9:00 AM

On 6/10 Dan Casperson and I were out on the sidewalk and Mike Busby came up to us and started talking about the inprovements in the area. He then started talking about the issue at 100. He said that he would of done thing differently. He also stated that he made sure that Paul knew to do it the right way in the future. Meaning shut off the Main Breaker first. He also stated the Insurance would pay any issues that was caused by the single phasing of the Transformer.

Chad Gamester

[signature]

July 05, 2016

Michael Simchik
100 Market Street
Portsmouth, NH 03801

Re: Eversource Issue - Evaluation of Electrical Equipment

Reference (a): The Impact That Voltage Variations Have on AC Induction Motor Performance. By Austin H. Bonnett, Fellow IEEE, Retiredfrom U.S. Electrical Motors, Emerson Motors Rob Boteler, "QS. Electrical Motors, Emerson Motors. From ACEEE Proceedings, 2001

Reference (b): Motor Protection Against Single-Phasing, Copper-Bussman Bulletin PSP

Dear Mr. Simchik,

A site visit was conducted at the 100 Market Street building in Portsmouth, NH, on June 20, 2016. Purpose of the visit was to evaluate possible damage to electrical equipment resulting from the utility company energizing one phase at a time (known as single-phasing) for the entire building, with the building's main circuit breaker in the "on" position.

For the remainder of this letter, the building at 100 Market Street will be referred to as the 100 Building.

Eversource recently installed a new transformer for the 100 Building, across the street from the 100 Building, at the Hanover Street parking garage. Previously, electricity for the 100 Building was supplied from the utility transformer located in a transformer vault in the basement of the 100 Building. That transformer vault is now used as a tie point to wire the new secondary conductors from the new transformer to the existing secondary conductors wired to the main switchgear in the 100 Building.

On June 2, 2016, power was shut-off to the 100 building at 5:10 am and was off for 20 minutes. The temperature during the power outage was in the low 50^0F. During that time the life safety generator for the 100 building energized automatically to provide power to the lighting, fire alarm and elevator circuits. Equipment wire to the generator was not affected by the new transformer providing electricity to the building one phase at a time since they were isolated from this event. None of the air conditioning units were operational during the power outage.

When Eversource energized the new transformer to supply energy to the 100 Building, the main circuit breaker for the 100 Building was left "on". Eversource energized one phase at a time by inserting the fuses into each phase. It took approximately 10 minutes to install the 3 fuses.

When normal power was restored to the building, one phase at a time, the thermostat in the spaces calling for cooling would have tried to start HVAC units serving those spaces, including the roof top air handler unit, the chiller and all the water source heat pumps. Three phase motors protected from phase loss would have shut-off upon sensing lack of all three-phases. Other motors, including pump motors, would have tried to start when two of the phases were energized.

When one-phase of a three-phase motor is energized, and the motor doesn't start, the electrical resistance (impedance) of a stalled motor is considerably less than a rotating motor. This is a result of negative phase sequence components in the voltage. Motors generally have low impedances for negative phase sequence voltage. The distortion in terms of negative phase sequence current will be substantial.

Negative phase sequence currents cause heating of the motor and consequently motor failure. The current flowing, in the remaining winding(s), may increase to 600% of the nameplate rating. These current levels are called "Locked Rotor" current. Winding insulation subjected to locked rotor current may fail in as little as 15 to 90 seconds. The winding insulation damage is permanent and cumulative. Motors that are trying to start under full loads will draw the most current, resulting in more obvious damage quickly. Other motors that are more lightly loaded may draw excessive current (greater than the nameplate rating) but not great enough to show signs of motor damage. However the excessive current, which overheats the windings, cause a breakdown of the wiring insulation, which can greatly reduce the life of the motor.

The following estimates the Voltage Unbalance and the Expected Rise in Heat that occurred due to single-phasing. Calculation is based on Phase A and B energized at 277 VAC each and Phase C at 0 VAC:

Step 1: Add together the three phase to phase voltages:
480 + 277 + 277 = 1034 volts

Step 2: Find the "average" voltage.
1034/3 = 345 volts

Step 3: Subtract the "average" voltage from one of the voltages that will indicate the greatest voltage difference. The result is that the greatest voltage difference is 135 volts
480 – 345 = 135 volts
345 – 277 = 68 volts

Step 4: Determine percent imbalance based on greatest voltage difference:
100 x (greatest voltage difference/average voltage)
= 100 x 135/345 = 39% voltage unbalance

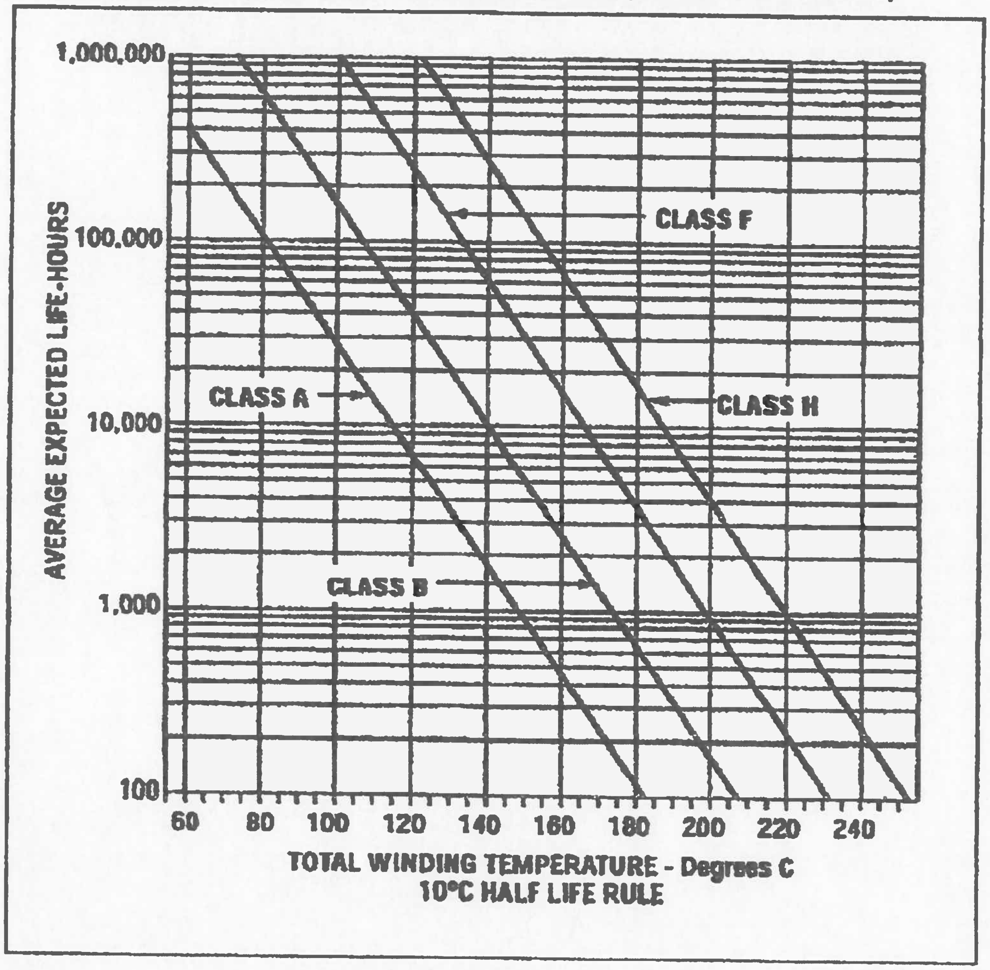
Step 5: Find the expected temperature rise in the phase winding with the highest current by the following equation:
2 x (percent voltage unbalance)^2
=2 x (39)^2 = 3042% temperature rise.

Therefore, for a motor rated with a 60°C rise, the unbalanced voltage condition in the above example will result in a temperature rise in the phase winding with the highest current of:

60°C x 3042% = 1825°C

Figure 1 below provides the means to estimate the impact voltage unbalance has on motor winding insulation life once a temperature change is determined. The Figure shows that for every 10°C increase in winding temperature, the expected thermal life of the winding is reduce by half.

Figure 1.
Temperature vs. Life Curves for Insulation Systems (Per IEEE 117 & IEEE 101)



As can be seen by Figure 1, a change in temperature of 1825°C is off the chart.

The immediate and obvious damage was to the Renzor air handling unit located on top of the roof of the 100 Building. The operating manual within the unit caught fire due to the excessive current in the winding and complete breakdown of the winding insulation in the unit. The cause of the overheating was likely from the 3-phase, 480 Volt motor trying to start on a single phase input, under full load.

The other noticeable occurrence was to the heat pumps located on the 5th floor, in the ceiling. Some of the 50 heat pumps tripped off and had to be manually reset. Not all heat pumps tripped off however, which may indicate there was excessive current in the windings but not enough to trip the unit off-line. However there may have been a sufficient amount of overcurrent to damage the wiring insulation (reducing the life of the motor) but not enough to trip the unit off line.

Other equipment that did not trip off-line but may have winding insulation damage include:

Basement:

Packaged Pumping System, Canaviis Corp, Model DJ-150-33 (480VAC, 3-phase)

Water Pump Motors – Shut down automatically by overload protection

Heat Pump (cover off, wiring exposed)

Well Pump motor, 3/4 hp, 1150 rpm

1st – 4th Floors: Split system AC unit in the spaces (480 VAC, 3-phase)

5th Floor: 50 Heat Pumps, McQuay (480 VAC, 3-phase)

Roof: Chiller, Evapco (480VAC, 3-phase)

Conclusion:

Due to the fire in the air handling unit as a result of energizing the 100 building one phase at a time, it is not unreasonable to expect winding insulation damage occurred to other three-phase motors that were trying to start, reducing their useful life. The heat pumps on the 5th floor that were tripped were obviously trying to start. It is not known how hot and for how long the units became before tripping. As noted above, every 10^0C rise in winding temperature will shorten a motor's life by half. To determine if any damage occurred, recommend performing insulation resistance testing on all motors that may have been affected by single-phasing, in accordance with manufacturer's instructions.

Please let me know if you have any questions.

Sincerely,

Lee D. Consavage

Lee Consavage, PE

August 25, 2016

Michael Simchik
100 Market Street
Portsmouth, NH 03801

Re: Eversource Issue - Evaluation of Damage to Electronic Equipment

Reference (a): IEEE Standard C62.41.1-2002 IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits (Chapter 7)

Reference (b) Interference Technology, Distinguishing between Surge- and Temporary Overvoltage-Related Failures of Metal Oxide Varistors in End-Use Equipment Designs. Authors : Philip F. Keebler, Kermit O. Phipps and Doni Nastasi, 11/22/2006

Dear Mr. Simchik,

A site visit was conducted at the 100 Market Street building in Portsmouth, NH, on June 20, 2016. Purpose of the visit was to evaluate possible damage to electrical equipment resulting from the utility company energizing one phase at a time (known as single-phasing) for the entire building, with the building's main circuit breaker in the "on" position. My first evaluation, which primarily investigated damage to motors, was summarized in a letter to you dated July 5, 2016. This letter evaluates damage to electronic equipment due to the same occurrence.

For the remainder of this letter, the building at 100 Market Street will be referred to as the 100 Building.

