TEST SURGE DELIVERY AND MEASUREMENT

Several basic questions must be decided before proceeding to surge test circuits and systems:

(1.) How should the test surges be applied to the EUT (Equipment Under Test), while insuring safety to personnel and other equipment;

(2.) What should the test program be; and

(3.) How can reliable test data be obtained.

These lead naturally to the concept of Diagnostic Surge Testing, defined as a quantitative approach using accepted, well-defined, repeatable test waves applied in progressively larger magnitudes via circuits described as surge couplers, until failures start to happen. Failure analysis can then be based on careful evaluation of the potentials, currents and energies involved monitored as necessary at the surge test source; at the point of delivery, and finally across the failure-prone components themselves. Subsequent steps include replacement of failed components, introduction of design changes and re-application of the surge test waves to verify design change effectiveness.

The Surge Generator

A variety of surge waves are needed in order to simulate the many different real-world surge environments in which electronic equipment finds itself. However, surge generator outputs designed to simulate these waves are characterized to a large extent in terms of wave-independent parameters. A typical surge generator is shown in Figure 1, along with a summary of these parameters. Although the waveform inside the circle in the figure represents an impulse, the terms are applicable to oscillatory waves as well:

V_{OC} = PEAK OPEN-CIRCUIT OUTPUT VOLTAGE

I_{SC} = PEAK SHORT-CIRCUIT OUTPUT CURRENT

$\left(\frac{V_{OC}}{I_{SC}}\right)$ = EFFECTIVE PEAK SOURCE IMPEDANCE

W_S = INTERNAL STORED ENERGY (JOULES)

$V_{DURATION}$ = TIME FOR V_{OC} TO DROP TO 50% OF PEAK V_{OC}

$I_{DURATION}$ = TIME FOR I_{SC} TO DROP TO 50% OF PEAK I_{SC}

Figure 1. Critical surge generator parameters

(1.) V_{OC}, the surge generator peak open-circuit voltage, indicates the maximum dielectric and other voltage-dependent stress that will be applied to the EUT. In the absence of any other information, V_{OC} is meaningless, since it might be stored on a capacitor of a few picofarads, hence could represent trivial energy.

V_{OC} is defined and/or measured with everything connected to the surge generator *except* the EUT; hence if the AC or DC, power or signal line driving the EUT loads the surge generator, it is the *loaded* output that is referred to as V_{OC}.

If a test calls for application of a 6KV surge to the EUT, 6KV must therefore be the surge generator output when it is driving the AC line back-filters, for example, that isolate the surge from the rest of the laboratory. The voltage developed by the test generator when totally disconnected from the circuit—i.e., unloaded by the back-filters and so on—is irrelevant to the test. This is a crucial and often misunderstood point.

If the wave is oscillatory instead of impulsive, then in addition to being characterized by a peak amplitude (and implicitly, polarity), its 'amplitude' also requires an indication of decrement—amplitude loss—per half-cycle or cycle.

(2.) I_{SC}, the surge generator peak short-circuit current, gives an idea of the kind of energy that the test surge can deliver but is only a rough guide if the short-circuit current surge duration is unspecified. A high amplitude for I_{SC}—hundreds or even thousands of amperes—is often specified for reasons already covered in Part I. In addition to the ones given there, however, another exists for sub-system modules such as power supplies. For such equipment, testing with realistically high currents is important to insure that circuits that may themselves be uninjured or only slightly damaged—such as transformers and bridge rectifier-capacitor combinations—will demonstrate their ability to 'pass-along' the surge to circuits they drive.

As with voltage, if the current surge is oscillatory, the decrement each half cycle or cycle is often specified, although less frequently than for voltage, as it, too, is an 'amplitude' parameter.

(3.) V_{OC}/I_{SC}, the ratio of open-circuit voltage to short-circuit current, is the surge generator's output impedance. It is a most useful parameter when determining whether a particular test is realistic. Does it make sense, for example, to surge a 30-ampere (AC line current) load with a 6KV, 200 peak ampere surge test generator? The 30-ohm generator (6000V/200A) will only deliver 700 volts to the 4-ohm load (120V-30A), so the answer is no; that's one reason why the new IEEE draft specification calls for what amounts to a 2-ohm source impedance for surging such heavy loads. (See Part I for further comments relative to load inductance and the relevance of 60Hz impedance to a spike situation.)

