Update on a Consumer-Oriented Guide for Surge Protection

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Significance
Part 6: Tutorials, textbooks, and reviews

As implied by the title, this paper presented a progress report on a long-term project undertaken by EPRI PEAC in a effort to bridge the gap between engineering documents and consumer-oriented publications. This goal was partly accomplished by the publication of a "Final Report" by EPRI PEAC (Special Publication 0545.R, "***Recommended Practice for Protecting Residential Structures and Appliances***") covering the same broad subject, complemented by the NIST Recommended Practice Guide Pub 960-6 (***Surges Happen!***), the latter included in this Part 6 of the Anthology.

Two documented case histories of lightning damage are narrated in this paper, a somewhat rare opportunity to inspect the aftermath of lightning damage and replicate some of the failure mechanisms in the laboratory.

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Abstract

Caught among contradictory stories on the need for surge protection as well as unsupported anecdotes of surge-related failures found in some editorial advertising, the typical consumer is in a quandary on how to best allocate personal resources to protect the expensive electronic equipment found in a modern household. To help provide some answers to this quandary, a team of experts had previously developed a basic engineering Recommended Practice on surge protection of residential electronics. The value of the theoretical concepts presented in the Recommended Practice is illustrated by two case histories where such concepts were not applied. In addition, "post mortem" examinations have been performed on appliances turned in as having failed as a result of a lightning surge. Those appliances that were in fact not damaged by lightning, although part of a claim settlement, were tested for surge immunity.

1. Introduction

1.1 The need for a Guide on Surge Protection

As home appliances and electronics have become more sophisticated they have also become more susceptible to damage from energy anomalies. These anomalies are most often caused by switching surges and lightning strikes. They are also causing more frequent homeowner insurance claims. While there is a considerable amount of knowledge about the various components of the issue (lightning, surge damage and protection, and grounding practices), there is no single definitive source for combined information. Therefore, a partnership was formed between State Farm, Illinois Power, the Electric Power Research Institute, and the National Institute of Standards and Technology to develop a document that would fill the need for a consumer-oriented, reader-friendly guide on surge protection. The initial goal of this partnership was to develop a recommended practice for protecting homes against surges and lightning. From this, the partners expect to convey best surge mitigation practices, to decrease appliance damage and the number of loss claims to insurance companies, and to reduce consumer worry about surge-related damage to their electronic appliances.

Like many electric utilities, Illinois Power, with over 500,000 customers, understood the need to provide an authoritative and well-documented reference document applicable to protecting property and equipment. With such a reference, electric power producers can more easily answer the many customer inquiries about surge protection as well as to better communicate with customers via specific power quality and equipment protection programs. Promoting such customer-oriented service programs is expected to be a win-win situation. In the case of Illinois Power, sponsoring this project was also an opportunity to help one of their large customers, State Farm Insurance in Bloomington, IL.

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1.2 From engineering writing to general-public writing

As a first phase of this project, a group of experts had developed a Recommended Practice document [EPRI Project 01 39-8002, 1997][1] on the origins and mitigation of surges in the residential environment. This 90-page document was written from the engineering point of view to document the consensus reached among these experts and serve as the basis for the next step, a consumer-oriented publication available to the general public. The need for a consumer-oriented guide stems from the practical fact that, for most situations, a generic surge protection system costs less than an engineering analysis to determine exact requirements. Consequently the partners recognized the value of developing a version of the guide written so the general public could understand and apply the basic concepts. The idea is that individual homeowners, who are concerned about their appliances, will better understand what to look for and how to correct deficiencies so that they might take sound and cost-effective actions.

To accomplish this objective, NIST, in concert with the co-authors of the present paper, is undertaking the writing of a shorter, reader-friendly guide on surge protection. One of the important theoretical points made in the engineering report was the need to provide coordinated grounding practices among the utilities (electric power, telephone, cable and satellite TV) serving a residence. To further document the importance of this coordination and the dire consequences of not following them, two case studies were performed on lightning-related incidents. Bench tests were performed on damaged equipment obtained by agents of State Farm, with the purpose to determine typical failure modes and assess surge vulnerabilities and immunity.

Three critical elements for the guide are recognized in this task:

1. To be clearly written in layman's language — a challenge to the editors
2. To originate from an objective source — hence the participation of NIST as the “publisher.”
3. To provide simple instructions on how to reduce surge vulnerabilities in the home — another editorial challenge for engineers accustomed to write engineering instructions.