Eversource recently installed a new transformer for the 100 Building, across the street from the 100 Building, at the Hanover Street parking garage. Previously, electricity for the 100 Building was supplied from the utility transformer located in a transformer vault in the basement of the 100 Building. That transformer vault is now used as a tie point to wire the new secondary conductors from the new transformer to the existing secondary conductors wired to the main switchgear in the 100 Building.

On June 2, 2016, power was shut-off to the 100 building at 5:10 am and was off for 20 minutes. During that time the life safety generator for the 100 building energized automatically to provide power to the lighting, fire alarm and elevator circuits. Equipment wired to the generator was not affected by the new transformer switchover.

When Eversource energized the new transformer to supply energy to the 100 Building, the main circuit breaker for the 100 Building was left "on". Eversource energized one phase at a time by inserting the fuses into each phase.

When tenants were allowed to enter the building after given the all-clear by the fire department, who were called to extinguish the fire in the air handling unit (see my Letter dated July 5, 2016), it was noted that several electronic systems were severely damaged and not functioning as a direct result of the occurrence earlier that morning.

It is common for overvoltages to occur after a power outage. Eversource's website has a webpage titled:

__Power Outages Do Happen And When They Do, Eversource Works Diligently To Safely And Quickly Restore Our Customers' Power__: Voltage irregularities can occur for any number of reasons during or after a storm, especially if there has been damage on or near your home. The safest thing to do is to unplug any sensitive electrical devices (TV, VCR, stereo, microwave, computer, answering machine, garage door opener, etc.).

Voltage irregularities result from natural and man-made sources, and are typically identified as surges (overvoltage) or sags (undervoltage). For this evaluation my focus is the source and type of overvoltage that may have occurred on June 2nd since that appears to be the cause of damage to the electronic equipment.

Reference (a), paragraph 1.1 includes a Duration of Event graph that identifies the potential damage to equipment based on the type of voltage irregularly. Surges are shown on the left side of the graph as high magnitude but short duration surges that usually do not damage electronic equipment. Temporary Overvoltages (TOVs) are shown on the right side of the graph as being lower magnitude voltage surges but of longer duration that does damage equipment. The Duration of Event graph is included as Figure 1 of this letter and shown below.

Reference (a), Para 7.2.4 provides a list of causes for TOV's, including a single phase fault and loss of a live conductor in a three phase system. The situation that occurred on June 2nd, by Eversource energizing one phase at a time, simulates loss of a live conductor by having less than 3 phases energized. The following is excerpted from Reference (a), Para 7.2.4:

> __7.2.4 TOVs Due To The Loss Of A Live Conductor__
>
> In three-phase systems, loss of any conductor can give rise to various conditions, such as unbalance, faults, and TOVs, which can indirectly result in transients. For example, loss of a neutral conductor in an unbalanced star-connected supply can result in a TOV where two phases attain the phase-to-phase voltage with respect to ground. This can cause a fault and possible transients associated with initiation or clearing of the fault. In that case, it is generally considered that the permanent stress voltage is the line-to-line voltage.

Reference (b) provides a good summary for defining the types of overvoltages and how they affect electronic equipment. In fact Reference (b) was written to provide general information about design protocol when designing protective circuits for electronic equipment to withstand voltage irregularities such as TOVs. Reference (b) is provided for general background information about how TOVs affect electronic equipment.

Figure 1.

Simplified Relationships Among Voltage, Duration, Rate Of Change & Effects On Equipment

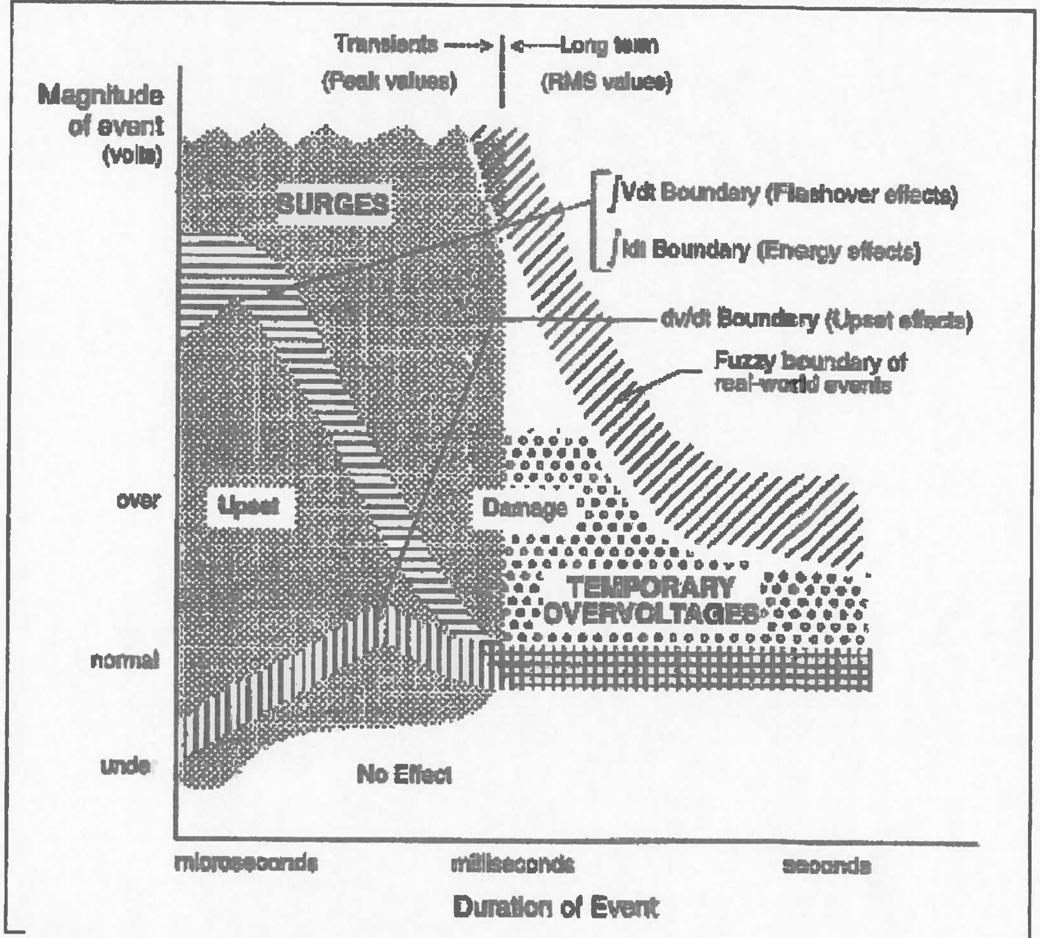


Figure 1 Notes:

1. The graph shows the relative position of effects and the order of magnitude of the amplitude and duration. Do not attempt to read numerical values from this graph.
2. The scope of the guide is shown by the two dot-pattern areas. The fine pattern relates to surges, the prime scope of this guide. The coarse pattern relates to TOVs, the secondary scope of this guide. For surges, the upper limit for the duration is one half-cycle of the applicable power frequency. Swells. overvoltage events longer in duration than a surge, but lasting only a few seconds are considered to be a subset of TOVs.
3. The values or positions of the boundaries between .no effect and .upset and between .upset and damage vary with the withstand characteristics of the equipment exposed to the surges.
4. The boundary between .upset and damage in the microsecond range is shown as the integral of *Vdt* to reflect the upturn in the volt-time characteristic of sparkover. Equipment responses that do not involve a sparkover are more likely to be influenced by the simple magnitude of voltage *V*.
5. This figure shows only one measure of surge severity emphasizing voltage and time relationships. Other possible measures include current peak and duration, rise time, and energy transfer.

Figure 1 above, which was excerpted from Reference (a), defines surges and TOVs graphically on a magnitude-duration plot with respect to the duration of an event (in milliseconds) and the magnitude of an event (in volts). According to these definitions, surges are transients of positive and/or negative polarity with duration less than 1/2 cycle (e.g., a few microseconds to a few milliseconds), and TOVs are positive polarity events of long term duration ranging from seconds to minutes. In Figure 1, the surges cover a wider area on the magnitude-duration plot than TOVs. Surges incident upon end-use equipment (either through the AC power input or through communication or network cables) can damage, upset, or have no effect on equipment. TOVs are only incident upon the AC power input of equipment and typically cause damage to equipment.

Conclusion:

Based on the severe damage that the electronic equipment experienced it is obvious a high impact voltage irregularly occurred. The Figure 1 graph in this letter identifies a TOV as a high impact voltage irregularity that damages equipment. Reference (a) further explains the conditions that may create a TOV, including loss of a phase conductor. In summary, it appears that on the morning of. June 2nd a long duration TOV was created by Eversource while energizing one conductor at a time with the 100 Building's main circuit breaker in the "on" position.

Please let me know if you have any questions.

Sincerely,

Lee D. Consavage

Lee Consavage, PE

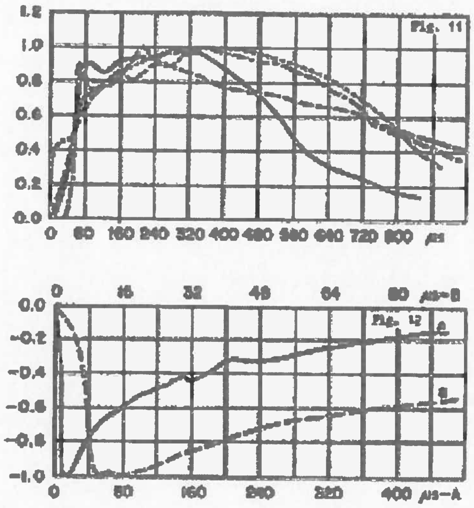


Figure 11
Formes de courant typiques — Impulsions positives
Typical current shapes — positive strokes

Figure 12
Forme de courant moyenne Premières impulsions négatives
A — échelle des temps inférieure B — échelle des temps supérieure
Mean current shape Negative first strokes
A — lower time scale B — upper time scale

Source: Berger et al. 1975 [B54]

Figure 17—Example of lightning current waveforms

7. TOVs

7.1 General

A wide range of phenomena, either resulting from normal system operation or from accidental conditions can produce TOVs, which should be distinguished from the switching surges discussed in 4.3. These overvoltages occur at the power system frequency and generally require operation of some existing protective overcurrent equipment to clear the circuit, should some equipment fail under that stress. Note, however, that equipment is generally designed to withstand TOV stresses. SPDs at the present state of technology—as applied for protection against lightning and switching surges—do not have the energy-handling capability that would be required for limiting these TOVs. Therefore, the following information on TOVs (which might be considered as being outside of the scope of this guide) is presented for consideration in the application of SPDs, a topic addressed in other documents of the IEEE Std C62™ series.

7.2 Magnitude of TOVs due to medium-voltage and low-voltage faults

TOVs can appear in a system following a fault condition. They are, in general, originated by insulation faults or loss of a supply conductor in the medium-voltage or low-voltage electrical installation. Product standards take into account these phenomena by appropriate insulation requirements and tests. IEC 60364-4-442:1999 [B5] provides some information and data, which are summarized here. Additional information is also given in B.9.

NOTE—In systems with medium-voltage and low-voltage lines mounted on the same poles, or systems with two different medium-voltage levels also mounted on the same poles, accidental commingling of the systems can occur, causing substantial overvoltages on the low-voltage system. In the application of SPDs to low-voltage systems, consideration of commingling is generally not included because such accidents are rare. However, if such exceptional events are to be considered, special SPDs need to be applied to survive the event or at least fail in an acceptable manner (Goedde et al. 1999 [B211]).

