There's an "*R*" in Varistor

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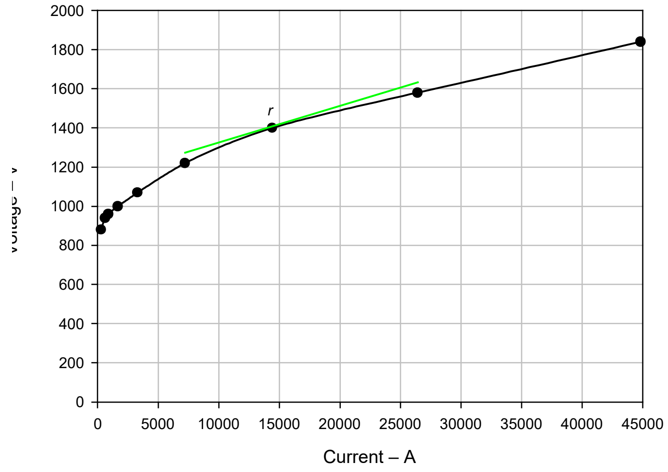
atis

What kind of "*R*"?

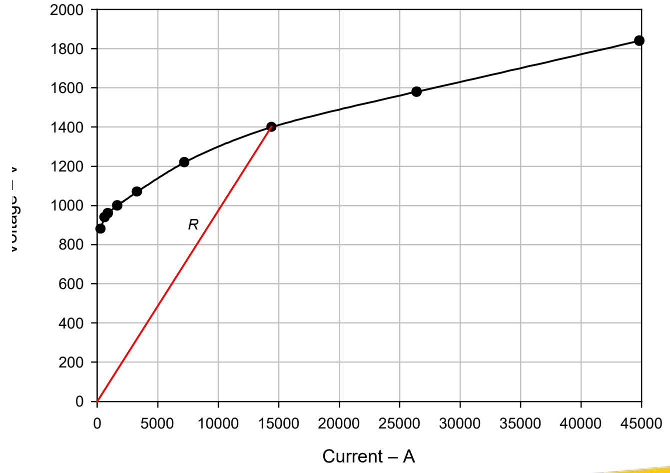
- Dynamic "*r*"

$$r = \frac{\Delta v}{\Delta i}$$



- Quotient of characteristic point values "*R*"

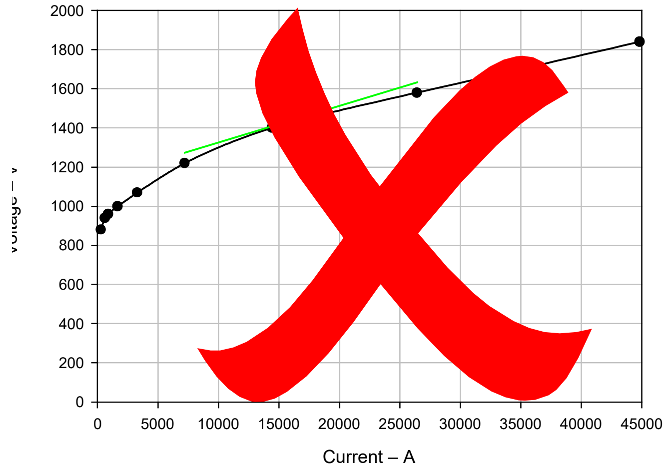
$$R = \frac{V}{I}$$



Answer to “What kind of “*R*”?”

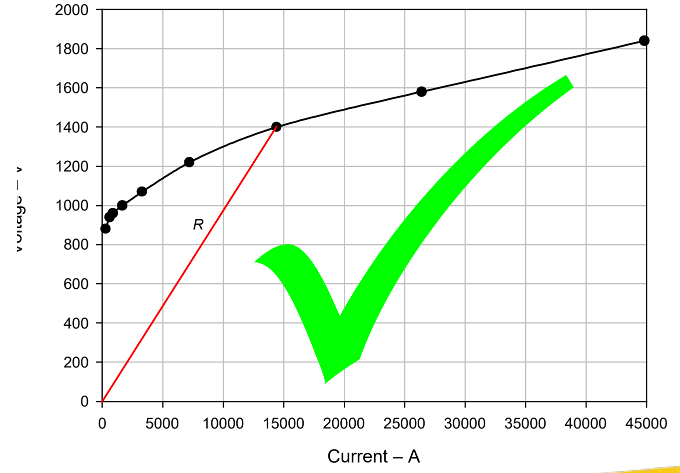
- Dynamic “*r*”

$$r = \frac{\Delta v}{\Delta i}$$



- Quotient of characteristic point values “*R*”

$$R = \frac{V}{I}$$



Why "*R*"?

- Work done in China shows that "R" is a useful parameter when working with Varistor voltage-current relationships
- Don't we have a relationship given in Varistor definitions?

varistor (voltage dependent resistor), VDR: component, whose conductance, at a given temperature range, increases rapidly with voltage within a given current range

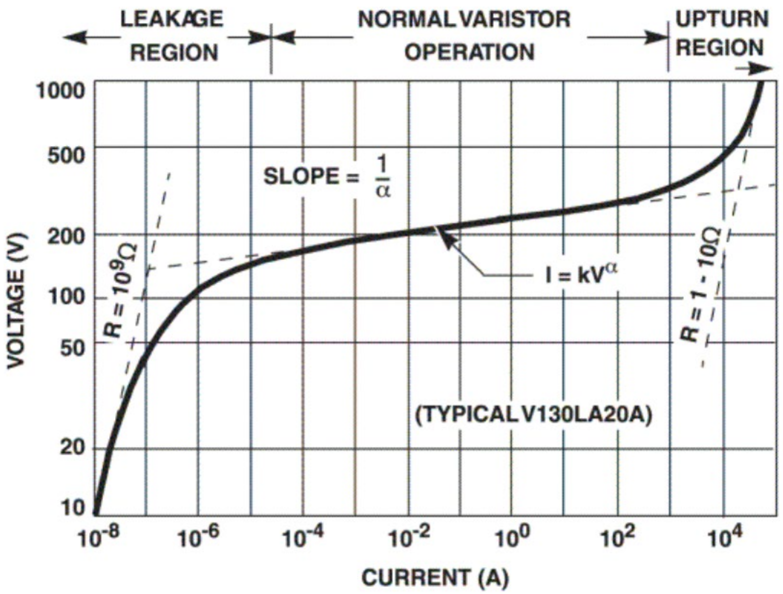
Note 1 to entry: This note applies to the French language only.
Note 2 to entry: Varistor is graphically symbolized as Z.
Note 3 to entry: This property is expressed by either of the following formulae:

$U = CI^{\beta}$ (1) or $I = AU^{\gamma}$ (2)

where

I is the current flowing through the varistor;
U is the voltage applied across the varistor;
β is the non-linearity current index;
γ is the non-linearity voltage index;
A and C are constants. (IEC 61051-1 ED3, Varistors for use in electronic equipment - Part 1: Generic specification)

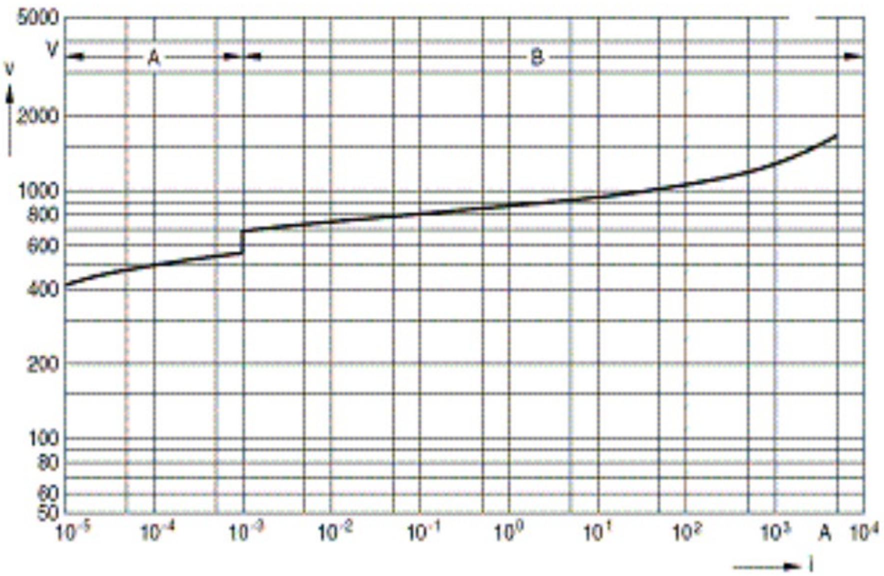
The Chinese characteristic takeaway — 1



Single voltage-current characteristic line.

(ITU-T K.128)

A is leakage segment (typical)
B is operational segment (maximum voltage)
(ITU-T K.128)



