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METHODOLOGY FOR METROLOGICAL EVALUATION OF A PTC RESETTABLE THERMISTOR

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Abstract. *This research aims the development of a methodology for experimentally characterizing a PTC polymeric thermistor LP60-110, used as an ove rcurrent and temperature protection device. Uncertainty of measurements of parameters, such as temperature, voltage, current and ohmic resistance is also determined.The tested thermistor has a positive temperature coefficient (PTC), which means that its ohmic resistance increases with temperature. An electric circuit was built to measure the thermistor characteristics, consisting of a stable voltage source and a variable resistance in series with the thermistor, which was placed in a dry oven. A K type thermocouple was attached to it , so that its temperature could be measured and controlled. By gradually decreasing the circulating current through the circuit, the Joule effect could be neglected, and the thermistor resistance was made only a function of ambient temperature, which is easier to measure. The acquired date were used to build several characteristics curves, which were analyzed and compared to the available ones from the manufacturers.The main contribution of this work is the development of a systematic procedure to obtain the thermistor performance data, so that the manufacturer data can be verified, together with its uncertainty, providing at the same time information not presently available in the market for system design.*

Keywords*:Uncertainty of measurement, PTC polymeric resettable thermistor; ,polymer; circuit protection; thermistor characteristic curves.*

1. INTRODUCTION

Thermistors are semiconductor devices used in electronic equipments. Due to the fact that their impedance greatly varies with temperature, they can be used to protect the circuits when there is for some reason an electric current overcharge, thus increasing their temperature due to the Joule effect. When their impedance increases when temperature increases, they are called positive temperature coefficient (PTC) thermistors. Negative temperature coefficient (NPC) thermistors are widely used for measuring small temperature differences in thermal phenomena.

The need of protecting the electronic circuits is due to the increase of their complexity, and, as a consequence, the increase of its fragility, thus requiring more efficient ways of protection. The search of an ideal protection against overloads has been of increasingly importance due to the development of the electronic science.

The PTC (Positive Temperature Coefficient) polymeric resettable thermistor started to be used in the 90’s, as a very important protection device because of its special characteristics. When there is an electric current overcharge, thus increasing its temperature, it melts away, resulting in volume expansion and opening of the electric circuit. Once the problem disappears, the molten material cools down and the thermistor recovers its properties (Lettelfuse, 1997). However, the technical specifications usually supplied by the manufacturers are very limited and based on direct observations and statistical data.

Further studies are required to better determine its performance characteristics, which are not well known. It can be used as an over current and temperature protection device in electronic circuits, for engine start up and as a temperature compensation device.

2. THERMAL CHARACTERISTICS OF A PTC THERMISTOR

The variation of the ohmic resistance (R) of a PTC thermistor with temperature (T) can be usually expressed as a polynomial function (Rangel, 2004)

$$R = R_o\left[1 + \alpha_1.(T - T_o) + \alpha_2.(T - T_o)^2 + ... + \alpha_n.(T - T_o)^n\right] \tag{1}$$

where R_o is its ohmic resistance at a reference temperature T_o.

Figure 1 shows a typical temperature variation of the PTC thermistor ohmic resistance.(UFPR, 2003). It can be seen that it increases sharply for values above the reference temperature. Figure 2 shows a typical curve electric curve versus voltage in the operating range (IFENT, 2003) and (UFPR, 2003).

The reasons for using a PTC thermistor are durability, low cost, high sensitivity, fast response and the fact it is a two wire sensor. However, it has a non linear response, small temperature operating range, it is fragile, it needs a current source and it is sensitive to self heating.

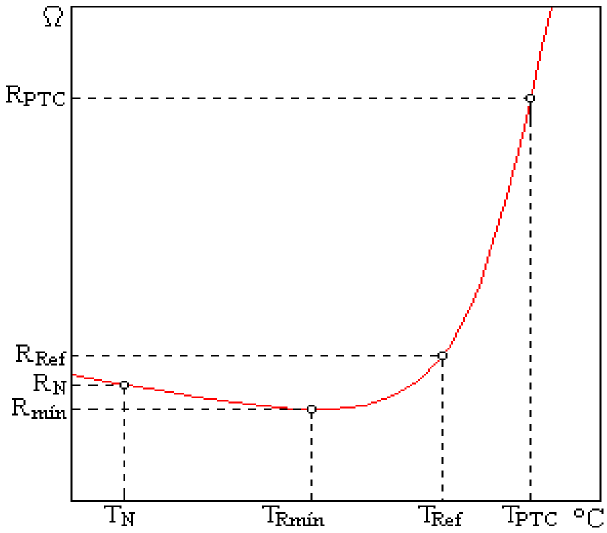

Figure 1 : Typical PTC thermistor characteristic curve. Ohmic resistance versus temperature.

