# Surge Protection of End-User Equipment

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Surges Happen !

**Significance and background**
Part 7 – Mitigation Techniques

This document is included in the Annex of Part 7 as historical background of a well-intentioned task that was completed at too slow a pace, missing its target date for serving as a reference for other in-process IEC standards projects concerned with low-voltage surge-protective devices. For the sake of historical accuracy and perspective, the document is presented here in its draft form, including typos and wishes that turned out unfulfilled in the quest for the end of the rainbow.

This “working document” was prepared for and circulated to the members of a just-appointed (in 1995) IEC Joint Working Group charged with developing a standard that would serve as a guide to several IEC Technical Committees involved in developing standards related to SPD test procedures, performance requirements, and application. The plan was to generate a comprehensive document that would provide a common data base to SC28A (LV Insulation Coordination), TC 64 (Electrical Installations) and SC77B (High-Frequency EMC), and TC91 (Lightning Protection), with the perception that if made available on a short schedule, these committees might want to wait until completion of this task.

Thus, this document was intended to call attention to the unresolved issues with a hope that it might indeed speed up the process of bringing consensus among the experts appointed for that purpose by the targeted committees.

As it turned out, however, progress was slow and the intended target committees proceeded on their own with developing and eventually releasing their documents at a faster pace. Nevertheless, the Joint Working Group (eventually changed to a working group of TC64 alone) continued its work until an IEC vote accepted the document in 2000. Unfortunately, editorial tweaking of the English version and unavailability of a French translation resulted in IEC publishing an English-only Technical Report (62066-2002) instead of the initial intent of a formal Standard.

# Surge Protection of End-User Equipment

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## Introduction

Technically valid and cost-effective surge protection of end-user equipment can only be achieved by matching the surge withstand capability of equipment (with or without added protection) to the surge environment, the latter being generally beyond the control of the end-user. Thus, three sets of questions must be answered by a facility engineer to arrive at a reliable approach:

1. What is the surge threat (voltage and current amplitudes, potential for energy deposition, frequency of occurrence) and is there any possibility of mitigation before impact on the end-user service entrance ?

2. What is the surge withstand capability of connected equipment ?

3. What interface protective devices should be added to ensure that the threat does not exceed the withstand capability of the equipment ?

In the following, the principles of effective surge protection are discussed in general terms. Because of the random nature of surge occurrences and the impossibility for standards to cover all situations, this discussion must remain at the level of general principles. The "mission" of an installation also influences the decision process, where high reliability has to be balanced against cost. Understanding these principles and applying them to each particular site can help achieve a high degree of reliability. Before going into more details, three general remarks should be made:

***For a given installation,*** if there is a large complement of equipment already provided with built-in surge-protective devices (SPDs), there is a possibility that the combined action of all SPDs might be sufficient to mitigate impinging surges. On the other hand, if only a few, or a single appliance is provided with a conspicuously low-clamping SPD, there is a possibility that the single SPD might attract all of a "large surge" and be destroyed in the process.

***One factor to keep in mind*** *is* the increasing use of "smart electronics" equipment which is connected both to the power system and to an information system such as telephone, video, data processing, command and control, etc. Exclusive attention to providing surge protection separately to each port of the equipment may leave open the possibility that differences in reference voltages – supposed to be at "ground potential" – would in fact be at different voltages and thus apply excessive stress across the components of the equipment connected between the power port and the communications port. Ironically in some cases, this difference of reference voltages can be the side-effect result of the otherwise intended action of an SPD.

***As a final note,*** it should be kept in mind that other failure mechanisms are possible, which could be misdiagnosed as surge-related failures. Thus, and generally with some hindsight, investigations of "surge failures" might benefit from opening the scope of a post-mortem to all possible causes, not just those related to presumed surge overstress.

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*1. This attachment is a “living document” -- a snapshot of the author's experience and awareness of the work by others in this field. As such, it should be considered as a working paper, not a "publication." Comments and suggestions for improvements are sincerely invited and will be incorporated into subsequent editions of this document.*

**Summary - Questions Requiring Answers**

On this page, a summary is presented in the form of questions to be answered for effective implementation of a surge protection *scheme*. The background of the questions is discussed in detail in the paragraphs indicated by reference to [numbers] following the questions.

***Non-technical questions***

This type of questions cannot be answered by a technical discourse on good practices for surge protection, but still need to be answered according to the broad policies and operational goals of the organization. They involve trade-off between reliability at any cost and acceptably imperfect but still high reliability at acceptable cost. A commercial installation may have varying degrees of protection against highly unlikely, but not impossible threats. National defense installations are good examples of achievable protection, but at a cost that might not be acceptable for commercial purposes. Thus, economic as well as technical judgment enters the process.

