

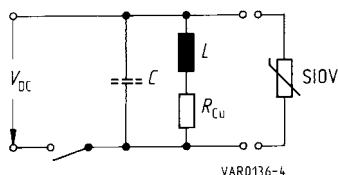
4 Calculation examples

4.1 Switching off inductive loads

The discharge of an inductor produces high voltages that endanger both the contact breaker (switching transistor and the like) and the inductor itself. According to equation 17 the energy stored in the coil is $\frac{1}{2} L i^2$. So, when the inductor is switched off, this energy charges a capacitor in parallel with the inductor (this capacitor can also be the intrinsic capacitance of the coil). Not allowing for the losses, and for $\frac{1}{2} C v^2 = \frac{1}{2} L i^2$, the values of figure 53 produce:

$$v^* = i^* \sqrt{\frac{L}{C}} = 1 \sqrt{\frac{0,1}{250 \cdot 10^{-12}}} = 20\,000 \text{ V}$$

To suppress this transient, a varistor is to be connected in parallel with the inductor as a fly-wheel circuit.



V_{DC}	= 24 V
L	= 0,1 H
R_{Cu}	= 24 Ω
I	= 1 A
C	= 250 pF

Required switching rate	= 10^6
Period	= 10 s
Required protection level	< 65 V

Figure 53 Limiting switching transients with a varistor as fly-wheel circuit

Operating voltage

The DC operating voltage is given as 24 V (cf. figure 53). If the possible increase in operating voltage is no more than 2 V, types with a maximum permissible DC operating voltage of 26 V should be chosen from the product tables to arrive at as low a protection level as possible. The types available in this category are

■ disks	S...K20, S...K20E2
■ SMDs	CU...K20G2, CT/CN...K20G
■ hicaps	SR...K20M...

Calculation Examples

Surge current

When it is cut off, the current through an inductor cannot change abruptly, so it flows across the varistor initially with the value of the operating current (here 1 A), then decaying towards zero following an exponential function.

The simplest ways of determining the current duration are simulation or measurement ($\tau = t_r^*$).

The time constant can also be calculated to an approximation with equation 13.

Here the varistor resistance of voltage class K20 is calculated for 1 A. As the protection levels of the various type series do not differ much, the S10K20 has been chosen arbitrarily to determine the resistance (the voltage is taken from the appropriate V/I characteristics).

$$R_{SIOV} = \frac{55 \text{ V}}{1 \text{ A}} = 55 \Omega$$

So τ according to equation 13 is

$$\tau = t_r^* = \frac{0,1 \text{ H}}{24 \Omega + 55 \Omega} \approx 1,3 \text{ ms}$$

For S10K20 with $t_r^* = 1,3 \text{ ms}$ and 10^6 load repetitions, one can derive

$$i_{\max} = 3 \text{ A} > i^* = 1 \text{ A}$$

from the derating curves.

Taking this result, one should check whether other types with lower current ratings satisfy the selection criterion:

$$\text{S05K20: } i_{\max} = 0,5 \text{ A} < i^* = 1 \text{ A}$$

$$\text{S07K20: } i_{\max} = 1,4 \text{ A} > i^* = 1 \text{ A}$$

E. g. using a varistor of Advanced series S...K20E2 would not achieve any advantages at 10^6 load repetitions because in this region the derating fields of this series are not different from those of the Standard series.

So the selection criterion of equation 9 is met by SIOV-S07K20 and all types with higher current ratings.

If an SMD is to be used, this can be selected from either the SIOV-CU or SIOV-CN ranges.

SIOV-CU: CU4032K20G2 is the electrical equivalent of S07K20.

SIOV-CN: CN1206K20G, with $i_{\max} = 1,5 \text{ A} > i^* = 1 \text{ A}$ fulfills the selection criteria.

Energy absorption

The maximum energy absorption capacity of SIOV-S07K20 for $t_r^* = 1,3 \text{ ms}$, $i_{\max} = 1,4 \text{ A}$ and 10^6 repetitions according to equation 18 is

$$W_{\max} = V_{\max} \cdot i_{\max} \cdot t_{r \max} = 60 \cdot 1,4 \cdot 0,0013 = 0,11 \text{ J (with } t_{r \max} = t_r^* \text{ according to 2.5.3)}$$

According to equation 17 the varistor must in the worst case absorb an energy of

$$W^* = 1/2 L i^{*2} = 1/2 \cdot 0,1 \text{ H} \cdot 1 \text{ A}^2 = 0,05 \text{ J} < W_{\max} = 0,11 \text{ J}$$

per switching cycle. Thus SIOV-S07K20 and CU4032K20G2 also satisfy the selection requirement of equation 10.