(4.) W is the symbol for energy, and for a surge generator, W_S indicates *stored* energy. Delivered energy depends not only on W, but also on the load; the upper limit will be $W_S/2$ for a load matched to the generator output impedance. (Though some early specifications ignore the fact, it is impossible to deliver energy to either a short- or open-circuit!) The combination of W_S, V_{OC} and I_{SC} provide enough information to compute at least a range of deliverable energy. $I_{DURATION}$ (see (6) below) can be acceptable as a substitute for W_S in such determinations.

(5.) $V_{DURATION}$ is the time from V_{OC} wave zero to decay to half of peak for an impulse, again noting that this is before connection of the EUT but *after* connection of everything else.

(6.) $I_{DURATION}$ is the time from I_{SC} wave zero to decay to half of peak, again for an impulse. In conjunction with I_{SC} itself, I_{SC} duration is an indication of wave energy content. Some surge specifications neglect I_{SC} duration, thereby providing the option of generating the test wave with an energy storage capacitor of a few picofarads.

Delivering The Surge: Common And Normal Mode

While radiated-field and flux-coupled surge testing are viable methods and find use in isolated applications, most surge tests are done using conductive coupling to the EUT (Equipment Under Test).

There are two basic types of conductive coupling: common mode and normal mode. The first is widely *mis*understood to mean application of a signal to two lines in common, with respect to ground. What 'common mode' really means is application of a signal one side of which is connected to 'common', an older term for ground. Thus a common mode surge (or a 'longitudinal' surge, as it is known in telecommunications) can be between just *one* line and ground, or many lines and ground, the most familiar configuration involving two lines and ground. Often the most damaging way to surge equipment is between neutral and ground, one of several highly-necessary common mode test configurations that represent the real world.

'Normal mode' is a term usually more or less limited to systems with two lines and a ground, and refers to signals applied between the two lines, not purposely involving ground. The general significance of normal mode is often extended to multi-line systems, so long as the applied signals don't overtly involve ground; hence a normal mode surge may be applied between not just one but several lines and an arbitrarily-chosen reference line, so long as none of the lines are ground, or common. In telecommunications, this set of alternatives for signal application is termed 'metallic', an apt description taken from the fact that only metal (i.e., wires) are involved, and not 'common' or ground. At the time of the definition, the non-metallic earth was used as return for telephone systems, before the advent of AC power made it unacceptable for voice.

A Comprehensive Surge-Test Plan

Table 1 gives a general surge-test plan for multi-line systems. It includes the widest range of both normal and common mode surge testing, with all combinations in which a single reference line is used. (Multiple reference lines, suitably addressed via couplers like those to be discussed for non-reference lines can be used in still more complex configurations for special cases.) Several points made in the table are worth emphasizing:

(1.) All surge testing should be done with both polarities for the first (or only) peak. The environment doesn't appear to prefer one polarity over the other, at least when lines into equipment are concerned.

(2.) The most difficult surge test to pass in many AC-powered systems is the one-line common mode test involving neutral and ground; and it can represent a worst case field surge as well.

(3.) A full-scale passive surge test program should precede application of normal power and/or signals for active surge testing; to insure that all failure modes due to surge per se are uncovered, prior to involving power follow and other power-related problems.

Care should be taken to distinguish conceptually between impedance changes that may result from application of power in active surging, and actual effects of the power and/or signals themselves. The active impedance situation should, therefore, be simulated when surge-testing the EUT without power.

(4.) Finally, when AC line power is involved, experience shows it is necessary for efficient, diagnostic surge testing, to control the phase of the AC line at which the surge is applied and to vary the phase in increments no larger than 45°. (Power station arresters, it has been found, must be surged in 15° increments to obtain a true profile of their operation. Other devices and circuits may also require this care.) Surging with random phase not only requires *far* more surges to insure 'covering' all phase possibilities but also makes difficult, if not impossible, repetition of surge conditions leading to specific EUT failure modes.

