ENERGY QUALITY x CAPACITORS BANK

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Abstract – **This work analyses capacitors bank installation in different locations of an industrial plant in order to correct power factor, taking into consideration the electrical energy quality and financial issues, through simulation in the MatLab software.**

KEYWORDS

Power factor, capacitors bank and harmonics.

I. INTRODUCTION

In the finance, maintenance and project areas of any industrial plant or company, the discussion of capacitor bank installation has become a relevant matter. Usually the companies when installing a set of capacitors bank are worried with the power factor correction only, in order to fit the present norms of the "Agência Nacional de Energia Elétrica", ANEEL.

The 64 article of ANNEL's resolution 456 dated November 29, 2000, establishes the minimum power factor allowed at the electrical system consumer units as of 0,92 (leading and lagging). According to article 65 of the same resolution, the exceeding reactive energy consumption is charged for power factors lower than the minimum allowed.

The companies take into consideration the financial aspect only and leave aside other important aspects of the consumed energy quality, when installing capacitors banks.

The capacitors bank installation may cause problems in the distribution system, such as: current and voltage peak during switching, phase and neutral harmonic distortions. These problems cause disturbances in low power equipments and in loads sensible to voltage variation, equipment damages, jeopardizes the protection and control system operation.

This study applies to industry electrical installations that has been modified since its installation or in new and modern ones, where there was only linear loads and now there is an increasing use of non-linear loads, such as, computers electronic lamps and inverters.

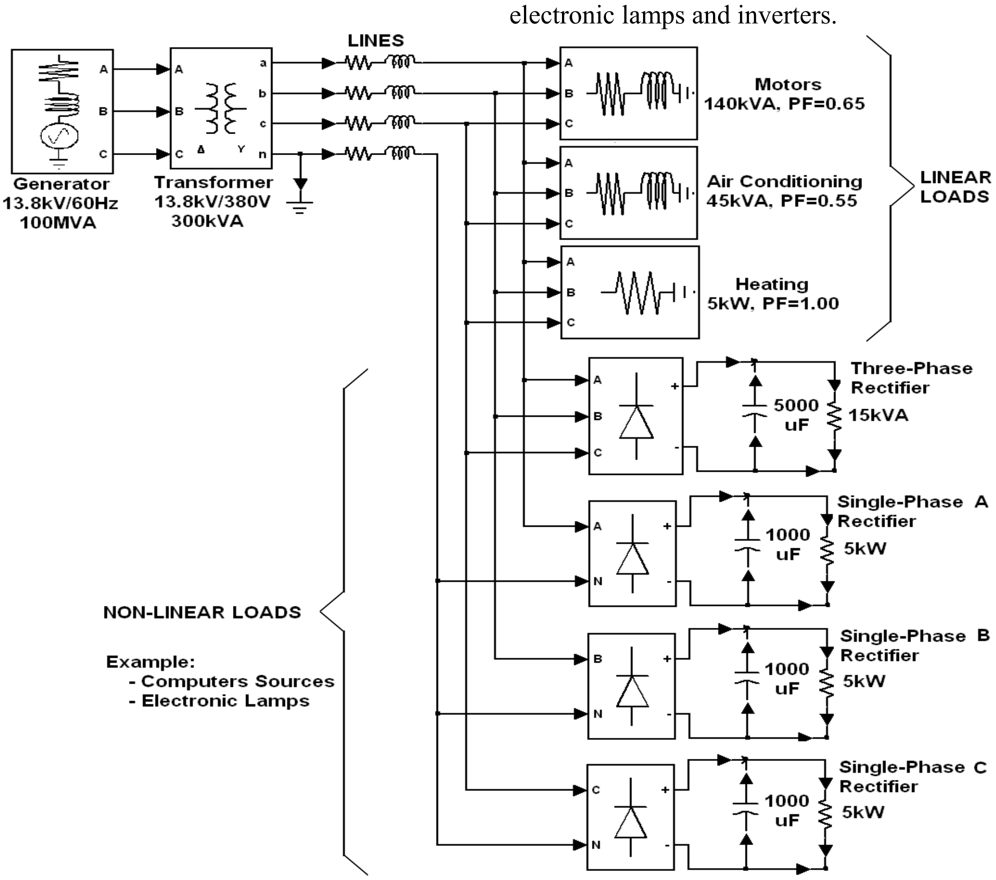


Figure 1 – Industrial Plant Simulated.

