SURGE TESTING TO INSURE PROTECTION AGAINST TELECOM-LINE AND POWER-LINE TRANSIENTS

Summary

Electronic equipment has progressed, historically, through a succession of components of increasing vulnerability. Starting with the toughest, namely relays, the progression has included vacuum tubes, transistors, IC's, and finally the most versatile yet tenderest devices of all, microprocessors. With each advance in capability and cost/performance ratio has come increasing sensitivity to switching-induced and lightning-induced transients or surges, on both telecom lines and on the AC and DC lines that provide primary and backup power.

Modern surge test equipment is available to produce both nationally and internationally agreed-upon "standard" transients, to prevent the mysterious failures that proliferate if protection isn't designed in—and tested—at the outset. In particular, the new IEEE Std 587-1980 gives explicit assistance in characterizing the so-called power-line surge "environment", i.e., what can be expected in various geographic exposure areas. Details of the new IEEE 587 specification are discussed, as well as some of the more traditional wave specifications for both signal and power lines. Ways are given to perform the required surge tests in the laboratory, instead of having to wait for problems to arise when the equipment is put into service in the field.

Introduction

The telecommunications industry was the first to provide protection against the damaging effects of spike-surges on both signal and power lines. However, two major changes have brought about the need to re-evaluate and upgrade present-day effectiveness of that protection.

The first is the ever-growing use of telecom lines for data. What was an unpleasant audible click has become, potentially, a severe loss in data integrity.

The second change is the advent of IC's, and more specifically, microprocessors. Their functional versatility is unquestioned; unfortunately, so are their susceptibility and vulnerability to electrical transients.

To assist in quantifying both surge threat-levels and the effectiveness of protection designed to withstand them, new consensus specifications have come into being and are gaining acceptance both in the U.S. and overseas. At the same time, test equipment both to generate and to measure spike-surges and their effects, has reached new levels of precision, repeatability and sophistication. The resulting quantification of protector performance itself, as well as that of total protection designs, is turning transient protection into an increasingly precise discipline.

Real World vs. Test World Surges

If transients measured on signal or power lines are the messy, complex, unrepeatable waves typified by those shown in Figure 1, why then are "standard" surge waves, such as those of Figures 2, 3 and 4, specified so precisely, and does precise conformance with the standards really matter?

Indeed it does, since only by agreeing on and then conforming to simplified versions of real-world waveforms, can we hope to obtain the necessary repeatability of surge test results. And if the test waves don't accurately enough represent their real-world counterparts, more often than not the surge standards must be iterated, not discarded. This highly-necessary iterative process has an almost decade periodicity. Sometimes the iteration actually does replace old waves with new; more typically, new ones are simply *added* for new or specific areas of application. In any event, this is the only path to successful, quantitative protection of the ESS, microprocessor-based modems, and whatever else the latest technologies will bring.

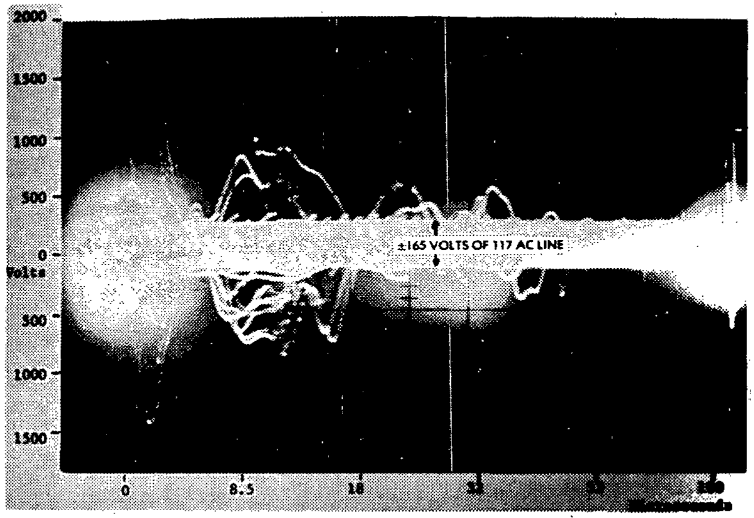

Figure 1. Typical surges on power line, taken over a 24-hour period. (Photograph courtesy F. Martzloff, General Electric Company.)