TABLE 1

DIAGNOSTIC SURGE TEST PLAN FOR MULTI-LINE SYSTEMS

SURGE MODE(1)	REFERENCE LINE(2)	SURGED LINE(S)(3)	PASSIVE ACTIVE	SURGE PHASE (ACTIVE, AC LINES ONLY)
NORMAL (METALLIC, LINE-TO-LINE OR SIMPLY NOT INVOLVING GROUND) TWO-LINE:	EVERY LINE EXCEPT GROUND	ALL OTHER LINES EXCEPT GROUND	BOTH	MAX. OF EVERY 45°; 15° IN SPECIAL CIRCUMSTANCES.
MULTI-LINE:	EVERY LINE EXCEPT GROUND	ALL OTHER LINES EXCEPT GROUND, IN GROUPS OF 2, 3, 4, ETC.	BOTH	SAME
COMMON (LONGITUDINAL, OR INVOLVING GROUND) TWO-LINE:	GROUND ("COMMON")	ALL OTHER LINES	BOTH	SAME
MULTI-LINE:	GROUND ("COMMON")	ALL OTHER LINES IN GROUPS OF 2, 3, 4, ETC.	BOTH	SAME

(1) ALL SURGES APPLIED IN BOTH POLARITIES, INCREASING PROGRESSIVELY FROM ZERO TO FULL AMPLITUDE.
(2) CAN BE TWO OR MORE LINES VIA MULTI-LINE COUPLERS, IN PARTICULAR CIRCUMSTANCES.
(3) ESPECIALLY INCLUDING NEUTRAL IN AC SYSTEMS.

Two-Line Normal Mode Surging: Two-Line Surge Couplers

Figure 2 shows a surge generator connected to lines driving an EUT (Equipment Under Test), in two-line normal mode configuration. The Surge Coupler that connects the high end of the ungrounded surge generator can be one of

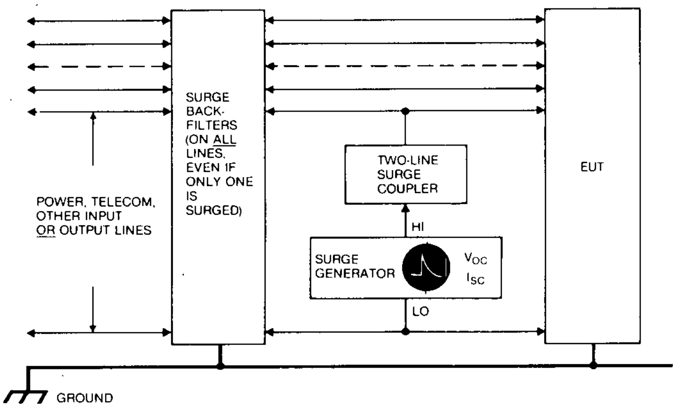

Figure 2. Two-line normal- or metallic-mode surging

a number of two-line types, as appropriate to both the EUT and the lines involved—power, signal, high or low impedance and so on.

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 3. Two-line surge couplers

Figure 3 shows some commonly-used, two-line surge coupler designs. First is a capacitor, surely the simplest. For power lines it is most appropriate and also finds use in other low-impedance applications. Its disadvantage is that usually the surge generator output impedance is low, hence the lines and EUT must be able to operate normally with the fairly large capacitor, in effect, connected directly across the two lines being surged even when the surge isn't present. The capacitor value, C, will be determined by the duration of the short-circuit current available from the generator—$I_{DURATION}$, since the time constant of the surge generator output impedance—(V_{OC}/I_{SC}) times C—should be several times $I_{DURATION}$ so that it won't limit applied test surge duration if/when breakdown or clamping occurs within the EUT.

Capacitor voltage rating must exceed V_{OC}, the peak surge voltage; and it must also be surge rated, so it can withstand repeated applications of worst-case surge current I_{SC}. Capacitors meeting these requirements aren't small, nor are they inexpensive. (It is usually true that if the capacitor meets the V_{OC} and I_{SC} requirements that it will have no trouble handling power-line or other voltages normally present on the lines to be surged; but this is still worth checking for each application.)

When the circuits and/or lines being tested can't tolerate the 5 to 500 ufd capacitor usually implied by the requirements sketched above, there are other techniques to be employed. These include use of several different kinds of surge protectors as Surge Couplers. These may be employed in series with *both* Out Hi and Out Lo, to relieve the lines and the EUT from not only the surge generator's low output impedance, but also the capacitance from the entire surge generator to ground.

