



Transient and Temporary Overvoltage Protection

Chapter 13

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Kermit Phipps, EPRI

SUMMARY

Real-world electrical environments in residential, commercial, and industrial facilities experience a gamut of overvoltage disturbances. Examples of overvoltage disturbances include surges and temporary overvoltages (TOVs). There are also a number of surge subcategories, such as ring-wave surges (typically generated within industrial facilities) and impulsive surges (mostly associated with lightning). Ring-wave surges typically do not cause damage to line fuses and metal-oxide varistors (MOVs) but may upset equipment. The impulsive surge, on the other hand, does typically damage line fuses, MOVs, and other components in end-use equipment.

MOVs are the most common front-end protective elements of most electronic appliances and equipment. They are designed to dissipate the energy that results from a surge voltage. This energy is a product of the clamping voltage and the current, which is dissipated by the MOV when its resistance suddenly decreases, thus clamping the surge voltage.

With proper coordination of line fuses and MOVs, equipment can be protected from multiple surges of less than 4,000 volts. However, while MOVs work well with short-duration surges, they are not—by themselves—designed to protect equipment from TOVs, which, according to the Institute of Electrical and Electronics Engineers, is “an oscillatory overvoltage associated with switching of relatively long duration.” Nevertheless, proper coordination of line fuses and MOVs may prevent equipment failure resulting from shorter-duration and lower-magnitude TOVs.

This chapter discusses the industry standard definitions for *surge* and *TOV*. Some characteristics and causes of temporary overvoltages are described in detail. Included is a discussion about an EPRI study of TOVs, which provides information regarding the duration and magnitudes of overvoltages. From this information, a suggested immunity level is derived. The chapter concludes with a discussion about line- and load-side protection and recommendations for equipment protection.

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Temporary overvoltages are typically caused by switching, faults, or nonlinearities.

WHAT IS A SURGE VERSUS A TEMPORARY OVERVOLTAGE?

Because TOVs and surges are both types of overvoltages that can cause damage to equipment, novice equipment designers—who are just becoming familiar with the different types of overvoltages in the areas of power quality and system compatibility—may confuse a TOV with a surge. Designers may also not be familiar with TOVs.

Because a TOV can easily be confused with a surge, some putative definitions are in order. To distinguish the differences, consider the industry standard definitions developed by the Institute of Electrical and Electronics Engineers (IEEE) for both surges and TOVs.

What Is a Surge?

Because surges are the result of natural and man-made electrical phenomena 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 the term applies to specific electrical environments and/or equipment. Generally, one can merge the various definitions of *surge* to create a single working definition:

A transient wave of voltage, current, or power in an electric circuit, which usually rises rapidly to a peak value and then falls more slowly to zero.

The duration of a surge is not tightly specified, but it is usually less than a few milliseconds.

Temporary Overvoltage Definitions

A temporary overvoltage is best defined in IEEE Standard 100-2000 and in IEEE Standard C62.41.1-2002. According to 100-2000, a TOV is “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.”

TOVs are typically caused by switching, faults, and/or nonlinearities. They are characterized by their amplitude, the oscillation frequencies, the total duration, and the manner in which they decay.

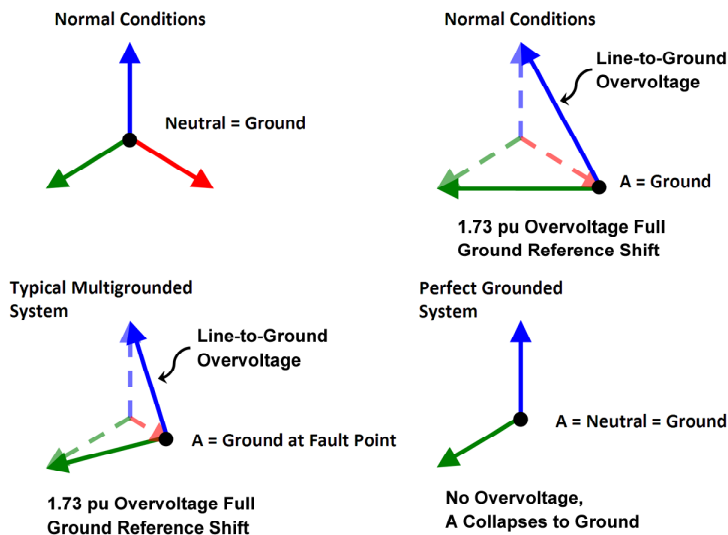
CAUSES AND CHARACTERISTICS OF TEMPORARY OVERVOLTAGE

The five most common causes of TOVs on the electric power system are faults, loss of a secondary neutral, ferroresonance, poor voltage regulation, and accidental contact with high-voltage circuits. Some but not all of these events are generated at the distribution level.

