PDHonline Course E301 (3 PDH)

Secondary Surge Protection

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Secondary Surge Protection

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Introduction

From an electric utility perspective, secondary surge protection means protecting the secondary of a distribution transformer from damaging overvoltage conditions. From a residential consumer's perspective, secondary surge protection concerns mitigating the effects of overvoltages on appliances, computers, and other household electrical appliances.

The sophistication of computer-controlled equipment found in homes today rivals the processing capability of business computer centers just a few short years ago. And these business computer rooms had special requirements for "clean" power whereas the typical residential home is exposed to all types of varying voltage conditions that can harm equipment.

There are numerous terms used to describe secondary voltage problems including, surges, spikes, noise, sags, swells, undervoltages, overvoltages, and outages. In fact, power quality is generally defined by the term's regulation, isolation, suppression, harmonics, noise, grounding, and interruptions. Figure 1 is a graphic of potential power quality issues.

Suppression includes methods to control spikes and transients. For our purposes we will define a spike as a short-term overvoltage condition of less than two per-unit of the normal voltage and a transient surge as any short-term overvoltage in excess of two per-unit. Regulation involves keeping sags and swells within acceptable limits. A swell is an increase in voltage, at the power frequency, for durations from one-half cycle to one-second. In contrast, sag is a reduction in voltage, at the power frequency, for durations of one-half cycle to a one-second. Harmonics are

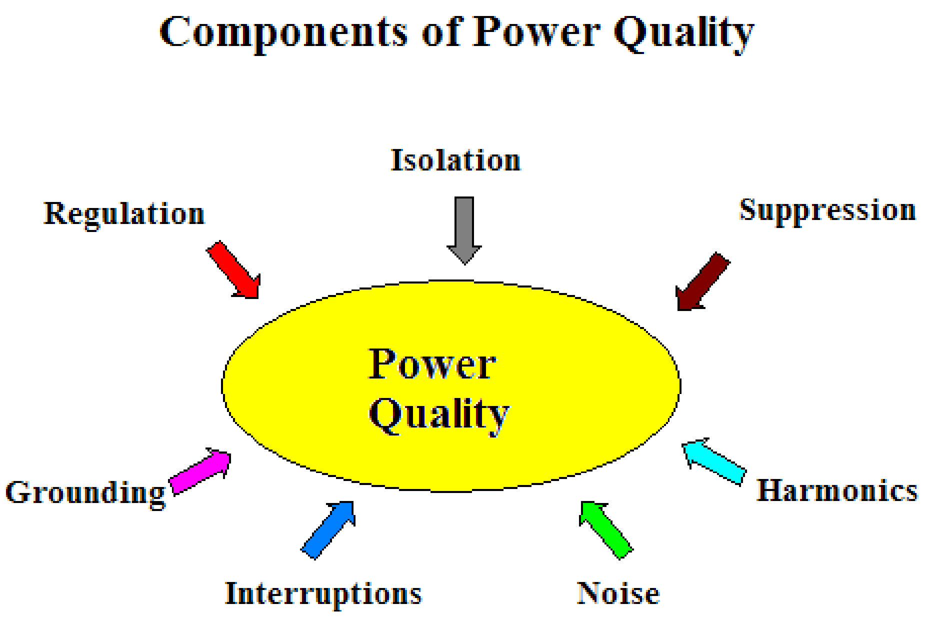


Figure 1

integer multiples of the fundamental power frequency and are caused by non-linear loads such as switching power supplies, etc. Noise is a low-energy random signal that appears on the voltage or current wave. Noise may be caused by fluorescent ballasts, doorbell transformers, electric heating elements, etc.

The most common form of secondary voltage condition is a transient surge followed by spikes and over/under voltage conditions. See Figure 2 for the incident rate of the various types of power line disturbances. It is interesting that the combination of spikes and surges total 88% of the typical power line disturbances.

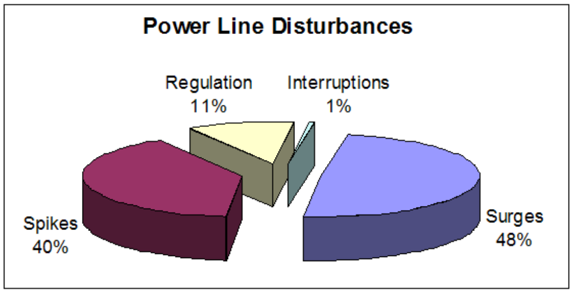


Figure 2

In the first chapter of this course we will look at the most common cause of transients, which is lightning. Subsequent chapters cover the basics of transients, surge protection device (SPD) equipment, standards, and the application of SPD equipment to residential applications.

Chapter 1
Lightning

Each year lightning is responsible for numerous deaths in the U.S. and millions of dollars in property damage to utility equipment and consumer electronics.

Since 1989 a lightning detection network has been in place over the continental 48 states. During this time, an average of 20,000,000 cloud-to-ground flashes has been detected every year. In addition, about half of all flashes have more than one ground strike point, so at least 30 million points on the ground are struck on average each year in the US. There are roughly 5 to 10 times as many cloud-to-cloud flashes as cloud-to-ground flashes.

Damage from lightning occurs as a result of both direct and indirect strikes. Lightning may directly contact a power line causing damage or it may contact a nearby tree or other object where the current flows through the ground and into an electrical circuit in thee house.

Lightning Flash Mechanism

Lightning originates in cumulonimbus clouds, which are the cloud formations that generate thunderstorms. These thunderstorm clouds are formed wherever there is enough upward motion, vertical instability, and enough moisture to produce a cloud that reaches up to levels somewhat colder than freezing. Thunderstorms are divided into two types: convective and frontal system storms. Convective thunderstorms are usually short-lived, lasting for 30 minutes to a few hours. Frontal storms can cover hundreds of miles as they travel across the country.

The formation of a thunderstorm requires three basic ingredients, moisture, cooling, and lifting action. The basic fuel is moisture, or water vapor, in the atmosphere. The air above the water vapor must cool off rapidly with height. There must be something in the atmosphere to push the moist air from near the ground up to where the air around it is cold. This may be a cold front or the boundary between where the cold air from one thunderstorm meets the air outside of the storm (called an outflow boundary) and anything else that forces the air at the ground together. When this happens, the moist air is pushed up. As the moist air rises it cools off and some of the water vapor condenses into liquid water cloud drops. This warms up the rest of the air mass so that it doesn't cool off as fast as it would if the air was dry. When the air mass gets into the colder atmosphere, it will be warmer and less dense than the air around it. Since it is less dense, it will start to rise faster without being pushed. Then more water vapor turns into liquid in the air mass and the air mass warms up more and rises even faster until all of water vapor is gone and the air mass eventually reaches a point in the atmosphere where it isn't warmer than the environment.

Strong updrafts and down drafts occur with regularity, even within small thunderstorms. The updrafts transport water droplets up into the cloud, while ice particles descend from the frozen upper regions of the cloud. As they do, they bump and collide with each other. Through this process, electrons shear off the ascending water droplets and collect on the descending ice particles. This generates an electric field within the cloud, with the top having a positive charge, and the bottom having a negative charge. An electric field is also generated between the bottom of the cloud and the surface of the earth, though not nearly as strong as the field within the cloud. As a result, most lightning occurs within the cloud itself. Lightning is a transient discharge of static electricity that serves to re-establish electrostatic equilibrium within a storm environment.

In a developing storm cloud, there is an electric attraction (i.e. electric field) between its top and bottom. As the charges begin to separate, the field strength grows, and the greater the magnitude of separation between the charges, the stronger the field. And this causes a stronger attraction between the positively charged top and the negatively charged bottom of the cloud. However, the atmosphere is a very good insulator, so a tremendous amount of charge must build up before lightning can occur. When that threshold is reached, the strength of the electric field overpowers the atmosphere's insulating properties, and lightning results.

Lightning discharges can be divided into two types: Cloud to ground (CG) discharges, which have at least one channel connecting the cloud to the ground and cloud discharges that have no channel to ground. These cloud discharges are classified as in-cloud (IC), cloud to air (CA), or cloud to cloud (CC).

Cloud-to-ground (CG) lightning is the most damaging and dangerous form of lightning. Although not the most common type, it is the one that is best understood. Most flashes originate near the lower-negative charge center and deliver negative charge to Earth. However, an appreciable minority of flashes carry positive charge to Earth. These positive flashes often occur during the dissipating stage of a thunderstorm's life. For some unknown reason, positive flashes are also more common as a percentage of total ground strikes during the winter months.

Intra-cloud (IC) lightning is the most common type of discharge. This occurs between oppositely charged centers within the same cloud. Usually the process takes place within the cloud and looks from the outside of the cloud like a diffuse brightening which flickers. However, the flash may exit the boundary of the cloud and a bright channel, like a cloud-to-ground flash, can be visible for many miles.

The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm to storm. Storms with the greatest vertical development may produce intra-cloud lightning almost exclusively. Some suggest that the variations are latitude-dependent, with a greater percentage of cloud-to-ground strikes occurring at higher latitudes. Others suggest that cloud-top height is a more important variable than latitude.

Depending upon cloud height above ground and changes in electric field strength between cloud and Earth, the discharge stays within the cloud or makes direct contact with the Earth. If the field strength is highest in the lower regions of the cloud a downward flash may occur from cloud to Earth.

Cloud-to-cloud (CC) lightning, as the name implies, occurs between charge centers in two different clouds with the discharge bridging a gap of clear air between them.

Cloud-to-Air (CA) lightning, occurs between charge center in a cloud and the surrounding air.

Figure 3 is a graphic showing the different types of lightning strikes.

