Selecting a Littelfuse Varistor

Application Note | July 1999 | AN9771.1

Introduction

The varistor must operate under both a continuous operating (standby) mode as well as the predicted transient (normal) mode. The selection process, therefore, requires a knowledge of the electrical environment. When the environment is not fully defined, some approximations can be made.

For most applications, the selection is a five-step process:

1. Determine the necessary steady-state voltage rating (working voltage)
2. Establish the transient energy absorbed by the varistor
3. Calculate the peak transient current through the varistor
4. Determine power dissipation requirements
5. Select a model to provide the required voltage-clamping characteristic

A final consideration is to choose the appropriate package style to suit the application.

Steady-State Voltage Rating

Consider the maximum continuous voltage that will be applied to the varistor including any high line conditions (i.e., 110% or more of nominal voltage). Ratings are given for continuous sinusoidal AC and DC voltages. If a nonsinusoidal waveform is applied, the recurrent peak voltage should be limited to $\sqrt{2}$x $V_{M(AC)}$.

Specifications for the UltraMOV™ Series varistor, for example, are shown in Table 1 for 140V AC rated devices to illustrate the use of the ratings and specifications table.

$V_{M(AC)}$ - These models can be operated continuously with up to 140V_{RMS} at 50Hz - 60Hz applied. They would be suitable for 120V_{AC} nominal line operation and would allow for about a 120% high line condition.

$V_{M(DC)}$ - Operation up to 180V_{DC} applied continuously is allowed.

Energy

Transient energy ratings are given in the **W_{TM}** column of the specifications in joules (watt-second). The rating is the maximum allowable energy for a single impulse of 10/1000µs current waveform with continuous voltage applied. Energy ratings are based on a shift of V_N of less than ±10% of initial value.

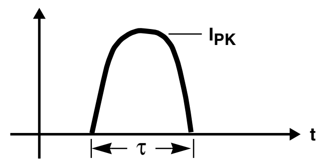
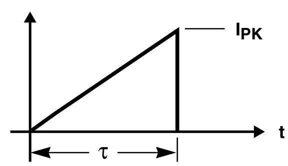
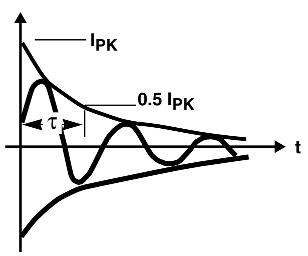
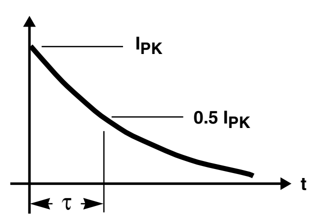
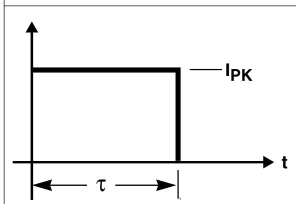
When the transient is generated from the discharge of an inductance (i.e., motor, transformer) or a capacitor, the source energy can be calculated readily but, in most cases the transient is from a source external to the equipment and is of unknown magnitude. For this situation an approximation technique can be used to estimate the energy of the transient absorbed by the varistor. The method requires finding the transient current and voltage applied to the varistor. To determine the energy absorbed the following equation applies:

$$E = \int_0^{\tau} V_C(t) I(t) \Delta t = K V_C I \tau$$

where I is the peak current applied, V_C is the clamp voltage which results, τ is the impulse duration and K is a constant. K values are given in Figure 1 for a variety of waveshapes frequently encountered. The K value and pulse width correspond to the current waveform only, assuming the varistor voltage waveform is almost constant during the current impulse. For complex waveforms, this approach also can be used by dividing the shape into segments that can be treated separately.

