

Varistor modeling for power electronics applications simulations

C. MIHALACHE*, S. NITU, F. IONESCU
 University "Politehnica" Bucharest, Department of Electrical Engineering
 Splaiul Independentei 313 Bucharest Romania

A varistor equivalent electrical network is presented together with the parameters that have to be obtained. The experimental current vs voltage characteristic for different varistors is revealed. Using a fitting software package, the parameters for the current vs. voltage static characteristic modeling are obtained. Finally, a simulation model ready to be used in different CAD software environments is obtained. The experimental results confirm the model.

(Received March 13, 2008; accepted May 5, 2008)

Keywords: Varistor, Power electronics, Simulation, CAD software

1. Introduction

The ZNR, which stands for Zinc Oxide Nonlinear Resistor, is a trade mark of epoch-making voltage dependent resistor elements.

The ZNR is a ceramic component comprising sintered ZnO and oxide additives, such as Bi₂O₃, CO₂O₃, MnO₂, Cr₂O₃, and Sb₂O₃. The major features of the ZNR varistor are:

- large withstand surge current;
- excellent clamping voltage characteristic attributed the large nonlinear exponent α , and small leakage current;
- fast follow-on current;
- any varistor voltage is available;
- symmetrical V-I characteristics.

Nonlinear resistors have the electric resistance which varies with the applied voltage. The V-I characteristics of varistor are approximately indicated by the following equation:

$$I = (V / C)^\alpha \quad (1)$$

where the I is a current which flows through the varistor. The V is the voltage of both varistor terminals. The C and α are constants. The α is called a voltage nonlinear exponent.

Typical V-I characteristics on a logarithmic scale are shown in Fig. 1. As is clear in the figure, the V-I characteristics of the ZNR varistor do not follow the equation (1) at all current ranges. At the extremely low current levels and also at high current levels, non-linear exponent falls. Those regions are divided into three by their characteristics.

- (a) Normal varistor region: the varistor characteristics follow the equation (1);
- (b) Low α region: at the extremely low current levels for example, in the order of nano ampere, the V-I characteristics of the varistor is the linear resistance characteristic. The temperature dependence is especially high at this level;
- (c) When high current flows into the ZNR, it shows extremely low resistance value.

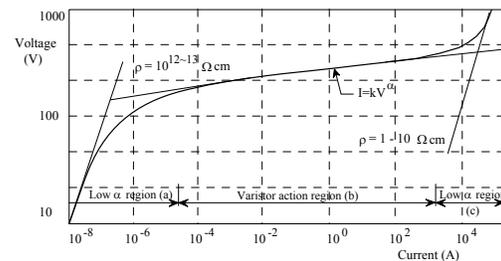


Fig. 1. The V-I Characteristics of ZNR.

An equivalent network for varistor modeling is already known (Fig. 2):

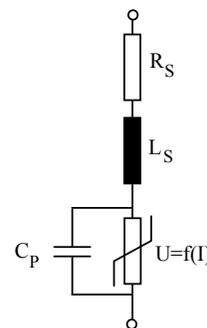


Fig. 2. Equivalent network for the varistor $U(I)$ characteristic modeling.

The paper goal is to present a simulation model for low voltage varistors ready to be used in different CAD software environments. The model parameters are obtained following the experimental results concerning current vs voltage characteristic for different varistors, as well as L_S and C_p measurements.

2. Varistor modeling

A correct estimation for parameters is very important for the model fidelity, especially in transient regimes.

2.1. Series resistance R_S determination.

The R_S value is mainly due to the wire terminals resistance. Since the estimation is done only for low voltage varistors, with a short terminals length, the resistance value is very small. An $R_S = 100 \mu\Omega$ value, based on wire resistance measurement, is considered to be a good estimation. [5].

2.2. Series inductance L_S determination

The L_S value is highly correlated with the varistor terminals geometry. For standard lengths (approx. 2 cm.) the measured value taken into account is about $L_S = 10nH$. Practically this value has to be adapted following the practical setup and the varistor physical position.

