

Introduction

This note details the common tests of varistor parameters and describes suitable test methods using simplified test circuits.

All tests are performed at 25°C, unless otherwise specified. The test circuits and methods given herein are intended as a general guide. Since the tests frequently entail high voltages and currents, the user must exercise appropriate safety precautions.

Engineering Evaluation

It is important to focus on the key characteristics and ratings to determine if the component can perform as expected. Typically, for a varistor, its nominal voltage, clamping voltage, standby current, insulation resistance, and capacitance are measured. The surge current, or energy, and waveshape available in the circuit together with its frequency of occurrence should be measured or computed. The characteristics of these expected transients should then be checked against the pulse ratings and the power dissipation ratings of the selected varistor type. Where suitable equipment is available, these ratings may be verified.

Product Qualification

A product qualification plan often will be used to detail the electrical and environmental tests to which sample components may be subjected. The suggested electrical characteristics tests could include (with appropriate conditions and limits): nominal varistor voltage, V_N ; maximum clamping voltage, V_C ; DC standby current, I_D (optional, especially for AC applications); insulation resistance; and capacitance. A test to ensure surge current withstand capability may be included in the qualification plan. This test must be carefully performed and specified (by using either 8/20 μ s or 10/1000 μ s waveshapes) consistent with the pulse lifetime rating chart of the varistor selected. Other qualification tests may be used to ensure mechanical integrity, humidity resistance, solderability, and terminal/lead strength.

Incoming Inspection

The equipment maker may wish to verify that shipments received consist of correct parts at the expected quality level. For incoming inspection of Littelfuse Varistors, it is recommended that sample testing include nominal varistor voltage (V_N) tested against the minimum and maximum voltages specified on the purchase drawing/specification. Other electrical sampling tests frequently performed can include insulation resistance and capacitance. Tests such as maximum clamping voltage, V_C , and DC standby current, I_D , are usually checked only on a periodic audit basis.

Field Maintenance

Field maintenance testing is done to verify that the varistor is still providing the intended protection function.

The nominal varistor voltage should be tested against the minimum limits for the model using the method described in the Nominal Varistor Voltage V_N section. If the varistor is open, short, or more than 10% outside either limit, it should be replaced. The DC standby current may also be measured.

Measurement of Varistor Characteristics [1]

Nominal Varistor Voltage V_N

This is measured at a DC test current, I_N of 1mA for product models. A simplified circuit for instrumenting this test, shown in Figure 1, is suitable for varistors up through a rating of 300V_{RMS}. Above the 300V_{RMS} rating, a higher supply voltage will be needed. Resistor R1 has a dual purpose. In conjunction with the variable voltage supply, E1, it forms a quasi-current source providing up to 6mA when switch S1 is closed. Also, R1 is used as a current sensor to measure current flowing through the varistor-under-test. To use the circuit, the operator places switch S2 in position I and S3 in position V_N . A test device is then inserted into the socket and S1 is closed. E1 is then adjusted to obtain a reading of 100V \pm 5V on the digital voltmeter. Approximately 1mA of current will be flowing in R1. When switch S2 is placed in position V, the varistor voltage will be indicated on the voltmeter. The values of R1 and E1 supply voltage can be scaled appropriately for other voltage-current test points.

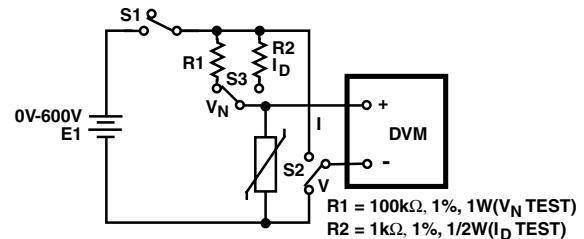


FIGURE 1. SIMPLIFIED CIRCUIT FOR VARISTOR VOLTAGE AND DC STANDBY CURRENT TESTS

If the varistor voltage test is implemented on automatic test equipment, a “soak” time of 20ms minimum should be allowed after application of test current before voltage measurement. This is necessary to allow varistor voltage to settle toward a steady-state value. Figure 2 illustrates the time response of a specimen varistor with a constant 1.0mA current applied. As can be seen, the varistor voltage initially may rise to a value up to 6% greater than final. With a 20ms or greater soak time, the measured value will differ by less than 2% from the steady-state value.