The Chinese characteristic takeaway — 2

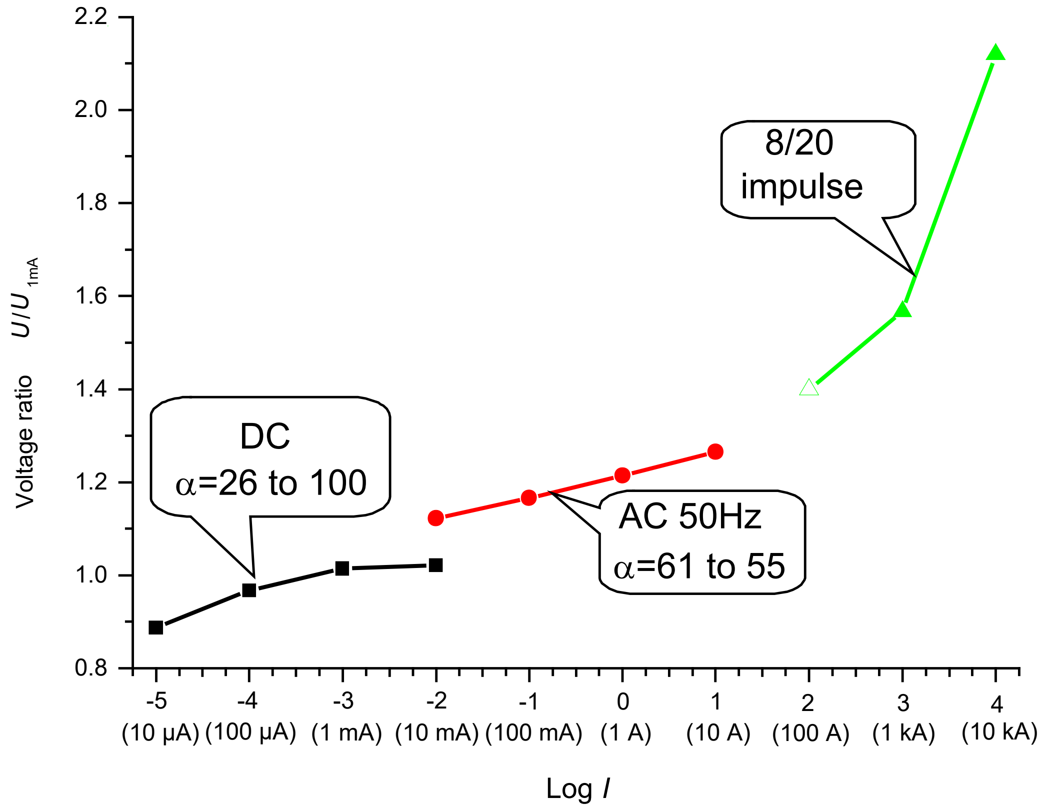
Three segment characteristic for

- d.c.,
- a.c. and
- impulse current

operational regions

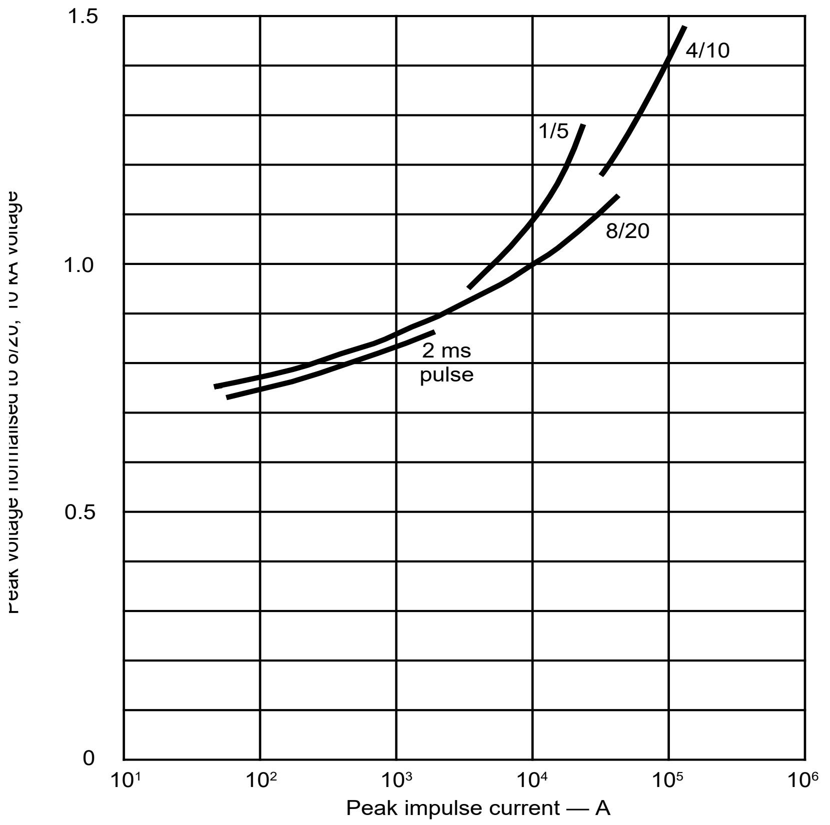
NOTE: In $I = AU^{\gamma}$ Chinese use α rather than γ.

(ITU-T K.128)



The Chinese characteristic takeaway — 3

- But wait – there's more!
  The impulse characteristic is di/dt dependent.
  NOTE: This is in addition to any inductive lead effects.
  (ITU-T K.128)

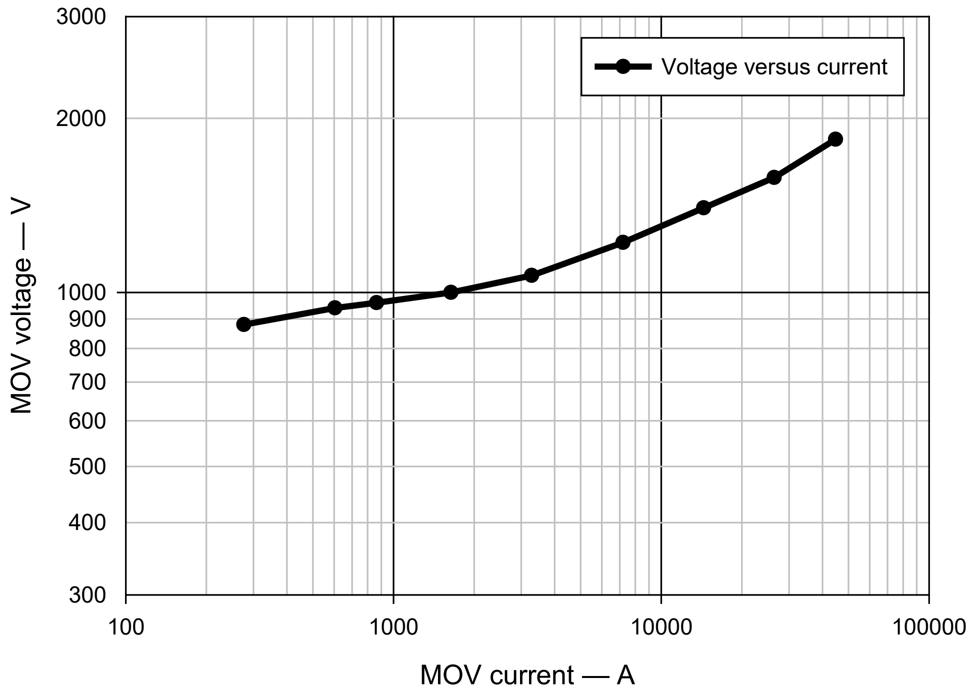


Modelling — Chinese data

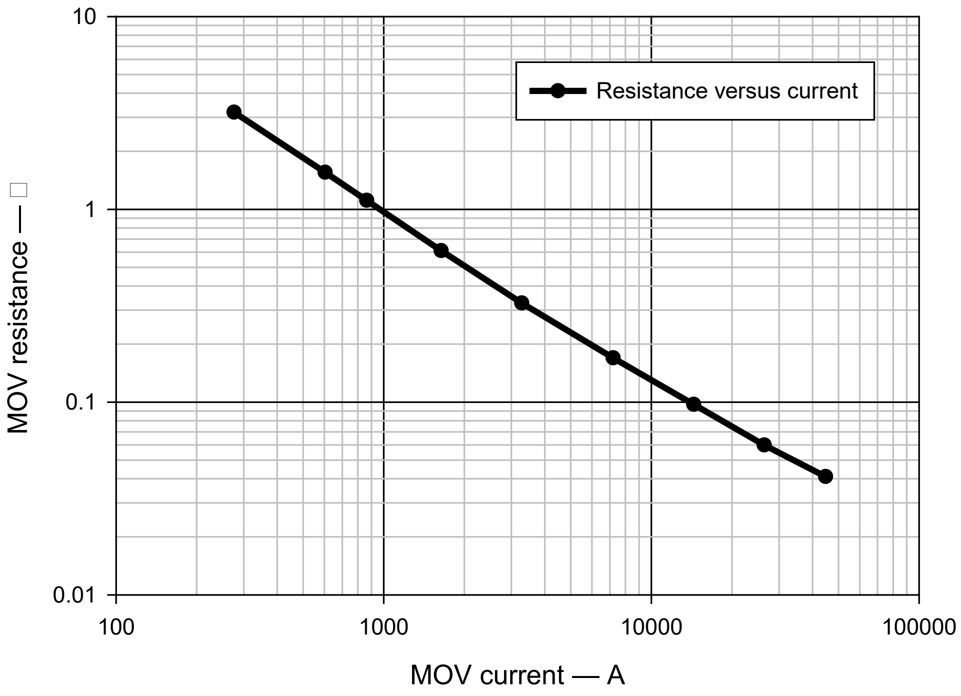
This analysis uses the measured and calculated values for an MOV arrester block shown in the right table

