall have an overall uncertainty not exceeding ±1% for the peak value and ±5% for the time parameters such as the front and the tail times in its range of use . " Although the requirements for measurements of front-chopped impulse voltages are not specified in the draft, an overall uncertainty not exceeding 2~3% for the peak value may be permitted.

2. Recommendation for Response Parameters
Response Characteristics of an impulse voltage measuring circuit is measured by using a circuit as shown in Fig.2.



G:Step responce generator Rd:Damping resistor
L:High vlotage lead D:Volage divider
O:Oscilloscope or Digital recorder

Fig.2. Step Response Measurement Circuit

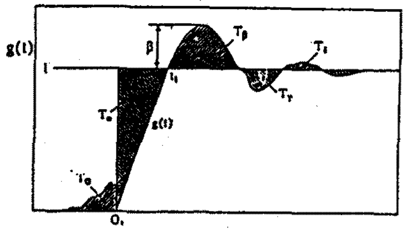


Fig.3. Defintion of Response Parameters

The step votage generator is placed at the metallic wall which serves as the earth return. The step voltage is injected into the input terminal and the output voltage is measured using a osilloscope or digital recorder. The normalized output voltage g(t) (step response) is shown in Fig.3. In this figure, O_1 is virtual origin of a step response and all time values used to evaluate response parameters are measured from O_1. The following response parameters are defined.

(1) Experimental response time:
(response time)

$$T=\int_{O_1}^{\infty}(1-g(t))dt$$

(2) Partial response time:

$$T_1=\int_{O_1}^{t_1}(1-g(t))dt$$

The t_1 is when the normalized step response first reaches the unit amplitude.

(3) Residual response time:

$$T_R(t_1)=\int_{t_1}^{\infty}(1-g(t))dt$$

Overshoot β: The amount by which the maximum value of the normalized step response g(t) exceeds unity.

(4) Initial distortion time T_0: The area bounded by zero line, the normalized step response g(t) and the straight line used to determine O_1.

(5) Settling time t_s:The shortest time for which the residual response time $T_R(t_s)$ becomes and remains less than 2% of t_s:

$$\left|\int_{t_s}^{\infty}(1-g(t))dt\right|\leq 0.02t_s$$

for all values of $t>t_s$

General recommendations for the step response are given by the response parameters mentioned above as follows:

The step response of a reference measuring system should remain within ±1% of its settling level from $0.25T_1$(or $0.3T_P$) to $2T_2$. The settling time t_s should not larger than $0.4T_1$(or $0.5T_P$). T_1,T_P and T_2 are the front time, the time to peak and the tail time to be measured respectively. The settling time t_s should not be larger than T_1 (or $0.5T_P$). When measuring impulse voltages chopped on the front at time T_c, the following conditions shall be met.

the settling time : $t_s\leq T_c$
the experimental response time T and the residual response time
T_R at time T_c : $T+T_R(T_c)\leq 0.05T_c$
the initial distortion time $T_0\leq 0.005T_c$

§3. Reference Divider for full Lightning Impulse Voltage

Impulse voltages to be measured are full lightning , front chopped and switching impulse voltages. Since applying one reference divider to measure all kinds of impulse voltages is difficult. It is preferable to develop an exclusive reference divider for each impulse voltage. From this point of view, a shielded resistor divider as shown in Fig.4 was designed to measure of full lightning impulse voltges. The rated voltage of the divider was determined to be 700kV which made it possible to calibrate industrial voltage dividers up to 3,500kV.