The second coupler shown in Figure 3 is simply a gas tube, selected to have a breakdown voltage as low as possible so that it will conduct a soon as possible on the surge leading edge. This method won't work if the circuit's normal voltage is in excess of 10 or 15 volts and it can supply current over a few tenths of an ampere, since the gas tube requires a low potential and/or current to allow it to extinguish after the surge has passed. In such cases, the 'hybrid' couplers also shown in Figure 3, involving varistors or back-to-back avalanche suppressors in series with the gas tube, may be used; with the varistor or avalanche suppressor clamping voltage allowing the gas tube to extinguish once the surge is over. (Using the gas tube in this circuit insures, in effect, a *total* disconnect, as it represents merely a few picofarads when non-conducting.)

Possibilities not shown in Figure 3 include use of varistors or avalanche devices alone, without the gas tubes. Elimination of the gas tube from the coupler has the advantage that the applied test wave won't be as artificially steep as it will with a gas tube suddenly conducting at a few hundred volts—or even a thousand for steep applied surges. Gas tubes tend to turn on in just a few nanoseconds, so applying what is supposed to be a 10 × 700 wave to a communications repeater via such tubes, as recommended by CCITT (Reference 6, Part I), will test the circuit with a few-hundred volt, few nanosecond initial step, that is an artifact of the test setup, presumably unrelated to the real-world situation being simulated.

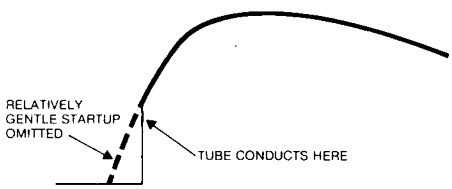

Figure 4. Gas-tube coupler modification to leading edge of classic 10 x 1000 wave

Figure 4 shows the way the slow start-up of a 10 × 1000 wave becomes a few-nanosecond edge with gas-tube coupling. On the other hand, use of a simple varistor or silicon protector alone for coupling will leave in-circuit the not-inappreciable protector capacitance—up to thousands of picofarads—after the surge is over and may to an even greater extent clip off the lower part of the surge wave below varistor conduction than does the hybrid configuration (see Figure 5). (The simple gas tube, *once* it conducts, gives all but 10 to 15 volts of the surge wave.) Nevertheless, readjustment of the surge amplitude can account for this, while there is almost no way to adjust for the gas-tube's initial applied voltage 'jump'. It would thus appear that CCITT and other specifying agencies, not to mention individual organizations setting up their own test methods, should consider using varistors and silicon avalanche devices as simple couplers *without* the tubes, when circuit capacitance isn't critical, adjusting surge generators to compensate for the resulting chop in the surge wave baseline in any case.

Single-Line Common Mode

Single-line common mode is the same as two-line normal mode, except that one of the lines—the reference for the surge—is ground, or common. Figure 6 shows one such configuration; in a given situation, there are as many as there are lines other than ground.

One-line common mode is singled out for treatment not only because it points up the widespread misunderstanding of the meaning of the word 'common' in this connection, but also because it is perhaps the most important mode to test when AC power is involved. A surge between neutral and ground is often the most potent failure-generator, and suppression or grounding and bonding techniques that minimize or eliminate consequent failures in test situations can significantly reduce surge-related field failures.

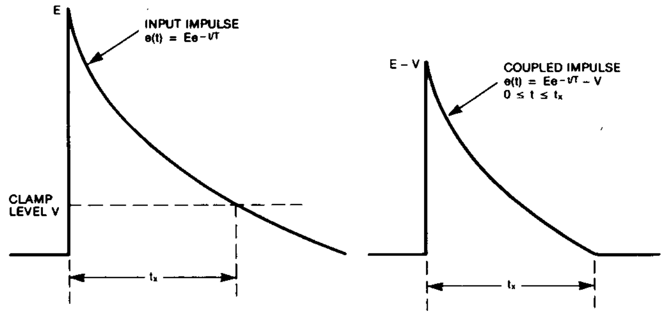

Figure 5. Low-end "chop" due to use of varistor or silicon avalanche suppressor in surge coupler, alone or with gas tube

Surge Back-Filters

In connection with both Figure 2 and Figure 6, surge back-filters are shown between input and/or output lines from the EUT and these lines' final sources or destinations, to prevent the test surge from surging the rest of the laboratory. The need for such filters is often recognized, but certain of their properties need emphasis.

(1.) Such filters, usually involving inductors, must not saturate on either the normal circuit voltage/current combinations, or on the surge applied *in conjunction with* the normal circuit voltage and current. Lack of appreciation for this point may yield fail-positives in active surge applications by driving the EUT with too low a surge when power is applied, due to saturation of the back-filter and the loading it then imposes on the surge generator.

