On the Propagation of Old and New Surges

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Significance
Part 4 – Propagation and coupling of surges

The 1991 revision of the IEEE Recommended Practice on Surge Voltages C62.41 introduced a new generation of surge waveforms; how they travel in low-voltage power systems will affect some of the earlier tenets on surge propagation characteristics. The emergence of cascaded surge-protective devices also raised a new set of concerns in which propagation characteristics play an important role, where system designers rely on the inherent impedance of the wiring between the two devices to provide the electrical separation necessary to obtain coordination.

During the development of the revised IEEE Recommended Practice in the late eighties, some reluctance was encountered in deleting the mention of wire diameter for the branch circuits. The wire size was included in the definition of the 'Location Categories' given in the 1980 version of the IEEE Std 587 Guide

The paper presents a review the propagation characteristics of the old and the new generation of surges waveforms encountered in low-voltage ac power systems. To complement information developed on this subject over the last ten years, measurements results are reported for the new 10/1000 µs waveform, and the effect (or, rather, the lack of significant effect) of wire diameter is documented by a simple experimental demonstration.

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INTRODUCTION

The revised IEEE Recommended Practice on Surge Voltages [1] has introduced a new generation of surge waveforms; how they travel in low-voltage power systems will affect some of the earlier tenets on surge propagation characteristics. The recent emergence of cascaded surge-protective devices [2], [3], [4], [5], raises a new set of concerns in which propagation characteristics play an important role. Until recently, the application of surge-protective devices was primarily based on the tenet that the classical 8/20 μs current waveform presents the most severe stress to the device. Whenever two devices were to be installed in a system with one device at the service entrance and one further into the building (the so-called cascade connection), system designers had relied on the inherent impedance of the wiring between the two devices to provide the electrical separation necessary to obtain coordination.

During the development of the revised IEEE Recommended Practice, some reluctance was encountered in deleting the mention of wire diameter for the branch circuits. The wire size was included in the definition of the 'Location Categories' given in the 1980 version of the IEEE Guide [6].

The objective of this paper is to review the propagation characteristics of the old and the new generation of surges waveforms encountered in low-voltage ac power systems. To complement information developed on this subject over the last ten years, measurements results are reported for the new 10/1000 μs waveform, and the effect (or, rather, the lack of effect) of wire diameter is documented by a simple experimental demonstration.

THE PROPAGATION OF SURGES — OLD AND NEW WAVEFORMS

Users of the new Recommended Practice now face the need to consider five representative surge waveforms. This section presents a summary of the propagation characteristics, with relevant references. These characteristics should be kept in mind during the discussions at this Forum.

1. The 100 kHz Ring Wave

The short duration of the first half-cycle of this waveform (0.5 μs rise time, compared to the travel time in a typical building) produces a propagation characteristic similar to that of traveling waves in transmission lines: reflections at impedance mismatches, and peak enhancement at unloaded (or lightly loaded) ends of lines [7], [8]. The subsequent oscillations at 100 kHz do not present these characteristics. For shorter lines (30 m or less), the inductance of the wiring is the dominant factor in the propagation.

2. The 1.2/50 μs — 8/20 μs Combination Wave

The relatively slow rise time of the voltage waveform, 1.2 μs, is long compared to the travel time in building wiring systems (200 m/μs propagation speed). Reflections die down during the rise time, so that there is no enhancement of the peaks (nor attenuation) at the open ends of the branch circuits [9]. The dominant parameter is the inductance of the wire. At the equivalent frequency of the 8 μs rise time of the current, typical wiring offers an impedance of about 0.2 Ω/m. Thus, a substantial driving voltage would be necessary to force a full 3 kA crest surge in a long branch circuit. The sparkover of wiring devices (or of a [gap + silicon carbide] arrester at the service entrance) will limit the driving voltage so that large 8/20 μs current surges are not expected in long branch circuits [10]. This conclusion had been at the root of the cascade coordination studies performed until recently.

3. The 5/50 ns burst of the Electrical Fast Transient (EFT)

This test waveform was initially developed in the IEC community for revealing any deficiency in the electromagnetic compatibility (susceptibility) of electronic equipment. The new IEEE Recommended Practice has endorsed the EFT as an 'Additional Waveform' to be considered. The fast rise of this waveform results in substantial stretching of the rise time, as well as attenuation of the surge peak, when more than a few meters of propagation are involved [11], [12]. Thus, the domain of application of this waveform is limited to interactions between adjacent equipment within the same building and propagation characteristics relieve users from concerns about EFT surges of remote origin.

