



IEEE Guide for Field Measurement of Fast-Front and Very Fast-Front Overvoltages in Electric Power Systems—Part 1: Measuring Techniques

IEEE Power and Energy Society

Developed by the
Power System Instrumentation and Measurements
Committee

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STANDARDS

IEEE Guide for Field Measurement of Fast-Front and Very Fast- Front Overvoltages in Electric Power Systems—Part 1: Measuring Techniques

Developed by the

Power System Instrumentation and Measurements Committee
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Abstract: Introduced in this guide are the definition, formation, and characteristics of fast-front and very fast-front overvoltages. The various measuring techniques, including technical details that may be adopted for field application, are also described. Field measurement results measured using the techniques described in this guide are included for reference.

Keywords: air insulated substation, capacitive sensor, electric field sensor, fast-front overvoltage, field measurement, gas insulated switchgear, IEEE 2426, recording instrument, signal transmission method, transformer bushing sensor, very fast-front overvoltage

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Introduction

This introduction is not part of IEEE Std 2426-2024, IEEE Guide for Field Measurement of Fast-Front and Very Fast-Front Overvoltages in Electric Power Systems—Part 1: Measuring Techniques.

Field measurements of transient voltage waveforms can be widely used in purposes of analyzing fault processes, locating the position of faults, determining actual overvoltage amplitude, recognizing new transient phenomena, assessing the existing insulation test methods, etc. In recent years, many countries, organizations, enterprises, and even individuals have carried out many field measurements of fast-front and very fast-front overvoltages in electric power systems using various measuring systems.

With the cooperation of experts from ten countries, CIGRE C4.45 published the technical brochure “Measuring techniques and characteristics of fast and very fast transient overvoltages in substations and converter stations” in 2021 to review the measuring techniques [B4]. However, until now, no IEEE or IEC standard/guide regarding the field measurement of fast-front and very fast-front overvoltages has been approved to instruct and standardize field measurements.

Field measurement of overvoltages differs significantly from measurements of standard impulse measurements in the laboratory in the following aspects:

- Different measuring object. In laboratory measurements, the measuring object is well-determined, and the impulses have a relatively fixed waveform of which the parameters vary within a small range, such as the standard lightning impulse voltage or the standard switching impulse voltage. However, in field measurements, the voltage waveform is unknown, irregular, and contains complicated frequency components.
- Different measurement environment. The laboratory measurement environment is characterized by relative stability and controllability, and weak interference. In contrast, the field measurement environment is much more complex, uncontrollable, and often exhibits an intense interference.
- Different performance parameters. In laboratory measurements, since the waveform is relatively fixed, the performance parameters characterized in the time domain are the main focus of attention. In field measurements, as the waveforms are irregular and generally cover a wide frequency range, features in the frequency domain become the key performance parameter of a measuring system.
- Different performance testing method. Subject to performance and feasibility, various types of sensors are usually used in field measurements rather than the traditional commercial voltage divider that is commonly used in the lab. Different sensors use different principles and layouts, therefore the performance test methods must be customized for each class of sensor.

Based on the urgent need for field measurement techniques from IEEE advanced corporate members and other potential users, a family standard consisting of three parts is planned, covering the measuring techniques, the performance requirements and testing methods for FFO measuring systems, and the performance requirements and testing methods for VFFO measuring systems, respectively. This guide is part I, whose main purpose is guiding users to develop their measuring systems.

The following standards and document have been used to prepare this document:

IEEE Std 4™-2013, IEEE Standard for High-Voltage Testing Technique.

IEEE Std C62.82.1™-2010, IEEE Standard for Insulation Coordination—Definitions, Principles, and Rules.

IEC 60071-1, Insulation Co-ordination—Part 1: Definitions, Principles and Rules.

CIGRE TB 836, Measuring techniques and characteristics of fast and very fast transient overvoltages in substations and converter stations.

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IEEE Guide for Field Measurement of Fast-Front and Very Fast-Front Overvoltages in Electric Power Systems—Part 1: Measuring Techniques

1. Overview

1.1 Scope

This guide provides the definition, formation, and characteristics of fast-front and very fast-front overvoltages. The various measuring techniques, including technical details that may be adopted for field application, are also described. Field measurement results measured using the techniques described in this guide are included for reference.

This guide supports the development of field measuring systems for fast-front and very fast-front overvoltages in electric power systems (including sensors, signal transmission devices, and recording instruments).