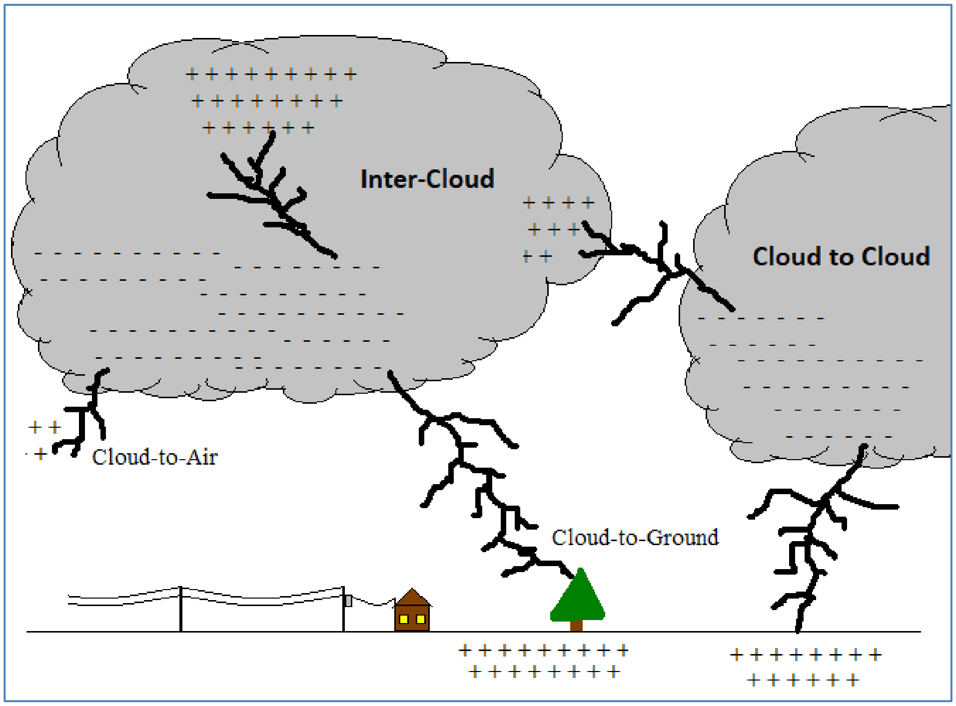


Figure 3

Lightning Example

For a detailed explanation of a lightning strike, consider the following scenario of a typical cloud-to-ground lightning strike (intra-cloud, cloud-to-cloud, and cloud-to-air lightning strikes are similar.) While lightning occurs instantaneously, it takes place over several steps:

Step 1 - Stepped Leaders

A cloud-to-ground lightning discharge typically initiates inside the thunderstorm. When enough electrons collect in the bottom of the cloud, a very faint, negatively charged channel, called the stepped leader, emerges from the base of the cloud. Under the influences of the electric field established between the cloud and the ground, the leader propagates towards the ground in a series of luminous steps about 50 meters in length and 1 microsecond in duration, in what can be loosely described as an "avalanche of electrons". Between steps there is a pause of about 50 microseconds, during which time the stepped leader "looks" around for an object to strike. If none is "seen", it takes another step, and repeats the process until it "finds" a target. It takes the stepped leader on the order of 50 milliseconds to reach its full length. As the stepped leader's channel approaches the ground, it carries about 5 Coulombs of negative charge, and has a very strong electric potential of about 100 million volts with respect to the ground. Note: A coulomb is the amount of charge transferred in 1 second by a current of 1 ampere (1 ampere second). It is equal in magnitude to the charge of 6.28 x 10^{18} electrons.

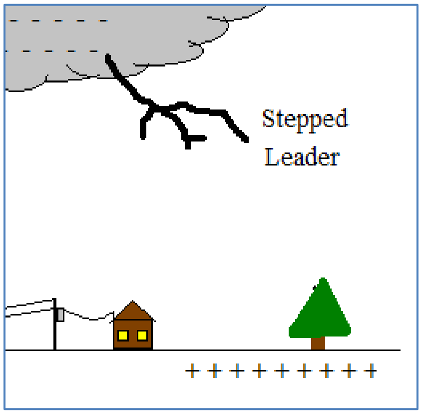


Figure 4

Step 2 - Streamers

When the stepped leader approaches the ground, its strong negative electric field repels all negative charge in the surrounding ground, while attracting all positive charge. This induces an upward moving positive charge from the ground and/or objects on the ground. When this positive charge collects into a high enough concentration, it forms bolts of ground-to-air paths known as streamers.

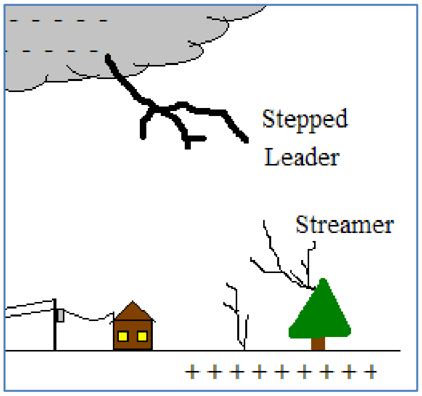


Figure 5

Step 3 - Ground Connection

When one of these positively charged streamers contacts the tip of a negatively charged leader, the following occurs:

- The leader channel's electric potential is connected to the ground.
- All other branches of the leader channel cease further propagation toward the ground, and all negative charge within these branches starts flowing to the ground through the newly established ground/cloud connection.

Step 4 - The Return Stroke

An electric current wave then propagates up the channel as a bright pulse. This discharge process takes less than 100 microseconds and is called the return stroke. It produces almost all the luminosity and charge transfer in most cloud-to-ground strokes. The lightning is traveling from the ground into the cloud, but because the process takes place so quickly, to the unaided eye is appears that the opposite is true. Electric charge flows up the channel behind the wave front and produces a ground level current. This current has an average peak value of about 30,000 amperes, though it can be as high as 300,000 amperes.

Step 5 - Dart Leaders

After the current has ceased flowing up the leader channel, there is a pause of about 20 to 50 milliseconds. After that, if additional charge is made available at the top of the leader channel, another leader can propagate down the established channel. This leader is called a dart leader because it is continuous instead of stepped. Dart leaders cause lightning to have a flickering appearance. Not every lightning flash will produce a dart leader, as enough charge to produce one must be made available within about 100 milliseconds of the initial stepped leader.

The dart leader deposits about one coulomb of charge along the channel and carries additional electric potential to the ground. The negatively charged dart leader then will induce a new, positively charged return stroke from the ground. The peak amplitude of the current usually decreases as additional dart leaders are produced. Therefore, the induced field changes are also smaller in amplitude and have a shorter duration than those of the first return stroke. Dart leaders and their subsequent return strokes are not normally branched like the initial stepped leader and return stroke.

The combination of each leader (stepped and dart) and the subsequent return stroke is known collectively as a stroke. All strokes that use the same cloud-to-ground channel constitute a single cloud-to-ground flash. A flash can be made up of a single stroke, or as many as tens of strokes.

The bright light of the lightning flash caused by the return stroke mentioned above represents a great deal of energy and this energy generates a sound wave (thunder). The energy of a lightning strike heats the air in the channel to above 50,000 degrees F in only a few millionths of a second. The air that is now heated to such a high temperature has no time to expand, so it is at a very high pressure. The high-pressure air then expands outward into the surrounding air compressing it and causing a disturbance that propagates in all directions away from the stroke as a shock wave, which then decays to an acoustic wave (thunder) as it propagates away from the lightning channel.

Cloud-to-ground lightning can also be initiated by stepped leaders that are positively charged. The resulting return stroke carries a negative charge and transfers positive charge from the cloud to the ground. The combination of the leader and the return stroke is called a positive flash. Usually there are no subsequent dart leaders down the existing channel, so only one stroke makes up a positive flash.

Positive flashes constitute less than 10 percent of all cloud-to-ground flashes and occur on the periphery of a thunderstorm away from the central rain shaft. Positive flashes are most often found in winter storms or during the dissipating stage of thunderstorms. However, the peak current of their return strokes is often much larger than the peak current of the negative return strokes. Thus, they are more lethal, and can cause greater damage than negative flashes. It is believed that a large percentage of forest fires and power line damage is caused by positive flashes.

Chapter 2
Transients

Transients disrupt the normal alternating current (AC) waveform. A 120-volt, 60 Hz AC waveform is a pure sine wave. It cycles 60 times per second reaching a peak positive value of +170 volts and a peak negative value of -170 volts. The 120-volt value is called the RMS voltage. RMS is the *root-mean-square* value of the voltage waveform and it is equal to a DC voltage with the same effective heating value. The RMS value is found by squaring every point on the waveform, finding the average value of the squares and then taking the square root of the average. For a pure sine wave, it is simply found by dividing the peak voltage value by the square root of two (1.414), therefore, a 170-volt peak, pure sine wave voltage will have an RMS value of 120 volts (170 / 1.414 = 120 volts). See Figure 6 for a typical sine wave.

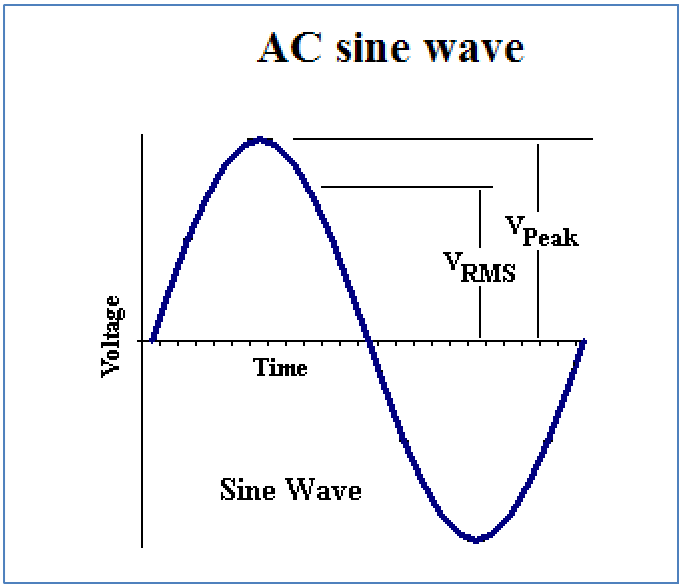


Figure 6

There are two types of transients that are typically considered when discussing SPDs: impulse transients, and ringwave transients. Both disturbances ride on the AC sine wave and they are described by their rise and decay times and their energy content. The energy content is measured in Joules. A *Joule* is a unit of measure for work done and is defined as the force of one Newton being displaced one meter.

