# METHODOLOGY FOR EXPERIMENTALLY DETERMINING THE CHARACTERISTICS OF MEDIUM VOLTAGE ZINC OXIDE VARISTORS

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***Abstract.*** *In this research, a methodology was developed to experimentally determine the characteristics of medium voltage zinc oxide varistors, which are typically non ohmic resistors used for protecting equipments. Because of the fact that its impedance depends both on applied voltage and temperature, the calibration of the varistors had to be done by varying both parameters. Also, because of the fact that at higher electric currents the Joule effect can raise the varistor temperature above the ambient, a thermocouple was attached to it so that its true temperature can be measured. At low operating currents, the varistor behaves like an ohmic resistor, and its impedance is high and heavily dependent on temperature. By gradually decreasing the current, the Joule effect was practically eliminated and the temperature dependence was experimentally decoupled from the voltage – current behavior. At medium currents, typical operating conditions, the varistor behaves like a non ohmic resistor, with ohmic resistances varying little when temperature and voltage are high. Finally, for higher currents the varistor becomes again an ohmic resistor. This research aims the development of a methodology for testing the varistor, providing reliable data for system designers; to determine its uncertainty, mainly at the critical points where there is an abrupt change of its protection characteristics, and typical performance parameters; and to model its behavior along the operating range. A* VTR25k20 *varistor was used in this development.*

***Keywords***: *Zinc oxide varistor, Performance Characteristics Determination, Uncertainty of Measurement*

## 1. INTRODUCTION

Varistors are ceramic electronic components used for surge protection, both in high power applications, like lightning or electrostatic discharge, and low power application, like the telecom sector, where continuously increasing intelligence in exchanges and throughout the networks leads to greater use of sensitive semiconductors. The stringent demands on uptime and availability mean that high susceptibility to disturbances in supply is intolerable.

A surge protector (Van Beneden, 2003 ) may either attenuate a transient by filtering, or diverting the transient to prevent damage to the load. Those that divert the transient fall into two broad categories : (a) crowbar devices that switch into a very low impedance mode to short circuit the transient until current is brought to a low level, and (b) clamping devices , that absorb the overvoltage surge by lowering its impedance to such a level that the voltage drop on an always – present series impedance is significant enough to limit it to an acceptable level.

A varistor displays a nonlinear, variable impedance. The varistor designer can control the degree of nolinearity over a wide range by exploiting new materials and construction techniques that extend their range of application. A varistor now offers a cost-effective solution for low voltage logic requiring a low protection level and low standby current. They can absorb much higher transient energies than transient suppressor diodes, and can suppress positive and negative transients. Their response time is smaller than for crow-bar type devices and can be built to withstand a very high current surge. They have a longer lifetime than diodes and their failure mode is a short circuit. This prevents damage to the load that may result if failure of the protection circuit is undetected.

This paper presents a methodology for evaluating the metrological characteristics of medium voltage zinc oxide varistors, so that both the circuit designer and user have more confidence on their performance and thus assurance that the circuit will operate as planned. Several parameters which are not frequently available are measured, and their uncertainty of measurement are estimated for performance reliability purpose .

## 2. VARISTOR CHARACTERISTICS

Metal oxide varistors (MOV) are typically constructed from sintered zinc oxide plus a suitable additive. Each intergranular boundary displays a rectifying action and presents a voltage barrier (Van Beneden, 2003 ). When they conduct, they form a low ohmic path to absorb surge energy. The term varistor is a generic name for voltage variable resistor. The resistance of a MOV is non linear and decreases as voltage magnitude increases.

The distinguishing feature of a zinc oxide varistor is its exponential variation of current (*I*) over a narrow range of applied voltage (*V*), (Brown, 2001)

$$I = k.V^{\alpha} \tag{1}$$

Parameter $k$ is dependent on device geometry. Parameter $\alpha$ defines the degree of non linearity in the resistance characteristics and can be controlled by selection of materials and the application of manufacturing process. A high $\alpha$ value implies a better clamp. Zinc oxide technology has enabled varistors with $\alpha$ in the range of 15 to 30, (Van Beneden, 2003 ). Figure 1 shows the V-I curve for a typical metal oxide varistor (MOV).

