



# **Ceramic transient voltage suppressors**

## Selection procedures

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## 1 Selection procedures

The selection procedure for ceramic transient voltage suppressors consists of the following main steps:

1. Defining the requirements of the application circuit
2. Determining the expected transient surge
3. Selecting of a suitable CTVS

The maximum possible loading of a CTVS is determined by both the electrical specifications of the intended application and its own physical capabilities. Note that we will differentiate between these two in this chapter. We will mark the maximum possible loading of the CTVS determined by the electrical specifications of the intended circuit with the superscript  $\llcorner^*\ggcorner$ .

### 1.1 Defining the requirements of the application circuit

- Operating voltage  $V_{op}$  of the circuit to be protected
- Minimum protection level (clamping voltage) needed for the circuit

### 1.2 Determining the expected transient surge

Determining the transient load on the CTVS when limiting overvoltage means that you have to know the surge current that is to be handled. For proper selection we need the following parameters of the transient load:

- Surge current  $I_{surge,max}^*$
- Pulse duration  $t_p^*$
- Estimated number of surge repetitions  $N$

#### 1.2.1 Surge current $I_{surge,max}^*$ and surge voltage $V_{surge,max}^*$

The surge current in a given application is either specified or can be calculated from the application's voltage. Either way, it has to be converted into a rectangular waveform and then derated to calculate the load the CTVS has to handle.

Case A: predefined surge current  $I_{surge,max}^*$

Often the surge current is predefined in specifications. After transformation into an equivalent rectangular wave, a suitable CTVS type can be selected with the aid of the derating curves.

Case B: predefined surge voltage  $V_{surge,max}^*$

If the surge voltage is predefined, the surge current in a specific network can be determined in one of the following ways:

- Simulation

The most convenient method to determine the surge load is by using the PSpice simulation

## Selection procedures

models of the EPCOS ceramic transient voltage suppressors. Thus, the surge current, the waveform and the energy content can be calculated. In these models, the maximum surge current is deduced for the lower limit of the tolerance band, i. e. setting TOL = -10.

### ■ Test circuit

The amplitude and waveform of the surge current can be determined with the aid of a test circuit (predefined network). The dynamic processes for overvoltages require adapted measuring procedures.

### ■ Graphical method

The overvoltage can be drawn into the V/I characteristic curve fields as a load line (with end points: open circuit voltage, short-circuit current). At the intersection of this load line with the CTVS curve selected to suit the operating voltage, the maximum protection level and the corresponding surge current can be read off. The waveform and thus the energy content cannot be determined by this method. Since the V/I characteristic curves are drawn in a log-log representation, the load line is distorted to a curve.

### ■ Mathematic approximation

The surge current is determined solely from the source impedance of the surge voltage ( $V_{\text{surge}}$ ). By subtracting the voltage drop across the CTVS (from the V/I curve) you can approximate the maximum surge current as follows:  $I_{\text{surge,max}}^* = (V_{\text{surge}} - V_{\text{CTVS}}) / Z_{\text{source}}$ . For reference refer to chapter "Design notes," section 1.1.

## 1.2.2 Preparation of surge current figures for CTVS selection

Once the surge current in the application is known ( $I_{\text{surge,max}}^*$ ), the data must be prepared for the actual selection of a CTVS.

For appropriate comparison of the obtained surge current figures with the maximum ratings of the CTVS devices, we need to first convert the surge current waveform into an equivalent rectangular wave by keeping the maximum surge current value. This is done using the rectangular wave method.

## 1.2.3 The rectangular wave method

The rectangular wave method is illustrated in figure 1. Keeping the maximum surge current value  $I_{\text{surge,max}}^*$ , you can change the surge current wave into a rectangular wave of the same area.  $t_r^*$  is then the duration of the equivalent rectangular wave and is identical to the "pulse width" in the de-rating curves.

The time period  $T^*$  is needed to calculate the average power dissipation  $P_{\text{diss,max}}^*$  resulting from periodic application of energy.