The *impulse transient* is the more destructive of the two and is generally caused by lightning. In the previous chapter we discussed the formation of lightning. In the lightning flash mechanism, the return stroke and subsequent stroke are important in the design of protection systems for electrical circuits. Of interest are the currents involved in the strokes. A lightning strike can be thought of as a current generator and the associated voltages that are produced are a function of the current generated and the impedance of the electrical circuit.

The electrical characteristics of a lightning strike are defined by the current and duration of the waveform. The properties of interest include peak current, rise time, and time to half-value. Figure 7 shows the relative properties for both a current waveform and a voltage waveform. This figure is based on a *negative* waveform.

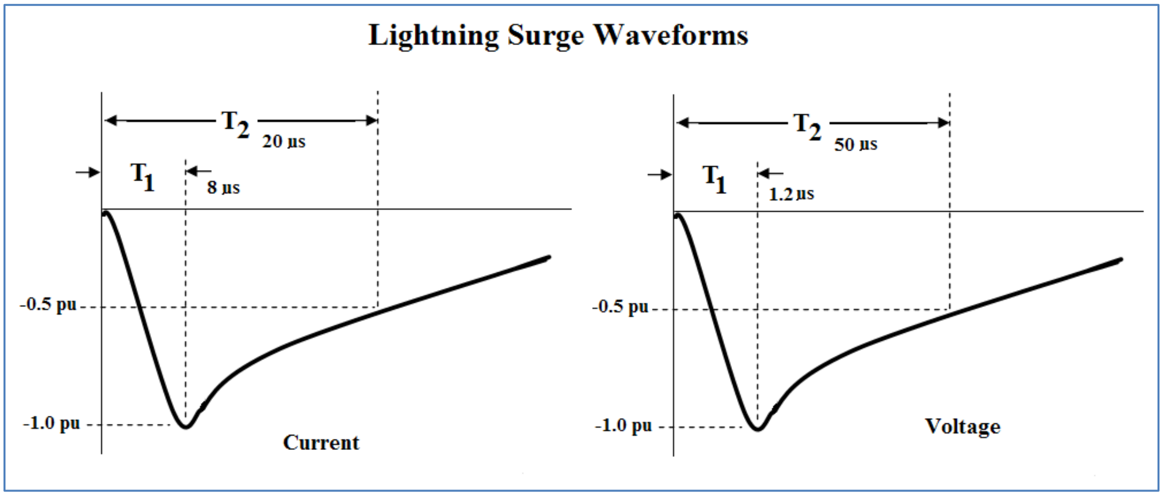


Figure 7

Looking at the current waveform in Figure 7, we see that the negative current waveform rises from zero current to a peak negative current (defined as -1.0 per-unit) in time T_1. The waveform then decays and at time T_2 it has reached one-half its original value (-0.5 per-unit.) Manufacturers have defined a standard waveform for test purposes to be a current wave with an 8 microsecond rise time and a 20-microsecond time to decay to 50% of the peak magnitude. This value is represented as an “8 x 20 current wave”. However, many strikes have faster rise times and much longer decay periods. Some researchers claim that a 1 x 1,000 waveform may be more representative of a typical lightning strike. A 1 x 1,000 waveform would have significantly more energy than an 8 x 20 waveform. Tests have shown that median peak current magnitude is about 30,000 amps, although strikes of over 300,000 amps have been observed.

Figure 7 also shows a typical voltage waveform. The characteristics are similar, except the standard rise time is 1.2 υs and the time to 50% of the peak voltage is 50 υs, or a 1.2 x 50 voltage waveform. As previously mentioned, the magnitude of the peak voltage is dependent on the current waveform and the impedance of the circuit.

Impulse transients can be thought of as fast rise time, high energy content waveforms that frequently destroy electrical equipment.

In contrast to the impulse transient, the ringwave is not as destructive, but it can be disruptive by causing equipment to operate incorrectly. A *ringwave* has a fast rise time, oscillates, and decays exponentially. A ringwave may be the result of a decaying impulse transient or it may be caused by inductive loads such as motors. Figure 8 shows a typical ringwave. This waveform is the industry standard for equipment tests and includes a fast rise time of 0.5 microseconds to the peak value followed by a 100 kHz (10 microsecond period) ring wave.

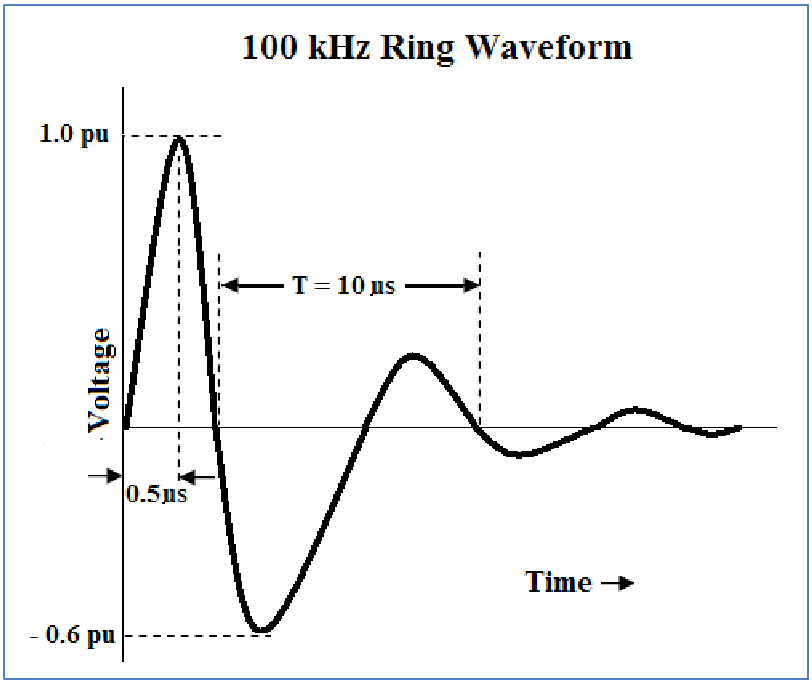


Figure 8

Next, let's look at how a surge enters a house. The secondary service from the utility to a residence can be thought of as a current surge generator. When lightning strikes a high-voltage primary line the lightning arrester on the transformer attempts to shunt the current to ground. Since the high-side and low-side of the transformer are connected to a common ground, surge current from the high-side will flow into the low-side neutral and into the secondary conductors.

Approximately one-half to one-third of the surge current discharging from the primary arrestor can appear across the secondary winding of a distribution transformer. Therefore, the secondary surge arrester at the service entrance should be rated for this level of surge current. The magnitude of primary surge currents can vary widely, but a 65,000-amp surge is not unreasonable, and the secondary surge device should be rated for at least 25-35,000 amps. The discharge voltage of the secondary surge arrester must be low enough to prevent flashover of the electrical outlets within house. A typical 120-volt outlet in a residential application can withstand about 3 kV. See the accompanying drawing for a better understanding of the surge current flows.

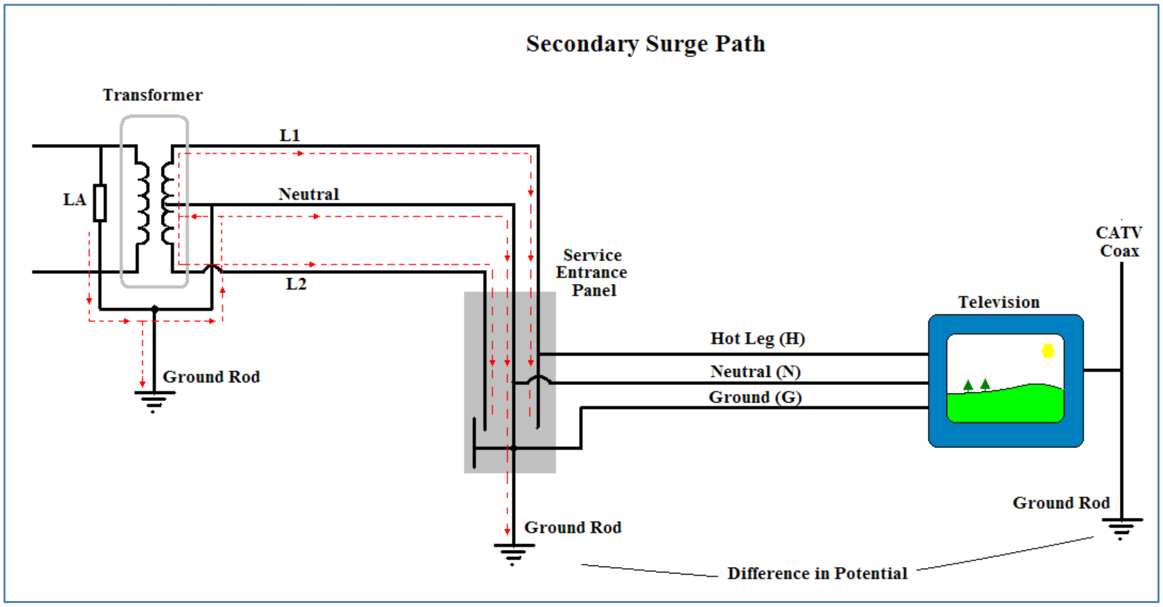


Figure 9

Current flowing into the service entrance raises the ground potential at the service entrance as well at other locations in the circuit branches. The surge will cause the voltage to rise in all conductors including the hot leg, neutral, and the ground conductor.

If another, isolated ground is present a potential difference will occur that may damage sensitive electronic equipment.