For CN1206K20G the result is $W_{\max} = 58 \cdot 1,5 \cdot 0,0013 = 0,11 \text{ J} > 0,05 \text{ J}$.

This varistor is therefore also suitable.

Calculation Examples

Average power dissipation

According to equation 19, applied energy of 0,05 J every 10 s produces an average power dissipation of

$$P^* = \frac{W^*}{T^*} = \frac{0,05}{10} = 0,005 \text{ W}$$

The product table shows a maximum dissipation capability of 0,02 W for SIOV-S07K20 and CU4032K20G2. So on this point too, the choice is correct (equation 11).

For the sake of completeness, the minimum permissible time between two applications of energy is calculated (equation 20):

$$T_{\min} = \frac{W^*}{P_{\max}} = \frac{0,05 \text{ J}}{0,02 \text{ W}} = 2,5 \text{ s}$$

For CN1206K20G, with $P_{\max} = 0,008 \text{ W}$ the result is

$$T_{\min} = \frac{W^*}{P_{\max}} = \frac{0,05 \text{ J}}{0,008 \text{ W}} = 6,2 \text{ s}$$

Maximum protection level

The *V/I* curve for S07K20 and/or CU4032K20G2 shows a protection level of 60 V at 1 A for the worst-case position in the tolerance field (P Spice supplied by EPCOS: TOL = +10).

The protection level for CN1206K20G is 55 V.

This means that all three types meet the requirement for a protection level < 65 V.

The hicap varistors SHCV-SR...K20... also satisfy all the selection criteria. Their use can have a positive effect as far as contact erosion and RFI are concerned. They also mean a reduction of the maximum protection level to 50 V.

4.2 Ensuring EMC of equipment connected to the 230 V mains

The example describes the selection procedure for a varistor that is to ensure the EMC of a device in accordance with IEC 61000-4-5 for 230 V operating voltage and a test voltage of 4 kV.

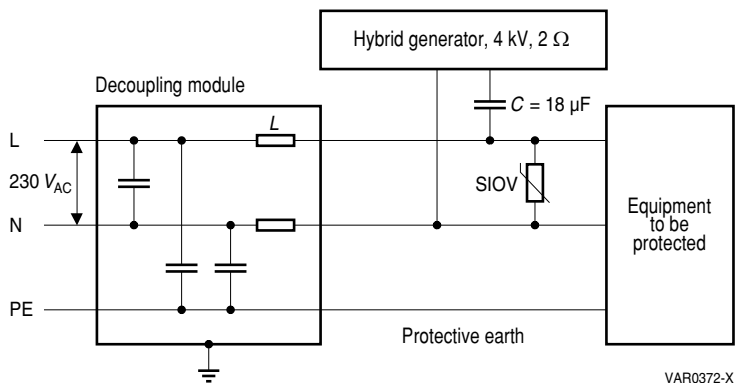


Figure 54 EMC test in accordance with IEC 61000-4-5 with $R_i = 2 \Omega$, charge voltage 4 kV on a 230 V_{AC} mains network

Line voltage:	230 $V_{AC} \pm 10 \%$
Hybrid test generator:	4 kV, 2 Ω
Number of repetitions:	10 times (5 times in each polarity)
Voltage endurance of the equipment to be protected	1 kV

Operating voltage

For European public AC power networks, IEC 60038 specifies that a mains voltage tolerance of $\pm 10 \%$ is to apply as from the year 2003. In this selection example, we shall assume this tolerance to apply. This means that a maximum required operating voltage of 253 V_{AC} must be taken into account when selecting the varistor (the negative tolerance is of no significance for varistor selection).

In order to achieve the lowest possible protection level, as described in 2.5.1, the varistor types with the voltage class closest to 253 V must be chosen, i.e. in this case the voltage class "K275".

For this voltage class, the following EPCOS components are available:

- SMD types SIOV-CU...K275G2
- disk types
(StandarD, AdvanceD, SuperioR series) SIOV-S...K275(E2)(E3)
- block types (HighE series) SIOV-B...K275
- strap types (HighE series) SIOV-L...K275...

Surge current

In order to determine the surge current capability, the SIOV-S14K275 will be taken as an example. For a given surge voltage, the maximum current will always be observed, if the varistor operates at the lower limit of the tolerance range (ref. fig. 7a).

For this reason, the clamping voltage reduced by the tolerance band width must be inserted in equ. 12, instead of the value reduced by the tolerance ($K = \pm 10\%$).

The surge generator's short circuit current would be:

$$i^* = \frac{4 \text{ kV}}{2 \Omega} = 2 \text{ kA}$$

From the V/I characteristics of the SIOV-S14 we derive a protection level of 1000 V for an S14K275.