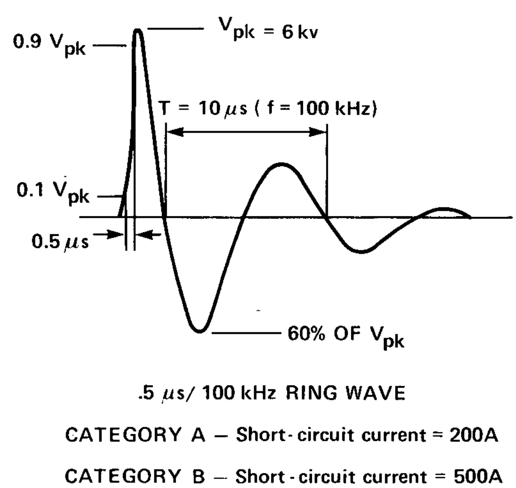

Figure 2 Theoretical 100kHz Test Surge, specified by the new IEEE Std 587-1980.

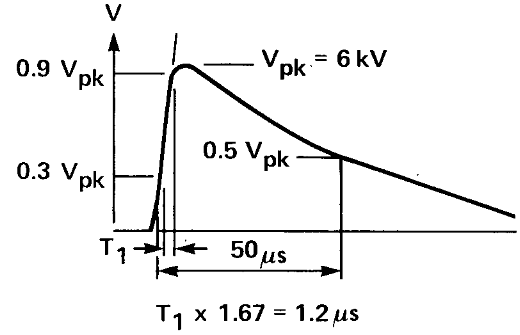

Figure 3. Theoretical classic power-line impulse voltage wave, usually 1.2 x 50.

Surge Test Specifications

The last several decades have inundated us with a welter of surge test specifications for equipment. They have been generated by various domestic and international agencies, both private and quasi-governmental. These have recently been winnowed down, however, for mainstream equipment test applications at any rate, to a rather manageable few, particularly in the field of power-line transients. (Specialized areas like *nearby* lightning, nuclear EMP, aircraft and automotive applications and so on, will continue to require their own specific waves, as will some tests for qualifying and life-testing surge-protectors themselves.)

Signal Lines: FCC, REA, CCITT

For signal lines, the longer-duration unidirectional impulse waves continue to dominate. While FCC docket 19528 Part 68[1] includes a 10 x 160* wave for longitudinal (common mode) surging, it then goes on to require a 10 x 560 wave for metallic connections (i.e., normal mode). REA[3] uses the still longer, probably more-traditional 10 x 1000. And CCITT[4] calls for 10 x 700 and 100 x 700, with extended specifications requiring 0.5 x 700 as well.

Of course, amplitudes vary widely from 800v for the FCC 10 x 560, to typically 1000 to 1500V for REA's 10 x 1000, all the way up to 6kV for the CCITT 700us impulses (presumably for lines lacking protection other than flashover.)

Table 1 summarizes the above situation in abbreviated form.

AC Power Lines: IEEE 587 and IEC 664

Two very new surge standards provide an even firmer consensus for power-line surges. In the U.S., IEEE Std. 587-1980[5] reaffirms the traditional 1.2 x 50 wave for short-branch circuits (at specific, recommended voltages and currents for given exposure levels). In addition, it includes the newer "ring-wave" already introduced by others,[6,7] in an attempt to more accurately simulate the oscillatory waves encountered on both short- and long-branch power circuits. Table 2 summarizes the

Table 1
FCC, REA, and CCITT SURGE WAVES FOR COMMUNICATION LINES

SPECIFYING AGENCY	APPLICATION	OPEN–CIRCUIT VOLTAGE WAVES	SHORT–CIRCUIT CURRENTS
FCC (Docket 19528 Part 68)	Longitudinal (Common mode)	10 x 160, 1500V	200A
	Metallic (Normal mode)	10 x 560, 800V	100A
REA (PE 60)	Trunk Carrier Systems	100 V/us, 1kV	10 x 1000, 500A
CCITT (Rec. K17)	Repeaters	.5 x 700,[1] 6kV	150–2400A[2]
		10 x 700, 6kV	150–2400A[2]
		100 x 700, 5kV	150–2400A[2]

(1) Extended specification. While the .5 x 700 is not included in CCITT Rec. K17, it is specified by many users in conjunction with it.

(2) Depends on output damping resistor selection. (Can theoretically be infinite if zero damping is selected.)

new Standard, which is likely to describe U.S. power-circuit surge testing for some time to come.

Internationally, the newly-issued IEC Standard 664[8] calls for essentially the same 1.2 x 50 impulse as does IEEE 587, at levels again "staged" to be appropriate to distance from the point of power entry to the structure involved.