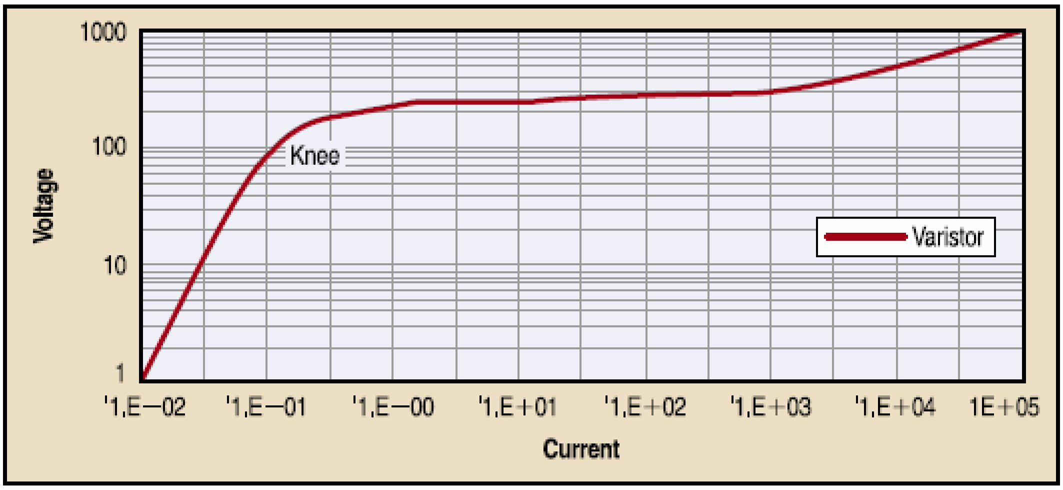



Figure 1 : Typical non linear voltage-current characteristics of a Metal Oxide Varistor (MOV), (Brown, 2001)

Varistors have a maximum continuously operating voltage rating, which indicates the maximum voltage the device is expected to see. It represents the active non linear range of the MOV, generally referred as *knee* of the curve.

The lower region bounded by this point is usually called the leakage current region and has an approximately constant relationship between voltage and current (R = V/I), with $\alpha = 1$. Its ohmic resistance (R) is greater than 10 MΩ, and is a highly dependent on temperature. The current is smaller than 0,1 mA.

For higher values of the current, above the *knee* of the curve, there is a non linear region usually called as the operating region, which characterizes the varistor, where $\alpha$ can reach the value of 30. In this region the current is smaller than 1 kA, like in a surge, and the voltage only increases slightly. The ohmic resistance is almost independent on temperature.

Finally, in the upper region, usually called the high current region, the relationship between voltage and current (R = V/I) is approximately constant and $\alpha = 1$.

One advantage of using MOV is its relatively large surge-current and energy ratings. When they are functioning in the active region they divert energy by conducting energy to ground or neutral, and absorving energy by converting it to heat, as shown in Fig. 2.

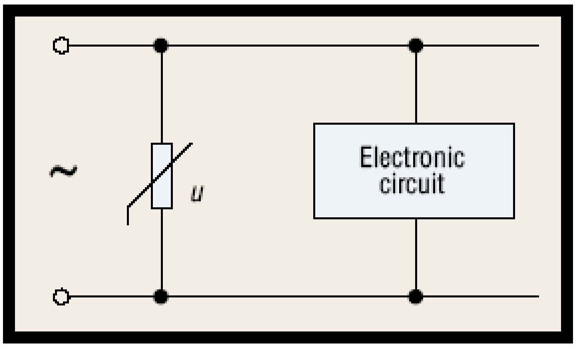



Figure 2 : Protection of an electronic device by a MOV, (Van Beneden, 2003)

A lightning stroke is a transient current with a rise time ranging from 1 μs to 10 μs and a subsequent decay lasting hundreds of microseconds. The current can have peak values from a few kA to 200 kA. When a lightning current hits a power line it is conducted to ground through a surge arrester or a flashover on the power system. The current flowing through the line of the system and ground impedance causes a high voltage transient (rise time of few microseconds and a tail of tens of microseconds). This transients couples through transformers and can excite natural resonances within low-voltage systems.

Lightning is not the only cause of transients. In fact, other causes are much more frequent and equally damaging to electronic equipment. Any switching operation can cause transient voltages. A few examples are:

- Switching capacitor banks on the utility supply or within a facility.
- Line and cable switching. This is important when the circuit is reenergized after an interruption.
- Motor and load switching operation within the facility

The aim of this paper is to develop a methodology for evaluating the metrological characteristics of medium voltage zinc oxide varistors. Several tests will be made for qualifying the varistor, including the curve analysis, uncertainty of measurement and temperature dependence.