7.2.1 TOVs due to faults between medium voltage and ground

Depending on the configuration of the grounding of the medium-voltage and low-voltage networks, the medium-voltage fault current flows into one or more ground electrodes and generates ac overvoltages in the low-voltage system by ground coupling.

The main parameters that influence the value and the duration of the overvoltages are listed below. All of these are determined by the designers of the power system, rather than from SPD application considerations.

a) The configuration of the ground electrodes of the medium-voltage and low-voltage network:
   - One, two, or three distinct ground electrodes
   - Common grounding electrodes or separated grounding electrodes for medium-voltage and low-voltage networks
   - The values and the number of ground electrodes of the low-voltage distribution system
b) The type of system grounding of the medium-voltage network:
   - Isolated
   - Resonant-grounded
   - Grounded through an impedance
   - Solidly grounded
c) The method used to clear the medium-voltage fault:
   - Long time for isolated resonant-grounded or impedance-grounded types
   - Short times (< 5 s) for low-impedance grounded types
   - Shorter time for solidly grounded types

TOVs appear at different places and apply in different ways:

- In the medium-voltage/low-voltage substation, the overvoltage stresses the insulation of the low-voltage equipment between live parts and exposed conductive parts if there is no common medium-voltage/low-voltage grounding.
- In multiple-grounded, four-wire systems the TOV that occurs on the medium-voltage side is transformer-coupled to the low-voltage side, resulting in L-L and L-N TOVs.
- In the low-voltage electrical installation, the overvoltage stresses the insulation of low-voltage equipment, between live parts and exposed conductive parts, if the neutral is not connected to the local grounding electrode.
- An overvoltage appears between the local ground of the low-voltage installation and remote ground. That overvoltage can stress, for example, the double insulation of Class II equipment used outside of a building or service entrance, which would not be connected to the main grounding terminal.

7.2.2 TOVs due to a short circuit between line and neutral conductors

After the transient situation, the magnitude of the short-circuit current is limited only by the impedances of the supply and building wiring. The currents involved can be very high, ranging between one hundred and tens of thousands of amperes. A protective device operates to clear the fault. During this period of a few milliseconds to a few hundred milliseconds (but in all cases less than 5 s), a TOV can occur in the unfaulted lines of the affected power circuit. The value of the overvoltage can be calculated from the impedances of the supply and building wiring. The value of 1.45 U_0 (U_0 being the phase-to-neutral voltage) is considered to be a representative upper limit (see IEC 60364-4-442:1999 [B5]).

7.2.3 TOVs due to low-voltage ground faults

After the transient situation, a TOV occurs during such a fault. In power systems generally used in North America, specifically TN systems (see B.9 for a description of the IEC codes IT, TT, and TN), ground faults can produce overvoltages comparable to those occurring in circuits where the fault is between phase and neutral. Indeed, the return path to the neutral of the transformer consists of a cross-section comparable to that of the phase conductors.

7.2.4 TOVs due to the loss of a live conductor

In three-phase systems, loss of any conductor can give rise to various conditions, such as unbalance, faults, and TOVs, which can indirectly result in transients. For example, loss of a neutral conductor in an unbalanced star-connected supply can result in a TOV where two phases attain the phase-to-phase voltage with respect to ground. This can cause a fault and possible transients associated with initiation or clearing of the fault. In that case, it is generally considered that the permanent stress voltage is the line-to-line voltage.

7.3 Probability of occurrence

7.3.1 TOVs due to faults between medium voltage and ground

Medium-voltage ac insulation faults to ground are likely to occur on overhead medium-voltage lines during thunderstorms or due to other incidents. When lightning strikes the medium-voltage system, operation of an SPD located on the medium-voltage side initiates a current flow through the corresponding ground electrode. In some existing networks, SPDs might still be of the air-gap type, and the surge current starts the flow of a medium-voltage fault current at the power frequency, which is not interrupted at the first zero crossing. The same chain of events unfolds in case of an insulator flashover. Medium-voltage system configurations are well-defined so that their ground-fault currents can be predicted by calculation even though they vary depending on the location of the ground fault.

If SPDs are installed on the medium-voltage side, close to an medium-voltage/low-voltage substation, they normally decrease the number of ground faults. The current flow through the SPD to ground is restricted to a short surge if the surge arrester is of the metal-oxide type. In case of gapped arresters, a short-duration ac current follows. In case of gaps alone, an ac follow-current occurs, to be cleared by the medium-voltage protective devices after a duration that depends on the type of device used.

Finally, the immunity specification of an item that is likely to be subjected to TOVs depends on its mode of application. An SPD, for instance, is permanently energized, whereas, at the lower end of the severity scale, a portable tool is connected to the low-voltage system only for a very short fraction of its life time; in the latter case, the probability of coincidence with an medium-voltage ground fault in the substation is then extremely low and the immunity specification is likely to be correspondingly low.

7.3.2 TOVs due to faults in the low-voltage installation

The likelihood of low-voltage insulation faults cannot be neglected in normal installations. The possibilities of faulted conditions increase in older installations and equipment that are not properly maintained or are exposed to hazardous or polluted environments. Generally, insulation faults are more likely to occur between active conductors and grounded conductive parts than between the active conductors considered hereafter. The effects of these ground faults (voltage drops and in particular overvoltages) affect the SPDs. These effects are determined by the location of the fault and, in the case of a fault to ground in TT systems, the impedance to earth of the ground electrodes.

If the SPD has been selected with a maximum continuous operating voltage (MCOV) lower than the overvoltage generated by the low-voltage insulation failures or the loss of a supply conductor, the current flowing through the SPD increases very quickly and thermal destruction of the SPD occurs. The effects of this failure might be limited to the SPD if appropriate coordinated thermal protection is incorporated. This SPD failure can then leave the installation or equipment without other overvoltage protection.

For the remaining cases, when the possibility of a loss of surge protection is deemed acceptable, other risks have to remain covered; in particular, an appropriate protection against short-circuits should be specified by the manufacturer and requested by the end-user.

Concerning the loss of the neutral conductor, the overvoltage is independent of the grounding system, but can reach values close to three times the phase to phase voltage in a three-phase system, applied between line conductors. The overvoltage can reach twice the phase-to-phase voltage in a single-phase, three-wire system whenever the loads in each side of the neutral are not balanced; this overvoltage is then applied across an SPD intended for surge protection of loads connected line to neutral. In the case of the loss of the neutral conductor, damage to the SPDs might be a small event in comparison with the damages suffered by other equipment in the installation, as long as the SPD failure occurs in an acceptable mode, for instance, by appropriate thermal protection.

7.4 TOVs' impact on SPDs

TOVs are a type of abnormal event that is difficult to prevent—if not impossible—in the normal course of operation of a power system. The probability of such occurrence and the levels of overvoltages that can be reached depend on the design of the power system. This design is generally determined by overriding system constraints other than the consequences of applying a TOV to an SPD.

Therefore, SPDs have to suffer the consequences of a TOV, and various scenarios are possible, ranging from an SPD selected with a high MCOV that will make it immune to most TOVs (but at the price of diminished surge protection) down to a low MCOV selected by a wish to provide surge protection with low limiting voltage for loads perceived as needing such low limiting voltage, but at a greater risk of destruction under TOVs (Martzloff and Leedy 1989 [B219]).

8. Development of recommended selection of representative surges

The database summarized in Clause 6, along with anecdotal information, illustrates the wide variety of surges that can be expected to occur in low-voltage ac power systems. Evaluation of the ability of equipment to withstand these surges, or of the performance of SPDs in dealing with this variety of surges, can be facilitated by a reduction of the database to a few representative stresses. It is unnecessary and not cost-effective to subject equipment to surges that would duplicate field-measured surges, since these measurements are site dependent and are likely to change with time.

The reduction process should lead to selecting a few representative surges that will make subsequent laboratory tests uniform, meaningful, and reproducible. Since the environment is subject to change both for the better and the worse, it would be prudent to use these representative surges as a baseline environment. However, this simplification should not bar any user from performing evaluations for different surge environment conditions if knowledge is available for a particular environment (over a sufficient period of time, such as one or more years) and the requirements warrant the cost and effort of additional tests.

A combination in the selection of location category and exposure level, as proposed in this guide and further defined in the companion recommended practice IEEE Std C62.41.2-2002, will then provide the appropriate degree of compromise between a conservative overdesign and a cost-conscious reduction of margins.

To assist equipment designers and users in making appropriate choices, a companion recommended practice, IEEE Std C62.41.2-2002, IEEE Recommended Practice on Characterization of Surges in Low-Voltage AC Power Circuits, has been developed on the basis of the surge environment described in this guide. A second companion recommended practice, IEEE Std C62.45-2002, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits, has also been developed to provide recommendations for performing surge tests that yield reliable results and enhance operator safety.

http://www.interferencetechnology.com/distinguishing-between-surge-and-temporary-overvoltage-related-failures-of-metal-oxide-varistors-in-end-use-equipment-designs/

Distinguishing between Surge- and Temporary Overvoltage-Related Failures of Metal Oxide Varistors in End-Use Equipment Designs

Author : Philip F. Keebler, Kermit O. Phipps and Doni Nastasi
11/22/2006

Equipment failure resulting from TOVs can be reduced by proper coordination of the line fuse and MOV.

Philip F. Keebler, Kermit O. Phipps and Doni Nastasi
EPRI Solutions
Knoxville, Texas, USA

Real world electrical environments in residential, commercial, and industrial facilities experience the gamut of undervoltage and overvoltage disturbances. Examples of undervoltage disturbances include voltage sags, momentary interruptions, and long-term undervoltages. Examples of overvoltage disturbances include surges and temporary overvoltages (TOVs). There are also a number of surge sub-categories—ring wave surges and combination wave surges, for example. Ring wave surges typically do not cause damage to line fuses and metal oxide varistors (MOVs). The combination wave surge, on the other hand, typically does cause line fuse and MOV damage and failure in end-use equipment. MOVs are designed to dissipate the energy that results from a surge voltage. This energy is a product of the clamping voltage and the resulting flow of surge current when the MOV clamps the surge voltage. With proper coordination of the line fuse and MOV, equipment can be protected from multiple ring wave and combination wave surges of less than 4,000 volts. MOVs are not designed to protect equipment from TOVs, but equipment failure resulting from short duration and lower magnitude TOVs may be reduced by proper coordination of the line fuse and MOV. This article first discusses the industry standard definitions for a surge and a TOV and describes the basic overcurrent and overvoltage protection circuits used in end-use equipment. Next, the article describes some characteristics of real MOV failures caused by surges and TOVs and provides some brief discussion on the coordination of line fuses and MOVs. Finally, the article presents a basic approach for determining how a line fuse and MOV will react to surges and TOVs, followed by actual test data. This information can be useful to equipment designers in determining the cause of line fuse and MOV failures and in sizing the line fuse and MOV to provide adequate protection against surges and thus reduce nuisance equipment failures that can drive up the cost of repairs and warranty claims.

WHAT IS A SURGE VERSUS A TEMPORARY OVERVOLTAGE?