Modern Surge Testing: The Key To Successful Protection

The design of surge protection usually brings something of a surprise to the uninitiated. The design involves so few components compared to the far more complex circuits often handled by the technologist, why then should a few protectors and their surrounding networks present such a thorny problem?

The answer is probably multi-fold, but it involves, at the very least, some of the following considerations:

1. Protectors are, by their very nature, highly non-linear; some even exhibit negative resistance. Using them in conjunction with even a few linear components means, for practical purposes, that closed-form solutions for performance of the resulting networks are unlikely, and at best, difficult and impractical.
2. As a corollary to (1), non-linear networks receive so little formal attention that their characteristics are often difficult to intuit, if they are not actually counter-intuitive.
3. Some protectors, namely carbon-block arrestors and gas tubes, are highly statistical in nature. In addition, their performance is based on their history and other complex factors: the number of surges received so far, exposure to dark or light, etc.

   With metal oxide varistors or MOV's, on a shot-to-shot basis performance is not statistical. However, history also enters, albeit to an influence level of only a few percent, as a function of the number of surges already taken at the previous surge polarity.
4. Systems using protectors are often very complex, involving large numbers of both inputs and outputs that require protection. Again, mapping the possible signal paths is not a task likely to yield closed-form solutions.

* The correct, traditional wave definitions are loosely used, and misused, by various specifiers. A x B (or A/B, internationally) signifies a front of A us and a duration of B us from wave *start* to 50% of peak. A is classically 5/3 the time from 30% to 90% for voltage waves, and 5/4 the time from 10% to 90% for current waves[2]. The FCC spec uses time to peak, however, and for the most part so does REA.[3]

5. In the last analysis, all surge protection design requires a firm understanding of grounds and ground systems; in particular those in the circuit or system in question. Yet grounds and ground design are very possibly the most sophisticated areas that exist in electronic systems.

As a result of all of the above, surge protection designs seldom work properly when they are *first* executed; the matter is just too complex. Hence the key to successful protection is, as the title of this section states, surge testing.

For some time now, sophisticated test equipment has been available to generate a range of "textbook-quality" impulse and ring waves, to meet virtually all existing wave specifications.[9,10,11] While such testers have had component test and evaluation as their primary design goal, their performance has been extended into circuit testing as well.

More recently, new surge generation equipment,[12,13] has been introduced to deal quite directly with the consensus specifications discussed in Section 2. Capabilities include coupling even the high-energy 6kV, 1.2 x 50 impulses to an active AC line in normal and all three common modes.[11,12,13] Design of this newer generation of surge test equipment has been aimed specifically at surging circuits and systems. This implies a number of capabilities that have heretofore been unavailable, certainly within the same instrument complex. They include:

1. The ability automatically to measure and digitally to display not just the positive or the negative peak, but also the maximum of the two for a given surge, for both peak current and *delivered* (not just open-circuit) peak voltage. Thus a breakdown that occurs within the EUT (Equipment Under Test) as a result of either a unidirectional *or* an oscillatory test surge, will be "caught" even if it isn't initiated until the portion of the wave occurs that is the opposite of the nominal surge polarity. (For unidirectional waves, the opposite polarity can occur due to overshoot, itself caused by either inductors or capacitors within EUT circuitry, or in the couplings to it.)
2. The ability to measure peak voltage *differentially* within the EUT, via a high-voltage probe of modest size. This probe is *inherently* differential, which is crucial since it is both inaccurate and potentially unsafe to introduce scope (or any other) ground into the EUT.
3. The additional, optional capability to measure—and digitally to display—peak current (again plus, minus, or the maximum of the plus and minus peak), flowing through a wire deep within the EUT. By this means it is possible to eliminate from the measurement, currents due to cable capacitance, protectors and other components that may physically precede the device(s) whose currents are of interest during the surge.
4. The opportunity to superimpose test surges simulating those found on power lines, on active lines actually powering devices or systems under surge test, without surging other

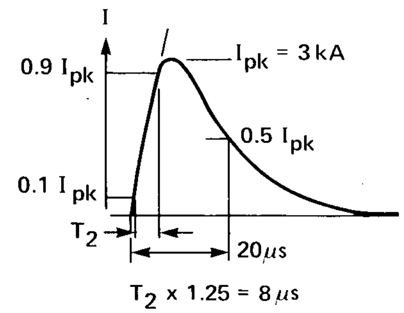

Figure 4. Classic power-line impulse current wave, usually 8 x 20.