## 3. EXPERIMENTAL PROCEDURE

### 3.1 Measuring instruments

Several ZnO VTR25k20 varistors were chosen for this work from VOLTTS. The tests were conducted in the Pressure and Temperature Laboratory of PUC-Rio (LPT) and in the REITEL Electronic Laboratory (LERÔ). A digital thermometer TOYO, model TY-990T, with a type K thermocouple sensor, was used to measure temperature, being calibrated at LPT, which is accredited by the Brazilian Calibration Network (RBC), with an uncertainty of ± 0,31 °C. A MINIPA multimeter, model ET-2039, was calibrated at MINIPA for DC voltage measurement in the 1 mV to 700V range with an uncertainty of ± (0,5 % of reading + 3 digits); for DC current measurement in the 0,01 A to 10 A range with an uncertainty of ± (0,8 % of reading + 3 digits) and for resistance measurement in the 0,1 Ω to 200 M Ω range with an uncertainty of ± (0,8 % of reading + 3 digits. Finally, a CRONUS 0,01 s resolution digital stop watch was used with an uncertainty of ± 0,17 s.

### 3.2 Measuring setup

During the tests, the varistor was placed inside a small capsule together with the type K thermocouple, which in turn was place inside a controlled temperature ICAMO dry oven, thus being able to vary its temperature in the 0 °C to 360 °C range. A REITEL controlled voltage source, model CC RT75V3A, was used to drive an electric current through the varistor. Both electric current and voltage were measured for different operating test conditions.

The following parameters were measured as a function of the varistor temperature (T).

- Voltage (V), current (I) and ohmic resistance (R) in the so called leakage current, normal operation and high current ranges of the varistor.
- V-T, R-T and I-T curves were constructed.
- Current variation with temperature.
- Measurement of leakage current, clamping voltage, allowable peak current, allowable energy and power dissipation.
- Uncertainty of all measurements.

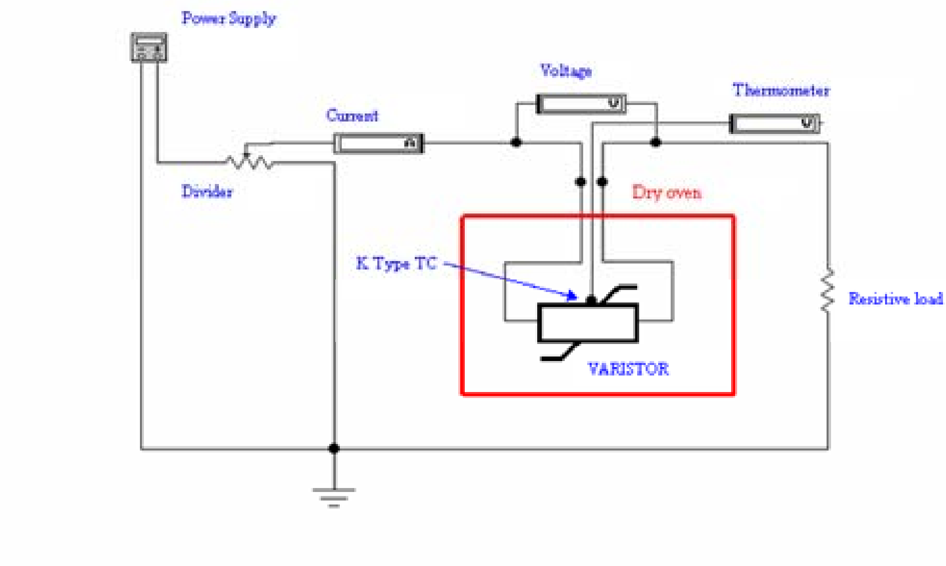



Figure 3 : Experimental set up used in the experiments.

As shown in Fig. 3, a power supply was used to set the voltage applied to the varistor during tests. A 68 kΩ potentiometer was used in a voltage divider circuit to tune the voltage applied to it. The current through the varistor was measured by the MINIPA ET-2039 multimeter set to the current mode operation.

### 3.3 Methodology for varistor performance evaluation

Values of voltage, electric current, ohmic resistance were measured in the 20 °C to 150 °C temperature range.
Several varistors were used during the tests to determine the average performance value, standard deviation and uncertainty of measurement.