Because TOVs and surges are both overvoltages and can cause damage to equipment, beginning equipment designers just becoming familiar with the different types of overvoltage electrical disturbances in the areas of power quality and system compatibility engineering may confuse a TOV with a surge. Also, designers may not be familiar with TOVs. A TOV can easily be confused with a surge. To distinguish the differences, let's start by examining the industry standard definitions developed by the IEEE for both surges and TOVs.

SURGE DEFINITIONS

Because surges are the result of natural and man-made electrical phenomenon and are present on different types of power and signal circuits in the electrical environment, the word surge is defined in various IEEE surge-related standards as it applies to specific electrical environments and/or equipment. Examples of these standards include those under the auspices of the IEEE Power Engineering Society (PES), namely several of the C62 standards [including the recently revised Trilogy sponsored by the Surge Protective Devices (SPD) Committee], the IEEE Standard 100-2000 – *The Authoritative Dictionary of IEEE Standards Terms*, and the IEEE Standard 1250-1995 (R2002) – *IEEE Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances*. The Trilogy includes three documents:

- IEEE Standard C62.41.1-2002 – IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits

- IEEE Standard C62.41.2-2002 – IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits
- IEEE Standard C62.45-2002 – IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits

The IEEE Standard C62.41.1-2002 is the document that provides the best comprehensive technical definition and description of surges and TOVs.

According to IEEE Standard C62.41.1-2002, the word surge has the following definition:

- Definition 1: "A transient wave of current, potential, or power in an electric circuit. NOTE: The use of this term to describe a momentary overvoltage consisting of a mere increase of the mains voltage for several cycles is deprecated.

Comment: This is a generalized definition of surge. For power systems, surge (also called a transient) is a subcycle overvoltage with a duration of less than a half-cycle of the normal voltage waveform. A surge can be of either polarity, can be additive to or subtractive from the normal voltage waveform, and is often oscillatory-decaying." IEEE Standard C62.41.1-2002.

According to IEEE Standard 100-2000, the word surge has the following definitions:

- Definition 2: "A transient voltage or current, which usually rises rapidly to a peak value and then falls more slowly to zero, occurring in electrical equipment or networks in service" (PE/PSIM1) 4-1995
- Definition 3: "A transient wave of voltage or current. (The duration of a surge is not tightly specified, but it is usually less than a few milliseconds.)" ([T&D/PE/SPD2] 1250-1995, C62.34- 1996, C62.48-1995)
- Definition 4: "A transient wave of current, potential, or power in an electronic circuit." ([SPD/PE3] C62.22-1997, C62.11-1999, C62.62-2000)

Each of these definitions of the word surge was developed by the IEEE PES during various standards development activities. Definition 2 was developed for power systems instrumentation and measurements within power engineering. Here, surges that occur on the power system can affect instrumentation and measurement equipment used in the power system. Definition 3 was developed for transmission and distribution systems within power engineering and SPD applications. The previously mentioned IEEE 1250-1995 (R2002) also adopted this definition with reference to upsetting equipment sensitive to voltage disturbances. Definition 4 was also developed with application to SPDs within power engineering. Definition 4 is the more recent definition of the word surge as developed by the IEEE SPD committee within C62.41 and is most widely applied to end-use equipment. This definition defines a surge as a transient wave that can be a current, a potential, or a power wave. It is also described as a subcycle overvoltage event with a duration less than ½ cycle (i.e., 8.33 milliseconds for 60 hertz systems and 20 milliseconds for 50 hertz systems).

Reviewing each of these definitions, one can see that a surge is technically described as a transient (i.e., short-lived disturbance) phenomenon of positive or negative polarity that can be representative of a rapidly rising voltage, current, and/or power, and that a surge may occur in the power system, electrical networks (e.g., facility power systems), and/or within equipment (i.e., end-use devices).

TEMPORARY OVERVOLTAGE DEFINITIONS

Temporary overvoltages (TOVs) are best defined in IEEE Standard 100-2000 and in IEEE Standard C62.41.1-2002. According to IEEE Standard 100-2000, a TOV is defined as:

- Definition 1: "An oscillatory phase-to-ground or phase-to-phase overvoltage that is at a given location of relatively long duration (seconds, even minutes) and that is undamped or only weakly damped. Temporary overvoltages usually originate from switching operations or faults (for example, load rejection, single-phase fault, fault on a high-resistance grounded or ungrounded system) or from nonlinearities (ferroresonance effects, harmonics), or both. They are characterized by the amplitude, the oscillation frequencies, the total duration, or the decrement. ([C/PE4] 1313.1-1996, C57.12.80-1978r)

- Definition 2: "An oscillatory overvoltage, associated with switching or faults (for example, load rejection, single-phase faults) and/or nonlinearities (ferroresonance effects, harmonics), of relatively long duration, which is undamped or slightly damped. ([SPD/PE] C62.22-1997))

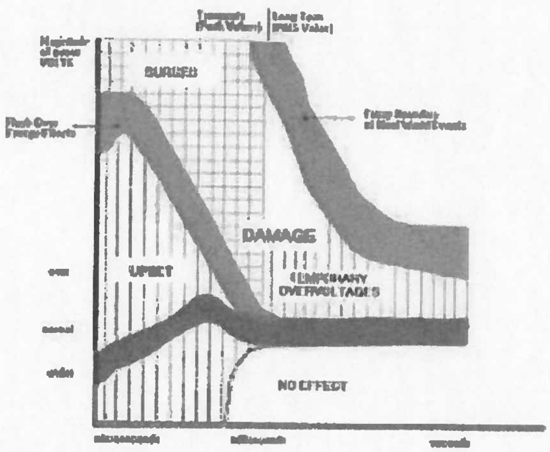


Figure 1. Basic relationship between magnitude, duration, rate of change, and equipment damage for voltage disturbances.

IEEE C62.41.1-2002 also defines surges and TOVs graphically on a magnitude- duration plot with respect to the duration of an event (in milliseconds) and the magnitude of an event (in volts). According to these definitions, surges are transients of positive and/or negative polarity with duration less than ½ cycle (e.g., a few microseconds to a few milliseconds), and TOVs are positive polarity events of long term duration ranging from seconds to minutes. In Figure 1, the surges cover a wider area on the magnitude-duration plot than TOVs. Surges incident upon end-use equipment (either through the AC power input or through communication or network cables) can damage, upset, or have no effect on equipment. TOVs are only incident upon the AC power input of equipment and typically cause damage to equipment.

With respect to magnitude, surges reach much higher magnitudes in the few thousands volt range with the higher magnitude events occurring in the positive region of the plot—above the normal line voltage. TOVs reach much lower magnitudes in the overvoltage range within a few hundred percent of the line voltage with the higher magnitude events being of shorter duration than the lower magnitude events, but often with much higher energy effect.

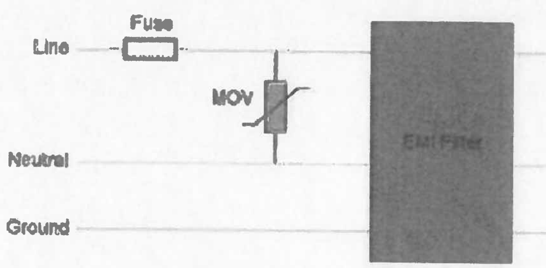


Figure 2. Basic AC power input protection circuit for end-use equipment.

BASIC CIRCUIT PROTECTION

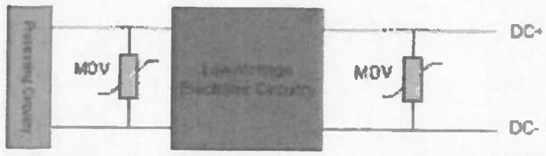


Figure 3. Basic low-voltage protection circuit for end-use equipment.

By design, MOVs are located in various circuitry locations of end-use equipment to provide protection of the equipment from surges. To provide protection against surges incident on the AC power input of equipment, they are located at the AC power input. Although most MOV applications are on AC power input circuits, like that shown in Figure 2, they may also be used on low-voltage control wiring such as in electrically activated lawn sprinkler systems and on the inputs of dimming circuits in electronic fluorescent and high-intensity discharge (HID) lighting ballasts like that shown in Figure 3.

MOVs and other SPDs located on AC power inputs and low-voltage control circuits are vulnerable to failure. MOVs are designed to absorb the electrical energy contained in surges to prevent that energy from causing damage to active and passive electronic components located downstream of the line fuse and upstream of a connection to a DC low-voltage control circuit. Upon activation by a surge voltage incident upon the AC line input, for example, MOVs effectively reduce the surge voltage to levels that will not cause damage to electronic components. In the course of dissipating energy and reducing the surge voltage, MOVs heat up, As a result, the amount of temperature rise in an MOV is related to the amount of energy that the MOV must absorb from the surge. It is the area under the curve of the resulting surge power waveform that determines how much energy the MOV must absorb. Surges of higher voltage magnitude (e.g., 3.2 kilovolts) and shorter duration (e.g., 50 microseconds) will cause less MOV heating than surges of lower voltage magnitude (e.g., 1.3 kilovolts) and the same duration. Also, larger diameter (e.g., 20 millimeter) MOVs are designed to handle more surge energy than smaller diameter (e.g., 14 millimeter) MOVs.

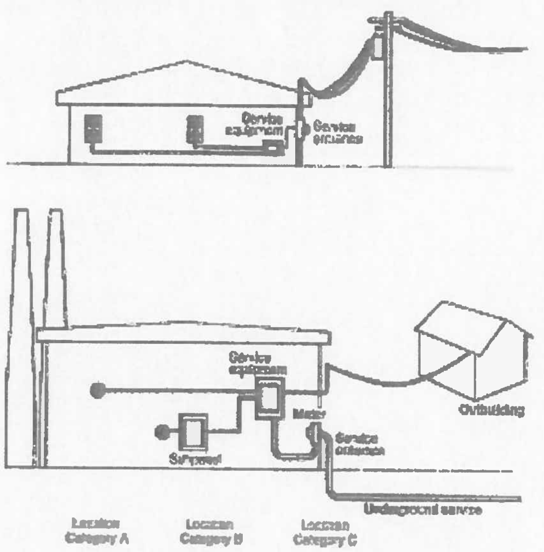


Figure 4. Location categories A, B, and C as defined in IEEE Standard C62.41.1-2002.

In designing any MOV into end-use equipment, the energy- handling capability of the MOV is one critical factor in selecting the MOV for the application. For end-use equipment applications with a higher exposure to surges of higher energy, an MOV with a higher energy-handling capability will survive longer than an MOV with a lower energy-handling capability. If a proposed location for equipment is at a high exposure to surges of higher energy, such as Location Category C, where surge voltages in a facility are of a higher magnitude, in Figure 4, and if an MOV is undersized, then the MOV will likely fail. On the other hand, if an MOV is improperly sized for the expected surge exposure level such that it does not dissipate the resulting energy, then the equipment may still be at a high risk arising from the possible loss of the

MOV. In the course of forensic analysis of failed equipment, is it possible to determine if the MOV failure was caused by surges or by TOVs?

CHARACTERISTICS OF MOV FAILURES

MOV failures result from the inability of the MOV to withstand the electrical energy applied to it during a surge. The energy that the MOV must absorb is a function of several variables including the maximum overvoltage occurring on line and the duration of the overvoltage. The energy-handling capability of the MOV is a function of the energy rating of= the MOV, which is a function of the diameter and thickness of the MOV, and the ability to remove the heat effectively before the MOV suffers permanent damage.

