Consumer Power Quality Problems: Troubleshooting by Telephone

Reprint of handbook edited and published by NRECA, 1999
Text by François D. Martzloff, National Institute of Standards and Technology
Graphics by Susan Spangler

Significance
Part 6: Tutorials, textbooks and reviews

This is a handbook developed for use by NRECA service representatives when dealing with customers making complaints over the telephone about power quality of their service, with a set of questions work sheets that could help diagnose the problem without requiring distant travel by service technicians, or to get them better prepared to do so.

The National Rural Electric Cooperative Association (NRECA) is the national service organization of more than 900 rural electric systems. These cooperatively owned utilities own and operate about 44% of the miles of distribution lines in the nation to provide power to less than 10% of the consumers. NRECA is the national service nation's people, primarily in the sparsely populated, rural areas of 46 states. NRECA was founded in 1942 to unite rural electric systems in a way that would permit them to develop the services and support needed to properly serve rural America. NRECA is on of the largest, rural-oriented cooperative organizations in the United States.

Consumer Power Quality Problems: Troubleshooting by Telephone

PROJECT 99-05

Prepared by

National Rural Electric
Cooperative Association
Cooperative Research Network
4301 Wilson Boulevard
Arlington, Virginia 22203-1860

and

François D. Martzloff
National Institute of Standards and
Technology
100 Bureau Drive
Gaithersburg, Maryland 20899

COOPERATIVE RESEARCH NETWORK

www.crnweb.org

The National rural Electric Cooperative Association (NRECA) is the national service organization of more than 900 rural electric systems. These cooperatively owned utilities own and operate about 44% of the miles of distribution lines in the nation to provide power to less than 10% of the nation's people, primarily in the sparsely populated, rural areas of 46 states.

NRECA was founded in 1942 to unite rural electric systems in a way that would permit them to develop the services and support needed to properly serve rural America. NRECA is on of the largest, rural-oriented cooperative organizations in the United States.

The Cooperative Research Network, a service of NRECA that was used to support this project, was created to conduct studies and carry out research of special interest to rural electric systems and their consumers.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

FOREWORD

Customer service representatives have a tough task when they have to respond to calls from consumers who are having problems with an appliance. "My television won't work. What's wrong?" "My computer lost its memory. What did the co-op do to cause this?" Complaints may be couched in vague terms, and the caller may tend to blame the electric cooperative.

This manual was commissioned by the Cooperative Research Network to address these kinds of complaints. Written with the help of an expert in household and small-business electricity problems, it provides a series of worksheets that guide representatives through a question-and-answer session with a caller, leading the caller from the general to the specific with the goal of finding the exact source of the problem (which often is *not* attributable to the cooperative).

Service representatives can use the worksheets in conjunction with the manual's simple explanations of the nature of disturbances and how to prevent or cure their effects to diagnose specific problems. On the basis of the diagnosis, the representative can tell the consumer what to do or can call in the cooperative's repair service to handle the problem. If the cause of a particular problem proves elusive, the representative can refer it to a specialist.

The manual should help representatives work more effectively and efficiently. It should help cooperatives avoid unnecessary service calls. And it should help consumers get quick solutions to their problems, whether utility-related or not.

Martin E. Gordon, P.E.
Senior Program Manager
Cooperative Research Network

EXECUTIVE SUMMARY

When an electricity consumer has a problem with an appliance—a light bulb that flickers, a television that "burns out," a motor that overheats, for example—a natural tendency is to complain to the electric utility. In actuality, many such problems are not the fault of the electric utility, and indeed may be beyond the control of the electric utility.

How does an electric cooperative, with limited customer-service resources, handle such complaints? How can it efficiently separate problems that it can fix from those that are beyond its control, and perhaps recommend cures or preventive measures to consumers for the latter problems? This manual suggests a way: It provides worksheets for customer service representatives to guide them through a dialogue with a customer calling for help. By following the guidance, a representative can ask the right questions, get at the root of a problem, and then decide on an appropriate action: send a repair crew, tell the customer how to fix the problem, or, for a problem that resists immediate solution, call in an expert in the field.

The manual is organized in two parts:

- **Part 1** reviews the nature of disturbances that can occur in the power supply to customers—disturbances such as voltage surges, lightning strokes, voltage swells, outages, brownouts, voltage sags, noise, harmonics, unbalanced phases, and interaction between the power system and a telephone or cable TV system. A customer service representative can learn in this part how the disturbances originate, how they affect electrical equipment, and what can be done about them.
- **Part 2** helps the customer service representative troubleshoot over the telephone. It contains worksheets, eight in all, covering the major categories of equipment—heaters, motors, and electronics of various types. Each worksheet is a blueprint for a question-and-answer session with a customer, designed to arrive at the cause of the customer's problem and a possible cure. By applying the simple theory in Part 1 and following the step-by-step instructions, the representative should be able to diagnose many problems and decide whether intervention by the cooperative is warranted.

The manual stresses a crucial fact: that problems with equipment connected to both an electric power system and a communication system—televisions with cable connections or personal computers with modem hookups, for example—can be caused by *either* system. Such problems are compounded when the two services enter at opposite ends of the building; physical separation of the entry point magnifies the disturbances. Such disturbances should never be blindly attributed to "power line surges"; often the communication link can be at fault, especially when it is improperly installed, as sometimes happens with cable connections.

Scattered throughout Part 1 are short case histories drawn from ordinary experiences—a chandelier that inexplicably flickers, motor controllers that shut down when the electric utility adjusts its power factor. With such experiences and simple electrical theory as background, customer service representatives should be able to analyze many of the problems posed by disturbances and find a solution for the consumer, or know when to call in expert help.

1 Disturbances and Remedies

In This Section: Introduction; the nature of disturbances; too much voltage; not enough voltage; other power-line disturbances; system interactions

Introduction

Many people believe that upsets or damage to electrical equipment can be blamed on disturbances caused by the power distribution system or by lightning. However, such a belief is an incorrect generalization; many times the problem is in the equipment itself, not the power system. This manual can help cooperatives' customer service representatives distinguish between equipment-related and system-related problems, and either suggest a solution the customer or alert the dispatcher that the cooperative's assistance is needed. The manual presents in simple terms the principles underlying unwanted upsets and damage and offers remedies for them.

This first part of the manual gives an overview of the disturbances that can occur in the power supply to the customer. It briefly describes the origins of the disturbances and explains which disturbances are avoidable, which are unavoidable, which are predictable, and which are entirely random occurrences. The first part is organized in four sections. The first two are concerned with the most frequent but brief disturbances—too much or not enough voltage (energy). The third section addresses less frequent disturbances that are almost permanent, such as noise, harmonics, notches, and voltage unbalance. The fourth and last section describes the possible interaction between the power system and a communications system, which is believed to be the cause of many failures that are often misinterpreted as caused by a "power line surge."

The second part of the manual is formatted as a collection of worksheets that suggest interactions between the customer service representative and the customer reporting a problem.

An important fact is that upset or damage to equipment that involves a communications system can also be caused by disturbances on the communications system and should not blindly be attributed to "power line surges." Ways to prevent this kind of upset or damage do exist, but some are beyond the control of the customer and the distributing utility. It is a matter of recognizing the situation and selecting a technically correct and cost-effective remedy. There may be cases where the risk or consequences of such damage or upset might be low, compared to the cost of prevention. Therefore, the choice of protecting or not protecting should be made thoughtfully, not left to neglect or ignorance. Armed with this knowledge, customer service representatives as well as customers will be guided toward a satisfactory resolution.

1

The Nature of Disturbances

Electric power is delivered to customers in the form of an alternating-current (AC) voltage that the utility strives to keep as constant as possible (Figure 1.1). However, disturbances can and will occur in this voltage, in the form of either too much or not enough. In turn, the energy consumed by the load—what the utility sells—is related to the voltage at which it is delivered. The AC voltage follows a sinusoidal pattern, with a complete cycle occurring 60 times per second—engineers call that a 60-hertz (Hz) AC voltage. This smooth waveform can be distorted under steady-state conditions, or have a transient overvoltage or undervoltage.

Some disturbances are brief—from millionths of a second (microseconds) to thousandths of a second (milliseconds). Other disturbances can be long, lasting from seconds to hours in the worst cases of service interruption.

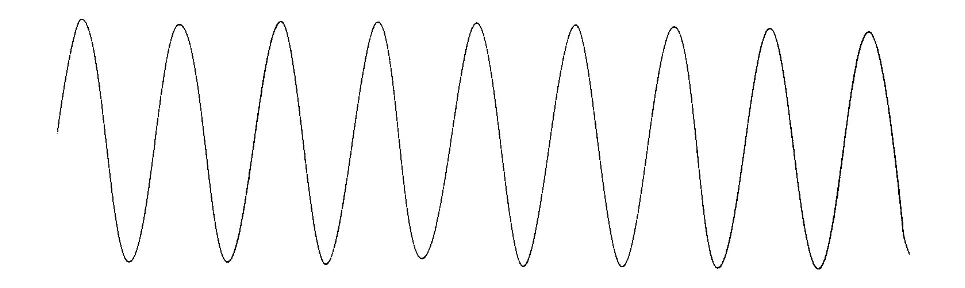

FIGURE 1.1: Sine wave of an AC voltage supply.

Too Much Voltage

Too much voltage can be the result of a normal or abnormal utility operation, or the effect of an external influence. Under normal operating conditions, the steady-state voltage is controlled by the utility within a narrow band. Deviations from this band are rare, and the utility can readily correct them, if informed of their occurrence, by acting on voltage regulators and tap changers.

On the other hand, there are momentary (transient) disturbances that occur under the typical operating conditions of a power system. There are two types of transient excessive voltage that can occur under normal circumstances, although by themselves they would be described as "abnormal":

1. A *surge* is an overvoltage that can reach thousands of volts, lasting less than one cycle of the power frequency, that is, less than 16 milliseconds.
2. A *swell* is longer, up to a few seconds, but does not exceed about twice the normal line voltage.

A third type of excessive voltage, a *temporary overvoltage*, is not a part of normal operation, but is associated with a fault in the power system. Temporary overvoltages can last a much longer time, and generally do not disappear until the fault is cleared.

SURGES

Types and Origins of Surges

Surges have been blamed as the cause of equipment upsets or damage under many names: power surges, spikes, glitches, impulses, and so forth. In this report, the term surge is used, with the understanding that it means events lasting less than one cycle of the power frequency.

The two major causes of surges are

- *Lightning*—an obvious and well recognized event (Figure 1.2)
- *Load switching*—a type of event that includes major power system operations as well as simple and seemingly benign switching by the customer

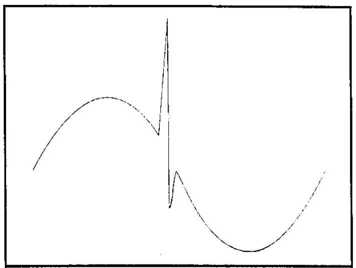

FIGURE 1.2: A surge induced by lightning on an AC voltage.

Next to outages, surges are the type of disturbance most frequently perceived by customers as the source of their problems, and therefore merit a detailed examination.