II. SIMULATED PLANT DESCRIPTION

It was taken into consideration the transformer and load feeders impedances in the simulation process. Figure 1 shows the squematic diagram of the industrial plant.

The system represents an industrial plant composed by the following equipments:

- Transformer (delta-Wye with grounded neutral) 13,8/0,38 kV, of 300 kVA;
- Three-Phase linear load of 140 kVA and power factor of 0,65 lagging;
- Three-Phase linear load of 45 kVA and power factor of 0,55 lagging;
- Three-Phase linear load of 5 kVA and unitary power factor;
- Three-Phase non-linear load of 15 kVA and;
- Single-Phase non-linear load of 5 kVA connected to each phase, in a total of 15 kVA.

The single-phase non-linear load represents the sources found in equipments such as fluorescents lamps and computers; the three-phase non-linear load represents motors and machines operated with variable speed; and the three-phase linear loads represent the directly operated motors, industry cooling and heating.

The transformer load is balanced and its secondary voltage is sinusoidal balanced.

The plant parameters and characteristics are verified before any capacitor bank installation.

Figures 2, 3 and 4 show the primary, secondary and neutral current waveforms and frequency spectrum, respectively.

Due to the non-linear loads, either the primary or secondary circuit current, do not present purely sinusoidal characteristics, although the total non-linear load is approximately 16% of the linear one installed.

Despite what most engineers think, a small percentage of non-linear loads sensitively affects the plant operational conditions.

It can be observed that the transformer primary current fifth harmonic component represents 27% of the fundamental, and the third harmonic component is null, due to the transformer connection of the electrical utilities. This can be observed in the 13,8 kV distribution feeders. In the secondary, the third and fifth harmonics represent 6,9% and 27,2% of the fundamental respectively. The total transformer secondary phase current harmonic distortion, THD, was of 34%, what is translated into a high sinusoidal wave distortion.

Although the loads are uniformly distributed, it could be observed a current flowing in the neutral with approximately inexistent fundamental component, and that the third harmonic component represents 21,12% of the fundamental phase current The most relevant neutral harmonic components are of zero-sequence.

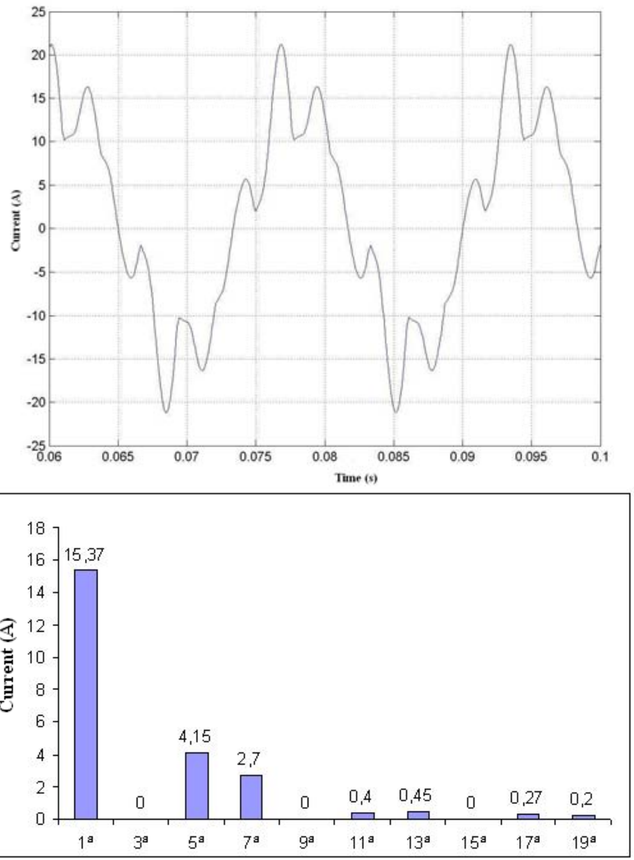


Figure 2 – Current on the Primary of the Transformer without Power Factor Correction, THD = 32% .

