Did a Power Surge 'Fry' Your Equipment?

A Rare and Candid Look at Equipment Damage, Power Quality, and Responsibility

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Introduction
The term 'surge' or 'power surge' existed long before the power quality industry exploded on the scene in the 1980's. Since that time, power quality professionals have made tremendous strides in the education process. Technology has enabled the routine capture of power disturbances in actual onsite conditions that were previously rarely ever seen. Surge suppressors are available in every size, shape, and color. So it is a paradox that the 'power surge' continues to be one of the most misused and misunderstood of all power quality terms. This is particularly true of homeowners and the service/repair industry. Surges are routinely blamed for any and every failure of equipment ranging from motors to consumer electronics.

This paper will address the power surge, its cause and effect, in both technical and everyday layman terms. Observations will be based on the author's experience of six years as an electronic technician, 15 years as a power quality engineer, which includes seven years of specifying surge protection and eight years of investigating damage claims. It will discuss some things rarely if ever discussed in public, namely, the relative frequency that surges appear to cause equipment damage compared to other power quality disturbances. It will include a candid look at cases that evaluate the effectiveness of surge protection. It hopes to make some practical sense out of a topic that often dances on the floor of confusion.

Know What to Expect
Before we deal with power disturbances that are abnormal, it is helpful to know what is normal. After monitoring the power quality at hundreds of commercial/industrial sites since 1987, the data gathered during times when things are working properly has proved helpful. Likewise, bank tellers are trained to know a real $20 bill so well that counterfeits are easier to detect.

Let us start with the understanding of nominal voltage. The nominal voltage is considered the rated transformer voltage and therefore the delivery voltage to the customer's point of service. ANSI C84.1-1989 lists the handful of standard nominal voltages used by electric utilities in the U.S. The document recommends a preferred tolerance of the average steady-state voltage to be within a range of ±5% of nominal (between 0.95 p.u. and 1.05 p.u.). A wider tolerance with a range of ±6%, -8% may be acceptable.

The term 'per unit' (p.u.) is used to indicate a percent of the nominal voltage. The table below summarizes these tolerances for a common commercial facility served by 208Y/120 V, and for a typical residence served by 120/240V.
<table>
<thead>
<tr>
<th>Nominal Voltage (rms)</th>
<th>Preferred Range</th>
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<tr>
<td></td>
<td>Maximum</td>
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<td></td>
<td>Service Point</td>
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<tr>
<td>208Y/120</td>
<td>218Y/126</td>
<td>197Y/114</td>
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<tr>
<td>120/240</td>
<td>126/252</td>
<td>114/228</td>
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**Case Study.**

When 'smart homes' were making the rounds at state fairs about 15 years ago, there was a problem getting all the electronics gadgets and controls working properly. With the first day of the fair approaching, pressure was on to find the problem. Circuit boards were replaced regularly as they suffered mysterious failure. Even with new equipment, operation was still erratic. About the fifth day of the fair, I went to visit this not so smart home. I asked what input voltage was required. I was told, "120/208 volts". Even though they wanted me to install a state-of-the-art power disturbance analyzer, I first asked to borrow a rather inexpensive voltmeter. I was surprised to find the voltage to be approximately 120/240 volts. I checked the small step-down transformer serving the home. It was rated 120/240 and doing exactly as it was supposed to do. Once the correct delivery voltage was supplied, everything ran great.

In my Air Force troubleshooting classes, we were taught that we were ALWAYS to check the incoming voltage first. Be careful not to take the voltage for granted, especially in a new installation; or with a new piece of equipment. The equipment rating must match the nominal voltage range. The nominal voltages in ANSI C84-1 are not just for electric suppliers; they are to be used by equipment manufacturers who design consumer appliances. For example, a TV has a nameplate voltage such that it should be able to plug into any standard household receptacle in the U.S. However, it is uncertain what the operating range of the TV may be. And it is very difficult to know what the voltage limits are before damage occurs. We will attempt to address this later.