Lightning Surges. There are four types of lightning surges, described here in order of severity. The first, rare but traumatic, is a **direct lightning stroke** to the building. Unless special protection systems have been provided (lightning rods in plain language, air terminals in protection jargon) with proper down-conductors and grounding, damage to the structure and equipment can be substantial. Of course, such an event cannot be blamed on the utility. Few residential customers go to the expense of installing a lightning protection system. Instead, they make an intuitive risk analysis: A typical lightning protection system can cost thousands of dollars, while the probability of a direct stroke (outside of known areas of high lightning activity) is about once every 200 years for a detached home.

The second type of lightning surge occurs when a **nearby stroke**, and the resulting flow of current in the earth, elevates the potential of the ground references of the building, including the power system neutral that is bonded to ground at the service entrance. This situation is called ground potential rise. Meanwhile, the power supply phase conductors, which are referred to ground through the secondary winding of the distant distribution transformer (whose neutral is grounded there) remain essentially at the ground potential of that distant transformer. A large difference of potential can then occur between the neutral and the phase conductors at the service entrance of the building. That difference of potential appears to be a surge delivered by the utility connection, but has nothing to do with the utility operations.

The third type of lightning surge is produced by the **radiation of electromagnetic fields** associated with a lightning strike at some distance from the building. Such a surge involves low energy but can still produce upsets and even damage in sensitive electronic circuits. The severity of these surges depends mostly on distance. Nearby strikes are rare but may have severe effects, distant strikes are more frequent (increasing with the area of collection, that is, with the square of the distance) but less severe. Again, these surges cannot be blamed on the utility, but some customers might believe that they came from the utility connection and attempt to place the responsibility on the utility.

The fourth and last type of lightning surge is one that actually **arrives on the service drop** of the utility, as a result of a direct stroke to some element of the distribution system. A surge induced in the utility distribution circuits by a nearby stroke, just like the third type discussed above, can also appear at the service entrance. In contrast to the first three types, this fourth type is truly an excessive voltage delivered by the utility to customers. However, the general practice among utilities is to provide surge arresters on their systems, so that the residual surge that can appear at a customer's service entrance is somewhat limited. The rare exception would be a direct stroke to the pole or service drop, where the utility surge arrester would not intervene before a surge heads for the service entrance.

Switching Surges. There are two types of switching surges:

- Those that result from normal switching of a load on or off by a customer or the utility
- Those that are incidental to an intended operation aimed at clearing a fault—a short circuit or severe overload.

Switching Surges from Normal Operations. The first type of switching surge ("normal" surge) occurs whenever a load—any type of load—is being switched, either within the distribution system or within the customer's installation. Therefore, these can occur quite frequently. Those associated with the switching of a local load, especially if it is an inductive load such as a motor, are generally short (a few microseconds) and do not involve a large amount of energy. However, there is another source of potentially large switching surges when capacitor banks are switched for power-factor correction. These can occur at random if the power-factor correction bank is controlled by the instantaneous state of the system, or they can occur at fixed times in the day if the capacitor bank is switched on and off by a timer. Capacitor switching surges from the utility have been found troublesome in installations where the customer also has some power-factor correction capacitors: Magnification of the surges can occur. (See box, "Capacitor Switching Surges.")

Capacitor Switching Surges

Capacitor banks have long been accepted as a necessary part of efficient electric power systems. Switching capacitor banks on and off is generally considered a normal operation for a utility system, and the transients associated with switching are generally not a problem for utility equipment. The low-frequency transients, however, can be magnified in a customer's facility (if the customer has low-voltage power-factor correction capacitors) or result in the nuisance tripping of power-electronic devices such as adjustable-speed drives. Actually, capacitor energizing is just one of the many switching events that can cause transients on a utility system, but, because of their regularity and impact on power system equipment, they quite often receive special attention.

There are a number of transient-related concerns that are generally evaluated when distribution shunt capacitor banks are applied to a power system. However, these considerations are related to the system design rather than its operation, and the customer has no control over them. Remedies will essentially be to learn how to live with these unavoidable transients. When they originate from the switching of a large capacitor bank, it is unrealistic to expect that the typical surge suppressor has the energy-handling capability to absorb them.

Characteristics of Energizing an Isolated Capacitor Bank. Energizing a capacitor bank results in an immediate drop in system voltage toward zero, followed by an oscillating transient voltage superimposed on the fundamental power frequency waveform. The peak voltage magnitude depends on the instantaneous system voltage at the instant of energization, and can rise to 2 times the normal system voltage under worst-case conditions.

Ordinarily, though, other components of the system help to keep the voltage rise to 1.2 to 1.8 times the normal value, and the transient oscillates at frequencies from 300 to 1,000,000 Hz. Figure 1.3 shows an example, recorded in the field, of a transient created by energizing a capacitor bank.

Transient overvoltages caused by capacitor switching are generally not a problem for utilities because their peak magnitudes are usually just below the level at which surge protective devices (SPDs) begin to operate. However, these transients will often be coupled through

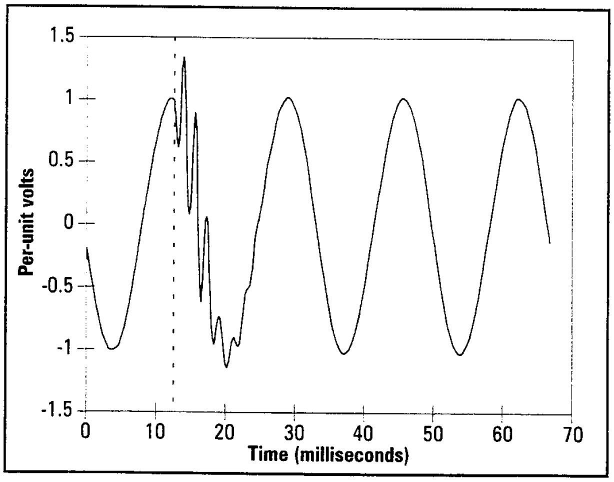

FIGURE 1.3: Typical voltage on a distribution bus during capacitor bank energizing.

step-down transformers to customer loads (Figure 1.4), where they can affect power-quality-sensitive customer equipment, such as computers.

If the customer uses capacitors for the correction of power factor on the low-voltage side, higher transient overvoltages can rise even higher. This effect—"voltage magnification"—occurs when a transient oscillation, initiated by the energization of a utility capacitor bank, excites a resonant circuit in the low-voltage system (the circuit is a combination of the inductance of the step-down transformer and the capacitance of the customer's power-factor correction bank). The result is a higher overvoltage at the lower voltage bus. The worst magnification occurs when the following conditions exist:

- The size of the utility's switched capacitor bank is more than 10 times larger than the customer's customer bank.
- The frequency of the energizing oscillation is close to the resonant frequency of the circuit formed by the step-down transformer and the customer's power-factor correction capacitor bank.
- The customer's load has relatively little resistance (this is typical of industrial plants where motors represent the major part of the load).

Ordinarily, these transient switching overvoltages might simply damage low-energy surge-protective devices or cause a nuisance trip of power-electronic equipment. Nevertheless, incidents have been reported of complete failure of end-user equipment.

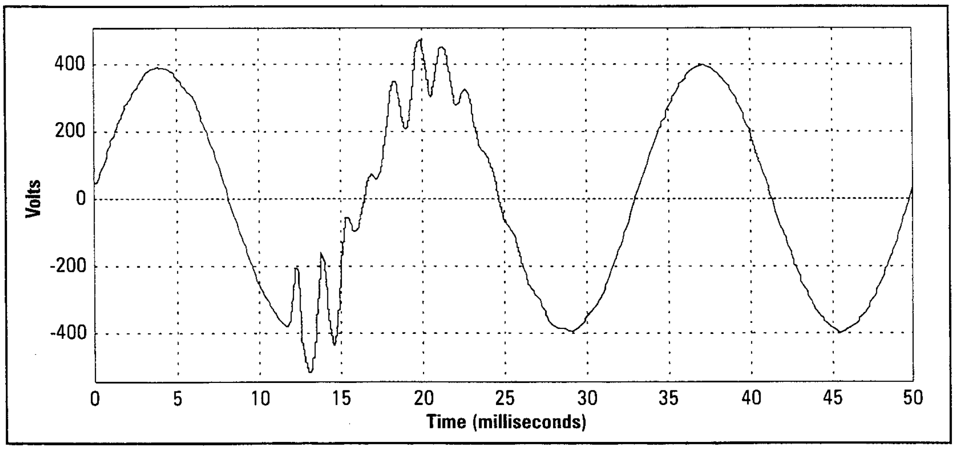

FIGURE 1.4: Example of a customer's bus voltage during utility capacitor switching.

Switching Surges from Fault-Clearing. The second type of switching surge, far less frequent, occurs when a system fault is cleared, either by the opening of a circuit breaker or the operation of a fuse. The latter can generate high surges if the fuse is located at the end of a long cable, in which the fault current can store substantial energy in the cable inductance.

The magnitude of these fault-clearing surges can reach several times the normal system voltage, and their duration ranges from hundreds of microseconds to a few milliseconds.

Effect of Surges on Equipment

Upset versus Damage. Surges impinging on equipment can cause upsets or permanent damage, with consequences ranging from barely noticeable to total destruction or consequential damage.

Among upsets, there are several possibilities:

- Barely noticeable, with self-recovery: a click in a sound system or a flash on a video screen
- Permanent and noticeable, requiring manual reset: blinking clocks and VCRs
- Permanent but not readily noticeable: data corruption

There are also several kinds of damage:

- Damaged components, repairable at a service shop
- Damaged components that are too costly to repair
- Obvious and irreparable damage requiring complete replacement of the equipment
- Damage such as internal equipment fire that could set other objects afire

Insurance statistics provide information on the relative frequency of damage among insured appliances. It is significant that video equipment is at the top of the list, and the discussion of multiple-port equipment damage under "System Interactions" at the end of Part 1 will explain why. A *port* is a connection between a piece of equipment and the outside world. The line cord of an appliance is a *power port*. The modular telephone jack on a fax machine, or the UHF connector at the back of a TV set is a *communications port*. In the modern home, both one-port and multiple-port appliances abound (Figure 1.5), and the same situation exists in commercial and industrial installations. When the time comes to understand the origin of the surge suspected to have caused damage to an appliance, it is important to determine if the appliance is a single-port or a multiple-port type.

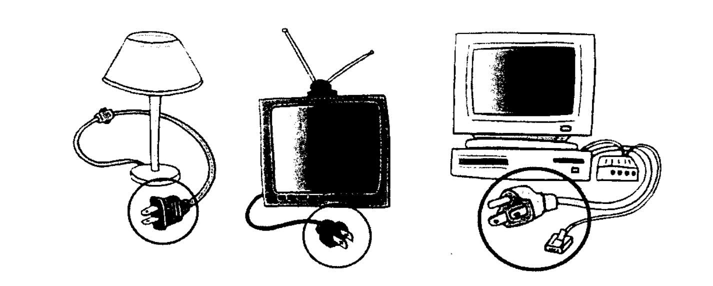

FIGURE 1.5: A lamp and a rabbit-ear TV are examples of single-port appliances. A computer with a telephone modem connection is an example of a two-port appliance. An ordinary house offers many examples of both single-port and multiple-port appliances.

Many appliances are still single-port equipment, in spite of the trend to provide sophisticated controls: a simple kitchen range is a single-port appliance, but a range controlled by a smart-house computer system is a two-port appliance. A TV set with rabbit-ear antenna is a single-port appliance, but the same set with a roof antenna or cable TV connection becomes a two-port appliance.