Table 2

Categories in IEEE Std 587-1980 for Power Lines

CATEGORY	DESCRIPTION	TYPICAL LOCATIONS	SURGE WAVE (S)	WAVE CHARACTERISTICS
A	Long branch circuits	AC wall outlets	Ring wave (damped cosine)	To 6kV: .5μs rise time, 100kHz frequency 200A short-circuit I
B	Short branch circuits	At the breaker box; computers; ovens; industrial lighting, etc.	1. Ring wave (damped cosine), and	Same as Category A, except 500A short-circuit I
			2. Impulse (unidirectional)	To 6kV, 1.2 x 50μs: 1.2μs front time, 50μs to ½ peak 8 x 20, >3kA short-circuit I
	Exterior circuits	At the weather-head; submersible pumps, etc.	Impulse (unidirectional)	To 10kV, 1.2 x 50μs: 1.2μs front time, 50μs to ½ peak 8 x 20, 10kA short-circuit I

equipment connected to the same lines. This capability includes surging single-phase AC or DC lines in normal and *all three* significant common modes ; and permits surging three-phase lines, in all modes for diagnostic purposes, but particularly in the most important ones for routine qualification and proof-testing.

5. The ability quantitatively to ascertain the existence of arcing at the peak of the surge wave, in a local parasitic network comprising inductance and capacitance in the circuit or system, perhaps including the wiring that supplies the test surge.

   The effect of such an arc is usually to add only a small amount to measured surge current. Simultaneously, however, it can actually increase the measured peak voltage at the EUT by from 10 to 50%.

Evaluating Protectors

The only way to know what protectors do themselves, under actual surge conditions, is to test them. Tests should be run first in Engineering, to more fully understand device performance. Then tests need to be run on a continuing, sampling basis to maintain incoming product quality, compare vendors and so on.

Protector Performance Characterization

Gas Tubes, MOV's and Avalanche Diodes all exhibit different properties, and each requires different waves for characterization of its critical parameters. A 6.8V Avalanche Diode does *not* clamp at 6.8V, for instance, and some gas tubes are far more statistical than others. MOV's, too, require characterization. Like the other two types, their performance—clamping level in particular—is a strong function of circuit parameters and drive.

Protector Life Tests

All protectors have wear-out characteristics when subjected to repeated surges over a period of time. Life varies widely among them, since they use different technologies and partly in consequence, find themselves in different applications. Life also is a strong function of surge levels, and can be statistical.

Thus even when it comes to as difficult an area as life, modern surge test equipment is helping to improve the availability of quantitative device characterizations.

Testing Complete Circuits and Systems

The final proof of a successful design is a final test—this is just as axiomatic in surge work as elsewhere.

CONDITIONS	COUPLER	APPLICATION NOTES
1. LOW-Z LINES (POWER, ETC.)	(C) SURGE-RATED CAPACITOR	$\left(\frac{V_{OC}}{I_{SC}}\right) C \geq$ SURGE WAVE DURATION (UNLESS LINE Z IS KNOWN)
2. HI-Z LINES WITH STANDING V< 10 TO 15 V AND NO SIGNIFICANT FOLLOW CURRENT CAPABILITY	TWO-ELEMENT GAS TUBE	APPLIED SURGE EDGE MAY BE STEEP DUE TO GAS-TUBE TURNON
3. HI-Z LINES WITH STANDING V>10 TO 15V	SILICON AVALANCHE DEVICES	AVALANCHE V> CKT STANDING VOLTAGE
4. SAME AS (3)	VARISTOR	VARISTOR CLAMP V> CKT STANDING VOLTAGE

Figure 5. Typical surge couplers for both AC and signal lines.

The key to surge testing completed equipment is the surge coupling method employed.[9,10] For communication lines, i.e., lines that can't tolerate large surge-test coupling capacitors in normal operation, often gas-tubes are used, either alone or in combination with clamping devices. For power lines, simple capacitor coupling often suffices. In both cases, surge filtering must be used in series with the normal lines just prior to the point of test-surge application, to prevent surging other equipment on the same line. Figure 5 shows typical surge couplers for various situations.

Concluding Remarks

Protection design and surge testing have both become highly quantitative. In the last half-decade, the advent of new consensus surge wave specifications has given rise to new test equipment to generate the waves and to measure their effects. As a result, circuit and system protection can be far more fully checked in the laboratory before serving its function in its intended, unforgiving environment.

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