Current A	Voltage V	Resistance Ω
276	880	3.18
604	940	1.56
864	960	1.11
1640	1000	0.610
3280	1070	0.326
7200	1220	0.169
14400	1400	0.0972
26400	1580	0.0598
44800	1840	0.0411

Modelling — Chinese data plots

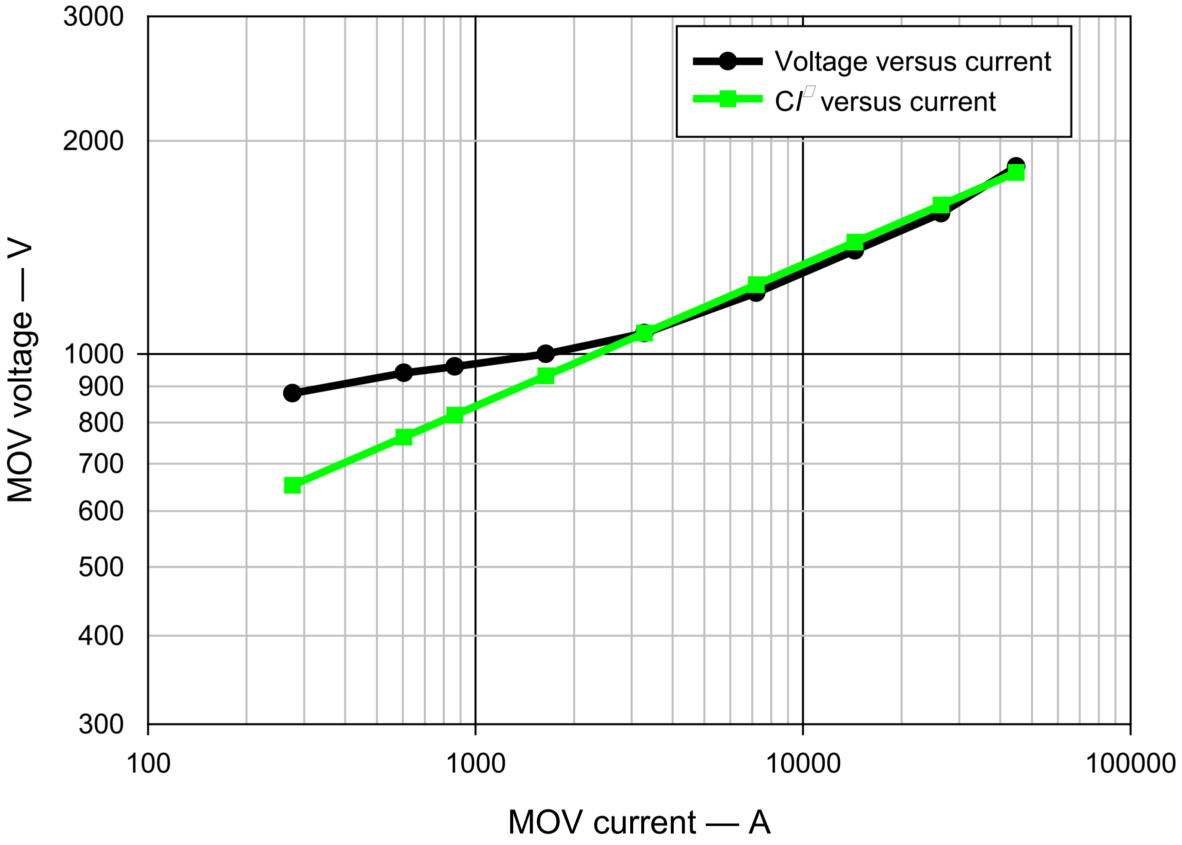


MOV sample, voltage versus current



MOV sample, resistance versus current

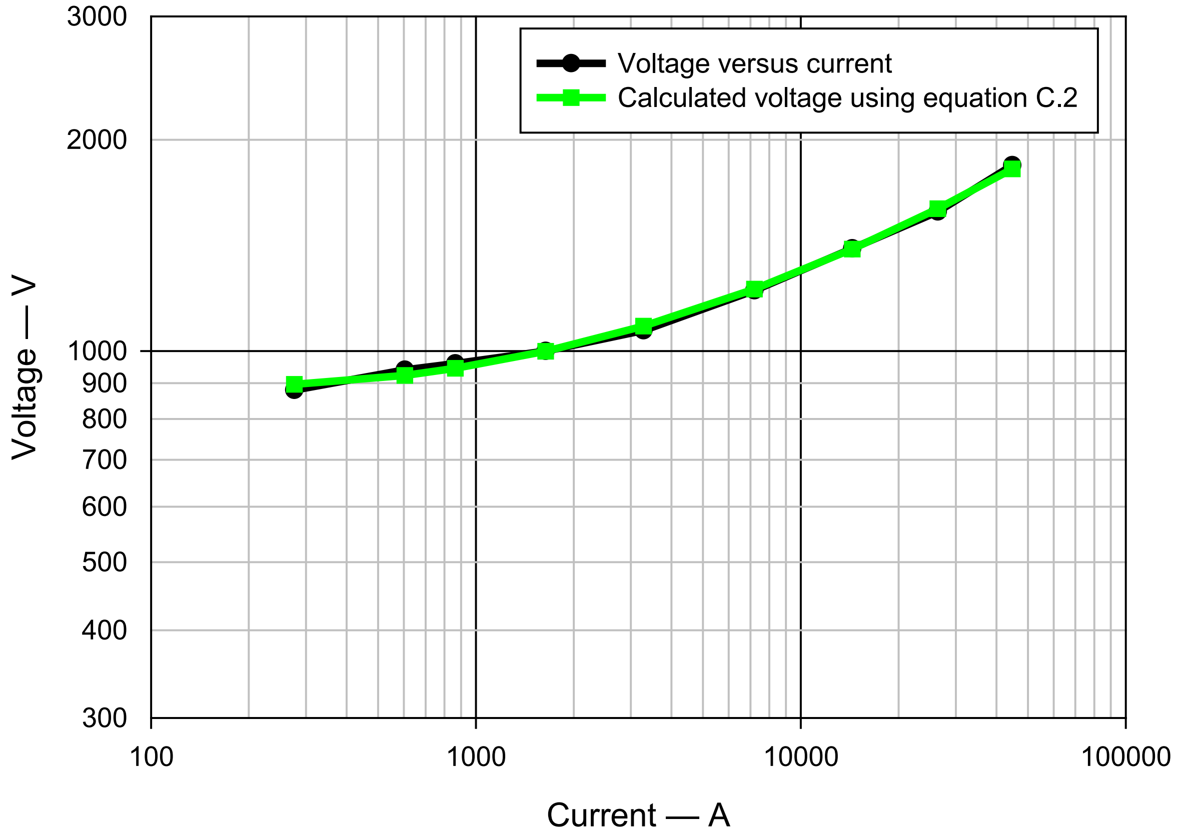
Equation Fitting — 2-term power law



Equation C.1

$U = CI^{\beta}$

Equation Fitting — Chinese Log(*I*) equation result

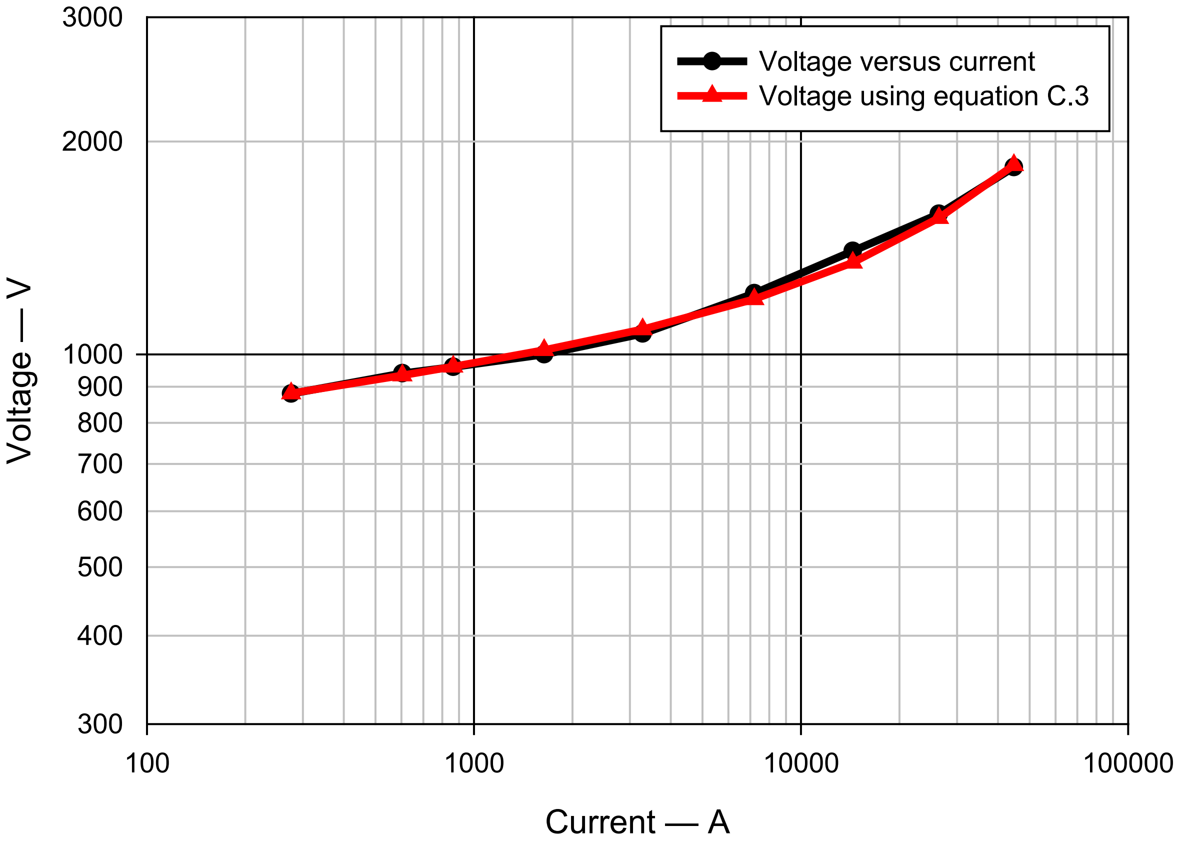


Equation C.2

$$R = 10^{A_0} \times I^{(A_1 + A_2 \cdot \log I) \times \log I}$$

A_0 is 3.2306
A_1 is -1.2465
A_2 is 0.05434

Equation Fitting —3-term power law



Equation C.3

$$U = A + CI^{\beta}$$

A is 815

C is 4.32

β is 0.51

References

- Wang zhen-lin, Li Sheng-tao “Engineering and Application of Zinc Oxide Voltage Dependent Ceramics” [M] , Beijing: Science Press, 2009
- Panasonic Electronic Component Co., Ceramic Department “Application Manual of ‘ZNR’” (2nd.edition), 1981.
- Wu wei-han, He jin-liang, Gao Yu-ming “properties and Applications of Nonlinear Metal Oxide Varistors” [M], Beijing, Qing Hua University Press, 1998
- ITU-T Recommendation K.128 (01/2018), Surge protective component application guide - metal oxide varistor (MOV) components

Summary of foregoing

- The characteristic point quotient "*R*" shows a strong correlation with current. The voltage at the point is *R* x *I*.