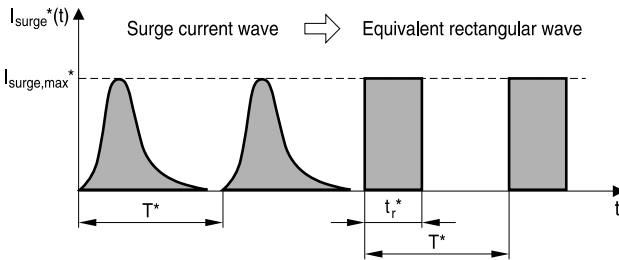


Figure 1  
Rectangular wave  
method

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If the pulse load

$$\int I_{\text{surge}}^*(t) dt$$

is known, then  $t_r^*$  can be calculated using the following equation:

$$t_r^* = \frac{\int I_{\text{surge}}^*(t) dt}{I_{\text{surge,max}}^*} \quad (\text{equ. 1})$$

### 1.3 Selecting a suitable CTVS for overvoltage protection

After determining the operating conditions necessary for the applications, the next step is to find a CTVS that can withstand the requirements

Select a CTVS that is suitable in terms of the following maximum ratings:

1. Maximum operating voltage:  $V_{\text{RMS,max}}$ ,  $V_{\text{DC,max}}$  in V
2. Maximum surge current:  $I_{\text{surge,max}}$  in A
3. Maximum energy absorption:  $W_{\text{max}}$  in J
4. Maximum power dissipation:  $P_{\text{diss,max}}$  in W
5. Maximum protection level:  $V_{\text{clamp,max}}$  in V

Determine the maximum possible voltage rise on the selected CTVS in case of overvoltage and compare this value to the electric strength of the component or circuit that is to be protected.

Maximum operating temperature:  $T_{\text{op,max}}$

**Note:**

For operating the CTVS above the specified maximum operating temperature  $T_{\text{op,max}}$ , you must consider the derating of the specified maximum figures according to the temperature derating curves stated for each CTVS (see chapter "General technical information", section 2.1.1).

### 1.3.1 Selecting a CTVS in terms of the maximum ratings

The electrical behavior of the CTVS results from the number of microvaristors connected in series or in parallel.

This implies that the electrical properties are controlled by the physical dimensions of the CTVS (refer to chapter "General technical information", section 2.1.1).

- Twice the ceramic layer thickness produces twice the protection level because then twice as many microvaristors are arranged in series.
- Twice the overlapping area produces twice the current handling capability because then twice the number of current paths are arranged in parallel.
- Twice the active volume produces almost twice the energy absorption capability because then there are twice as many absorbers in the form of zinc oxide grains.

Keep this in mind when selecting a CTVS.

### 1.3.2 Maximum operating voltage $V_{RMS,max}$ and $V_{DC,max}$

Step 1:

Maximum permissible AC and DC operating voltages are stated in the product tables for all CTVS components. The operating voltage must not exceed these maximum ratings.

To obtain as low a protection level (clamping voltage) as possible, a CTVS should be selected so that the maximum permissible operating voltage  $V_{DC,max}$  is close to the operating voltage of the application  $V_{op}$ .

Of course, you may also select a CTVS with a higher permissible operating voltage  $V_{DC,max}$ . This procedure is used, for example, when it is more important to have an extremely small leakage current than the lowest possible protection level (clamping voltage). In addition, the life time of the varistor is also increased by a higher security margin between  $V_{op}$  and  $V_{DC,max}$ .

#### Note:

- CTVS are transient voltage suppression devices and therefore not designed for voltage regulation. It is important to ensure that the intended operating voltage does not exceed the specified maximum permissible operating voltage.
- Non-sinusoidal AC voltages have to be compared with the maximum permissible DC operating voltage  $V_{DC,max}$  so that the peak or amplitude of the applied voltage does not exceed the maximum permissible DC voltage  $V_{DC,max}$  (only CU varistors).
- In the case of power line applications, you must take into account the tolerance of the line operating voltage (e.g. European supply systems to IEC 60038: 230 V +10% = 253 V).

### 1.3.3 Maximum surge current $I_{surge,max}$

Step 2:

The definition of the maximum possible operating voltage in the previous step will have narrowed down the choice of an optimum CTVS to the types of a defined voltage class (maximum permissible AC operating voltage). Then you check, with reference to the conditions of the application,

## Selection procedures

what kind of load the CTVS can be subjected to. From the derating curves you can obtain maximum figures for rectangular surge current waves. For correct comparison with these maximum permissible values, the real surge current wave (any shape) has to be converted into an equivalent rectangular wave. This is best done graphically by the rectangular method illustrated above.

The maximum permissible surge current of the CTVS ( $I_{\text{surge,max}}$ ) depends on the duration of current flow  $t_r^*$  and the required number of surge repetitions  $N$  in the application. Taking these two parameters, the maximum surge current  $I_{\text{surge,max}}$  can be read from the derating curves.