TABLE 1. ULTRAMOV RATINGS AND SPECIFICATIONS EXAMPLE

MODEL NUMBER	DEVICE MODEL NUMBER BRAND-ING	MAXIMUM RATING (85°C)					CHARACTERISTICS (25°C)				
		CONTINUOUS		TRANSIENT			VARISTOR VOLTAGE AT 1mA DC TEST CURRENT		MAXIMUM CLAMPING VOLTAGE 8 x 20µs		TYPICAL CAPACI-TANCE
		RMS VOLTS	DC VOLTS	ENERGY 2ms	PEAK CURRENT 8 x 20µs						
		$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM} 2 x PULSE	I_{TM} 1 x PULSE	V_{NOM} MIN	V_{NOM} MAX	V_C	I_{PK}	f = 1MHz
		(V)	(V)	(J)	(A)	(A)	(V)		(V)	(A)	(pF)
V07E140	7V140	140	180	13.5	1200	1750	200	240	360	10	160
V10E140	10V140	140	180	27.5	2500	3500	200	240	360	25	400
V14E140	14V140	140	180	55	4500	6000	200	240	360	50	900
V20E140	20V140	140	180	110	6500	10000	200	240	360	100	1750

WAVESHAPE	EQUATION	K†
	$I_{PK}\sin\left(\frac{\Pi}{\tau}t\right)$	0.637
	$I_{PK}\left(\frac{t}{\tau}\right)$	0.5
	$I_{PK}\sin(\pi t)e^{-t/\tau}$	0.86
	$I_{PK}e^{-t/1.44\tau}$	1.4
	I_{PK}	1.0

† Based upon alpha of 25 to 40

FIGURE 1. ENERGY FORM FACTOR CONSTANTS

Consider the condition where the exponential waveform shown below is applied to a V130LA1 type Littelfuse Varistor.

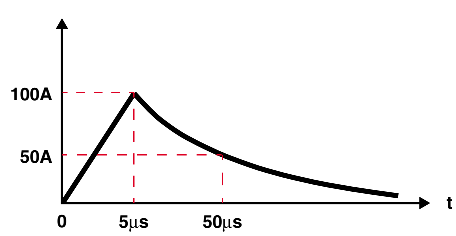


FIGURE 2.

The waveform is divided into two parts that are treated separately using the factors of Figure 1: current waveform Section (1) 0 to 5µs and (2) 5µs to 50µs. The maximum voltage across the V130LA1 at 100A is found to be 500V from the V-I characteristics of the specification sheet.

Section (1) $E = kV_C I\tau = (0.5)\ (500)\ (100)\ (5)\ (10^{-6}) = 0.13J$

Section (2) $E = kV_C I\tau = (1.4)\ (500)\ (100)\ (50\text{-}5)\ 10^{-6}) = \underline{3.15J}$

3.28J Total

Peak Current

The peak current rating can be checked against the transient current measured in the circuit. If the transient is generated by an inductor, the peak current will not be more than the inductor current at the time of switching. Another method for finding the transient current is to use a graphical analysis. When the transient voltage and source impedance is known, a Thevenin equivalent circuit can be modeled. Then, a load line can be drawn on the log - log, V-I characteristic as shown in Figure 3. The two curves intersect at the peak current value.

The rated single pulse current, I_{TM}, is the maximum allowable for a single pulse of 8/20µs exponential waveform (illustrated in Application Note AN9767, Figure 21). For longer duration pulses, I_{TM} should be derated to the curves in the varistor specifications. Figure 4 shows the derating curves for 7mm size, LA series devices. This curve also provides a guide for derating current as required with repetitive pulsing. The designer must consider the total number of transient pulses expected during the life of the equipment and select the appropriate curve.

Where the current waveshape is different from the exponential waveform of Figure 11 of AN9767, the curves of Figure 4 can be used by converting the pulse duration on the basis of equivalent energy. This is easily done using the constants given in Figure 1. For example, suppose the actual current measured has a triangular waveform with a peak current of 10A, a peak voltage of 340V and an impulse duration of 500µs.