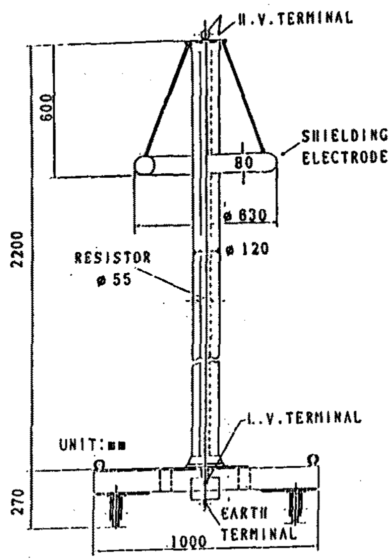
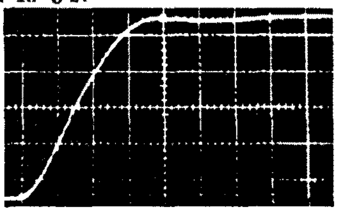


Fig.4. 10kΩ,700kV Reference Divider for Full Lightning Impulse Voltage

A model of this divider was manufactured on trial. The high voltage arm is a resistor which is wound non-inductively by resistance wire with 0.2mm in diameter after Ayrton-Perry winding on an insulating tube with 55mm in diameter and 2200mm in length. The wire has a high resistivity of 133 $\mu\Omega$-cm and a low resistance-temperture coefficient of $\pm 20\times10^{-6}$/℃. The low voltage arm consists of metalic film resistors with the resistance-temperature coefficient of $\pm 10\times 10^{-6}$/℃.

Therefore,the voltage ratio which is determined by the resistance ratio between the high and the low voltage arms is kept at a constant value regardless of temperature changes. The measured experimental response time was under 30ns as shown in Fig.5. This divider meets the requirements of the reference measuring system as described in §2.

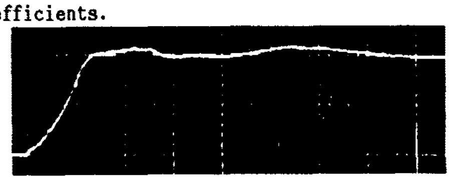


20ns/div

Fig.5. Step Response of Reference Divider for Standard Lightning Impulse Voltage

§4.Reference Divider for Chopped Impulse Voltage

In order to measure front chopped impulse voltages with an overall uncertainty not exceeding ±2~3% for the peak value,an excellent divider with the response time under 10ns would be necessary. However, it is difficult to realize such excellent characteristics by a shielded resistor divider. Therefore, a parallel resistor-capacitor divider with a shielding electrode was adopted. The divider has almost the same dimension as that shown in Fig.4. A model of the divider was built on trial. The high voltage arm consists of a series arrangement of ten elements. Each element has a 850Ω wire-wound resistor and a 100pF condenser which are connected each other in parallel. The low voltage arm consists of metalic film resistors. The measured response time was under 10ns as shown in Fig.6. Concerning the voltage ratio, which is determined mainly by the resistance ratio between the high and the low voltage arms, it can be kept at a constant value regardless of temperature changes because the resistors have low resistance-temperature coefficients.



10ns/div

Fig.6. Step Response of Reference Divider for Front Chopping Impulse Voltage

§5. Reference Divider for Switching Impulse Voltage

Switching impulse voltages are measured generally with capacitor voltage dividers because their front and tail times are much longer than those of the lightning impulse voltages. However, it is difficult to keep the voltage ratio at a constant value because the condensers which consist of the capacitor voltage divider have a capacitance-temperature coefficient of about ±0.1%/℃. Furthermore, the capacitance value changes as the time proceeds. Therefore, a shielded resistor divider with a high resistance value was adopted. Figure.7 shows the design example of the divider. The divider has a high voltage arm of a 200kΩ wire-wound resistor with a low resistance-temperature coefficient and the rated voltage of 500kV for switching impulse voltages. A model of the divider was built on trial and the measured response time was about 40 ns as shown in Fig.8(a). The potential distribution around the divider calculated with a computor. The shielding electrode makes uniform the potential distribution near the high voltage arm and much decreases the capacitance to earth of the arm as shown in Fig.9. In the case of a divider without the shielding electrode, the response time increases to about 1,000ns as shown in Fig.8(b). This type divider meets the requirements of the reference measuring system.

