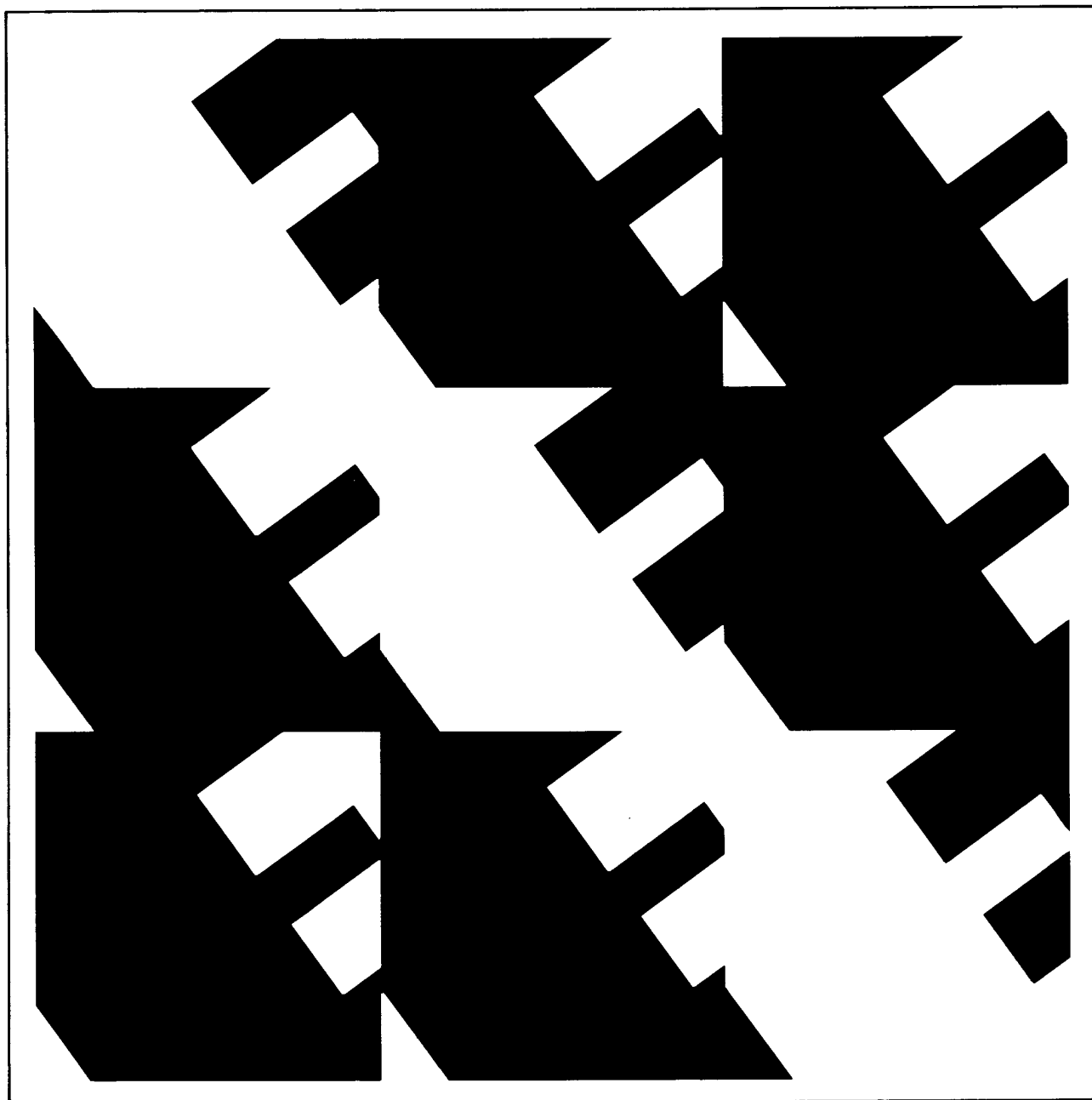


IEEE Guide for Surge Voltages in Low-Voltage AC Power Circuits

ANSI/IEEE C62.41-1980



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1. Scope

This guide primarily addresses ac power circuits with rated voltages up to 277 V line to ground, although some of the conclusions offered could apply to higher voltages and also to some dc power systems. Other standards have been established, such as ANSI/IEEE C37.90a-1974, Guide for Surge Withstand Capability (SWC) Tests, intended for the special case of high-voltage substation environments, and ANSI/IEEE Std 28-1974, Standard for Surge Arresters for AC Power Circuits, covering primarily the utilities environment. This guide intends to complement, not conflict with, existing standards, and to present a practical basis for the selection of voltage and current tests to be applied in evaluating the surge withstand capability of equipment connected to these power circuits, primarily in residential, commercial, and light industrial applications. Although the data have been recorded primarily on 120, 220/380, or 277/480 V systems, the general conclusions may be valid for 600 V systems, but more data are needed for the higher voltages.

While the major purpose of this guide is to describe the environment, a secondary purpose is to lead toward standard tests and the preparation of an application guide. Standard tests will provide a realistic evaluation of the surge withstand capability of equipment connected to the power circuits suitable for most installations. Of necessity, the complex real situation must be simplified to produce a manageable set of standards. Proper application, or coordination of equipment capacity and environmental characteristics, of course remains the responsibility of manufacturers and users.

The surge voltages (see 8.1) considered in this guide are those exceeding 2 per unit (or twice the peak operating voltage) and having durations ranging from a fraction of a microsecond to a millisecond. Overvoltages of less than 2 per unit are not covered here, nor are transients of longer duration resulting from power equipment operation and failure modes. Because such low-amplitude and long-duration surges are generally not amenable to suppression by conventional surge protective devices, they require different protection techniques from those discussed in this guide.