(2.) Filters are also necessary on all other lines connected to the EUT except ground, since breakover within the EUT during surge may pass the energy along to any line even if it isn't involved explicitly in the surge, via EUT internal component or insulation breakdown or flashover. No point in connection with surge testing is so generally overlooked, and therefore none has more serious implications for auxiliary damage or, more important, personnel hazard.

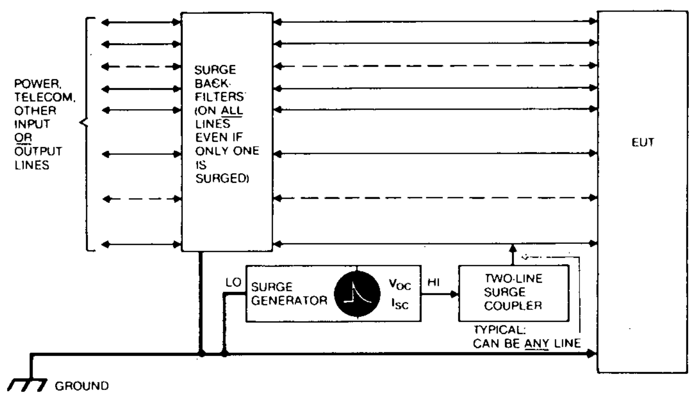

Figure 6. Single-line common-mode surging

Multi-Line Common Mode Surging; Multi-Line Surge Couplers

Testing in multi-line normal mode isn't as usual as multi-line common mode (although it is included in Table 1 and should be given consideration in setting up a complete test plan). Figure 7 shows a multi-line *common* mode test setup, which can as easily represent a multi-line normal mode situation if the surge generator reference (or Lo) is changed to an ungrounded line, and the multi-line surge coupler shown in the diagram is also not ground-connected.

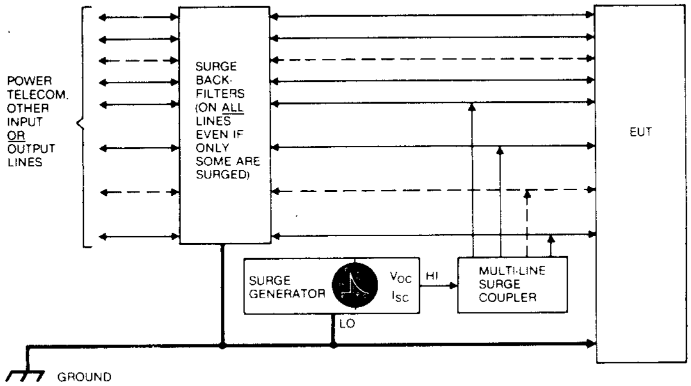

Figure 7. Multi-line common-mode surging

Figure 8 shows alternatives for multi-line surge couplers, analogous to the two-line couplers of Figure 3. They indicate the availability—albeit in some cases limited—of multi-element gas tubes for the application, and show how varistors and/or silicon avalanche protectors must be individually connected to maintain the advantage of low-capacitance loading afforded by use of gas tubes. Three-element tubes are reasonably common, as they have already moved extensively into telecommunication protection. Five-element tubes are scarce but should become more available as they take hold in repeater protection, for simultaneously crowbarring the two input lines and the two output lines to ground in the event of a surge on any of the four.

CONDITIONS	COUPLER	APPLICATION NOTES
1. LOW-Z LINES (POWER, ETC.)	REF LINE; LINE 1, LINE 2, LINE N; C; SURGE-RATED CAPACITORS	$\left(\frac{V_{OC}}{I_{SC}}\right) C \geq$ SURGE WAVE DURATION (UNLESS LINE Z IS KNOWN)
2. HI-Z LINES WITH STANDING V < 10 TO 15 V AND NO SIGNIFICANT CURRENT CAPABILITY	REF LINE; LINE 1, LINE 2, LINE N; COMMON ELECTRODE; MULTI-ELECTRODE GAS GAP	APPLIED SURGE EDGES MAY BE STEEP DUE TO GAS-TUBE TURNON
3. HI-Z LINES WITH STANDING V > 10 TO 15 V (REPEATERS, ETC.)	REF LINE; LINE 1, LINE 2, LINE N; SILICON AVALANCHE DEVICES	AVALANCHE V > CIRCUIT STANDING VOLTAGE
4. SAME AS (3)	REF LINE; LINE 1, LINE 2, LINE N; VARISTORS	VARISTOR CLAMP V > CIRCUIT STANDING VOLTAGE

Figure 8. Multi-line surge couplers

Beyond this point, multi-element gas tubes can be obtained only in specific situations. Multi-pin gas-filled connectors have been developed for simultaneous protection of a large number of input and output lines to common, but their availability is limited.