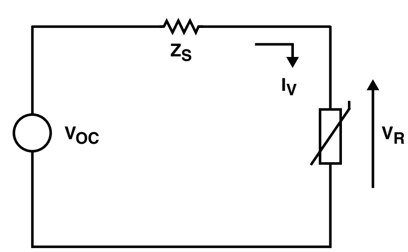


FIGURE 3A. EQUIVALENT CIRCUIT

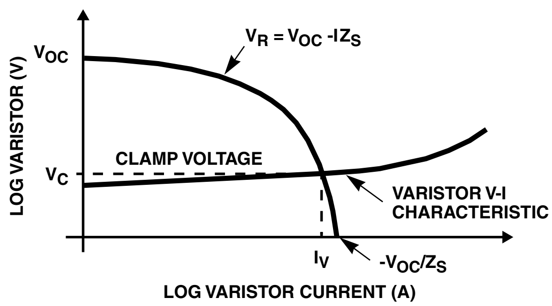


FIGURE 3B. GRAPHICAL ANALYSIS TO DETERMINE PEAK I

FIGURE 3. DETERMINING VARISTOR PEAK CURRENT FROM A VOLTAGE SOURCE TRANSIENT

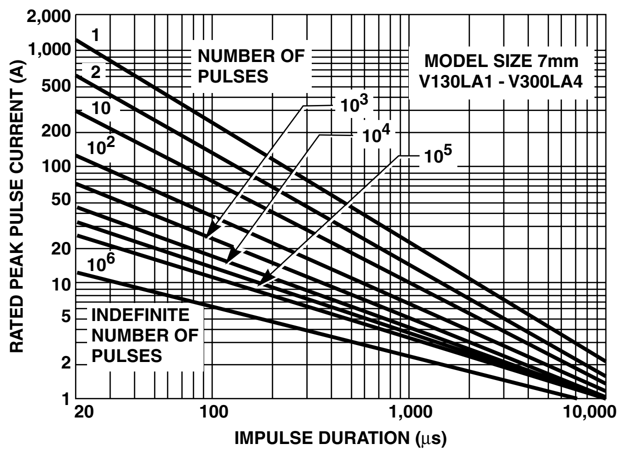


FIGURE 4. PEAK CURRENT DERATING BASED ON PULSE WIDTH AND NUMBER OF APPLIED PULSES

Then:

$$E = (.5)(10)(340)(500)(10^{-6})$$
$$= 850mJ$$

The equivalent exponential waveform of equal energy is then found from:

$$E_{TRIANGULAR} = E_{EXP}$$
$$850mJ = 1.4\, V_C I \tau_{EXP}$$

The exponential waveform is taken to have equal V_C and I values. Then,

$$\tau_{EXP} = \frac{850mJ}{1.4\,(340)\,(10)}$$
$$= 179\mu s$$

Or:

$$\tau_{EXP} = \frac{K^* \tau^*}{1.4}$$

Where: K^* and τ^* are the values for the triangular waveform and τ_{EXP} is the impulse duration for the equivalent exponential waveform.

The pulse rise portion of the waveform can be ignored when the impulse duration is five times or more longer. The maximum number of pulses for the above example would exceed 10^4 from the pulse derating curves shown in Figure 4.

Varistor Voltage

The varistor nominal voltage **(V_{NOM} or V_N)** represents the applied voltage where the varistor transitions from its “standby” mode to its low impedance “clamping” mode. It is measured at the 1mA conduction point. The minimum and maximum limit values are specified in the ratings table.

Power Dissipation Requirements

Transients generate heat in a suppressor too quickly to be transferred during the pulse interval. Power dissipation capability is of concern for a suppressor if transients will be occurring in rapid succession. Under this condition, the power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the ratings tables for the specific device type. It is to be noted that varistors can only dissipate a relatively small amount of average power and are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation (likewise, varistors are not suitable as voltage regulation devices). Furthermore, the operating values need to be derated at temperatures above the absolute maximum limits as shown in Figure 5.

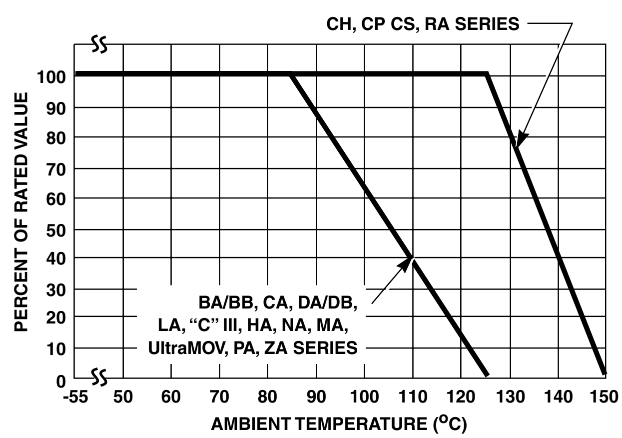


FIGURE 5. CURRENT, ENERGY, POWER DERATING vs TEMPERATURE

Voltage Clamping Selection

Transient V-I characteristics are provided in the specifications for all models of varistors. Shown below in Figure 6 are curves for $130V_{AC}$ rated models of the LA series. These curves indicate the peak terminal voltage measured with an applied 8/20µs impulse current. For example, if the peak impulse current applied to a V130LA2 is 10A, that model will limit the transient voltage to no higher than 340V.