Multiple-Port Equipment. More and more electronic equipment in homes and businesses requires a communications link, hence a communications port in addition to the usual power supply connection, the power port. Examples of such two-port appliances include fax machines, telephone answering machines, personal computers with modem or printer connections, and cable-connected TV receivers and VCRs.

A possible problem is that although each of the power and communications systems may include a scheme for protection against surges, the surge current flowing in the surged system causes a shift in the voltage of its reference point while the other, nonsurged, system reference point remains unchanged. The difference of voltage between the two reference points appears across the two ports. Depending on the nature of the appliance and its immunity, this difference of voltage may have some upsetting or damaging consequences. The problem is so important that it is discussed in more detail in "System Interactions" at the end of Part 1.

Remedies against Surges

General Approach. At first glance, it would seem that if surges could be prevented from happening, many problems could be prevented. However, lightning cannot be eliminated. (There are some yet unproved schemes to dissipate the charges in a cloud and thus prevent lightning strokes.) Similarly, switching surges that occur in the utility system cannot be eliminated by the time they arrive at a customer's service entrance. Therefore, the general remedy is to install (insert) surge-protective devices at one or more points of a customer's installation.

Surge-Protective Devices: What's in a Name?
The devices that can protect against surges are called *surge-protective devices*, or SPDs, by engineers, but that might sound too much like jargon to most customers. The name that seems to stick in the general public is *surge suppressor*, which many manufacturers use for their trade designation, with a variety of catchy trademarked names. The Underwriters Laboratories chose to call them *transient voltage surge suppressors* (TVSSs), and that name or acronym generally appears next to the UL sign on the product. In the utility industry, the generic name used in the transmission and distribution parts of the system is *surge arrester*.

Actually a surge cannot be suppressed nor arrested; the correct word to describe what happens is diverted. What these protective devices do is simply divert a surge to ground, where it can do no harm. So a name that makes sense would be *surge diverter*, but it was not picked. The consumer industry has settled on TVSS, while the utilities stay with the long-used word *arrester* and use it for the more rugged devices that a utility installs at the service entrance.

The surge protection schemes for residential customers are these:

- Insert a TVSS for each sensitive appliance (Figure 1.6)
- Accept the offer (if made) from the utility to provide "whole-house protection" (Figure 1.7)

Wholehouse protection consists of a protective device at the service entrance complemented by TVSSs for sensitive appliances within the house. The service entrance protection is an adapter inserted by the utility between the revenue meter and its base. Variations exist, such as a separate box connected to the meter base box.

With whole-house protection—that is, an arrester at the service entrance and one or more TVSSs inside the building—the issue of "cascade coordination" arises. The concern is that, if the various protective devices are not selected with due consideration, the stress of incoming surges may not be shared according to the capability of each device. (See box, "Cascade Coordination.") This is a concept that the residential customer should not be expected to assess; it is the utility's responsibility to consider it and offer an integrated, coordinated package of service entrance protection and TVSSs.

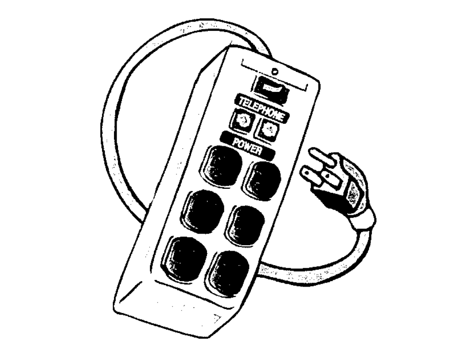

FIGURE 1.6: A typical TVSS with power and telephone protection.

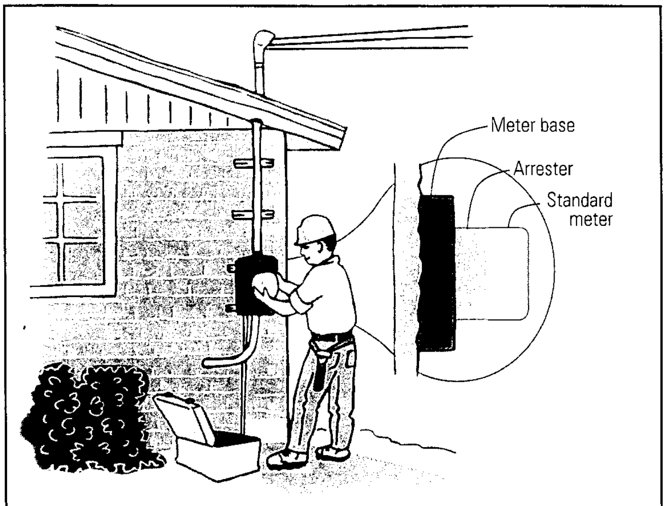

FIGURE 1.7: A meter-base arrester installed by the utility.

1

Cascade Coordination

Cascading surge-protective devices is a concept whereby two (or more) protective devices are connected at two (or more) different points of a power system. The "upstream" device (the one closest to the utility's distribution system) is the first line of defense; it is designed to divert the bulk of an impinging surge. The "downstream" devices (those closest to the equipment to be protected) are intended as a final stage, diverting any remaining surges, including those generated within the customer's wiring.

Successful coordination of cascaded devices is achieved when the heavy-duty upstream device does indeed divert the bulk of the surge, instead of letting the downstream devices attempt to divert an excessive amount of the surge current. In keeping with the terminology of this manual, the upstream device will be referred to as an *arrester*, while the lighter duty, downstream devices will be referred to as *suppressors*. The basic and critical parameters for successful coordination of the arrester/suppressor cascade include the relative voltage clamping of the devices, their electrical separation through wiring inductance, and the actual waveform of the impinging surge.

A well-designed cascade arrangement maximizes the benefit of surge protection with a minimum expenditure of hardware. Another benefit of a cascade is the diversion of large surge currents at the service entrance, so that they do not flow in the building, and side effects are thus avoided.

It is one thing to design a cascade based on optimum coordination where all the parameters are under the control of the designer. Such an opportunity exists in utility systems implemented under centralized engineering. It is an altogether different challenge to attempt, after the fact, coordinating the operation of surge-protective devices connected to the power system by diverse and uncoordinated (and uninformed) users.

Promoting a coordinated approach may come too late for the de facto situation in which millions of suppressors are in service with a relatively low clamping voltage. This situation will impose an upper limit to the clamping voltage of a candidate retrofitted arrester. Therefore, close attention must be paid to the selection of the relative clamping voltage of the devices, in view of the conflicting requirements for performance under surge conditions—a successful cascade—and reliably withstanding temporary power-frequency overvoltages. Nevertheless, coordination still may be possible if the available tradeoffs are understood. In the future, well-informed users could avoid the pitfalls of poor coordination or the disappointment of implementing protection schemes that cannot provide the hoped-for results.

An illustration of the effect of the relative voltages and device separation on the energy sharing between two devices appears in Figure 1.8. The figure shows a plot of the percentage of the total energy dissipated in the suppressor, as a function of the distance separating the two devices, for various combinations of clamping voltages. In the plot, H, M, and L correspond respectively to a high (250 V), medium (150 V), and low (130 V) voltage rating, in a 120-V rms circuit application. In the designations H-H, H-M, H-L, etc., the first letter is the rating of the arrester and the second letter is the rating of the suppressor.

Figure 1.9 shows an example of a coordinated scheme where the current in the suppressor is indeed small compared to the current in the arrester. This encouraging result can serve as the basis for the selection of the two devices in a scheme that a utility can offer to its customers as an integrated package.

The active element in most surge protective devices is one or several disks of metal oxide varistor (MOV) that perform the current diversion function. The surge diversion capability of arresters and suppressors increases with their diameter. A typical cascade might consist of a 40-millimeter-diameter arrester and a 20-millimeter-diameter suppressor, described as a 40-mm/20-mm cascade.

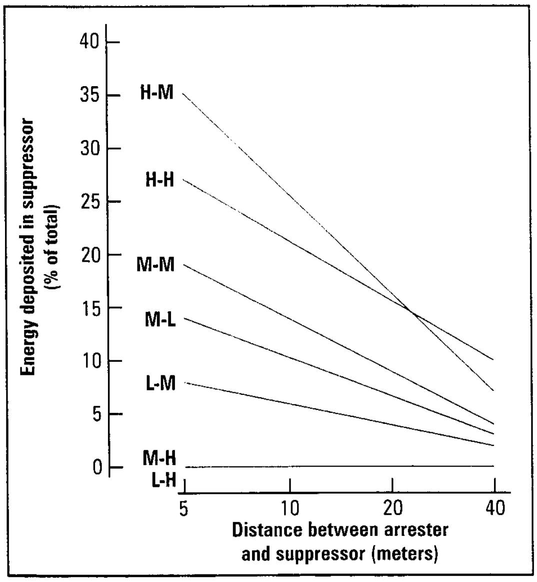

FIGURE 1.8: Relative energy deposited in the suppressor by a typical high-energy surge for various combinations of 250-volt (H), 150-volt (M), and 130-volt (L) ratings, as a function of separation distance.

Although the reality of having many millions of 130-volt suppressors installed on 120-volt systems makes a well-coordinated cascade difficult or perhaps unattainable, at least in the near future, a cooperative can still take certain steps to improve coordination in a protection system. As a compromise, a cascade with equal voltage ratings for the arrester and the suppressor can offer successful coordination, if the impinging surges are relatively short. The coordination of a simple cascade of an arrester and a suppressor of equal voltage rating, both connected line-to-neutral, is slightly improved by the larger diameter of the arrester. However, an unfavorable combination of tolerances for the two devices can wipe out the improvement—for example, if the arrester clamping voltage is at the upper end of the tolerance band and the suppressor is at the lower end of the tolerance band, effectively making the suppressor the lower device hence the one that will have to divert most of the surge.

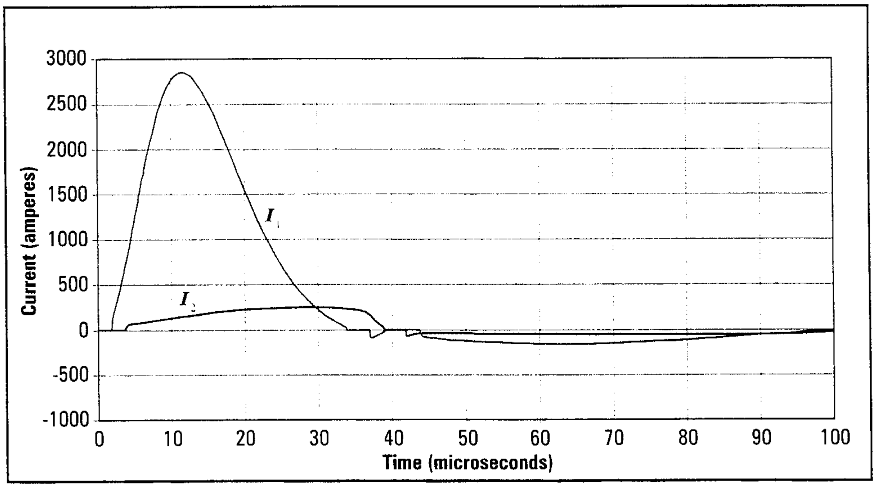

FIGURE 1.9: Division of surge current in a cascade of two 150-volt devices: I_1 is the current in a 40-mm-diameter arrester and I_2 is the current in a 20-mm-diameter suppressor, with 10-meter separation for the same 3000-ampere surge as in Figure 1.8.