4. The 5 kHz Ring Wave

This waveform has been included, as an 'Additional Waveform', in the new IEEE Recommended Practice. While there is an abundance of data from computer simulations of capacitor switching transients, little experimental data are available on the propagation of this waveform [13]. However, the relatively low frequency of this waveform makes it readily amenable to theoretical analysis based on simple lumped parameters of the power system, provided of course that the nonlinear characteristics of varistors are included.

5. The 10/1000 μs Unidirectional Wave

This waveform has been included, as an 'Additional Waveform', in the new IEEE Recommended Practice. Its relatively longer rise time, and more important, its long duration, raise new questions about a coordination based on the inductive impedance separating two cascaded devices [4]. Refer to the measurements reported in the next section, showing that inductance still dominates the initial portion of the 10/1000 μs event, but that the long tail of the waveform will force a resistive element, rather than an inductive element, to enter in a successful coordination scheme.

IMPEDANCE MEASUREMENTS FOR DIFFERENT WIRE SIZES AND WAVEFORMS

Three pieces of "Romex" cable [2 conductors + ground] of different conductor diameter (AWG #14, 12, and 10), each 10 m long and having its two current-carrying conductors joined at one end, were connected in series. The ground conductor was left floating. This set of three was then connected across the output of a surge generator capable of producing the 100 kHz Ring Wave, the Combination Wave, or the 10/1000 μs Unidirectional Wave (Figure 1). Thus, all three cables were exposed to the same current waveform. The impedance of this load circuit caused a departure from the nominal short-circuit waveforms delivered by the surge generator, which was recorded in each case.

A differential voltage probe was used to record the voltage drop at the origin of each cable (Figure 1), corresponding to each of the three successive current waveforms (Figures 2-4 and Table 1). Note in the voltage traces that during the portion of the waveform when current is changing, there is little difference in the voltage drop along the three cables #14, #12, and #10. In other words, the length of the cable is the dominant factor, in spite of the nearly 3:1 difference in the specific resistance of the #10 (3.3 Ω/km) and #14 (8.3 Ω/km) conductors. If any skin effect is involved in the propagation, that factor is also included in the comparison.

This lack of difference for *surge propagation* should be contrasted with the concerns about *voltage drop for 60 Hz loads*, covered in a fine print note [1] of the National Electric Code [14]. In keeping with the accepted practice in the surge-testing community, the ratio of current and voltage *peaks* is reported as the *effective impedance* for that particular waveform.