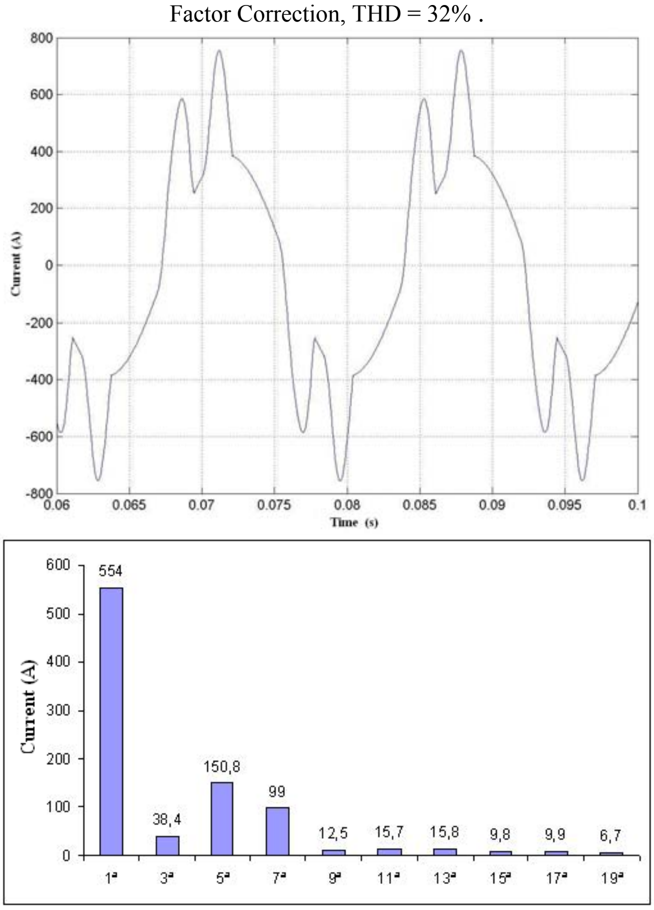
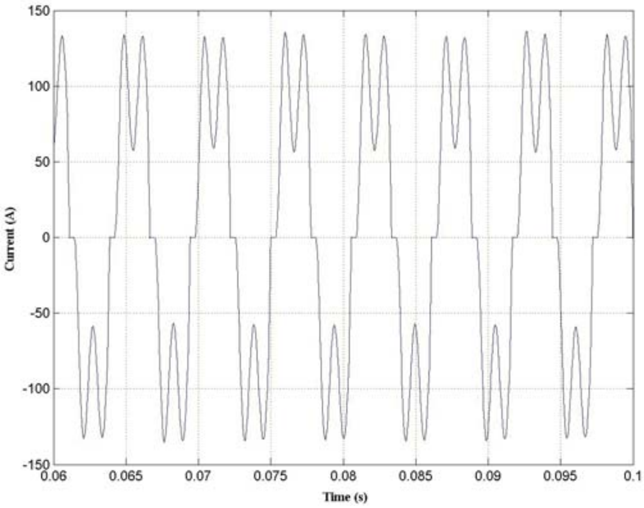


Figure 3 – Current on the Secondary of the Transformer Power Factor Correction, THD de 34%.



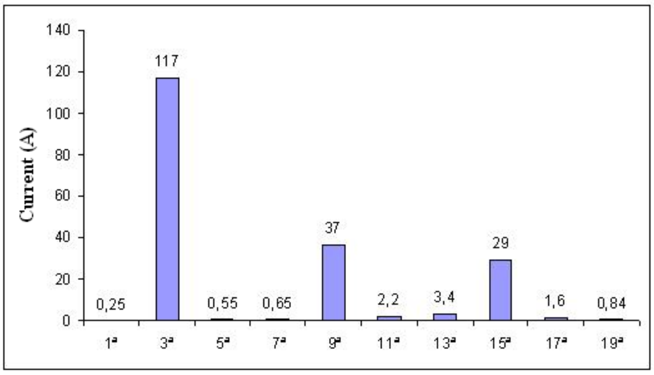


Figure 4 – Current on the Neutral Line without Power Factor Correction.

The transformer provides the load an active power of 73,1kW and reactive of 46kVAr per phase, what comes to a total apparent power of 259,1kVA and power factor of 0,846. With this low power factor, the company would have to pay for the exceeding reactive energy consumed.

III. CAPACITOR BANK INSTALLATION

The most usual solution available in the market for power factor correction is the bank capacitor installation to compensate the exceeding reactive.

The correction was made with the capacitor bank installation in three different ways, taking into account the correction to unitary power factor:

- Correction at the primary of the transformer [1];
- Correction at the secondary of the transformer (most usual);
- Load correction (recommended).