Faults

The system grounding configuration constrains the types and levels of overvoltages that can occur during a line-to-ground fault. A single line-to-ground fault shifts the ground potential at the fault location. The severity of this shift in ground reference depends on the grounding configuration, as shown in the figure to the left. On a solidly grounded system with a good return path to the grounding source, practically no reference shift occurs. On an ungrounded system, a full offset may occur—the line-to-ground voltage on the unfaulted phases rises to the line-to-line voltage, which is 1.73 per unit. On a multigrounded distribution system with a solidly grounded station transformer, overvoltages above 1.3 per unit are rare.

Phase Shift Caused by Line-to-Ground Faults



A single line-to-ground fault shifts the ground potential at the fault location depending on the grounding configuration.

With a broken neutral on a 120/240V service to a residence, the voltage in the neutral conductor can float.

In some cases, a double line-to-ground fault causes overvoltages that are slightly higher than the single line-to-ground fault. But because single line-to-ground faults are more common, systems are often designed for primarily the single line-to-ground fault.

IEEE suggests overvoltage multiplier factors for different systems, as shown in the table below. The multipliers include the neutral shift during line-to-ground faults at a voltage of 105% (the ungrounded system therefore has an overvoltage of $1.73 \times 1.05 = 1.82$). The higher overvoltage factor of 1.35 for multigrounded systems with metal-oxide arresters was identified as a more

conservative factor for four-wire systems because of the reduced saturation of newer transformers and the use of metal-oxide arresters (they are always connected, so they are more sensitive to overvoltages than older arresters, which have an isolating gap).

Loss of a Secondary Neutral

Open neutral connections in 120/240 V customer installations can occur and have been reported under several circumstances, including:

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

Note that all of the above are “when” clauses—not “if and when”—because all of these circumstances are likely to occur at some point.

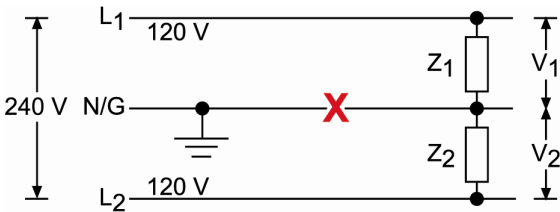
With a broken neutral on a 120/240 V service to a residence, the voltage in the neutral conductor can float. The overvoltage is a function of the load imbalance between the two 120-V legs. The leg with lighter loading will have higher voltage, and the leg with heavier loading will have lower voltage. The figure to the left shows a diagram of this circuit condition (note the broken neutral represented by a red X).

In the case of a broken neutral, which is a worst-case scenario, the voltage on the lightly loaded leg can reach nearly 240 V. Under most circumstances, even if the neutral is broken, the earth should form a connection from the earth-to-neutral bond at the service entrance back to the transformer’s neutral through the pole ground. But unfortunately, this impedance can be high enough to still cause a significant overvoltage on the leg with lighter loading.

Overvoltage Factors Based on Different Grounding Configurations

Type of System	Overvoltage Factor
Ungrounded	1.82
Four-Wire Multigrounded (Spacer Cable)	1.50
Three- or Four-Wire Ungrounded (Open Wire)	1.40
Four-Wire Multigrounded (Open-Wire Gapped)	1.25
Four-Wire Multigrounded (Open-Wire Metal-Oxide Arrester)	1.35

A Broken Neutral at a Residential Service



A voltage divider with an open neutral causes an overvoltage on the leg with lighter loading.

Occasionally, overvoltages occur because of the malfunction or misapplication of utility voltage-regulation equipment.

