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DEVELOPMENT OF DATA TREATMENT SOFTWARE FOR CALIBRATION OF NONINVASIVE MEASUREMENT OF X-RAY TUBE POTENTIAL

Samanda C.A.Correa [1], *Ricardo T.Lopes* [2], *Márcia T.Carlos* [3] *Paulo H.B.Becker* [4]

[1] Samanda C.A.Correa, Rio de Janeiro, Brazil, scorrea@con.ufrj.br
[2] Ricardo T.Lopes, Rio de Janeiro, Brazil, ricardo@lin.ufrj.br
[3] Márcia T.Carlos, Rio de Janeiro, Brazil, marcia@ird.gov.br
[4] Paulo H.B.Becker, Rio de Janeiro, Brazil, P.Becker@iaea.org

Abstract: A data treatment software that serves as support for high voltage dividers in the non-invasive meters calibration is presented. This software calculates quantities like the absolute peak potential, maximum peak potential, average peak potential, practical peak voltage, ripple, average current, exposure time and current-time product through voltage and current waveforms. The software was evaluated using theoretical waveforms, where it showed that works correctly. In this work is also presented the results obtained with the analysis of voltage and current experimental waveforms.

Keywords: calibration, kVp, software.

1. INTRODUCTION

In many countries substantial efforts are put into quality control programme in diagnostic radiology due to the fact that the extensive use of X-ray in medicine for diagnosis of injuries and deseases represents the largest man-made source of public exposure to ionizing radiation. Both the image quality and the dose received by the patient depend critically of the performance characteristics of voltage high generators and X-ray tubes, thus the assessment and control of their operation parameters is an essential part of a quality control programme. One very importante set of the X-ray equipment performance characteristics control involves determining the accuracy and reproduciblility of the peak potential (kVp), current (mA), exposure time and current-time product (mAs), besides other factors like the ripple.

At the customers's site, the X-ray equipment operation parameters adjust is generally performed using non-invasive measuring techniques, named non-invasive meters. These instruments must be capable of performing measurements of the X-ray equipment operation parameters with accuracy, repeatability and reproducibility, and for that reason their calibration is fundamental.

Invasive technique is the method mostly used and recommended for International Electrotechnical Commission (IEC) to calibrate the non-invasive meters [1]. This method applies high voltage dividers, that are test device connected between the generator and the X-ray tube and provides isolated low level analog voltage signals proportional to the voltage and current applied across the tube. The signal waveforms can be displayed on an external osciloscope or digitalized through a conversion board. Quantities correlated with kVp, such as absolute peak potential (kVpabs), maximum peak potential (kVpmax), average peak potential (kVpave) and practical peak voltage (PPV), and quantities like ripple, average current and exposure time can be calculed through digitalized voltage and current waveforms. However, the estimate of these quantities through digitalized waveforms is not simple, and requests specific mathematical analysis that varies with the type of voltage high generator. The objective of this work is to propose a data treatment software named *"Programa de Análise de Curvas de Tensão e Corrente"* (PACTC) developed using the Labview plataform. The PACTC serves as support for high voltage dividers in the non-invasive meters calibration and X-ray equipment adjust. This software calculates quantities like kVpabs, kVpmax, kVpave, PPV, ripple, average current, exposure time and current-time product for three different kinds of X-ray equipment and was built in agreement with recommendations from IEC61676 [1], AAPM [2] and Ranalo [3].

1.1 LABVIEW

Labview (Laboratory Visual Instrument Engeneering Workbench) is a graphical programming language used as a prowerful and flexible instrumentation and analysis software system in industry and academia. Labview uses the graphical programming language G to create programs called Virtual Instruments or VI in a pictorial block diagram form which eleminates many syntactical details of other programming languages such as C and MATLAB that use a text based programming approach. Labview also includes many tools for data acquisition, analysis and display of results. The analysis library contains a multiple of functions in signal generation, signal processing, filtering and statistics. Labview is available for all the major platforms and is easily portable across platforms. Each VI contains three parts [4]:

1) The front panel contains the user interface like knobs, push buttons, graphs and many other controls (inputs) and indicators (output). Inputs can be fed using the mouse or the keyboard.