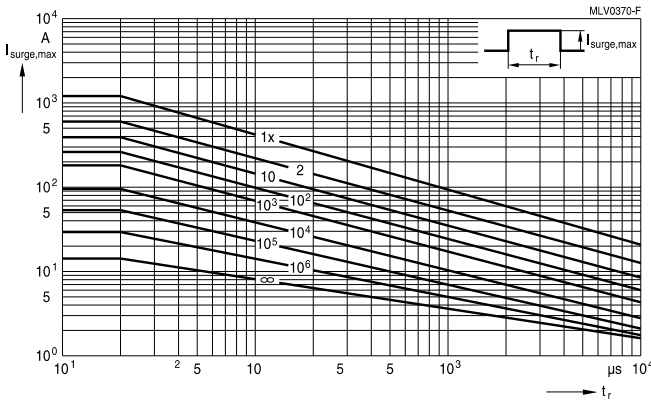


Figure 2  
Example: pulse derating diagram

This figure is compared to the maximum possible surge currents in the intended electrical environment of the CTVS.

Selection criteria:

$$I_{\text{surge,max}}^* \leq I_{\text{surge,max}} \quad (\text{equ. 2})$$

### 1.3.4 Maximum energy absorption $W_{\text{max}}$

Step 3:

When a surge current flows across the CTVS, there will be absorption of energy. The amount of energy to be absorbed by the CTVS can generally be calculated by the following equation:

$$W = \int_{t_0}^{t_1} v(t) \cdot i(t) dt \quad (\text{equ. 3})$$

Common ways to determine the surge energy:

- Calculation method  
Often the energy absorption can be read directly from a storage oscilloscope or can be calculated from the voltage/current curve using numerical methods.
- Simulation  
Determination of the energy absorption by PSpice simulation is even more convenient.

## Selection procedures

### ■ Graphical method

Otherwise the equation can be solved graphically with sufficient accuracy by using the rectangular wave method. The surge current wave  $I_{\text{surge}}^*(t)$  is converted as explained in the above section into an equivalent rectangle and then multiplied by the highest voltage  $V_{\text{max}}^*$  appearing on the CTVS.

$$W^* = V_{\text{max}}^* \cdot I_{\text{surge}}^* \cdot t_r^* \quad (\text{equ. 4})$$

$V_{\text{max}}^*$  can either be derived from the V/I characteristic as the value matching  $I_{\text{surge,max}}^*$ , or likewise be determined with the aid of an oscilloscope as the maximum voltage drop across the CTVS

To check the selection requirement  $W^* \leq W_{\text{max}}$  (equation 6), you have to determine the maximum permissible energy absorption for the intended varistor. This can be calculated by equation 4 as a function of time the energy is applied ( $t_r^*$ ) and the number of repetitions N from the derating curves.

Selection criteria:

$$W_{\text{max}} = V_{\text{max}} \cdot I_{\text{surge,max}} \cdot t_r \quad (\text{equ. 5})$$

$$W^* \leq W_{\text{max}} \quad (\text{equ. 6})$$

### 1.3.5 Energy of an ESD pulse

IEC 61000-4-2 specifies 15 kV as the highest charging voltage (severity level 4, air discharge) for the 150 pF discharge capacitor according to figure 3.

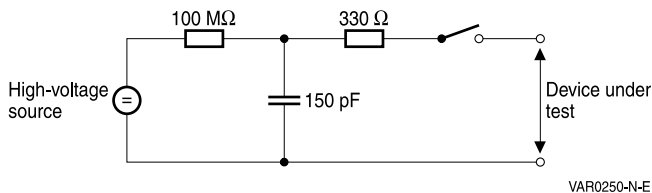


Figure 3

## Selection procedures

This means that the stored energy is

$$W^* = 0.5 \cdot C \cdot V^2 = 0.5 \cdot 150 \cdot 10^{-12} \text{ F} \cdot 15^2 \cdot 10^6 \text{ V}^2 < 0.02 \text{ J} \quad (\text{equ. 7})$$

The 330  $\Omega$  resistor limits the surge current to a maximum of

$$I^* = \frac{V^*}{R} = \frac{15000 \text{ V}}{330 \Omega} = 45 \text{ A} \quad (\text{equ. 8})$$

If this surge current is to be handled by a multilayer varistor, then, according to equation 10 in chapter "Design notes", the effect of the varistor on this value of the current amplitude is negligible.

For CT0805M6G, for example, this means that

$$I^* = \frac{(V_{\text{surge}} - V_{\text{VAR}})}{Z_{\text{surge}}} = \frac{15000 \text{ V}}{330 \Omega} = 45 \text{ A} \quad (\text{equ. 9})$$

By transforming the discharge current (figure 1) into an equivalent rectangular wave, we obtain  $t_r^* \approx 40 \text{ ns}$ .

No value can be deduced from the derating curves for such an extremely short current flow time.

The energy absorption of multilayer varistors and CeraDiodes during ESD discharges lies in the region of  $\mu\text{J}$ .