In Figure 9 a television is connected on the load side of the service entrance panel and is also connected to a cable TV coax cable that has its own ground. Since the CATV ground is not connected to the service entrance ground a voltage difference develops across the television and depending on the magnitude of the voltage difference may damage the television. If the CATV coax is tied to the service entrance ground the likelihood of a voltage difference appearing between the power supply conductors and the coax is greatly reduced.

Chapter 3
Surge Protection Devices

The purpose of *Surge Protection Devices* (SPDs), which are also known as *Transient Voltage Surge Suppression* (TVSS) devices is to reduce the magnitude of surges to a level that the device being protected can withstand. SPDs do not necessarily eliminate the surge or reduce it to zero – they just attempt to limit the surge to some pre-defined value. SPDs can be used to protect just about any type of electrical circuit including power circuits, data networks, telephone circuits, and cable TV. SPDs can also reduce noise in an electrical circuit. It is important to recognize what SPDs cannot do. SPDs cannot eliminate the effects of sags and swells in the voltage and they do not reduce the effects of harmonic distortion. They also cannot reduce power bills by reducing noise on the electrical circuit.

Transient Voltage Surge Suppression manufacturers use the terms *modes of measurement* when defining the characteristics of their protective devices. Considering a standard three-wire, 120-volt electrical circuit in the United States, the modes of measurement include the normal and the common mode. See Figure 10.

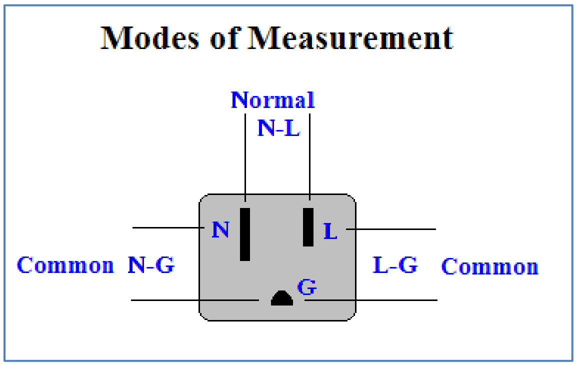


Figure 10

The *normal mode* is from the phase conductor (hot leg) to the neutral conductor and this is sometimes also called the *transverse mode*. The *common mode* includes the phase conductor to the ground conductor and the neutral conductor to the ground conductor.

To protect sensitive electronic equipment SPDs must offer protection for all modes.

SPD Characteristics

In its simplest form, SPDs are a device that acts as a pressure relief device and shunts excessive current to ground to prevent potentially damaging voltages from appearing across the equipment being protected. Figure 11 shows a very simple protective device, which is wired in parallel with the equipment being protected.

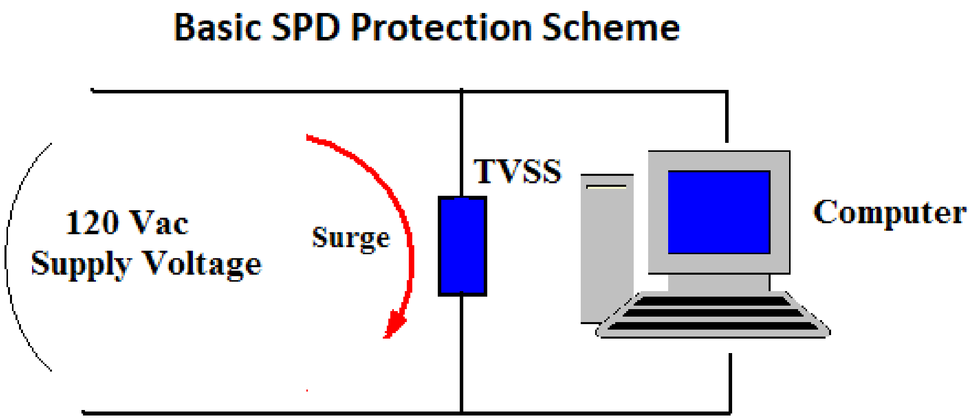


Figure 11

The SPDs in Figure 11 is a variable resistor that appears as an almost infinite resistance at normal load levels. However, as the voltage across the resistor increases due to a transient condition the variable resistor changes resistance and begins to conductor, shunting a portion of the transient current to ground. The voltage across the equipment then becomes a function of the magnitude of the current flowing through the device and the resistance of the device. As this process implies, the higher the current, the higher the voltage that will be present across the device and the equipment the device is protecting. Therefore, manufacturers specify the voltage limit at a given transient current. For currents above this level, the device will not maintain the voltage at the specified limit.

The voltage limit is called the *clamping voltage* and is the maximum voltage the device will allow across its terminals at a given current. Figure 12 shows typical MOV and SAD varistor clamping voltages versus current applied.

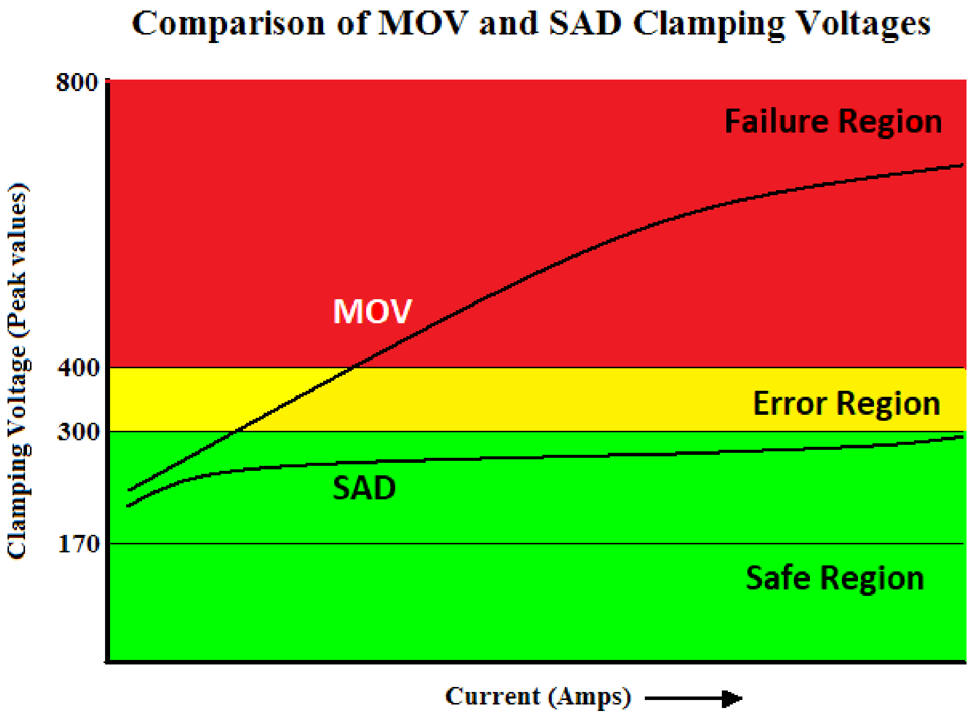


Figure 12

As you can see from Figure 12 the voltage across the MOV increases, albeit non-linearly, as the applied current increases and at some current level the voltage across the MOV rises to an unacceptable level. For most consumer electronics 300 volts is commonly given as the maximum allowable peak voltage across the device. Depending on the electronic equipment at a voltage of between 300-400 volts (peak-to-peak) the equipment may malfunction or even fail and above 400 volts peak, the equipment most likely will fail. Manufacturers typically list the clamping voltage of their MOV devices, but it is obvious from Figure 12 that an MOV does not really clamp the voltage at any given value. In comparison to the MOV, a Silicon Avalanche Diode will do a much better job of "clamping" the voltage to an acceptable level.

In addition to the clamping voltage, another consideration is the *total energy dissipation* capability of the device. This is generally reported in Joules. The energy dissipation capability is important – and generally the larger the number the better – but the standards do not define how manufacturers should report this value and it is not consistently applied from one manufacturer to the next. For instance, the most important issue with energy dissipation is the capability of the device per phase or per mode, however some manufacturers report the total energy dissipation from all three modes, which will overstate the actual capability of the device. Another factor to consider is what voltage level is used to define the energy dissipation characteristic? It should be the energy dissipation at the stated clamping voltage, but again, the UL and IEEE standards do not address the energy dissipation.

A better measure of SPDs performance than total energy dissipation is the maximum surge current capability of the device. The *maximum surge current* is maximum current the device can withstand without damage to the SPD itself. This does not mean that the clamping voltage will be maintained at the maximum surge current – just that the device will not self-destruct.

The maximum continuous operating voltage (MCOV) is another item to consider with MOV type arresters. For surge arresters the MCOV should be at least 125% of the nominal voltage where the unit is applied. For SPD the MCOV is generally just slightly greater than the nominal operating voltage.

Some manufacturers list the *response time* of their SPDs. The response time is the time required for the device to begin conducting and shunting the transient to ground. From a practical standpoint this is not relevant since all modern devices have turn on times that are significantly greater than the frequency response of the systems where they are applied.

Clamping voltage is perhaps the most important characteristic to consider when selecting a SPDs. Other important features include surge current capability, filtering, fusing, and failure alarms.

Types of Surge Protection Devices (SPDs)

Most SPDs made today employ either *metal oxide varistors* (MOV's) or silicon avalanche diodes (SAD's). MOV's are by far the most common type of varistor used in SPDs. Other devices include gas tubes, LCR filters, and hybrids.

Metal Oxide Varistors (MOV's) are non-linear resistors where the resistance of the device changes based on the voltage applied. They are ceramic semiconductors and they do not conduct electricity until the voltage across the semiconductor exceeds a certain level. The voltage level at which an MOV will conduct is a function of the chemical make up of the MOV and the thickness of the device. The energy rating is determined by the density of the material in the MOV and the area of the MOV. The voltage-current relationship in an MOV is non-linear, so at some point an increasing current will cause a disproportionate increase in voltage. The advantages of MOV's are that they have high energy capability, they are reliable, and they are consistent in their operating characteristics. Disadvantages include their non-linear characteristic, susceptibility to conducting due to temporary overvoltages, and potential failure at higher currents. They also will degrade overtime due to exposure to repeated surges. The most common MOV material is zinc oxide with a small amount of other metal oxides included such as cobalt or manganese.