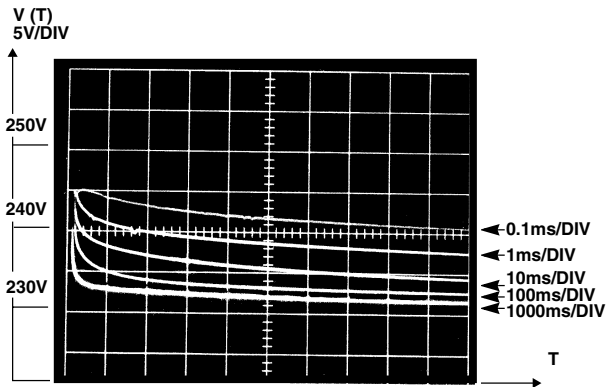


FIGURE 2. VOLTAGE-TIME V(T) CHARACTERISTICS OF A LITTELFUSE VARISTOR (V130LA10A) OPERATING AT A CONSTANT DC CURRENT OF 1.0mA

For varistor models that are commonly used on 60Hz power lines, the V_N limits may be specified for a 1.0mA peak AC current applied. If an AC test is preferred by the user, a schematic approach similar to that shown in Figure 1 is used, except an AC VARIAC™ is substituted for the DC power supply, and an oscilloscope is substituted for the voltmeter. This circuit is equivalent to that of a typical curve tracer instrument.

To avoid unnecessary concern over minor measurement anomalies, three behavioral phenomena of metal-oxide varistors should be noted. First, it is normal for the peak varistor voltage measured with AC current to be about 2% to 5% higher than the DC value, as illustrated by Figure 3. This “AC-DC difference” is to be expected, since the one-quarter cycle period of a 60Hz wave is much less than the 20ms minimum settling time required for DC readout.

Second, it is normal for the varistor voltage to increase slightly when first subjected to electrical current, as shown in Figure 4. This might be considered a “break-in” stabilization of the varistor characteristics. During normal measurement

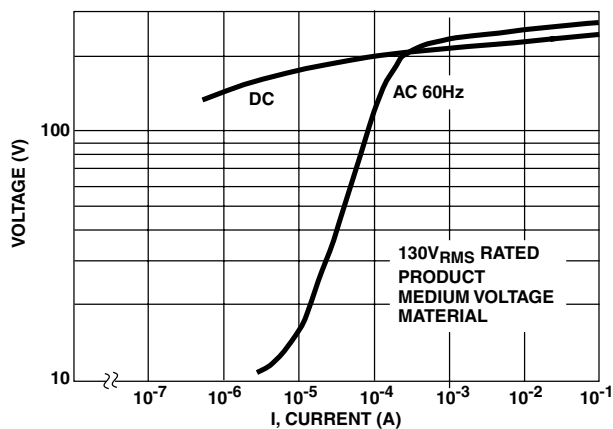


FIGURE 3. AC AND DC CHARACTERISTIC CURVES

the voltage shift typically is less than 1%. This voltage shift is of little consequence for most measurement purposes but might be noticeable when viewing a DVM as in the test method of Figure 1. The visual DVM observation should be made shortly after power is applied, with measurement to not more than three significant figures.

Third, it is normal for the varistor voltage-current characteristic to become slightly asymmetrical in polarity under application of DC electrical stress over time. The varistor voltage will increase in the same direction as the polarity of stress, while it will be constant or will decrease in the opposite polarity. This effect will be most noticeable for a varistor that has been subjected to unipolar pulse stresses or accelerated DC life tests. Therefore, to obtain consistent results during unipolar pulse or operating life tests, it is essential to provide a polarity identification for the test specimens. However, for initial readout purposes, this effect usually is insignificant.

Maximum Clamping Voltage, V_C

Two typical current impulses that may be used to define the varistor clamping voltage are the 8/20 μ s and the 10/1000 μ s pulses. Figure 5 shows typical varistor test waveforms for these two impulses.

The clamping voltage of a given model varistor at a defined current is related by a factor of the varistor voltage. Therefore, a test of the nominal varistor voltage against specifications may be sufficient to provide reasonable assurance that the maximum clamping voltage specification is also satisfied. When it is necessary to perform the V_C test, special surge generators are required. For shorter impulses than 8/20 μ s, precautions must be observed to avoid an erroneous “overshoot” in the measurement of the clamping voltage. The Equipment for Varistor Electrical Testing section gives general information on surge generators; a brief description of the “overshoot” effect follows.