For the CT0805M6G, for example, according to equation this means that

$$W^* = V^* \cdot I^* \cdot t_r = 45 \text{ V} \cdot 45 \text{ A} \cdot 40 \cdot 10^{-9} \text{ s} = 80 \mu\text{J} \quad (\text{equ. 10})$$

Thus the largest part of the energy content of the ESD pulse is absorbed by the 330  $\Omega$  discharge resistor.

All types of the MLV and CeraDiodes series are able to meet the (severest) ESD test level 4 to IEC 61000-4-2. Figure 4 demonstrates this for multiple pulses taking the low capacitance type CT0603L25HSG as an example.

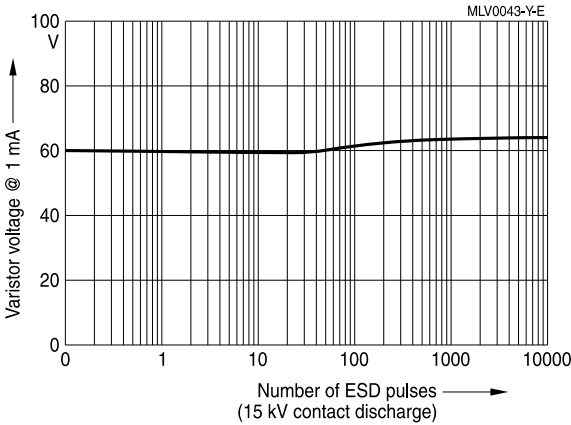


Figure 4  
ESD stability of varistor  
voltage for type  
CT0603L25HSG

Due to the steep edge of the ESD pulse, the inductance determined by mechanical construction of a device and of the layout of the test circuit is of great importance for the test result. The CTVS selection should therefore always be verified by an ESD test circuit.

### 1.3.6 Average power dissipation $P_{diss,max}$

Step 4:

The actual power dissipation of a CTVS is composed of the basic dissipation  $P_0^*$  in steady-state conditions caused by the operating voltage and, possibly, the average of periodic energy absorption. If ceramic transient voltage suppressors are chosen from the product tables in agreement with the maximum permissible operating voltages,  $P_0^*$  will be negligible within the specified ambient temperature range.

Periodic energy absorption produces an average power dissipation of

$$P_{diss}^* = \frac{W^*}{T^*} = \frac{(V_{surge,max}^* \cdot I_{surge,max}^* \cdot t_r^*)}{T^*} \quad (\text{equ. 11})$$

$W^*$	[J]	Energy absorption
$T^*$	[s]	Time period
$V_{surge,max}^*$	[V]	Maximum applied surge voltage
$I_{surge,max}^*$	[A]	Maximum applied surge current
$t_r^*$	[s]	Pulse duration

## Selection procedures

By solving this equation for  $T^*$  it is possible to calculate the minimum time  $t_{\min}$  that must elapse before energy is applied again without exceeding the maximum permissible average power dissipation of the CTVS:

$$t_{\min} = \frac{W^*}{P_{\text{diss,max}}} \quad (\text{equ. 12})$$

**Note:**

CTVS devices are not to be “operated” at  $P_{\text{diss,max}}$ . They are not suitable for “static” power dissipation, e.g. voltage stabilization. There are other kinds of components, like zener diodes, designed primarily for this kind of application, but with much lower surge current handling capability.

Selection criteria:

$$P_{\text{diss}}^* \leq P_{\text{diss,max}} \quad (\text{equ. 13})$$

### 1.3.7 Maximum protection level (clamping voltage) $V_{\text{clamp,max}}$

Step 5:

The maximum possible voltage rise in the event of a surge current is checked with the aid of the V/I curves or PSpice models. This figure can be read directly from the curve for a given surge current (for worst-case varistor tolerances). If the voltage value thus obtained is higher than acceptable, the following possibilities may assist in reducing the protection level.

- Choose a type with a larger case size. The protection level is lower for the same surge current because the current density is reduced.
- Choose a tighter tolerance band. A special type is introduced that only utilizes the bottom half of the standard tolerance band for example. This would mean a drop in the protection level by approx. 10%.
- Insert a series resistor. This reduces the amplitude of the surge current and thus the protection level of the CTVS.

**Note:**

If the protection level obtained from the V/I curve is lower than required, you can change to a varistor with a higher protection level (i.e. higher voltage class). This has a favorable effect on load handling capability and operating life. The leakage current is further reduced.