Whether the overvoltage that occurs on the line voltage is a surge or a TOV, the MOV will begin to conduct current at some voltage level. The current that flows through an MOV during conduction is defined by the IEEE Standard C62.41.1 as the surge current. If the MOV must conduct current as a result of a TOV, then the resulting TOV initial current that flows may damage the MOV. As described earlier for the case of MOV conduction attributable to surge currents, MOV damage from conduction of TOV-initiated currents will depend upon how much TOV energy the MOV must dissipate. If the energy-handling capability of the MOV is exceeded, then the MOV will fail.

After an MOV failure, the only way to tell whether the failure was caused by a surge or a TOV is physical inspection of the MOV and the line fuse. Little to no electrical properties will be present in an MOV after its failure. Thus, using a digital ohmmeter or an MOV tester will be virtually useless in determining the cause of an MOV failure after it has been removed from a piece of equipment.

Physical inspection will require that the equipment be opened to reveal the protection circuitry on the AC power input section. Inspection of the line fuse is also necessary because the fuse also may or may not be damaged as a result of a surge or TOV. Most importantly, an opened fuse may be the result of one or more failed power electronic components in the equipment's power supply or other power-related circuit inside the equipment with no involvement of surges, TOVs, or the MOV. After the fuse and MOV have been located, the investigator should determine if the fuse is open. If the MOV appears to be intact, then it can be removed and can be tested with an MOV tester. If the MOV test is acceptable, then it is likely that the equipment failure did not involve surges, TOVs, or the MOV. However, in testing the fuse, the investigator will need to use an ohmmeter to determine if the fuse element has been damaged and/or has opened. In most cases, it will be obvious that the fuse has been damaged as evidenced by a disintegrated fuse element and/or charred glass (if the fuse container is made of glass). In the case of some fuses, especially the ones with an inherent time delay, element damage can be "hidden", and a visual inspection may not reveal the damage (i.e., the fuse may appear to be good, when it is actually bad).. In fuse failures, it is also possible that the element has not been totally severed (i.e., it has a very small but measurable impedance). Using a milli-ohmmeter will be useful in determining if this is the case.

Upon opening a piece of equipment, one may find that, in most applications, the fuse and MOV will be located on the top or on the bottom of a printed circuit board in plain sight. This location makes the visual inspection of the fuse and MOV easy. The location of the fuse and MOV will be near the point where the AC power is brought into the equipment and close to the electromagnetic interference (EMI) filter. One may also find that the fuse and MOV are not visible. In an increasing number of equipment designs where a composite EMI filter is used, the fuse and MOV may actually be inside a metal can that is used to house the EMI filter.

A composite EMI filter typically includes the line fuse, MOV, over-temperature protection device, and EMI filter components (i.e., capacitors and inductors). One may ask why the line fuse and MOV are included in the composite EMI filter. If the EMI filter includes an International Electrotechnical Commission (IEC)-type female connector for the AC line power cord, then the fuse and MOV must be located inside the can for the fuse and MOV to be located upstream of the input to the EMI filter. In other cases, the EMI filter may be required to be shielded from radiated emissions sources nearby inside the equipment. In these cases, the fuse and the MOV must also be located inside the filter can to preserve the electromagnetic integrity of the AC line input.

Most importantly, note that the can of the filter may be filled with some type of potting material. The use of potting material helps to reduce arcing between component traces on the EMI filter circuit board and between component surfaces and the grounded EMI filter can. Potting material also helps to improve heat dissipation of the fuse, MOV, and filter elements inside the can. Dissipation of heat ability in this case is especially important in helping to extract heat from the MOV when it passes surge current. Heat dissipation through potting material will also help to reduce MOV failure caused by short duration TOVs. When conducting fuse and MOV failure investigations, the potting material must be removed to expose the surfaces of the fuse and MOV. Removal of potting material should be accomplished in such a way as not to cause further damage to the fuse and MOV. Mechanical removal of the potting material is the best method.

Another benefit of the composite EMI filter is that it can act to provide a fire barrier against hot and molten material that may be expelled from a fuse and/or MOV during a failure. In cases where the fuse and MOV are inside a filter can, the investigator will have to open the can to inspect the fuse and MOV.

Figure 5. Failure of circuit traces connecting the line fuse to the MOV inside an EMI filter can.

Figure 5 shows three examples of how TOVs may damage an MOV (middle) and other electronic components such as an electrolytic capacitor (left) and an inductor (right) used in a switched mode power supply. Damage to circuit traces on printed circuit boards may also occur where the line fuse and MOV are improperly coordinated. Traces may be lifted from the board due to the forces created when high currents flow. It is important to illustrate these cases because failures associated with AC line input circuitry sometimes do not result in the failure of other components in addition to fuses and MOVs.

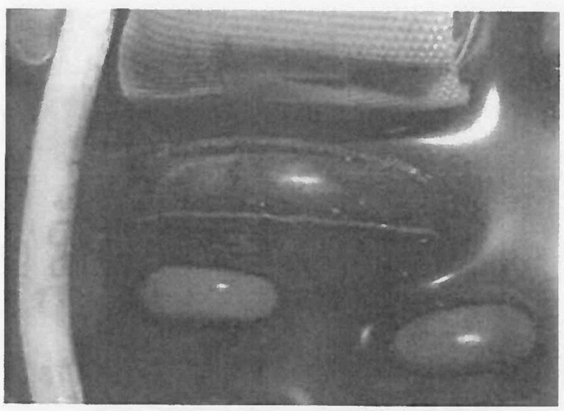


Figure 6. MOV partially embedded in potting material; MOV is split as a result of a TOV (fuse is also opened but not shown here).

Figure 6 shows an example of an MOV failure in end-use equipment. This MOV is partially potted and the line fuse is fully potted (not shown). The blue capacitors below the MOV and the common mode inductor above the MOV are both part of the EMI filter for this equipment. This MOV failed as a result of a TOV incident upon the AC line input. The potting material helped to absorb heat from the MOV and helped prevent the MOV from disintegrating. The MOV failure resulted in the epoxy coating of the MOV being pushed away from the surge absorbing material. This fuse and MOV failure resulted in full equipment failure resulting in the necessity of returning the equipment to the manufacturer.

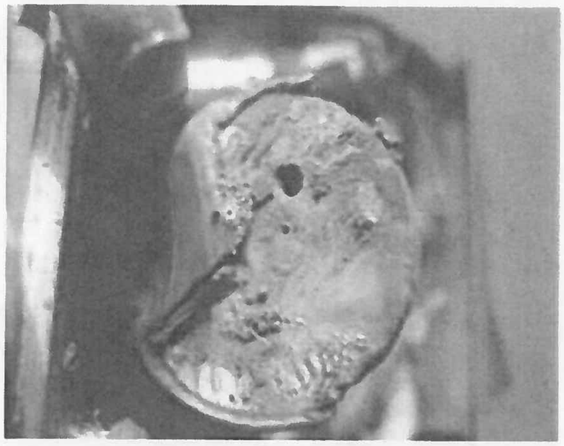


Figure 7. MOV failure caused by thermal runaway and internal equipment fire in a surge protective device.

Figure 8. MOV failure caused by thermal runaway and internal equipment fire in another surge protective device.

In visually inspecting MOV failures, thermal runaway may also occur if an MOV with too low of a maximum continuous operating voltage (MCOV) is applied in end-use equipment. In such a case, exposure of the MOV to a longterm overvoltage may be higher than the maximum allowable voltage for the MOV, and thermal runaway of the MOV may occur without blowing the line fuse. Figure 7 and Figure 8 show two examples of MOVs in surge protectors that failed as a result of MOV thermal runaway. In both examples, the MOV ignited and a significant part of the MOV material was burned by the fire caused by its own thermal runaway. If an investigator discovers this type of MOV failure surrounded by other burned insulation and electronic components, then thermal runaway can be suspected.

COORDINATION OF METAL OXIDE VARISTORS AND FUSES TO ACHIEVE ADEQUATE LEVELS OF PROTECTION

Design requirements imposed by Underwriters Laboratories (UL) require that the fuse be located upstream of the MOV. In MOV applications where equipment immunity from surges occurring from line to neutral is desired, the fuse location requirement imposed by UL is required because the MOV is connected from a source of power (i.e., line) to neutral. The same is true for MOVs connected from line to ground when surge immunity from line to ground is required. MOVs connected from neutral to ground do not require fuse protection. Fuse protection of an MOV will reduce the likelihood of an MOV fire resulting from extreme surge currents flowing through the MOV. The neutral to ground MOV should have the same MCOV rating when selecting MOVs. Also, it is good design practice to thermally protect the MOV to prevent potential fire hazards due to loss of neutral in facility wiring systems.

Some manufacturers with little experience in surge protection design will try to locate the MOV upstream of the fuse in their equipment designs. Without the basic understanding of protecting equipment from fire caused by MOV failures, initially there is more concern with either protecting every component (including the line fuse) from surges and reducing the number of nuisance equipment failures caused by opened fuses. Locating the MOV upstream of the fuse would reduce nuisance equipment failures but would also violate UL requirements. Thus, this practice is not allowed by UL or recommended by the power quality community for obvious reasons. Nuisance equipment failures (caused by opened fuses and failed MOVs) can be avoided and adequate immunity against surges can be provided if the overcurrent protection offered by a fuse and the overvoltage protection offered by an MOV are sized and coordinated in the proper manner.

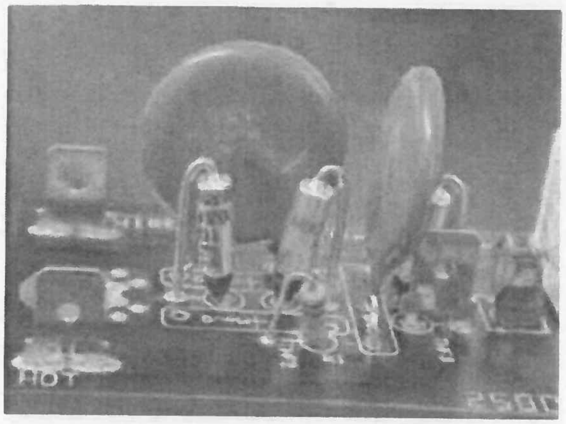


Figure 9. Arrangement of thermal cut-off (TCO) MOVs with one MOV removed from the circuit (to show the TCOs) (adapted from Littelfuse, Inc.).

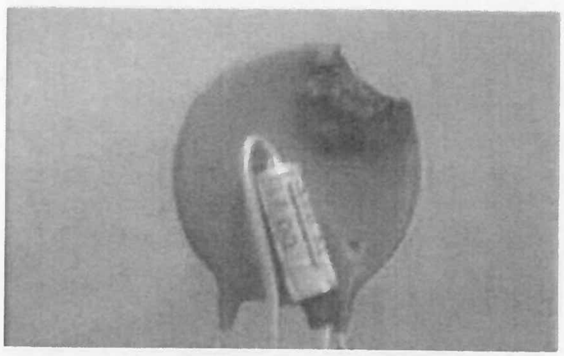


Figure 10. A ceased MOV failure caused by interruption of the conduction current by an external TCO (adapted from Littelfuse, Inc.).