2) The block diagram is the VI's source code constructed in G and is the actual executable program. The block

diagram has other lower-level Vis and built in functions.The blocks can be connected using wires to indicate the dataflow. Front panel objects have corresponding terminals on the block diagram to allow dataflow from the user to the program and back to the user.

3) Sub-Vis are analogous to subroutines in conventional programming languages.

2. DATA TREATMENT SOFTWARE

The PACTC was developed using the Labview version 6.0i, and the values of the kVpmax, kVpabs, kVpave, PPV, ripple, average current, exposure time and current-time product were calculated using the following methodology [5]:

- *Absolute peak potential*

This is the maximum value of voltage waveform during the exposure. This definition is useful in determining stresses on the X-ray tube and generator. It is of little importance clinically.

- *Maximum peak potential and average peak potential*

The kVpmax is the maximum value of the x-ray tube potential in a specified time interval and the kVpave is the average of all peak values during a specified time interval.

The intervals of the exposure time that contains overshoot should be excluded from kVpmax and kVpmed measurements. The excluded time is shown in the Figure 1.

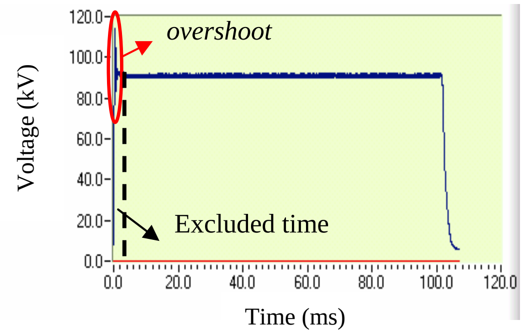


Fig 1. Excluded time.

- *Practical peak voltage*

The PPV was calculated from the instantaneous values of the tube voltage by using the following equation [2]:

$$PPV = \frac{\sum_{i=1}^{n} U_i w(U_i)}{\sum_{i=1}^{n} w(U_i)} \qquad (1)$$

where *w(Ui)* is a weighting function obtained theoretically in [2].

- *Ripple*

The ripple was calculated through:

$$R(\%) = 100\left(\frac{kV\max - kV\min}{kV\max}\right) \qquad (2)$$

where kVmax and kVmin are respectively the maximum and minimum value of voltage waveform during in a time interval. This time interval is shown in Figure 2.

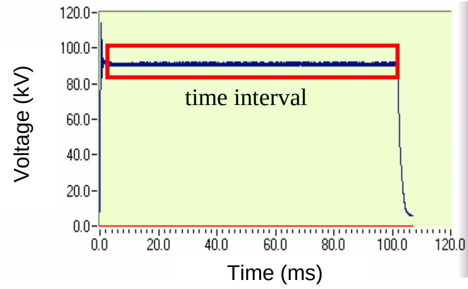


Fig 2. Time interval.

- *Average current*

The average current is the average of all current values during a specified time interval. The intervals of the exposure time that contains overshoot should be excluded.

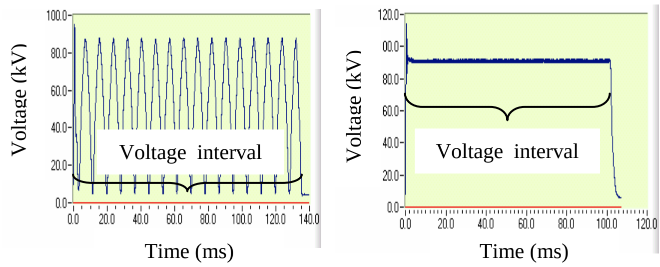
- *Exposure time and current-time product*

For X-ray equipment with high frequency generator and average frequency generator, the exposure time is calculated considering the voltage interval between the first and last value of 75% of kVpave, and for X-ray equipment with single phase generator the exposure time is calculated considering the voltage interval between the first and last value of 20% of kVpave. The voltage interval used to calculate of the exposure time is shown in the Figure 3.