This guide applies to single-phase gas-insulated switchgear (GIS) tubes, air-insulated substations (AIS), and other equipment with a voltage level of 110 kV and above.

1.2 Purpose

This guide provides a practical reference document which supervisors, engineers, technicians, and researchers may refer to when developing measuring systems for conducting fast-front and very fast-front overvoltage measurements in the field.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{6,7}

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60071-1, Insulation Co-ordination—Part 1: Definitions, Principles and Rules.

IEEE Std 4™-2013, IEEE Standard for High-Voltage Testing Technique.

IEEE Std C62.82.1™-2010, IEEE Standard for Insulation Coordination—Definitions, Principles, and Rules.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

fast-front overvoltage (FFO): Transient overvoltage which is usually unidirectional with time-to-crest value (T_r) $0.1 \mu\text{s} < T_r \leq 20 \mu\text{s}$, and time-to-half value (T_h) $< 300 \mu\text{s}$.

front time (T_r): See IEEE Std 4-2013.

time-to-crest value (T_r): See IEEE Std C62.82.1-2010.

time-to-half value (T_h): See IEEE Std C62.82.1-2010.

very fast-front overvoltage (VFFO): Transient voltage that is usually unidirectional with $T_r \leq 0.1 \mu\text{s}$, possible superimposed oscillations at a high-frequency range of $300 \text{ kHz} < f_1 < 100 \text{ MHz}$, and at a low-frequency range of $30 \text{ kHz} < f_2 \leq 300 \text{ kHz}$.

3.2 Acronyms and abbreviations

AIS	air-insulated substation
A/D	analog to digital
CT	current transformer

⁸*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

CVT	capacitive voltage transformer
EF	electric field
FFO	fast-front overvoltage
GIS	gas-insulated switchgear, also including hybrid gas-insulated switchgear (HGIS) and gas-insulated line (GIL)
HFCT	high-frequency current transformer
IOES	integrated optical electric field sensor
OHL	overhead transmission line
OIP	oil-impregnated paper
PMF	polarization-maintaining optical fiber
UHV	ultra-high voltage
VFFO	very fast-front overvoltage, also called VFTO

4. Formation and characteristics of fast-front and very fast-front overvoltages

4.1 Fast-front overvoltage

Fast-front overvoltages (FFOs) are mainly caused by the lightning strikes, switching operations, or faults in the power grid. As shown in Figure 1, FFOs have a time-to-crest value ranging from $0.1 \mu\text{s}$ to $20 \mu\text{s}$ and a time-to-half value shorter than $300 \mu\text{s}$ (see IEC 60071-1). Although the standard voltage waveform of FFOs accepted for high-voltage tests is globally acknowledged as the standard lightning impulse voltage ($1.2/50 \mu\text{s}$), actual on-site FFO waveforms vary from this standard waveform.

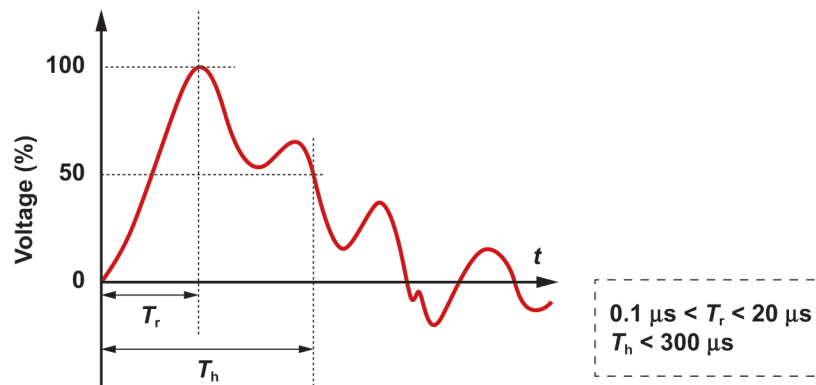


Figure 1—Definition and value of parameters for FFO

An FFO that is caused by lightning strikes generally has its waveform affected by the type of lightning strikes (shielding failure, backflash, or induced lightning), structure and layout of the overhead transmission line (OHL), grounding resistance, lightning protection devices (such as lightning arresters) arranged on the OHL or in the substation, and the phase angle of power frequency voltage on the occurrence of a lightning strike. Moreover, due to the randomness of natural lightning, the amplitude and the time-to-crest value of the FFO waveform can vary within a wide range [B4], [B15], [B17], and [B19].