Neither in the figures nor in Table 1 is a situation depicted in which several reference lines are driven by the surge generator Out Lo, although this is referenced in Note (2) below the Table. Clearly a multi-line coupler can be used for both generator Out Hi and Out Lo if the simulation requires it; but this would represent a special need in terms of present general understandings of spike-surge phenomena.

Ground Fault Due To Surge Filters; Isolation Transformers; Grounded Versus Ungrounded Surge Generators

It should be clear that a suitable surge test program requires design capability. It must take into account many factors that are normally 'givens': common versus normal mode, complex grounding considerations, surge coupling, 'pass-alongs' between individual system modules and between systems, filter requirements and interactions, methods for driving the power line itself, implications of EUT and surge generator impedances, the concept of neutral versus ground and so on. There are still other areas basic to an understanding of surge testing. They include ground fault implications of surge back-filters, the use of isolation transformers to eliminate them, and the all-important question of maintaining low ground-potential rise with grounded and ungrounded surge generator configurations to minimize disruption of other equipment and to maximize personnel safety.

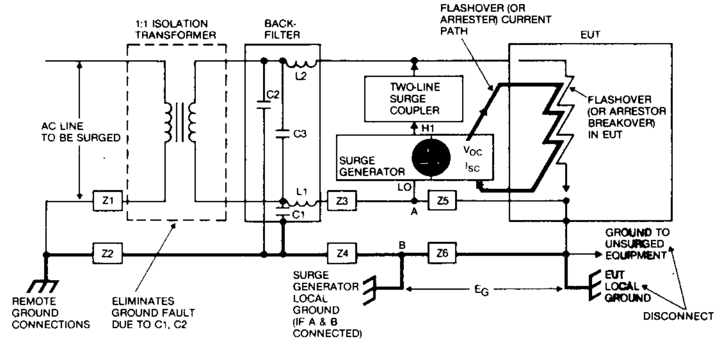

Figure 9. Isolation transformer to eliminate ground fault due to surge back-filter (parasitics not shown)

Figure 9 shows a typical two-line normal mode surge configuration, with surge back-filters implemented in simplest form via series chokes and shunt input capacitors. In the most general configuration, three capacitors are shown: C1 and C2 from input lines to ground, and C3 across them. The lower surged line is taken as neutral, the upper as 'high'.

Clearly 1 to 50 ufd of capacitance from each line to ground in an AC system will trip any GFCI (ground-fault-circuit interrupter) in the AC power system, since even if the capacitors were exactly equal, the currents through them would be vastly different in view of the totally unequal voltages on 'high' and neutral with respect to ground. Thus in no installation using GFCIs can surge filtering be accomplished in this way.

The isolation transformer shown in Figure 9 gets around the GFCI problem, maintaining good practice and personnel safety in this regard at least, by isolating the input lines from the surge back-filter. Capacitors on the transformer secondary will cause no unbalance—not even at the GFCI critical milliampere level—between current in the two current-carrying input lines. The price paid, however, is in the size, weight and heating of the isolation transformer itself, not insignificant even at the 2KVA level (for a 15A line, for example), and still more significant at levels of 6KVA (for 50A), and 12KVA (for 100A).

Figure 9 shows an ungrounded surge generator, often implemented by using a grounded surge generator with pulse transformer output equipped with a floating secondary. There is no ground potential rise, E_G, as no surge current flows through ground impedance Z_6 *even* if there is flashover or purposeful clamping from surge high to low *or* ground within the EUT. (This analysis, like the figure, ignores parasitic capacitances which may also have to be taken into account in specific situations.)

However, if points A and B are connected, in effect grounding the surge generator at a local point, surge current can flow through Z_6 under some flashover or clamp conditions within the EUT, and the 'ground' furnished to subsequent areas in the laboratory may carry pulses with peaks to thousands of volts.