Through the voltage intervalo considered the exposure time is calculated by:

Exposure time=(N/R)1000 [ms] (3)

where N is the number of samples of voltage interval and R is the data acquisition rate.



Sigle phase generator High frequency generator

Fig 3. Voltage interval used to calculate of the exposure time.

The current-time product was calculate through of the product of the average current (mA) and exposure time (s).

The PACTC is shown in the Figure 4.

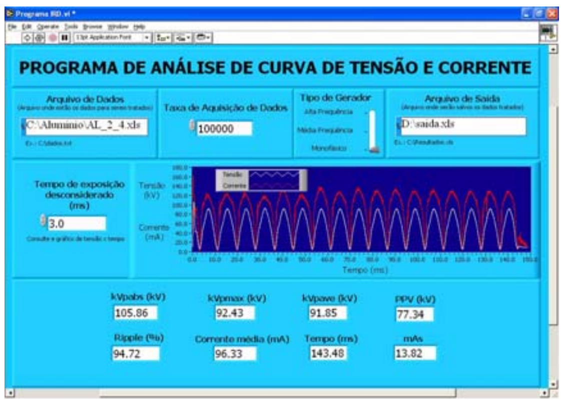


Fig. 4. Programa de Análise de Curva de Tensão e Corrente.

2.1 THEORETICAL WAVEFORMS

Theoretical waveforms were created using signal generation Sub-Vis of the Labview.

The waveforms for single phase rectification were simulate through the Sine Wave VI that generates the pattern according to the following equation [4]:

$$y_i = \left| \; a * \mathrm{sen}(phase[i]) \; \right| \qquad (4)$$

for i = 0, 1, 2, …, n-1

where a is the amplitude, n is the number of samples and $phase[i]$ = initial phase + f*360.0*i, f is the frequency in normalized units of cycles/sample.

The waveforms for average frequency rectification and high frequency rectification were simulate using Sawtooth Wave VI. This subroutine works according to the following formula [4]:

$$y_i = \left| \; a * sawtooth(phase[i]) \; \right| \qquad (5)$$

for i = 0, 1, 2, …, n-1

where a is the amplitude, n is the number of samples,

$$sawtooth(phase[i]) = \begin{cases} \dfrac{p}{180.0} \rightarrow 0 \le p < 180 \\ \dfrac{p}{180.0} - 2 \rightarrow 180 \le p < 360 \end{cases} \qquad (6)$$

p = $phase[i]$ modulo 360.0, $phase[i]$ = initial phase + f*360.0*i, f is the frequency in normalized units of cycles/sample.

The Figure 5 show the simulate waveforms for single phase rectification and average frequency rectification.

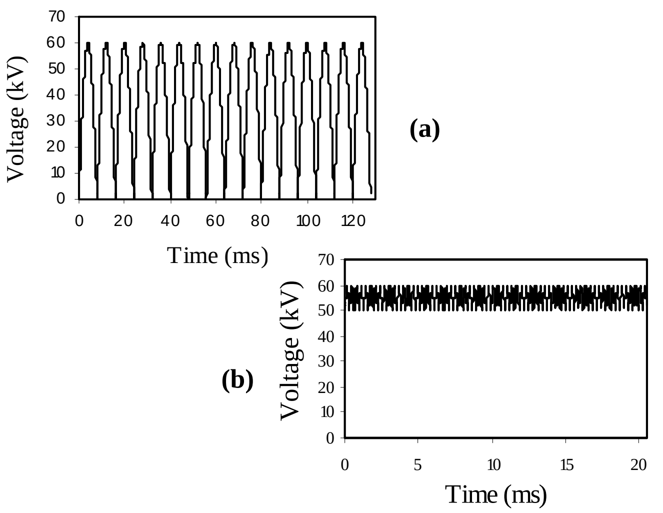


Fig. 5. Simulate waveforms: (a) Single phase rectification, (b) Average frequency rectification.