#### 3.3.1 Characteristic curve with no through electric current (static tests)

Without driving an electric current through the varistor, its ohmic resistance was measured at 25 °C, using the type K thermocouple. This test was considered as a baseline for evaluating the effect of the self heating of the varistor on its performance. Ten (10) measurements were used for determining the performance. The ohmic resistance ($R_{VAR}$) was measured by the MINIPA ET-2039 multimeter set to the 20 MΩ scale (1 % of reading + 1,5 digits). Because of the fact that the varistor resistance was larger than what the instrument could measure at this scale, a $R_R$ = 10,05 MΩ resistance (± 1 %) had to be placed in parallel with it. In fact, the varistor resistance has to be calculated from the measured equivalent resistance (R).

$$R_{VAR} = \frac{R.R_R}{R_R - R} \tag{2}$$

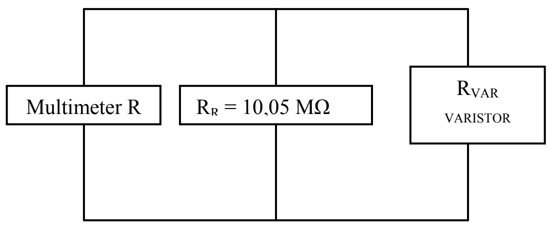



Figure 4 : Varistor static resistance measurement

#### 3.3.2 Characteristic curve with a through electric current (dynamic tests)

Driving an electric current through the varistor, its voltage was measured as a function of the capsule temperature, in thermal equilibrium with the oven, using the type K thermocouple. The ohmic resistance was calculated as the ratio between the voltage and the electric current through the varistor. The following parameters were measured

- Leakage current region
- Operating region
- Current variation with temperature
- Nominal voltage variation with temperature
- Ohmic resistance variation with temperature in the operating region.
- Maximum operating voltage
- Leakage current
- Clamping voltage
- Maximum surge current
- Maximum energy absorption
- Maximum power dissipation

### 3.4 Uncertainty of measurement

#### 3.4.1 Uncertainty of varistor resistance measurement in static tests

The MINIPA ET-2039 multimeter set to the 20 MΩ scale measures resistance, both $R$ and $R_R$ , to within 1 % of the reading, for k = 2. Thus, the standard uncertainties $u_R$ and $u_{R_R}$ , can be expressed as :

$$u_R = a.R \quad \text{, where } a = 0{,}01/2 = 0{,}005 \tag{3}$$

$$u_{R_R} = a.R_R \text{ , where } a = 0{,}01/2 = 0{,}005 \tag{4}$$

The following expression can be used to calculate the combined uncertainty of varistor resistance measurement ($u_{R_{VAR}}$) , as a function of standard uncertainty of equivalent resistance measurement ($u_R$) and parallel resistance ($u_{R_R}$), using Eq. (2), according to (ISO GUM,1995)

$$u_{R_{VAR}} = \sqrt{\left(\frac{\partial R_{VAR}}{\partial R}.u_R\right)^2 + \left(\frac{\partial R_{VAR}}{\partial R_R}.u_{R_R}\right)^2} \tag{5}$$

$$\frac{\partial R_{VAR}}{\partial R} = \left(\frac{R_R}{R_R - R}\right)^2 \tag{6}$$

$$\frac{\partial R_{VAR}}{\partial R_R} = -\left(\frac{R}{R_R - R}\right)^2 \tag{7}$$

Using Eq. (3), (4), (6) and (7) in Eq. (5), the following expression can be obtained :

$$\frac{u_{R_{VAR}}}{R_{VAR}} = a.\sqrt{\left(\frac{R_{VAR}}{R}\right)^2 + \left(\frac{R_{VAR}}{R_R}\right)^2} \tag{8}$$

$$U_{R_{VAR}} = 2.u_{R_{VAR}} \tag{9}$$

Equation (8) shows that using a parallel resistance $R_R$ for measuring the varistor resistance $R_{VAR}$ always increases its uncertainty of measurement with respect to the multimeter value *a*, because $R_{VAR}$ is larger than *R* and $R_R$.

Equation (6) is valid if only one measurement is made. However, an analysis of Eq. (3) shows that the combined uncertainty can be large. In order to reduce it, several measurements (*n*) have to be made. Assuming that the varistor temperature remains the same for all resistance measurements, the following expression can be written for the expanded uncertainty ($U_{\overline{R}_{VAR}}$) of the mean value ($\overline{R}_{VAR}$).

$$U_{\overline{R}_{VAR}} = 2.\frac{u_{\overline{R}_{VAR}}}{\sqrt{n}} \tag{10}$$

The combined uncertainty ($u_{\overline{R}_{VAR}}$) in Eq. (7) must be calculated using Eq. (4), (5) and (6), with, respectively, the mean values $(\overline{R})$ and $(\overline{R}_R)$.