## 1.4 Remarks on automotive protection

### 1.4.1 Load dump

Under this condition peak voltages up to 200 V can occur, lasting for few hundred ms, yielding energy levels up to 100 J. In accordance with ISO 7637 (see chapter "Protection standards," section 1.3.2), the load dump pulse 5 is specified by the parameters:

■ Charge voltage (test level)	$V_S$
■ Internal resistance	$R_i$
■ Rise time	$t_r$
■ Duration	$t_d$

The easiest way to determine the amount of energy dissipation by the varistor is to perform a software simulation (using e.g. PSpice) to determine which portion of the energy of this pulse the varistor absorbs. The value calculated by this method  $W^*$  must be lower than the value specified in the product tables  $W_{max}$ .

ISO 7637 requires that at least one load dump absorption must be tolerated. In other specifications repeated load dumps up to 10 times are permissible. To comply with such regulations the automotive industry specifies load dump values for 10 repetitions for their applications.

The product tables in the data sheets show supplementary maximum energy values for load dump absorption  $W_{LD}$  (with 10 · pulses).

If requested, EPCOS can perform load dump simulations according to the customer's specifications.

For such cases, we require information concerning the parameters listed above (charge voltage  $V_S$ , internal resistance  $R_i$ , rise time  $t_r$ , duration  $t_d$ ) plus the number of repetitions desired. A specific simulation example is given in section 1.5.4.

## 1.5 Selection by PSpice simulation

### 1.5.1 CTVS model

The development of a EPCOS CTVS model for the “PSpice design center” circuit simulation program allows varistors to be integrated into the computer-aided development of modern electronic circuitry.

In the PSpice modeling concept, the CTVS is represented by its V/I characteristic curve, a parallel capacitance and a series inductance.

The structure of this equivalent circuit is shown in figure 5.

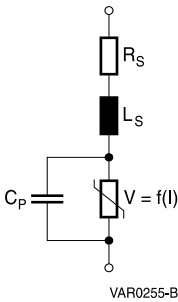


Figure 5  
CTVS model, basic structure

$V = f(I)$	V/I characteristic
$C_p$	CTVS capacitance
$L_s$	Series inductance
$R_s = 100 \mu\Omega$	Series resistance

In the model, the V/I characteristic curve is implemented by a controlled voltage source  $V = f(I)$ . An additional series resistance  $R_s = 100 \mu\Omega$  has been inserted to prevent the impermissible state that would occur if ideal sources were to be connected in parallel or the CTVS model were to be connected directly to a source.

The following approximation is used for the mathematical description:

$$\log(V) = b_1 + b_2 \cdot \log(I) + b_3 \cdot e^{-\log(I)} + b_4 \cdot e^{\log(I)} \quad I > 0 \quad (\text{equ. 14})$$

This means that the characteristic curve for any specific CTVS can be described by the parameters  $b_1$  through  $b_4$ . Figure 6 shows the typical V/I characteristic curve for the CTVS CN2220K30G(K2) and the corresponding parameters  $b_1$  through  $b_4$ .

The tolerance bandwidth of the V/I characteristic curve can be shifted to include cases of

- upper tolerance bandwidth limit: highest possible protection level for a given surge current
- lower tolerance bandwidth limit: highest possible (leakage) current for a given voltage

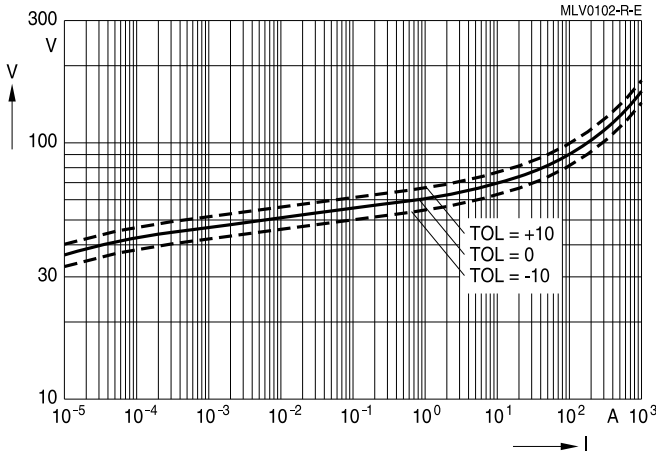


Figure 6  
V/I characteristic curve of  
CN2220K30G(K2) with  
tolerance band

Example: parameters for CN2220K30G(K2)

b1	1.7741151
b2	0.0237055
b3	-0.0015772
b4	0.0176357

In the model, the capacitance values stated in the product tables are used. The dependence of the capacitance on the applied voltage and frequency is extremely low and can be neglected here.

It is not permissible to neglect the inductance of the CTVS in applications with steep pulse leading edges. For this reason, it is represented by a series inductance. As opposed to this, the internal inductance of the CTVS may be neglected.