The ripple used in the waveforms simulation are according to the Table 1 [3].

Table 1. Ripple.

Voltage High Generator	Theoretical Ripple (%)	Ripple used in the Simulation (%)
Single phase	100	100
Average frequency	4 to 20	16
High frequency	1 to 15	5

The simulate waveforms were analyzed using an Excel spreadsheet and the PACTC. The results were compared.

2.2 EXPERIMENTAL WAVEFORMS

Experimental waveforms were obtained using three X-ray equipments, one with two pulse generator model Neo-Heliophos from Siemens (A), other with average frequency generator model Polimat from Siemens (B) and one with high frequency generator model Plus 800 from VMI (C).

The voltage and current waveforms were measured through a system formed by a high voltage divisor model Dynalyser III from Radcal Corporation, a fast analogue to digital conversion board model PCI-MIO-16E-4 from National Instruments, and a data acquisition software, as shown in Figure 6.

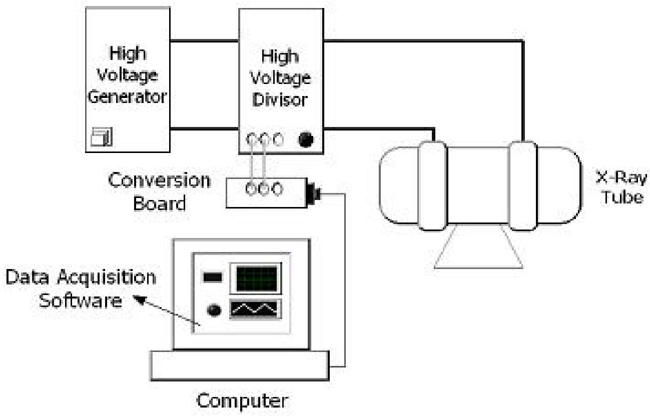


Fig. 6. Schematic experimental arrangement.

The current used was 100 mA in the B and C equipments. The A equipment possesses current adjustment through the two focal spot sizes that can be selected by the operator, the small focal spot and the larger focal spot, the the chosen in this work was the small focal spot.

All the waveforms were obtained using data acquisition rate of 100.000 sample/second.

3. RESULTS

3.1 Theoretical Waveforms

The Tables 2, 3 and 4 show the comparison between the values of the kVpmax, kVpabs, kVpave, PPV and ripple, calculated through Excel spreadsheet and PACTC for theoretical waveforms of the A, B and C equipments, respectively.

Table 2. Single phase rectification.

Excel					PACTC				
KVpabs (kV)	**KVpmax (kV)**	**KVpave (kV)**	**PPV (kV)**	***Ripple* (%)**	**KVpabs (kV)**	**KVpmax (kV)**	**KVpave (kV)**	**PPV (kV)**	***Ripple* (%)**
20	20	20	20	100	20	20	20	20	100
30	30	30	28	100	30	30	30	28	100
40	40	40	37	100	40	40	40	37	100
50	50	50	45	100	50	50	50	45	100
60	60	60	53	100	60	60	60	53	100
80	80	80	68	100	80	80	80	68	100
90	90	90	76	100	90	90	90	76	100
100	100	100	84	100	100	100	100	84	100
120	120	120	99	100	120	120	120	99	100
140	140	140	114	100	140	140	140	114	100

Table 3. Average frequency rectification.

Excel					PACTC				
KVpabs (kV)	**KVpmax (kV)**	**KVpave (kV)**	**PPV (kV)**	***Ripple* (%)**	**KVpabs (kV)**	**KVpmax (kV)**	**KVpave (kV)**	**PPV (kV)**	***Ripple* (%)**
20	20	20	20	16	20	20	20	20	16
30	30	30	28	16	30	30	30	28	16
40	40	40	38	16	40	40	40	38	16
50	50	50	47	16	50	50	50	47	16
60	60	60	56	16	60	60	60	56	16
70	70	70	65	16	70	70	70	65	16
80	80	80	74	16	80	80	80	74	16
90	90	90	83	16	90	90	90	83	16
100	100	100	93	16	100	100	100	93	16
110	110	110	102	16	110	110	110	102	16

Table 4. High frequency rectification.