2. Lightning-Damage Case Studies

In general much more technical information had been collected in the Recommended Practice development effort than a typical, or even highly motivated, homeowner could use. Even so, some voids in understanding appliance failures still existed, namely exactly why some appliances fail and other do not. Both field experience and lab evaluations of appliances show that susceptibility to surges varies by appliance type, make, and model. According to insurance claim records, the most commonly damaged appliances include telephones and modems, computerized equipment, televisions, VCRs, and satellite receiver systems, which are all generally “multi-port” appliances.

The theory for failures presented in the recommended engineering practice document was the likelihood that voltage potential differences between ports was the Achilles’ heal of many residential appliances and systems. To back up this theory, a sampling of multiple-port appliances was obtained from appliances surrendered as part of insurance claims in the state of Tennessee. Postmortems and laboratory experiments were conducted to better understand the failure modes of these appliances.

Two known lightning incidents occurred recently in the Knoxville area, providing a unique opportunity to document the mechanisms and failure modes of residential electronics. The first incident involved a small house made primarily of wood where the power service entrance and the cable TV entrance were at opposite ends of the house – the classic error in installation practice. The second incident involved an expansive residence with an elaborate audio-video system with a centralized equipment rack distributing signals to speakers and video monitors.

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[1] *Citations in the text appearing as [Author, Date] are listed in alphabetical order in Section 6, Bibliography.*

2.1 The case of the Cozy Cabin

At this rural site in Eastern Tennessee, a wood-structure residence suffered two successive failures of video equipment during lightning storms, a few months apart. The owners allowed PEAC personnel to visit the site and acquire the second failed TV receiver for a post-mortem.

2.1.1 Site configuration

The power service entrance is located at one end of the house, while the cable TV service entrance is located at the opposite end. A visit to the site revealed that the cable TV shield was grounded only by a questionable ground rod next to the house foundation (within the drip line, and thus in dry soil, see Figure 1). Furthermore, this grounding connection was not bonded to the grounding connection of the power service entrance, a clear violation of the National Electrical Code, according to the current edition as well as several, if not all, earlier editions [NFPA 70, 1999].

The local cable TV company was informed of this situation and took what they believed an appropriate action: the incoming cable was first routed under the house, in the crawl space, to allow bonding the shield to the power service grounding connection. From there, the cable was returned to its original point of entry into the house, at the opposite end. It would seem that under such a configuration, a lightning current surge traveling along the cable shield (instead of a proper bonding conductor), might create sufficient voltage drop along the path under the house to create problems. However, the interaction was not pursued further with the cable company. A recommendation was made to the owner of the house to install a surge reference equalizer near each of the video equipment in the house.

2.1.2 Post mortem and surge tests

One of the failed TV receivers was made available to PEAC for examination. No evidence of damage was found on the power side of the chassis, but a clear indication of surface flashover was observed between the cable input ‘ground’ termination (connected to the incoming cable shield) and the shielding can of the tuner (Figure 2). After cleaning as best as possible the carbonized path of the flashover, a surge voltage was applied between the power cord of the receiver and the ‘ground’ of the cable input: flashover occurred for a 2 kV Ring Wave. By removing the material to a greater depth and covering it with epoxy, the gap did withstand a greater level, and failed at 2.5 kV. That flashover occurred at another part of the original insulation, thus providing valid information on the original withstand capability.

2.1.3 Conclusions from the Cozy Cabin

This case study illustrates the classic situation of separate service entrances, compounded with incorrect bonding. The examination and test demonstrate that at least 2.5 kV can be developed across the power port and the cable TV port of the receiver under a condition of distant or nearby lightning strike. This finding is consistent with the results of other tests reported under Section 4.

Another significant finding from this case history is the anecdotal confirmation of allegations that cable TV installation practices prevailing in many residential situations might be in violation of the National Electrical Code (NEC). This violation makes even more hazardous the now well-recognized occurrence of undesirable separation between utilities entrances.

