SURGE SUPPRESSOR FIRES

Surge suppressors are devices used in electronic power equipment to protect the equipment from voltage transients (spikes) that could otherwise cause damage.

BY MARK E. GOODSON—The most common example of a surge suppressor application is a power strip, as shown in photo 1. The surge suppressor in this application is actually an internal device (or group of devices) which attempts to protect data processing equipment from high voltage spikes that come from the AC power line. Photo 2 shows several surge suppressor components as they are located internally in the power strip.

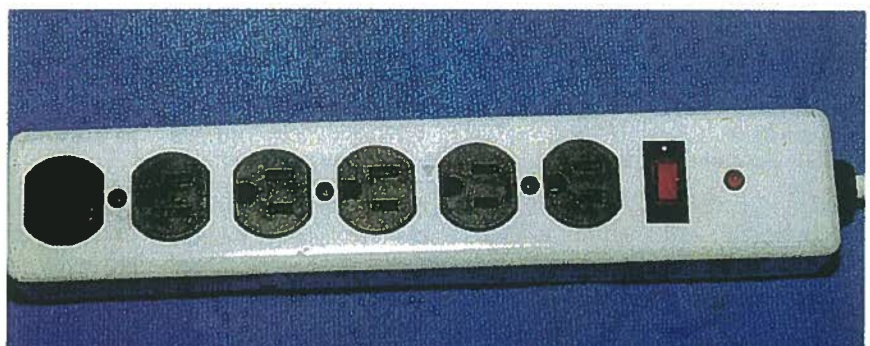


PHOTO 1—Front view of surge suppressor strip

Theory of operation

The surge suppressor referred to in this article are generically known as Metal Oxide Varistors, or MOVs. The MOV can best be thought of as a switch that has a certain the hold, and is sired in parallel form (shunt) across the incoming power leads to an appliance. Figure 1 shows the schematic of an MOV in parallel across the incoming leads of a transformer. The voltage rating of the MOV would be chosen such that it would be greater than the nominal 120 VAC supply that is anticipated, but less in value than a voltage which might damage circuitry. For a 120 VAC input transformer, an MOV might be selected which would be rated at 150 or 175 volts (these are AC RMS values). For this example, an MOV rated at 150 volts RMS will be nonconductive for a 120 VAC waveform. If, however, the incoming voltage were 175 volts, the MOV would serve to clamp the voltage at about the 150 volt level. Rather than the transformer seeing a 175 VAC sine wave, it now sees a 'clipped' sine wave, as shown in Figure 2. The MOV, acting as a switch with a 150 VAC threshold, closes when the voltage exceeds