There are plenty of other examples of equipment damage simply due to mismatched voltages. The foodservice industry has many types of cooking equipment that can be ordered to operate at either 208 volts or 240 volts. It is not uncommon for a new oven to be delivered, rated at 208 volts when the restaurant is served 240 volts, or vice versa. The funny thing is that the tolerance range of the supply and the equipment could overlap such that the equipment may actually work. As the two ranges get farther apart, the oven may not cook properly or digital components may be damaged.
Know the Common Terms
When dealing directly with customers, it is crucial to make sure that all parties are using the same terms for the event being described. Based on our experience, it seems that about 90% of residential and commercial electric consumers will use the term 'surge' to describe every type of power disturbance known (and some unknown).

This is sometimes difficult to overcome, especially when you really want to use plain language. It will confound the average customer when you tell them that the Institute of Electrical and Electronic Engineers (IEEE) put 'power surge', 'surge', and 'spike' on a list of terms to be avoided. This was done precisely because of the ambiguity of these terms. It should come as no surprise that many people who wrestle with power quality problems today have not read the IEEE Emerald Book. What was once only the concern of high-tech firms, hospitals, manufacturing, etc. is now the concern of anyone who uses a computer or buys a stereo system. There is still a tremendous education barrier when it comes to power quality and the average consumer.

Some definitions of 'surge' include:
IEEE C62.41-1991, Surge Protection
'surge' -- a transient wave of current, potential, or power in an electric circuit.
IEEE Std 1100-1999, Powering and Grounding Electronic Equipment (Emerald Book)
'surge' -- see 'transient'
'transient' -- a subcycle disturbance in the ac waveform that is evidenced by a sharp, brief discontinuity of the waveform.
Webster's New World Dictionary
'surge' -- 3. a sudden, sharp increase in electric current or voltage in a circuit

We will use the IEEE Recommended Practice for Monitoring Power Quality, Std. 1159-1995 for our definitions and characteristics of "typical" power system phenomena. They correlate to the Emerald Book and other power quality documents. We will save surge for last.

Long-term (greater than one minute) rms voltage variations of less than 0.9 p.u. are undervoltages; likewise those that are greater than 1.1 p.u. are overvoltages.

The case of the smart home and the restaurant oven may not be considered power quality problems as much as they would be called carelessness or negligence. But using power quality terms, they would be cases of a sustained overvoltage or undervoltage rather than surges. Surge suppression would not have corrected this problem. But who gets the blame--the 'power surge', because the technician wrote on his repair ticket "damage due to power surge".

Although the term 'power surge' does not inherently dictate origin, it appears natural to assume that all power surges come from the power company. We will see that this is part of the confusion.

Short-term (0.5 cycle to one minute) rms voltage variations between 0.1-0.9 p.u. are voltage sags; whereas, those greater than 1.1 p.u. are voltage swells. They will be described in terms of the minimum or maximum voltage measured during the event, as a percent of nominal, or p.u.
An interruption is the complete loss of voltage (less than 0.1 p.u.) and can be divided by duration. **Momentary interruptions** are those less than 3 seconds in duration; **temporary interruptions** are those between 3 seconds and 1 minute; while **sustained interruptions** are those with durations of greater than 1 minute.

Finally, since 'surge' is ambiguous, the term 'transient' is used in the power quality world. A **transient** is a very short duration, typically sub-cycle, event that can be either impulsive or oscillatory. They are typically described as some sort of discontinuity of the waveform, and either add or subtract energy. Some power monitors may use the term 'impulse.' But the rest of the world will simply label them as 'surges' or 'spikes'. A better term may be **transient voltage surge**, TVS. This would make a direct link between this type of disturbance and the transient voltage surge suppressor, or **TVSS**, which is used to mitigate such an event. TVSS are better known as surge suppressors. A more recent term in some technical documents is surge protective device, or **SPD**.

The following figures depict various transient surges.