The PSpice simulation models can be downloaded from the internet ([www.epcos.com/tools](http://www.epcos.com/tools)).

### 1.5.2 Limits of the CTVS model

For mathematical reasons, the V/I characteristic curves are extended in both directions beyond the current range ( $10 \mu\text{A}$  up to  $I_{\text{surge,max}}$ ) specified in this data book, and cannot be limited by the program procedure. The validity of the model breaks down if the specified current range is exceeded. For this reason, it is imperative that the user takes consideration of these limits when specifying the task; the upper limit depends on the type of varistor. Values of  $< 10 \mu\text{A}$  may lead to incorrect results, but do not endanger the component.

As opposed to this, values exceeding the type-specific surge current  $I_{\text{surge,max}}$ , may lead not only to incorrect results in actual practice but also to destruction of the component.

## Selection procedures

Apart from this, the CTVS model does not check adherence to other limit values such as maximum continuous power dissipation  $P_{\text{diss,max}}$  or surge current deratings. In addition to carrying out simulation procedures, the adherence to such limits must always be ensured, observing the relevant specification given in the data book.

In critical applications, the simulation result should be verified by a test circuit.

The model does not take into account the low temperature coefficient of the varistors.

### 1.5.3 Simulation example for telecom application

In this example the aim is to test whether selecting a standard varistor CN2220K30G(K2) would meet the test conditions specified by the German Telecommunications Administration:

Figure 7 shows the test circuit with a 2 kV charge voltage, figure 8 shows the corresponding model used in PSpice.

To achieve open-circuit voltage of 2 kV, the charging capacitor must be charged to 2.05 kV. In order to prevent an undefined floating of  $R_{m2}$ , an additional resistor  $R_1 = 10 \text{ M}\Omega$  is inserted at the output end.

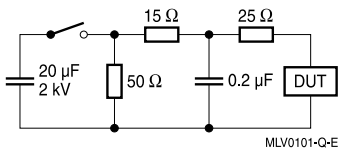


Figure 7

Simulation of the test pulse 10/700  $\mu\text{s}$  applied to the device under test CN2220K30G(K2)

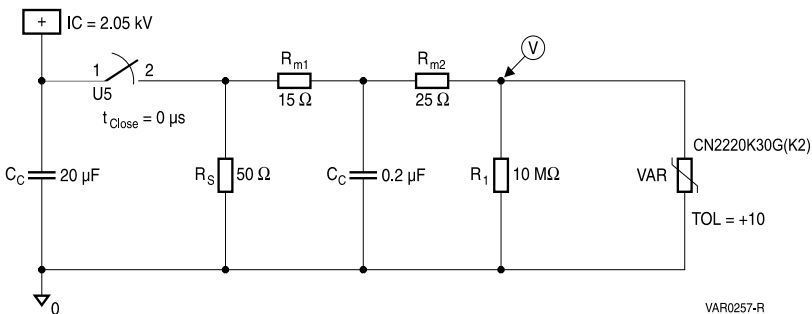


Figure 8

Simulation of the test pulse 10/700  $\mu\text{s}$  applied to the device under test CN2220K30G(K2)

## Selection procedures

For the varistor, the upper characteristic curve tolerance (TOL = +10) limit is used to simulate the worst case, i.e. highest possible protection level. It is not considered necessary to model the device to be protected in this diagram since, in relation to the varistor, this is generally of higher resistance for pulse loads.

Figure 9 shows the curve of the open-circuit voltage (varistor disconnected) and the maximum protection level (with varistor).

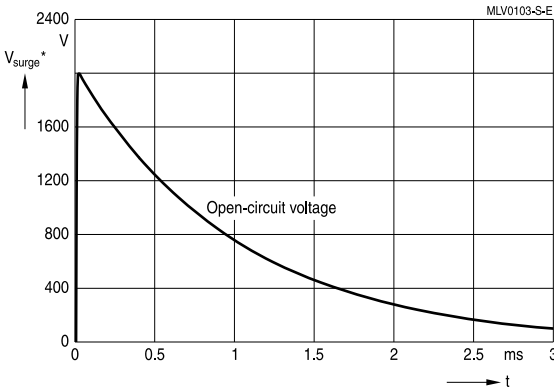


Figure 9  
Open-circuit voltage  
(varistor disconnected)

## Surge current

Figure 10 shows the voltage and current curves, with the

$$\int I_{\text{surge}}^*(t) dt \quad (\text{equ. 15})$$

included in the drawing.