***Technical questions***

- Environment

  - Frequency of occurrence of lightning (flash density)
  – Typical ground impedance values seen at the power system entrance
  - Presence or absence of capacitor switching
    – How far?
    - How large ?
    – Any record of pst problems ?
  – Long cables with fuses at the end ?
  - De-energizing transformers on the primary side ? -
  Grounding configurations
    – Deliberate lightning protection system -
    Incidental lighting terminals
  - If multi-port equipment:
    – Power port protection provided ? -
    Communications port provided ?

- Equipment characteristics
  - Known surge immunity ?
    - Inherent immunity (capacitor input) -
    Built-in SPDs
      - Clamping voltage
      - Current handling capacity

  - Unknown surge immunity
    - Inquiry with manufacturer possible ?

  - Susceptibility to disturbances other than surges ?

## 1. Identification of Surge Threats

Surges conducted by the power system can impinge upon end-user equipment from two sources: external surges (direct and indirect lightning, utility system switching) and internal surges (primarily load switching, including clearing of faults by fuses or circuit breakers, and also direct lightning strikes to the building structure).

***Lightning surges*** are somewhat dependent upon geography and season, as well as on the utility distribution system design (grounding impedance). A new development in this field is the change from the traditional use of isokeraunic data (based on the number of days per year for which occurrence of a lightning storm is reported), to the actual number of flashes occurring in any region of the United States, thanks to a network of lightning flash detection stations. Thus, much more realistic information is now available on the frequency of occurrence of lightning according to geographic area.

***Switching surges*** include the energizing of capacitor banks that can create relatively low-frequency surges (500 Hz to 5000 Hz) at relatively high voltages, but less than lightning-induced surges De-energizing capacitor banks can occasionally be associated with restrikes that create large overvoltages (several times the system voltage; this rare occurrence depends on the characteristics of the switch used, some vacuum switches being known to produce such events.

***Switching of loads*** by the end-user includes inductive load switching as well as capacitive switching if the end-user is making use of power-factor correction capacitor banks. When the end-user part of the system includes some form of a transformer, step-down or isolation, consideration must be given to the discharge of the core energy when such transformer is switched off.

***For the limited but possible case*** of a direct lightning strike to a building, there is a growing recognition in the engineering community that the so-called "lightning protection system" (understood as lightning rods, down-conductors and earth electrode intentionally installed) also includes every metallic element on the roof of buildings (and sides of tall buildings) typically heating, ventilation, and air-conditioning equipment, as well as communications towers and dishes. These involve conductors, conduits and ducts going right through the heart of a building, rather than the deliberate down-conductors neatly installed along the outside of the building walls. A lightning strike to these elements will result in a current seeking a path to ground not only through the building structure, but also through the incoming utility grounding system. Depending upon the impedance of the building grounding system, this current will create significant differences of voltage between the building grounding system – which includes the incoming multiple-grounded neutral – and the line conductors. Such a difference of voltage, if not limited by a service-entrance SPD, would most likely produce a flashover between the building ground and the utility lines. Thus, SPDs installed at the service entrance have to provide sufficient current-handling capacity not only for incoming surges on the power service, the case generally considered in application notes, but also for that part of an outgoing lightning current seeking ground by way of the utility grounds.

From the preceding generic identification of threats, specific questions can be derived. Some will have generic answers, other may be highly application or site-dependant. They are presented below according to the nature of the source under the headings of lightning surges, utility switching surges, and internally-generated surges.

A brief discussion is also presented on the issue of the possible need of ***surge reference equalizers*** for equipment involving power ports and communications ports. More details on the need for surge reference equalizers, as well as several surge-protection topics have been provided through papers on surge protection published by the author. The literature also contains many relevant papers by others deserving an acknowledgment. However, for the purposes of the present discussion and simplifying the reading, references to the literature have not been included, with the exception (and apologies because of the appearance of exclusive self-references) of those papers collated in a 1985-1995 booklet, provided together with the present discussion, and identified in the text as [Xyy].