Silicon Avalanche Diodes (SAD's) have a flatter clamping curve than MOV's, are reliable, and offer consistent performance. They do not have very high energy dissipation capability though and are more expensive than MOV's. SAD's will perform consistently for years provided the device's amperage rating is not exceeded. As the name implies, SAD's are made from silicon (with some exceptions).

Gas tubes have higher energy capability than either MOV's or SAD's but are more expensive. They tend to be unpredictable and do not provide consistent operation. Gas tubes are frequently used in data line and telephone applications.

An LCR filter is not really a SPD but it can be used in combination with other devices to offer a superior SPD. An LCR filter includes inductors and capacitors to provide excellent noise attenuation and predictability. They are expensive and have low energy capability.

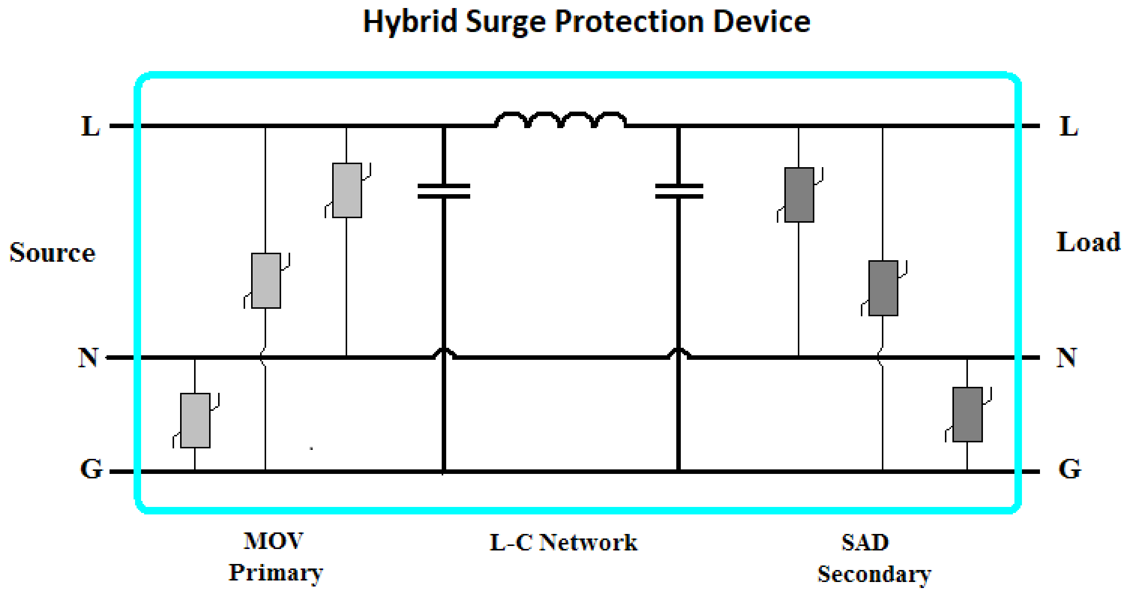
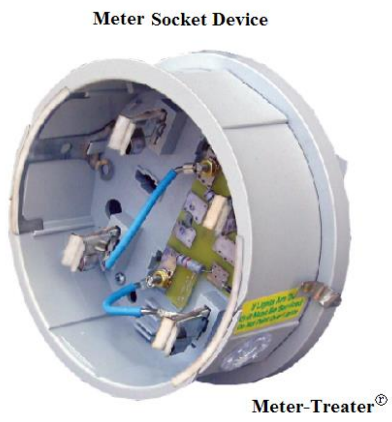


Figure 13

Figure 13 above is a hybrid SPD. A Hybrid SPDs can offer the best of all devices. Some hybrid designs include MOV's on the front end for their high energy capability, and LCR filter for noise, and SAD's on the back end to provide a superior clamping voltage. Hybrids are naturally more expensive than other SPDs products. With a hybrid device, the MOV's take the initial brunt of the surge protecting the SAD's from potentially damaging currents. The MOV's are not well suited to clamping the voltage, but the SAD's can consistently clamp the voltage at the design limit. The LCR network helps reduce ring waves and other noise on the circuit.



Transient Voltage Surge Suppressors are classified for use in either data circuits or power circuits. For either application manufacturers make devices that are meant to be used for service entrance locations, point-of-use locations, and internal to the device. For instance, for a power circuit, the service entrance device may be in a collar that is inserted between the meter base and the meter. One such device is made by Meter Treater® and must be installed by the local electric utility. The adjacent photograph is of a Meter Treater® installation. Their website is www.metertreater.com.

Point-of-use devices include plug strips, wired-in devices, and plug-in devices. A typical point-of-use device is shown on the right. In this photo the device is protecting a computer, computer, monitor, and DSL modem. Notice the incoming phone line and outgoing phone lines on the side of the device.

The photo on the left is of a typical MOV that is wired into a circuit board in a product for protection.

Another consideration is whether the SPDs is wired in parallel or series. For most residential applications the devices are wired in parallel to the equipment being protected. Series units have inductors in series with the power leads and can reduce transients to very low levels. The disadvantage to series SPDs is that they must be sized to handle to expected load current, which increases the cost of the device.

Chapter 4
Standards

Several nationally recognized standards refer to Surge Protective Devices. The most important standards are probably IEEE C62, UL 1449, and the National Electric Code®. Other relevant standards include ANSI and ITIC.

IEEE C62.41

The IEEE C62.41 standard defines the waveforms to consider for SPDs. The standard refers to the 8x20 current wave and 1.2x50 voltage wave previously mentioned as well as the standard ring wave.

The standard also defines the operating environment categories for SPD equipment. The categories are designated as A, B, and C. UL 1449 uses a similar categorization designated as Types 1, 2, and 3.

Category C (Type 1) - Permanently connected device that is installed either before or after the service disconnect overcurrent device and intended to be installed without an external overcurrent protective device.

Category B (Type 2) - This category includes an SPD installed after the service disconnect overcurrent device and is used to protect heavy appliance outlets and other connected loads such as a stove or water heater.

Category A (Type 3) - The final category is for point-of-use devices (e.g., “surge strips”) that are connected at least 30 feet from the service entrance disconnect. Type 3 device may be cord connected, direct plug-in, and receptacle type SPD’s.

See Figure 14 for a graphic of the categories.

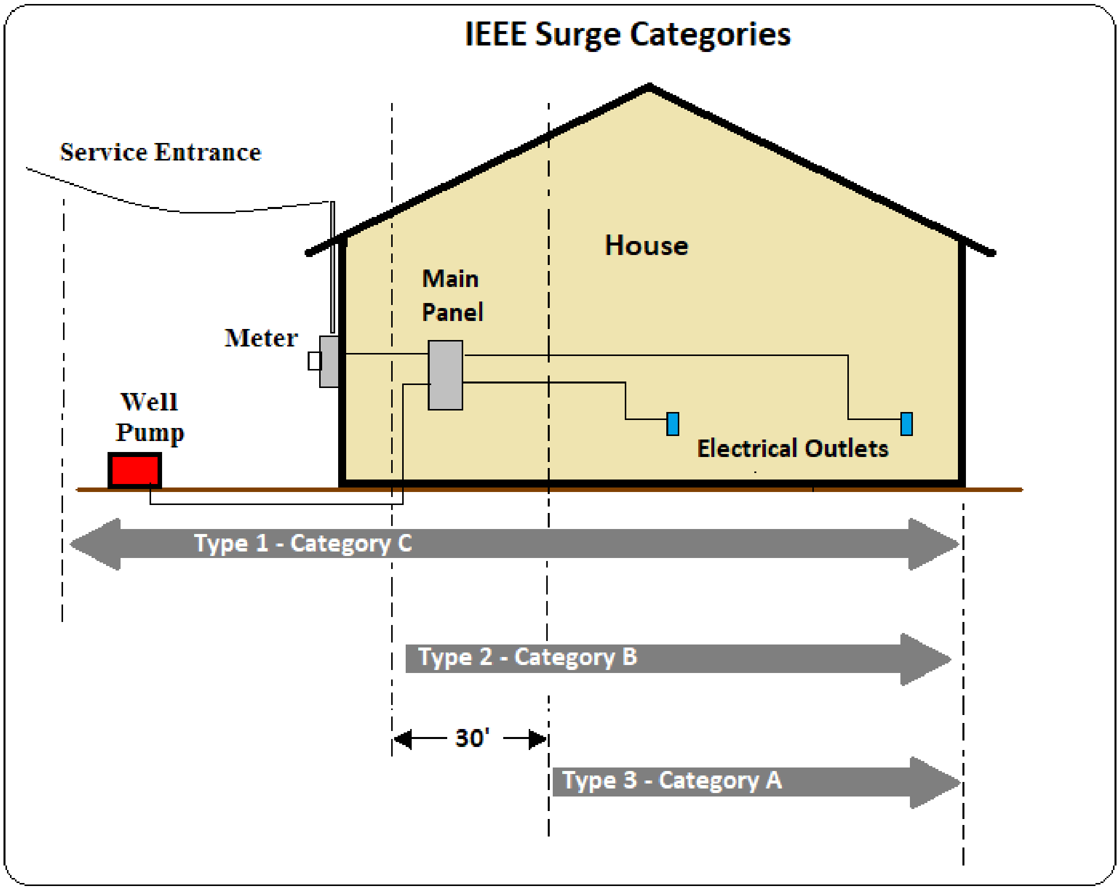


Figure 14

IEEE C62.41 also defines, for test purposes, the expected severity of transients that within each of the category areas. The standard sets three levels of exposure in each of the areas. The following table has the criteria for each category.