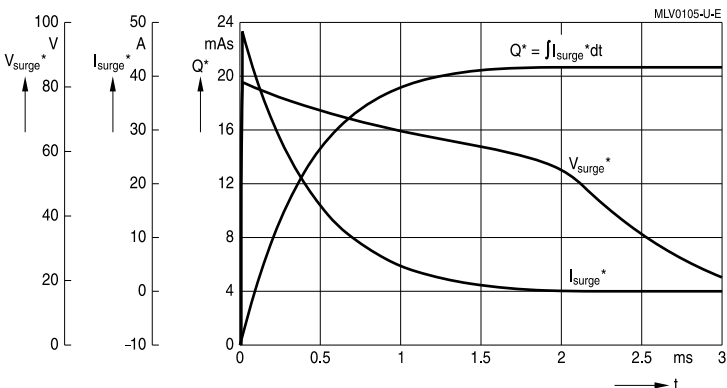


Figure 10

PSpice simulation: voltage, current and pulse load curves for the CN2220K30G(K2)

## Selection procedures

A maximum current  $I_{\text{surge,max}}^*$  of 48.2 A can be deduced from the curves.

Then, according to equation 1

$$t_r^* = \frac{\int I_{\text{surge}}^* dt}{I_{\text{surge,max}}^*} = \frac{20.8 \text{ mAs}}{48.2 \text{ A}} = 432 \mu\text{s} \quad (\text{equ. 16})$$

According to figure 11, the resulting maximum surge current  $I_{\text{surge,max}}$  for 10 loads is 60 A.

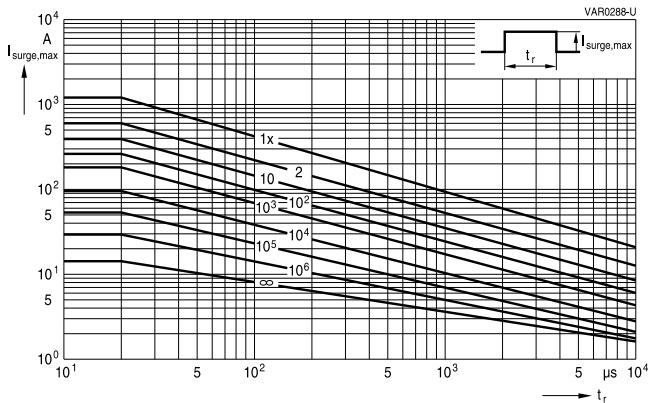


Figure 11

A maximum surge current  $I_{\text{surge,max}}^* = 60 \text{ A}$  (10 times) can be deduced for  $t_r^* = 432 \mu\text{s}$  from the derating curves for CN2220 valid for voltage class M6 ... K30

The selection criterion of equation is fulfilled:

$$I_{\text{surge,max}} = 60 \text{ A} > I_{\text{surge,max}}^* = 48.2 \text{ A} \quad (\text{equ. 17})$$

### Energy absorption

PSpice displays the energy absorption directly as

$$W^* = \int V_{\text{surge,max}}^* \cdot I_{\text{surge,max}}^* dt = 4.2 \text{ J} \quad (\text{equ. 18})$$

The resulting permissible time interval between two pulses according to equation is

$$t_{\text{min}} = \frac{W^*}{P_{\text{diss,max}}} = \frac{1.4 \text{ J}}{0.002 \text{ W}} = 70 \text{ s} \quad (\text{equ. 19})$$

This means that the requirement of a minimum time interval between pulses of 70 s or more is fulfilled.

### Highest possible protection level

In figure 10 the highest possible protection level can be deduced as 85 V. Thus it is possible to diminish the transient “overvoltage” of 2 kV to 4.3% of its value.

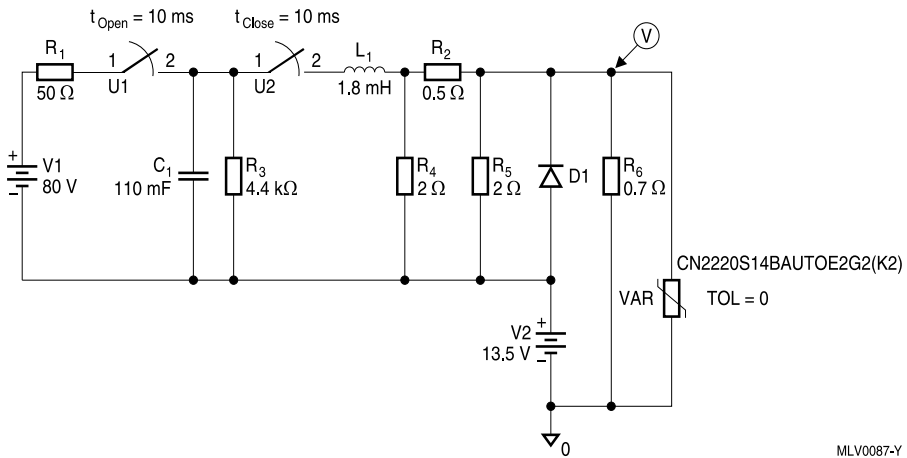
**Note:**

The specification stated above can also be met using the specially developed telecom varistors.