The L_S value it is important for high steep voltage. Different tests have been made using a $(8/20\mu s)$ current generator and a low voltage ISKRA V300K20 varistor [5].

For low voltage / current levels the varistor behavior is an inductive one since the current is delayed to the voltage. Increasing the voltage / current levels the offset between the current and the voltage decreases, passing from a "resonant behavior". Finally a capacitive effect is observed with the current forwarding the voltage.

This behavior corresponds to a "global inductance" decreasing with the current. The varistor microscopic structure [6], [7], shows that varistor inductivity due to the structure is excluded. Practically a correlation between the varistor inductivity and the current throw it is excluded. The compromise is to consider for the L_S a constant value due to the terminals length and to use for the current – voltage characteristic the peak values from diagrams like Fig. 3.

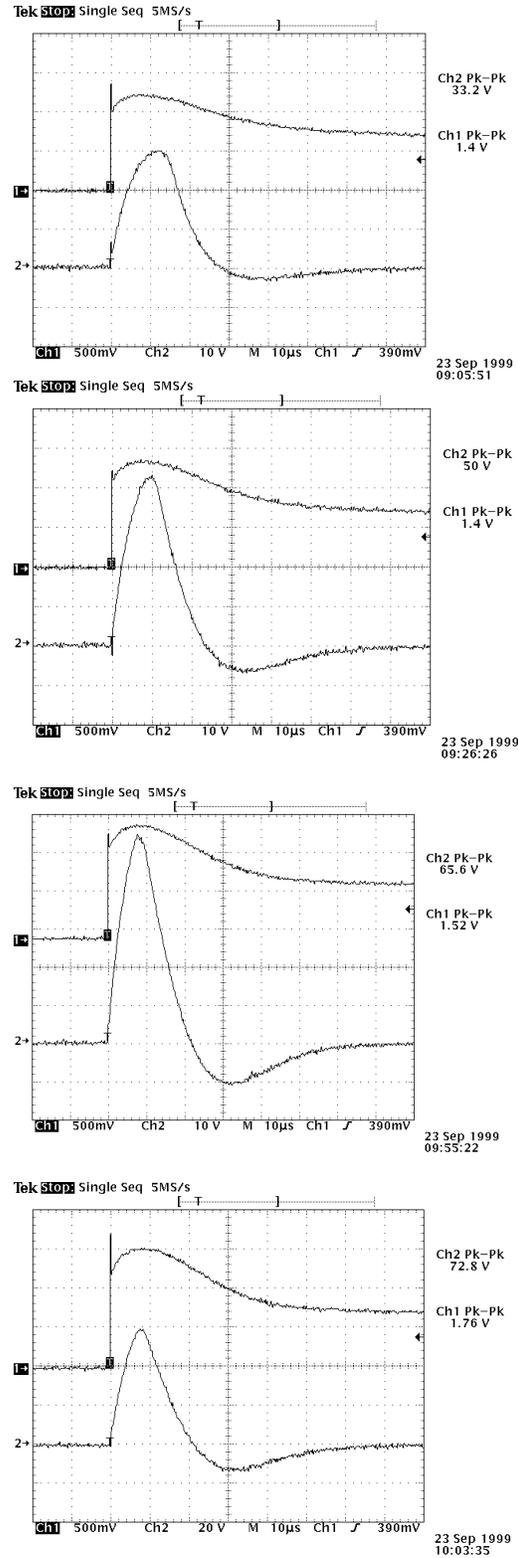


Fig. 3. Voltage (ch1, 1:1000) and current (ch2, 0.01V / A) for a low voltage varistor (ISKRA V300K20).

2.3. C_p determination

Several tests have been made using a programmable RLC meter for low voltage varistors C_p determination [5]. Fig. 4 presents C_p variation with temperature and frequency. These results show that a measured value for C_p at 55°C temperature and 10kHz frequency is a good approximation for the model.