An improved MOV design provides for thermal protection for the MOV without the use of coordinating fuses. Thermal protection and prevention of complete MOV destruction are provided by embedded thermal cut offs (TCOs), which are available in different opening temperatures. This new type of MOV is called the TMOV. The TCO must be positioned and oriented with respect to the MOV if it is to be effective in thermally protecting an MOV. When subjected to a TOV, MOVs can short at a random point on the disk and can begin to self-heat rapidly when conduction current is sustained through the MOV. Figure 9 illustrates an example of a typical arrangement of MOVs and TCOs.

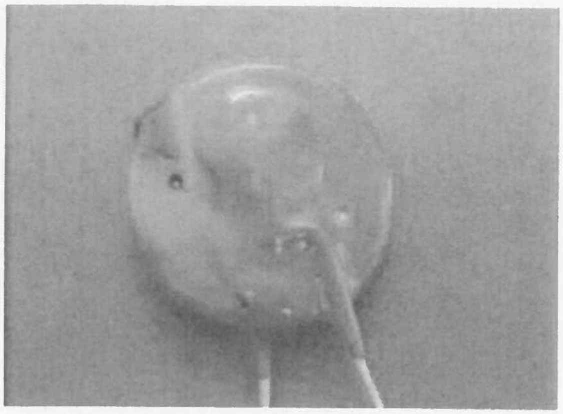


Figure 11. A ceased MOV failure caused by interruption of the conduction current by an internal TCO (adapted from Littlefuse, Inc.).

In recognizing MOV failures, it is worthwhile to illustrate the prevention of an MOV failure that was caused by including an external TCO next to the MOV. Figure 10 illustrates this type of failure.

TMOVs are also available with internal TCOs. Figure 11 illustrates how an MOV might look when its conduction current is interrupted by a TCO internal to the MOV.

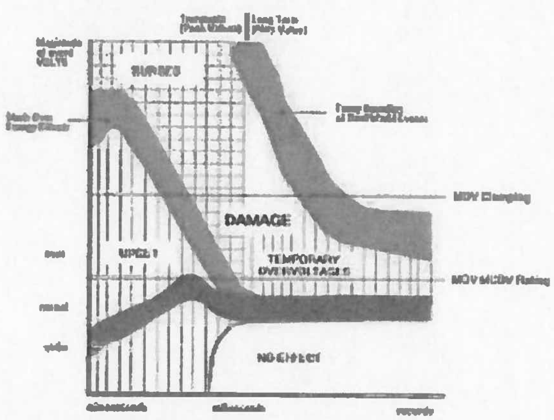


Figure 12. Location of MOV critical v voltage ratings on a voltage magnitude-duration plot.

It is not uncommon for manufacturers to receive dysfunctional equipment from the field. Upon failure investigations, manufacturers often find that only the line fuse has been blown with no damage to other components including the MOV. Manufacturers know that there are a number of causes for line fuse failure including internal component failure especially associated with the power supply. In other cases, manufacturers may find that both the fuse and MOV have been destroyed. However, most manufacturers do not think about line fuse failures caused by overcurrent conditions resulting from surges, TOVs, and even inrush currents that occur during a surge or after the return of line voltage after a voltage sag or momentary interruption, respectively.

Surge- and TOV-related line fuse failures, addressed in this article, are caused by MOV current conduction. This conduction is a function of the MOV clamping voltage rating of the MOV. If the MOV clamping (suppression) voltage (CSV) is selected too low, then there is a greater chance that the MOV will conduct as a result of a TOV, thus possibly damaging the line fuse and the MOV.

The maximum continuous operating voltage (MCOV) rating of an MOV is also another critical specification for MOVs. If the MCOV is selected too low (i.e., too close to the maximum expected line voltage including the expected overvoltage of about 10%), then the MOV will conduct as a result of high line voltage. Figure 12 illustrates an example of the CSV and

MCOV rating with respect to the areas in a voltage magnitude-duration plot where surges and TOVs typically occur. In this situation, the MOV is likely to experience thermal runaway (see Figures 7 and 8) and to be damaged, possibly causing a fire inside the equipment. Thus, selecting an MOV with a high CSV and MCOV rating will help avoid line fuse and MOV failures caused by high line voltage conditions and TOVs. On the other hand, the equipment designer must select the clamping voltage low enough to clamp surges before they damage other internal components such as noise capacitors inside an EMI filter and the bridge rectifier. In 120-volt applications, selecting an MOV with a CSV of 395 and a MCOV of 150 will be sufficient. In 277-volt applications, selecting an MOV with a CSV of 845 and a MCOV of 320 will be sufficient.

EXAMPLE APPROACH AND TEST DATA

Example Approach

Well-planned laboratory surge and TOV tests may be carried out to investigate surge- and TOV-related failures and failure prevention through coordination of line fuses and MOVs. Coordination studies may be aimed at identifying coordination of existing designs with too many fuse and/or MOV failures or targeted coordination for new designs. A single line fuse connected in series with a single MOV may be subjected to various surges and TOVs of various duration to learn more about how to recognize fuse and MOV failures. Single fuse-single MOV and grouped fuse-MOV test circuit configurations should be used to determine coordination.

TEST CONFIGURATION	TEST PARAMETERS	CIRCUIT CONFIGURATION & COMPONENT SELECTION	ENDING STEP
Surge (combination wave)	8 µsec x 20 µsec Phase Location = 90° Surge start voltage = 1 kV Surge step voltage = 500 V Surge end voltage = 6 kV	One fuse, one MOV, series connected Originally-sized fuse Originally-sized MOV	Apply surge until fuse or MOV failure; Surge voltage at first failure is V_{fail}
	8 µsec x 20 µsec Phase Location = 90° Apply surge at V_{fail} – 500 V	X number of single fuse-single MOV series circuits Originally-sized fuse Originally-sized MOV	
Temporary overvoltage (TOV)	TOV start voltage = 1.5 p.u. TOV step voltage = 0.3 p.u. TOV end voltage = 2.4 p.u.	One fuse, one MOV, series connected Originally-sized fuse Originally-sized MOV	Apply surge until fuse or MOV failure
		X number of single fuse-single MOV series circuits Originally-sized fuse Originally-sized MOV	
Surge (combination wave)	Same as in Row 1	One sample of end-use equipment	Same as in Row 1
Temporary overvoltage (TOV)	Same as in Row 2	One sample of end-use equipment	Same as in Row 2
Surge (combination wave)	Same as in Row 1	X samples of end-use equipment	Same as in Row 1
Temporary overvoltage (TOV)	Same as in Row 2	X samples of end-use equipment	Same as in Row 2

Table 1. Approach for determining fuse and MOV damage resulting from surges and TOVs.

Table 1 illustrates an example approach for conducting surge and TOV tests (1) on series-connected, single-line fuse-MOV samples, (2) on series-connected line fuse-MOV samples connected in parallel, and (3) on end-use equipment containing a line fuse and MOV. A selected number (e.g., six in these tests) of circuits with a single fuse and a single MOV may be placed in parallel on a test card to investigate how the fuse-MOV combination shares the real overcurrent condition presented by the surge or TOV. This circuit configuration simulates end-use equipment powered by an actual branch circuit in a facility. The number ("X" in the third column of Table 1) of circuits with a single fuse and a single MOV included on a test card can be determined, for a specific enduse equipment application, by determining how many pieces of like equipment can be placed on a single 20-amp branch circuit, for example. In an application where one piece of equipment draws 1.3 Arms at 277 V_{rms}, 12 pieces of equipment can be placed on a 20-amp circuit (derated to 16 amps). Thus, 12 series circuits with a single fuse and a single MOV can be placed in parallel on a test card for laboratory testing.

	Cycles												
Single Line Fuse-MOV Sample	64												Figure 13
	32												
	16												
	8												
	4												
	2												
Group of 6 Line Fuse-MOV Samples	64												Figure 14
	32												
	16												
	8												
	4												
	2												
TOV Event (p.u.)		1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	

Table 2. Summary of TOV test data for the line fuse and MOV tested in this case.

	Surge Count												
Single Line Fuse-MOV Sample	1000												Figure 15
	800												
	600												
	400												
	200												
	100												
	80												
	60												
	40												
	30												
	20												
	10												
Group of 6 Line Fuse-MOV Samples	1000												Figure 16
	800												
	600												
	400												
	200												
	100												
	80												
	60												
	40												
	30												
	20												
	10												
Surge Voltage		500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	

Table 3. Summary of surge test data for the line fuse and MOV tested in this case.

Test Data

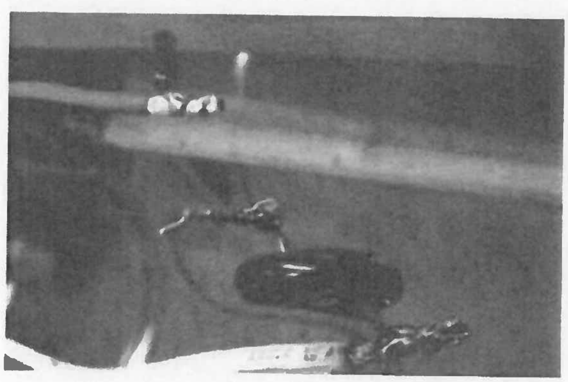


Figure 13. A 3-amp, slow-blow 350-volt line fuse and 510-volt MOV after one 1.71 p.u. (473.4 V_{rms}) 64-cycle duration TOV: disintegrated fuse and MOV damaged (epoxy surfaces lifted).

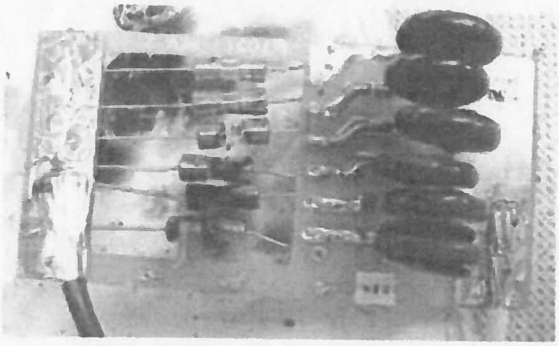


Figure 14. Six parallel arrangements of 3-amp, slow-blow fuses in series with 510 volt MOVs on a test card after one 1.71 p.u. (473.4 V_{rms}) 64-cycle duration TOV: four out of six fuses blown with three out of six MOVs damaged (epoxy surfaces lifted).

Table 2 illustrates the summary of TOV test data for the 3-amp, slow-blow line fuse and the 510-volt, 20-mm MOV tested in this example case. The arrows in the tables illustrate how the testing was performed. Table 2 contains test data for the single line fuse-MOV sample case and for the group of six series line fuse-MOV samples in parallel. In the TOV testing, TOVs from 1.0 p.u. (per unit) to 2.0 p.u. were planned in steps of 0.1 p.u. with TOV duration starting at 2 cycles and ending in 64 cycles in double steps. In Table 2, one can see that for both cases (single and grouped line fuse and MOV), the line fuse-MOV combination survived the TOVs ranging from 1.0 p.u. at 2 cycles up to a 1.7 p.u. TOV at 32 cycles with failure of the fuse and MOV at 1.7 p.u. at 64 cycles. From Figure 13, one can also see that the line fuse was completely destroyed and that the MOV suffered splitting of its epoxy-covered case. (The MOV was not completely destroyed in terms of its physical structure.) Figure 14 illustrates the results of conducting these tests on parallel-connected line fuse-MOV circuits. Four out of six fuses were blown. Figure 14 also shows that the fuses that suffered the greatest destruction were also supporting TOV current drawn by the MOVs that experienced the most damage resulting from the TOV event. The four fuses that suffered physical damage to their outside cases supported TOV current from the four MOVs that suffered splitting of their epoxy cases.