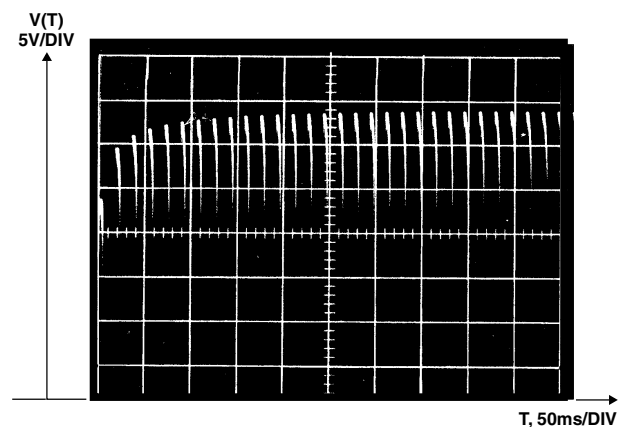


FIGURE 4. V130LA10A) VARISTOR VOLTAGE FOR THE INITIAL CYCLES OF 60Hz OPERATION AT A PEAK CURRENT OF 1.0mA

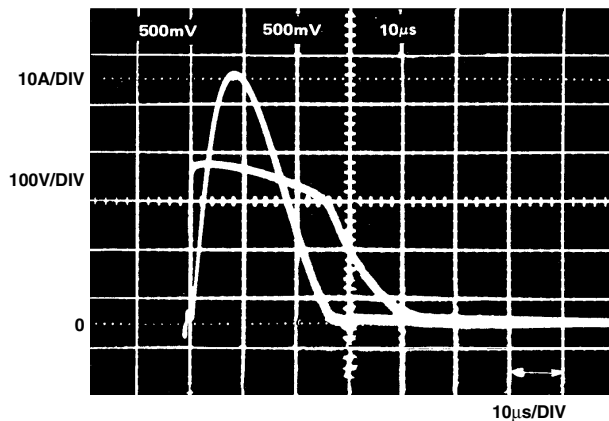


FIGURE 5A. 8/20µs, WAVE $I_p = 50A$, $V_p = 315V$

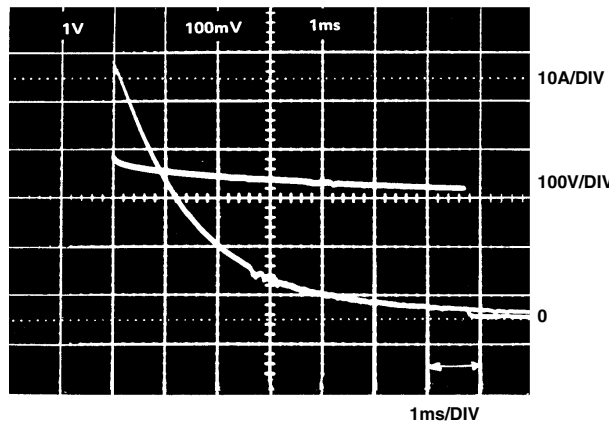


FIGURE 5B. 10/1000µs, WAVE $I_p = 50A$, $V_C = 315V$

FIGURE 5. TYPICAL CLAMPING VOLTAGE TEST WAVEFORMS (LITTELFUSE
FIGURE 6. VARISTOR TYPE V130LA10A)