Figure 1 (top) and Figure 2 (bottom) are the same transient surge due to switching on of a nearby load, most likely air conditioning.
Figure 3 (top) and Figure 4 (bottom) depict the same transient surge, due to the operation of milling equipment.

The transient surges pictured above represent the vast majority of such disturbances in that they originate from electrical loads switching on and/or off. They are found in industrial, commercial, and residential electrical environments. We could just have easily depicted transient surges from a home's electric can opener. Are transients common? Yes. Are they damaging? This is more difficult. On the surface they seem to cause no harm. They can be recorded day and night in practically every location.

**Key Elements Contributing to this Paper**
Much has been published about the types of disturbances, their typical causes and typical impact on equipment. Very little has been documented regarding equipment damages. Some of the conclusions from past studies of monitoring utility distribution systems include: swells are very rare, sags are the most common power disturbance, and that transient surges are primarily from lightning and capacitor switching. Studies of monitoring installed within facilities further indicate that many if not most transients originate within the facility due to equipment switching.
Key inputs driving the observations and conclusions in this paper are:

1. Monitoring database. OG&E Electric Services has had permanent voltage recording at service entrances of 37 commercial/industrial sites for a total of over 1000 site-months. Data confirms that voltage sags are by far the most common type of disturbance. Although sags vary according to depth and duration, it can be stated that in general they do not cause damage. This is good since they are so common. They do have some other detrimental effects such as shutting down process-controllers and costing industry billions of dollars a year. OG&E has also performed hundreds of short-term power quality audits for every class of customer.

Besides sags, many momentary interruptions have been captured. Their occurrence will vary according to location but they are also considered common. There are thousands of momentary interruptions in a given year over the entire OG&E system. Again the impact is shutdown of industry and loss of product and profit. What about damages?

2. Damage claims database. For the past eight years, OG&E has centralized its damage claim department under the power quality functions. This has led to some enlightening observations. Some may be subjective; some are inconclusive for reasons that will become obvious. For the first seven years of our power quality program, monitoring and investigations focused only on commercial/industrial customers. Damage claims due to power quality events were practically nonexistent. Since over 90% of damage claims come from the residential segment, it opened a new arena of discovery.

3. TVSS performance information. Another key factor leading to this paper is the fact that OG&E has leased whole house and device TVSS to residential customers for the past eight years. This program is also in close contact with the power quality department. So feedback from dissatisfied customers is filtered through the eyes of power quality. Customers are motivated to provide feedback because the program provides insurance coverage of damaged equipment.

Barriers to Sound Conclusions
There will be some gaps in the conclusions based on:

1. Monitors are not located at residences when damage occurs.
2. Customers do not report satisfactory performance of TVSS. Naturally, if the devices are working, the user does not typically know it. They only know if the devices do not work when they think they should have, such as during a thunderstorm.
3. Conventional theory about transient surges says that transients may disrupt, decay, or destroy electronic components. This evidence only deals with equipment reportedly damaged. It cannot confirm nor deny the possible degradation of electronic components over time due to transient surges.
**Damage Cause Category**

The damages included in this material are those involving electrical/mechanical/electronic equipment. In other words, it does not include things like fence damage, food spoilage, etc. Primary causes of damages reported are listed in order beginning with the most common.

1. Open Neutral
2. Utility Equipment Failure
3. Negligence
4. Nature

This next list arranges the primary causes according to dollar loss, beginning with the most costly.

1. Open Neutral
2. Negligence
3. Utility Equipment Failure
4. Nature

**Open Neutral**

This condition has received virtually no national attention, but it can literally ruin almost every appliance in the home. It occurs almost exclusively on residential 120/240V systems. The electric service includes two 'hot' legs, L1 and L2, and a neutral, N. Either hot leg and neutral provide 120V power to the home. Power for 240V equipment, typically air conditioners and clothes dryers, is obtained between L1 and L2.