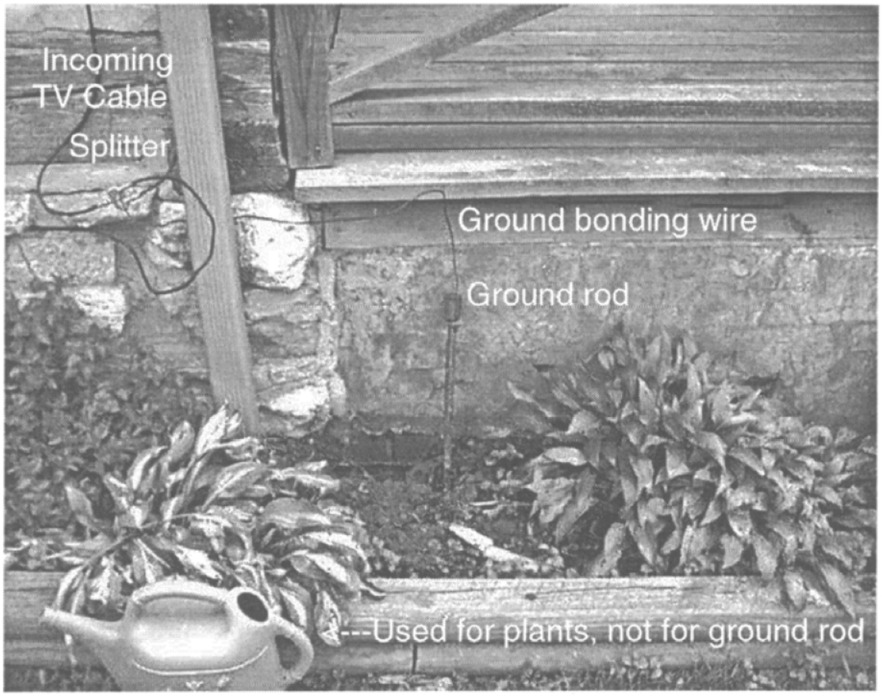

Figure 1
Cable TV service entrance and 'ground bonding'

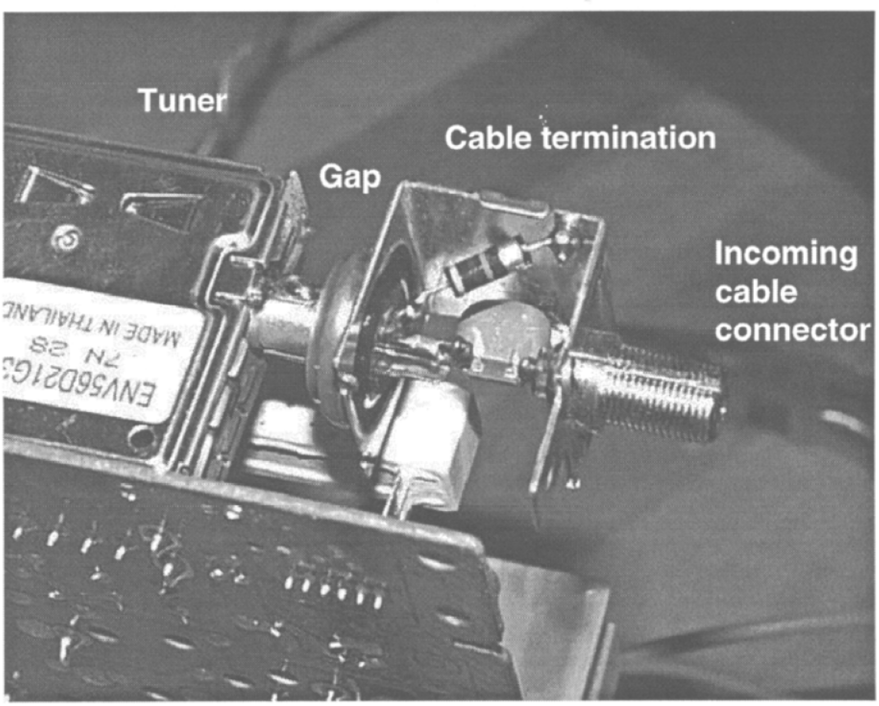

Figure 2
Cable TV input termination and UHF tuner at rear of TV receiver

2.2 The Case of the Rambling Residence

A residential estate insured by State Farm was the scene of a lightning incident where a tree adjacent to the house was struck (and subsequently died). Extensive damage was inflicted to the audio-video components distributed from a central rack throughout the residence and its surroundings (large patio and swimming pool with outdoor lighting and audio speakers).