Excel					PACTC				
KVpabs (kV)	**Kvpmax (kV)**	**KVpave (kV)**	**PPV (kV)**	***Ripple* (%)**	**KVpabs (kV)**	**Kvpmax (kV)**	**KVpave (kV)**	**PPV (kV)**	***Ripple* (%)**
20	20	20	20	5	20	20	20	20	5
30	30	30	29	5	30	30	30	29	5
40	40	40	39	5	40	40	40	39	5
50	50	50	49	5	50	50	50	49	5
60	60	60	59	5	60	60	60	59	5
70	70	70	68	5	70	70	70	68	5
80	80	80	78	5	80	80	80	78	5
90	90	90	88	5	90	90	90	88	5
100	100	100	98	5	100	100	100	98	5
110	110	110	107	5	110	110	110	107	5

The values of the exposure time and average current are presented in the Table 5, and the currrent-time product is shown in Figure 7.

Table 5. Values of the ripple and exposure time.

Single phase rectification				Average frequency rectification				High frequency rectification			
Excel		PACTC		Excel		PACTC		Excel		PACTC	
Time (ms)	Current (mA)	Time (ms)	Current (mA)	Time (ms)	Current (mA)	Time (ms)	Current (mA)	Time (ms)	Current (mA)	Time (ms)	Current (mA)
149	60	149	60	93	93	93	93	108	98	108	98
132	60	132	60	90	93	90	93	94	98	94	98
115	60	115	60	84	93	84	93	76	98	76	98
99	61	99	61	78	93	78	93	54	98	54	98
82	61	82	61	71	93	71	93	42	97	42	97
65	61	65	61	61	93	61	93	31	97	31	97
49	61	49	61	53	92	53	92	25	97	25	97
32	62	32	62	29	92	29	92	20	97	20	97
15	64	15	64	27	92	27	92	10	97	10	97

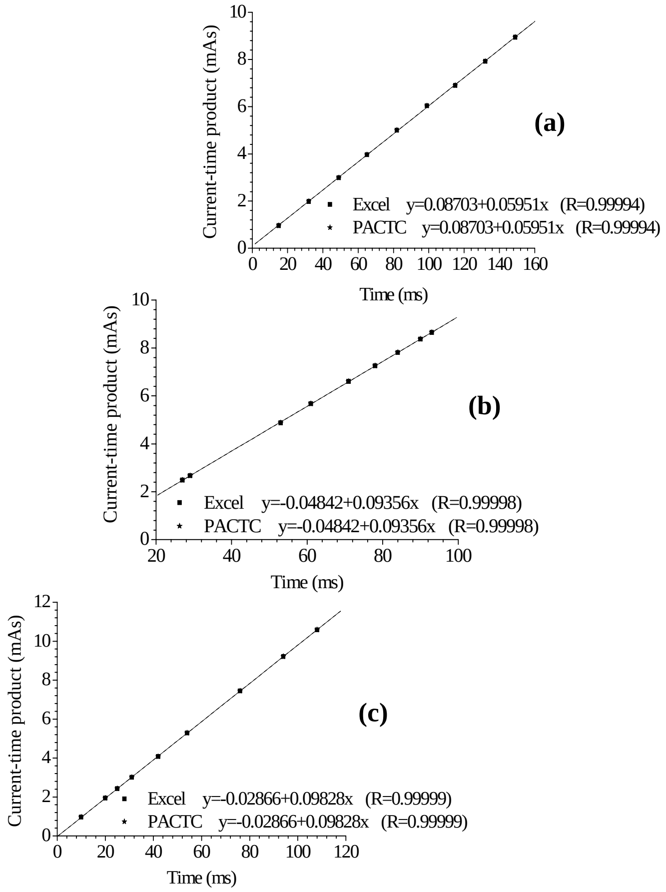


Fig. 7. Current-time product. (a) Single phase rectification, (b) Average frequency rectification, (c) High frequency rectification.