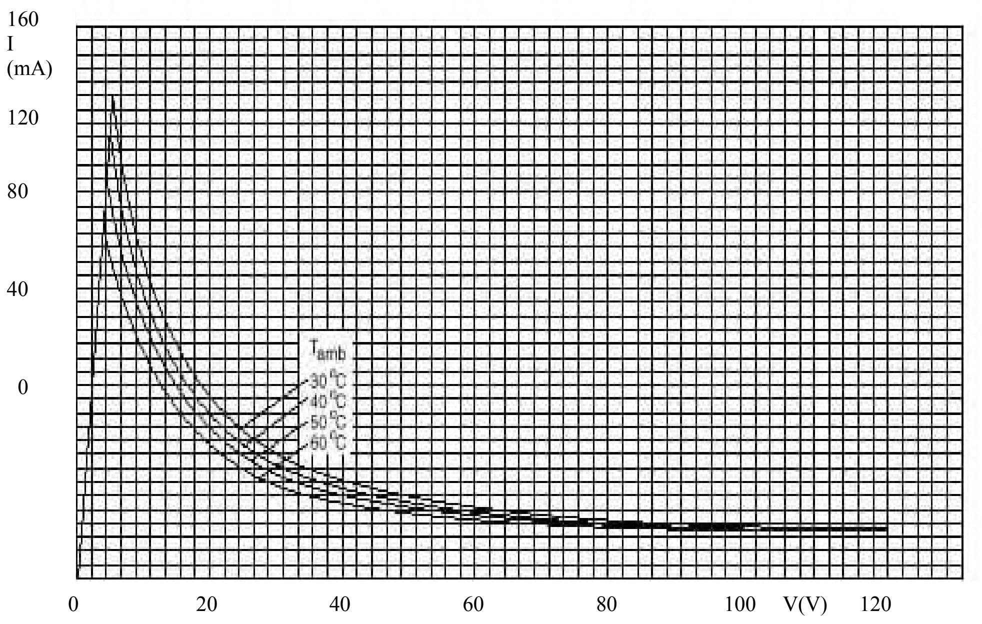

Figure 2 : Typical PTC thermistor characteristic curve. Electric current versus voltage.

A Wayon resettable PTC thermistor, model LP60-110, was tested in this research for being widely used in telecommunication applications. Its performance is similar to Raychem's, model RXE 110 and Boums', model MF-R110. The following performance data are supplied by the manufacturer. (a) Minimum Current : 1,1 A, (b) Maximum Current : 2,20 A, (c) Maximum Cut off time : 8,2 s, (d) Maximum Voltage : 60 V, (e) Power : 1,51 W, (f) Miminum ohmic resistance : 0,14 Ω, and (g) Maximum ohmic resistance : 0,25 Ω.

3. EXPERIMENTAL PROCEDURE

3.1 Measuring instruments

Several PTC polymetric resettable thermistors were chosen for this work from Wayon, model LP60-110. 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 PTC thermistor 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 RT80V10A, was used to drive an electric current through the PTC thermistor. Both electric current and ohmic resistance were measured for different operating test conditions.

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

- Voltage (V), current (I) and ohmic resistance (R) in the so called operational, transition and cut off ranges of the thermistor, including the Joule effect.
- Stability of the electrical measurements as a function of temperature.
- V-T, R-T and I-T curves.
- The influence of temperature in the characteristics of the thermistor.
- Uncertainty of all measurements.
- Time required for the thermistor to turn on as a function of temperature.

Figure 3 shows the experimental set up.