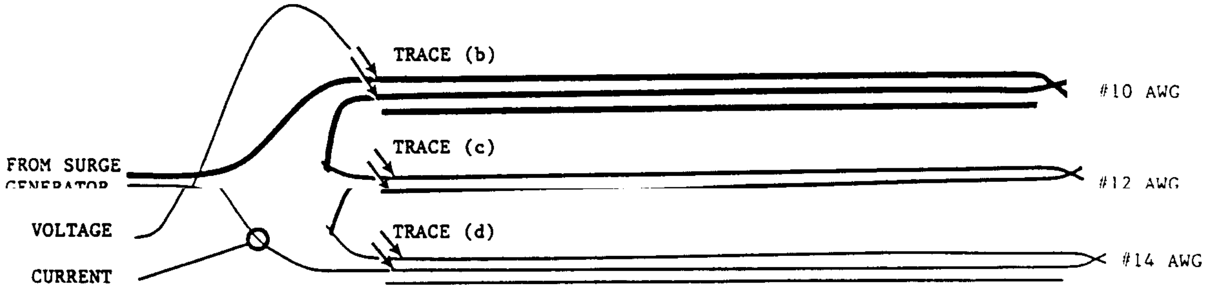

Figure 1. Series connection of test cables

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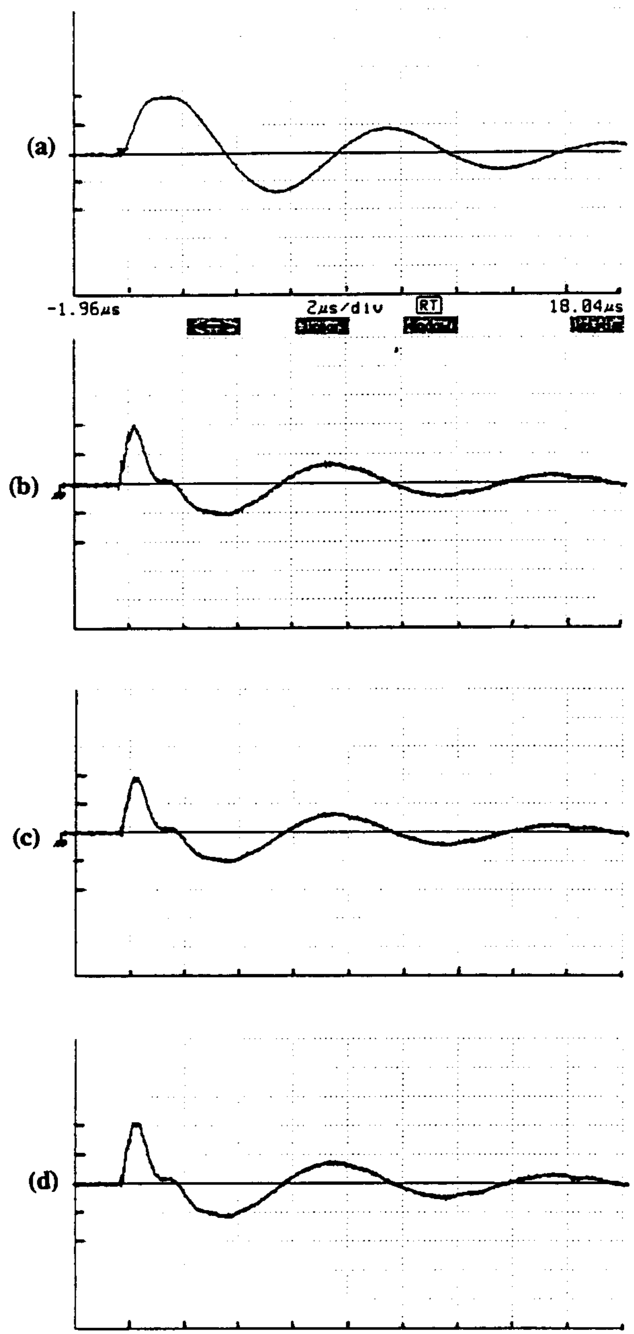
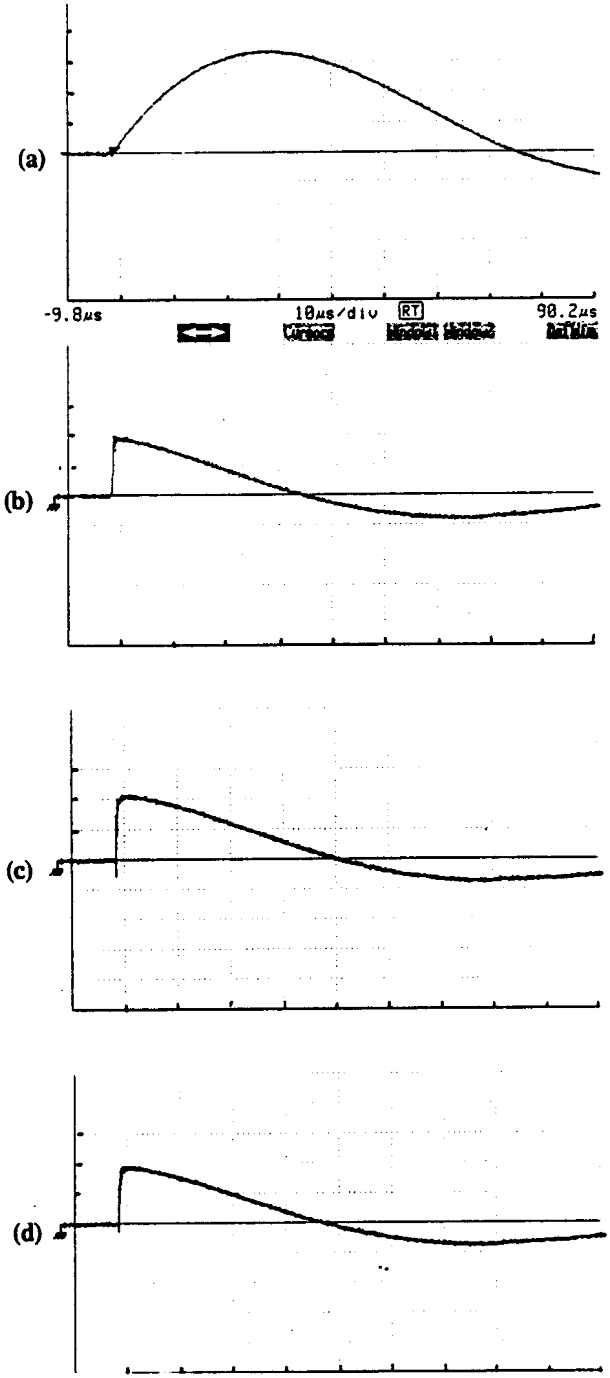
[1] *Fine print notes (FPN) of the NEC are only 'Explanatory Material', in contrast with 'Mandated Rules'.*