Lets consider that the voltage remains practically sinusoidal and that the current has a high distortion related to its sinusoidal waveform, figures 3, 4 and 5. Thus the plant apparent power will be calculated according to equation (1) [3].

$$S^2 = (VI_1)^2 + V^2(I_2^2 + I_3^2 + \ldots + I_n^2) \tag{1}$$

$$S_1^2 = (VI_1)^2 \tag{2}$$

$$S_1 = \sqrt{P_1^2 + Q_1^2} \tag{3}$$

$$D = V^2(I_2^2 + I_3^2 + \ldots + I_n^2) \tag{4}$$

Where

S - apparent power;

S_1 - apparent power related to the first harmonic;

D - distorted power;

P_1 - active power related to the first harmonic;

Q_1 - reactive power related to the first harmonic;

I_i; $i = 1,2,3,\ldots n$ - current of harmonic order i.

The plant apparent power has three components:

$$S = \sqrt{P_1^2 + Q_1^2 + D^2} \tag{5}$$

Where

$$P_1 = \sqrt{3} V_1 I_1 \cos\phi_1 \tag{6}$$

$$Q_1 = \sqrt{3} V_1 I_1 \operatorname{sen}\phi_1 \tag{7}$$

When installing the capacitor bank there is solely reactive power compensation related to the current first harmonic, which means, only Q_1 is compensated. But still the power factor, given by (8) is corrected because $\cos\phi_1$ has a relevant value before the bank installation.

$$FP = \frac{1}{\sqrt{1 + THD^2}} \cos\phi_1 \tag{8}$$

The three ways of correction mentioned before, will be analyzed, presenting the current and voltage characteristics in the secondary of the transformer.

Figures 5, 6 and 7 show the secondary current wave forms and frequency spectrum, what means, the current that flows in the plant feeders for the three correction cases, unitary power factor respectively.

Analyzing figures 5 to 7, it can be verified that the current THD in the secondary of the transformer is lower, 32,2%, in the case that the capacitors bank is installed at the primary of the transformer, on the other hand, the current peak in bank switching, in this case, shows the biggest problem as the current can get up to 1500 A, compared to the 800 A in steady operation. This peak may cause a great number of damages to the system such as low power equipment burn out.

As the capacitor bank placement gets closer to the load, the THD increases, that results in a higher current wave distortion in the secondary of the transformer. It can also be observed, in figure 7, that the bank installed at the load may cause problems to equipments that operate by zero-crossing as no-breaks.

Figure 8 presents the voltage peak at the switching of the capacitors bank on the three phases rectifier output.

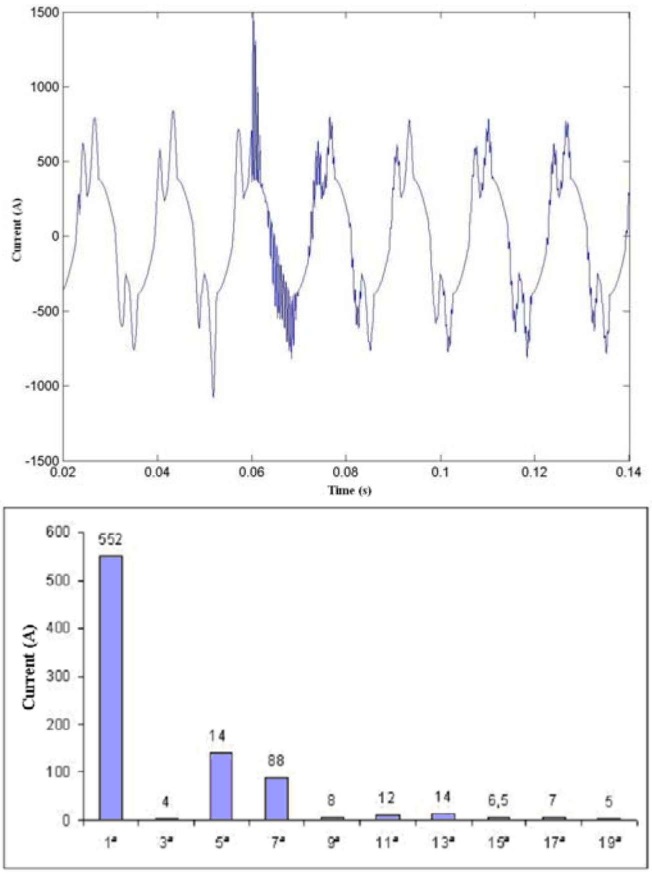


Figure 5 – Current and Spectrum on the Secondary of the Transformer with Capacitors Bank on the Primary, THD = 32,2 %.