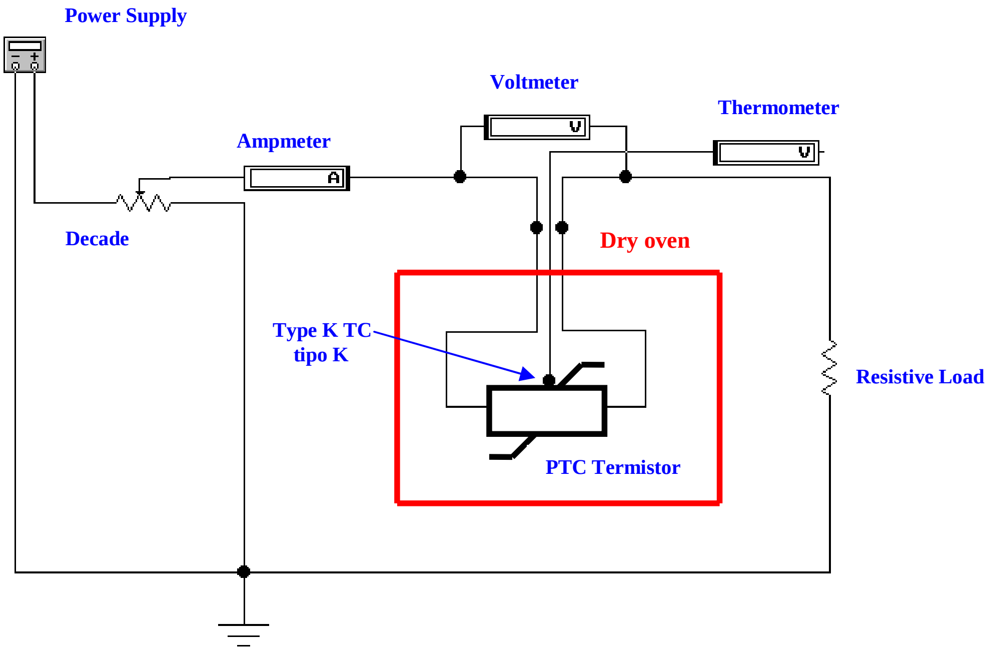

Figure 3 : Experimental set up used in the experiments.

3.3 Performance evaluation

Values of voltage, electric current, ohmic resistance and shut off time were measured every 1 °C in the 18 °C to 140 °C temperature range. Electric current was varied every 0,01 A in the 0,001 A to 1,87 A range.

Ten (10) thermistors were used during the tests to determine the average performance value, standard deviation and uncertainty of measurement.

3.3.1 Performance evaluation of the PTC thermistor with no through electric current (static tests)

Without driving an electric current through the thermistor, its ohmic resistance was measured as a function of the capsule temperature, in thermal equilibrium with the oven, using the type K thermocouple. This test was considered as a baseline for evaluating the effect of the self heating of the resettable PTC thermistor on its performance.

3.3.2 Performance evaluation of the PTC thermistor with a through electric current (dynamic tests)

Driving an electric current through the thermistor, its ohmic resistance was measured as a function of the capsule temperature, in thermal equilibrium with the oven, using the type K thermocouple. A value of 1,1 A was set for the electric current, as defined by the manufacturer as the minimum operating value. The ohmic resistance was calculated as the ratio between the voltage and the electric current through the thermistor.

3.3.2.1 Evaluation of the PTC thermistor shut off time

When a given electric current is driven through the PTC thermistor, exchanging heat to the ambient at a fixed temperature, there is a build up of self heating effects, raising its temperature until a very large ohmic resistance is attained, resulting in very low electric current, and the circuit is then considered to be open. Shut off time is defined as the time required for this effect to happen.

3.3.3.2 Minimum self heating current

With the ambient at 25 °C, the electric current was gradually increased from 1 mA up to a value where the ohmic resistance changed due to temperature variation, indicating that the self heating effects were not negligible anymore. This was considered to be the minimum self heating current.

3.3.3.3 Maximum operating voltage

With the ambient at 20 °C, the voltage applied to the PTC thermistor was varied in the 1 V to 80 V range, until the thermistor was burnt at (79 ± 1) V. Then, the ambient temperature was varied from 20 °C to 70 °C. It was concluded that the voltage should not be above (70 ± 1) V.

3.3.3.4 Leakage current

It was observed that when there is a shut off a minimum current of 11 mA is necessary to keep the PTC thermistor off.

3.3.3.5 Stapling current

Tests showed that above 1,87 A the circuit would immediately open, which was then considered as the maximum operating electric current, or the maximum shut off current.