Reducing this by the tolerance ($\pm 10\%$), we obtain $V_{\text{SIOV}} = 1000 \text{ V} \cdot \frac{0,9}{1,1} = 820 \text{ V}$.

By inserting this in equation 12, we obtain the surge current amplitude (worst case)

$$i^* = \frac{4000 \text{ V} - 820 \text{ V}}{2 \Omega} = \frac{3180 \text{ V}}{2 \Omega} = 1590 \text{ A}.$$

The selected varistors must be able to handle a surge current of this amplitude ten times consecutively, regardless on polarity.

In accordance with IEC 61000-4-5, the hybrid generator is designed to supply surge current waveforms of type 8/20 μs (figure 8a) in the case of a short-circuit. As the protection level of the varistor in this case is low in comparison to the no-load generator voltage, we can assume the 8/20 μs wave form to apply in this type of load as well. As shown in figure 21, this wave form can be transformed into an equivalent rectangular wave with $t_r^* = 20 \mu\text{s}$, which is to be used.

Look up this type in the derating diagram (drawing S14K50...320), in order to check whether or not an S14K275 can be subjected to the a.m. surge current load. As a result of the investigation, a current of 1590 A (8/20 μs) is only permissible for 2 consecutive load cycles. For the required number of repetitions of 10 times, the current i_{max} would be 1000 A only.

Since $i^* > i_{\text{max}}$, S14K275 is not a suitable choice for the given application conditions.

The type with the next higher surge current capability, would be S14K275E2. The derating field yields $i_{\text{max}} (10 \times) = 1500 \text{ A}$. For this reason this type is not suitable either.

As a result, the selection check procedure must be repeated for the type series having the next higher power dissipation capability, SIOV-S20 series. In this case, the type in question is the varistor type S20K275:

Here, equation 12 results in

$$i^* = \frac{4000 \text{ V} - \left(950 \cdot \frac{0,9}{1,1}\right) \text{ V}}{2 \Omega} = \frac{4000 \text{ V} - 780 \text{ V}}{2 \Omega} = \frac{3220 \text{ V}}{2 \Omega} = 1610 \text{ A}.$$

Calculation Examples

For 10 load repetitions (at $t_r^* = t_r = 20 \mu\text{s}$) the derating field of the S20K275 shows

$$i_{\max} = 2500 \text{ A.}$$

With this value, the S20K275 meets the selection criterion of equation 9:

$$i^* \leq i_{\max}.$$

Energy absorption

Since the energy absorption, as calculated by equation 6, is directly correlated to the surge current, the S20K275 also fulfils the selection criterion of equation 10:

$$W^* \leq W_{\max}.$$

Power dissipation

In order to determine the power dissipation, we must calculate the energy absorbed by the S20K275 when conducting the surge current. According to equation 16:

$$W^* = v^* \cdot i^* \cdot t_r^* = 780 \text{ V} \cdot 1610 \text{ A} \cdot 20 \cdot 10^{-6} \text{ s} = 25 \text{ J.}$$

As a pulse repetition rate, IEC 61000-4-5 specifies a maximum of one pulse/60 s. Inserting this in equation 19 results in:

$$P^* = \frac{W^*}{T^*} = \frac{25 \text{ J}}{60 \text{ s}} \approx 0,4 \text{ W.}$$

From the product table, the maximum permissible periodic load, i.e. average maximum power dissipation of an S20K275 is found to be 1 W. With this, the selection criterion of equation 11,

$$P^* \leq P_{\max}$$

is also met.

Protection level

The protection level is found to be 900 V (from the *V//I* characteristics for a value of 1610 A). In this case, the 4 kV "overvoltage" is limited to 23 %.

The protection level is lower than the voltage strength of the equipment to be protected, which is equal to 1000 V.

With the fulfilment of this final criterion, the StandarD SIOV-S20K275 has been found to meet all selection criteria and can thus be deemed suitable for the application.

Comparison to PSpice

The selection of the varistors for table 3 was carried out using PSpice calculations. The results for S20K275 correlate well with the values calculated here.

Calculation Examples

Other suitable types

If the physical dimensions of the chosen component, SIOV-S20K275, are too large, similar selection calculations show that the EnergetiQ varistor SIOV-Q14K275, which has a lower component height, is also suitable. For comparison:

$$\text{SIOV-S20K275} \quad h_{\max} = 25,5 \text{ mm}$$

$$\text{SIOV-Q14K275} \quad h_{\max} = 19,5 \text{ mm}$$

Remark:

It is not possible to find a SMD varistor type solution suitable for a load as high as 4 kV. The type series SIOV-CU4032, which has the highest load ratings, is only suitable for loads of up to 1 kV across 2 Ω (see table 4).

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