The quantities calculated through Excel spreadsheet and PACTC for theoretical waveforms are too similar, what show that the PACTC works correctly.

3.2 Experimental Waveforms

A) Peak Potential

The Figures 8, 9 and 10 show the values of the kVpmax, kVpabs, kVpave, PPV calculated through the PACTC for experimental waveforms obtained using the A, B and C equipments, respectively.

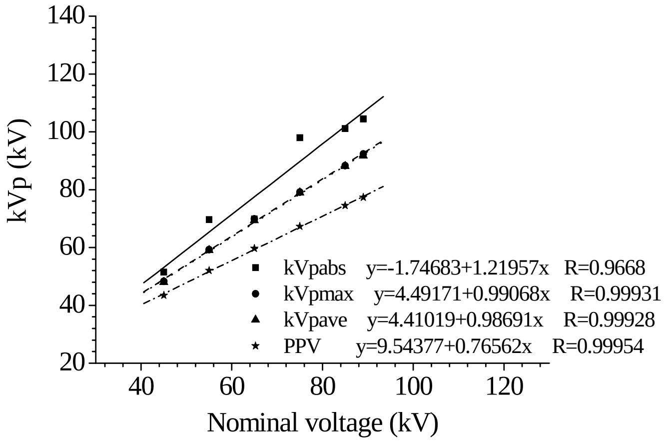


Fig. 8. Single phase rectification X-ray equipment.

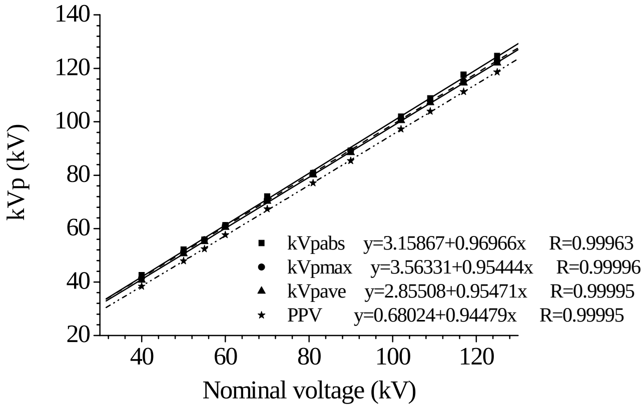


Fig. 9. Average frequency rectification X-ray equipment.

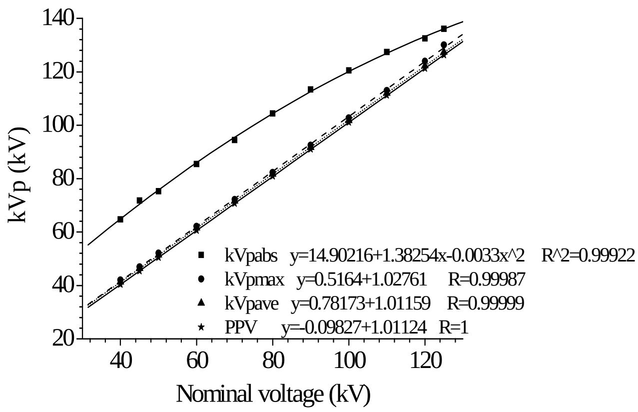


Fig. 10. High frequency rectification X-ray equipment.

The Figures 8, 9 and 10 show that the kVpmax and kVpave values are too similar. These results occurred due the X-ray equipments possess the constant voltage pecks during the exposure time, as shown in Figures 11, 12 and 13.

Through the Figures was also observed that the kVpabs values are only larger than kVpmax and kVpave values in the X-ray equipments with overshoot. Moreover, was verified that the difference between the PPV and the kVpmax increase with the ripple, what is waited due the PPV calculation considers tube voltages in the range 20-150 kV.