### 3.4.2 Uncertainty of varistor voltage as a function of current in dynamic tests

Several varistors were used in the experiments. The spread of measurements takes into account the fact the varistors have slightly different properties and, also, there is an uncertainty of measurement of temperature, current and voltage. A better way to take into account all those factors is a curve fiiting which has the advantage of interpolating the non measured points, giving at the same time the estimated averaged value and its uncertainty (ISO GUM, 1995), (Orlando, 2009) and (VIM, 2000).

When fitting the varistor voltage (*V*) as a function of current *(I)*, at a given temperature (*T*), the following expression can be used to calculate the combined uncertainty of measurement (*u*) as a function of standard uncertainty of voltage measurement $(u_V)$,, current measurement ($u_I$) and root mean square of the fitting ($u_{fit}$) :

$$u = \sqrt{u_V^2 + u_{fit}^2 + \left(\frac{\partial V}{\partial I}\right)^2 .u_I^2} \tag{11}$$

$$u_{fit} = \sqrt{\frac{1}{n-1}.\sum_{i=1}^{n}\left[V(I_i) - V_i\right]^2} \tag{12}$$

where, $I_i$ and $V_i$ are, respectively, measured current and voltage across varistor. $V(I_i)$ is the a function used fit the data, evaluated at the measured current ($I_i$), resulting in the calculated varistor voltage.

The expanded uncertainty of measurement (U) can be calculated as :

$$U = t.\ u \tag{13}$$

where t is the t-student value for 95,45 % probability level and (n-1) degrees of freedom (ISO VIM, 1995)

#### 3.4.3 Statistical test for determining significance of current variation with temperature

Using the uncertainty of measurement, Eq. (13), the zero average statistical test was made between the V-I curves obtained at the two extreme temperature values to check if the results are statistically significant. Using the curve fitted equations for varistor voltage, respectively at 23 °C ($V_{23}$) and 83 °C ($V_{83}$), with uncertainties $U_{23}$ and $U_{83}$ , the normalized error function (E) , Eq. (14), following (Orlando,2009),was calculated for different current values I.

$$E = \frac{\left|V_{23} - V_{83}\right|}{\sqrt{U_{23}^2 + U_{83}^2}} \tag{14}$$

Assuming a normal error distribution, if $E \geq 1$, the results are statistically different to a significance level of approximately 5 %, meaning that the curves vary with temperature.

## 4. RESULTS AND ANALYSIS

### 4.1 Characteristic curve with no through electric current (static tests)

Ten measurements were made for the varistor ohmic resistance. The expanded uncertainty of measurement was calculated using Eq. (7). For 95,45 % probability level, it can be said that the true value is in the uncertainty interval of (72,9 ± 2,9) MΩ.

An analysis of the results shows that if a parallel resistance is used, both $R$ and $R_R$. resistances must be measured more accurately, if a more accurate value of the varistor resistance is desired. A larger number of measurements can produce the same results.

### 4.2 Characteristic curve with a through electric current (dynamic tests)

#### 4.2.1 Leakage current region

Three varistors were used to test the repeatability of results. The voltage ($V_i$ ) was set in the 13,9 V to 35 V range, in steps of 0,1 V, with a measurement uncertainty (k=2) of 1 % of the reading. The current ($I_i$) was then measured with a 0,8 % uncertainty (k=2) of the reading. The difference between the measured values was smaller than the multimeter resolution (10 µA). Therefore, just one varistor was used to fit the experimental data, resulting in one voltage-current for each temperature, respectively, 25 °C, 50 °C and 75 °C. The following function was used to fit the experimental data by the least square method, resulting in the lowest root mean square of the fitting ($u_{fit}$) :

$$V(I_i) = a.x_i^3 + b.x_i^2 + c.x_i + d \tag{15}$$

$$x_i = Ln(I_i) \tag{16}$$

where *Ln* is the natural logarithm.

Table 1 presents the coefficients of Eq. (15) for each temperature, together with the minimum and maximum uncertainties (k=2), respectively at the maximum (35 V) and minimum (13,9 V) voltage values, according to Eq. (11), (12) and (13).

It was observed that the smallest contribution to the uncertainty of predicting voltage from measured current was due to current, meaning that the uncertainty of measuring current during the experiments was acceptable. The largest contribution was due to curve fitting, meaning that other functions could result in smaller uncertainties. Also, it was observed that the uncertainty increases when the temperature increases.