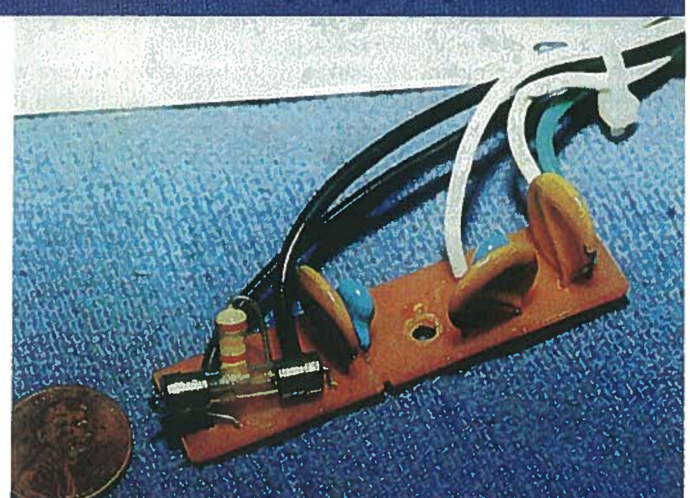


PHOTO 2—Internal component view of surge suppressor strip

150 VAC, and then opens up when the voltage drops below 150 VAC.

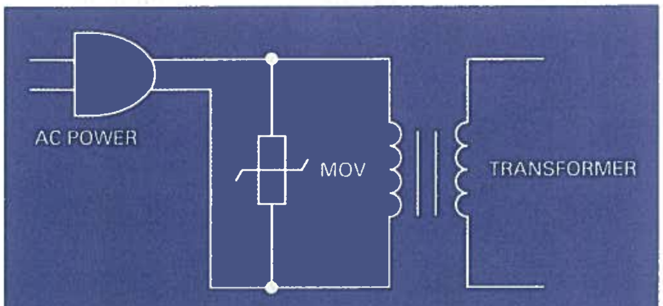


Fig. 1: Power transformer with MOV across input

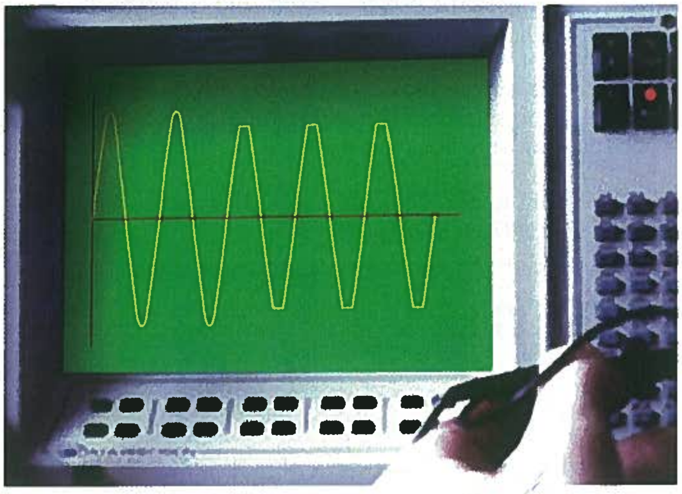


Fig. 2: Sine wave clipped by MOV

In modeling the MOV as an ideal switch, we have a device that draws no current when the voltage is below the threshold voltage, and this same device draws infinite current when the voltage exceeds the threshold. Below and near the threshold, the current draw of the switch is in the microampere region. When the threshold is greatly exceeded, the MOV is capable of drawing in excess of several hundred amperes. As soon as the voltage drops below the threshold, the current level will (theoretically) drop to the microampere level. In order to demonstrate the rapid transition of an MOV, a test was run using a computer, a programmable AC voltage source, and an MOV rated at 160 volts. The voltage to the MOV was applied for 2 cycles at a given voltage, turned off for 5 seconds, and then increased by 1 volt and once again powered for 2 cycles. The power dissipated by the MOV remained at about .15 watts as AC voltage was in the 194 to 198 VAC level. When the voltage changed to 199 volts, power jumped to over 16,000 watts (for about 400 uS); the MOV was first heard to pop, and then it stated smoking and burst into flames.

In order to demonstrate fire causation tendencies, an additional test was conducted on a MOV rated at 150 volts, and which was fed 240 volts AC. Figure 3 shows a plot of temperature as a function of time.

Application of MOVs

The modern day MOV is the mainstay of many surge suppressors. It works by clipping voltage spikes and keeping these spikes or transients at levels that will not damage electronic equipment. MOVs are commonly used on power strips, computers, printers, stereos, televisions, telephone systems, burglar alarm systems, and even GFIs (Ground Fault Interrupters). They are intended for squelching transient voltage spikes, which by definition are somewhat random and often unpredictable.