Ferroresonance

Ferroresonance is a special form of series resonance between the magnetizing reactance of a transformer and the system capacitance. A common form of ferroresonance occurs during single-phasing of three-phase distribution transformers¹. This most commonly happens on cable-fed transformers because of the high capacitance of the cables. The transformer connection is also critical for ferroresonance. An ungrounded primary connection leads to the highest magnitude of ferroresonance. Due to ferroresonance in this condition, utilities use three-phase transformer connections with a grounded-wye primary, especially on underground systems. The chance of ferroresonance is determined by the capacitance (cable length) and by the core losses and other resistive loads on the transformer².

Poor Voltage Regulation

Occasionally, overvoltages occur because of the malfunction or misapplication of utility voltage-regulation equipment. Some scenarios that could cause overvoltages include:

- Regulator installed or set incorrectly.
- Malfunctioning voltage regulator.

- Capacitor-bank controllers with an incorrect clock setting.
- Malfunctioning capacitor-bank controller.

If one or more capacitors are switched on at light load, the capacitors can push the voltage above normal. Another factor that can cause a high voltage is the sudden loss of load. If a recloser is downstream of a regulator and the recloser trips, the remaining customers may have high voltage until the regulator adjusts its taps to compensate.

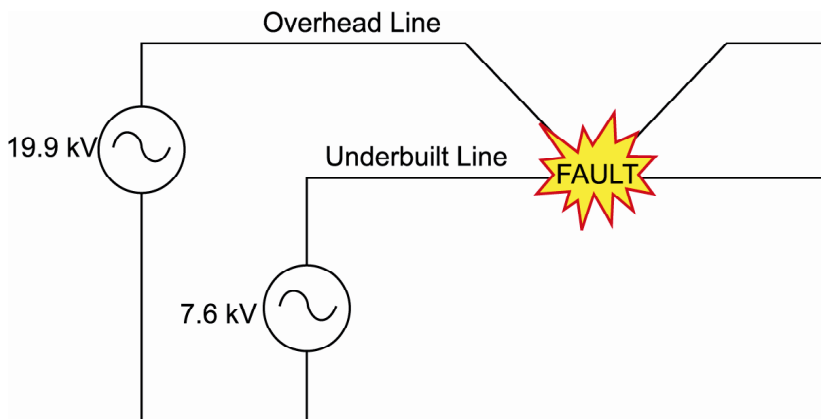
Accidental Contact with High-Voltage Circuits

Faults caused by the contact between transmission circuits and distribution circuits are another hazard that can expose distribution equipment and customer equipment to extremely high voltages. Consider the example of a fault from a subtransmission circuit to a distribution circuit shown in the figure below. Overvoltages are not extremely high as long as the distribution circuit stays connected. But if a distribution interrupter opens the circuit, the voltage on the faulted distribution conductor jumps to the full transmission-line voltage. With voltages being higher than normal, damage to end-use equipment can be expected. The distribution interrupter, either a circuit breaker or recloser, may not be able to clear the fault (the recovery voltage is many times normal) and may fail trying.

Faults farther from the distribution substation cause higher voltages, with the highest voltage at the fault location. Current flowing back toward the circuit causes a voltage rise along the circuit.

In this situation, distribution transformers would saturate, and metal-oxide arresters would move into heavy conduction. Transformer saturation distorts the voltage but does not appreciably reduce the peak voltage. When 19.92 kV comes in contact with 7.62 kV, the maximum voltage on the 7.62-kV phase is 2.61 times normal voltage

A Fault Caused by Transmission and Distribution Lines Crossing



If a distribution interrupter opens a circuit during a transmission-line cross, the voltage on the faulted distribution conductor jumps to the full transmission-line voltage.

The two databases created during the Distribution Power Quality projects can be queried for any events with a given set of magnitude and duration parameters, including the five most common TOV scenarios.

without the dampening effect of arresters. Arresters can reduce the peak voltage, but customers may still see substantial high voltages.

EPRI SURVEY OF TOV EVENTS

There is an existing database of power-line disturbance data taken by EPRI as part of a multi-year nationwide project. Since the completion of the Distribution Power Quality (DPQ) Project in 1996³, the data have been queried and polled in many ways and have been used in countless technical reports and presentations in order to illustrate the types of events that occur and the frequency of their occurrence on distribution circuits across the United States.