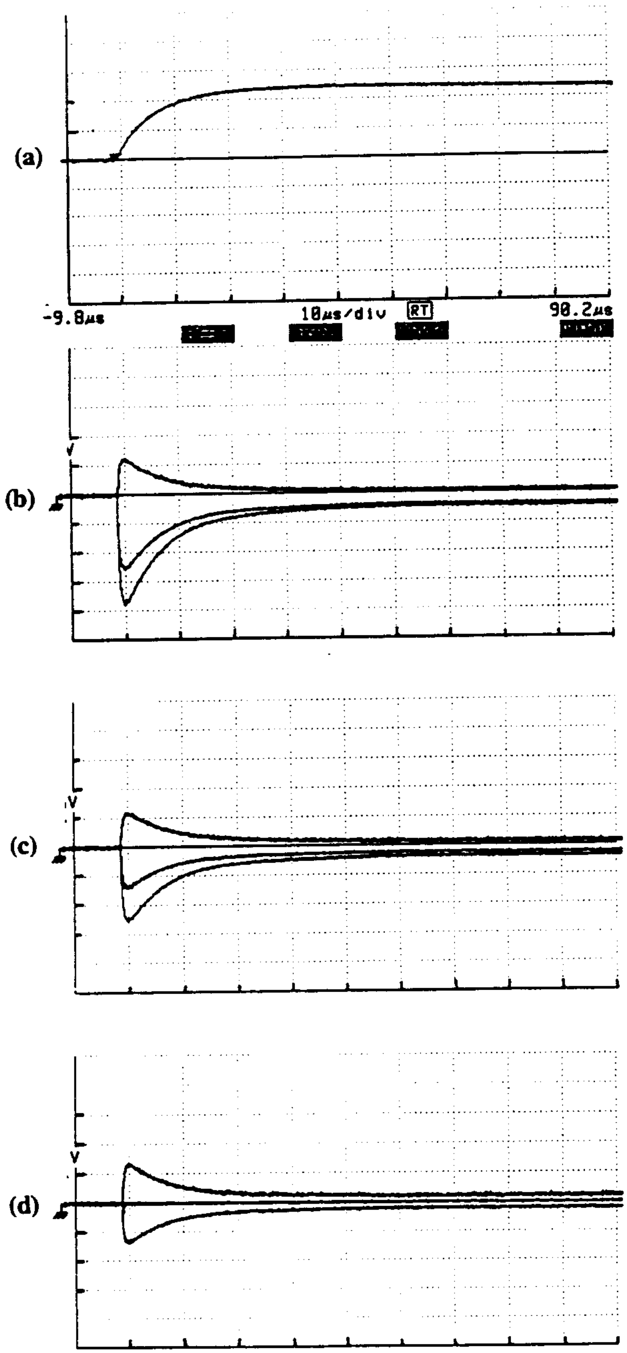
(a) Current trace: 50 A/div
(b) Voltage trace, #10)
(c) Voltage trace, #12) 400 V/div
(d) Voltage trace, #14)
(All at 2 μs/div)

Figure 2. Voltage drops with Ring Wave



(a) Current trace: 50 A/div
(b) Voltage trace, #10)
(c) Voltage trace, #12) 400 V/div
(d) Voltage trace, #14)
(All at 10 μs/div)

Figure 3. Voltage drops with Combination Wave



(a) Current trace: 50 A/div
(b) Voltage trace, #10)
(c) Voltage trace, #12) 400 V/div
(d) Voltage trace, #14)
(All at 10 μs/div)

Figure 4. Voltage drops with 10/1000 μs unidirectional wave

TABLE 1
MEASURED CURRENTS AND VOLTAGES, CALCULATED IMPEDANCE (10 m CABLE)
FOR THREE WIRE SIZES AND THREE WAVEFORMS

Nominal generator waveform	Ring Wave			Combination Wave			10/1000 μs Wave		
Peak current, I_p (A)	100			170			120		
Actual rise time of current (μs)	0.8			22			25		
Wire size (AWG)	10	12	14	10	12	14	10	12	14
Peak voltage during surge (V_p)	800	790	800	760	780	800	100	100	110
Effective impedance V_p/I_p (Ω)	8.0	7.9	8.0	4.5	4.6	4.7	0.8	0.8	0.9

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