### *Lightning Surges*

A distinction must be made between the parameters of the lightning discharge itself (the common wisdom is to consider crests up to 200 kA as probable at the 5% or 2% level) and the currents that will appear in the conductors of a power system. Even the worst-case threat of a direct attachment of a lightning flash to the conductors of a power system must be considered with a clear view that the high values of currents quoted in the literature will produce multiple paths to ground, thus a reduction to a much lower level for the surges appearing at the service entrance. On the other hand, a conservative factor to keep in mind is that the attachment of a lightning flash is not limited to overhead conductors. A strike to earth may result in large currents seeking nearby underground conductors that may be erroneously deemed as not exposed to lightning.

Where a surge arrester is applied that depends on absorbing the energy associated with the lightning current (as most do), one must also keep in mind that several strikes occur in a single flash, producing an accumulation of heat in the arrester. Many specification sheets provided by manufacturers, especially the so-called TVSS (for "Transient Voltage Surge Suppressors") aimed at the consumer market, show a one-shot rating, not a multiple-strike rating. This fact explains in part the apparent upward auction of greater current ratings[2] among SPD manufacturers, where the high values cited should not be seen as an inference that such high values are expected on site, but represent a safety margin for multiple strikes. That margin is tentatively demonstrated in the laboratory by a single, higher test current. Few laboratories are equipped with a surge generator capable of delivering multiple surges at the close interval of an actual lightning flash.

### *Utility Switching Surges*

Utility switching operations take place under two scenarios: normal operation of a power system, and corrective actions under abnormal conditions. From the point of view of surges, the most important scenario is that of switching capacitor banks. When a capacitor bank is energized at random time with respect to the power-frequency sine wave, the initial effect of the connection is a quasi-short circuit on the power system, as the uncharged capacitor appears as a low impedance. The system voltage experiences an abrupt dip that can reach near zero. An oscillation then ensues, with an amplitude and a frequency that are determined by the system RLC parameters. Thus, the characteristics of this type of surge are very site-specific, starting with the first question is whether or not utility capacitor switching takes place "near" the site. Unfortunately, the definition of "near" is not obvious. Paper [B3] narrates a case history where switching a capacitor bank on a 23 kV system caused repeated failures of varistors incorporated in 480-V adjustable speed drives located 3 km (2 miles) away. A noteworthy aspect of this case history is that the best solution involved installation of an arrester at the medium-voltage level, rather than at the final low-voltage level as originally provided in the equipment. The explanation is fairly simple: given a fixed amount of energy to be absorbed by a varistor, if this is to be done at the low-voltage level, a large current will be involved, requiring a large cross-section of the varistor that could be achieved only with parallel combination of discs (not a trivial matching challenge). On the other hand, absorbing the same energy at a higher voltage – still requiring the same ***volume*** of zinc-oxide material – results in a thicker varistor disc of reasonable thickness/diameter aspect ratio.

Since the time of that incident, many studies have been performed by many researchers on capacitor switching, including magnification and resonance effects if harmonic filters are present in the system. With progress in availability of synchronous closing, and concerns on adverse effects of capacitor switching surges, some relief is available, but at a cost that might not appear justified in systems where only limited resources are available.

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*2. As opposed to the downward auction of claims for the lowest clamping voltage, mentioned later under the discussion of appropriate interface surge-protective devices.*

In the case history cited, the solution was easy to implement because the medium-voltage system was under the control of the industrial end-user. In the case where the interface between utility and end-user would not occur until the low-voltage level, a dialogue between utility and end-user would be useful for the purpose of finding the most cost-effective approach to both parties, rather than a unilateral and occasionally adversarial quest of the minimum cost to be incurred by each party acting in splendid isolation.

Other utility switching operations include load shedding and faults -- during the fault and after clearing of the fault. These events are not negligible from the point of view of sags and swells, but do not produce surges comparable to lightning or capacitor switching surges. Thus, if an installation is provided with surge protection that can deal effectively with the latter two major threats, the other utility switching surges are readily covered and need not be included in the questions concerning the surge environment.

### *Internal surges*

In a manner similar to utility surges, normal and abnormal operation of the end-user's power system can create surges. These are influenced by the physical dimensions of the building that determines the natural frequency of oscillations that are stimulated by switching loads. Although the voltage levels could be high in systems that do not include any SPDs – a rare situation nowadays – the potential for energy deposition from this type of surge is much lower than that of surges impinging at the service entrance. The extreme case of such low energy is the so-called EFT Burst, a train of 5/50 ns pulses that represent interference caused by the switching action of air contactors. Initially developed by the IEC, the specification of an EFT Burst test is now included in the menu of "Additional Waves" of ANSI/IEEE C62.41 and therefore merits some discussion.