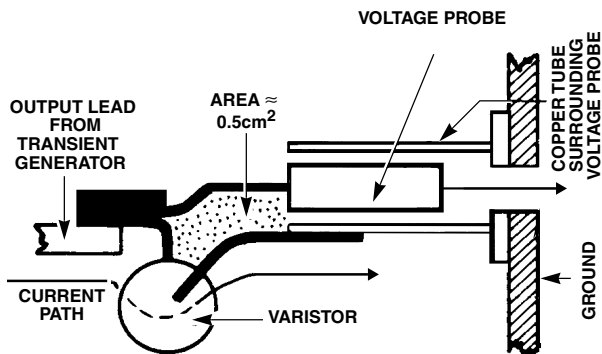


FIGURE 7A. MINIMAL LOOP AREA

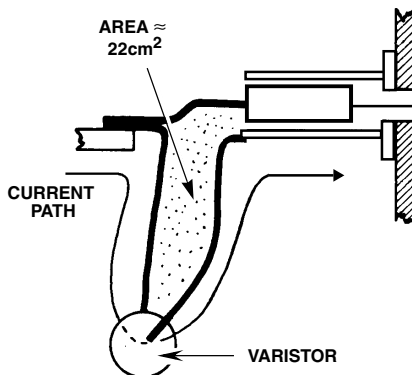


FIGURE 7B. EXCESSIVE LOOP AREA TYPICAL
“OVERSHOOT” OF LEAD-MOUNTED VARISTOR
WITH STEEP CURRENT IMPULSES

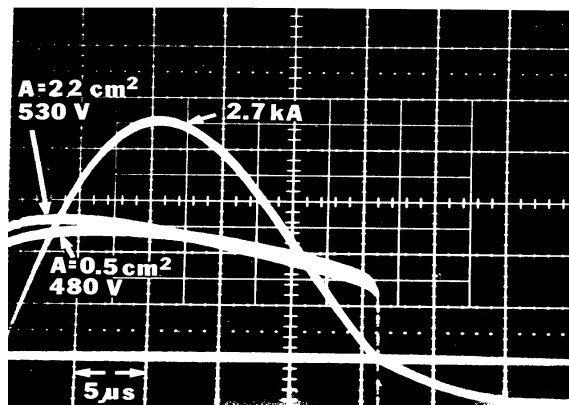


FIGURE 7C. CURRENT RISE OF 8µs

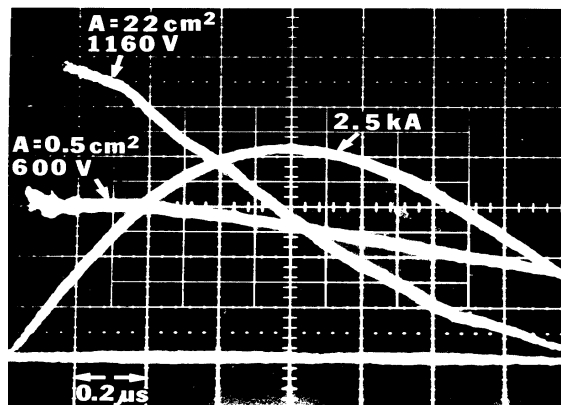


FIGURE 7D. CURRENT RISE OF 0.5µs

FIGURE 7. EFFECT OF LEAD LENGTH ON “OVERSHOOT”

The Littelfuse Varistor specification sheets show the VI characteristic of the devices on the basis of maximum voltage appearing across the device during a current pulse of 8/20 μ s. If current impulses of equal magnitude but faster rise are applied to the varistor, higher voltages will appear across the device. These higher voltages, described as “overshoot,” are partially the result of an intrinsic increase in the varistor voltage, but mostly of the inductive effect of the unavoidable lead length. Therefore, as some applications may require current impulses of shorter rise time than the conventional 8 μ s, careful attention is required to recognize the contribution of the voltage associated with lead inductance [1].

The varistor voltage, because of its nonlinearity, increases only slightly as the current amplitude of the impulse increases. The voltage from the lead inductance is strictly linear and therefore becomes large as high current amplitudes with steep fronts are applied. For that reason, it is impractical to specify clamping voltages achieved by lead-mounted devices with current impulses having rise times shorter than 0.5 μ s, unless circuit geometry is very accurately controlled and described.

To illustrate the effect of lead length on the “overshoot,” two measurement arrangements were used. As shown in Figures 6A and 6B, respectively, 0.5cm² and 22cm² of area were enclosed by the leads of the varistor and of the voltage probe.

The corresponding voltage measurements are shown in the oscillograms of Figures 6C and 6D. With a slow current front of 8 μ s, there is little difference in the voltages occurring with a small or large loop area, even with a peak current of 2.7kA. With the steep front of 0.5 μ s, the peak voltage recorded with the large loop is nearly twice the voltage of the small loop. (Note on Figure 6D that at the current peak, L di/dt = 0, and the two voltage readings are equal; before the peak, L di/dt is positive, and after, it is negative.)

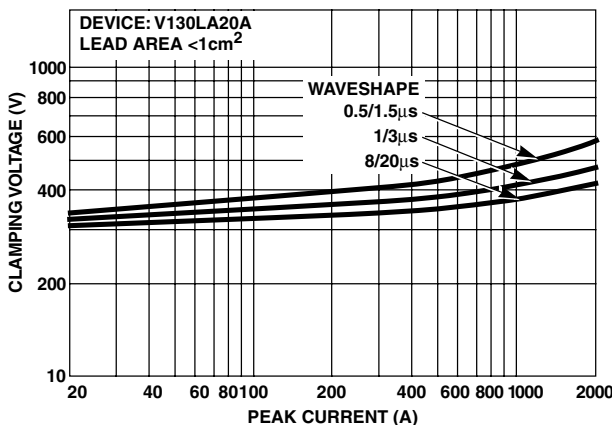


FIGURE 8. TYPICAL “OVERSHOOT” OF LEAD-MOUNTED VARISTOR WITH STEEP CURRENT IMPULSES

Hence, when making measurements as well as when designing a circuit for a protection scheme, it is essential to be alert to the effects of lead length (or more accurately of loop area) for connecting the varistors. This is especially important when the currents are in excess of a few amperes with rise times of less than 1 μ s.

With reasonable care in maintaining short leads, as shown in Figure 6A, it is possible to describe the “overshoot” effect as an increase in clamping voltage relative to the value observed with a 8/20 μ s impulse. Figure 7 shows a family of curves indicating the effect between 8 μ s and 0.5 μ s rise times, at current peaks ranging from 20A to 2000A. Any increase in the lead length, or area enclosed by the leads, would produce an increase in the voltage appearing across the varistor terminals - that is, the voltage applied to the protected load.

DC Standby Current, I_D

This current is measured with a voltage equal to the rated continuous DC voltage, V_{M(DC)}, applied across the varistor. The circuit of Figure 1 is applicable where current sensing resistor R2 has a value of 1000 Ω . The test method is to set the voltage supply, E1, to the specified value with switch S1 closed and S2 in the V position. Then S2 is placed in position I and S3 in position, I_D. S1 is then opened, the test device is inserted in the test socket, and S1 is closed. The DVM reading must be converted into current. For example, if a maximum standby current of 200 μ A is specified, the maximum acceptable DVM reading would be 0.200V.