The neutral is grounded at the utility transformer and again at the service entrance. The National Electrical Code®, NEC®, identifies this as the grounded conductor since it is required to be grounded to the grounding electrode (i.e. ground rod) via the grounding electrode conductor (GEC).

When this connection becomes loose, voltages in the house may fluctuate up and down depending on the balance of load between the two phases. They are rarely balanced. When a customer reports that their lights are "bright and dim", it is almost a sure sign that the neutral is loose. Sometimes the neutral connection is totally broken. This may happen over time due to a tree limb rubbing through it or corrosion in the connector. It can happen abruptly due to heavy icing or a large branch falling on the conductor.

This condition can subject your 120V electrical equipment to voltage fluctuations between zero and 240V. In PQ terms, this is NOT a surge; it is an overvoltage. Most TVSS are as helpless in this condition as the appliance itself. Some TVSS literally explode, emitting smoke and flames. This can be even more dangerous than the overvoltage itself. Cases have occurred where carpet and wallpaper has been ruined because the fire department was called to put out a fire in the TVSS.

Some TVSS actually sacrifice themselves and at least protect downstream equipment. Most TVSS utilize metal oxide varistors (MOV) for clamping transients. The TVSS has a clamping voltage based on peak voltage for milliseconds. But MOVs also have a maximum continuous
operating voltage (MCOV). This is the RMS voltage that it can safely operate. It is typically 130Vrms or 150Vrms. The MOV may survive if the overvoltage is short-lived; however, every half cycle as it conducts trying to clamp what it thinks is only a transient, it heats up. Eventually thermal runaway leads to abrupt failure. If the TVSS is good enough to have a thermal fuse it can prevent the catastrophic failure of the MOV.

Unfortunately the whole house meter socket TVSS allows the overvoltage into the house distribution wiring and directly to anything plugged in.

There are other factors that make this condition more or less severe, such as impedance of the wiring, the quality of the grounding, and the balance of loads at that moment.

**Case Study.**

A homeowner wonders why the lights are getting bright and dim, so he calls an electrician. The electrician bills the homeowner for a service call to tell him that it is the utility's problem. He measures voltage at the panel before leaving - 135V on L1 and 105V on L2. At this time no electronics are damaged. By the time the utility serviceman arrives, something in the back of the TV has "popped" and it no longer works. The voltage is now 90V on L1 and 150V on L2. The serviceman replaces the connections at the transformer and voltage is back to 120V on both L1 and L2. Now the cordless phone is found to be inoperative and the new oven with the digital control board will not work. A neighbor who is served by the same transformer has no damage. Another neighbor on that transformer discovers the next day that the microwave oven and the VCR will not operate. This is just one example of the strange effect that a loose neutral can have on different homes and different appliances. They do not all respond the same way to the same conditions. In reality they may not even all experience the exact same conditions due to variations within each home.

**Utility Equipment Failure**

For years power quality professionals have touted the importance of checking internal wiring and grounding as a key to resolving sticky power quality problems. One reason this is recommended is that loose connections have been found to be a common problem in distribution systems. This is still true today because the laws of thermodynamics are still active. Things tend to go from order to disorder, from good to bad, from shiny to rusty, and from tight to loose. This is equally true for electrical connections on the utility system. They are really mechanical connections that someday will become loose. We have already mentioned the problem with the neutral.

Other connections may become loose as well. The hot conductor and its connections may deteriorate or be broken. Thousands of connections sit through extreme temperatures season after season and a percentage will loosen through thermal cycling. Lightning strikes conductors, insulators, poles, transformers, and even underground facilities. Ice storms literally weigh poles down to the point of breaking. If it doesn't cause a failure initially, then it can certainly advance its deterioration.
Very few damage claims are received due to the ordinary operation of the utility system. Switching is constantly going on, capacitors by the thousands switch daily or seasonally, and even outages occur due to failed equipment almost daily. Most of the time there is no report of damage. Yet it is typically when a transformer fails violently, or a fuse blows, or an underground cable fails that can lead to damage. A rare but destructive mode of failure is when the conductors of one voltage falls into the conductors of a different voltage. This is proportionately worse the higher the voltage.