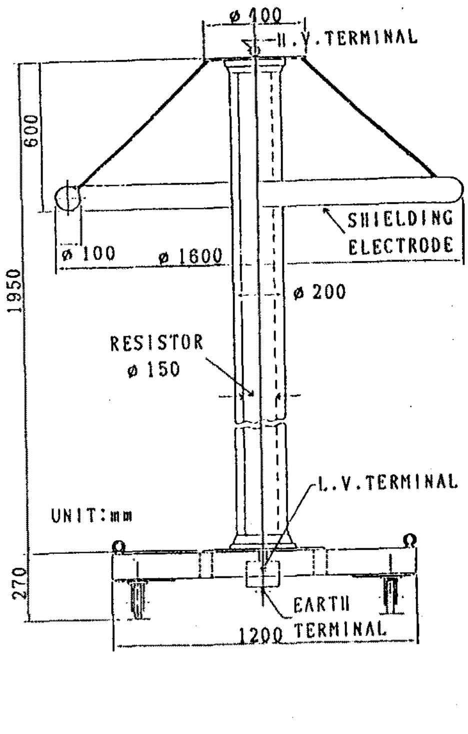
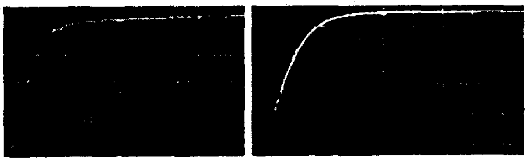


Fig.7. 200kΩ,500kV Reference Divider for Swithing Impulse Voltage



50ns/div 1000ns/div
(a) Step Response with Shielding Electrode (b) Step Response without Shielding Electrode

Fig.8. Measured Step Response

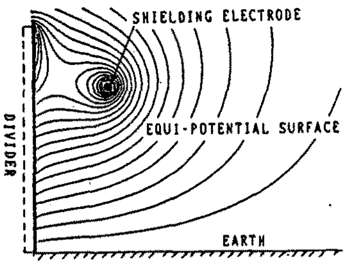


Fig.9. Potential Distribution

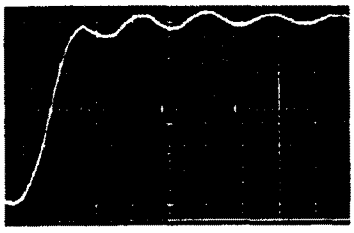
§6. Reference Shunt for Impulse Current

Since the coaxial tubular type of current shunts is superior to all other types for the measurements of large impulse currents, it is the most suitable as a reference shunt. The response time of the tubular shunts is given approximately as follows:

$$T = \frac{\mu_0}{6} \cdot \frac{d^2}{\rho}$$

where, T: Response time, s
μ_0: Pearmiability of free space, $4\pi \times 10^{-7}$ H/m
d: Wall thickness of resistance tube, m
ρ: Resistivity of the tube material, Ω-m

When an alloy of Ni and Cr (ρ:110μΩ-cm) is used for the resistor tube with the wall thickness of 0.01cm, the response time should be under 2ns calculated from the formula above. In the case of using Manganin (ρ:44μΩ-cm), the response time should be under 5ns. Figure.10 shows measured response for a 20mΩ 2kA tubular shunt with the wall thickness of 0.08mm and the response time is under 2ns. In addition, the resistance-temperature coefficients for these materials are very low. Therefore, tubular shunts fully satisfy the requirements of the IEC revised draft.



2ns/div

Fig.10. Step Response of 20mΩ,2kA tubular shunt

§7. Comparison Tests

According to the IEC revised draft, the international comparison tests were carried out from 1988 to 1990 at several national laboratories such as EdF, KEMA, CESI and PTB etc. Although Japan didnt participate in these international comparison test, our UHV laboratory is performingthe first comparison test in Japan. The outline will be described below.

(1) Comparison Test of Impulse Voltage Measuring Systems.

The 10kΩ, 700kV shielded resistor divider (divider A) described in §4 and a 5kΩ, 500kV shielded divider(divider B) were used as a reference divider and as a divider under test respectively. The voltage ratio of each divider was determined by calculation of the ratio based on the measurement of the resistance of individual components in the measuring system. Each voltage ratio and the response time are as follows:

Table 1. Characteristics of Dividre A and B

	voltage ratio	response time
divider A	17,040	30ns
divider B	18,780	25ns

The test circuit is shown in Fig.11. The two dividers and the impulse voltage generator were arranged in a Y position.