The project included a monitoring period that began in June of 1993 and lasted through September of 1995. It included a set of power-line monitors in 277 locations across the United States, with the cooperation of 24 host utilities. As the name indicates, these monitors were installed at distribution locations such as just outside the substations, at the middle of distribution feeders, and near the end of distribution feeders.

In the year 2000, EPRI began another nationwide power quality survey, but with additional types of monitoring equipment and at different system locations (primarily distribution locations). The Distribution Power Quality II Project included the analysis of data from about 480 existing monitors across the United States, covering the time period between August of 1993 and December of 2002, although the majority of the data covered the time period of April of 2000 through April of 2002⁴.

The two databases created during these projects can be queried for any events with a given set of magnitude and duration parameters. The table below shows the boundaries used in the query for events based on the five most common TOV scenarios.

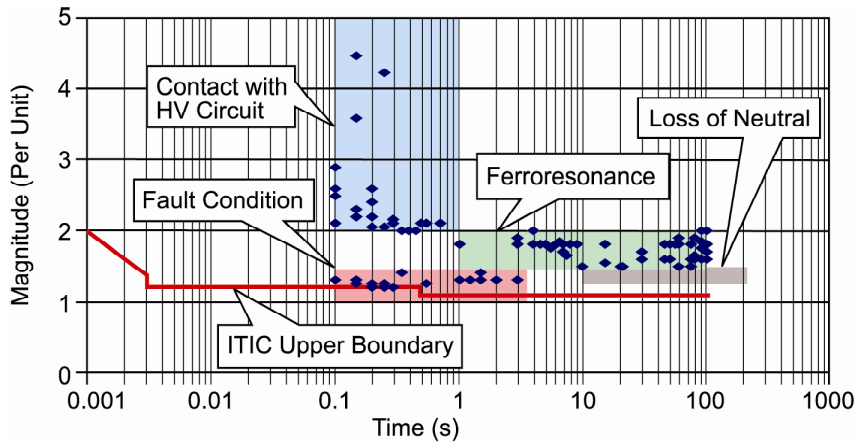
The scatter plot on the following page is the result of a database query for all five types of TOV events. The data points represent magnitudes and durations of TOV events that were recorded during the original DPQ project. Although the actual causes of these events are unknown, they are shown here only because their magnitude and durations fall into the range considered typical for TOV events described in this chapter. As a result, no importance should be placed on the number of events within a particular category. Bounding rectangles show the relative positions of four of the five queries (events due to poor regulation fall outside the graph area because of their long durations).

The upper boundary of the Information Technology Industry Council (ITIC) curve is shown for reference. The ITIC publishes a well-known curve representing the expected tolerance of computer equipment (no failures or interruption in performance are expected for events occurring below the curve). However, the ITIC curve is not intended to be a design criterion for equipment or the AC power system.

Query of the DPQ/DPQ II Database Based on Magnitude and Duration of a TOV Event

Magnitude	Duration	Event
1.2 to 1.3 PU	0.1 to 2 s	Fault
1.3 to 1.5 PU	60 to 300 s	Loss of secondary neutral
1.1 to 1.15 PU	> 30 min	Poor regulation
1.5 to 2.0 PU	1 to 180 s	Ferroresonance
2.0 to 5.0 PU	0.1 to 1 s	Contact with a high-voltage circuit