Through the cooperation of the State Farm agents, the home owners graciously allowed PEAC engineers to visit the residence and observe the configuration of the system in an attempt to better understand the mechanisms leading to the damage. State Farm also made available to PEAC the complement of damaged or presumed damaged equipment that had been promptly replaced as part of the claim settlement. Thus, this case history, unlike most lightning incidents, offered an unusual opportunity for documenting the process and consequences. It was made very clear to the owners that the visit was prompted by the curiosity of electrical engineers and not by State Farm agents.

Three activities were undertaken for that purpose:

- Bench examination of returned equipment and surge testing of undamaged equipment
- Site visit of the residence
- Laboratory coupling of electric field stress into a remote speaker-to-amplifier connection

2.2.1 Bench Examination

The complete central rack of audio-video entertainment equipment, as well as the remote speakers had been replaced as part of the claim settlement. Local State Farm agents were able to retrieve the damaged entertainment equipment from the house and send it to PEAC for examination. Bench tests for each electrical appliance began by plugging it into a 120-V ac outlet. Physical signs of normal operation were noted such as illuminated displays, response of controls, or audio/video output. The equipment cover was removed for an internal inspection. In most of the equipment, physical damage such as a burned-out transistor was very apparent. Table 1 lists the home entertainment equipment that was submitted, and their condition.

A significant finding was that all of the power supplies in the equipment were functional, indicating that the lightning surge either did not enter through the ac power port, or was not severe enough to cause damage to the power supplies.

Table 1 Equipment submitted for bench tests

Qty.	Equipment	Condition
1	Stereo tuner/amplifier	Illuminated display was not working
3	DSS receiver	Damage to telephone circuit
2	Twelve-channel integration amplifier	Damage to power transistors
12	Indoor speaker	Woofer damaged
4	Indoor/outdoor speaker	Woofer damage on all but two units
1	Independent color TV receiver	No damage

The examination and, as appropriate, tests revealed the following conditions:

Except for its non-operational display, the stereo tuner/amplifier appeared undamaged.

- The visible damage to the DSS receivers was nearly identical in all three units. Apparently, the surge had entered through the telephone port and had damaged the small surface-mount electronics that make up the modem circuit. However, because the satellite receivers could not be operated without their antenna and code-reading cards, the extent of the functional damage could not be determined

- The two 12-channel amplifiers had sustained damage to their output transistors that drive the speakers. The power supplies and fuses were not damaged. Furthermore, it was found that some speaker outputs were still operational. This situation suggested a possible mechanism that damaged only some of the output transistors, and therefore not attributable to a "power-line surge." In turn, that hypothesis was later verified by a laboratory test, as described in 2.2.3 below.

- Speakers, tested by connecting them to an amplifier that was known to be functioning properly, were found to have their woofers damaged, but the tweeters still operational.

Other electrical appliances in the house including television sets and VCRs not connected to the centralized system were not included in the returned package and therefore presumed as not damaged. This finding helps to confirm the conclusion that the long leads interconnecting the distributed system components acted as energy collectors, feeding the induced voltages or currents into the communications ports of the equipment.

2.2.2 Site Visit

The purpose of the visit was to look for clues to explain the specific damage that was observed in some of the equipment. The following observations were made:

- Approximate distances between the lightning strike and affected equipment
- Location and grounding at the service entrances of cable TV, power, and telephone
- Other wiring and general installation practices

The overall physical layout of the house, damaged tree, and electronic equipment are shown in Figure 3. The mature tree that was struck is much taller than the house and is the tallest of the trees in the immediate area. The bark was stripped from the tree trunk for most of its height. As shown in the figure, the trunk is only approximately 15 meters from the house and even closer to the patio, where some of the audio speakers were installed. Outdoor speakers are also located in the pool area and connecting walkways.

From this informal examination, it appears that no electrical codes were violated. Furthermore, the cable TV and telephone entered the residence together with the electrical service at the same location (garage), as is the practice recommended in the engineering report.

One of the observations during the laboratory inspection of the audio amplifiers was that the power supplies of the units were not damaged, but their output transistors that drive the speakers and the speakers themselves were damaged. Before arrangements could be made for the site visit, it was speculated that the surge energy had been coupled into the speaker wires, which are probably very long and very near to the lightning strike, rather than as a "power-line surge." The visit to the installation verified this theory. The home entertainment equipment, including amplifiers, is centrally installed in the basement of the house. Speakers are located throughout the house, the patio, and the swimming pool area. The wire length between the outdoor speakers and the central amplifier is about 30 meters, and some of the wires run within 10 meters of the tree trunk.