2. References

2.1 Standards Publications

ANSI C62.2-1969, Guide for Application of Valve Type Lightning Arresters for Alternating Current Systems¹

ANSI/IEEE C37.90a-1974, Guide for Surge Withstand Capability (SWC) Tests

ANSI/IEEE Std 28-1974, Standard for Surge Arresters for AC Power Circuits

IEC No 664 (1980), Insulation Coordination within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment²

ANSI/IEEE Std 100-1977, Dictionary of Electrical and Electronics Terms

¹ANSI documents are available from The American National Standards Institute, 1430 Broadway, New York, NY 10018.

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

2.2 Other References

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- [2] JOHNSON, I. B. IEEE Tutorial Course: Surge Protection in Power Systems, IEEE Power Engineering Society 79EH0144-6-PWR, 1978.
- [3] BODLE, D. W., GHAZI, A. J., SYED, M., and WOODSIDE, R. L. *Characterization of the Electrical Environment*, Toronto and Buffalo, NY: University of Toronto Press, 1976.
- [4] MARTZLOFF, F. D., and HAHN, G. J. Surge Voltage in Residential and Industrial Power Circuits, *IEEE Transactions on Power Apparatus and Systems*, vol PAS-89, July/Aug 1970, pp 1049-1056.
- [5] LENZ, J. E. Basic Impulse Insulation Levels of Mercury Lamp Ballast for Outdoor Applications, *Illuminating Engineering*, Feb 1964, pp 133-140.
- [6] MARTZLOFF, F. D., and CROUCH, K. E. Coordination de la protection contre les surtensions dans les réseaux basse tension résidentiels, *Proceedings 1978 IEEE Canadian Conference on Communications and Power*, 78CH1373-0, pp 451-454.
- [7] MARTZLOFF, F. D. Surge Voltage Suppression in Residential Power Circuits, Corporate Research and Development, General Electric Company, Schenectady, NY, 1976, Report 76CRD092.
- [8] BULL, J. H. Impedance of the Supply Mains at Radio Frequencies, *Proceedings of the 1st Symposium on EMC*, Montreux, May 1975, 75CH1012-4 Mont.

3. The Origin of Surge Voltages

3.1 General. Surge voltages occurring in low-voltage ac power circuits originate from two major sources, system switching transients and direct or indirect lightning effects on the power system.