The Results of TOV Database Queries

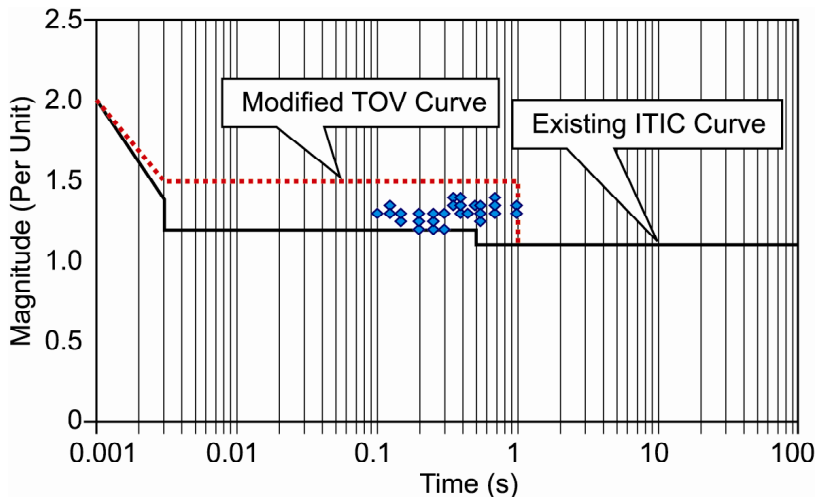


The TOV data from the DPQ project indicate that TOVs fall outside the tolerance envelope of single-phase information-technology equipment designed to meet the ITIC voltage-tolerance curve.

DEFINING IMMUNITY

As shown in the previous figure, all TOV events in the DPQ database are above the ITIC upper boundary, indicating that they may damage equipment or cause a malfunction. It is clear that the ITIC curve and the existing DPQ data can be used in establishing if not an immunity requirement then at least a design guide for protection against not just transient overvoltages but temporary overvoltages as well.

A More Robust Design Curve Based on Existing TOV Data and the ITIC Curve



A modified voltage-tolerance curve that envelopes more TOVs may encourage manufacturers to build products with higher overvoltage immunity.

The International Electrotechnical Commission (IEC) has an upper boundary that depends on equipment type. For example, the IEC requires that an uninterruptible power supply (UPS) be immune to TOV events up to 1.5 PU. The 1.5 PU corresponds to the findings of the EPRI DPQ project in North America, which is a completely different power system than is found in Europe. Based on the IEC UPS immunity limits for TOVs, a design curve can be established by modifying the existing ITIC curve for typical power quality events to include TOV and loss of neutral up to 1.5 PU, as shown in the illustrated example below.

The modified curve does not include left-branching TOVs (voltages higher than 2 per unit and lasting less than 1 millisecond) and right-branching TOVs (voltages lower than 1.2 per unit and lasting more than 100 seconds). This is because it is not practical to build equipment to withstand the type of voltages that are seen when commingling of circuits occur, nor is it practical to be able to build equipment to withstand a sustained ferroresonance. Fortunately, these events are rare. However, in the case where the magnitude is large and/or the overvoltage lasts more than 1 second, protection against such an overvoltage is typically performed by a sacrificial component—usually some type of surge-protection device that automatically cuts off the load and may perish in the process of opening the circuit to the load, requiring the device to be replaced.

ARRESTERS USED FOR LINE-SIDE PROTECTION

There is very little that can be done on the line side to protect against excessive temporary overvoltages caused by commingling of lines during storms or auto accidents that knock down a pole. However, over the years, a number of engineers have experimented with the application of station-class lightning arresters for protection against temporary overvoltages.

The use of two arresters at different voltage ratings increases the reliability of suppression of the TOV during a temporary commingling of lines.

Normally, an arrester is used for transient-voltage protection due to lightning events and static discharges. However, due to the amount of energy associated with a temporary overvoltage, the arresters are quick to fail. When the arrester fails, an arc forms between it and the lines, forming a low-impedance shunt until the circuit is cleared. An arrester with a disconnect can be used without seriously jeopardizing the normal performance against lightning.

A better approach in this scheme is the use of two arresters at different voltage ratings, which increases the reliability of suppression of the TOV during a temporary commingling of lines. It is likely that the lower-voltage arrester will be sacrificed in the process, but the arrester is inexpensive when compared to the damage that a TOV can cause along the influenced line. Although an arrester may be an inexpensive solution, it is not a bullet-proof solution because end-user equipment still needs to be robust to ensure survival during high-energy transients and temporary overvoltages.

PROTECTION OF EQUIPMENT

Effectively protecting equipment from surges and temporary overvoltages requires a consideration of many factors, such as the surge environment within a building, physical limitations of the protective devices, front circuit components such as diodes and capacitors, and requirements for an acceptable (non-dangerous) mode of failure when a protective device succumbs to a transient or TOV. The first step to ensure robustness is to address the energy-handling ability of MOVs and understand the surge environment.