The EFT Burst reflects a concern about interference with data-processing equipment, not damage of equipment. Because it involves a very fast voltage rise, even below the clamping threshold levels of SPDs, that type of interference cannot be mitigated by SPDs; filters would be required if mitigation were necessary to avoid interference. The voltage levels cited in the standards describing the EFT Burst (up to 4 kV in the test specifications) should not be interpreted as representing levels of actual occurrences. They are levels prescribed by the authors of the standards, based on the key observation that equipment that can ride through the prescribed EFT regimen exhibit better noise immunity in the field than equipment which cannot ride through the EFT Burst.

In large facilities supplied by the utilities at distribution voltage levels (4 kV and up), or where the internal power distribution is done at a 480 V level with subsequent step-down to single-phase 120 V branch circuits, the issue of transformer de-energizing arises. If a step-down transformer is de-energized on the primary side with light load on the secondary, the magnetic energy stored in the transformer core must be discharged in whatever impedance exists on the secondary. If that impedance is relatively high in relation to the energy level of the stored energy, high transient voltages might result. With the expanding practice of populating branch circuits with plug-in SPDs, or with equipment incorporating built-in SPDs, the scenario of high transient voltages has been replaced by a situation where the SPD with the lowest clamping voltage must be able to ☐ discharge the core energy. The manufacturer of the transformer, or an expert in transformer technology should be consulted to assign a realistic value to the amount of magnetic energy stored in the transformer. A review by the facility engineer of the loads left connected to the transformer secondary at the time of opening the primary will then allow comparing the transformer stored energy and the SPD energy-handling capability. Among all the SPDs effectively connected in parallel [3] in the installation, it will be the SPD with lowest clamping voltage that will attract most of the energy, so that it is important to identify which one will be involved.

*3. This is a situation that should not be confused with the issue of SPDs connected in cascade, where there is an upstream SPD and a downstream SPD. Cascade coordination issues are discussed in papers [B14], [B15], [B18].*

Another surge threat was identified in the early eighties, and for some time reflected in draft standards. This threat involves the scenario of an installation with long cables supplying several circuits at the user end. If a fault in one of these end-circuits is cleared by a current-limiting fuse, the energy associated with the fault current flowing in the cable inductance will be dumped in the other end-circuits. Tests and computations were performed that demonstrated that such a scenario is possible. The German standards organization (VDE) actually prescribed a test of a 100/1300 uus surge applicable to industrial equipment, and that test was for several years cited in a comprehensive listing of tests under consideration in the IEC. However, tests performed by the author and computations by his co-author [B 10], [B 13], [B 17] demonstrated that such a scenario must be very rare because, if frequent, the millions of varistors now installed in low-voltage power systems would fail upon occurrence of such an event – hence the premise that it is frequent is flawed. The latest draft revision of the IEC surge immunity tests has dropped this particular test requirement. Nevertheless, it might be prudent for the facility engineer to verify that the configuration of the particular system is unlikely to produce such a scenario.

## 2. Inherent Surge Immunity of Equipment

Any equipment, regardless of its design, has a threshold of stress beyond which failure is likely. When referring to "surge immunity" the idea is to express a characteristic that makes the equipment immune to common levels of stress – a very subjective assessment. Standards-writing bodies are attempting to bring order to this poorly defined concept by specifying test protocols and minimum stress levels for equipment, not only for surges, but for all types of electromagnetic disturbances. This process is far from complete, and enforcement is only at the beginning, so that two types of equipment will be found on the market: those with, and those without specified surge immunity.

### *The Rare Bird: Equipment with Specified Immunity*

Under the influence of international standards, driven to a large extent by the European organizations, equipment marketed world-wide after January 1996 will bear the CE mark implying conformity to electromagnetic compatibility requirements, including surge immunity. However, these requirements are generally expressed in terms of surge voltage withstand, not necessarily in terms of surge current withstand, unless implied by the specification of a particular type of surge generator. At the present time, equipment offered on the U.S. market is not regulated by mandatory standards of surge immunity. The choice is left to manufacturers for providing and publishing specific immunity levels.

Two different cases must be considered: the equipment has an inherent high immunity, or the immunity is ensured by incorporation of a built-in SPD. An example of the first case is typical data-processing equipment powered through a "switch-mode power supply" that includes an intermediate DC capacitor link supplied by a full-wave bridge rectifier. Seen from the AC side, such a circuit appears as a capacitor connected across the line – an excellent surge absorber. The second case includes equipment where a conservative and prudent manufacturer might have provided an SPD that may or may not have sufficient surge ***current*** handling capability. That issue, involving concepts of cascaded SPD coordination, is discussed in the literature as well as in the papers cited in the preceding footnote 3.