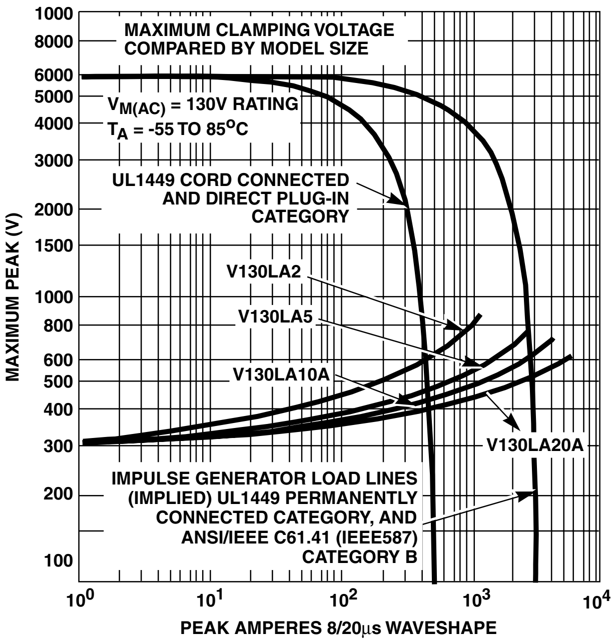


FIGURE 6. TRANSIENT V-I CHARACTERISTICS OF TYPICAL LA SERIES MODELS

If the transient current is unknown, the graphical method of Figure 3 can be utilized. From a knowledge of the transient voltage and source impedance a load line is plotted on the V-I characteristic. The intersection of the load line with the varistor model curve gives the varistor transient current and the value of clamped peak transient voltage.

The ability of the varistor to limit the transient voltage is sometimes expressed in terms of a clamp ratio. For example, consider a varistor applied to protect the power terminals of electrical equipment. If high line conditions will allow a rise to $130V_{AC}$, then 184V peak would be applied. The device selected would require a voltage rating of $130V_{AC\,RMS}$ or higher. Assume selection of a V130LA2 model varistor. The V130LA2 will limit transient voltages to 340V at currents of 10A. The clamp ratio is calculated to be,

$$\text{Clamp Ratio} = \frac{V_C \text{ at } 10A}{\text{Peak Voltage Applied}}$$

$$= \frac{340V}{184V} = 1.85$$

The clamp ratio can be found for other currents, of course, by reference to the V-I characteristic. In general, clamping ability will be better as the varistor physical size and energy level increases. This is illustrated in Figure 7 which compares the clamping performance of the different Littelfuse Varistor families. It can be seen that the lowest clamping voltages are obtained from the 20mm (LA series) and 60mm (BA series) products. In addition, many varistor models are available with two clamping selections, designated by an A, B, or C at the end of the model number. The A selection is the standard model, with B and C selections providing progressively tighter clamping voltage. For example, the V130LA20A voltage clamping limit is 340V at 100A, while the V130LA20B clamps at not more than 325V.