The measurement of DC standby current can be sensitive to the device behavioral phenomena of “break-in” stabilization and polarization of the VI characteristics, as described in the Nominal Varistor Voltage V_N section. If the device under test has prior unipolar electrical history, polarity indicators should be observed and test values interpreted accordingly.

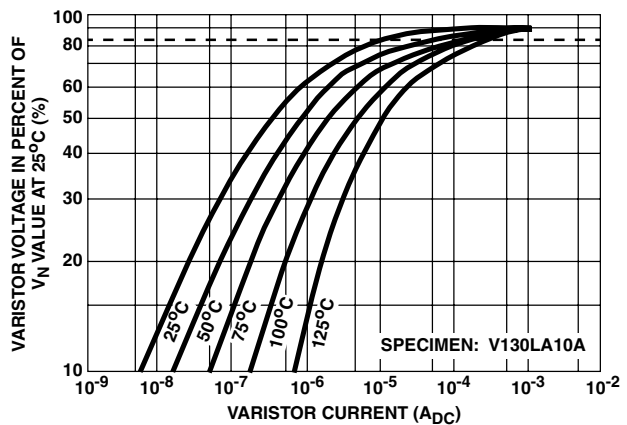


FIGURE 9. TYPICAL TEMPERATURE DEPENDENCE OF DC STANDBY CURRENT VARISTOR TYPE V130LA10A

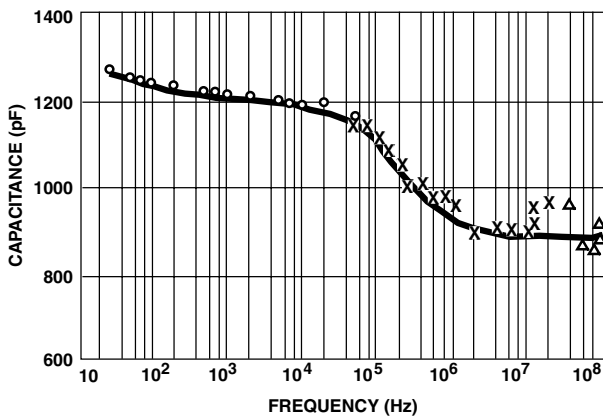


FIGURE 10. CAPACITANCE VARIATION WITH FREQUENCY

The value of DC standby current also can be sensitive to ambient temperature. This is unlike varistor characteristics measured at currents of 1mA or greater, which are relatively insensitive to ambient temperatures. With $V_{M(DC)}$ around 85% of V_N , Figure 8 shows the typical DC standby current of a model V130LA10A varistor in the order of 10 μ A or 20 μ A at room temperature. I_D increases to about 80 μ A at 85 $^{\circ}$ C, the maximum operating temperature without derating.

Capacitance

Since the bulk region of a Littelfuse Varistor acts as a dielectric, the device has a capacitance that depends directly on its area and varies inversely with its thickness. Therefore, the capacitance of a Littelfuse Varistor is a function of its voltage and energy ratings. The voltage rating is determined by device thickness, and the energy rating is directly proportional to volume.

Littelfuse Varistor capacitance can be measured through use of a conventional capacitance bridge and is found to vary with frequency, as shown in Figure 9. Typically, capacitance measurements are made at 1MHz. Dissipation factor also is frequency-dependent, as shown in Figure 10.

When measured with a DC bias, the capacitance and dissipation factor show little change until the bias approaches or exceeds the V_N value. Furthermore, the capacitance change caused by an applied voltage (either DC or AC) may persist when the voltage is removed, with the capacitance gradually returning to the prebias value. Because of this phenomenon, it is important that the electrical history of a Littelfuse Varistor be known when measuring capacitance.

Miscellaneous Characteristics

A number of characteristic measurements can be derived from the basic measurements already described, including the nonlinear exponent (alpha), static resistance, dynamic impedance, and voltage clamping ratio. The data, however,

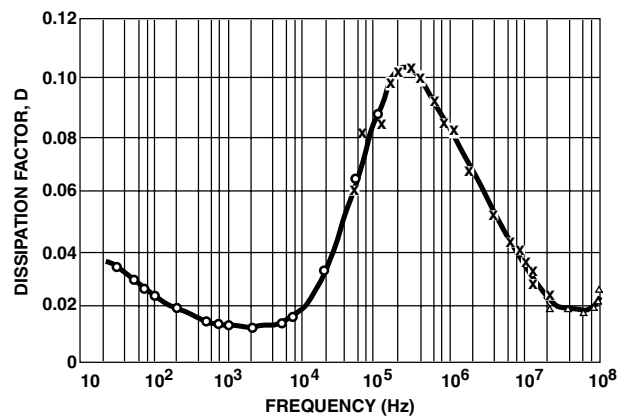


FIGURE 11. DISSIPATION FACTOR VARIATION WITH FREQUENCY

may be obtained by measurement methods similar to those already given for nominal varistor voltage and maximum clamping voltage. These miscellaneous characteristics may be useful in some cases to enable comparison of Littelfuse Varistors with other types of nonlinear devices, such as those based on silicon carbide, selenium rectifier or zener diode technologies.