3.2 Lightning Transients. Measurements and calculations of lightning effects have been made to yield data on the levels that can be produced, even if the exact mechanism of any

particular surge is unknown. The major mechanisms by which lightning produces surge voltages are the following:

(1) A direct lightning strike to a primary circuit injects high currents into the primary circuit, producing voltages by either flowing through ground resistance or flowing through the surge impedance of the primary conductors.

(2) A lightning strike that misses the line but hits a nearby object sets up electromagnetic fields which can induce voltages on the conductors of the primary circuit.

(3) The rapid change of voltage that may occur when a primary arrester operates at low discharge currents to limit the primary voltage couples effectively through the capacitance of the transformer and produces surge voltages in addition to those coupled into the secondary circuit by normal transformer action.

(4) Lightning strikes the secondary circuits directly. Very high currents can be involved, exceeding the capability of conventional devices.

(5) Lightning ground current flow resulting from nearby direct-to-ground discharges couples onto the common ground impedance paths of the grounding network.

3.3 Switching Transients. System switching transients can be divided into transients associated with (1) major power system switching disturbances, such as capacitor bank switching; (2) minor switching near the point of interest, such as an appliance turnoff in a household or the turnoff of other loads in an individual system; (3) resonating circuits associated with switching devices, such as thyristors; and (4) various system faults, such as short circuits and arcing faults. One switching transient, for example, results from fast-acting current protective devices such as current-limiting fuses and circuit breakers capable of arcing times of less than 2 μ s. These devices leave trapped inductive energy in the circuit upstream; upon collapse of the field, high voltages are generated.

Transient overvoltages (see 8.1) associated with the switching of power factor correction capacitors, on the other hand, have lower frequencies than the high-frequency spikes with which this guide is concerned. Their levels, at least in the case of restriking-free switching operations, are generally less than twice normal voltage. Nevertheless they should not be disregarded.

A switching operation involving restriking is

another example. Air contactors or mercury switches can produce, through escalation, surge voltages of complex waveshapes and of amplitudes several times greater than the normal system voltage. The most visible effect is generally found on the load side of the switch and involves the device that is being switched as well as the switching device. In the case of the device being switched, the prime responsibility for protection rests with either the manufacturer or the user of the device in question. The presence and source of transients may be unknown to the users of those devices. This potentially harmful situation occurs often enough to command attention.

4. Rate of Occurrence and Voltage Levels in Unprotected Circuits

4.1 General. The rate of occurrence of surges varies over wide limits, depending upon the particular power system. Prediction of the rate for a particular system is always difficult and frequently impossible. The rate is related to the level of the surges; low-level surges are more prevalent than high-level surges (see 8.2).

It is essential to recognize that a surge voltage observed in a power system can be either the driving voltage or the voltage limited by the sparkover of some clearance in the system. Hence the term *unprotected circuit* must be understood to be a circuit in which no low-voltage protective device has been installed, but in which clearance sparkover will eventually limit the maximum voltage (see 8.3). The distribution of surge levels, therefore, is influenced by the surge-producing mechanisms as well as by the sparkover level of clearances in the system. This distinction between actual driving voltage and voltage limited by sparkover is particularly important at the interface between outdoor equipment and indoor equipment. Outdoor equipment has generally higher clearances, hence higher sparkover levels: 10 kV may be typical, but 20 kV is possible. In contrast, most indoor wiring devices used in 120-240 V systems have sparkover levels of about 6 kV; this 6 kV level, therefore, can be selected as a typical cutoff for the occurrence of surges in indoor power systems.

4.2 Rate of Occurrence versus Voltage Level. Data collected from many sources (see Appendix A) have led to the plot shown in Fig 1.