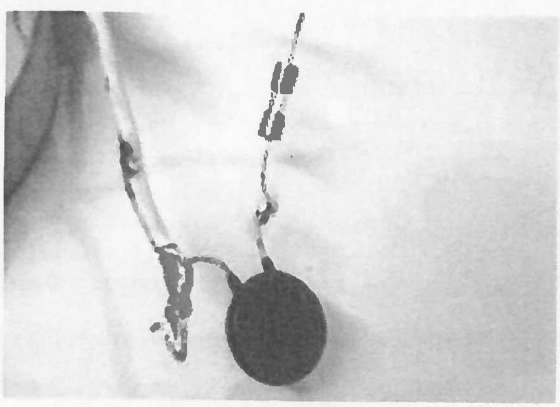


Figure 15. A 3-amp, slow-blow, 350-volt line fuse and 510-volt MOV after one 2.5-kV surge: opened fuse, no damage to MOV.

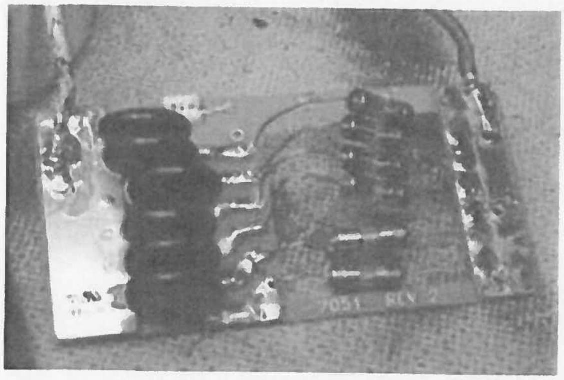


Figure 16. Six parallel arrangements of 3-amp, slow-blow fuses in series with 510-volt MOVs on a test card after 39 5.5-kV surges: five out of six fuses blown with no MOV damage.

Table 3 illustrates the summary of surge test data for the same 3-amp, slow-blow line fuse and the 510-volt, 20-mmMOV tested in the second part of this example case. Table 3 contains test data for the single line fuse-MOV sample case and for the group of six series line fuse- MOV samples in parallel. In the surge testing, surges from 500 volts to 6000 volts were planned in steps of 500 volts with surge counts (number of surges) starting at 10 and ranging up to 1000. From Table 3, one can see that the test results are different for the single and the grouped line fuse-MOV cases. In the single line fuse-MOV case shown in Figure 15, the line fuse-MOV combination survived the surges ranging from 500 volts at 10 surges up to 2500 volts up to 10 surges with failure of the fuse at 2500 volts at 10 surges. In the grouped case where the line fuses and MOV share the surge current, five out of six line fuses failed when subjected to 40 surges at 5500 volts. No damage to any of the six MOVs occurred in these tests. From Figure 16, one can also see that the line fuses suffered no physical damage to their outside cases (only the fuse element was blown for the five out of six fuses), and the MOVs also suffered no damage (splitting or destruction) of their epoxy covered cases.

CONCLUSION

The surge and TOV electrical disturbance events are two completely different types of events. As stated earlier, MOVs are designed specifically to reduce surge voltage appearing on input and output circuits in end-use equipment. When surge voltage is reduced to acceptable levels that will not damage internal end-use electronics, surge currents must flow as a result of the voltage clamping action designed into the MOV. However, MOVs are not designed to protect end-use equipment from TOV events. Although TOV events are lowervoltage events, they are much longer in duration than surges. In equipment design, the size and type of fuse and MOV does matter when trying to coordinate the fuse and MOV where the objective is to reduce premature return of failed equipment that otherwise would have continued to operate. As a result though, when the fuse is coordinated closer to the MOV, meaning the fuse is able to withstand the resulting surge current, it is difficult to determine the failure mode (failure caused by surges or TOVs).

However, it is very clear where there are multiple failures of like pieces of enduse equipment such as power supplies and corresponding catastrophic fuse failures that it is very probable that the cause of equipment failure is related to TOV events, either internal or external to the facility. In cases where there are two pieces of end-use equipment out of a group of equipment found with benign fuse failure, but not catastrophic, it is reasonable to conclude that the failure is related to a surge event when no other failed components are determined.

BIBLIOGRAPHY

[1] Effects of Temporary Overvoltage on Residential Products, Part II: System Compatibility Research Project. EPRI, Palo Alto, CA: 2005. 1010892.

[2] Martzloff, F. D., and Leedy, T. F., "Selecting Varistor Clamping Voltage: Lower is Not Better!" Proceedings, International Zurich Symposium on EMC, 1989.

[3] Phipps, Kermit O., and Connatser, Bradford R., "Understanding MOVs for Applying Robust Protection Against Surges" Interference Technology EMC Directory & Design Guide, 2005.

[4] Traynham, Paul W., "Using Thermally Protected MOVs in TVSS or Power Supply Applications" Littelfuse®, Inc., 2001.

FOOTNOTES

1. PE/PSIM is Power Engineering/Power Systems Instrumentation and Measurements
2. T&D/PE/SPD is Transmission & Distribution/ Power Engineering/Surge Protective Device
3. SPD/PE is Surge Protective Device/Power Engineering
4. CE/PE/TR is Consumer Electronics/Power Electronics

ABOUT THE AUTHORS

Philip F. Keebler *has conducted System Compatibility Research on personal computers, lighting, medical equipment, and Internet data center equipment. The lighting tasks were associated with characterizing electronic fluorescent and magnetic HID ballasts, electronic fluorescent and HID ballast interference, electronic fluorescent and HID= lamp failures. He has drafted test protocols and performance criteria for SCRP tasks relating to PQ and EMC. Mr. Keebler also manages the Electromagnetic Compatibility (EMC) Group at EPRI Solutions where EMC site surveys are conducted, end-use devices are tested for EMC, EMC audits are conducted, and solutions to electromagnetic interference (EMI) problems are identified. He has completed his service as editor developing a new EMC standard for power-line filters, IEEE 1560.*

Kermit O. Phipps *is a NARTE Certified EMC engineer and conducts tests and evaluations of equipment performance in accordance with standards of ANSI/IEEE, IEC, U.S. Military, and UL, as well as with the EPRI System Compatibility Test Protocols for EPRI Solutions. He conducts research on surge protection, power-line filters, shielding effectiveness, and electromagnetic interference. Mr. Phipps is the author and co-author of test plans, protocols, and research papers presented at international power quality and EMC conferences. Most recently, he has completed his voluntary work as chairman in developing a new EMC standard for power-line filters, IEEE 1560.*

Doni Nastasi *is responsible for managing projects, power quality testing, field investigations, equipment design, and power quality training. Since joining EPRI Solutions in 1992, Mr. Nastasi has designed electronic circuits and developed software to improve laboratory testing capabilities. He designed an automated flicker measurement system, performed on-site flicker investigations at customer sites, and performed flicker tests on incandescent lamps and fluorescent ballasts for EPRI System Compatibility Research projects. He has used EPRI Solutions' portable sag-testing equipment to perform more than 50 on-site power quality investigations at industrial facilities. He has contributed to corporate publications such as Power Quality Briefs, Case Studies, and Applications, and has co-authored technical papers on topics such as voltage sags, surges and flicker.*

April 17, 2017

Michael Simchik
100 Market Street
Portsmouth, NH 03801

Re: Eversource Issue - Evaluation of Damage to Electronic Equipment

Reference (a): IEEE Standard 242-2001 (Buff Book), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

(b) Aurora Energy, Protecting your electrical appliances, Surge Diverters, https://www.auroraenergy.com.au/help-and-advice/safety/safety-at-home/protecting-your-electrical-appliances

(c) Open Phase Conditions in Transformers Analysis and Protection Algorithm. Presented at 2013 66th Annual Conference for Protective Relay Engineers by Amir Norouzi. http://www.cce.umn.edu/documents/cpe-conferences/mipsycon-papers/2013/openphaseconditionsintransformersanalysisandprotectionalgorithm.pdf

(d) Voltage sags and what to do about them .Jack Smith, Senior Editor, Plant Engineering magazine, 08/08/2002. http://www.csemag.com/home/single-article/voltage-sags-and-what-to-do-about-them/0499ada0dfbb1d6747ee2bf3adacd2ee.html

(e) Voltage Dips And Sensitivity Of Consumers In Low Voltage Networks, Günther Brauner, Christian Hennerbichler, Vienna University of Technology, 2001 http://www.cired.net/publications/cired2001/2_31.pdf

(f) Fluid Power Design Data Sheet 30 - Finding the Cause of Solenoid Coil Burn-Out. http://www.womackmachine.com/engineering-toolbox/design-data-sheets/finding-the-cause-of-solenoid-coil-burn-out.aspx

Dear Mr. Simchik,

A site visit was conducted at the 100 Market Street building in Portsmouth, NH, on June 20, 2016. Purpose of the visit was to evaluate possible damage to electrical equipment resulting from the utility company energizing one phase at a time (known as single-phasing) for the entire building, with the building's main circuit breaker in the "on" position. My first evaluation, which primarily investigated damage to 3-phase motors, was summarized in a letter dated July 5, 2016.

The purpose of today's letter is to summarize damage to single-phase equipment that occurred during the same single-phasing event that damaged 3-phase motors.

For the remainder of this letter, the building at 100 Market Street will be referred to as the 100 Building.

In May 2016, Eversource installed a new utility transformer for the 100 Building. The new transformer is located across the street from the 100 Building, at the Hanover Street parking garage. Previously electricity for the 100Building was supplied from the utility transformer located in the transformer vault in the basement of the 100Building. The transformer vault is now used as a tie point to wire the new secondary conductors from the new transformer to the existing secondary conductors which are then wired to the main switchgear in the 100Building.

On the morning of June 2, 2016, during the swap over from the old utility transformer to the new utility transformer, Eversource caused a single-phasing event to occur in the 100 Building. The result was that various types of equipment located in the 100 Building were damaged beyond repair, including the heating and ventilation roof-top unit (which caught fire), EDT electronic equipment (which caused the room to have a faint burnt smell), the solenoid in the fire alarm master box and the elevator controller.

According to reference (a), paragraph 14.2, one of the primary requirements of electric utility companies is to protect the consumer from single-phasing events as stated below:

> *14.2 Service requirements*
>
> *Consideration of the design, operation, and protection of service lines between a consumer and utility power supplier should be based on deep mutual understanding of each other's needs, limitations, and problems. The electric power supply for an industrial or commercial power system should meet the following basic requirements listed below:*
>
> *a) Accommodate normal peak power demand and provide ability to start large motors without excessive voltage sag.*
>
> *b) Maintain deviations from normal frequency and normal voltage within acceptable tolerances.*
>
> *c) Maintain consistent phase rotation in a multiphase system.*
>
> *d) Maintain voltage-wave distortion, harmonics, and voltage surges within acceptable tolerances.*
>
> ***e) Maintain three-phase supply during normal conditions to avoid voltage unbalance and single-phasing.***

The most effective method used by utility companies to prevent single-phasing events from occurring when swapping-over transformers is to open the main circuit breaker in the consumer's main switchboard. This was not the case during the transformer swap-over on June 2. The main circuit breaker was left in the closed position which resulted in several pieces of equipment suffering severe damage. Surge protection devices are ineffective in preventing damage from single-phasing events.