- The Chinese Log(*I*) and 3-term power equations are reasonable curve fits to the voltage-current characteristic.

- A more accurate term and definition would be:
  metal oxide varistor, MOV: non-linear resistor made of a sintered mixture of zinc and other metal oxides whose conductance, at a given temperature and within a given current range, increases rapidly with current

SPICE (Simulation Program with Integrated Circuit Emphasis)

This section creates an LTspice model for a varistor using the modified power-law $U = 815 + 4.32 \times I^{0.51}$ equation derived earlier expressed as a current $I = (0.231*U-188.3)^{1.96}$.

LTspice comes with various Arbitrary Behavioural Voltage or Current Sources, which can be controlled by equations:

- Type E. Voltage Dependent Voltage Source
- Type F. Current Dependent Current Source
- *Type G. Voltage Dependent Current Source*
- Type H. Current Dependent Voltage Source

LTspice varistor Type G. Voltage Dependent Current Source

This section creates an LTspice model for a varistor using the $I = (0.2313*U-188.23)^{1.96}$ equation. This equation is unidirectional and needs to be made bidirectional and placed in LTspice equation format:

GRES 1 2 VALUE={sgn(V(1,2))*(0.2313*abs(V(1,2))-188.23)**1.96}

In words, the Type G voltage dependent current source (having terminals 1 and 2) draws a current equal to:
The polarity of the terminal voltage multiplied by (0.2313 times the absolute terminal voltage minus 188.23) raised to the power of 1.96.