3.3.3.6 Maximum peak current

According to the manufacturer, the maximum peak current with is around 40 A. This test, however could not be performed because no adequate instrument was available.

3.3.3.7 Maximum energy absorption

The determination of the maximum amount of energy that the thermistor could absorb without any damage was calculated using the maximum voltage of 70 V and the maximum shut off current of 1,87 A and absorption time along its lifetime.

3.3.3.8 Maximum thermal dissipation

The determination of the maximum thermal dissipation was calculated when multiplying the average voltage of 0,4 V by the average current of 1,1 A. According to the manufacturer a value of 1,51 W should be allowed.

3.4 Uncertainty of measurement

Ten (10) PTC thermistors were used in the experiments. The spread of measurements takes into account the fact the thersmistors 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, for example, the thermistor resistance (R) as a function of temperature (T), Eq. (1), the following expression can be used to calculated the combined uncertainty of measurement (u), as a function of uncertainty of resistance measurement (u_R), temperature measurement (u_T) and root mean square of the fitting (u_{fit}) :

$$u = \sqrt{u_R^2 + u_{fit}^2 + \left(\frac{\partial R}{\partial T}\right)^2 . u_T^2} \qquad (2)$$

$$u_{fit} = \sqrt{\frac{1}{n-1} . \sum_{i=1}^{n} \left[R(T_i) - R_i\right]^2} \qquad (3)$$

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

$$U = t.\, u \qquad (4)$$

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

When there is no curve fitting, and the resistance is measured ***n*** times for the same temperature, the average value ($\overline{R}$) is taken as the estimate of the true value, and the standard deviation (u_R) is taken as the best estimate of the standard uncertainty (u). The combined uncertainty is calculated according to Eq. (4).

$$\overline{R} = \frac{1}{n} . \sum_{i=1}^{n} R_i \qquad (5)$$

$$u_R = \sqrt{\frac{1}{n-1} . \sum_{i=1}^{n} \left(\overline{R} - R_i\right)^2} \qquad (6)$$

4. RESULTS

4. 1 Performance evaluation of the PTC thermistor with no electric current (static tests)

Three (3) regions could be identified from measurements. (a) Operating region, from 20 °C to 124 °C, where the electric current remains approximately constant, (b) Transition range, from 125 °C to 128 °C, where the electric current starts varyimg, and, (c) Shut off region, from 129 °C to 140 °C, where there is no current because of the high ohmic resistance. Figure 4 shows the resistance variation with temperature. In the operating region, the resistance value is about the same as its uncertainty of measurement. However, the objective of the test was to determine the temperature in which there is a shut off and the resistance is much larger. A plot of the resistance as a function of temperature shows that in the neighborhood of (129 ±1) °C there is a sharp variation of the resistance, easily indicating the beginning of the shut off region. Figure 5 shows the variation of the resistance with temperature in the operating region, including a curve fit equation.

4.2 Performance evaluation of the PTC thermistor with an electric current (dynamic tests)

Three (3) regions could be identified from measurements. (a) Operating region, from 20 °C to 70 °C, where the electric current remains approximately constant, (b) Transition range, from 71 °C to 76 °C, where the electric current starts varying, and, (c) Shut off region, from 77 °C to 140 °C, where there is no current because of the high ohmic resistance. During the tests, the power supply was set to (70,00 ± 0,04) V, and the resistive load initially to (64,0 ± 0,2) Ω, resulting in a current of (1,10 ± 0,04) A. By varying the load, the current can vary.

Preliminary tests showed that above 1,87 A the circuit would immediately opens, which was then considered as the maximum operating electric current. Figure 6 shows the variation of the resistance with temperature in the operating region and a curve fit of it.