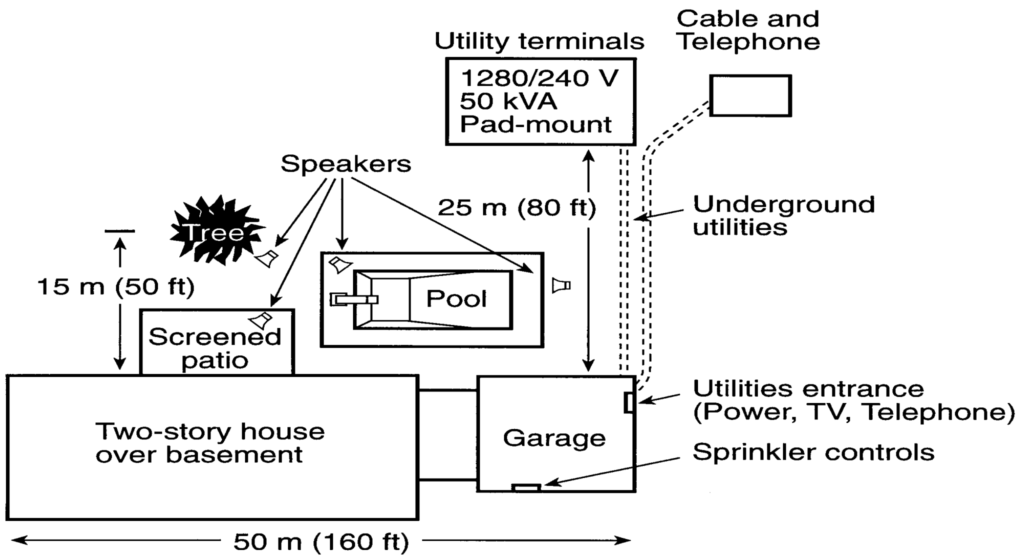

Figure 3
Schematic configuration of the Rambling Residence

2.2.3 Laboratory Coupling of Electric Field

To validate the hypothesis of a failure mechanism involving the coupling of electric field energy into the speaker wire run, a qualitative laboratory test was staged, using the surviving channel of the amplifier to drive a speaker. An audio signal from a tape deck was fed into the amplifier input to monitor its operation during the test.

A conventional Marx impulse generator at the NIST High-Voltage Laboratory was used to apply a 1.2/50 :s high-voltage field between two parallel plates, each 2 m x 1 m. A length of 5 m of speaker wire feeding the audio output from the system audio amplifier was sandwiched between the two plastic foam sheets separating the lower (grounded) plate, to which the amplifier chassis was bonded, from the upper (impulsed) plate. A UPS was used to power the tape deck supplying the audio input signal to the power amplifier, which was also powered by the floating UPS.

With increasing amplitude of the impulse, a total potential of up to 30 kV was developed between the speaker wire and the chassis of the amplifier, but no distress was observed at that level. Note that the actual field strength during the incident is unknown but suspected to be quite high, so that this test does not pretend to duplicate the incident, but only to illustrate a possible mechanism.

The effective length of the wire was then increased by connecting to each wire a piece of foil of about 0.02 m^2, simulating the increased capacitance effect of about 50 m of wire. Again, the impulse was applied in increasing steps. At 70 kV, a flashover occurred between the two plate edges, ***but not involving the speaker wire***. Immediate failure of the amplifier output circuit was noted. From this anecdote, we conclude that the rapid field change (not recorded during the test but certainly faster than the standard 1.2/50 :s impulse) did have the capability to couple enough surge energy into the capacitance divider of wire/ground plane and cause destructive failure of the output transistor effectively connected across that capacitance. Such a scenario can be considered a reasonable emulation of the circumstances surrounding the “Lightning Incident at the Rambling Residence.”

Thus, this qualitative laboratory demonstration provides one more piece of evidence that electronic appliances can be damaged by surges impacting their communications port, to the point that expecting protection by simple application of SPDs on the power port is not enough, and comprehensive protection is a necessity.

2.2.4 Conclusions from the Rambling Residence

Generally, electronic equipment can be protected from surges by proper installation and with the use of surge suppressors. In the rare case of a nearly direct strike, however, there is little that can be done in widespread residential settings to prevent damage, unless a thorough mitigation study and extensive protection implementation would be performed. While that type of protection is theoretically possible and has been implemented — at considerable cost — for facilities involving national security, airports, communications centers, etc., it is generally not considered as economically justifiable for residential installations. A central home entertainment system with remote speakers, such as the one installed at this house, is an easy victim for coupling of surge voltages or surge currents in the long runs of cable.