In large business or industrial installations with internal feeders, subpanels, and fairly long branch circuits, the question of cascade coordination is more complex than for a simple residence. It should be assessed by the specialist responsible for the electrical installation.

SWELLS

Origins of Swells

The disturbance called a *swell* is a brief increase in the line voltage, typically less than 20 or 30%, associated with load rejections and sluggish voltage regulation response. The AC voltage sine wave remains essentially undistorted, but its amplitude is increased for a few cycles or a few seconds (Figure 1.10).

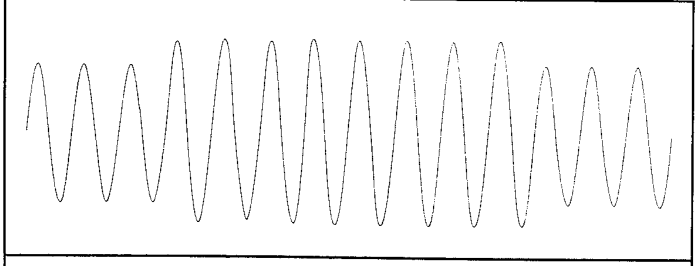

FIGURE 1.10: A voltage swell lasting eight cycles.

Effect of Swells on Equipment

Swells lasting only a few cycles are unlikely to cause any damage, and only the most sensitive electronic equipment might experience a momentary disturbance. On the other hand, swells lasting more than a few cycles can cause a trip-out of protective circuitry in some power-electronic systems. Variable-frequency drives (also called adjustable-speed drives) often include an overvoltage sensor in their electronic control, which can cause a trip of the system, with or without restart. The safety issue of automatic restart versus mandated manual-only restart is well known among plant engineers.

Remedies against Swells

For the residential consumer, there is no concern about damage and only a small likelihood of some upset of an electronic appliance. A user of variable-speed drives (these are beginning to appear in residential heating and air-conditioning systems) might experience a trip-out during a swell. That possibility raises the question of ability to withstand swells, to be taken up with the vendor of the variable-speed drive.

There is no device that can suppress a swell the way a suppressor "suppresses" a surge; the remedy must be inherent immunity of the equipment. Thus, there is little that the user—residential or industrial—can do short of requesting the vendor to provide appropriate designs for the equipment.

TEMPORARY OVERVOLTAGES

Types and Origins of Temporary Overvoltages

Temporary overvoltages are abnormal disturbances, at the power frequency, that occur under the usual (normal or abnormal) operating conditions of a distribution system. The principal causes are system faults over which the utility has little or no control (animals, storms, vehicle collisions) and a troublesome situation of a lost (open) neutral connection in the service drop to customers, in particular the residential 120/240-V three-wire systems.

Distribution System Faults. Overvoltages on the distribution system originate from a variety of system faults such as line-to-ground insulation failure within the distribution transformer. Overvoltages caused by system faults can reach 2.5 times the normal voltage. Depending on the settings of the protective schemes, it can take as long as 5 seconds to clear the circuits.

A rare but possible system fault occurs when the same pole carries two systems at different voltages and a collision, high wind, or ice causes one set of conductors to fall onto the other. This scenario will produce overvoltages proportional to the difference of the two system voltages.

Open Neutral. An open neutral situation can occur as a result of corrosion in underground service drops, falling branches or ice on three-conductor overhead service drops, and even a loose connection of the neutral in a service panel. Service drops with aluminum neutral conductors are more prone to this type of fault.

Utility engineers can report many anecdotes about that type of disturbance.

As the box "When a Neutral Opens" explains, what happens is that if the loads on the two sides of the 120/240-V customer installation are not balanced, the side with the lightest load experiences a large increase from 120 V, theoretically almost up to the full 240 V.

When a Neutral Opens

Open neutral connections in 120/240-V customer installations can occur under several circumstances, including:

- When corrosion of an aluminum underground service reaches an acute stage
- When the neutral wire of a separate-conductor service drop is broken by falling branches or icing
- When an intermittent loose connection exists in the service panel

(Note that all of the above are "when" clauses—not "if and when"—because all of these circumstances are somewhat likely to occur at some point; it is only a matter of probability and frequency of occurrence.)

In typical installations, the two halves of the power supply, on each side of the center-tap neutral connection, are seldom exactly balanced, and sometimes are highly unbalanced. If the installation neutral becomes disconnected from the utility neutral, voltages V_1 and V_2 appear on each side of the now-disconnected installation neutral (see Figure 1.11). The only remaining connection is the two lines, L_1 and L_2, across which the full 240-V supply is maintained.

The potential at the midpoint between the two loads Z_1 and Z_2 will be somewhere between the potential of L_1 and L_2, in inverse proportion to the values of Z_1 and Z_2. If, for instance, Z_2 is much lower than Z_1, a TVSS connected on the L_1 side will experience a severe overvoltage (as will the equipment represented by Z_1). However, while most equipment has some tolerance for a moderate overvoltage, TVSSs, in particular those that claim low clamping voltage, are quite sensitive to that condition. This situation is probably the cause of most reported catastrophic failures of TVSSs.

Some publications on power quality include an illustration of a screwdriver (presumably intended to tighten loose connections) with a caption that reads "the most useful power-quality tool"!

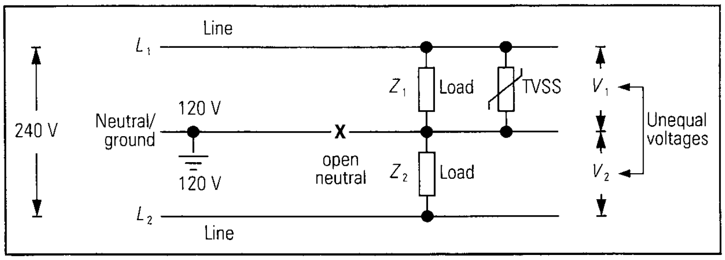

FIGURE 1.11: Unequal line voltages caused by an open neutral.

Effects of Temporary Overvoltages on Equipment

Overvoltages, whether a result of distribution system faults or open neutrals, can be quite destructive for equipment if allowed to last more than a few cycles (in which case they might fall in the category of *swells*). Power equipment is designed to survive these overvoltages: transformers are likely to saturate, providing some voltage reduction on the secondary. Distribution arresters are generally selected for their ability to survive temporary overvoltages. However, many consumer-type TVSSs are likely to fail during a temporary overvoltage [see box, "Lower Is Not (Necessarily) Better"]. In fact, the major cause of TVSS failures is a temporary overvoltage, rather than an unusually large surge.

1

Lower Is Not (Necessarily) Better!

The fundamental purpose of a surge-protective device is to reduce the stress imposed on load equipment when surges occur on the AC power system. Surge protective devices (SPDs) do this by diverting the current of an impinging surge to ground through a low impedance. The effect is a substantial reduction of the impinging voltage surge.

An SPD is a voltage divider in which the voltage on its low side (the side connected to the load) becomes lower as the surge current increases, "clamping" the voltage impressed on the load.

Before the proliferation of SPDs, made possible by the development of metal-oxide varistors (MOVs), the perception existed that the threat of surges was the voltage they can develop at the terminals of a load. Thus, people thought that clamping that voltage to a low level was desirable and, intuitively but erroneously, the lower the better. This perception was reinforced by the decision of the Underwriters Laboratories to require manufacturers of TVSSs (UL Standard 1449) to show the clamping voltage of their product on the package, picking from a list of discrete steps starting with 330 V for 120-V applications. This UL requirement triggered a downward "auction" among manufacturers who wanted to be in the 330-V category, overlooking the undesirable side effects of such a tight clamping.

Actually, most load equipment is more robust to surges than TVSS manufacturers imply by offering these low clamping voltages. For instance, a 500-V clamping voltage would be quite adequate for protecting equipment. Furthermore—the point of the axiom "Lower is not better!"—a TVSS clamping at 500 V would not respond to most swells or temporary overvoltages, a characteristic that is highly desirable. Such a passive situation would help in retarding the aging process of MOVs. More important, it certainly would reduce the incidence of the catastrophic failures that are periodically reported in trade magazines.

Some manufacturers have responded to the argument by offering guarantees or no-questions-asked replacement. Nevertheless, failure of a TVSS from a temporary overvoltage might still be a traumatic experience for a homeowner. Those few manufacturers who subscribe to the "Lower is not better" philosophy should be rewarded by being chosen when consumers go through the quandary of trying to select from the multitude of TVSSs offered on the shelves.

Remedies against Temporary Overvoltages

The nature of temporary overvoltages makes it difficult if not impossible to prevent them, and therefore they must be accepted as a probable, but hopefully rare, event. Surges can be diverted because the energy levels to be absorbed in the diversion are limited. In contrast, a temporary overvoltage involves the full power of the system, and no device can absorb that level of energy. As noted above, some equipment can be designed to withstand the overvoltages, but that decision is beyond the control of a utility.

Not Enough Voltage

OUTAGES

Outages represent the worst type of disturbance for the operations of a customer. They can have a duration as short as a few cycles, the typical situation when the breaker of a feeder trips out on a fault and the fault is cleared, with automatic reclosing (Figure 1.12). Other outages can be much longer, as when the distribution equipment suffers a major fault (downed lines, catastrophic failure of transformers or switchgear).

Outages rarely damage equipment directly. Indirectly, of course, industrial processing equipment (for metals, plastics, textiles, semiconductor devices, and so forth) shut down by an unscheduled outage can suffer damage. The material under process is not only ruined but can also jam the equipment, with painful and time-consuming cleanup operations.

Less dramatic consequences or cessation of operation can range from inconvenience to loss

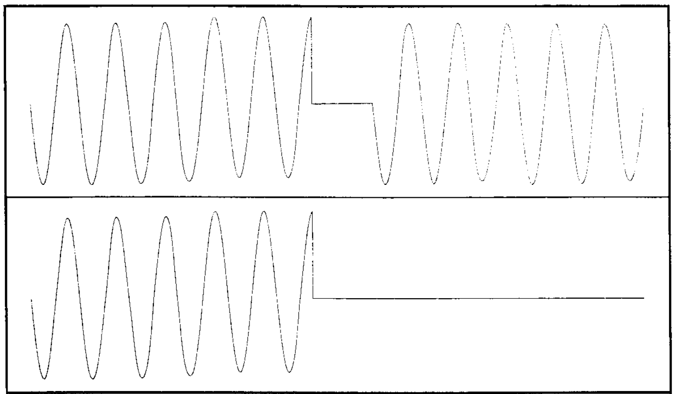

FIGURE 1.12: A very brief outage (top) and a very long outage (bottom).

of revenue. Individual consumers also can suffer from loss of power needed for heating, air conditioning, and food refrigeration. One utility, with a mixture of seriousness and facetiousness, used to describe the severity of outages by the number of claims filed for spoiled freezer loads of frozen raspberries!

The obvious remedy against outages at the customer level is to provide a standby source of power, either a storage battery or an engine-generator set. The battery-power approach, generally called an *uninterruptible power supply* (UPS), is a very popular remedy. It is applied at all power levels, from the small package favored by reliability-conscious computer users, to a building-wide system where loads are segregated into essential and nonessential. There are various types of UPS offered by manufacturers in a highly competitive market, each with performance characteristics aimed at minimizing or avoiding altogether the momentary disturbance when power is transferred from the utility to the standby source.