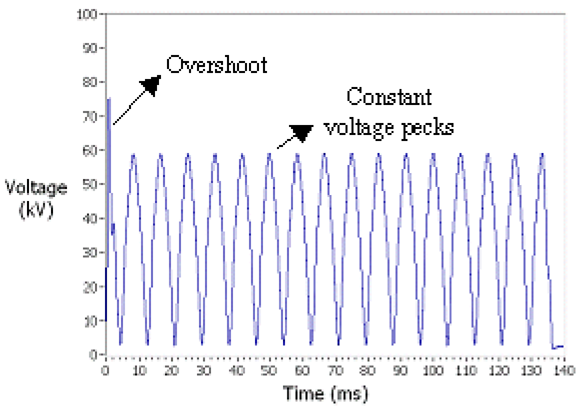


Fig. 11. Single phase rectification X-ray equipment experimental waveform.

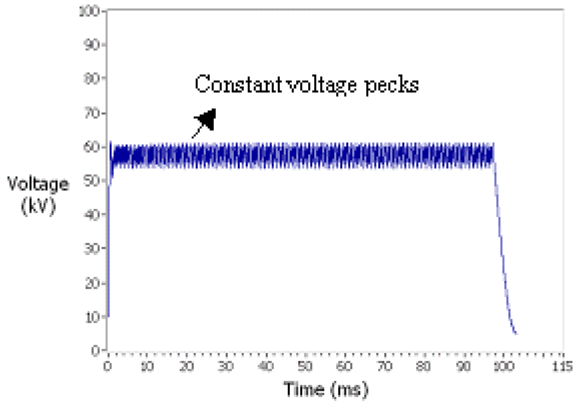


Fig. 12. Average frequency rectification X-ray equipment experimental waveform.

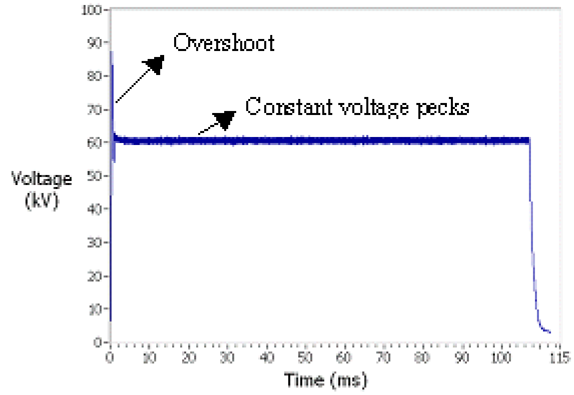


Fig. 13. High frequency rectification X-ray equipment experimental waveform.

B) Ripple

The Figure 14 show the hipple behavior, where can be observed that these values are in the theoretical range shown in the Table 1.

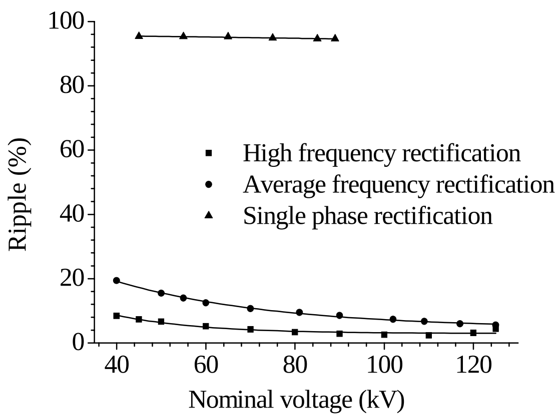


Fig. 14. Ripple.

C) Average Current

Through the Figure 15 can be observed that the average current from C and A X-ray equipments varies considerably with the nominal voltage. The same doesn't occur with the other X-ray equipment that presents fairly constant current in function of the nominal voltage.