**Case Study.**
A crossarm for a 34.5 kV distribution system broke and the conductors fell into the 2400 V system that was built on the same structure. Even with fault relays on the utility side, the damage was immediate and broad. The damage was to electronic equipment in nearby businesses exceeded $50,000. Damage occurred on electronics whether it had TVSS or not, and surge suppressors were damaged as well.

**Negligence**
This was meant to be a candid and honest look at the types of events that lead to damaged electrical equipment. Even though it is desired that mistakes are never made, they are. We could report about such things as transformers being installed with the wrong voltage. What did we say at the beginning of this paper? Always check the power supply first. Yet occasionally someone will replace a transformer and make it hot before checking the output voltage. Applying 480V to a residence with 120V equipment is not good.

**Case Study.**
A utility crew arrives at the worksite to replace a failed transformer. The new transformer came from stock and was loaded onto the truck by a new employee. The crew makes the connections and energizes the transformers. As they prepare to leave, someone is running out of a nearby home stating that the TV is "fried" and smoking, lamps have exploded, and the refrigerator is making a "funny noise". A crewmember checks the voltage serving the house and to his shock finds that it is 240/480V rather than the expected 120/240V. They immediately pull the meter and pull the fuses to the transformer. Unfortunately the damage has already been done, not only to that home but also to five other homes. Each customer owns four TVs, five VCRs, expensive stereos, computers, etc. It is an expensive mistake. Is this considered a surge? Although it could be rightly labeled another case of overvoltage, the term power surge just got a big boost.

**Nature**
People buy TVSS for various reasons. They may live in a lightning prone area, such as Oklahoma. They may have been sold TVSS at the time they purchased a computer. They may just be afraid of damage to the new TV or stereo because they have heard bad stories about power surges. It still seems that lightning is the best reason to invest in TVSS. There are close to 10,000 customers with whole house surge protection. Most of them are satisfied, but a few are not. Here is why:
**Case Studies.**
1. Central heat and air system damaged during a storm.
2. Solid-state board in heating unit failed during lightning.
3. Phones, TVs, VCRs, and computers damaged during severe lightning.
4. TV quit working even though there was no storm.
5. Computer printer damaged about the time of thunderstorm.

All of the above cases had whole house surge protection; some also had individual devices. Did a surge come into the home from the utility system? None of the surge protectors were damaged so the manufacturer denied the claim. Can things other than "surges" cause damage? The answer is "yes"!

1. During any storm and even in good weather, it is not uncommon for the power to go off and on, as in a momentary interruption. This is due to normal fault-clearing breakers and reclosing devices designed into the utility system for decades. If an air-conditioner, or heat pump is running when the power goes off, it should have a time delay relay to prevent the compressor from coming on right away. If not, it is possible that high head pressure in the compressor could lead to premature failure and burnout. This happens on a regular basis. It was not a 'Voltage surge' but a 'current surge' in the equipment itself that caused the damage. Nine times out of ten the HVAC technician will tell the customer that he had a "big" power surge.

2. Lightning struck the vent pipe on the roof of the house, traveled to the heating unit and found the board. The incoming electrical system was bypassed altogether.

3. In this case, not only did the home have TVSS at the service entrance, but every piece of electronics was individually protected, including the modem and telephone ports. Proper grounding was in place. Lightning struck the chimney of the neighbor just a few feet away. The most likely answer is that the nearby electromagnetic pulse coupled into the power and data lines, bypassing all of the protection.

4. Sometimes things just break for no apparent reason. Possible reason include poor quality product, abuse of product, faulty wiring, degradation due to transient surges over time, etc. Big screen TVs seem to be vulnerable to a momentary interruption some of the time.