Varistor Rating Assurance Tests

Continuous Rated RMS and DC Voltage [$V_{M(AC)}$ and $V_{M(DC)}$]

These are established on the basis of operating life tests conducted at the maximum rated voltage for the product model. These tests usually are conducted at the maximum rated ambient operating temperature, or higher, so as to accelerate device aging. Unless otherwise specified, end-of-lifetime is defined as a degradation failure equivalent to a V_N shift in excess of $\pm 10\%$ of the initial value. At this point the device is still continuing to function. However, the varistor will no longer meet the original specifications.

A typical operating life test circuit is shown in Figure 11. If the varistor is intended principally for a DC voltage application, then the AC power source should be changed to DC. It is desirable to fuse the varistors individually so testing is not interrupted on other devices if a fuse should blow. The voltage sources should be regulated to an accuracy of $\pm 2\%$ and the test chamber temperature should be regulated to within $\pm 3^{\circ}$ C. The chamber should contain an air circulation fan to assure a uniform temperature throughout its interior. The varistors should receive an initial readout of characteristics at room ambient temperature i.e., $25 \pm 3^{\circ}$ C. They should then be removed from the chamber for subsequent readout at 168,500, and 1000 hours. A minimum of 20 minutes should be allowed before readout to ensure that the devices have cooled off to the room ambient temperature.

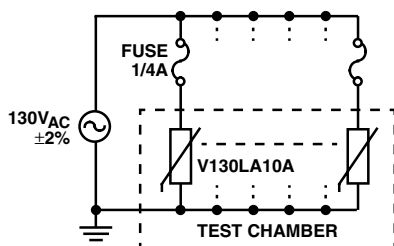


FIGURE 12. SIMPLIFIED OPERATING LIFE TEST CIRCUIT

Transient Peak Current, Energy, Pulse Rating, and Power Dissipation Ratings

Special surge generator equipment is required for testing. Since high energy must be stored at high voltages to perform these tests, especially on larger sizes of Littelfuse Varistors, the equipment must be operated using adequate safety precautions.

The peak current rating, I_{TM} of Littelfuse Varistors is based on an 8/20 μ s test impulse waveshape. The specifications include a maximum single value in the ratings table. A pulse rating graph defines the peak current rating for longer impulse duration as well, such as for a 10/1000 μ s wave. A family of curves defines the rated number of impulses with a given impulse duration and peak current.

Energy rating, W_{TM} , is defined for a 10/1000 μ s current impulse test wave. This waveshape has been chosen as being the best standard wave for tests where impulse energy, rather than peak current, is of application concern. A direct determination of energy dissipated requires that the user integrate over time the product of instantaneous voltage and current.

Peak voltage and current are readily measured with available equipment. Therefore, the energy rating can be tested indirectly by applying the rated peak impulse current of a 10/1000 μ s waveshape to the test specimen. Then, the energy dissipated in the varistor can be estimated from the known pulse waveshape. For a 10/1000 μ s waveshape the approximate energy is given by the expression $E = 1.4V_C I t$.

For example, a model V130LA10A varistor has a single pulse rating for a 10/1000 μ s impulse waveshape of about 75A peak, and a maximum clamping voltage at 75A of about 360V. Thus, the computation of estimated energy dissipation is 38J.

The transient power dissipation rating, P_{TAM} , is defined as the maximum average power of test impulses occurring at a specified periodic rate. It is computed as the estimated energy dissipation divided by the test pulse period. Therefore, varistors can be tested against this rating by applying two or more impulses at rated current with a specified period between pulses. For example, a model V130LA10A varistor has a pulse rating of two 10/1000 μ s test impulses with a peak current of about 65A. The estimated energy dissipation per pulse computed as per the preceding example is about 30J. If a period of 50s is allowed after the first test pulse, the estimated

average power dissipation can be computed as about 0.6W, which is the specification rating. It should be noted that Littelfuse Varistors are not rated for continuous operation with high-level transients applied. The transient power dissipation rating is based on a finite number of pulses, and the pulse rating of the varistor must be observed. See Figure 12.

