

American National Standard

guide for transformer impulse tests

ANSI/IEEE C57.98-1986



american national standards institute, inc.

September 22, 1986

SH10519

An American National Standard

IEEE Guide for Transformer Impulse Tests

Sponsor

**Transformers Committee of the
IEEE Power Engineering Society**

Secretariat

**Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association**

Approved March 11, 1982

IEEE Standards Board

Approved August 19, 1985

American National Standards Institute

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Foreword

(This Foreword is not a part of ANSI/IEEE C57.98-1986, IEEE Guide for Transformer Impulse Tests.)

Early in 1955, a working group was appointed by the Dielectric Tests Subcommittee of the AIEE Transformers Committee to prepare an Impulse Test Guide for oil-immersed transformers. The first draft of the guide, prepared by one member of the group, was not acceptable to the majority of the working group members. Another approach was begun in 1958, when members of the working group agreed to draft a portion of the guide in which they had a particular interest. The content of this 1986 guide is the consolidation and editing of these writings of the working group members.

The standards of ANSI, IEEE, and NEMA plus the purchaser's specifications determine the specific requirements for impulse tests. This guide will not change the standards in any way, but adds background information that will aid in the interpretation and application of these standards. These standards now provide for some alternate ways of conducting some tests or parts of tests. These alternates have been developed by different testing laboratories with consideration for their individual problems of transformer design, test facilities, etc. It is the object of this guide to discuss these differences and to show how effective failure detection can be achieved with the testing techniques employed. Although the guide is written primarily for power transformers, it is applicable generally to distribution and instrument transformers.

The guide assumes the reader has an educational or practical background equivalent to that of a graduate electrical engineer with some knowledge of transformers.

In late 1975 a task force was established within the Working Group for revision of Dielectric Tests to review the original guide. It was their purpose to review the existing guide and revise areas where up-to-date oscillograms and procedures could be obtained.

At the time it approved this guide, the C57 Committee had the following membership:

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1. Impulse Testing Techniques

1.1 General. Insulation is recognized as one of the most important constructional elements of a transformer. Its chief function is to confine the current to useful paths, preventing its flow into harmful channels. Any weakness of insulation may result in failure of the transformer. A measure of the effectiveness with which insulation performs is the dielectric strength. It was once accepted that low-frequency tests alone were adequate to demonstrate the dielectric strength of transformers. As more became known about lightning phenomena, and as impulse testing apparatus was developed, it became apparent that the distribution of impulse-voltage stress through the transformer winding may be very different from the low-frequency voltage distribution.

Low-frequency voltage distributes itself throughout the winding on a uniform volts-per-turn basis. Impulse voltages are initially distributed on the basis of winding capacitances. If this initial distribution differs from the final low-frequency inductance distribution, the impulse energy will oscillate between these two distributions until the energy is dissipated and the inductance distribution is reached. In severe cases, these internal oscillations can produce voltages to ground that approach twice the applied voltage.

As circuit voltages became standardized, impulse levels corresponding to the respective voltage classes were also standardized. Impulse levels, now referred to as basic lightning impulse insulation levels (BIL), were established in 1937 by an AIEE-EEI NEMA Committee on Insulation Coordination. This committee was formed to consider laboratory technique and data, to determine the insulation levels in common use,

to establish the insulation strength of all classes of equipment, and to establish insulation levels for various voltage classifications. Through the use of these BIL's, apparatus can be specified on the basis of demonstrating that the insulation strength of the equipment will be equal to or greater than the selected basic level, and protective equipment can be selected to provide adequate protection. The BIL's and other insulation-test voltages are listed [2].¹

1.2 References. This standard shall be used in conjunction with the following publications.

- [1] ANSI/IEEE C57.12.00-1980, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.²
- [2] ANSI/IEEE C57.12.90-1980, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.
- [3] ANSI/IEEE C57.12.91-1979, IEEE Test Code for Dry-Type Distribution and Power Transformers.
- [4] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.
- [5] BELLASCHI, P. L. Characteristics of Surge Generators for Transformer Testing. *AIEE Transactions*, vol 51, 1932, pp 936-951.

¹ Numbers in brackets correspond to those of the references in 1.2 of this standard.

² ANSI documents are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[6] CRAGGS, J. D., and MEEK, M. J. *High Voltage Laboratory Techniques*. London, England: Butterworths Scientific Publications, 1954.

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[8] HAWELY, W. G. *Impulse-Voltage Test*. London, England: Chapman and Hall Ltd, 1959.

[9] MILLER, C. J., and WITTIBSCHLAGER, J. F. Management of Steep Front Impulse Waves with an Isolated Screen Room Installation. *AIEE Transaction*, vol 77, pt 1, 1958, pp 262-271.

[10] PURVIS, W. J. Impulse Failure Detection Methods in Transformer Testing Proceedings. *High Voltage Symposium*, paper no 14, Ottawa, Ont, Canada, 1956.

[11] RIPPON, E. C., and HICKLING, G. H. The Detection by Oscillographic Methods of Winding Failures During Impulse Tests on Transformers. *JIEE*, vol 96, pt 2, 1949, pp 769-790.

[12] STEWART, H. C., and HOLCOMB, J. E. Impulse Failure Detection Methods As Applied to Distribution Transformers. *AIEE Transactions*, vol 64, 1945, pp 640-644.