LTspice varistor sub-circuit creation

1. Insert a resistor symbol in the circuit

2. Change the symbol from a component into an Type G X1X2 sub-circuit (current source set by voltage) as described at https://electronics.stackexchange.com/questions/313333/ltspice-how-to-vary-resistances-in-a-simulation-depending-on-the-value-of-a-vol

3. Insert a SPICE sub-circuit statement referencing the Type G X1X2 sub-circuit and the equation.

LTspice varistor test circuit — description

The circuit components are:

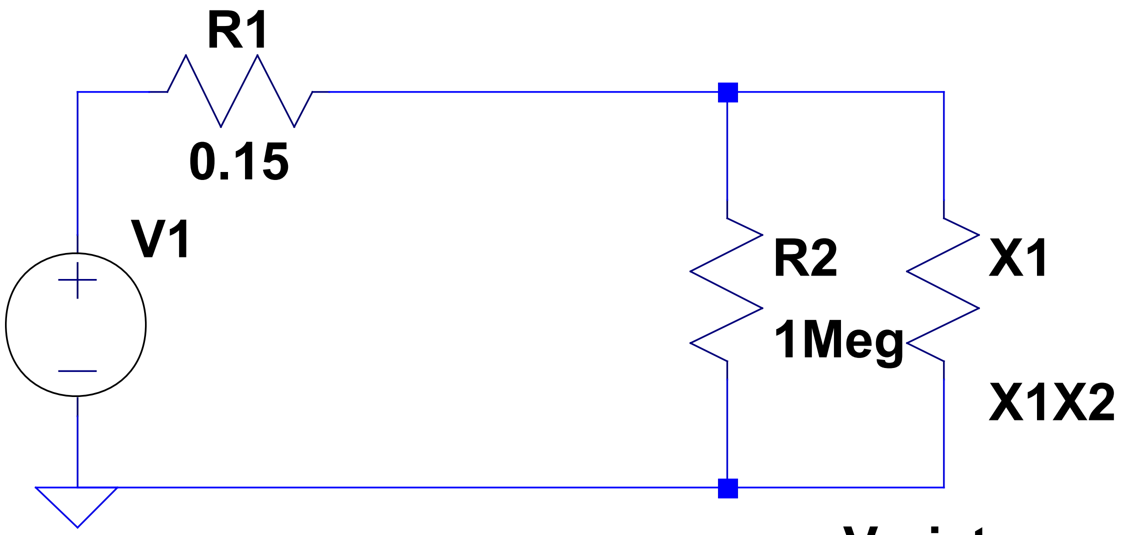
- V1 is a double exponential surge generator having a peak voltage of 10 kV, a 1.5 μs front time and a 50 μs decay time.
- Series resistor R1 limits the peak generator current into the varistor
- Shunt resistor R2 simulates the varistor leakage resistance.
- X1 is the varistor sub-circuit drawing a current defined by
  GRES 1 2 VALUE={sgn(V(1,2))*(0.2313*abs(V(1,2))-188.23)**1.96}
- The simulation run time is 200 μs

LTspice varistor test circuit — diagram

```
.SUBCKT X1X2 1 2
GRES 1 2 VALUE={sgn(V(1,2))*(0.2313*abs(V(1,2))-188.23)**1.96}
.ENDS
```

```
.tran 0 200us 0
```