For large industrial loads, schemes of dual feeders with an automatic transfer switch have been applied successfully by mutual agreement between the customer and the utility. Such an approach is justified when the financial and operational cost of an outage justifies the investment in a dual feeder system. Pessimists have noted, however, that when an installation depends on two feeders, it might be subjected to twice as many sags because each feeder carries a likelihood of sags.

SAGS

Power quality engineers call "sag" an event when the line voltage is reduced for a few cycles to a level of less than 80% of the normal voltage (Figure 1.13). This type of disturbance can trigger upset or shutdown of control circuits. Sags rarely cause equipment damage but are the cause of many complaints of malfunction.

Sags have their source in faults in a feeder that cause a large current to be drawn in the feeder, hence a voltage drop in the bus from which other feeders draw power. Many power quality engineers consider sags as the major cause of equipment malfunctions—but rarely, if at all, of damage. Upsets affect primarily the information technology equipment. Also affected are simple power devices controlled by a magnetic motor starter, which can drop out and stop a process.

Field studies of sag-related disturbances in processing equipment have revealed that the source of the problem can be a simple relay in the control system, rather than a major disturbance in the power equipment. In such cases, a very effective remedy is to provide the control system with a UPS, or even with a simple constant-voltage transformer that can ride through most sags.

BROWNOUTS

In periods of high demand where the system capacity is reached and would be exceeded, utilities resort to the scheme of deliberately reducing the voltage by a few percent. The effect is a

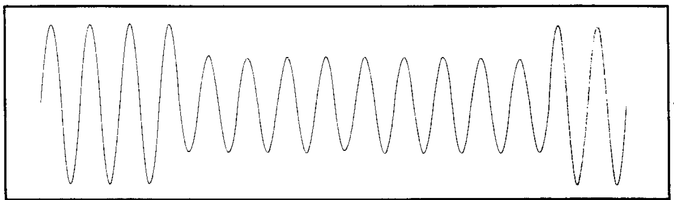

FIGURE 1.13: A sag lasting 10 cycles with the line voltage reduced to 55% of normal.

1

reduction of the power consumed by most loads, with some exceptions in the case of process controls that include a voltage regulating scheme that defeats the objective of the brownout.

SUSTAINED UNDERVOLTAGES

A very severe brownout might cause overheating of compressor motors, and some people believe that domestic refrigerators therefore should be disconnected when the lights are very dim. This perception needs clarification, and utility engineers should quantify the risks involved.

Another damaging consequence might be the failure of some electronic voltage regulators built into computer-based equipment (generically called "information technology" equipment). Such equipment has an intermediate regulating stage that can become overloaded and overheat when attempting to compensate for the voltage reduction. Anecdotes have been circulated, and the phenomenon has been demonstrated in the laboratory, but is confined to isolated cases. It is recounted here as a yet another hint that equipment failures should not blindly be attributed to surges.

CHARACTERISTIC CURVES

The information technology industry has developed a characteristic curve describing the tolerance of equipment to undervoltages (mostly sags) and overvoltages (mostly surges). That curve, well known to power-quality specialists as the *CBEMA curve*, has recently been updated and is now called the *ITIC curve* (for the Information Technology Industry Council). See box, "The CBMA Curve."

FLICKER

When light sources (mostly incandescent but also some fluorescent) are supplied from a power line in which repetitive sags occur, a flickering effect is produced that humans find annoying. The correct term to describe the

The Case of the Flickering Chandelier

In one anecdote, a customer complained of flickering lights to the electric utility, which installed a strip-chart recorder at the service entrance in response (as if that could detect small fluctuations!). Of course, none were detected. It turned out that the customer had left an empty electric skillet on while supper was being enjoyed in the dining room. In that vintage-era house, the skillet (1500 watts on a #14-AWG wire) and the chandelier were on the same branch circuit. The flicker was caused by the thermostat of the skillet cycling on and off. Flickering candles on the dining room table may be romantic, but a flickering chandelier is declared annoying.

The CBMA Curve

In the late 1970s, computer manufacturers and users reached a consensus on the power quality (use of the term had just started) that would be necessary to ensure undisturbed operation of computers. The concept—as a design goal, not a specification—was first proposed as relevant to mainframe computers and presented in the form of a double curve showing a lower limit and an upper limit for acceptable mains voltage, or, in other words, the desirable tolerance of equipment to power supply variations. This chart became known as the CBEMA curve and was soon considered—perhaps not an appropriate extension—as applicable to some electronic equipment other than computers, and was cited in several standards. The original curve was a challenging consensus-building effort. It was a committee agreement on what people thought the equipment could stand. It was not thoroughly tested or verified at that time. Although the power-supply technologies of business equipment have improved, some manufacturers are still reluctant to incorporate them into their products because of competitive market constraints.

In the 1990s, increasing interest in solving power quality problems led to extensive research in the tolerance of various equipment to power supply disturbances, in particular sags. Changing technology in computer equipment—now classified as information technology equipment (ITE) also led to a revision of the limits, and a revised curve was issued in 1996 by the Information Technology Industry Council (ITIC), together with an application note (Figure 1.14).

Updates to this information may be found at the Web site http://www.cbema.org/itic/site_map/index.html

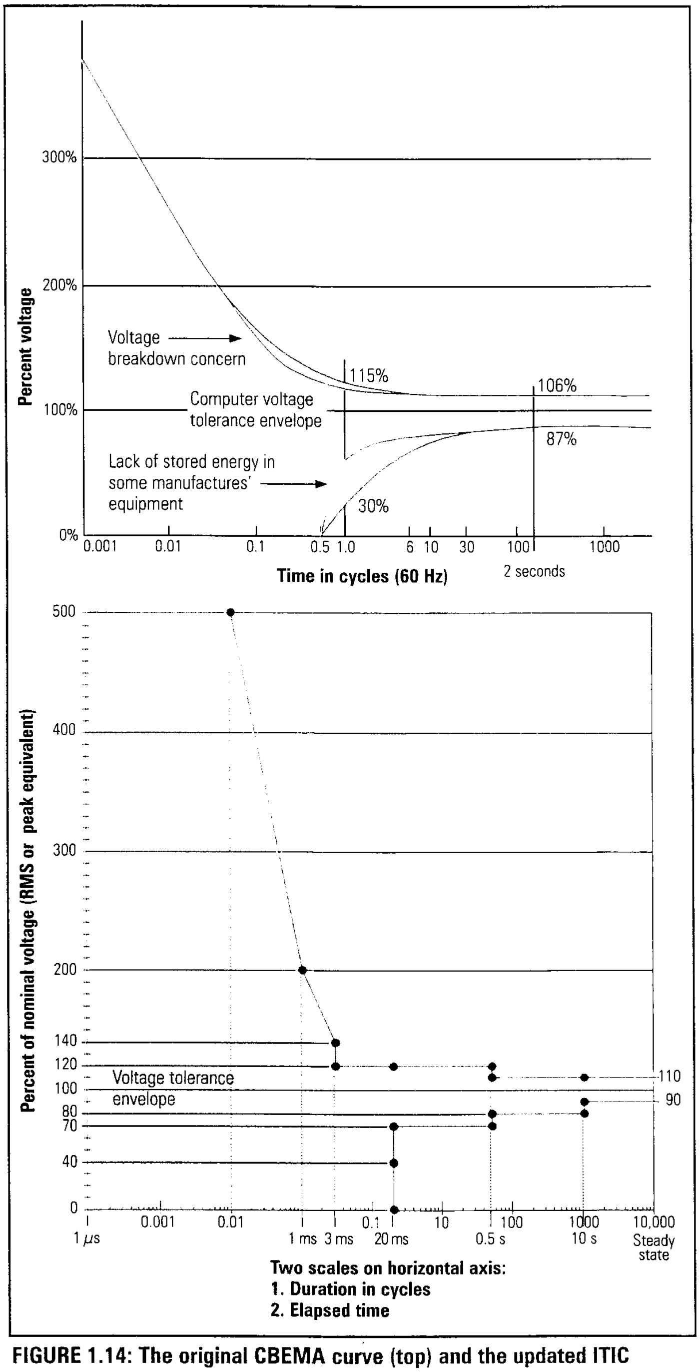

FIGURE 1.14: The original CBEMA curve (top) and the updated ITIC curve (bottom).

behavior of the power supply is *voltage fluctuation*, but *flickering* is often used to describe the quality of the power, even though it is only the effect, not the cause.

Voltage fluctuations can be considered repetitive sags of low amplitude (the human eye can detect light output variations caused by a fraction of a percent fluctuation in the voltage, when the fluctuations occur at rates ranging from a few seconds to about 20 per second). Typical sources are arc furnaces (not too many around) and welding machines (arc and resistance spot welding).

There is no remedy that the customer can apply when the fluctuations come from an intermittent load of a neighbor. (Be sure that the skillet or flat-iron is not on!) If the complaint sounds serious, the only remedy is for the utility to investigate where the intermittent load is, and negotiate a solution with the offender. Power quality specialists are acquainted with a variety of solutions, but each is to be applied case by case.

1

Other Power-Line Disturbances

Other disturbances, less frequent than the "too much" and "not enough" just described, can also occur as the result of the operation of the distribution system and interactions with customer loads. These disturbances include noise, harmonics, notches, unbalance, and carrier signals.

NOISE

The term *noise* is loosely used to describe small disturbances (a few volts at most) at high frequencies (note the plural). See Figure 1.15. The sources of noise include chattering relays (a short-duration event) and coupling of radio frequencies from a nearby broadcast antenna (a quasi-permanent situation).

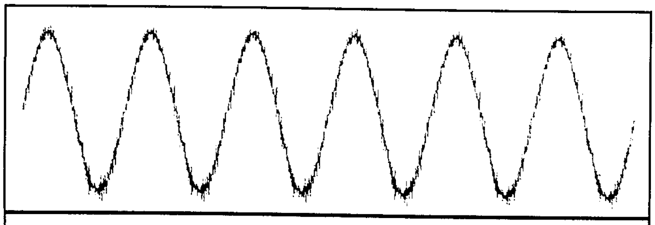

FIGURE 1.15: Noise superimposed on an AC voltage.

In keeping with Federal Communications Commission (FCC) requirements, most domestic equipment has a filter in the power cord that limits the emission of high frequencies back into the power cord. Industrial equipment has similar FCC requirements, but less stringent. By reciprocity, this filter also limits the penetration of line-conducted noise into equipment; this fact is worth keeping in mind when considering the purchase of a TVSS making claims of adding noise filtering to its prime mission of surge protection.

HARMONICS

Harmonics are currents and voltages at frequencies that are multiples of the fundamental 60-Hz waveform (Figure 1.16). They are the result of normal operation of certain loads, called *nonlinear* because their impedance is not constant or because they draw currents that are not proportional to their impedance. This type of load is becoming more widespread as consumer electronics proliferate and as new, sophisticated power-control schemes aimed at improving efficiency are built into some major appliances. The presence of large harmonics is readily visible in the voltage waveform. Small, but potentially objectionable, harmonics require a more sophisticated instrument, such as a power-quality monitor, to detect and quantify them.