Table 1

IEEE C62.41 Expected Voltage and Current Surges

0.5-100 kHz Ring Wave All Modes					8x20 current wave and 1.2x50 voltage wave All Modes				
Location Category	**Exposure**	**Voltage (kV)**	**Current (Amps)**	**Imp (Ohms)**	**Location Category**	**Exposure**	**Voltage (kV)**	**Current (kA)**	**Imp. (Ohms)**
A1	Low	2	70	30	B1	Low	2	1	2
A2	Medium	4	130	30	B2	Medium	4	2	2
A3	High	6	200	30	B3	High	6	3	2

B1	Low	2	70	12	C1	Low	6	3	2
B2	Medium	4	330	12	C2	Medium	10	5	2
B3	High	6	500	12	C3	High	20	10	2

As you can see from the table, the ring wave form is only applied to category "A" and "B" locations. The 8x20 current waveform and the 1.2x50 voltage waveform are applied in both category "B" and "C" locations, but not in category "A" locations.

UL 1449

The Underwriters Laboratory (UL) standard number 1449 formally adopted the waveform tests of IEEE C62.41. This standard contains requirements for SPDs including permanently connected, cord-connected, and plug-in devices of up to 600-volts. It is intended for load side devices only and does not pertain to SPDs on the line side of the disconnect device.

In addition to the expected standard safety tests required by UL, this standard also has a requirement that the suppressed voltage capability of the unit be tested and published. Based on these tests the voltage suppression capability of the unit is assigned a voltage rating that is the *next highest* standard value from Table 2.

Table 2 **Suppressed Voltage Ratings** **Volts Peak-Peak**		
330	900	2,500
400	1,000	3,000
500	1,200	4,000
600	1,500	5,000
700	1,800	6,000
800	2,000	

Therefore, a unit that has a test suppression value of 380 volts will be classified as a 400-volt unit.

The units are also subjected to a maximum surge current test. Panel units and receptacle units must withstand 10,000 amps at 6 kV. Strip units and plug-in devices must be capable of withstanding 3,000 amps at 6 kV. Furthermore, series operated units must have an available fault current withstand rating, or *Amps Interrupting Current* (AIC), but parallel operated units are not required to have an AIC rating.

One word of caution, many plug-in strips will only have a UL-1363 rating. This is not a UL endorsement of the units' transient suppression capability, but just an assurance that the unit meets the UL safety standards.

CBEMA Curve

Some surge device manufacturers will say in their literature that their device protects equipment per the "CBEMA Curve". The Information Technology Industry Council (ITIC), www.itic.org, publishes a specification for the acceptable operating voltage ranges for electronic equipment. The specification is commonly referred to as the "CBEMA Curve" because the organization was previously known as the Computer and Business Equipment Manufacturer's Association (CBEMA). Figure15, shows the voltage specifications of the CBEMA Curve.

The CBEMA Curve is applicable to 120-volt systems and describes both transient and steady-state conditions. The specifications are based on RMS voltage values rather than peak values, which usually describe transient conditions. The curve has time, in milliseconds, along the x-axis and voltage, in percent of nominal RMS, along the y-axis. The CBEMA curve defines seven operating regions for electrical equipment plus two other regions where the equipment may either be damaged or operate incorrectly. The regions are,

- Operating Regions
    - Steady-State
    - Voltage swell
    - Low frequency ringwave
    - High-frequency impulse
    - Voltage sag 1
    - Voltage sag 2
    - Dropout
- No Damage Region
- Prohibited Region

The normal operating region of the CBEMA Curve is shown in light blue in Figure 15. The *steady-state* region includes an area between 90 and 110% of the nominal RMS voltage where the voltage can vary between these values for an indefinite time.

The *voltage swell* region is a transient condition of up to 120% of the nominal RMS voltage for no more than one-half second. The *low frequency ringwave* region is includes an area from

200% of nominal peak voltage for up to one millisecond for a 5 kHz ringwave or up to 140% of the nominal peak voltage for up to three milliseconds for a 200 kHz ringwave. The high-frequency impulse region is for a transient of up to one millisecond in duration and is defined by both the amplitude and energy component of the transient.

Voltage sag 1 allows the RMS voltage to drop down to 80% of the nominal RMS voltage for up to 10 seconds (10,000 milliseconds). *Voltage sag 2* allows the voltage to drop down to 70% of the nominal RMS voltage for up to one-half second.

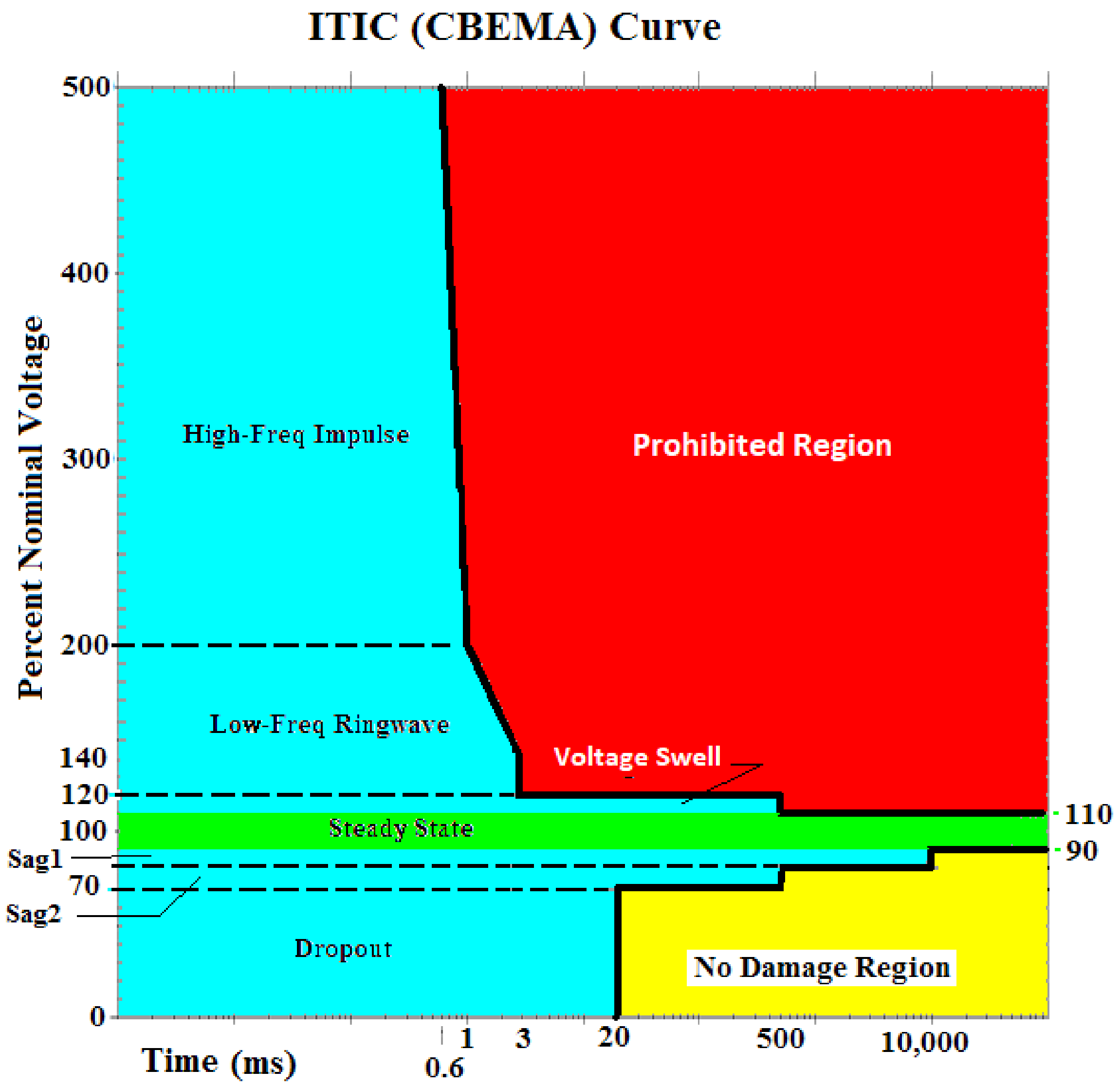


Figure 15

The *dropout* region is any voltage below 70% of the nominal RMS voltage for up to 20 milliseconds. Beyond 20 milliseconds, the curve defines the *no damage* region where the equipment is not required to operate correctly, but no damage should occur to the equipment for operation in this region.

The final area is the prohibited region where operation is likely to cause damage and mis-operation of the equipment.

ANSI Standard

Another standard that references operating voltages for electrical equipment is the American National Standards Institute (ANSI) standard C84.1, American National Standards for Electric Power Systems and Equipment – Voltage Ratings. This standard defines the acceptable voltage levels at the service entrance and at the point of utilization. This standard is for steady-state values and is not applicable to transients. The standard also specifies a larger bandwidth for temporary voltages that may occur during the normal course of operating an electric system. Figure 16 shows the standard graphically.