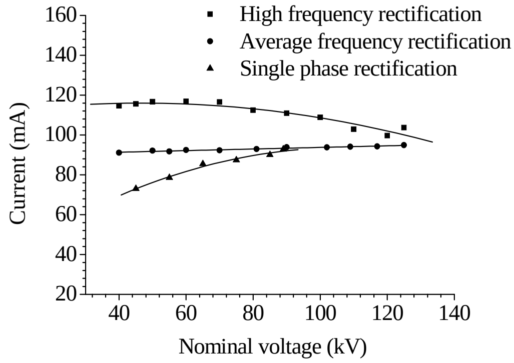


Fig. 15. Average Curret.

The Figure 16 shows the current waveform from C and A X-ray equipments, where can be observed that the current variation from C equipment for 70 kV is larger than for 125 kV nominal voltage. While for the A equipment the current variation for 50 kV is smaller than for 90 kV nominal voltage.

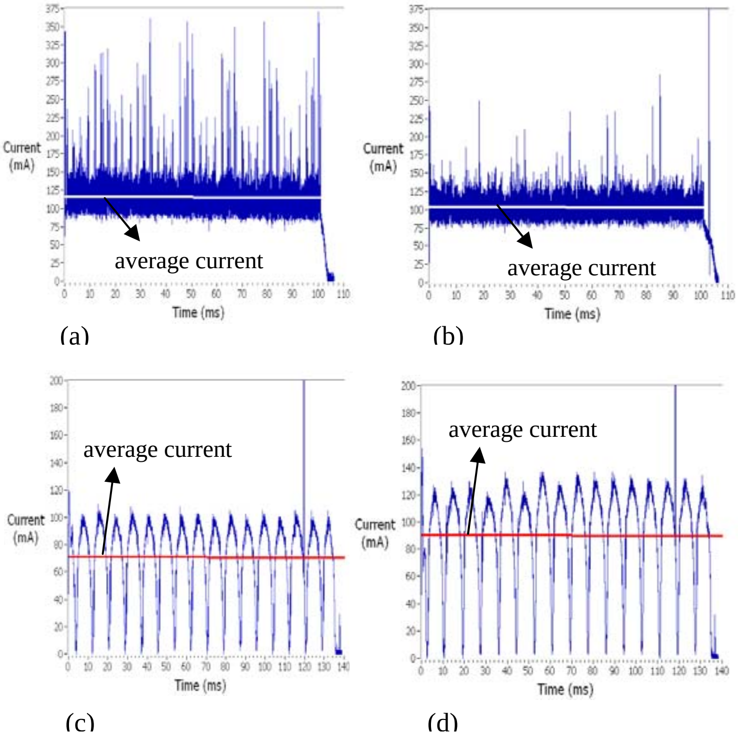


Fig. 16. Curret waveform: (a) high frequency rectification with 70 kV, (b) high frequency rectification with 125 kV, (c) single phase rectification with 45 kV, (d) single phase rectification with 89 kV.

D) Current-time Product

The current-time product behavior is similar to the average current behavior in function of the nominal voltage, as can be observed in the Figure 17. In other words, the current-time product from C and A equipments varies with the nominal voltage, while the same doesn't occur with the B equipment.

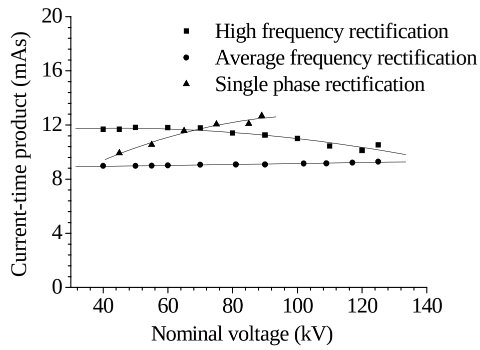


Fig. 17. Current-time product.

4. CONCLUSION

The data treatment software (PACTC) presented in this article demonstrated to be a powerful tool in the non-invasive meters calibration and X-ray equipments adjust.

Through the comparison between the calculated quantities using the Excel spreadsheet and PACTC for theoretical waveforms, was demonstrated that PACTC works correctly. Furthermore, was also observed that the PACTC makes possible to study and to evaluate the voltage and current experimental waveforms behavior in different kinds of X-ray equipments in few seconds.

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