In any case, when the effective equipment immunity is identified, it is then possible to make an informed decision on the need to provide additional surge protection. A question will have to be asked, however, whether this added protection has to be selected taking into consideration the presence of an integral SPD, once again raising the issue of cascade coordination. This aspect will be discussed at greater length in the next section covering the need for surge mitigation.

### *The Common Variety: Equipment with Unspecified Immunity*

In contrast to the rare bird, typical equipment found on the U.S. market at this time does not have conspicuous and published specifications of surge immunity. In some cases, the information may be obtained from the manufacturer, in some cases not. This situation can leave the end-user in several degrees of disarray:

- The totally ignorant end-user might have no concern at all or have an inherent trust that all will be well, until disaster strikes, at which point panic retrofits are implemented.

- The partially informed end-user will seek preventive surge protection, but not necessarily based on sound and cost-effective engineering. This is a situation akin to the purchase of insurance coverage, a reasonable and not unusual strategy.

- The well-informed end-user will be in a position to optimize the cost/benefit ratio, including an awareness that uncertainties are still unavoidable, but can be narrowed.

## 3. The Need for Surge Mitigation

Surge mitigation is generally obtained by appropriate application of SPDs and, to the extent possible, by sound engineering practices on wiring and grounding the equipment. As mentioned for switching surges, some preventive mitigation is also possible by selecting switchgear with low likelihood of causing switching surges.

### *Surge-Protective Devices*

When comparison of the surge environment and the surge withstand capability of the equipment reveal that the margin between the two is insufficient, SPDs are applied to provide the necessary mitigation. The ideal situation, found in the high-voltage world of electric utilities, proceeds in reverse order: a suitable surge arrester is *first* selected that can achieve a well-defined protective level for the power system (`Basic Insulation Level" – BIL) ***after which equipment*** connected to the system is specified with an appropriate margin above the BIL. In effect, the BIL established by the SPDs becomes the overall surge environment of the power system.

In the low-voltage end-user world, the situation is different: even the well-informed individual end-user has little leverage on the manufacturers decision to provide a given immunity level, so that this level tends to be *a de facto* situation, ***after which SPDs*** are specified if necessary. The overall environment remains uncontrolled.

An improvement can be made, however, in the initially uncontrolled surge environment of the end-user by installing an appropriate ***SPD at the service entrance. T***he end-user does have control of that device, and thus can set a surge environment situation akin to that established by the utility BIL. This winning situation has only recently emerged because a misguided concept promulgated by the IEC and embraced by several organizations had encouraged the reverse, a higher voltage at the service entrance. That concept, now rejected, was first proposed in IEC publication 664, presenting a descending "staircase" of voltages from the uncontrolled environment outside of the building to lower and lower surge levels further on inside the building. According to that concept, a service entrance arrester would establish a first level, say 4000 V for a 120-V system, progressively decreasing by discrete steps down to say, 800 V at the end of branch circuits. Encouraged by this concept, promulgated by a credible source, equipment manufacturers and in particular SPD manufacturers proposed a protection scheme where the service entrance SPD had a higher clamping voltage than SPDs further downstream in the building. Thus was created the controversy of cascade coordination.

### *Cascaded SPD Coordination*

With the advent of gapless arresters and the application of new numerical simulation tools for varistor applications, it became apparent that the down-staircase sought by IEC 664 was an illusion. IN the scenario where a service entrance SPDs is installed with a clamping level substantially above the level of downstream SPDs, the latter will tend to "protect" the upstream SPDs by drawing most of the surge current. Numerical examples of this situation are given in {B14], [B 15], and [B 18]. The shorter the distance between the two SPDs and the slower the rise of the surge, the more energy will go to the downstream device.

However, this scenario of an uncoordinated cascade, where the downstream device (presumably with less current-handling capacity than the upstream device) is not the recipe for disaster: actually, it is the prevalent situation in most of the U.S. households where no service-entrance is provided, but the occupant installs plug-in TVSSs and/or the equipment contains built-in SPDs. We know that this arrangement, while not ensuring the utmost protection, does not result in intolerable rates of equipment failure. The service-entrance arrester with higher voltage in fact does not contribute to the protection, but does no harm. The only objection is that it is a waste of resources.