[13] Surge Testing. *Electrical Transmission and Distribution Reference Book*. Westinghouse Electric Mfg Co, 1944.

[14] THOMASON, J. L. Impulse Generator Circuit Formulas. *AIEE Transactions*, vol 53, 1934, pp 169-176.

2. Impulse Wave Shapes

Impulse tests are made with wave shapes that simulate those encountered in service. From the data compiled by the AIEE-EEI-NEMA committee about natural lightning, it was concluded that system disturbances from lightning can be represented by three basic wave shapes; full waves, chopped waves, and front-of-waves. In Fig 1 these three waves are represented in their approximate magnitude and time.

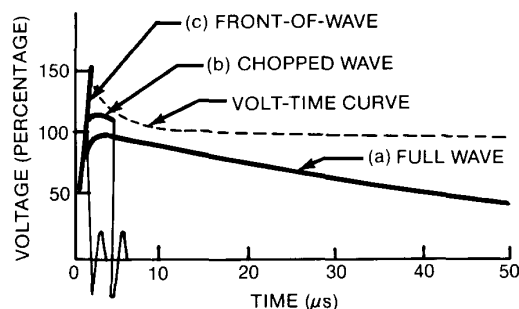


Fig 1
Impulse Wave Shapes

It is recognized that lightning disturbances will not always have these basic wave shapes. However, by defining the amplitude and shape of these waves, it is possible to establish a minimum impulse-dielectric strength that transformers should meet. A curve can be drawn through the points established by the amplitude and normal duration of each wave as shown in Fig 1. For the front-of-wave and chopped wave, the points would be located at the intersection of a vertical line drawn at the time-to-chop and a horizontal line drawn through the crest, while for the full wave the vertical line would be located at the time of half value [4]. This curve is referred to as the volt-time curve of the composite insulation structure of the transformer. The strength of the insulation to wave shapes other than those defined by [4] can be approximated from the curve.

Impulse tests demonstrate that the insulation will withstand impulses that lie below the volt-time curve. Applying protective equipment that has a volt-time curve lower than that of the transformer assures adequate protection of the transformer insulation. If a lightning disturbance travels some distance along the line before it reaches a transformer, its wave shape approaches that of the full wave as shown in Fig 1 by curve "a." This is a wave that rises from zero to crest value in 1.2 μs and then decays to half of crest value at 50 μs. It is generally referred to as 1.2 × 50 wave. The part of the wave between zero and the crest is called the front and the part beyond the crest is called the tail.

A wave traveling along the line might flash over an insulator after the crest of the wave has been reached. This wave is simulated by the

chopped wave that is chosen to be of magnitude as defined in [2]. It is shown by curve "b."

If a severe lightning stroke hits directly at or very close to a terminal the surge voltage may rise steeply until it is relieved by a flashover, causing a sudden, very steep collapse in voltage. This condition is represented by the front-of-wave curve "c."

As can be seen in Fig 1, these three waves are quite different in duration and in rates of voltage rise and decay and consequently produce different reactions within the transformer winding. The full wave, because of its relatively long duration, causes major oscillations to develop in the winding and consequently stresses not only the turn-to-turn and section-to-section insulation throughout the winding but also develops relatively high voltages, compared to power frequency stresses, across large portions of the winding and between the winding and ground (core or adjacent windings).

The chopped wave, because of its shorter duration, does not allow the major oscillations to develop as fully and generally does not produce as high voltages across large portions of the windings or between the winding and ground. However, because of its greater amplitude it produces higher voltages at the line end of the winding, and because of the rapid change of voltage following flashover of the test gap it produces higher turn-to-turn and section-to-section stresses.

The front-of-wave is still shorter in duration and produces still lower winding-to-ground voltages deep within the winding. Near the line end, however, its greater amplitude produces higher voltages from winding to ground, and this combined with the rapid change of voltage on the front and following flashover produces a high turn-to-turn and section-to-section voltages near the line end of the winding.

The selection of the type and number of test waves is determined by the test specification. These various test specifications may include a number of purchaser specifications in addition to the ones approved by [2].

3. Impulse Test Circuit

Impulse waves are generated by an arrangement that charges a group of capacitors in parallel and then discharges them in series; see [5],

[6], [7], [8], [13], and [14]. The magnitude of the voltage is determined by the initial charging voltage, the number of capacitors in series at discharge, and the regulation of the circuit. The wave shape is determined largely by the constants of the generator and the impedance of the load.

Transformer impedance can be represented as a mesh network of inductance and capacitance. Fig 2 represents a transformer and also the parameters of a typical impulse generator. The total impedance between the impulsed terminal of the transformer and ground will hereafter be called the effective impedance.

To illustrate how the various transformer and impulse-generator parameters affect the generated wave shape, some simple circuit examples will be given. Assume that for the following examples, a capacitor, which will be referred to as the generator capacitance C , is charged to a constant value and then the various circuit parameters are connected to the generator capacitor terminals through a quick-closing switch as the breakdown of a gap. The circuit will be assumed to have zero resistance and inductance except as indicated. Fig 3 shows the circuit parameters and the resulting wave shape for each example. In all these examples a high-impedance oscillograph will be connected at points X-X, to indicate the variation of voltage with respect to time as the various parameters are connected. In each example the capacitor will be charged initially to the same voltage.

Fig 2
Impulse Circuit