Since the visit to the residence was motivated, as stated, by the curiosity of PEAC engineers rather than by a customer complaint, there was no need to offer a prescription for protection. Instead, the visiting engineers offered the general statement that for a direct strike such as the one that had occurred, providing a high level of protection confidence by a comprehensive retrofit would probably cost more than the equipment that was damaged. In contrast, the dead tree was the one irreplaceable loss that was most painful for the owners. Techniques for protecting trees exist (an extensive array of grounding cables along the limbs, [NFPA 780, 1997] and are sometimes applied to trees recognized as having great historical or esthetic value, but the cost is generally a deterrent for typical residential surroundings.

3. Post-Mortems on Returned Equipment

An assortment of residential equipment returned to State Farm as settlement of lightning-related claims was made available to PEAC. These included submersible well pumps, audio and video equipment, and telephones. The goal was to determine the failure mechanisms of the samples, whether it be failed power supply components, input/output ports, or other types of equipment failures.

Individual pieces of equipment were examined for mechanical condition, signs of electrical insulation breakdown, and if it seemed appropriate, powered to test their possible functionality. Most were in fact damaged, as tabulated below, but a few appeared still operational. This apparent functionality may well be a case of “walking wounded” so that the intention of the examination was not to contest the claim of damage, but to gain insight into the failure levels and mechanisms.

3.1 Equipment condition

3.1.1 Well pumps

Fifteen submersible well pumps in the size range of ½ hp to 1 hp were examined. These pumps spend their lives underwater while connected to the power system conductors, and are therefore susceptible to lightning damage.

The units were visually inspected and resistance was measured between pairs of motor terminals and between case and terminals. No conclusive evidence was observed on most of the samples, however one sample had very interesting evidence of lightning damage. It had burn marks present at the point where the voltage is applied to the stator winding. It also had a bulge in the stator that appeared to have been caused by excessive current through the winding.

3.1.2 Television Sets

Seven television sets were received for inspection. Of these units, the failures most commonly observed were in the power supply. Four of seven units had open fuses, suggesting that components inside had drawn excessive current and had failed, causing a short circuit. Two of the units had shorted rectifier diodes, further confirming this theory. One television had an open fuse, but was fully functional after a fuse replacement. One of the more interesting cases was a television that had its tuner severely damaged, but the power supply was not damaged.

Television sets, being two-port devices, require some type of isolation between antenna port and ac power port. Different protection schemes were observed in the television sets depending on their age. Older sets utilized an antenna isolation scheme, with television chassis connected to the one of the line cord conductors. Newer designs had direct antenna connections (no isolation), but had isolation built into their power supplies.

3.1.3 VCRs

Five VCRs were inspected. Two had damaged power supply components. One had apparent damage to the tuner. VCRs have the same two ports as televisions and therefore require the same type of isolation. All of the VCR samples studied at PEAC had the isolation scheme built into the power supplies rather than in the antenna port.

3.1.4 Stereo Equipment

Nine individual stereo components were examined. One had damaged power supply components. Three of the amplifiers had damaged output transistors. Two of these were from the “Rambling Residence.” Others were functional.

3.1.5 Telephones

Five telephones were examined, from which three had damaged ICs. These may have been damaged by lightning. Most electronic phones are equipped with plug-in adapters. These adapters may sustain damage, but seem to protect the telephone equipment from damage on the ac power port.

3.2 Conclusions for Post Mortems

There were almost as many types of equipment failure modes as there were samples to examine. The samples that had apparent lightning damage presented the signs one could expect from insulation failure, most often with subsequent damage done by the power-frequency fault current following the insulation breakdown.

4. Surge Immunity Tests

The returned equipment that was found still operational was then used for destructive surge testing by subjecting them to Ring Waves or Combination Waves on their power port or on their communication port. Two types of surge tests were conducted:

1. Application of the surge to the power port only. This test is primarily a surge current withstand capability for the rectifier that connects the DC link capacitor to the ac mains. During a surge, this capacitor acts as a “surge absorber” and can draw a substantial charging current [Mansoor et al., 1999]. Ultimately, the voltage in the DC link might reach an excessive level for the downstream components, but from the few limited tests performed here, it appears that either the rectifier fails, followed by opening of the fuse, or that the fuse itself opens without downstream failure. In either case, however, the appliance is a candidate for a trip to the repair shop, or a total loss damage claim, as indicated in the post-mortems.