This prediction shows with certainty only a *relative* frequency of occurrence, while the *absolute* number of occurrences can be described only in terms of low, medium, or high exposure. These exposure levels can be defined in general terms as follows:

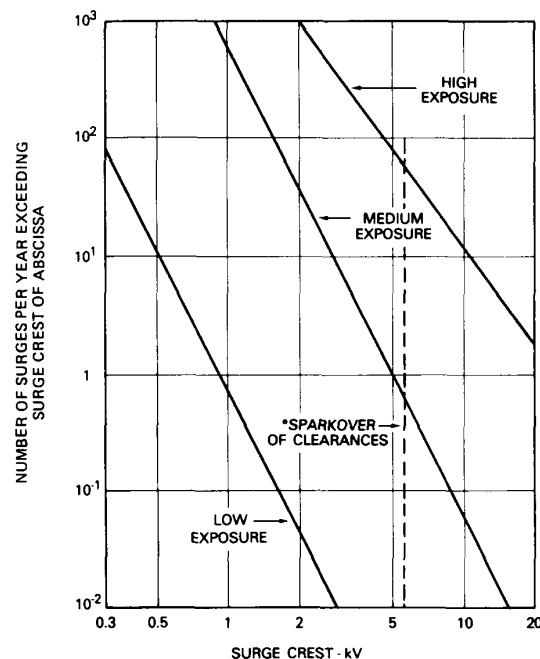
(1) **Low Exposure.** Systems in geographical areas known for low lightning activity, with little load switching activity.

(2) **Medium Exposure.** Systems in geographical areas known for high lightning activity, with frequent and severe switching transients.

(3) **High Exposure.** Rare but real systems supplied by long overhead lines and subject to reflections at line ends, where the characteristics of the installation produce high sparkover levels of the clearances.

The two lower lines in Fig 1 have been drawn at the same slope, since the data base shows reasonable agreement among several sources on that slope. All lines may be truncated by sparkover of the clearances, at levels depending on the withstand voltage of these clearances. The high-exposure line needs to be recognized, but it should not be indiscriminately applied to all

Fig 1
Rate of Surge Occurrences versus Voltage Level at Unprotected Locations



*In some locations, sparkover of clearances may limit the overvoltages (see 8.3).

systems. Such application would penalize the majority of installations, where the exposure is lower (see 8.4).

From the relative values of Fig 1, two typical levels can be cited for practical applications. First, the expectation of 3 kV transient occurrence on a 120 V circuit ranges from 0.01 to 10 per year at a given location — a number sufficiently high to justify the recommendation of a minimum 3 kV withstand capability. Second, the sparkover of wiring devices indicates that a 6 kV withstand capability may be sufficient to ensure device survival indoors, but a withstand capability of 10 kV, or greater, may be required outdoors.

4.3 Timing of Occurrence. Surges occur at random times with respect to the power frequency, and the failure mode of equipment may be affected by the power frequency follow current. Furthermore, the timing of the surge with respect to the power frequency may affect the level at which failure occurs (see 8.5). Consequently when the failure mode is likely to be affected, surge testing should be done with the line voltage applied to the test piece.

5. Waveshapes of Representative Surge Voltages

5.1 General. This section presents the rationale of representative waveshapes independent of specific energy levels; the choice of waveshape, nevertheless, was influenced by a general consideration of the energy associated with specific waveforms. (Section 6 addresses the question of energy.)

5.2 Waveshapes in Actual Occurrences

5.2.1 Indoor. Measurements in the field, measurements in the laboratory, and theoretical calculations indicate that most surge voltages in indoor low-voltage systems have oscillatory waveshapes, unlike the well-known and generally accepted unidirectional waves specified in high-voltage insulation standards (see 8.6). A surge impinging on the system excites the natural resonant frequencies of the conductor system. As a result, not only are the surges typically oscillatory, but surges may have different amplitudes and waveshapes at different places in the system. These oscillatory frequencies of surges range from 5 kHz to more than 500 kHz. A 30–100 kHz frequency is a realistic measurement of a “typical” surge for most resi-

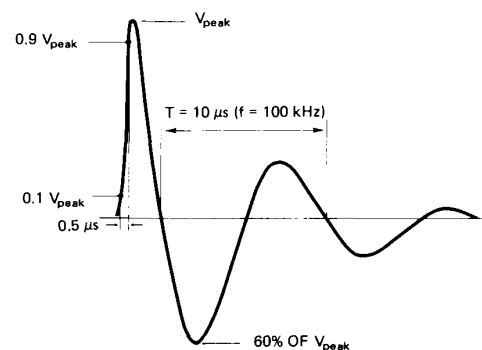
dential and light industrial ac line networks.