The isolation transformer doesn't solve the ground potential rise problem then. The only solutions are:

(1.) Don't carry the ground any further—make the EUT the 'end of the line'. But this still leaves the EUT ground—presumably including its case—at a high spike potential!

(2.) Use an ungrounded surge generator (and watch out for the parasitic capacitances, not shown in the diagram); or

(3.) If A and B must be connected—because the surge generator must be grounded or for some other reason—reduce Z_6 to zero or as close to zero as possible, and remove the case of the EUT from possible contact with personnel for good measure. Also make the EUT the 'end-of-the-line' for ground, as in (1.) above, for extra insurance with regard to other equipment.

Monitoring Within Surged Equipment

There may be excellent reasons for monitoring the results of the applied surge, deep within the EUT, to find the peak voltage reached across a particular component or circuit for example, or its specific breakdown mode. Figure 10 shows a recommended monitoring scheme, which further illuminates some of the considerations touched on in the preceding section in regard to ground and isolation of other signals to and from the EUT.

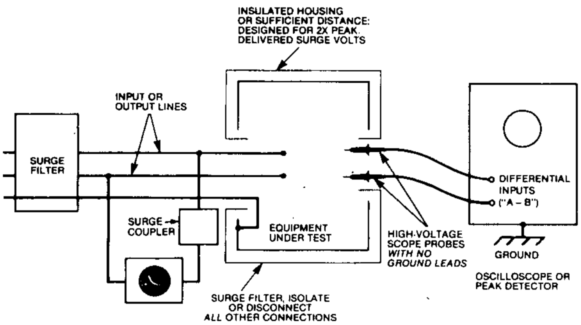

Figure 10. Monitoring within surged equipment

The most important point to be made in connection with Figure 9 is the requirement for a barrier surrounding the EUT, to provide safety and a guarantee against flashover to any other object. This barrier may be simply sufficient separation—including from the floor, which must be presumed to contain conduit or other metal. Alternatively, the entire barrier can be physical insulation. In either case, it should be complete, except where penetrated for insertion of input or output lines, and measurement probes; and it should be safe for a peak voltage equal to at least twice the peak of the incident test surge. (Circuits in breakdown can oscillate at high rf frequencies, and can thereby increase applied peaks by a factor approaching two.)

All other lines must be removed from the EUT; or if it is not possible to do so, then they must be surge-back-filtered like the lines actually being surged; since if flashover occurs within the EUT, it may be conducted to any port.

Monitoring is accomplished, as indicated, most readily on a differential basis. This enables use of safely grounded oscilloscope or peak detectors, *with high voltage probes that have no ground leads attached.* "Ground" within the EUT may not be ground at all, and the scope (or peak detectors) should *not* generally be connected to it.

Probes with safe peak-voltage margin for at least twice the applied surge peak should be employed. Ordinary low-voltage scope probes are unsafe, even if the *resulting* circuit peak voltages are thought to be just a few hundred volts; since under fault conditions an internal EUT flashover or other malfunction may apply enough voltage to destroy the probe, the monitor device input circuits, and possibly even other equipment, if it can once enter the laboratory ground system via this route.

Of course, elimination of other input and output lines, or even altering their impedance and so on with filters, may give a less than totally realistic result for surge response. However, nothing short of surging with actual lightning or the other physical phenomena being simulated can eliminate this conceptual limitation. Until generation of such natural phenomena becomes both necessary and practical, the suggested methodologies stand as a reasonable and generally successful approach.

As a final point, oscilloscope (or other monitor) common-mode and noise rejection should be carefully checked. This is best accomplished with both inputs first monitoring the total input surge, and then EUT ground; to insure that oscilloscope readings aren't unduly limited by noise.

Concluding Remarks

Spike-surge testing of powered electronic equipment has become practical, with the advent of quantitative specifications on standard waves for a variety of different situations. Led by this quantitative approach, it is now possible to couple without undue losses, to calculate, and even to measure the energy levels involved in test surges. Results include increased understandings of failure modes pertinent to specific equipments, waves and so on.

Methods for applying the surges have been developed for normal and all forms of common-mode, along with coordinated filtering to prevent them from reaching unsurged lines. Equally important has been evolution of a simple, safe approach to monitoring surge results deep within the equipment under test, for diagnostic purposes, without jeopardizing the overall system or laboratory ground system.

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This article was prepared for ITEM by Peter Richman, President, Keytek Instrument Corp.