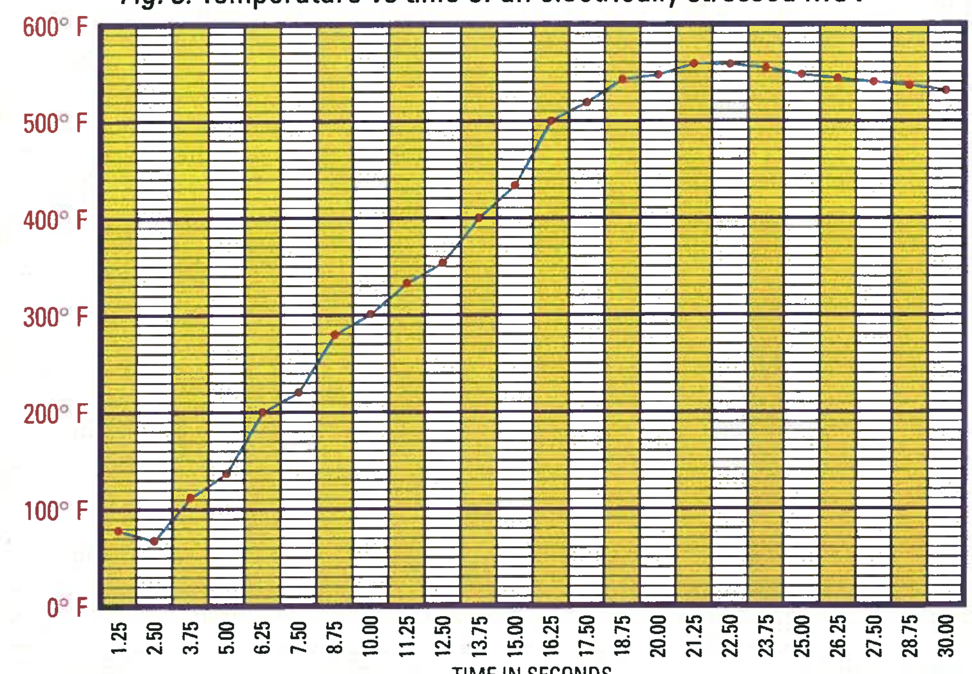
On a GFI, an MOV would be useful in protecting the circuitry from voltage transients created when a pool pump motor is in use. In that GFIs are commonly around swimming pool equipment, the GFI circuitry would see some of these voltage spikes during normal operation of the electric pump motor. Testing by the writer on a pool system showed voltage transients approaching 300 volts AC. The MOV placed on the GFI can protect the circuitry from the voltage spikes; in use, the MOV is placed across the incoming line and neutral terminals for the GFI. The use of an MOV in protecting a GFI is described in a publication by National Semiconductor[1].

On a power strip with surge suppression capabilities, it is not uncommon to use 3 separate MOVs. An MOV is placed across the line to neutral circuit, the line to ground to circuit, and the neutral to ground circuit, as shown in Figure 4. The neutral to ground circuit is one that probably requires explanation. It is not unheard of to have a duplex outlet wired such that the line and neutral wires are reversed; while this violates the NEC, appliances will still function. By including an MOV across the neutral to ground connection, one will be insured of having surge suppression regardless of how an outlet is wired. Just as with the GFI, the MOVs used in the power strip application are intended for short lived disturbances, which we have been calling transients.

Real world MOV performance

In an ideal world, the use of MOVs for surge suppression would not be a problem. It is because the world is not ideal that many of us routinely investigate fires; fires are

Fig. 3: Temperature vs time of an electrically stressed MOV



sometimes the result of a device being designed for the ideal world, and not the real world. MOVs are no exception to the rule that ideal world and real world performance are quite different.

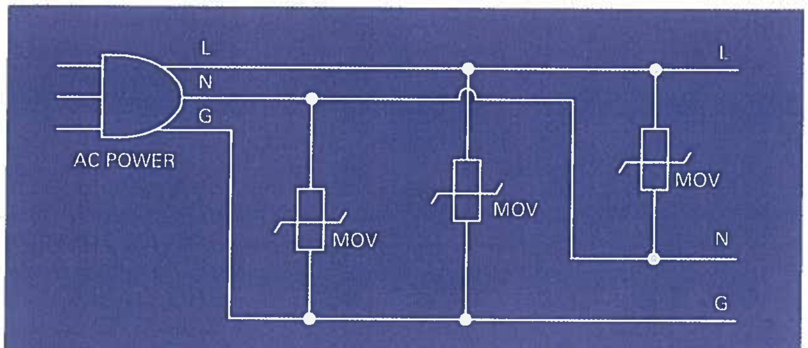


Fig. 4: LNG surge suppressor

One IEEE publication makes use of 3 terms in describing increases in voltage: transient, swell, and Temporary Over Voltage (TOV)[2]. Using the IEEE terms, we have the following definitions:

Transient-a disturbance where the increase is less than several cycles
Swell-an increase in voltage for more than one cycle and less than a few seconds
TOV-an increase in voltage lasting several hundred milliseconds or longer.

The conditions described by these definitions are extremely important in understanding MOV performance. The first realty associated with MOVs is that they do not see line disturbances that are only 'transient' in nature. If we assume a 120 VAC sine wave at 60 Hz as the norm, a 20 or 30 uS pulse with an amplitude of 50 volts that is superimposed on the sinusoid could be considered as transient in nature. If instead the MO V was protecting a branch circuit that suddenly changed from 120 to 240 VAC, and then remained at this higher voltage, this would certainly be considered a swell (at a minimum) and possibly a TOV. While one may think this increase in voltage is rare, it is exactly the kind of voltage variation that can occur when a condition known as a 'floating neutral' occurs. Regardless of how this voltage shift is classified (swell or TOV), or why it originated, a 240 VAC line that is applied to an MOV rated at about 200 volts or lower will cause the MOV to 'explode' violently. Photo 3 shows two 130 volts MOVs, one that is new and one that has been subjected to a continuous overload of 240 volts. The MOV disintegrated within 1/2 cycle of the 240 VAC being applied.


Photo 3—Destroyed and new MOV.

The second reality associated with MOVs is that they are not ideal switches; they do have a finite impedance. The value of this impedance is dynamic, and changes with both the voltage applied (and its duration) and as a function of previous surge suppression activities. If a switch is not ideal (i.e., it has some resistance), then it will heat up, with the power being dissipated a function of the current and the resistance; the formula is of course I^2*R. The energy is of course I^2*R*T, where I is the current in amperes, R is the resistance in ohms, and T is the time in seconds. In one experiment conducted by the author, the fault current that flowed through a 150 volt MOV when 240 AC was applied was measured at 280 amperes. In a data sheet published by one manufacturer of surge suppressors, peak surge current was listed as 6500 amperes.

An additional reality with MOVs is that they can degrade over time, depending upon the usage that they see. If an MOV is called upon to 'arrest' a transient voltage spike, the energy that is converted to heat during the arrest can actually alter the MOV. One of the standards that applies to MOVs ANSI/IEEE C62.33[3], lists a parameter known as Lifetime Rated Pulse Current Tests. The same standard also lists a parameter known as Rated Peak Single Pulse Transient Current Test. The implication of all this information is that MOVs do change their performance over time. As such, they can be expected to fail. If they fail in such a way that the threshold voltage is approaching the normal line voltage, a fire can occur.

The C62.33 standard also speaks of failure modes for MOVs. The standard defines a Short Circuit Failure Mode, one in which the MOV drops in impedance to a value of less than 100 ohms when 1 VDC is applied. Another failure mode, Degradation Failure Mode, occurs when the voltage threshold has changed to less than 90% of original voltage value. Both of these failure modes are once again indicative of a device that changes its performance over time and usage.