Finally, it was observed that for a given applied voltage, the current increases with temperature, or in other words, the ohmic resistance decreases with temperature.

Table 1 : Curve fit of the voltage – current experimental data. Uncertainty is expressed for k = 2.

| | VARISTOR TEMPERATURE | | |
|---|---|---|---|
| | 25 °C | 50 °C | 75 °C |
| a | -0,128452 | -0,144369 | 0,129394 |
| b | -0,421208 | -0,60575 | 0,736717 |
| c | 5,295126 | 4,68182 | 5,088352 |
| d | 35,194820 | 33,501560 | 29,501961 |
| Uncertainty at V = 13,9 V | ± 0,23 V | ± 0,64 V | ± 1,28 V |
| Uncertainty at V = 35,0 V | ± 0,41 V | ± 0,72 V | ± 1,32 V |

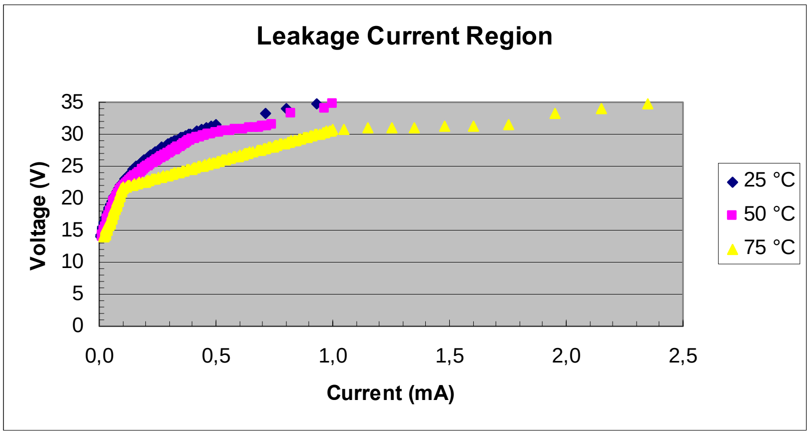



Figure 5 : Voltage – Current curve as a function of temperature.

### 4.2.2 Operating region

Three varistors were used to test the repeatability of results. The voltage ($V_i$ ) was set in the 35 V to 43 V range, in steps of 1 V, with a measurement uncertainty (k=2) of 1 % of the reading. The current ($I_i$) was then measured with a 0,8 % uncertainty (k=2) of the reading. The difference between the measured values was smaller than the multimeter resolution (10 μA). Five varistors were used to fit the experimental data, resulting in on voltage-current for each temperature, respectively, 23 °C, 43 °C, 63 °C and 83 °C. Equation (15) was used to fit the experimental data by the least square method, with $a = b = 0$.

Table 2 presents the coefficients of Eq. (15) for each temperature, together with the minimum and maximum uncertainties (k=2), respectively at the maximum (43 V) and minimum (35 V) voltage values, according to Eq. (11), (12) and (13).

It was observed that the smallest contribution to the uncertainty of predicting voltage from measured current was due to current, meaning that the uncertainty of measuring current during the experiments was acceptable. The largest contribution was due to curve fitting, meaning that other functions could result in smaller uncertainties. Also, it was observed that the uncertainty is approximately constant

Finally, it was observed that for a given applied voltage, the current increases with temperature, or in other words, the ohmic resistance decreases with temperature.

Table 2 : Curve fit of the voltage – current experimental data. Uncertainty is expressed for k = 2.

| | 23 °C | 43 °C | 63 °C | 83 °C |
|---|---|---|---|---|
| a | 0 | 0 | 0 | 0 |
| b | 0 | 0 | 0 | 0 |
| c | 5,6977 | 5,3742 | 4,8907 | 4,8489 |
| d | 34,992 | 34,718 | 34,812 | 34,386 |
| Uncertainty at V = 35 V | ± 0,50 V | ± 0,63 V | ± 0,45 V | ± 0,47 V |
| Uncertainty at V = 43 V | ± 0,56 V | ± 0,68 V | ± 0,52 V | ± 053 V |

### 4.2.3 Current variation with temperature

Setting the voltage (V) in the 35 V up to 43 V range, in 1 V steps, the current (I) was measured. Temperature was set at 23 °C and 83 °C, respectively. Data from five (5) varistors were used for determining the repeatability. Using the uncertainty of measurement, statistical tests were made between the curves obtained at the two temperature values to check if the results are statistically significant.