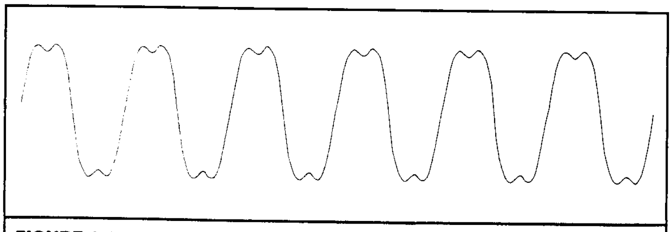

FIGURE 1.16:An AC voltage distorted by harmonics.

Effect of Harmonics on Equipment

As a result of the increase in occurrence of harmonics, the subject has become a hot topic (pun intended) because the effect on equipment can be severe overheating. The problem starts because nonlinear customer loads generate currents at harmonic frequencies. (In the jargon of the applicable standards, this is called *harmonic emission*.) There are several undesirable results from this situation:

1. Effective (root mean square, or RMS) currents in conductors are increased, in particular in the neutral of three-phase systems. These increased currents can cause overheating because the wiring installation, done in accordance with earlier versions of the National Electrical Code (NEC®, trademark of the National Fire Protection Association), made no provision for that situation.
2. The harmonic currents circulate in the delta-connected secondary of wye-delta transformers but not in the primary side, therefore primary overcurrent protection is not effective and the secondary can be severely overheated.

3. If the harmonic currents are not filtered out or canceled at the point of common coupling (as they are in 2 above), the currents flow in the utility distribution system and cause a voltage distortion in the supply of adjacent loads, proportional to the current and the utility system impedance. In other words, systems with relatively low available short circuit capacity will experience more voltage distortion for a given nonlinear load than systems with high capacity.

Remedies against Harmonics

Remedies against harmonics are essentially compromises in a range of extremes. One such compromise is to control harmonic emission by mandating limits for each and every piece of equipment, the approach presently taken by some European countries. Another approach, which has gained acceptance in the United States, is a voluntary compromise where limits for harmonic emissions at the point of common coupling are only recommended.

Consumers have practically no control over the harmonics that their equipment can generate, but the perception in the United States is that, for the moment, they do not pose problems. This laissez-faire attitude might change if harmonic-generating loads such as electronic ballasts and variable frequency drives for heating and air conditioning were to become a larger portion of the total consumer load.

In commercial and office buildings with older wiring and a large amount of information technology equipment, supplied single-phase from a three-phase system with shared neutral, harmonics can cause overheating problems. Later versions of the NEC recognized the problem and have mandated larger ampacity for shared-neutral conductors.

Industrial customers are more concerned about harmonics because some of their loads can have a significant emission. Remedies include the providing filters as a retrofit option. As of 2001, the issues are still the subject of much debate, and should be reviewed by power-quality specialists before expensive and possibly counterproductive measures are implemented.

NOTCHES

"Notches" can be created in the supply voltage when large power-electronic drives in adjacent loads cause a momentary short circuit between the phases that power the drive, each in turn. These are called *commutation notches* and occasionally cause some interference with other loads that use the 60-Hz power frequency as a controlling signal (Figure 1.17).

In a sense, notches may be considered as a special case of harmonic emission, and the remedies, if interference is noted, are similar to those mentioned for harmonics in general.

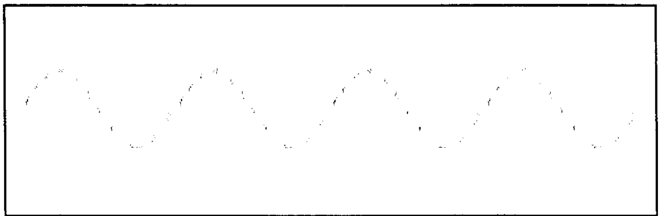

FIGURE 1.17: Commutation notches on an AC voltage.

UNBALANCE

Voltage unbalance between phases occurs when a three-phase system supplies single-phase loads that draw unequal currents. Three-phase loads supplied under those conditions can be adversely affected, with overheating of motors in particular as a symptom. Variable-frequency drive systems have a tendency to magnify the problem by skipping some of the six half-cycles that are expected, each in turn, to deliver power to the drive. Thus, a severe current unbalance can result from a moderate voltage unbalance.

The remedy for this situation is under the control of the end user and is simply to reassess the allocation of single-phase loads from the three-phase system.

CARRIER SIGNALS

Occurrences of interference from carrier signals have been described in anecdotes. These are isolated cases for which case-by-case remedies have been developed by power-quality specialists.

System Interactions

THE PROBLEM

A special kind of surge problem is that of an interaction between the power system and a communications system, as briefly mentioned in the beginning section of this part, "Surges." This case merits special attention because it can be misinterpreted as being caused by the utility power supply. Furthermore, the problem can arise even if both of the systems have been provided with surge protection, leaving a customer thus afflicted puzzled or disappointed. The effect of this interaction is to shift the reference potentials of the two ports during a surge, as explained in the box "Shifting Reference Potentials."

Shifting Reference Potentials

To illustrate the problem of shifting reference potentials, a laboratory replica of a residential wiring system was used to make measurements during surge events produced by injecting a surge into the wiring. In Figure 1.18, a modem-equipped PC is connected by its power port to a branch circuit, and by its modem port to the telephone service of the house. For a worst-case scenario, the power and telephone services enter the house at opposite ends.

An open loop is formed by the copper pipe or ground conductor used as a bonding conductor, the equipment grounding conductor of the branch circuit feeding the PC, and the telephone wires from the network interface device (NID) to the PC. If a surge impinges on the external telephone plant, it is diverted by the NID via the copper pipe to the common grounding point of the house, at the power service entrance. The surge current in the copper pipe creates a changing magnetic flux around the pipe, which induces a voltage in the loop. This voltage will appear between the two PC ports if they are separated by a high impedance (of unknown surge voltage withstand capacity). With the telephone wires routed away from the copper pipe—which can be expected in residential wiring—a large loop is formed, embracing the flux produced by the surge current in the copper pipe.

Figure 1.19 shows the recording obtained in the laboratory replica of residential wiring. For a rate of change in the surge current of 75 A/µs (amperes per microsecond), typical of standard test waveforms, a peak of 4.3 kV is induced in the loop and appears between the two ports.

A relatively simple retrofit solution is to equalize the difference of voltage between the two systems by a device designed for the purpose and inserted in both communications and power links just before they enter the appliance. This device, defined in IEEE Standard 1100-1992 as a "surge reference equalizer," is

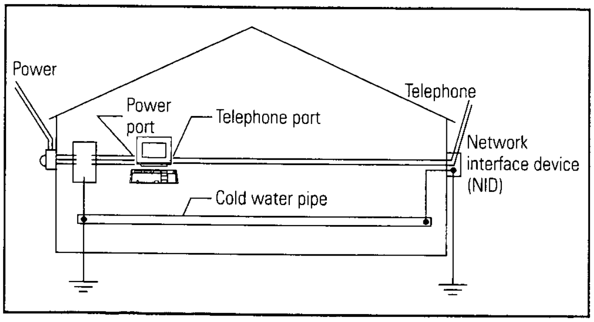

FIGURE 1.18: Power and telephone services enter the house at opposite ends. A personal computer is connected across the two systems.

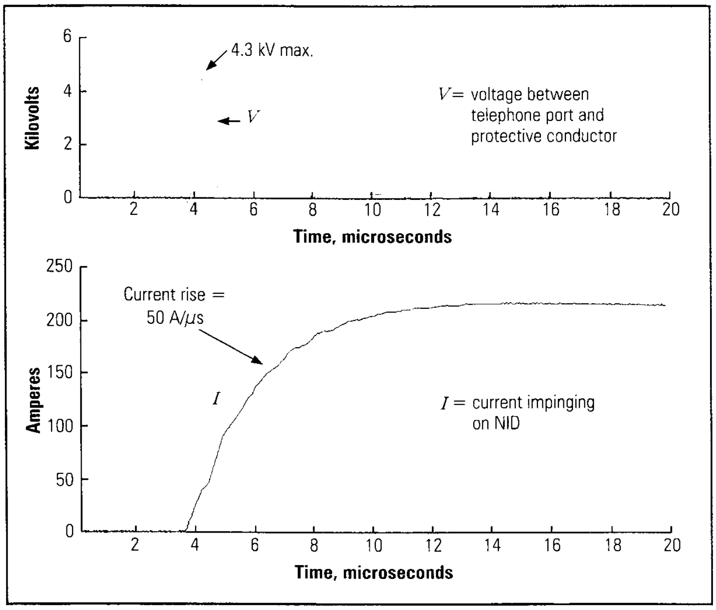

FIGURE 1.19: Voltage and current recorded with telephone and power services entering at opposite ends of the house.

Some appliances that require little power are often equipped with an intermediate power supply integrated with the plug, and feeding a low-voltage DC or AC to the main part of the appliance. If properly designed, this intermediate power supply, by acting as an isolator, will assume the stress that would otherwise appear across the ports of the main part of the two-port appliance.

Of course, the problem would be eliminated if the communications link were to use fiber optics. That solution is increasingly used in business and industrial environments, but the technology and marketing for fiber optics have not yet reached the consumer applications.

commercially available as a unit featuring a plug and receptacle for the power link, as well as a pair of telephone jacks or TV coaxial fittings for the communications link. By way of illustration of a surge reference equalizer's effectiveness, Figure 1.20 shows a reduction of voltage from 4.3 kV down to 200 V, obtained by inserting a typical surge reference equalizer in the power and telephone lines at the point of connection of the PC.

A smaller loop would exist if the telephone and power service entered at the same end of the house, the recommended practice. With such a configuration, a reduction in the voltage difference of about 75% of the large loop value was found in the cited test series, still justifying the provision of a surge reference equalizer for good protection.

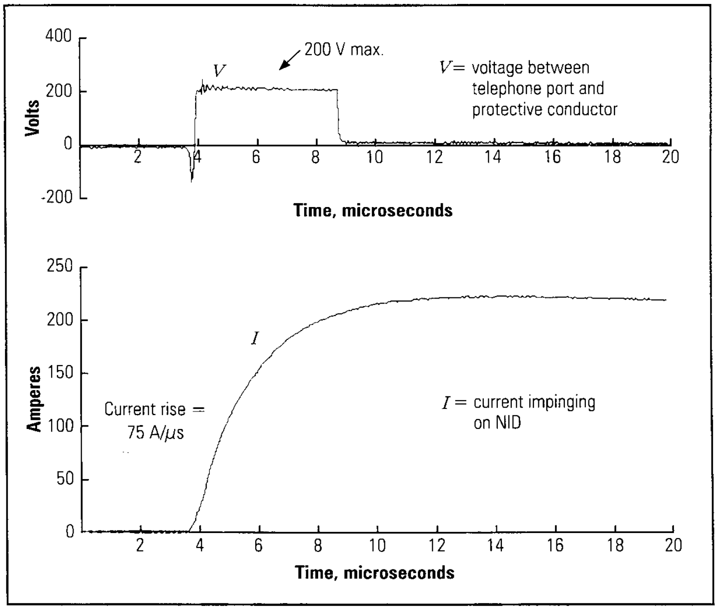

FIGURE 1.20: Mitigation obtained by inserting a surge reference equalizer in both the power line and the telephone line.