A correct determination for C_p is emphasized in Fig. 6 showing the current throw the varistor and the voltage across it for a chopper structure (Fig. 5).

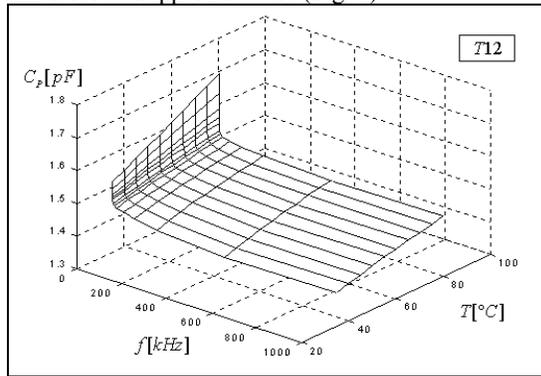


Fig. 4. C_p variation with temperature and frequency for a low voltage varistor.

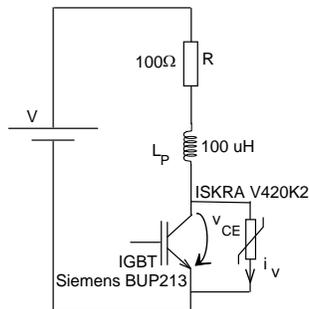
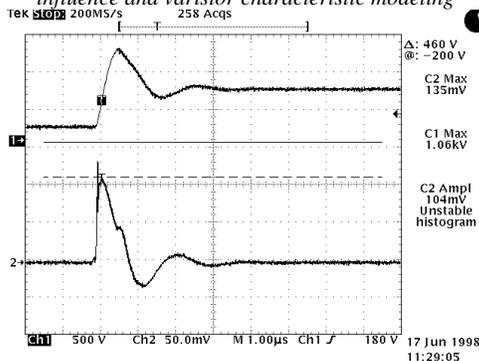
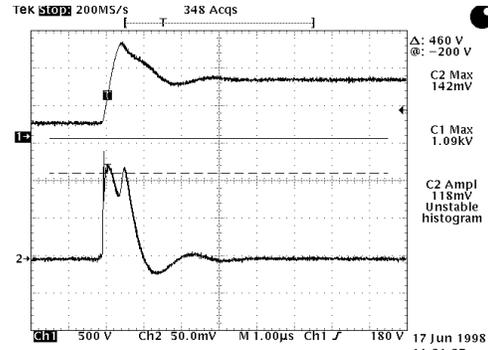


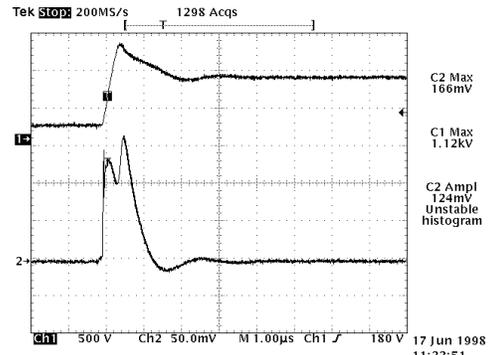
Fig. 5. Experimental model for the study of the C_p influence and varistor characteristic modeling



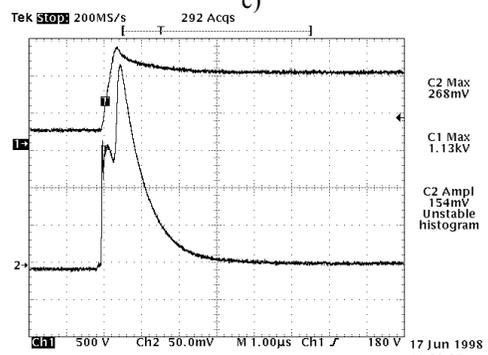
a)



b)



c)



d)

Fig. 6. v_{CE} voltage (ch1) and i_v current (ch2, 100mV/1A) for different V voltage levels (Fig. 5).