There are several types of devices that are available to industry to protect equipment against TOVs, such as constant-voltage transformers (CVTs) and uninterruptible power supplies. However, these devices are not used by

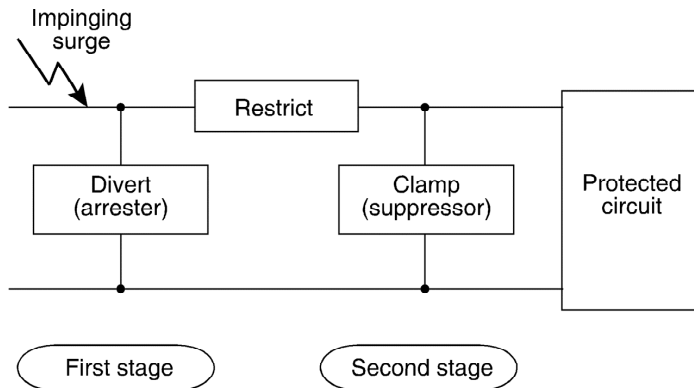
the public in general. The average homeowner may use a UPS to protect a computer, but other household appliances containing electronic controls usually can rely only upon built-in protection.

In the low-voltage (end-user) environment, surge-protection schemes act by diverting an impinging surge through a low-impedance path to return the surge current to its source, or they act by restricting the propagation of a surge between its point of origin and the equipment to be protected. Protection can be accomplished in one or several stages, depending on the system configuration and the degree of freedom available to the users for connecting protective devices at different points of their systems.

In its simplest form, diversion can be effected by a device connected in parallel (line to neutral or line to ground) as opposed to in series, hence the commonly used name “shunt-connected SPD” (surge-protective device). A shunt-connected SPD is also categorized in industry standards as a “one-port SPD.” In a more comprehensive form, surge protection is brought about in several stages by combining diversion and restriction.

As shown in the figure on the following page, the first stage of a multistage approach diverts the current caused by an impinging high-energy surge through a high-energy-handling device (arrester), which is typically installed at the service entrance or other service panel. Between the first and second stages of multistage surge protection, some restriction to the propagation of surge currents in branch circuits is inherently provided by the inductance of the premises wiring or by insertion of a discrete inductor. The second stage is provided by an SPD of a lesser surge-handling capability than the arrester, often called a *surge suppressor* or *surge protector*, which is typically located close to the equipment in need of protection as an add-on, plug-in device or incorporated within the equipment by the manufacturer.

A Multistage Approach to Protecting Equipment from Surges



A multistage approach to surge protection includes diverting, restricting, and clamping high-energy surges.

The multistage approach to surge protection has been implemented by the majority of manufacturers, giving emphasis to the diverting function of a shunt-connected SPD, such as the one shown in the figure below. The definition of a surge-protective device adopted by the IEEE as well as by the IEC explicitly states that an SPD should contain at least one nonlinear component, such as an MOV. This position reflects the implicit design philosophy that surge protection can be accomplished by diverting the surge through a shunt-connected component.

A Multistage SPD



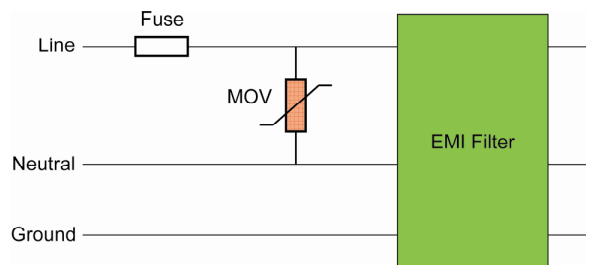
Most multistage hybrid SPDs contain both nonlinear MOVs and linear inductors but emphasize the diverting function.

BASIC CIRCUIT PROTECTION

To protect equipment from surges, MOVs are located in various circuit locations of end-use equipment. To protect against surges incident on the AC power line, they are located at the AC power input of the equipment before the electromagnetic interference (EMI) filter, as shown in the first figure below. MOVs may also be used on the DC bus of computer power supplies, 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 the application shown in the second figure.