In contrast, a well-chosen service-entrance SPD with appropriate low clamping voltage will assume the role of effective guardian at the service entrance, avoiding the circulation of large surge currents toward the internal SPDs (an undesirable situation from the point of view of EMC), and providing stress relief for the internal SPDs. For the industrial or large commercial end-user, where the entrance of the service is done at a voltage higher that the end-use voltage, depending on a service entrance arrester operating on the higher system voltage has the advantage cited in case history [B3] of more favorable and feasible aspect ratio of varistor discs. The cascade coordination by selection of clamping voltages of course will involve the step-down ratio of the power transformer. Furthermore, the step-down transformer will inherently provide additional impedance to decouple the downstream SPD from the upstream SPD, a key factor in a successful cascade.

In an ideal world, a successful cascade would be established by starting at the service entrance with a clamping level compatible with the characteristics of the incoming power. From there, progressively increasing clamping voltages would be assigned to downstream SPDs. Unfortunately, the real world had proceeded in reverse. Initial equipment failures when the first solid-state appliances were introduced has created a climate of concern, which in fact has been somewhat exaggerated and also encouraged by TVSS vendors. The fact of the matter is that nowadays, most electronic appliances have an inherent immunity level of at least 600 V to 800 V, so that the clamping voltages of 330 V widely offered by TVSS manufacturers are really not necessary. Objective assessment of the situation leads to the conclusion that the 330 V clamping level, promoted by a few manufacturers, was encouraged by the promulgation of UL Std 1449, showing that voltage as the lowest in a series of possible clamping voltages for 120 V circuits. Thus was created the downward auction of "lower is better" notwithstanding the objections raised by several researchers [B8] and well-informed manufacturers. One of the consequences of this downward auction can be premature ageing of TVSS that are called upon to carry surge currents as the result of relatively low transient voltages that would not put equipment in jeopardy. At this point, there is near-zero probability that the trend will be reversed. The only possible course of action open to the facility engineer is to see to it that plug-in devices installed by end-users acting as independent agents are selected from vendors that offer an unconditional warranty for their product. This aspect quickly turns into the question "Which brand should one purchase for the best protection, of for the most cost-effective protection ?" Such a question could only be answered at the outcome of an exhaustive test series performed by an independent laboratory. A National Laboratory is not chartered to perform product rating tests. Notwithstanding the regrettable low threshold established by UL 1149, that standard has the unusual characteristic of including both safety-oriented tests (the usual goal of UL standards) and some performance tests aimed at demonstrating a stated clamping level and some indication of endurance. The original UL 1449 had not included tests of failure modes –the mind set was simply that failure was a failure. A new edition of UL 1449 will call for tests demonstrating the absence of hazards when a failure occurs as the result of abnormal overstress.

For the selection of a service-entrance arrester, especially if at a medium-voltage, the situation is better because the design and application of these devices are more directly influenced by utility design philosophy than by consumer mass-market strategies. The collective experience of electric utilities and their traditional suppliers of distribution-level SPDs has refined the selection of damping voltage and maximum continuous operating voltage to a realistic and reliable level.

### *Surge Reference Equalizers*

Surge reference equalizer is the name given to a family of plug-in devices now offered on the market to assure surge protection of electronic appliances that feature a power port and a communication port. When an SPD provided on one of the systems – power or communications – operates upon occurrence of a surge, the resulting ***surge current*** in the power system or the grounding system conductors, a ***voltage shift*** occurs at the ports of the appliance. Depending upon the design of the appliance, such a shift can produce failures. Some numerical examples are given in papers [B 19] and [B20]. The possibility of such a scenario (a review of the arrangement of the systems should be made by the facility engineer in the case of complex, multiple appliance installations) does make a case for providing an SPD at the point of end-use, even if the service entrance SPDs have established an acceptable level of residual surges in the differential mode (for instance, line-to-neutral for the power port and tip-ring for a telephone port).

A wide variety of surge reference equalizers is now available on the market. Unfortunately, no standard has yet been developed to provide guidance on selecting an appropriate device. Here again, a UL listing under file 1449 is at least credible evidence that reasonable performance, in addition to safety, will be provided by the device. Establishing liaisons among standard bodies, appliance manufacturers and surge reference equalizer manufacturers should be a pressing goal, but it has not yet occurred.

### *Installation Practices*

Almost `needless to say', installation practices should not negate the expected benefits from SPDs. An excellent SPD can be made useless by poor installation practices, in particular excessive lead length and impedance of the ultimate ground connection. The ***IEEE Emerald Book*** provides detailed information on these points.