The T transistor switches an inductive-resistive load without free-wheeling diode generating an over voltage occurring between collector and emitter. This over voltage is limited by an ISKRA V420K20 varistor.

The measured current is composed by the charging current for C_p (i_c) and by the main current throw R_v resistance (i_{Rv}). In steady state $i_v = i_{Rv}$, having $i_c = 0$, also when $i_{Rv} \gg i_c$. Following this considerations the current figured on the varistor current - voltage characteristic is, in fact, i_{Rv} .

On Fig. 6a. the current through the varistor presents two peaks: the first one related to the C_p charging and the second one related to the non-linear resistance R_v conduction. On Fig. 6a. the peak current for i_v is completely related to the C_p charging, so for the beginning $i_v \cong i_c$. Consequently, by the increasing of the DC voltage level, the over voltage level (also applied to the varistor) increases too. Taking into account the varistor $I(V)$ strong non-linearity or that region, the current (i_{Rv}) will be highly increased, his peak value being greater than the peak value for (i_c) (Fig. 6b,c,d).

These facts, leads to the conclusion that there are situations when the over voltage is limited only by C_p . Consequently a realistic C_p determination is essential for a good varistor model.

2.4. $U = f(I)$ determination

The best fitting $U = f(I)$ relation for a varistor is:

$$U = 10^{m_1 + m_2 \cdot \log(I) + m_3 \cdot e^{-\log(I)} + m_4 \cdot e^{\log(I)}} \quad (2)$$

For m_i ($i = \overline{1,4}$) determination, the experimental $U = f(I)$ has to be revealed. Since the current range is large, three polarization methods have been employed:

- I) DC voltage for currents below 10mA;
- II) square voltage waveform for currents between 1mA ÷ 50A;
- III) non repetitive current pulses (8/20 μ s) for high currents.

A fitting software program was used for m_i determination.

3. Experimental results for model confirmation

Following the procedures already described in second paragraph, parameters model for different varistors have been obtained [5]. The parameters have been employed in a PSPICE model. For exemplification an example concerning an ISKRA V420K20 will be presented.

3.1. Static behaviour of the model.

Fig. 7 shows the experimental $U = f(I)$ curve for a ISKRA V420K20 varistor obtained following the methods presented in 2.4. paragraph.

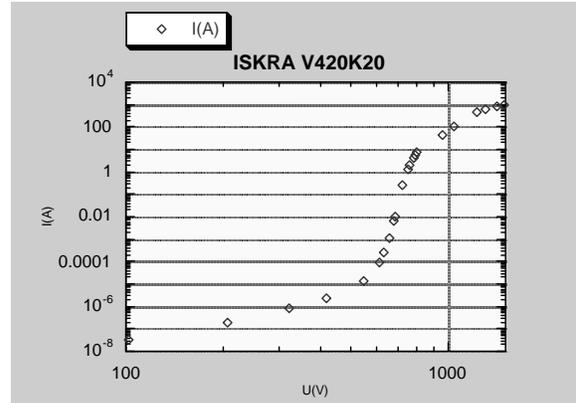
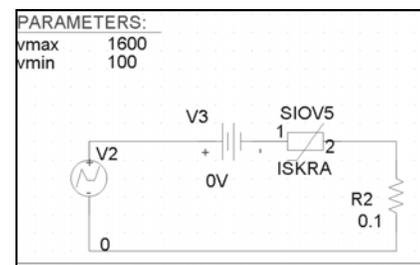
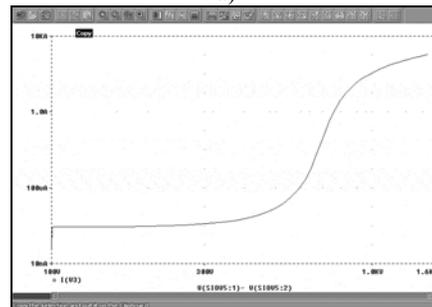


Fig. 7. Experimental $U = f(I)$ for a ISKRA V420K20 varistor

Fig. 8a presents the PSPICE simulation circuit since Fig. 8b presents the simulated $U = f(I)$ characteristic.



a)



b)

Fig. 8. PSPICE simulation for ISKRA V420K20 varistor $U = f(I)$: a) simulation circuit; b) simulated $U = f(I)$ curve

The V2 source applies a DC voltage between $v_{\min} = 100V$ and $v_{\max} = 1600V$.