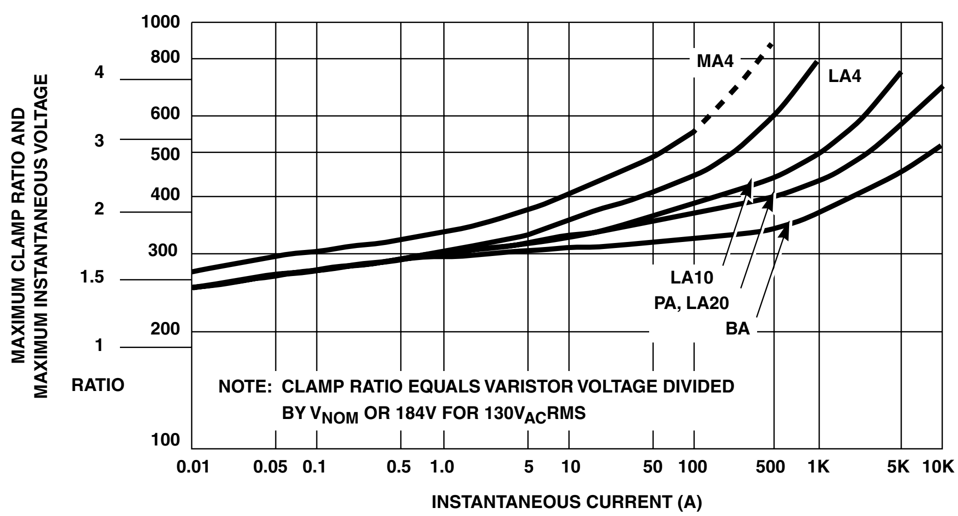


FIGURE 7. VARISTOR V-I CHARACTERISTICS FOR FOUR PRODUCT FAMILIES RATED AT $130V_{AC}$

PEAK CURRENT (A)	ENERGY (J)	MAXIMUM STEADY-STATE APPLIED VOLTAGE	DISC SIZES/ PACKAGES
		VOLTS AC RMS: 4, 10, 25, 130, 150, 250, 264, 275, 460, 660, 750, 1,000, 2,800, 6,000	
		VOLTS DC: 3.5, 14, 35, 175, 200, 330, 365, 369, 615, 850, 970, 1,200, 3,500, 7,000	
80 - 500	0.5 - 5.0	CP, SERIES	22, 20, 16 GAUGE
30 - 1000	0.1 - 25	AUML†, ML†, MLE †, MLN †, CH SERIES	0603 0805 1206 1210 1812 2220 5 x 8mm
40 - 100	0.07 - 1.7	MA SERIES	3mm
50 - 6500	0.1 - 52	ZA SERIES	5, 7, 10, 14, 20 (mm)
100 - 6500	0.4 - 160	RA SERIES	5 x 8, 10 x 16, 14 x 22 (mm)
1,200 - 10,000	11 - 400	C-III, LA, UltraMOV SERIES	7, 10, 14, 20 (mm)
6500	70 - 250	PA SERIES	20mm
25,000 - 40,000	270 - 1,050	HA, HB, DA/ DB SERIES	32, 34 40 (mm)
50,000 - 70,000	450 - 10,000	BA/ BB SERIES	60mm
30,000 - 40,000	270 - 1050	NA SERIES	34mm SQ.
20,000 - 70,000	200 - 10,000	CA SERIES	32, 40, 60 (mm)
65,000 - 100,000	2,200 - 12,000	AS †† SERIES	32, 42, 60 (mm)

†Littelfuse multilayer suppression technology.

FIGURE 8. VARISTOR PACKAGE STYLES AND RATINGS RANGE

Varistor Ordering Information

The varistor part number includes ratings information. Some types include the working voltage, others indicate the nominal voltage. See the varistor ordering nomenclature guides below.

ULTRAMOV TYPES

V XX E XXX LX X X

DEVICE FAMILY:
Varistor

DISC DIAMETER:
07, 10, 14, or 20 (mm)

ENCAPSULATION:
E = Epoxy

$V_{M(AC)RMS}$:
130 to 625 (V)

LEAD FORMATION:
- L1 = Straight
- L2 = Crimped
- L3 = In-Line
- L4 = Trim/Crimp (Bulk pack only)

PACKAGING:
- B = Bulk Pack
- T = Tape and Reel
- A = Ammo Pack

NONSTANDARD LEAD SPACING OPTIONS (DO NOT ADD IF STANDARD) (NOTE 2):
- 5 = 5mm Lead Spacing
- 7 = 7.5mm Lead Spacing
- 1 = 10mm Lead Spacing

OTHER VARISTOR TYPES

BA, BB, CA, CP, CS, DA, DB, HA, HB, LA, NA, PA, VARISTOR SERIES

V 130 LA 20 A

- A: Selection - Clamping Voltage (A or B)
- 20: Relative Energy Indicator or Disc Size
- LA: Product Series
- 130: Max RMS Applied Voltage
- V = Metal-Oxide Varistor (MOV)

CH, MA, ZA, VARISTOR SERIES

V 220 MA 4 A

- A: Selection - Clamping Voltage (A or B)
- 4: Relative Energy Indicator
- MA: Product Series
- 220: V_N(DC) Nominal Varistor Voltage
- V: MOV Varistor

The five major considerations for varistor selection have been described. The final choice of a model is a balance of these factors with device packaging and cost trade-offs. In some applications a priority requirement such as clamp voltage or energy capability may be so important as to force the selection to a particular model. Figure 8 illustrates the Littelfuse varistor package styles in a matrix that compares energy and current ratings to the working voltage range.