5.2.2 Outdoor and Service Entrance. Surges encountered in outdoor locations have also been recorded, some oscillatory (see 8.6), others unidirectional. Because the prime concern here is the energy associated with these surges, the waveshape to be selected must involve greater energy than that associated with the indoor environment. Secondary surge arresters have a long history of successful performance, meeting the specification of ANSI/IEEE Std 28-1974 as detailed below. Consequently these specifications can be adopted as a realistic representation of outdoor waveshapes.

5.3 Selection of Representative Waveshapes. The definition of a waveshape to be used as representative of the environment is important for the design of candidate protective devices, since unrealistic requirements, such as excessive duration of the voltage or very low source impedance, place a high energy requirement on the suppressor, with a resulting cost penalty to the end user. The two requirements defined below reflect this tradeoff.

5.3.1 Indoor. Based on measurements conducted by several independent organizations in 120 and 240 V systems (Appendix A), the waveshape shown in Fig 2 is reasonably representative of surge voltages in these power circuits. Under the proposed description of a “0.5 μ s–100 kHz ring wave,” this waveshape rises from 10 to 90% in 0.5 μ s, then decays while oscillating at 100 kHz, each peak being 60% of the preceding peak.

Fig 2
Proposed 0.5 μ s–100 Hz Ring Wave
(Open-Circuit Voltage)



The fast rise can produce the effects associated with nonlinear voltage distribution in windings and the dv/dt effects on semiconductors. Shorter rise times are found in many transients, but as those transients propagate into the wiring or are reflected from discontinuities in the wiring, the rise time becomes longer.

The oscillating and decaying tail produces the effects of voltage polarity reversals in surge suppressors or other devices that may be sensitive to polarity changes. Some semiconductors are particularly sensitive to damage when being forced into or out of conducting states, or when a transient is applied during a particular portion of the 60 Hz supply cycle (Appendix B). The response of a surge suppressor can also be affected by reversals in the polarity, as in the case of RC attenuation before a rectifier circuit in a dc power supply.

The pulse withstand capability of many semiconductors tends to improve if the surge duration is much shorter than 1 μ s. For this reason the first half-cycle of the test wave must have a sufficient duration.

5.3.2 Outdoor. In the outdoor and service entrance environment, as well as in locations close to the service entrance, substantial energy, or current, is still available. For these locations, the unidirectional impulses long established for secondary arresters are more appropriate than the oscillatory wave.

Accordingly the recommended waveshape is $1.2 \times 50 \mu$ s for the open-circuit voltage or voltage applied to a high-impedance device, and $8 \times 20 \mu$ s for the discharge current or current in a low-impedance device. The numbers used to describe the impulse, 1.2×50 and $8 \times 20 \mu$ s,

are as defined in ANSI/IEEE Std 28-1974. Figure 3 presents the waveshape and a graphic description of the numbers.

The waveshapes selected to represent the environment can be produced in the laboratory with conventional high-voltage impulse generators or with custom-made generators (Appendix C).

In the case of the oscillatory wave, the test circuit can deliver either the open-circuit voltage shown or the short-circuit current specified in Sec 6. (The short-circuit peak is specified in Sec 6, but the actual waveform will be influenced by the load circuit parameters.) In the case of the unidirectional wave, current practice in laboratories is to produce either a waveshape of voltage or a waveshape of current, depending on the nature of the test specimen: $1.2 \times 50 \mu$ s for insulation voltage withstand tests, $8 \times 20 \mu$ s for discharge current tests. For qualification or acceptance tests of a device whose characteristics are unknown, it would be desirable to have a single test generator capable of producing the open-circuit voltage wave shown, with a short-circuit current equal to the discharge current wave shown.

6. Energy and Source Impedance

6.1 General. The energy involved in the interaction of a power system with a surge source and a surge suppressor will divide between the source and the suppressor in accordance with the characteristics of the two impedances. In a gap-type suppressor, the low impedance of the arc after sparkover forces most of the energy

Fig 3
Unidirectional Waveshapes (ANSI/IEEE Std 28-1974)