1

The root of the problem is the grounding practices of the two utilities—power and communications, either telephone or cable—which are not always coordinated. In some cases, the prescriptions of the National Electrical Code are not followed. During a surge event, the normal, intended, expected operation of one of the surge protectors causes the surge current to flow to the grounding electrode of the installation. This current induces a voltage in the circuits of the installation, which appears across the two ports of appliances, and shifts the reference potentials of the two utilities. If the two utilities enter at opposite ends of the house, the problem is more acute. To check whether this undesirable (and difficult to correct) situation exists, a customer in a single-family residence just has to look at the outside of the house.

A case history has been documented in which the two services not only entered at opposite ends of the house, but also did not have their ground references bonded—not even remotely (see box, "The Case of the Cozy Cabin"). That was a clear violation of the NEC, which the cable TV utility did correct when notified. However, it is a hint that many installations nationwide might have the same deficiency. Insurance statistics indicate that the largest number of claims for "lightning damage" is for video equipment. It is likely, even if not conclusively recorded, that most of these incidents involve the two-port configuration.

The Case of the Cozy Cabin

A good example of a situation that fosters system interaction occurred in a small house in a rural setting—a cozy cabin—where the power and cable TV services entered at opposite ends of the cabin, precisely the scenario described in the box "Shifting Reference Potentials." This installation had come to the attention of a power-quality engineer because two failures of a TV set occurred within a few months.

Examining one of the sets, the engineer found that a flashover had occurred at the input of the TV signal, where an isolating gap separates the cable TV ground from the set chassis, which is ultimately connected to the power system ground via the power cord. The engineer performed laboratory tests after cleaning the carbonized flashover path under conditions simulating the configuration of the cozy cabin, and indeed a flashover was observed at the insulating gap when the shift in potentials reached 2.5 kV. That level is well below the 4.3 kV found in the study described in "Shifting Reference Potentials." System interaction was clearly the cause of failure.

This case history helps to confirm allegations that cable TV installation practices prevailing in many residential situations might be in violation of the U.S. National Electrical Code. This violation is made even more hazardous by the separation of the service entrances. Therefore, one of the first questions that should be answered when inquiries are made on possible causes for damage to a TV or VCR is whether the two services enter at the same end or opposite ends of the house and whether the cable TV service is bonded to the power ground. If the bonding is clearly missing, the cable company should be requested to correct the violation. Even if the services enter at the same end of the house, providing a surge reference equalizer just in the back of the TV set would be good insurance against another incident.

REMEDIES AGAINST SYSTEM INTERACTIONS

Fortunately, industry has recognized the problem and offers a line of devices specially designed to protect against those special, but prevalent, surge problems. This type of device can be recognized easily because it has (1) an input line cord with output power receptacles and (2) two telephone modular jacks (or video coax connectors) to insert in the telephone connection (or video cable connection). The proper engineering term for this device is *surge reference equalizer* (SRE), but here again, popular usage has not adopted the engineering jargon and the device is often called simply a *surge suppressor*, with added words to draw attention to the two-port system.

To place the operation of a surge equalizer in perspective, visualize the two ports of the equipment and their ground references, as in Figure 1.21. During a surge event on one system, there is a transient unbalance between the two input references, which can be made worse when the service entrances are at opposite ends. Inserting an SRE just behind the TV set almost re-establishes a balance between the two ports. The ideal situation would be to first have the two services on the same side, and as a finishing touch, still provide an SRE.

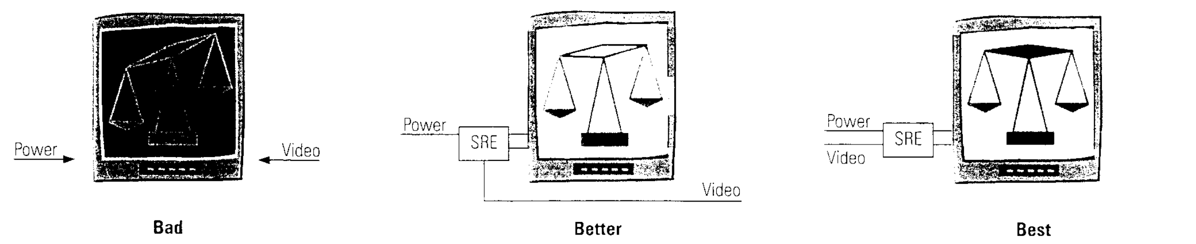

FIGURE 1.21: Shifting reference potential can be remedied by inserting a surge reference equalizer on the communications and power lines (here, the appliance is a TV and the communications line is a TV cable, but a PC with a telephone modem connection presents the same problem). In the ideal situation, the communications and power lines enter the house on the same side, and the SRE is most effective.

2 Questions to Ask

In This Section: Customer-owned offenders; how to use the worksheets; identifying residential and commercial appliance categories; Worksheet EDE: electronic, dual, external; Worksheet EDI: electronic, dual, internal; Worksheet ES: electronic, simple; Worksheet HE: heat, electronic; Worksheet HM: heat, mechanical; Worksheet ME: motor, electronic; Worksheet MM: motor, mechanical; Worksheet PLC: Power line conditioning

This part of the manual is intended to facilitate the interactions between a customer and a cooperative's service representative in tracking down the cause of malfunction or damage and offering remedies when possible. Hopefully, this procedure will serve the common interests of both parties, but, as a note of caution, not all problems can be solved over the telephone, and in some cases it might be necessary to call in a power quality specialist to study the problem and identify possible solutions, just as some medical problems can be described over the telephone to the family doctor and a suitable prescription be picked up at the local pharmacy, but other problems require a visit to the doctor's office and even a referral to a specialist.

While the main thrust of the manual is the effect of the utility supply on equipment—with the equipment characterized as "victim"—there are also cases of disturbed equipment that are associated with the customer's own operations where some other equipment can be characterized as a troublemaker or "offender." These offenders are listed in Table 2.1, for a quick check that the reported problem does not fall in that category, so that the dialogue can then focus on the suspected interaction between the utility power supply and the equipment problem.

Customer-Owned Offenders

Some appliances generate disturbances that can cause a malfunction of other appliances in the same installation, or even in neighbors' installations. These disturbances are not attributable to the utility, but an uninformed customer might still make it a subject of complaint to the utility. Table 2.1 describes typical disturbances, their causes, and possible remedies.

TABLE 2.1: Home-Based Disturbances, Causes, and Remedies

Disturbance	Cause	Remedy
TV remote disabled when lamp is on	Interference from fluorescent lamps	Change type of lamp
Flickering lamps	Load cycling (electric skillet, laser printer)	Plug loads in other branch circuits

2

How to Use the Worksheets

The procedure of troubleshooting consists of the following steps:

1. Obtain from the customer a description of the victim equipment, and categorize the type, using Table 2.2, a list of appliances likely to be found in residential and small-business installations.
2. Turn to the diagnostic worksheets corresponding to the type of victim equipment identified in step 1. The worksheets are structured in three parts:
   a) History and symptoms
   b) Tentative diagnostics and remedies
   c) Disposition of case
3. Obtain from the customer as much background information as possible, using Part A of the worksheet as a script for the dialogue.
4. Reviewing the information thus obtained, ask further questions as appropriate according to Part B of the work sheet.
5. Present to the customer a tentative diagnostic and possible remedy (some problems might be beyond simple remedies).

Identifying Residential and Commercial Appliance Categories

For the purpose of narrowing the tentative diagnosis, Table 2.2 lists several categories of equipment victims. To allow good understanding between the customer and the service representative, it will be useful to pin down, early in the dialogue, what is the specific appliance category to be discussed. When the category is thus pinned down, the "script" for the dialogue can be found in one the the eight work sheets at the end of the manual. The customer representative should photocopy blank work sheets and keep a supply of them to be filled in as the dialogue progresses, then file them for future reference or additional review. For easy reference to the corresponding work sheet, the categories identified by the table are associated with a code that appears in bold type on the top right corner of the work sheet.

MOTOR-DRIVEN APPLIANCES AND HEATING APPLIANCES

For each category (motor-driven or heating), there can be two or more types, depending on the type of control used:

- Mechanical control (on-off, rotary, etc.— no sophisticated keypad or other electronic control)
- Electronic control (keypad, display, etc.)

These different controls influence the tentative diagnosis. Consequently, motor-driven and heating appliances are divided into four kinds, with the following codes in Table 2.2:

1. Motor, mechanical: MM
2. Motor, electronic: ME
3. Heat, mechanical: HM
4. Heat, electronic: HE

ELECTRONIC (COMMUNICATIONS) APPLIANCES

This generic category includes telephones, audio and video equipment, and personal computers. Here again, two types must be recognized:

1. Appliances with a simple, one-link connection to a power system (or to a telephone system for simple sets).
2. Appliances with a dual connection to both power and communication. Such appliances can be subdivided further into two types:
   a) Appliances that are powered as well as linked to an *external* communication system such as telephone line, rooftop antenna, cable TV, or satellite dish. The exposure of this type of appliance is significant because surges of external origin can come in through either the power line or the communication link. They can be caused by system disturbances or by remote lightning strokes.
   b) Appliances that are powered as well as linked to an *internal* communication system, such a garage door opener, burglar alarm, intercom, thermostat, or

computer-controlled appliance. The exposure of this type of appliance, even though it involves two systems, is lower than that of systems with external links. Disturbance or damage associated with the internal communication links is limited to the rare case of a very close lightning stroke inducing a voltage in those internal links.

The absence of a communication link, or the type is a link is present, will influence the diagnosis. The types of electronic appliances can be assigned these codes in Table 2.2:

- Electronic, simple: ES
- Electronic, dual, external: EDE
- Electronic, dual, internal: EDI

POWER LINE CONDITIONING EQUIPMENT

Surge suppressors and uninterruptible power supplies are given the code PLC in Table 2.2.

TABLE 2.2: Categories of Equipment Victims

Codes:

EDE = electronic, dual, external
EDI = electronic, dual, internal
ES = electronic, simple
HE = heat, electronic
HM = heat, mechanical
ME = motor, electronic
MM = motor, mechanical
PLC = power line conditioning

Appliance	Category as victim	Work sheet
Air conditioner, central, conventional	Motor, mechanical	MM
Air conditioner, central, variable speed	Motor, mechanical Electronic, dual, internal	MM EDI
Air conditioner, window	Motor, mechanical	MM
Antenna rotating system	Electronic, dual, external	EDE
Attic fan, thermostat controlled	Motor, mechanical Electronic, dual, external	MM EDI
Automatic lawn sprinkler	Electronic dual, external	EDE
Boom box	Electronic, simple	ES
Burglar alarm, telephone link	Electronic dual, external	EDE
Burglar alarm, independent	Electronic dual, internal	EDI
Cell phone charger	Electronic, simple	ES
Central computer for business	Electronic, dual, external	EDE
Centrex telephone system	Electronic, dual, external	EDE
Clock radio	Electronic, dual, simple	ES
Clothes dryer	Motor, mechanical or electronic Heat, mechanical or electronic	MM or ME HM or ES
Coffee maker	Heat, mechanical	HM
Computer network	Electronic, dual, external only or internal	EDI or EDE
Computerized thermostat system	Electronic, dual, internal	EDI
Dehumidifier	Motor, mechanical	MM
Desktop publishing system	Electronic, dual, internal only or external	EDI or EDE