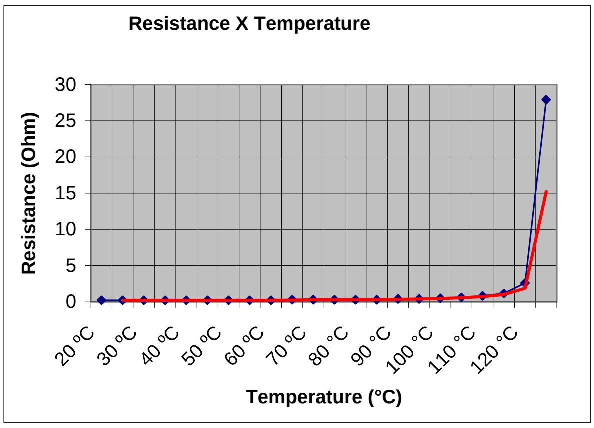

Figure 4 : PTC Thermistor chacateristic curve (no current)

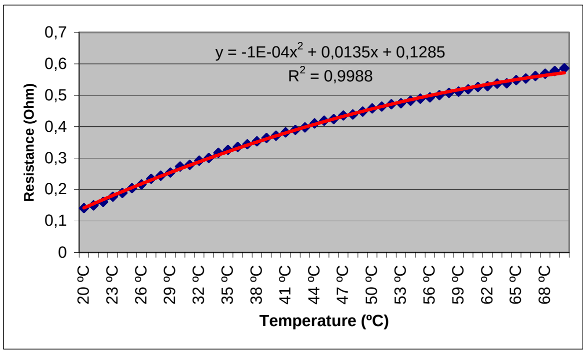

Figure 5 : PTC Thermistor Resistance as a function of temperature in the operating region (no current)

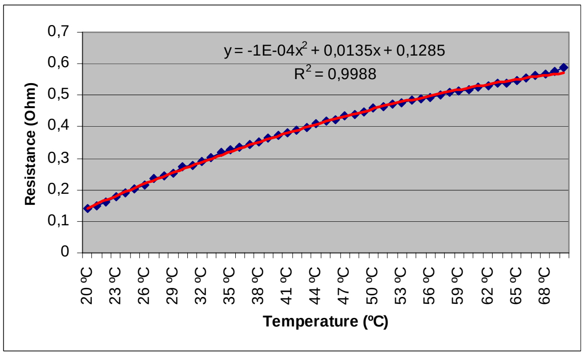

Figure 6 : PTC Thermistor Resistance as a function of temperature in the operating region (1,10 A current)

4.2.1 Evaluation of the PTC thermistor shut off time

The determination of the shut off time at different ambient temperatures (from 20 °C to 100 °C) and 1,87 A electric current was measured with a 0,01 s resolution digital stop watch, with an estimated uncertainty of ± 0,17 s due to manually turning it on and off, and the help of an incandescent lamp to indicate when the current would go to zero. Ten (10) thermistors were used in the tests. The expanded uncertainty of time in Fig. 7 was estimated in ± 2,77 s.

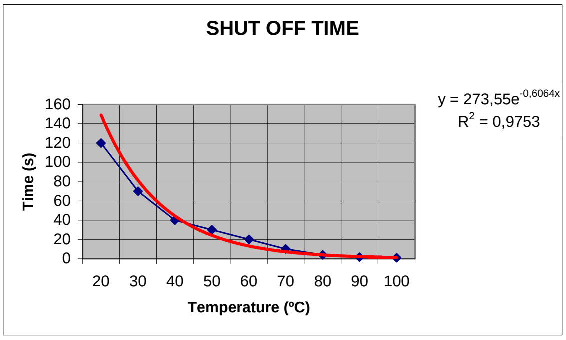

Figure 7 : Shut off time as a function of temperature

4.2.2 Minimum self heating current

With the ambient at 25 °C, the electric current was gradually increased from 1 mA up to a value where the ohmic resistance changed due to temperature variation, indicating that the self heating effects were not negligible anymore. This was considered to be the minimum self heating current.

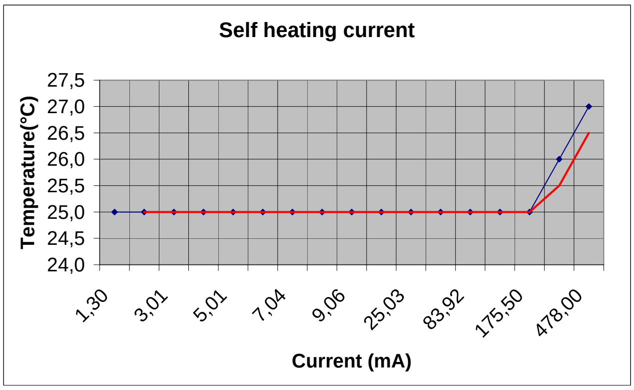

Figure 8 : Self heating current

4.2.3 Maximum operating voltage

The manufacturer informs that the maximum operating voltage applied to the PTC thermistor is 60 V**.**With the ambient at 20 °C, the voltage applied to the PTC thermistor was varied in the 1 V to 80 V range, until the thermistor was burnt at (79 ± 1) V. Then, the ambient temperature was varied from 20 °C to 70 °C. It was concluded that the voltage should not be above (70,00 ± 0,04) V.