Using Eq. (15) and (16), and the coefficients of Tab. 2, the error function Eq. (14) was calculated for different values of current, as shown in Tab. 3. It can be seen that $E \geq 1$, and, therefore, the V – I curve varies with temperature to a 5 % significance level.

Table 3 : Current variation with temperature. Uncertainty is expressed for k = 2.

| | VARISTOR at 23 °C | | VARISTOR at 83 °C | | |
|---|---|---|---|---|---|
| CURRENT | VOLTAGE | UNCERTAINTY | VOLTAGE | UNCERTAINTY | ERROR |
| mA | V | V | V | V | |
| 1,0 | 35,0 | 0,50 | 34,4 | 0,47 | 0,88 |
| 1,5 | 37,3 | 0,52 | 36,4 | 0,48 | 1,34 |
| 2,0 | 38,9 | 0,53 | 37,7 | 0,49 | 1,65 |
| 2,5 | 40,2 | 0,54 | 38,8 | 0,50 | 1,88 |
| 3,0 | 41,3 | 0,54 | 39,7 | 0,50 | 2,09 |
| 3,5 | 42,1 | 0,55 | 40,5 | 0,50 | 2,25 |
| 4,0 | 42,9 | 0,56 | 41,1 | 0,51 | 2,35 |

### 4.2.4 Nominal voltage variation with temperature

According to (IEC 60600-1, 1989) the measured voltage through the device when the current is 1 mA is defined as the varistor nominal voltage. Five (5) varistors were used to determine the repeatability of the parameter. During the experiments, and for each varistor under test, the temperature was set in the 20 °C to 90 °C range, in 5 °C steps. The voltage was then adjusted and measured so that the measured current was 1 mA. This procedure was repeated five (5) times for determining the uncertainty of the results. A straight line was fitted to the data of each varistor sample, Eq. (15) with $a = b = 0$ *and* $x = T$, resulting in five relationships between the nominal voltage and the varistor temperature, at 1 mA current. Uncertainty was calculated using Eq. (11), (12) and (13), substituting I for T.

Table 4 : Nominal Voltage variation with temperature. Uncertainty is expressed for k = 2.

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| a | 0 | 0 | 0 | 0 | 0 |
| b | 0 | 0 | 0 | 0 | 0 |
| c | -0,0188 | -0,0100 | -0,0189 | -0,0264 | -0,0264 |
| d | 41,228 | 41,049 | 41,210 | 41,738 | 41,738 |
| Uncertainty at T = 20 °C | ± 0,43 V | ± 0,43 V | ± 0,42 V | ± 0,44 V | ± 0,44 V |
| Uncertainty at V = 90 °C | ± 0,42 V | ± 0,42 V | ± 0,41 V | ± 043 V | ± 043 V |

It was observed that the smallest contribution to nominal voltage prediction from temperature measurement, with an uncertainty of ± 0,31 °C, was due to temperature, meaning that its measurement uncertainty was adequate. The largest contribution was due to voltage measurement, meaning that if a smaller uncertainty value is desired, the voltage measurement uncertainty must be smaller.

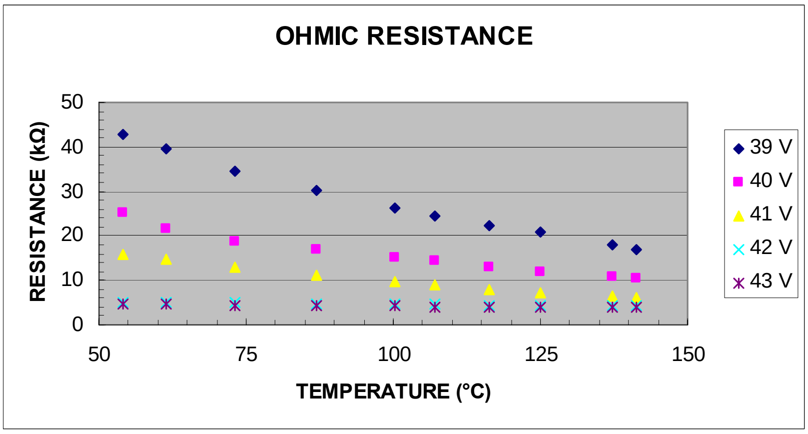
Similarly to current variation with temperature, the error function Eq. (14) was calculated for different values of temperature, comparing two different samples at each time.. It was observed that E< 1 for values of temperature up to 80 °C, meaning that the samples are statistically alike to within 5 % significance level. For larger values of temperature, the samples behave differently, because E >1.