Fire Causation

That MOVs can cause fires is no surprise to those who are well aware of their characteristics. The best example that this writer knows of comes from a woman whose business burned down. The fire was thought to have been caused by a power strip, but the fire was so destructive that the only remaining piece of the power strip was an empty metal shell - the terminals, line cord, circuit breaker, and MOVs were not recovered. When asked why she though that the power strip has caused a fire, the business owner stated that she had already bought 4 of them and every time she plugged one in, it started smoking and emitting flames. Each time, she had unplugged the unit, and then plugged the next one in. After 4 separate 'fire' episodes, she went to the store and bought a new brand. Examination of the 4 surge protectors by this engineer (they were not damaged by the building fire) confirmed that each of the MOVs protecting the line - ground circuit was burned open. The line-neutral and neutral-ground MOVs were intact, and the wiring at the building was correct. In addition, voltage checks found no reason for an abnormal voltage. What was determined was that the MOVs across the line - ground circuit were of an imbreakdown. Simply put, the MOVs were dissipating more energy than they were rated for, and thus disintegrated. The power strips that failed originally (all 4 of them) were made by a different manufacture than the one suspected of causing the fire. In this case, there was no physical evidence remaining on the 'suspect power strip on which to come to the conclusion that it caused the fire.

Is this an unsafe product?

Because of its fire-causation tendencies, one must wonder if the MOV is a dangerous product. The answer, in this writer's opinion, is 'NO.' The MOV is reacting in the only manner it can when it is electrically overstressed. What is unsafe is the manner in which MOVs are designed into some circuits - many MOVs have been incorporated into designs in a way that ignores the fact that MOVs can cause fire.

One way of designing around the fire-causing tendencies of MOVs is to use an 'arrestor disconnector,' as it is referred to by IEEE[4,5]. An arrestor disconnector is a device which serves to disconnect an arrestor (i.e., an MOV) if the MOV is entering a region of operation which is unsafe. In its simplest form, an arrestor disconnector could be a fuse placed in series with the MOV, as shown in Figure 5. Indeed, one product manufacturer uses such a scheme to protect the MOV in its GFI design[6]. In this design, the fuse will prevent the MOV from causing a fire by its usual disintegration; the fuse is designed to open before the MOV is destroyed. The disadvantage to this scheme is that one the MOV is open it offers no protection from transients. Also, the user of the GFI will have no notice that the MOV circuit has now opened; any surge protection benefits that the MOV offers have now been removed. A further compromise that occurs in placing the MOV in series with the fuse is that the fuse blows too quickly (and thus protects the MOV), the transient may continue and the load that the MOV was designed to protect will still be damaged.

A second way in which to protect the MOV is to place the fuse so that it protects both the MOV and the lad, as shown in Figure 6; when the MOV begins to fail and thus blows the fuse the entire load becomes dead. The obvious advantage is that the user is now