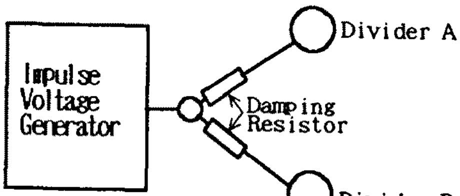


Fig.11. Test Circuit for Comparison Measurement

The standard lightning impulse voltage with the front time of 0.84μs and the tail time of 40μs was applied to the two dividers and their output voltages were recorded simultaneously using a 10 bit, 10^8sample/s,RTD 710 digitizer with two input channels. The differences were calculated as the value from the divider B minus the value from the divider A and expressed as a percentage of the value from the divider A as follows:

$$\delta V = (V_B - V_A)/V_A \times 100 \quad (\%)$$
$$\delta T_1 = (T_{1B} - T_{1A})/T_{1A} \times 100 \quad (\%)$$
$$\delta T_2 = (T_{2B} - T_{2A})/T_{2A} \times 100 \quad (\%)$$

Where, V_A, V_B : Measured peak value
T_{1A}, T_{1B} : Measured front time
T_{2A}, T_{2B} : Measured tail time

Figure.12 shows the typical records obtained for the both dividers. Ten impulse voltages of 150kV were applied to the dividers and more ten impulses were applied after exchanging the

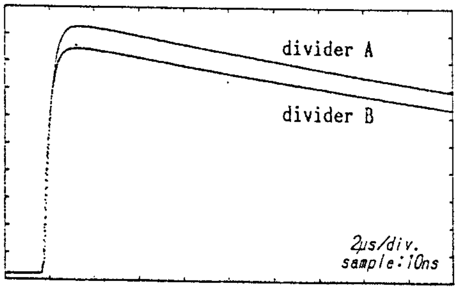


Figure.12 Typical Records Obtained for Dividers A and B

connection to the input terminals of the digitizer.These results were shown by the average of 20 measurements in table.2.

Table 2. Relative Diferences

δV(%)	δT_1(%)	δT_2(%)
+0.38	+3.36	+0.37

(2) Comparison test of Impulse Current Measuring Systems

A 20.4mΩ, 20kA tubular shunt (shunt A) and a 20.2mΩ, 20kA tubular shunt (shunt B) were used a reference shunt and as a shunt under test respectively. The response time of each shunt is under 2ns. The comparison test circuit is shown in Fig.13. The impulse current generator was built as symmetrically as possible with respect to earth.The both shunts were connected in series and the connection point between the both divider was earthed.

Ten impulse currents with the front time of 1μs and the tail time of 20μs were injected in the both shunts. Their outputs were recorded simultaneously using a RTD 710 digitizer.

Next, the both shunts were connected to the impulse current generator in the opposite direction (i.e. connect A to D and B to C)and ten impulse current were injected.

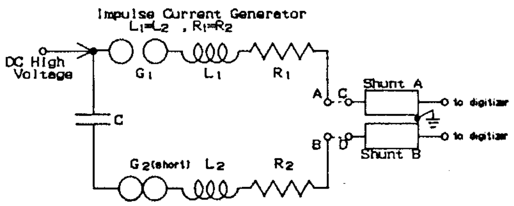


Fig.13. Test circuit for comparison measurement

From the results, difference were calculated and averaged in the same manner as the difference in the impulse voltage comparison test.Table.3 shows the results.

Table 3. Relative Diferences

δI(%)	δT_1(%)	δT_2(%)
+0.11	+0.39	+1.25

The results of the both comparison tests mentioned above satisfied the requirements of the IEC revised draft.

§8. Conclusion

This paper is a preliminary report on the development of reference dividers and shunts, and on the comparison test in Japan. Two PTB reference dividers which had been circulated in many countries were transported to Japan last month and the international comparison test is being carried out in our UHV laboratory. More detailed informations concerning the topic would be obtained in the near future.

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