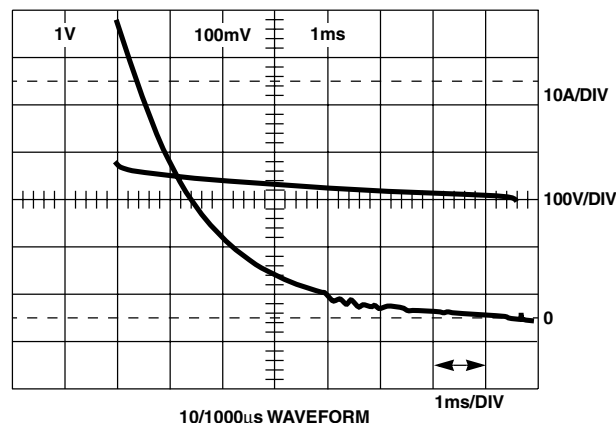


FIGURE 13. SURGE TEST WAVEFORMS

Table 1 outlines a suggested program of testing to verify varistor transient and pulse ratings with a minimum of expensive, time-consuming testing. New specimens should be used for each test level and failure judged according to the specification criteria.

TABLE 1. TESTING OF TRANSIENT CURRENT, ENERGY, PULSE RATING, AND POWER DISSIPATION RATINGS

TEST PARAMETER	NO. PULSES AT RATED CURRENT (ALTERNATING POLARITY)	TEST WAVESHAPE (μ s)	MINIMUM PULSE PERIOD (s)
Maximum Peak Current	1 (Same Polarity as Readout)	8/20	NA
Pulse/Energy Rating, Power Dissipation	2	10/1000 or 2ms Square Wave	50
Pulse Rating	10	8/20	25
Pulse Rating	100	8/20	12

Continuous Power Dissipation

Since Littelfuse Varistors are used primarily for transient suppression purposes, their power dissipation rating has been defined and tested under transient impulse conditions. If the devices are to be applied as threshold sensors or coarse voltage regulators in low power circuits, then a dissipation test under continuous power is more appropriate. This continuous power test will aid the user in determining if the device is suitable for his specific application.

A circuit for continuous power dissipation testing is shown in Figure 13. The DC power supply voltage should be set to a value of approximately twice the nominal varistor voltage of the product model under test. In that case, nearly constant power dissipation is maintained in the varistor. Since the circuit transfers nearly equal power to the series resistor and varistor-under-test, the series resistor value is simply chosen to achieve the test design value of power dissipation. In Figure 13 a nearly constant power dissipation of about 0.6W is obtained.

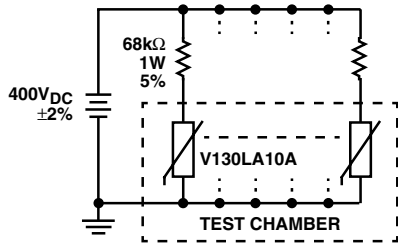


FIGURE 14. CONSTANT POWER LIFE TEST CIRCUIT

Mechanical and Environmental Testing of Varistors

Introduction

Many tests have been devised to check the reliability of electronic components when subjected to mechanical and environmental stresses. Although individual equipment makers may specify their own tests on component purchase documents, these tests are often based on an equivalent MIL-STD specification. Therefore, it is convenient to summarize these tests in MIL-STD terms. Since the ratings of Littelfuse Varistors may vary with product series and model, the test conditions and limits should be as specified on the applicable detail specification.

Littelfuse Varistors are available in a high reliability series. This series incorporated most standard mechanical and environmental tests, including 100% pre-screening and 100% process conditioning.

UL Recognition Tests

The standards of Underwriters Laboratories, Inc. (UL) under which applicable Littelfuse Varistors have been tested and recognized are:

- UL-1449 Transient Voltage Surge Suppressors, File E75961
- UL-1414 Across the Line Components, File E56529
- UL-497B Protectors for Data Communications, File E135010

The tests were designed by UL and included discharge (withstand of charged capacitor dump), expulsion (of complete materials), life, extended life, and flammability (UL94V0) tests, etc.

Equipment for Varistor Electrical Testing

Impulse Generators

A convenient method of generating current or voltage surges consists of slowly storing energy in a capacitor network and abruptly discharging it into the test varistor. Possible energy storage elements that can be used for this purpose include lines (lumped or distributed) and simple capacitors, depending on the waveshape desired for the test. Figure 14 shows a simplified schematic for the basic elements of an impulse generator.