### 4.2.5 Ohmic resistance with temperature in the operating region

Setting the voltage (V) in the 39 V to 43 V range, in 1 V steps, the current was measured and the ohmic resistance was calculated at 10 temperature values in the 54,1 °C to 141,1 °C range.

Figure 6 shows that the ohmic resistance decreases when temperature increases. For values of temperature well above 140 °C, the ohmic resistance becomes very small. For any value of varistor voltage there is a current, changing its characteristics.

Figure 6 : Ohmic resistance variation as a function of temperature in the operating region.




### 4.2.6 Maximum operating voltage

The manufacturer states that the nominal operating voltage at 1 mA is (39 ± 4) V. This range has been verified in this work at 23 °C. For voltage values above 43 V the current increases sharply, as in a short circuit. During the experiments a 10 A limiting value of current was selected for not burning the measuring instrument safety fuse.

### 4.2.7 Leakage current

It has been verified that for values smaller than the minimum operating voltage (35 V), the varistor ohmic resistance is high ( in the MΩ range) and the current (called leakage current) through it is very small (in the µA range). Thus, if the varistor is placed in parallel with the circuit to be protected it does not divert any current from it, practically equal to the leakage current. This was well examined in item 4.2.1, for 25 °C, 50 °C and 75 °C temperatures. Table 1 shows the V-I curve fitting where the current varies from about 10 µA to 1 mA, respectively for 13,9 V and 35 V.

### 4.2.8 Clamping voltage

The manufacturer states that the varistor clamps a voltage value up to 77 V, at a 20 A current. It has been observed that for voltage values in the 83 V to 100 V range the varistor works as a clamping device, although with some changes in performance. It is destroyed for larger voltage values.

### 4.2.9 Maximum surge current

According to the manufacturer, the maximum peak current with is around 2000 A. This test, however could not be performed because no adequate instrument was available.

### 4.2.10 Maximum energy absorption

The manufacturer states a maximum energy absorption of 0,03 J. However, a maximum value of (0,014 ± 0,0001) J was obtained in the experiments.

### 4.2.11 Maximum power dissipation

A maximum power dissipation of (0,080 ± 0,001) W was measured in the experiments. The manufacturer states 0,2 W.

## 5. CONCLUSIONS

In this work a methodology was developed to evaluate the metrological characteristics of a medium voltage zinc oxide varistor. In order to assure the reliability of measurements, all the instruments were calibrated in an accredited laboratory. The varistor was placed inside a dry oven, with air circulating around it. A K type thermocouple was attached to it so that its temperature could be measured. It was soon observed that the heat transfer to the environment could interfere in the results. It was decided to place the varistor inside a capsule, with still air inside, and thus reducing the heat transfer coefficient.

The varistor was tested in the static mode, without electric current through it, and in the dynamic mode, with an electric current through it. The heating effect could than be determined.

In the static mode, three operating regions were observed to characterize the varistor performance, which are, leakage current, operating and high current regions.

The ohmic resistance was directly measured with a multimeter. Because of the fact that the varistor resistance was larger than what the instrument could measure at the scale, a smaller resistance was placed in parallel with it, increasing the uncertainty of measurement. Several measurements were then made to reduce it. A methodology was developed to calculate it.

In the dynamic mode similar regions were detected and the tests followed IEC 60060-1 procedures.

In the leakage region the varistor voltage was fitted to the the logarithm of current. For low voltage values, the current is very low (a few μA), the ohmic resistance is very high and the curve is almost linear in the beginning. Thus, if the varistor is placed in parallel with the circuit to be protected, it does not divert practically any current from it. The voltage at the end of the region is about 35 V, and the current reaches 1 mA. The voltage – current curve is very much influenced by temperature.

In the operating region , as in a surge, the varistor voltage only increases slightly with current. Voltage range was measured from 35 V to 43 V. Ohmic resistance varies little when temperature and voltage are high.

In the high current region, for voltage values above 43 V, the current increases sharply, as in a short circuit. Voltage is clamped in the 83 V to 100 V, and the varistor is destroyed for higher voltage values.

A comparison between the data supplied by the manufacturer and those measured by the developed methodology showed that the first one oversizes the measured values, what can cause problems related to circuit performance.

Finally the methodology was developed to test the performance of a medium voltage zinc oxide varistor, which can be used to better understand its behaviour in protection equipments. The uncertainty analysis was used to determine the influence of the metrological characteristics of voltage, current and temperature measuring instruments on the varistor behavior, aiming, eventually, redesigning the measuring system for more accurate performance determination.

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