The experimental curve (Fig. 7) and the simulated one (Fig. 8b) are very close.

3.2. Transient behaviour

The experimental set-up has already been presented in Fig. 5.

The simulation results (Fig. 9), using SPICE show a current (bottom waveform) through the model series inductance L_S (equivalent to the current flowing by the entirely varistor) very close to those obtained on the experimental model (Fig 10) (bottom waveform, 1A/div).

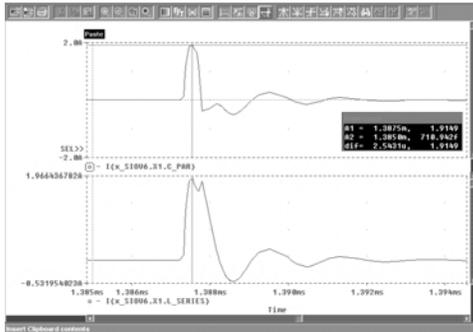


Fig. 9. Simulation results for the varistor characteristic modeling.

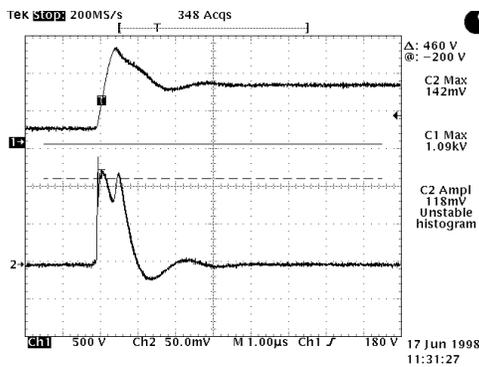


Fig. 10. Experimental results for the varistor characteristic modeling.

4. Conclusions

A varistor equivalent electrical network was presented. The importance of each parameter was detailed. Correct estimation of parameters is important for both static and transient regimes. Especially the importance of parallel capacity C_p was emphasized. A correct PSPICE varistor model could be obtained. Using the same equivalent network a PSIM model was also obtained. The PSIM model behavior in transient regimes is currently under study.

References

- [1] A. Bui, K. Abdullah, A. Loubière, M. Tao, Q. C. Nguyen, J. Phys. D: Appl. Phys. **24**, 757 (1991).
- [2] F. Ionescu, C. Mihalache, Experimental tests for varistor electrical model improvement", Simpozion ICPE, 28-29 sept. 2000.
- [3] D. Floricău, F. Ionescu, C. Mihalache : Symposium on Advanced Topics in Electrical Engineering – Universitatea Politehnica din București, 4 decembrie 1998 - vol. Electrical Apparatus and Power Static Converters p. 33-36.
- [4] L. M. Levinson, H. R. Philipp, IEEE Trans. On parts, Hybrids and Packaging PHP-**13**(4), 338 (1977).
- [5] C. Mihalache Contribution to the study of the zinc oxide based varistors behavior as protection for power semiconductor devices working in power static converters. PhD thesis, University "Politehnica" Bucharest, July 2001.
- [6] H. Tang, V. Scuka "Transient response of low-voltage varistors", ETEP Vol. 9, nr. 2, 1999.
- [7] M. Tao, A. Bui, O. Dorlanne, A. Loubiere "Different single grain junctions within ZnO varistor", Journal of Applied Physics, vol. 61, 1987.

*Corresponding author: cristinel.mihalache@gmail.com