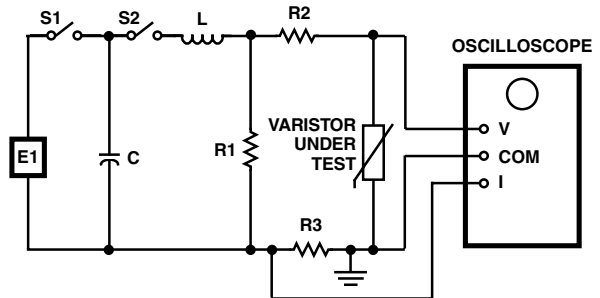


FIGURE 15. SIMPLIFIED CIRCUIT OF SURGE IMPULSE GENERATOR

The circuit is representative of the type used to generate exponentially decaying waves. The voltage supply, E1, is used to charge the energy storage capacitor, C, to the specified open-circuit voltage when switch S1 is closed. When switch S2 (an ignition or a triggered gap) is closed, the capacitor, C, discharges through the waveshaping elements of the circuit into the suppressor device under test. With capacitances in the order of 1 μ F to 10 μ F and charging voltages of 10kV to 20kV, the typical 8/20 μ s or 10/1000 μ s impulses can be obtained by suitable adjustment to the waveshaping components L, R1, and R2, according to conventional surge generator design [2, 3, 4, 5].

Measurement Instrumentation

Transient measurements include two aspects of varistor application: (1) detection of transients to determine the need for protection, and (2) laboratory measurements to evaluate varistor performance. Transient detection can be limited to recording the occurrence of transient overvoltages in a particular system or involve comprehensive measurements of all the parameters which can be identified. Simple detection can be performed with peak-indicating or peak-recording instruments, either commercial or custom-made.

Test Waves and Standards

The varistor test procedures described in this section have been established to ensure conformity with applicable standards [6], as well as to reflect the electromagnetic environment of actual circuits [7] which need transient protection.

Test Waves

A number of test waves have been proposed, in order to demonstrate capability of survival or unimpeded performance in the environment. A proposal also has been made to promote a transient control level concept [7] whereby a few selected test waves could be chosen by common agreement between users and manufacturers. The intent being that standard test waves would establish certain performance criteria for electronic circuits.

Source Impedance

The effective impedance of the circuit which introduces the transient is an extremely important parameter in designing a protective scheme. Impedance determines the energy and current-handling requirements of the protective device.

When a transient suppressor is applied, especially a suppressor of the energy-absorbing type, such as a varistor, the transient energy is then shared by the suppressor and the rest of the circuit, which can be described as the "source".

As in the case of waveshapes, various proposals have been made for standardizing source impedances. The following list summarizes the various proposals intended for AC power lines:

1. The Surge Withstand Capability (SWC) standard specified a 150Ω source.
2. The Ground Fault (UL-GFCI) standard is 50Ω source [8].
3. The Transient Control Level (TCL) proposals of Martzloff et. al. [7] include a 50Ω resistor in parallel with a 50μH inductor.
4. The installation category concept of ANSI/IEEE Standard C62.41-1980 implies a range of impedances from 1Ω to 50Ω as the location goes from outside to inside.
5. The FCC regulation for line-connected telecommunication equipment implies a 2.5Ω source impedance [9]. However, the requirement of the FCC is aimed at ensuring a permanent "burning" of a dielectric puncture and does not necessarily imply that the actual source impedance in the real circuits is 2.5Ω.
6. Reported measurements [10] indicate the preponderance of the inductance in branch circuits. Typical values are μH per meter of conductors.
7. There is no agreement among the above proposals on a specific source impedance. Examining the numbers closer, one can observe that there is a variance between 2.5Ω to about 50Ω. Going back to ANSI/IEEE Standard C62.41-1980 by using the Open Circuit voltage (OCV) and SCI (short circuit current) for the different location categories, one can calculate a source impedance.

Any practical power circuit will always have some finite impedance due to the resistance and inductance of the power line and distribution transformer. Table 2 shows representations of the surge source impedance implied in the environment description of ANSI/IEEE C62.41-1980.

TABLE 2. SOURCE IMPEDANCE AT DIFFERENT LOCATION CATEGORIES IN LOW VOLTAGE AC SYSTEMS (UP TO 1000V)

Category A Ring Wave	6kV/200A = 30Ω
Category B Ring Wave	6kV/500A = 12Ω
Category B Impulse	6kV/3kA = 2Ω
Category C Impulse	10kV/10kA = 1Ω

The impedance of industrial or commercial systems generally supplied by underground entrances, or a separate substation of relatively large kVA rating, tends to be low, and the injection of any lightning transients occurs at a remote point. This results in lower transient peaks than those that can be expected in residential circuits, but the energy involved may be, in fact, greater. Therefore, transient suppressors intended for industrial use should have greater energy-handling capability than the suppressors recommended for line-cord-powered appliances.

References

For Littelfuse documents available on the web, see <http://www.littelfuse.com/>

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- [10] F.D. Martzloff, "The Propagation and Attenuation of Surge Voltages and Surge Currents in Low-Voltage AC Circuits," IEEE Transactions on Power Apparatus and Systems, PAS-102, pp. 1163-1170, May 1983.