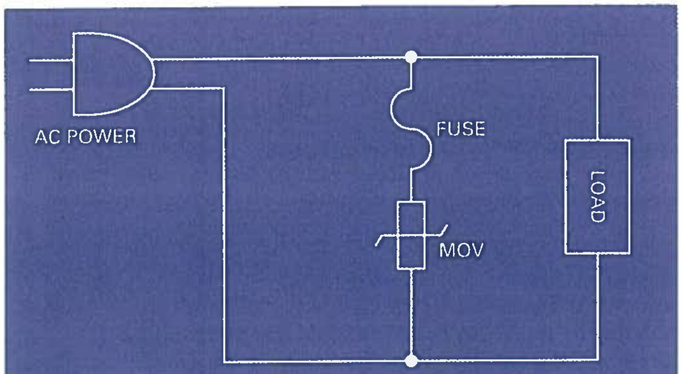


Fig. 5: Load with MOV in series with fuse

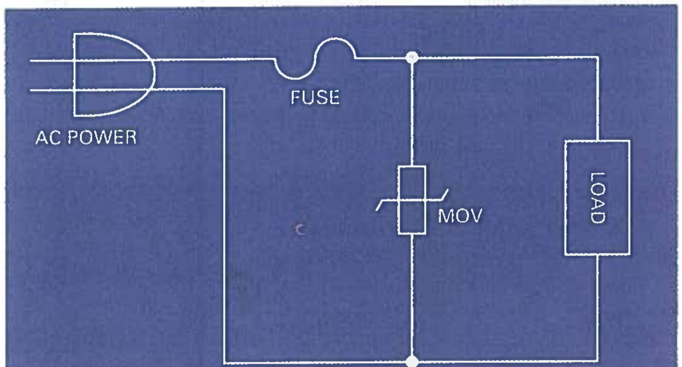


Fig. 6: Load with fuse in series with both load and MOV

aware of the blown fuse, because none of his appliances downstream will function. The disadvantage is the same - the same incoming pulse which caused the fuse to blow and thus protect the MOV has now de-energized the load. If the load is a computer, there is then the chance of lost data, corrupted files, etc. With the fuse protecting only the MOV (as in Figure 5), data will not be lost; the surge protection that the MOV offered has been lost, with future spikes or transients being unsuppressed.

Some manufacturers use a thermal fuse or Thermal Cut Off (TCO) to achieve thermal protection for a surge suppressors. In operation, the TCO will respond to heat from the MOV, and will electrically open up if the MOV is getting too hot. The temperature value that the TCO is set at varies according to application. The author has seen numerous products that place TCOs on MOVs, to include power strips, surge protection outlets, and even AC to DC adapters. In use, the TCO responds to gradual overheating of the MOV, which would occur if the MOV is degrading over time. The TCO would not usually respond in sufficient time so as to prevent a fire during a TOV condition; the thermal time lag would usually be too slow to allow for reacting to this condition.

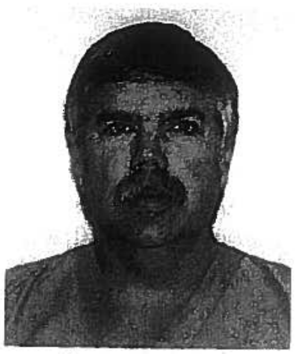
In terms of design choices and components values, the IEEE has recommended that surge arrestors used by utility companies be rated equal or greater than TOV[7]. The rationale is obviously that a surge suppressor should not fail or be placed out of service because of a TOV condition. Using this same reasoning, it follows that a safe design for an appliance operating at 120 VAC would be to specify the MOV at a rating of greater than 240 VAC - which is the maximum nominal voltage seen when a floating neutral occurs.

Underwriters Laboratory has recently rewritten UL 1449, Transient Voltage Surge Suppressors, because of the fire tendencies of MOVs[8]. A review of this standard shows numerous changes, all made in an attempt to make items such as power strips with surge suppressors operate safely. More importantly, the new standard emphasizes that a power strip should fail in such a way that a hazard is not created. The earlier version of UL 1449 encompassed less than 40 pages while the current version is over 100 pages in length.

Summation

Most surge suppressors make use of MOVs, which by nature are intended for minimizing the effects of short-lived power disturbances. Because real-would power systems include conditions more hazardous than short-lived transients, many MOVs will predictably fail under such conditions. The MOV is not a defective product, even though when it fails it can produce fires. It is imperative that persons designing surge suppression circuits account for the environment in which an MOV is used in so as to reduce the risk of fires.

References
[1] National Semiconductor, LM1830 Data Sheet.
[2] IEEE, Standards Collection C62, Surge Suppression, 1995
[3] IEEE, Standard C62.33, Standard Test Specification for Varistor Surge Protective Devices, 1981
[4] IEEE, Standard C62.1, Standard for Gapped Silicon-Carbide Surge Arrestors for Power Circuits, 1989.
[5] IEEE, Standard C62.11, Standard for Metal Oxide Surge Arrestors for Alternating Current Power Circuits, 1993
[6] Roberts, Earl, Overcurrents & Undercurrents, Repcon Publishing, 1996.
[7] IEEE, Standards C62.2, Standard for the Application of Gapped Silicon-Carbide Surge Arrestors for Alternating-Current Systems, 1987.
[8] Underwriters Laboratory, Standards for Safety, UL 1449 Transient Voltage Surge Suppressors, 1996.



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