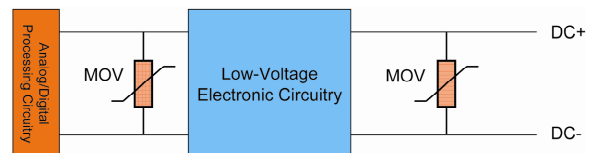
MOVs and other SPDs located on AC power inputs and low-voltage control circuits are vulnerable to failure. MOVs are designed to absorb the electrical energy contained in surges to prevent that energy from causing damage to active and passive electronic components located downstream of the line

Location of an MOV to Protect the AC Power Input



Most MOVs are installed at the inputs of AC power circuits.

Low-Voltage Applications of MOVs



Some MOVs are installed on DC buses and control circuits.

Nuisance failures of equipment 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 a metal-oxide varistor are sized and coordinated in the proper manner.

fuse and upstream of a connection to a DC low-voltage control circuit. For example, when a surge impinges upon the AC line input, MOVs effectively reduce the surge voltage to levels that will not cause damage to electronic components. In the course of reducing the surge voltage and dissipating energy, MOVs heat up.

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 that have higher voltage magnitudes (such as 3.2 kilovolts) and shorter durations (such as 50 microseconds) will cause less MOV heating than surges of lower voltage magnitudes and the longer duration. Also, MOVs with larger diameters (such as 20 millimeters) are designed to handle more surge energy than MOVs with smaller diameters.

Coordination of MOVs, Fuses, and Thermal Cut-Offs to Achieve Adequate Levels of Protection

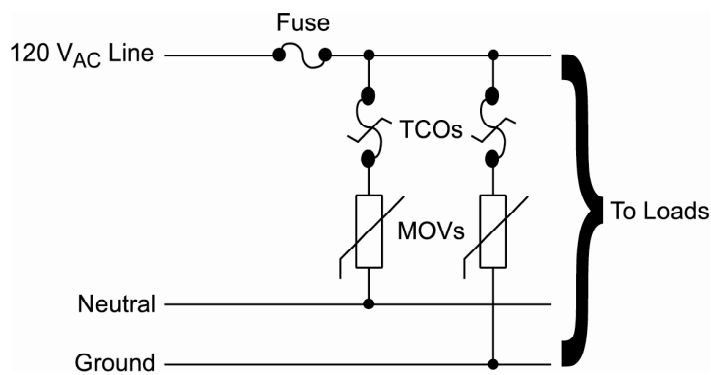
Design requirements imposed by Underwriters Laboratories (UL) require that a fuse be located upstream of an MOV when the MOV is connected line-to-neutral or line-to-ground. However, MOVs connected from neutral to ground do not require fuse protection. Fuse

protection of an MOV will reduce the likelihood of an MOV fire resulting from extreme surge currents flowing through the MOV. All of the front-end MOVs should have the same MCOV rating. In addition, 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 the design of surge protection 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 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 also violate UL requirements. Thus, this practice is not recommended by the power quality community for obvious reasons. Nuisance failures of equipment (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.

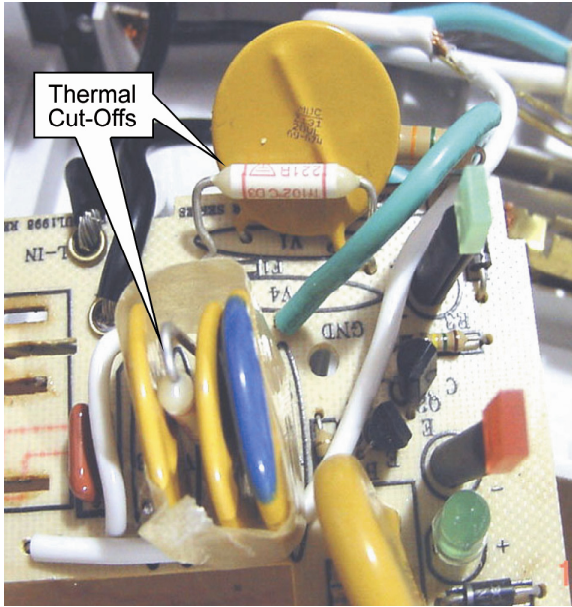
An improved MOV design provides for thermal protection for the MOV without the use of coordinating fuses. Thermal protection can be provided by external or embedded thermal cut-offs (TCOs), which are available for different operating temperatures. The diagram to the left shows a circuit with thermally protected MOVs. An external TCO must be positioned and oriented with respect to an 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 rapidly begin to self-heat when conduction current is sustained through the MOV. Therefore, the TCO must touch the MOV to be protected. The figure at the top of the following page illustrates an example of a typical arrangement of MOVs and TCOs.