### 1.5.4 Simulation example for automotive application

In the next example the aim is to test if the varistor is able to meet a specific load dump test condition. This pulse occurs in a event of a discharged battery being disconnected while the alternator is generating charging current.

The figure shows the test circuit where a 60 V overvoltage is superimposed on the battery voltage of 13.5 V.



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Figure 12

Simulation of the test pulse for load dump applied to the device under test  
CN2220S14BAUTOE2G2(K2)

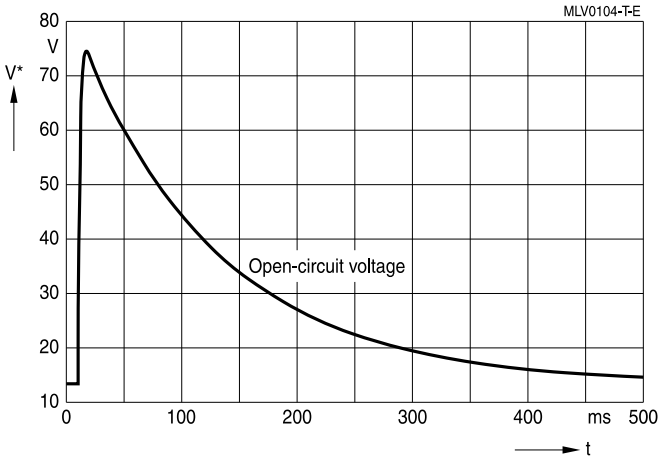


Figure 13  
Open-circuit waveform with disconnected load resistor and disconnected varistor

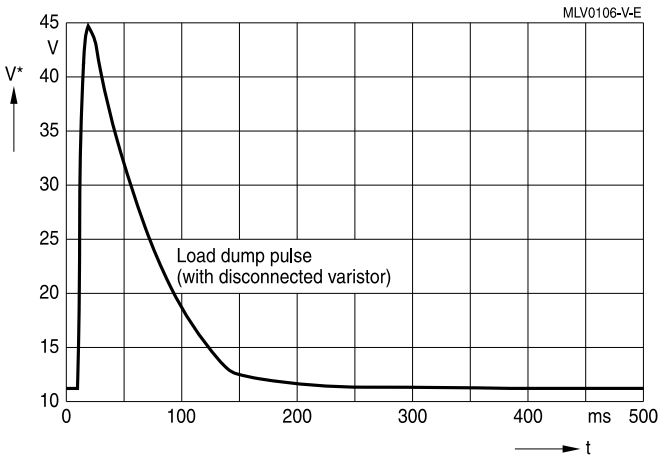


Figure 14  
Loaded waveform  $V^*$  with  $0.7 \Omega$  load resistor

## Selection procedures

Figure 15 shows the current, voltage and energy through the chosen varistor. It can be seen that the simulated energy is below the maximum specified energy of 25 J for the CN2220S14BAUTOE2G2(K2).

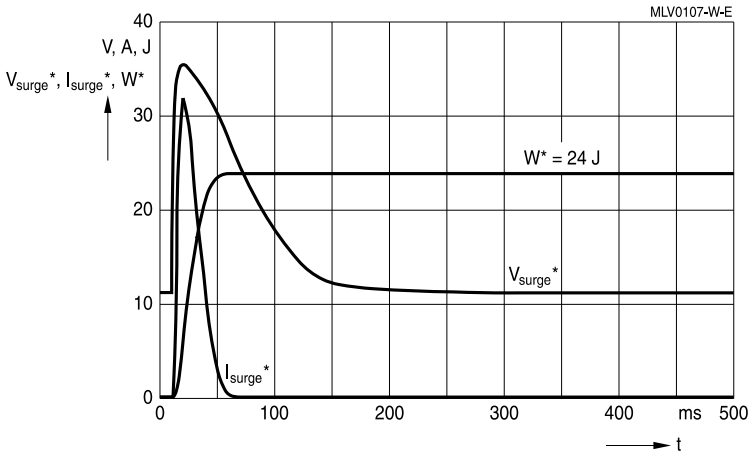


Figure 15

The current, voltage and energy through the chosen varistor CN2220S14BAUTOE2G2(K2)