4.2.4 Leakage current

It was observed that when there is a shut off a minimum current of (11,00 ± 0,04) mA is necessary to keep the PTC thermistor off.

4.2.5 Stapling current

Tests showed that above (1,87 ± 0,04) A the circuit would immediately open, which was then considered as the maximum operating electric current, or the maximum shut off current. However, the manufacturer informs a value of 2,20 A.

4.2.6 Maximum peak current

According to the manufacturer, the maximum peak current with is around 40 A. This test, however could not be performed because no adequate instrument was available.

4.2.7 Maximum energy absorption

The determination of the maximum amount of energy that the thermistor could absorb without any damage was calculated using the maximum voltage of (70,00 ± 0,04) V and the maximum shut off current of (1,87 ± 0,04) A and the absorption time along its lifetime. The maximum energy absorption in the experiments was (2,6 ± 0,1) mJ, which was not specified by the manufacturer.

4.2.8 Maximum thermal dissipation

The determination of the maximum thermal dissipation was calculated when multiplying the average voltage of 0,4 V by the average current of 1,1 A, resulting in (0,44 ± 0,04) W. According to the manufacturer a value of 1,51 W should be allowed.

4.3 Comparisons between the measured values and those supplied by the manufacturer

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

It is suggested that the developed methodology be used to certify the thermistor performance. The uncertainty of measurement of critical values could be reduced by specifying more accurate instruments.

Table 1 : Comparisons between the measured values and those supplied by the manufacturer

Parameter	UNIT	MANUF.	MEASURED	
			Value	Uncertainty
Maximum operating voltage	V	60	70	0,04
Leakage current	mA	NA	11,00	0,04
Maximum shut off current	A	2,2	1,87	0,04
Maximum peak current	A	40	NA	NA
Maximum energy absorption	mJ	NA	2,6	0,1
Maximum thermal dissipation	W	1,51	0,44	0,04
Shut off time	s	8,2	>1,00	0,17

5. CONCLUSIONS

In this work a methodology was developed to evaluate the metrological characteristics of a PTC resettable thermistor. In order to assure the reliability of measurements, all the instruments were calibrated in a accredited laboratory. The thermistor was placed in a 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 thermistor inside a capsule, with still air inside, and thus reducing the heat transfer coefficient.

The thermistor 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 thermistor performance, which are, operating, transition and cut off regions.

In the operating region, the uncertainty of measuring its low resistance (0,2 Ω) was high, and the results were used to show trends. However, in the transition and cut off regions the uncertainty of measurement was much smaller due to a large thermistor resistance value, and the results were used to characterize its performance. Therefore, the cut off temperature was determined to be (129 ± 1) °C (k=2), which was not supplied by the manufacturer, and is useful for protection system designers.

In the dynamic mode similar regions were detected and the tests followed procedures from Standards CEC 44000, EM 14400, IEC 738-1 and DIN 44080. In the transition region several data were taken to compensate the lack of information from the manufacturer and, thus, helping designers. In the cut off region, the electric current was measured under different circuit conditions, because the risk of damaging the equipment can be high for overload conditions.

It was shown that in the electric current range from zero to an upper limit of 1,1 A, as stated by the manufacturer, the equipment is not switched off. The use of no current (static test) for determining the thermistor performance was important to establish the maximum current for which the overheat (Joule effect) is still not important (0,30 ± 0,02) A, and thus preventing an error in measuring the cut off point.

The paper presents information on several measured parameters. The acquired data was used to build several characteristic curves, which were analyzed and compared to the available ones from the manufacturer. The data were fitted by equations to facilitate the task of protection system designers, and the uncertainty of measurement was estimated.

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

Finally the methodology was developed to test the performance of a PTC polymeric resettable thermistor (LP60-110), which can be used to better understand its behaviour in protection equipments.

6. ACKNOWLEDGEMENTS

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