THERE’S AN “R” IN VARISTOR

Summary
Recent analysis of the varistor voltage-current characteristic has shown this component is more a current dependent resistor than a voltage dependent resistor. This document explains how this conclusion was reached.

Warning
The document content is of a general nature only and is not intended to address the specific circumstances of any particular individual or entity; nor be necessarily comprehensive, complete, accurate or up to date; nor represent professional or legal advice.

Acknowledgement
Much of the material for this post was extracted from "There’s an “R” in Varistor" by M J Maytum, presented at the annual ATIS Protection Engineers Group (PEG): Electrical Protection of Communications Networks Conference held at UL LLC Corporate Office in Northbrook, Illinois on 5-7 March 2019. Subsequent blog materials There’s an R in varistor and Modelling an MOV voltage versus current characteristic provided the document figures.
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THERE’S AN “R” IN VARISTOR

1 Introduction

The IEC definition of varistor is a resistor, the resistance of which is strongly varying with the applied voltage. This is made even more blatant by the other commonly used term VDR, standing for voltage dependent resistor. Recent Chinese work on varistors contradicts this idea and maintains that what we know as a varistor is a current dependent resistor. This post examines the variation of the varistor resistance parameter with applied current and voltage. The conclusion is that the Chinese are right.

2 Varistor - voltage or current dependent?

2.1 Varistor data

The Chinese varistor data presented is shown in the following table:

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Resistance Voltage/Current (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>276</td>
<td>880</td>
<td>3.18</td>
</tr>
<tr>
<td>604</td>
<td>940</td>
<td>1.56</td>
</tr>
<tr>
<td>864</td>
<td>960</td>
<td>1.11</td>
</tr>
<tr>
<td>1640</td>
<td>1000</td>
<td>0.610</td>
</tr>
<tr>
<td>3280</td>
<td>1070</td>
<td>0.326</td>
</tr>
<tr>
<td>7200</td>
<td>1220</td>
<td>0.169</td>
</tr>
<tr>
<td>14400</td>
<td>1400</td>
<td>0.0972</td>
</tr>
<tr>
<td>26400</td>
<td>1580</td>
<td>0.0598</td>
</tr>
<tr>
<td>44800</td>
<td>1840</td>
<td>0.0411</td>
</tr>
</tbody>
</table>

The varistor resistance, R, is simply the division of the table voltage by the table current. A logarithmic plot of the table voltage versus current shows the typical varistor characteristic.

Figure 1 – Varistor characteristic
2.2 Varistor resistance – voltage dependence

Figure 2 is a logarithmic plot of the Table 1 resistance against voltage.

![Varistor resistance vs voltage characteristic](image)

**Figure 2 – Varistor resistance voltage dependence**

It can be seen that the Figure 2 relationship of resistance and current is not linear.

2.3 Varistor resistance – current dependence

Figure 3 is a logarithmic plot of the Table 1 resistance against current.

![Varistor resistance versus current characteristic](image)

**Figure 3 – Varistor resistance current dependence**

Figure 3 demonstrates that the resistance against current has a better defined relationship than the resistance against voltage (Figure 2). The resistance, $R$, against current, $I$,
relationship can be approximated to \( \text{LOG}(R) = 2.57 - 0.859 \times \text{LOG}(I) \). This explains why the Chinese are saying that the varistor resistance/conductance is related to current rather than voltage.

3 Varistor definition

This finding is at variance with the traditional varistor definition. The IEC 61051-1, ED 3, varistor definition is:

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

To reflect the true relationship the definition should be modified to something more modern like:

**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

4 Modelling the varistor characteristic

4.1 2-term power law

From the preceding, for modelling the varistor resistance or voltage, it is logical that current should be the controlling parameter used in the data set curve fitting equations. The IEC 61051-1 ED3 includes a 2-term power law equation, \( V = B \times I^C \), in its varistor definition, where \( B \) and \( C \) are constants. However, this is misdirection as it will be shown this equation is only valid over a small range of currents.

Using the IEC 61051-1, ED3 equation the best fit results in, \( V = 370 \times I^{0.1412} \), the result is shown in Figure 4:

![Figure 4 – IEC 61051-1 2-term power law equation match](image)

Clearly, although the equation values minimize errors, the equation is not a good fit to the data. Over a small current range, say 10:1, the equation is useful. Here the current range is 160:1, which is too large for the 2-term power law equation.
4.2 3-term power law

Changing to a 3-term power law equation, with an extra constant $A$, gives $V = A + B \times I^C$, results in a much better fit as shown in the Figure 5 below.

![Figure 5 – 3-term power law fit](image)

In this case the best fit equation was $V = 815 + 4.32 \times I^{0.1412}$. The failing of this equation is that the voltage can never be less than 815 V for currents of less than 1 A.

4.3 Chinese equation

What did the Chinese recommend? For voltage, the equation given was $V = I \times 10^{(3.2306 - 1.2465 \times \log(I) + 0.05424 \times \log(I) \times \log(I))}$, which is shown plotted in the Figure 6.

![Figure 6 – Chinese equation fit](image)
Although not quite as good a fit as the 3-term power law, the Chinese equation misbehaves at lower currents for example at currents of 50 A, 10 A, 1 A and 0.1 A it returns unrealistic voltages of 930 V, 1093 V, 1700 V and 3400 V. It is always advisable to check what happens when values are used outside the curve fitting data set range.

4.4 Equation limitations
The IEC 61051-1, ED3, equation needs warning for the appropriate (small) current range it can be used on. Similarly the Chinese equation needs a warning that it returns unrealistic voltage values at lower currents. The 3-term power law is the best of all, but needs the warning that the voltage cannot be less than 815 V at lower currents.

4.5 Extended current range modelling
The “275 V 14 mm MOV characteristic modelling over 9 current decades” blog shows how to create an equation from data sheet voltage current characteristic values that is valid over a current range of 10 µA to 6 kA. The resultant equation for typical voltage versus current is \( V = 482 + 4.59 \times (I)^{0.5} + 15.4 \times \ln(I) \). The first two parts of the equation amount to a 3-term power law. The third part, 15.4*LN(I), helps to modify the characteristic by developing a negative voltage when the current falls below 1 A.

5 Actions
It would be impossible to change VDR to IDR (current dependent resistor). But attempts should be made to change definitions, see 3, and spread the understanding that a varistor is a current dependant resistor (the purpose of this document).