5. Although there were many electronic appliances in the office, only one of several printers failed. It happened to be plugged into a standby power supply (SPS). Transient surges are commonly recorded on the output of some SPS whenever they internally switch to battery. It is difficult to say with certainty why some things fail, but circumstantial evidence can be very helpful in eliminating certain suspects.

**A Word About Responsibility**
All players may share some responsibility for ensuring power quality in the residential and small commercial segment. Certainly the providing utility has responsibility to strive to maintain the steady-state voltage within acceptable limits. If negligence directly caused the event and it led to equipment damage, then it is reasonable to expect compensation. Every utility will treat these cases according to their own guidelines as well as those directed by regulatory bodies.
The homeowner has ultimate responsibility for his/her equipment. They must recognize that not all equipment is built to the same level of quality. Some equipment survives a "normal" event whereas others do not. Some equipment is built to be serviced. Some electronics are built to be disposable. They need to recognize that poor and inadequate wiring and grounding may contribute to damage risk. Consumers should purchase quality TVSS from manufacturers that stand behind the product.

The TVSS industry has made some attempts in recent years to distinguish good products from bad, and best from good. However, the problem of overvoltages must be addressed.

There is shared responsibility by manufacturers of electronics who design and build appliances that are too susceptible to voltage variations that may be considered normal.

Homebuilders, electricians, and both HVAC and electronic technicians all need to become more educated and involved in providing quality services and products to consumers.

**Summary and Conclusions**

The first and easiest conclusion to draw at this point is that technicians and consumers will continue to use the term 'surge' for any and every power disturbance if they are dealing with damaged equipment. This term seems to best describe what has happened.

The second conclusion is that 'surge suppressors' do not guard against all types of power disturbances. So there is a false sense of security as well as expectations. Those who market TVSS need to be careful and truthful. There are still consumers who think a TVSS will keep their computer running during a momentary interruption because they are trained to describe the event as a power surge.

TVSS vary widely in quality and response. UL 1449 has helped those with quality products to prove it, but most consumers do not look for the UL 1449 label. The consumer is at a great disadvantage to really evaluate TVSS. It is recommended that TVSS fail in a safe mode and protect equipment from overvoltages as well as transient surges.

We conclude that low-level low-energy transient voltage surges are fairly common in every electrical environment due to capacitive and inductive load switching. Although somewhat inconclusive they do not appear to be a big concern on a day-to-day basis. Transients from utility capacitors rarely show up in a facility. The most common source of damaging transient surges in Oklahoma County is lightning, with an average of nearly 18,000 strikes per year (flash density of 8-16/km/year). Yet there are still unknowns. Lightning detection data has helped to correlate lightning to immediate damages. There are questions about the long-term impact of transients. Obviously the magnitude and the frequency of occurrence play a role. Bottom line ends up with the same conclusion: it is prudent to protect electronics with some type of TVSS.

Another conclusion is that various types of power events besides transients may lead to electronic damage. Events such as 'open neutrals' and utility equipment failure, though fairly uncommon, may happen anywhere and anytime, and can be very destructive. Insurance
companies may or may not cover such losses, which could easily range from $1500+ on average, depending on the quality and quantity of electronic gadgets in the home. Even momentary interruptions may result in damage to a very small percent of electronics.

We conclude, not surprisingly, that electronic equipment varies in quality and in response to power disturbances. They could be better designed. By that, we do not mean installing a 130Vrms MOV on a circuit board in an oven or clothes dryer. A minor overvoltage may blow the MOV, requiring a service call that could cost $200 or more. Manufacturers should be accountable for such mistakes.

Electric utilities provide the most unique service there is--one that travels at nearly the speed of light, one that provides a quality of life unprecedented in the history of mankind, and one that keeps businesses in business, one that is both indispensable yet taken for granted. They need to serve their customers as the power quality professionals and not retreat behind walls due to deregulation and reregulation. One thing is certain--as long as there are power surges, people will assume that they came from the power company, whether they did or not.

References


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