TABLE 2.2: Categories of Equipment Victims (Cont.)		
Appliance	**Category as victim**	**Work sheet**
Digital clock, electronic	Electronic, simple	ES
Digital clock, mechanical	Motor, mechanical	MM
Digital video disk player	Electronic, simple	ES
Doorbell, sophisticated	Electronic, dual, internal	EDI
Distributed home entertainment system	Electronic, dual, internal and external	EDI and EDE
Electric car battery charger	Electronic, simple	ES
Exercise equipment	Motor, mechanical or electronic	MM or ES
Fax machine	Electronic, dual, external	EDE
Fire alarm system	Electronic, dual, internal and external	EDE and EDI
Fluorescent lamp, compact	Electronic, simple	ES
Fluorescent light, magnetic ballast	Heat, mechanical (equivalent to)	HM
Fluorescent lighting system	Electronic, dual, internal	EDI
Fluorescent light, electronic ballast, single	Electronic, simple	ES
Food mixer	Motor, mechanical	MM
Freezer	Motor, mechanical	MM
Furnace	Motor, mechanical or electronic	MM or ME
Garage door opener	Electronic, dual, internal	EDI
Ground-fault circuit interrupter, receptacle	Electronic, simple	ES
Ground-fault circuit interrupter, service panel	Electronic, simple	ES
Ham radio, transmitter with antenna	Electronic, dual, external	EDE
Ham radio, receiver without external antenna	Electronic, simple	ES
Heat pump	Motor, mechanical or electronic	MM or ME
Hi-fi system, concentrated	Electronic, simple	ES
Hi-fi system, distributed	Electronic, dual, internal and external	EDI and EDE
Home security system, telephone link	Electronic, dual, external	EDE
Hot water heater, isolated	Heat, mechanical	HM
Hot water heater, computer controlled	Heat, mechanical Electronic, dual, internal	HM EDI
Humidifier	Motor, mechanical	MM
HVAC (heating, ventilating, and air conditioning) controls	Electronic, dual, internal	EDI
Instant hot water for beverages	Heat, mechanical	HM
Intercom system	Electronic, dual, internal	EDI
Light bulb, incandescent	Heat, mechanical	MH

TABLE 2.2: Categories of Equipment Victims (Cont.)		
Appliance	**Category as victim**	**Work sheet**
Light dimmer	Electronic, simple	ES
Microwave oven	Electronic, simple	ES
Personal computer, isolated	Electronic, simple	ES
Personal computer, telephone modem	Electronic, dual, external	EDE
Personal computer, cable modem	Electronic, dual, external	EDE
Point-of-sale cash register	Electronic, dual, external	EDI
Power tool	Motor, mechanical	MM
Motion-detection lighting	Electronic, simple	ES
Rechargeable flashlight/emergency lighting	Electronic, simple	ES
Range, kitchen	Heat, mechanical or electronic	HM or HE
Refrigerator	Motor, mechanical	MM
Satellite dish receiver	Electronic, dual, external	EDE
Sink disposal	Motor, mechanical	MM
Sump pump	Motor, mechanical or electronic	MM or ME
Surge suppressor, permanent connection	Power line conditioner	PLC
Surge suppressor, plug-in	Power line conditioner	PLC
Surge suppressor, service entrance	Power line conditioner	PLC
Surveillance camera system	Electronic, dual, external	EDE
Telephone answering machine	Electronic, dual, external	EDE
Telephone desk set, powered	Electronic, dual, external	EDE
Telephone desk set, simple	Electronic, simple	ES
Television receiver, cable input	Electronic, dual, external	EDE
Television receiver, rabbit ear	Electronic, simple	ES
Television receiver, satellite input	Electronic, dual, external	EDE
Trash compactor	Motor, mechanical	MM
TVSS, permanently connected	Power line conditioner	PLC
TVSS, plug-in	Power line conditioner	PLC
TVSS, surge reference equalizer	Power line conditioner Electronic, dual, external	PLC EDE
Uninterruptible power supply	Power line conditioner	PLC
Vacuum cleaner	Motor, mechanical	MM
Vacuum cleaner, central system	Motor, mechanical Electronic, dual, internal	MM
Videocassette recorder, satellite input	Electronic, dual, external	EDE
Videocassette recorder, cable input	Electronic, dual, external	EDE

TABLE 2.2: Categories of Equipment Victims (Cont.)		
Appliance	**Category as victim**	**Work sheet**
Video conferencing	Electronic, dual, external	EDE
Washer, dishes	Motor, mechanical or electronic Heat, mechanical or electronic	MM or ME HM or HE
Washer, clothes	Motor, mechanical or electronic	HM or HE
Water well pump, submersed	Motor, mechanical or electronic Electronic, dual, external	MM or ME EDE
Water well pump, indoor, aboveground	Motor, mechanical or electronic	MM or ME

EDE

Worksheet EDE

Electronic, dual, external

A. HISTORY AND SYMPTOMS

Appliance identity

- ☐ Name of customer____________________
  ____
- ☐ Appliance in question____________________
- ☐ Where located in building? ____________
- ☐ Approximate age?_____years

Symptoms

- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?

- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem

- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?

- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions

- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe:____________________
    ____
- ☐ Don't know ____

System interaction

- ☐ Proper bonding of power system and communications system? (Y/N) ____
- ☐ Surge reference equalizer installed? (Y/N) ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
System interaction (most likely). See under A.	Install surge reference equalizer.
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair
Surge on the power line	Was there a surge reference equalizer? If yes, a temporary overvoltage is likely. If no, install surge reference equalizer.
Temporary overvoltage	Repair if appliance is expensive, or replace.

C. DISPOSITION OF CASE

EDI

Worksheet EDI

Electronic, dual, internal

A. HISTORY AND SYMPTOMS

Appliance identity

- ☐ Name of customer________________________
- ☐ Appliance in question__________________
- ☐ Where located in building? ______________
- ☐ Approximate age?_____years

Symptoms

- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?

- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem

- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?

- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions

- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe: ________________________
- ☐ Don't know ____

Other information and remarks by customer:

How extensive are the communication links (garage antenna, intrusion switches, thermostat controls, etc.)?

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair
Surge on the power line	Was there a surge reference equalizer? If yes, a temporary overvoltage is likely. If no, install surge reference equalizer.
Temporary overvoltage	Repair if appliance is expensive, or replace.

C. DISPOSITION OF CASE

ES

Worksheet ES
Electronic, simple

A. HISTORY AND SYMPTOMS

Appliance identity
- ☐ Name of customer________________________
  ____
- ☐ Appliance in question____________________
- ☐ Where located in building? ______________
- ☐ Approximate age?_____years

Symptoms
- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?
- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem
- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?
- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions
- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe: ________________________
    ____
- ☐ Don't know ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair
Surge on the power line	Was there a surge reference equalizer? If yes, a temporary overvoltage is likely. If no, install surge reference equalizer.
Temporary overvoltage	Repair if appliance is expensive, or replace.

C. DISPOSITION OF CASE

HE

Worksheet HE
Heat, electronic

A. HISTORY AND SYMPTOMS

Appliance identity
- ☐ Name of customer ____________________
- ☐ Appliance in question ____________________
- ☐ Where located in building? ____________
- ☐ Approximate age? _____ years

Symptoms
- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?
- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem
- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?
- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions
- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe: ____________________
- ☐ Don't know ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair
Surge on the power line	Was there a surge reference equalizer? If yes, a temporary overvoltage is likely. If no, install surge reference equalizer.
Temporary overvoltage	Repair if appliance is expensive, or replace.

C. DISPOSITION OF CASE

HM

Worksheet HM
Heat, mechanical

A. HISTORY AND SYMPTOMS

Appliance identity

☐ Name of customer______________________
____
☐ Appliance in question____________________
☐ Where located in building? _______________
☐ Approximate age?_____years

Symptoms

☐ Quit working during normal operation ____
☐ Would not start when turned on ____
☐ Smoke came out ____
☐ Acrid smell ____
☐ Blinking displays ____
☐ Other ____

Has that condition happened before?

☐ Previous repair history ____
☐ Did not report it ____
☐ Reported it but no action ____
☐ Suggested action failed ____
☐ Don't know ____

Weather at the time of the problem

☐ Blue sky ____
☐ High winds ____
☐ Ice storm ____
☐ Distant thunder ____
☐ Local lightning ____
☐ Don't know ____

Similar problem in neighbor's home?

☐ Yes ____
☐ No ____
☐ Don't know ____

Power system conditions

☐ Apparently normal ____
☐ Problem occurred in conjunction with:
A utility outage? ____
Other incident? ____
Describe: __________________________
____
☐ Don't know ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair
Temporary overvoltage	Repair if appliance is expensive, or replace.

C. DISPOSITION OF CASE

ME

Worksheet ME

Motor, electronic

A. HISTORY AND SYMPTOMS

Appliance identity

- ☐ Name of customer____________________

  ____
- ☐ Appliance in question____________________
- ☐ Where located in building? ____________
- ☐ Approximate age?_____years

Symptoms

- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?

- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem

- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?

- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions

- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe: ____________________

    ____
- ☐ Don't know ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
Mechanical overload	Check for jamming or seized bearing; clean out or repair.
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair
Surge on the power line	Was there a surge reference equalizer? If yes, a temporary overvoltage is likely. If no, install surge reference equalizer.
Temporary overvoltage	Repair if appliance is expensive, or replace.

C. DISPOSITION OF CASE

MM

Worksheet MM
Motor, mechanical

A. HISTORY AND SYMPTOMS

Appliance identity

- ☐ Name of customer ____________________
- ____________________
- ☐ Appliance in question ____________________
- ☐ Where located in building? ____________________
- ☐ Approximate age? _____ years

Symptoms

- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?

- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem

- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?

- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions

- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe: ____________________
  - ____________________
- ☐ Don't know ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
Mechanical overload	Check for jamming or seized bearing; clean out or repair.
End-of-life burnout. (How old is equipment?)	Replace.
Mechanical switch failure	Repair

C. DISPOSITION OF CASE

PLC

Worksheet PLC

Power line conditioning

A. HISTORY AND SYMPTOMS

Appliance identity

- ☐ Name of customer________________________
- ________________________
- ☐ Appliance in question________________________
- ☐ Where located in building? ______________
- ☐ Approximate age?_____years

Symptoms

- ☐ Quit working during normal operation ____
- ☐ Would not start when turned on ____
- ☐ Smoke came out ____
- ☐ Acrid smell ____
- ☐ Blinking displays ____
- ☐ Other ____

Has that condition happened before?

- ☐ Previous repair history ____
- ☐ Did not report it ____
- ☐ Reported it but no action ____
- ☐ Suggested action failed ____
- ☐ Don't know ____

Weather at the time of the problem

- ☐ Blue sky ____
- ☐ High winds ____
- ☐ Ice storm ____
- ☐ Distant thunder ____
- ☐ Local lightning ____
- ☐ Don't know ____

Similar problem in neighbor's home?

- ☐ Yes ____
- ☐ No ____
- ☐ Don't know ____

Power system conditions

- ☐ Apparently normal ____
- ☐ Problem occurred in conjunction with:
  - A utility outage? ____
  - Other incident? ____
  - Describe: ________________________
  - ________________________
- ☐ Don't know ____

Other information and remarks by customer:

B. TENTATIVE DIAGNOSIS AND REMEDY

Diagnosis	Remedy
Surge suppressor and uninterruptible power supply: End-of-life burnout Temporary overvoltage (most likely) "Large" surge (quite rare)	Replace
Uninterruptible power supply only: Battery problem?	Replace

C. DISPOSITION OF CASE