2. Application of the surge between power port and communication port. This is the scenario illustrated by the Cozy Cabin case history in this paper. The tests served to document further the process and the levels at which failure can occur.

4.1 Power port tests

Combination wave surges were applied to the equipment between the two power port conductors. Beginning with a peak voltage of 1 kV, the test sample was surged and then checked for functionality. If the equipment sustained no apparent damage, then the surge voltage was increased and re-applied in 1 kV steps until either the equipment failed or until a maximum of 6 kV was delivered.

Three well pumps from the original group were functional and therefore were available for surge tests. The coil resistance was measured and recorded before applying any surges. The well pumps demonstrated a strong immunity to these surges. All three samples survived all tests to and including 6 kV and with no notable changes in performance or in coil resistance. This remarkable withstand capability might be attributed to the presence of a built-in SPD.

Two working televisions were available for surge tests. Each unit was energized, and using an antenna, was tuned to a local station having a strong signal. The two units failed at 3 kV. Upon examination of the circuits, both had suffered open fuses and failed power supply components. Rectifier diodes were found shorted inside one of the units. Recall that in the post-mortem examinations, inside four of the sets, there were open fuses and two samples had shorted rectifier diodes.

Three VCRs were functional and were subjected to surge tests. The first sample failed at 3 kV.

An open fuse and failed rectifier diodes were found inside. The second sample failed at 4 kV, but without opening fuses and with no visible damage. A probable result was a damaged voltage regulator. The third sample withstood surges up to 5 kV, where a open fuse resulted. The fuse was replaced and the unit functioned normally. Surges were repeated, opening the fuse again at 4 kV. The difference in survivability among the VCRs seemed to be transformer size. Modern power supply transformers are miniaturized, operating at higher frequencies than the 60 Hz power frequency. The VCR samples that had physically larger transformers survived the higher surge voltages. The sample that blew the fuses and withstood the surge tests had the largest transformer of the three VCRs tested.

Five individual stereo components, specifically two cassette decks, two amplifiers, and one CD player were tested. This type of stereo equipment is designed for use as interconnected systems of media-playing devices, amplifier, and speakers. The goal of the surge tests was to assess the immunity of individual components' power supply circuits. Therefore, each piece was tested without connection to other components. After each surge, the tested sample was briefly connected to necessary components to verify that it was working properly. A very consistent outcome was observed. All of the samples survived the surge tests up to and including 6 kV.

Only one telephone sample was available for surge tests. It was of the cordless variety, with an external power supply adapter. This unit survived all of the surge tests with no apparent damage.

4.2 Two-port tests

Televisions and VCRs are of a similar category of equipment in that they both have the same input ports: ac power and antenna, for which the ‘ground’ reference can be raised to different potentials during a surge event. The power port has no direct connection to the equipment grounding conductor because a two-prong ac plug is used. However, at the service entrance, the neutral — one of the two conductors of the cord — is bonded to the ground bus of the service panel. The antenna input is referenced to ground via a connection to a grounding rod outside the residence and (per NEC), a bonding conductor. Manufacturers use various techniques to isolate these two ports from each other inside the equipment. The purpose of these tests was to etermine the surge voltage at which this isolation breaks down.

Most of the equipment was less than 6 years old and therefore represents the current state of technology. By observation of a few samples, there seem to be two isolation schemes. Older technology seemed to use a potted ring (an amorphous, plastic insulating material) paralleled with a resistor to isolate the shielded conductor of the antenna from the chassis of the tuner. Newer sets have isolation in their switch-mode power supplies and directly connect the shielded antenna conductor to the tuner chassis. All VCRs that have been observed use the latter technique.

Surge tests were conducted on five televisions and three VCRs to determine the voltage level at which spark-over would occur between these power and antenna ports. The two power port conductors (line and neutral) were tied together because the two conductors act together to create the power port, and because there is no rationale to support the separate application of surges to each of the conductors of that port individually. Using a 0.5 :s — 100 kHz ring wave, a 500 V peak surge was applied between power port and shield of the antenna port. Subsequent tests were performed at incremental steps of 500 V until spark-over occurred or until a maximum of 6 kV was reached. This voltage level was recorded and an oscillogram was taken. A decision was then necessary. If a surge voltage of 500 V less than the recorded value would also produce sparkover, it is possible that a carbon trace exists in the device, and tests were discontinued. If there was no sparkover at the reduced voltage, the unit was subjected to a 1.2/50-8/20 :s Combination Wave, starting at 500 V and increasing in increments of 500 V until breakdown or a maximum of 6 kV was reached.