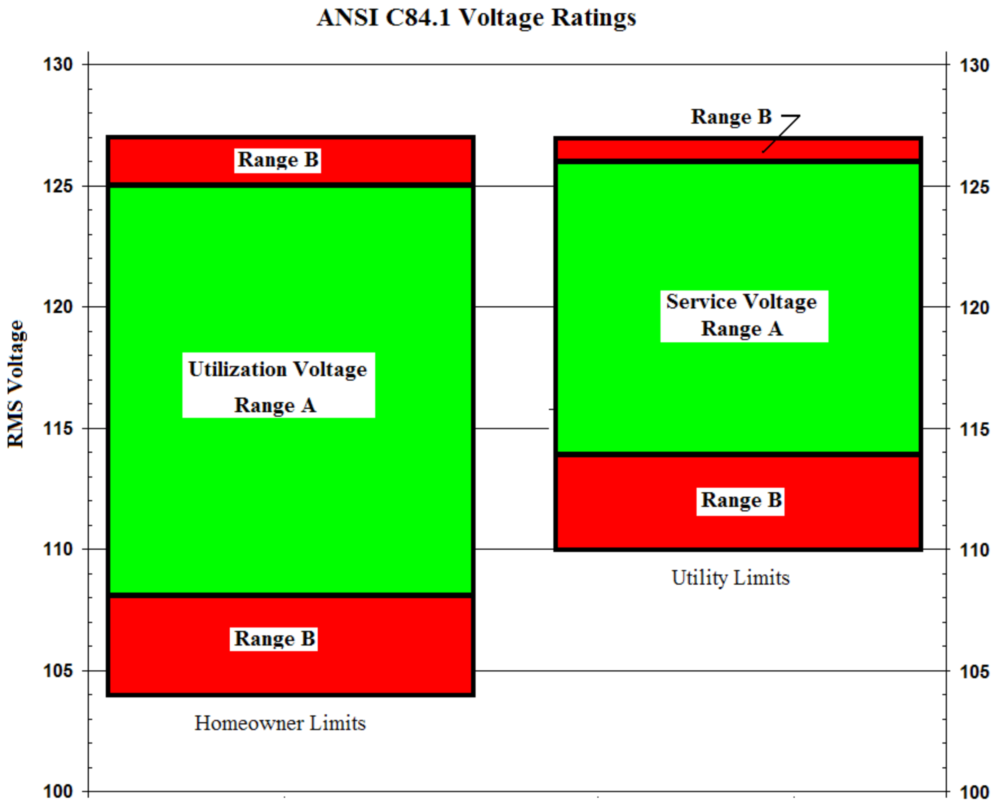


Figure 16

The normal range is known as Range "A" and for temporary conditions it is Range "B". A utility may provide a voltage profile in Range "B", but if the Range "B" profile persists; the utility should take corrective action and there is not a time frame defined for improving the voltage profile. The voltage at the point of utilization may also be out of the Range "A" limits and may require the homeowner to take corrective action to operate with the Range "A" limits.

The service voltage (from the utility) should normally be in Range "A", which is between 114 and 126 volts for a 120-volt nominal system. Range "B" is 110 to 127 volts. At the point of utilization, the Range "A" values should be between 108 and 125 volts and for Range "B" it should be between 104 and 127 volts.

National Electric Code (NEC®)

There are two articles in the National Electric Code (NEC®) that address surge protection devices. Article 280 concerns surge arresters and article 285 covers transient voltage surge suppressors. According to Article 280 of the NEC® a surge arrester is a device that is connected at the service entrance before the main overcurrent protective device and is intended to protect the system from lightning surges. Article 285 defines transient voltage surge suppressors as devices of less than 600-volts that are applied on the load side of the main overcurrent protective device.

For either a surge arrester of less than 600-volts or a SPD the Code says the device must,

- Have a voltage rating of at least the maximum continuous phase-to-ground voltage.
- Be a listed device.
- Have the short circuit current rating marked on the device.
- Not be installed at a location where the available short circuit current exceeds the rating of the device.

The Code says the device may be connected between any two conductors including,

- Ungrounded conductors.
- An ungrounded conductor and a grounded conductor.
- An ungrounded and a grounding conductor.
- A grounded conductor and a grounding conductor.

Note: Article 250 of the NEC® makes a distinction among the three types of ground conductors. The *grounding electrode conductor* connects the neutral of the power system to earth via a grounding electrode (such as a ground rod). The *grounded conductor* is a current carrying conductor that is grounded such as the neutral in a 120/240-volt system, or the white wire in a typical residential wiring application. The *grounding conductor* is the green or bare wire in a typical residential wiring application.

The Code specifies that the grounded conductor and the grounding conductor can only be connected together during the operation of the surge device.

Poor grounding affects the proper operation of surge equipment and contributes to equipment damage. The NEC® says that resistance of a driven ground rod should be less than twenty-five (25) ohms for most applications.

A ground rod driven into the earth of uniform resistivity conducts current in all directions. As the distance from the electrode increases, the impact of the earth's resistance decreases. At a distance approximately equal to the depth of the electrode, the Earth does not create additional resistance to the electrode. Therefore, a distance equal to the depth of the electrode is known as the "Effective Resistance Area".

The majority of ground rods installed consists of a single electrode, driven vertically into the earth. The ground resistance with a single rod is dependent on the soil resistivity, rod length, and the rod diameter.

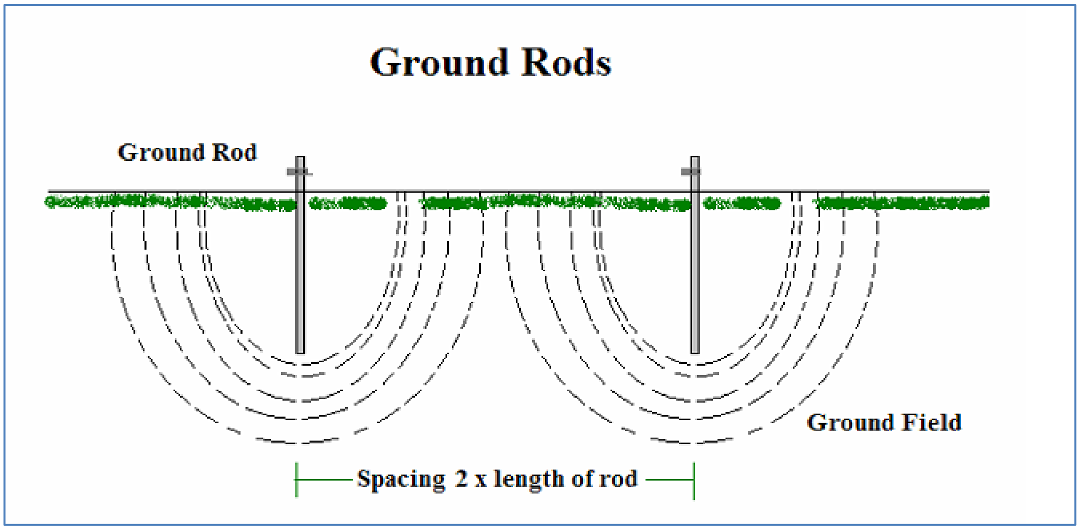


Figure 17

When multiple rods are installed, they should be separated by a distance equal to the twice the length of the rods to prevent the additional rods from encroaching on the effective resistance area of the other rod. Figure 17 shows the ground field surrounding a ground rod.

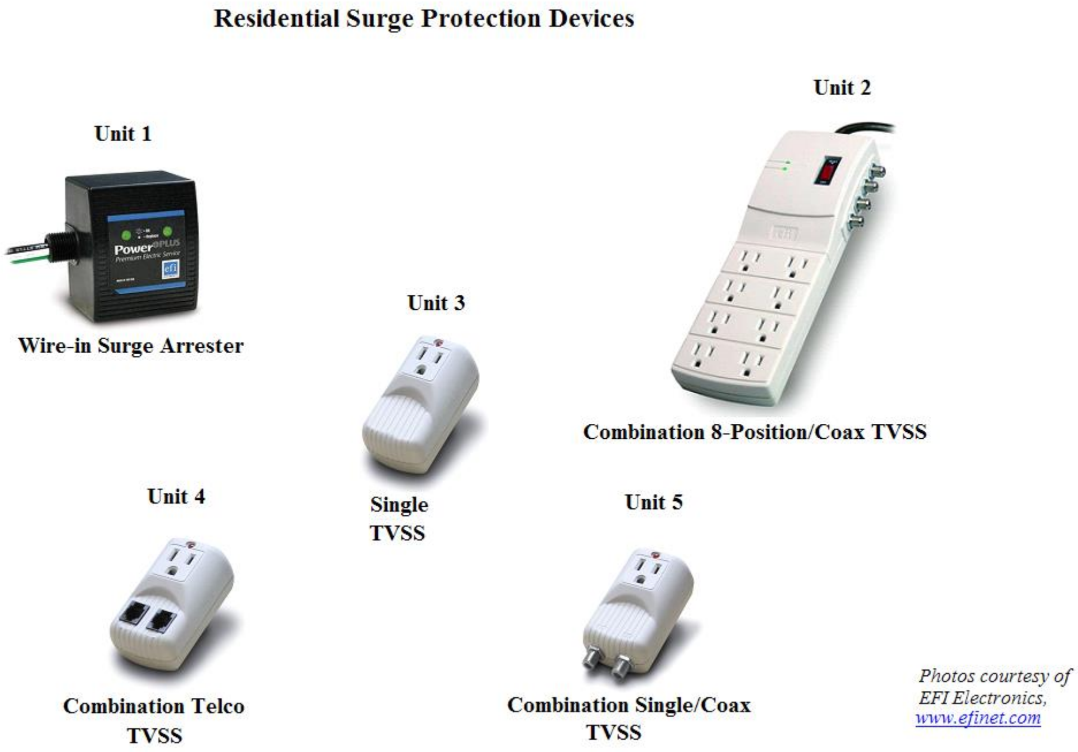
Soil resistivity has the greatest impact on the performance of a grounding system. In fact, soil resistivity is the key factor that determines what the resistance of a grounding electrode will be, and to what depth it must be driven to obtain low ground resistance.

Soil moisture, soil mineral content and temperature all affect earth resistivity.

The most common grounding system consists of just one ground electrode connected to the electric system. When one rod will not yield the desired ground resistance, multiple rods must be installed. Installing two or more electrodes in parallel is an effective method of reducing ground resistance. Multiple rods can be installed in a straight line or in some form of circle, triangle, or rectangle and connected by a bare copper wire. The specific geometric pattern is unimportant provided the proper spacing is maintained between the rods.

Chapter 5
Applications

The following is a simple example of applying overvoltage protection in a typical residential application. There a many different approaches to protecting equipment and this is just one example. Figure 18 shows a surge arrester and four SPDs that are likely to be found in a residential application.