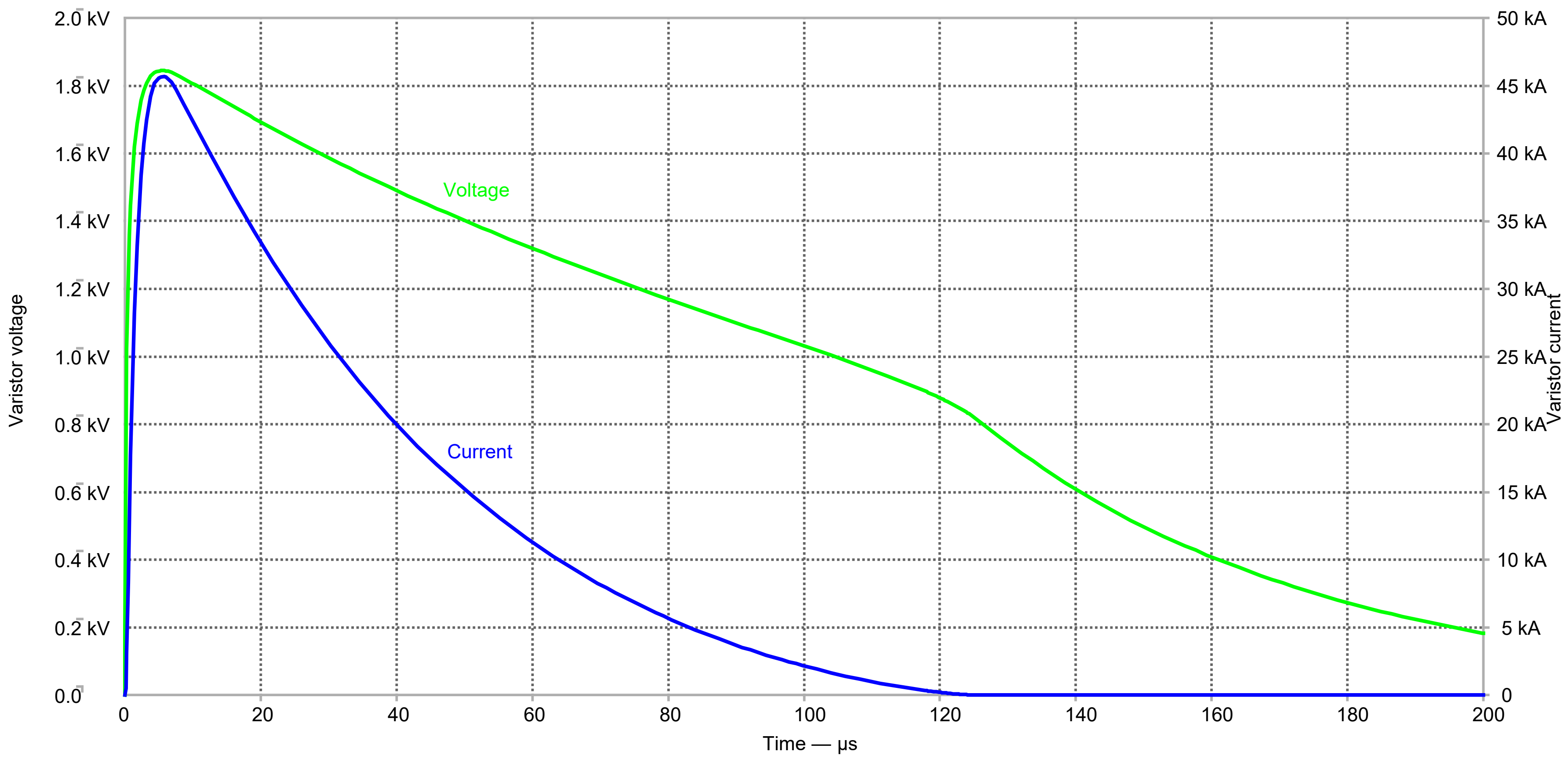
Voltage surge generator



EXP(0 10000 0 1.5u 0 50u)

Varistor Type G sub-circuit

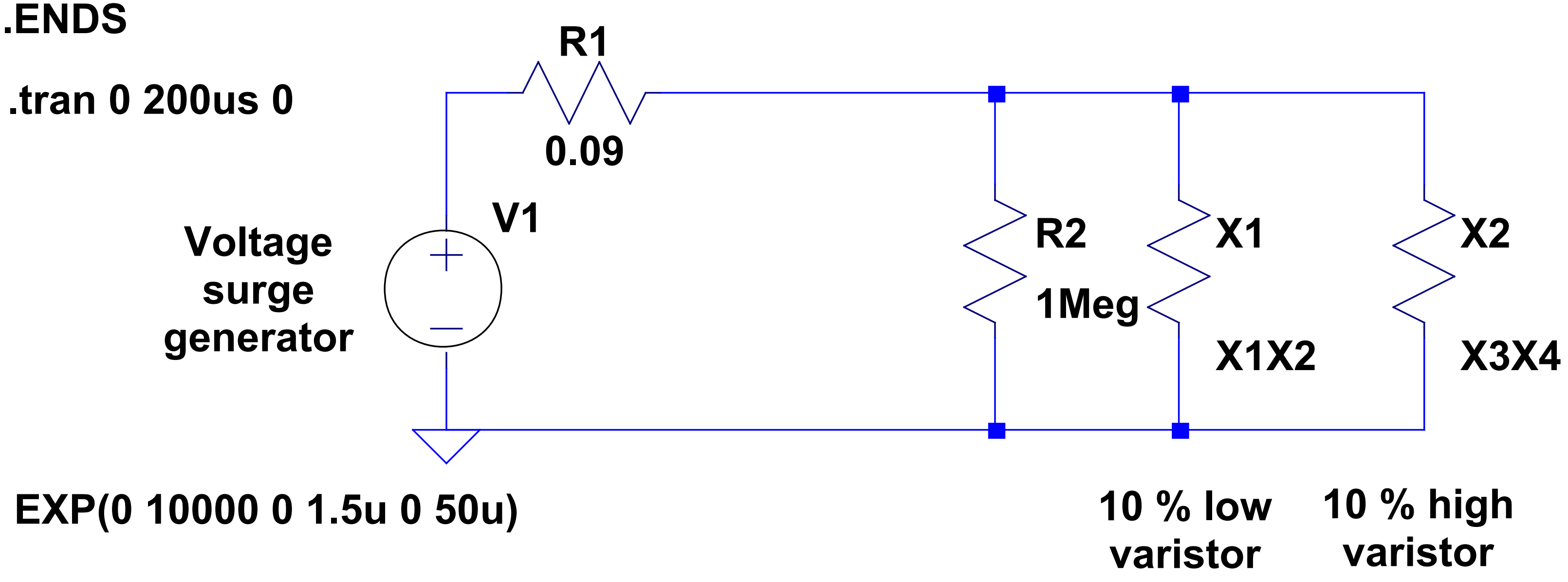
LTspice varistor test circuit — voltage and current