Diagram of a TCO/MOV Surge-Protective Circuit



A thermal cut-off prevents an MOV from self-destruction during thermal runaway.

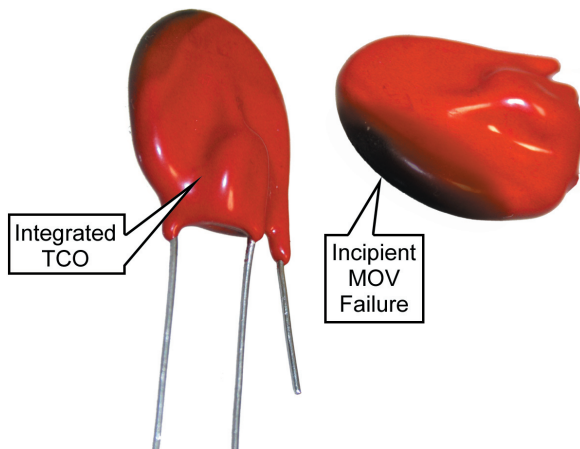
Locations of TCOs in a Typical Application



External TCOs must be precisely located next to MOVs to protect them from thermal runaway.

Some MOVs have integrated TCOs, in which case they are called TMOVs. The figure below shows a TMOV with the outline of the integrated TCO clearly visible (left). The right side of the figure shows a TMOV that started to fail (see the scorched left part of the disc) but was saved from thermal runaway by the TCO interrupting the current through it.

A TMOV Saved by Its Internal TCO



The internal thermal cut-off of this TMOV saved the device from catastrophic failure caused by thermal runaway.

It is not uncommon for equipment users to send dysfunctional equipment from the field to the manufacturers for investigation. Upon failure investigations, manufacturers often find that only the line fuse has been blown with no damage to other components, including the MOVs. Manufacturers know that there are a number of causes for the failure of line fuses, 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.

Surge- and TOV-related failures of line fuses are caused by MOV current conduction. This conduction is a function of the MOV's rating for clamping voltage. If the MOV clamping (suppression) voltage 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 (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. Thus, selecting an MOV with a high clamping voltage and MCOV rating will help avoid failures of line fuses and MOVs caused by a high line voltage 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 clamping voltage of 395 V and an MCOV of 150 V will be sufficient in most cases. In 277-volt applications, selecting an MOV with a clamping voltage of 845 V and an MCOV of 320 V will be adequate.

CONCLUSION

A reasonable amount of protection against transients and temporary overvoltages can be achieved by adding protective schemes to both the line and the equipment side of the distribution system. A surge is different from a TOV, but in both cases, the popular metal-oxide varistor is used.

MOVs are designed specifically to reduce surge voltage appearing on input and output circuits in end-use equipment. When a surge voltage is reduced to a level 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 TOVs. Although TOVs have lower peak voltages than surges, they are much longer in duration than surges. In equipment design, the size and type of fuse and MOV matter when trying to coordinate the fuse and MOV to reduce premature failure of equipment that otherwise would have continued to operate. As a result, 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 (whether the failure was caused by surges or TOVs).

Four primary principles can be followed for selecting effective surge protection. First, the physical size of the MOV should be a minimum of 20 mm in diameter for surviving a raw surge environment. Second, to survive continually changing voltage levels, an MOV should have a maximum continuous operating voltage that is at least 25% higher than the rated line voltage. Third, the SPD information published by the manufacturer or the results of private stress testing should clearly demonstrate a robust design by showing that the SPD survived a minimum of 1,000 surges at 1-minute intervals at the selected surge environment category, preferably the IEEE C62.41.2 2002 Combination Wave at 6 kV and 3 kA as a minimum. And last but not least, MOVs should have thermal cut-offs or some other protection against thermal runaway and the consequential risk of fire. By adhering to these four principles, one can ensure a robust and safe SPD design.

NOTES

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