Photos courtesy of EFI Electronics, www.efinet.com

Figure 18

The devices in Figure 18 include a wire-in surge arrester that is suitable for Class C applications. The other four units are SPDs and include: Unit #2 an 8-outlet/coax combination unit, Unit #3 a single outlet unit, Unit #4 a combination outlet/telco unit, and Unit #5 a single outlet/coax combination unit.

Table 3 has representative values for the electrical characteristics of these devices (These values do not necessarily represent the true characteristics of the actual devices shown in Figure 18 – they are representative for illustrative purposes only.) Let’s look briefly at Table 3 before continuing.

From Table 3 we see that all five of the units provide both normal (L-N) and common (L-G, N-G) mode protection. The maximum continuous overvoltage level for all five units is above the expected operating voltage of 127 volts or less (see Figure 16).

Units #2 through #5 have a clamping voltage of 330 volts, which should be adequate for most consumer electronic equipment.

Notice that Units #2 through #5 list the energy dissipation in Joules. With previously mentioned caveats about energy dissipation, 700 Joules of energy dissipation at the clamping voltage for the normal mode is generally considered adequate, so each of these units offers reasonable energy dissipation. More importantly, each of the units have superb surge current withstand capability with the lowest rating being 34,000 amps.

Table 3

Surge Device Specifications

(Representative values)

Specification		**Unit 1**	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**
Protected Modes		L-N L-G N-G	L-N L-G N-G	L-N L-G N-G	L-N L-G N-G	L-N L-G N-G
MCOV		180v	130v	130v	130v	130v
Category	A3 200A	710v	NR	NR	NR	NR
	B3 500A	780v				
	C1 3,000A	820v				
Clamping Voltage		NR	330v	330v	330v	330v
Energy Dissipation (Joules)		NR	960/mode	720/mode	720/mode	720/mode
Maximum Surge Current		100kA	54kA	34kA	34kA	34kA

Note: “NR” means the value is not reported by the manufacturer.

Look at Figure 19 for an example of the application of these devices to a residence. There are eight locations in this residence where (the author believes) surge equipment should be installed. For each of the locations noted in Figure 19, one of the units in Figure 18 and Table 3 can be used for protection.

A rule of thumb for residential protection is that a three-pronged attack should be used to address surge protection. This approach includes grounding, service entrance protection, and point of use protection.

The first step is to ensure that a proper ground exists. The utility ground, telephone ground, and cable TV grounds should be interconnected, and the grounding should be 25 ohms or less at the service entrance.

The next step is to install a surge arrester at the utility service entrance as the first line of defense against lightning surges and to protect “white” appliances such as refrigerators, washing machines, ovens, and air-conditioners.

The final step is to install point-of-use protection at equipment with electronics such as televisions, computers, and telephone answering machines.

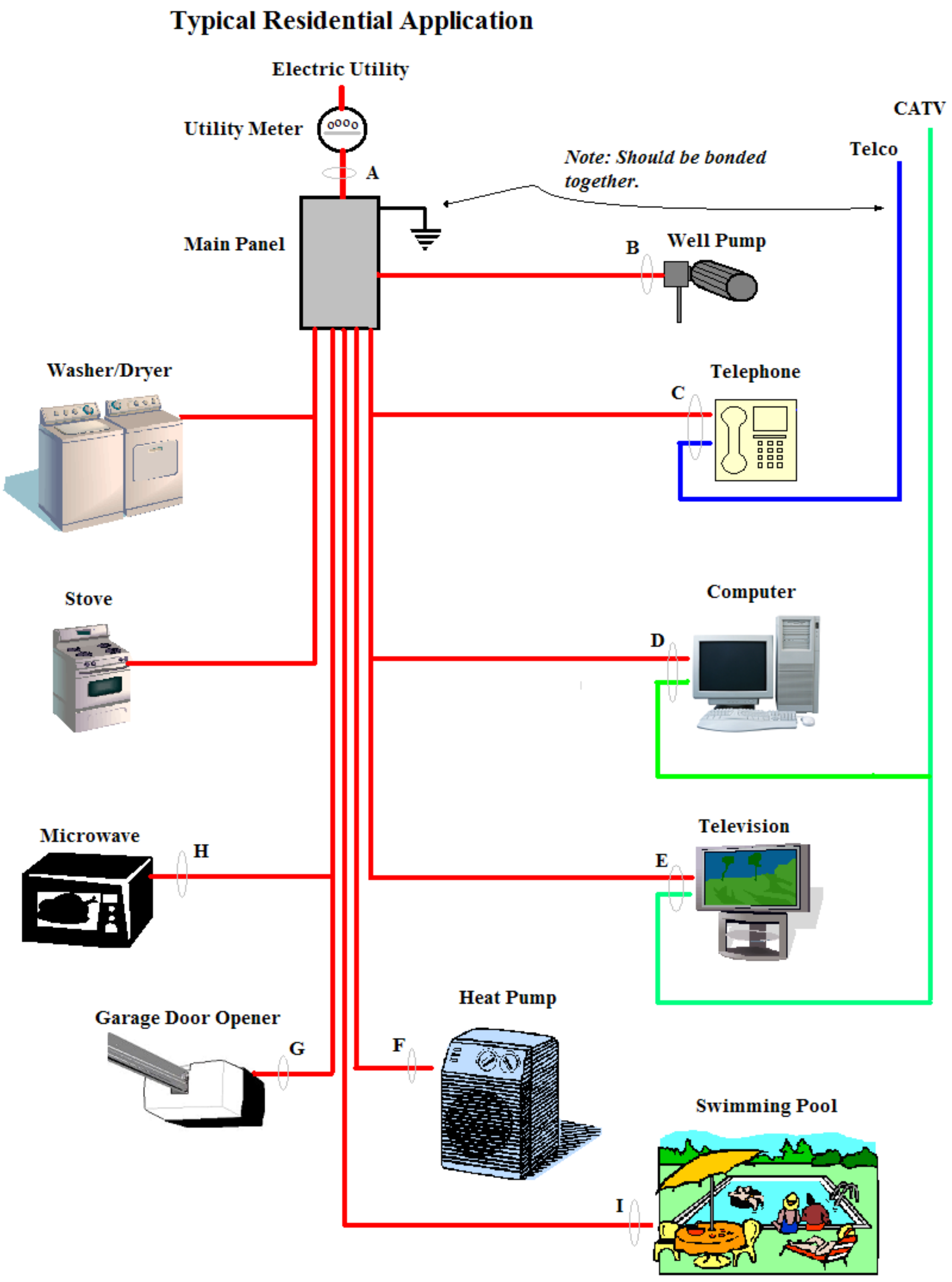

Typical Residential Application
Electric Utility
Utility Meter
A
Main Panel
Note: Should be bonded together.
CATV
Telco
B
Well Pump
Washer/Dryer
Telephone
C
Stove
Computer
D
Microwave
H
Television
E
Garage Door Opener
G
Heat Pump
F
Swimming Pool
I

Figure 19

Location A. The first location is at the main panel. At this location a utility collar surge arrester such as a Metertreater® can be used or a wire-in unit can be installed in the main panel such as Unit #1 in Figure 18. This unit should have a maximum surge current rating of at least 25,000 amps. Unit #1 is rated for a service entrance location (Category "C") and will limit the overvoltage to 820 volts for a 3,000 amp surge, which should be sufficient to protect "white" appliances and prevent outlets from sparking over to ground. Furthermore, Unit #1 has an outstanding 100,000 amp surge withstand capability.

Location B. Normally a pump would not require further protection, but well pumps are usually some distance from the house and by their nature are a separate ground, which can set up a difference of potential that may damage the pump. A well pump should be protected by a surge arrester like Unit #1.

Location C. A digital phone/answering machine is easily damaged due to the difference of potential between the power side and telephone side of the device. A telephone should be protected with a SPD like Unit #4.

Location D. A computer will most likely have both a power connection and a telephone or cable TV connection to the Internet. In this example, the computer has a cable modem, so a SPD similar to Unit #2 will provide an adequate number of outlets for the computer peripherals (remember all of the computer equipment should be plugged into the same outlet to minimize ground potential differences) and connections for the cable modem. If the computer uses a DSL modem, then a Unit #4 device can be plugged into the Unit #2 SPD or a special 8-outlet/telephone combination SPD can be used.

Location E. Like the computer, a Unit #2 device will protect the television and its peripherals such as a VCR or DVD player.

Location F. An argument can be made that a heat pump does not need any additional protection beyond the service entrance surge arrester, but a heat pump is generally located a significant distance from the main panel, it has some electronics, and the compressor is very expensive to replace. For these reasons, a Unit #1 surge arrester is a good investment for a heat pump.

Location G & H. Garage door openers and microwaves are frequently damaged by lightning surges due to the electronics in the devices. A Unit #3 SPD is suitable for these applications.

Location I. A pool pump is like a well pump in that it is remote from the main panel surge arrester. Also, the NEC requires a driven ground at the pool pump for safety, but this naturally allows a difference of potential to develop between the service and separate ground. A surge arrester such as Unit #1 is also a good investment for a swimming pool pump.

The protection scheme described above should provide a reasonable level of protection for a typical residential application. Remember the three-step approach to protection: Grounding, service entrance, and point-of-use protection.

Summary

Every year thousands of dollars of consumer equipment are damaged from surges. Not only is sensitive electronic equipment at peril, but common appliances such as microwaves, heat pumps, garage door openers, and well pumps are frequently destroyed by surges.

While transient conditions that damage equipment are hard to quantify, manufacturers have agreed on a common set of standards to test the capability of their protective devices. Adherence to standards such as UL 1449 may give consumers some comfort that the surge protection device will provide a quantified level of protection.

Protecting electrical equipment in a residential application involves ensuring that a proper grounding system is in place and that service entrance protection is provided as well as individual protection at each point-of-use. Lastly, consumers need to understand that surge protection involves a degree of luck, because the magnitude of some surges is so severe that no amount of surge protection will protect the equipment.

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