The units that had isolation built into the antenna port sparked-over at the series capacitor of the antenna port. The breakdown voltage level averaged approximately 2.5 kV in these units. Units whose power supply outputs were electrically isolated from the inputs via transformers generally fared better. One sample survived and performed normally after all surge tests. Physical size of the transformer seemed to have some impact on the results. Larger transformers seemed to tolerate surges better than smaller ones.

4.3 Conclusions to two-port surge immunity tests

Some type of isolation scheme is used in televisions and VCRs to electrically isolate the antenna input from the power supply input. A general observation based on the small number of test samples is that older televisions (before VCRs were popularly used) seem to have their isolation built into the antenna ports using an insulating plastic material. Newer technology seems to have moved the isolation from the antenna port to the power supply port by utilizing the high-frequency chopper output transformer. During these surge tests, it was observed that the power supply isolation method was more immune to damage than the antenna port isolation method.

Based on this small number of VCR samples, a general observation is that VCRs use power supply transformers as isolation, similar to the newer TV sets, and have no isolation between antenna input to tuner chassis. Generally, this type of isolation scheme withstood higher surge voltages than the antenna port isolating ring that can be found in older television sets, therefore VCRs seem to have the same (or slightly greater) levels of immunity as any television set.

5. From the Engineering Report to the Consumer-Oriented Publication

The engineering report completed as the first phase of the project [EPRI Project 01-39-8002, 1997] and described in the PQA’97 summary paper [Key et al., 1997] was written for engineers, not for the general public. The ultimate goal of the project, however, has been from the beginning to produce a self-standing but brief publication aimed at the general public, in particular electrical contractors, builders, insurance agents, and interested homeowners. In the 1980's a Federal Information Processing Standards Publication [FIPS Pub 94, 1983] was developed by the then

National Bureau of Standards (NBS) for the “computer room” environment. At that time, when the residential electronics had not yet started their exponential growth, FIPS 94 became — and remains — a widely read reference. It was first envisioned that a similar publication, albeit less voluminous, might be issued by the National Institute of Standards and Technology (NIST), the successor of NBS. The project end-goal subsequently evolved to plan for a shorter publication, limited to the perceived limits of a typical reader’s attention span, but still under the sponsorship of the generic perspective of NIST.

The target date for general availability of this publication is now late 1999, giving interested parties an opportunity to implement feasible retrofit recommendations in time for the Y2K lightning season. Hopefully, the recommendations will also influence future installations.

6. General Conclusions

The combination of the theoretical considerations, presented in the cited engineering report, with further documentation presented in this paper, clearly demonstrates that the two-port interaction plays a large role in appliance failures during surge events. That concept will be emphasized in the final proposed NIST Special Publication, which remains the ultimate goal of the project.

Nevertheless, readers of the present paper might be interested in a list of technical and practical conclusions, leading to recommendations they might wish to make to their colleagues or clients pending availability of the NIST publication:

- The expanding use of multi-port appliances is increasing surge vulnerability in residential environments. More attention to their design and installation wiring is needed. The concept of “compatibility levels” can help.
- The power port might not even be one of the ports involved in the damage.
- The typical homeowner is likely to assume the worst after a lightning event and mis-diagnose lightning damage. “If it works it is probably not damaged” may be a reasonable point to publicize. (Notwithstanding a justifiable concern about keeping a “walking wounded” in case of serious damage to other equipment in the residence.)
- In fact, when lightning strikes, the configuration of the residence appliances and wiring may be more important than the level of the threat. This is particularly true for non-power born surges.
- House wiring systems will play an increasing role in determining vulnerability of appliances as installed in specific locations, as more wires are run and more appliance ports are referenced to each other.

7. Acknowledgments

Roger Witt provided encouragement to the authors and comments on this paper, as well as making arrangements for the return of equipment and site visits.

The owners of the two residences, whose identity and exact location are not given here to preserve their privacy, provided a rare opportunity for documenting these two enlightening case histories, for which the authors are indeed grateful.

8. Bibliography

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