According to Reference (c), Section III-B2 (Open Phase Conditions in Transformers with Ungrounded Primary) (Page 7);

> *What is common among all such transformers with ungrounded primary winding is that upon loss of a single phase there will be substantial voltage unbalance on both primary and secondary side of the transformer. As discussed in III-A2 only half of the phase-phase voltage will appear on two of the primary coils.*

The result is that equipment wired to the affected phases will experience a 50% drop in voltage during the voltage sag.

Voltage sag, as defined by IEEE, is a reduction in voltage for a short time. The voltage reduction magnitude is between 10% and 90% of the normal root mean square (RMS) voltage at 60 Hz. The duration of a voltage sag event, by definition, is less than 1 minute and more than 8 milliseconds, or a half cycle of 60-Hz electrical power.

A surge protector (or surge suppressor or surge diverter) is an appliance or device designed to protect electrical devices from voltage spikes. A surge protector attempts to limit the voltage supplied to an electric device by either blocking or shorting to ground any unwanted voltages above a safe threshold. It is design to protect equipment from over-voltage spikes not undervoltage conditions. According to Aurora Energy (reference (b)):

> *Surge Diverters restrict incoming voltages to predetermined levels, directing the associated fault current to earth. The earth connection of the diverter must be sound and of low resistance to ensure it provides adequate protection. If not properly selected and installed for the magnitude of the surge expected, they may be destroyed by the energy which passes through them when they operate.*
>
> *These devices minimize the effect of rapid voltage increases above a design threshold voltage but do not provide protection against prolonged voltage decreases or momentary interruptions. These are generally used to protect against lightening striking overhead lines.*

The substantial voltage unbalance is the reason the 3-phase motor in the roof-top heating and ventilation unit caught fire. According to reference (a):

> *14.3.1.6 Voltage unbalance*
>
> *Voltage unbalance and loss of a phase (single-phasing) may be caused by events such as large single-phase loads, unequal impedances (e.g., due to untransposed conductors in the supply system), one open fuse, or the failure of one pole to close properly in a circuit breaker or contactor. A single-phase condition is an extreme case of voltage unbalance. The voltage unbalance creates negative-sequence current, which cause an increase in motor losses, heating of generator rotors, and heating of motor windings. Severe negative-sequence conditions can lead to motor failures. In NEMA MG 1-1998, a voltage unbalance of no more than 1% is allowed in order to avoid excessive temperature rise. A voltage unbalance of 3.5% can result in a 20% to 25% increase in motor temperature rise and shorten the motor insulation life by over one half.*

Reference (a), Table 14-3 shows the effect of voltage unbalance on motor losses and temperature rise. For example a voltage unbalance of 5% can cause up to 120 degrees C (248 degrees F) temperature rise in motors.

The reason for the damage to the elevator controller circuit boards and power supply is not as obvious, especially since the controller is wired to the life safety panelboard which is wired to the generator. Which means the controller was only subjected to the single-phasing event for the 5-seconds it took for the generator to detect the fault condition, turned-on and then transfer all loads wired to the life-safety panel from the faulty grid power to the generator power within 5-seconds of the detecting the fault condition. All the other equipment wired to the life safety panel, which is mostly lighting, was not damaged.

The EDT electronic equipment, which was not wired to the generator, was also damaged by the single-phasing event.

The one thing that electronic equipment have in common is their DC power supplies. Equipment that have DC power supplies would try to compensate for the voltage drop by discharging the built-in capacitors. The longer the duration of the single-phasing event the greater the damage suffered by the equipment. According to reference (d);

> *When a sag occurs, the power supply inside electronic devices uses some of its stored energy to compensate for the loss of input voltage. If enough energy is lost due to the sag, then the power supply may lose its ability to maintain an exact DC voltage to all the active components, such as integrated circuits, inside the device — even for a few milliseconds. This is long enough to corrupt data in microprocessor-based electronics and to cause malfunctions of digital equipment.*

Research completed at the Vienna University of Technology subjected various types of equipment to voltage sags to determine their point of malfunction. For computer systems, the malfunction occurred within 500 milliseconds (0.5 seconds) for a 50% voltage sag. Reference (e) summarizes the results of the report as follows:

> *In distribution systems power quality is of increasing importance as the low voltage consumers use microelectronic components for control and operation, which are sensitive to voltage dips and power interruptions.*
>
> *Measurements of the immunity of low voltage devices to voltage depressions of different amplitude and duration have shown, that the area of malfunction can be described in many cases by a single point, which represents the minimum voltage needed for continuous operation and the maximum permissible duration of a voltage dip (fig. 1). If the voltage falls below the minimum for steady state operation or exceeds the permissible duration of a voltage dip, a malfunction will occur.*
>
> *It was found, that the allowed duration of a short interruption for personal computers is between 80 ms to 450 ms with an accumulation around a value of about 200 ms.*

In my opinion, the damage to the elevator controller and the EDT equipment occurred within 5 seconds. Therefore by the time the elevator controller was transferred to generator power it is likely it was already damaged. The fact that it was so severely damaged provides justification for my conclusion.

The damage to the solenoid in the master box may also be explained by the resulting voltage sag from the single-phasing event. According to reference (f);

> *Improper match between the electrical source and the coil rating is sometimes a cause for coil burn-out, including voltage too Low. Operating voltage should not be more than 10% below coil rating. Low voltage reduces the mechanical force of the solenoid. It may continue to draw inrush current without being able to pull in.*

Single-phasing events are well-known in the industry as events to be avoided due to the fact that result is often damaged equipment. The most practical solution to avoiding single-phasing events is to open the main circuit breaker serving the building. Shutting off all 3-phases of incoming power simulates a typical power outage. All the equipment damaged on June 2 had experienced several power outages in the past without any noticeable effect.

The following is what I believe to be the sequence of events that led to the damaged equipment at 100 Market Street. This summary is based on my discussions with the building owner and facilities manager:

1. In May 2016 Eversource installed a new utility transformer for the 100 Market Street building. The new transformer is located across the street at the parking garage.

2. Additionally Eversource installed 3 sets of 4-conductors (one conductor for each phase plus a neutral, 12 conductors total) from the secondary side of the new transformer (at the Parking Garage) into the transformer vault in the basement of 100 Market St.

3. Eversource wired the primary side of the new utility transformer to primary conductors using fused cut-outs for the overcurrent protection. At that point the fuses have not been installed in the new cut-outs.

4. The day before the transformer swap-over, Eversource notified the building owner that power would be cut to the building to allow Eversource to complete the transformer swap-over. Additionally Eversource stated that it was not necessary to notify the tenants of the upcoming power outage since the work would be completed early in the morning, before the tenants arrived. Additionally Eversource stated it would be just like a typical power outage

5. On the morning of the swap-over from the old transformer to the new transformer, Eversource first disabled one of the primary side phases by removing one of the 3 fuses from one of the cut-out switches installed on the primary side of the old transformer. The action resulted in the single-phasing event.

6. The main circuit breaker for the 100 Building was left in the closed position, which allowed power to flow from the old transformer to all the equipment in the 100 Building, even though one of the phases was disabled. At this point some of the equipment in the building experienced no effect from the single-phasing event since they were not wired to affected phase. Other equipment experienced a 50% drop in voltage. All 3-phase motors experienced the substantial voltage unbalance. Several of the heat pump units automatically opened their internal circuit breakers to protect the equipment.

7. The generator for the 100 Building detected the substantial voltage unbalance, started-up and transferred the life safety equipment from the normal (unbalanced voltage) to the generator within 5 seconds of detecting the voltage unbalance. It was within those 5 seconds that damage most likely occurred to the CLC microprocessor board and the CLC power supply for elevator controller and the EDT equipment

8. The additional fuses were removed from the primary side of the transformer resulting in a complete shut-down of power to the 100 Building.

9. Eversource then entered the 100 Building transformer vault to complete wiring the new secondary conductors from the new transformer to the existing secondary conductors which are then wired to the main switchgear.

10. Once the wiring was completed Eversource then energized the new transformer one phase at a time, once again causing a single-phasing event and resulting voltage sag. Any equipment that were able to withstand the first voltage sag probably were rendered useless with the second event.

Conclusion:

On June 2, 2016, a single phasing event was experienced by electrical and electronic equipment located in the100 Building when the utility company de-energized and then re-energized the building one phase at a time without opening the building's main circuit breaker. Single phasing events can damage electronic equipment within 1 second and therefore is the subject of several Institute of Electrical and Electronic Engineers (IEEE) publications on how to protect against these events. It does not appear these guidelines were followed when Eversource completed the transformer swap-over on June 2, 2016.

Not all equipment in the building was overtly damaged. The explanation could be that some equipment did not experience the single-phasing event since they were not wired to the affected phases. Additionally, equipment wired to uninterruptable power supplies would be protected against voltage sags.

Reference (a) provides guidance to utility companies on how to protect against single phasing events. Shutting off the main circuit breaker to the building would have protected all equipment in the building from the single phasing event.

Please let me know if you have any questions.

Sincerely,

Lee D. Consavage

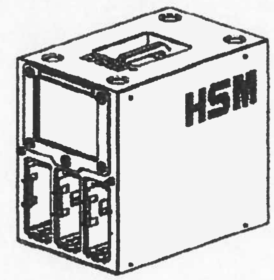
Lee Consavage, PE

July 14, 2016

CT Proposal # E0515D-18

Mr. Dan Casperson
EDT Ensconce Data Technology
100 Market St – Suite 202
Portsmouth, NH 03801

EDT



Dear Dan:

We are pleased to offer you this budgetary proposal for the following assembly:

Assembly	Quantity	Unit Price	Total Cost	Lead Time
108797 Rev. 1 DS200 HSM	4	$49,500.00	$198,000.00	See Note 3

Notes:

1. The above cost is for budgetary purposes only and is to be confirmed once a full proposal phase is completed.
2. Columbia Tech suspects that obsolete items may be present and Engineering resources will e required to identify proper alternate items. The cost for any Engineering resources required is not included on the above cost and will be quoted separately as required.
3. Lead time of the assembly will be confirmed after a full proposal phase is completed.

Columbia Tech offers a vast array of world class Engineering Services including:

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- Test Equipment Design
- Test Fixture Development

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In an effort to improve the control of our printed circuit board assemblies while providing an added benefit to our customers of traceability, Columbia Tech will be implementing a Bar Code Serial Number Tracking Label on all printed circuit boards we assemble.

Thank you for your time and interest in Columbia Tech and the opportunity to quote your requirements. We look forward to working with you.

If you have any questions or comments please feel free to contact me at (508) 929-4643.

Sincerely,

Alexis Vallejos

Vice President, Successful Product Launches

cc: Chris Coghlin, Jim Coghlin, Gerry Burns, Bill Laursen, Scott Nordstrom.