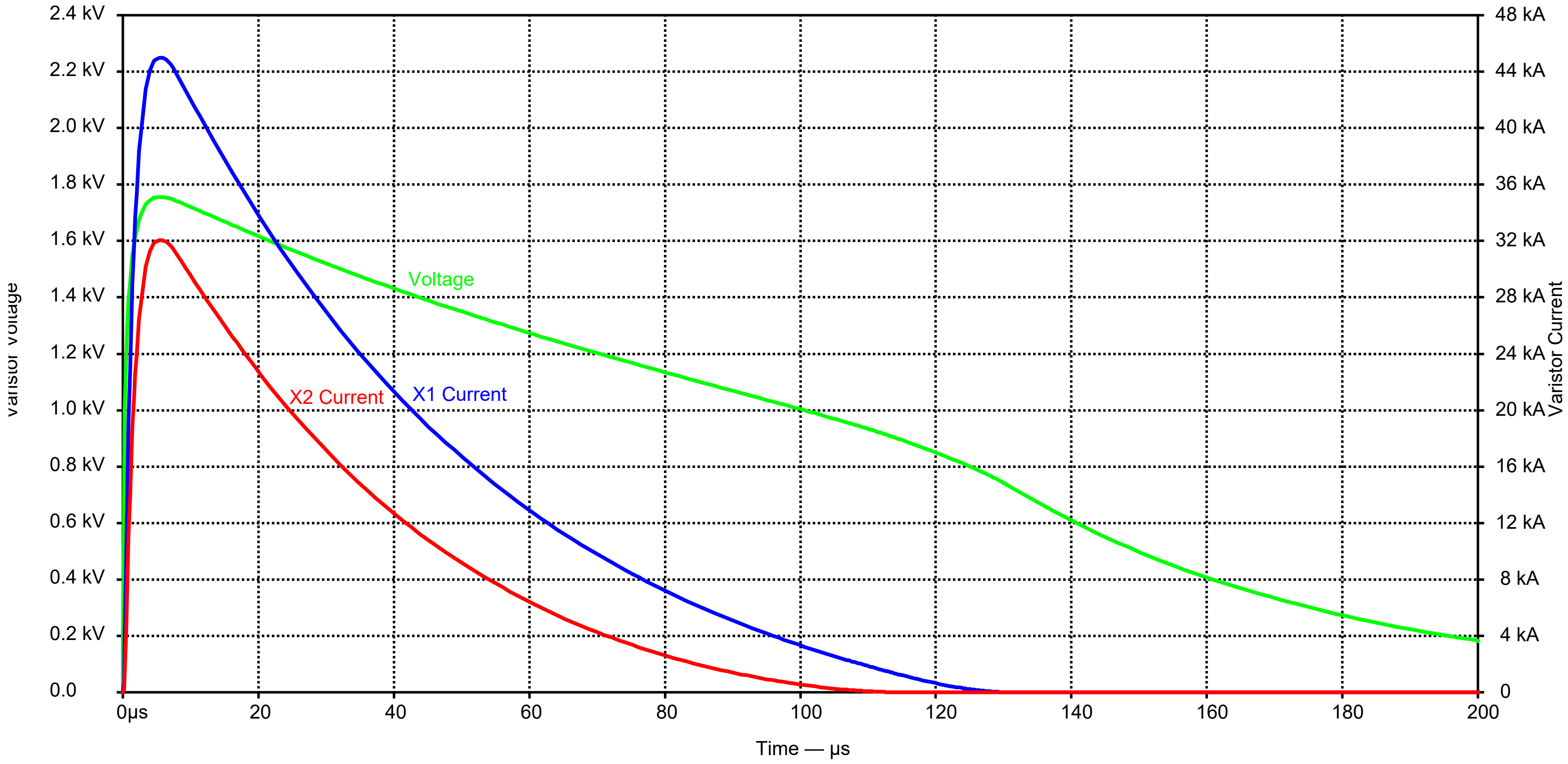
LTspice dual varistor test circuit — one 10 % high, other 10 % low in voltage from typical

```
.SUBCKT X3X4 3 4
GRES 3 4 VALUE={sgn(V(3,4))*(0.2313*abs(V(3,4))-207)**1.96}
.ENDS

.SUBCKT X1X2 1 2
GRES 1 2 VALUE={sgn(V(1,2))*(0.2313*abs(V(1,2))-169.4)**1.96}
.ENDS
```



LTspice dual varistor test circuit — voltage and current waveforms



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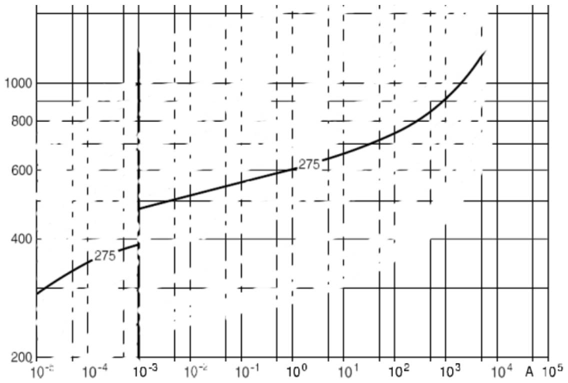
Summary of LTspice results

- LTspice sub-circuits can model varistor voltage-current behaviour over a wide current range. (Spot point voltage and current tables can also be used)
- Key to this is having a robust equation (best fit in region where accuracy is critical) relating the voltage and current values.
- If a full range of voltage and current values is available the d.c. operating range could have also been modelled
- LTspice is free and can be downloaded from: https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

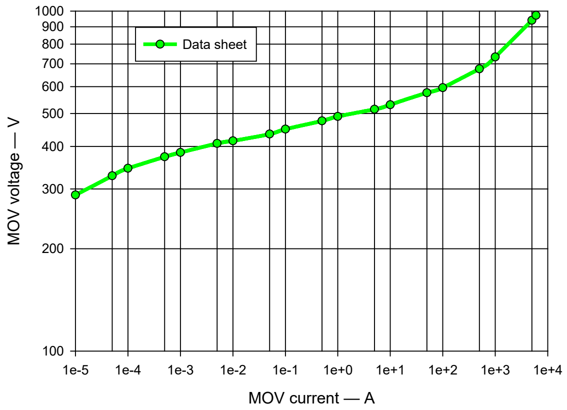
Questions?

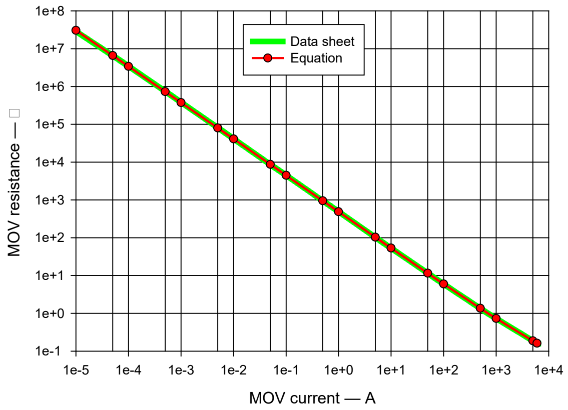
14 mm MOV — large current range example

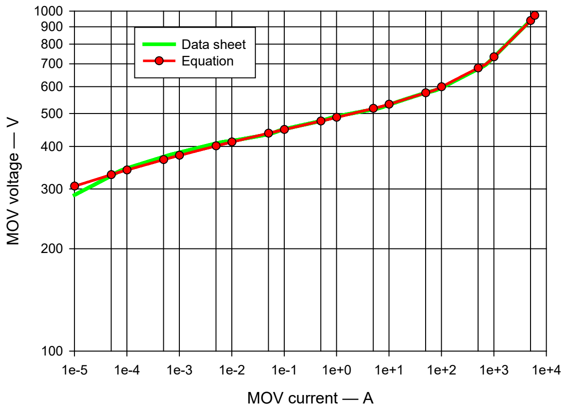


Top left: Selected MOV data sheet characteristic
Bottom left: transcribed MOV characteristic
Bottom middle: calculated and equation resistance
Bottom right: Data sheet and equation characteristics

Best fit equation: $v = 482 + 4.59*(i)^{0.5} + 15.4*\mathrm{LN}(i)$
over current range of 10 µA to 6 kA







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