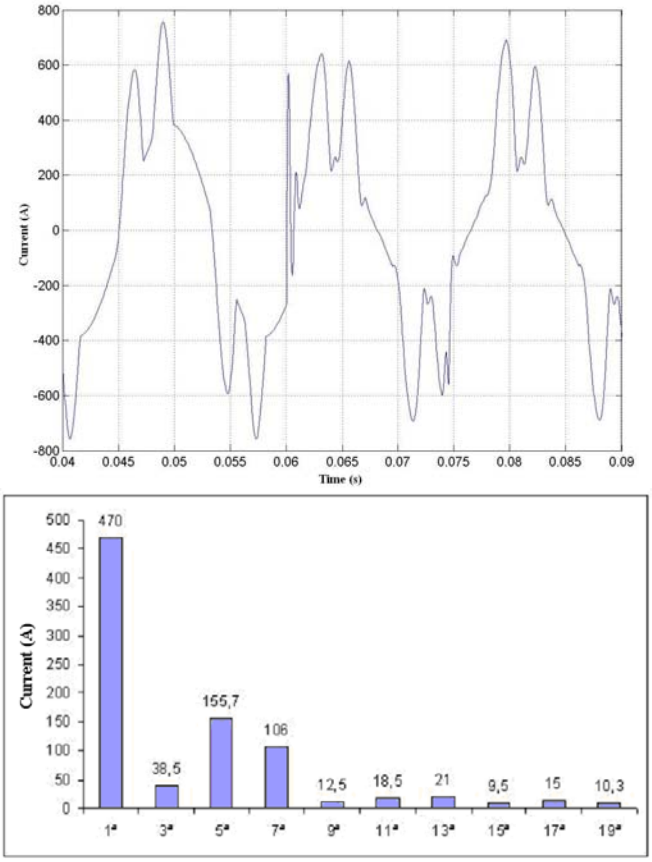


Figure 6 – Current and Spectrum on the Secondary of the Transformer with Capacitors Bank on the Secondary, THD=41,7%.

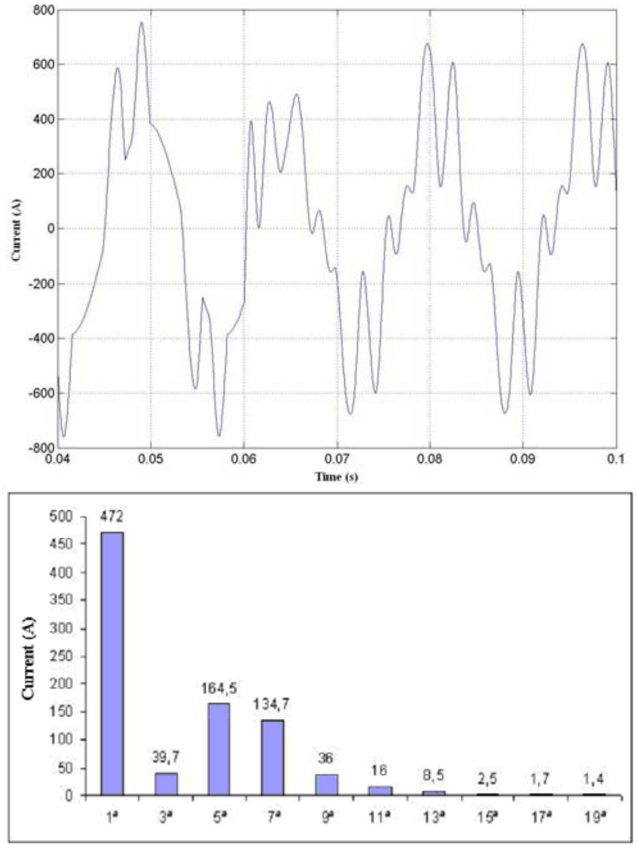


Figure 7 – Current and Spectrum on the Secondary of the Transformer with Capacitors Bank on the Load, THD = 46,7%.

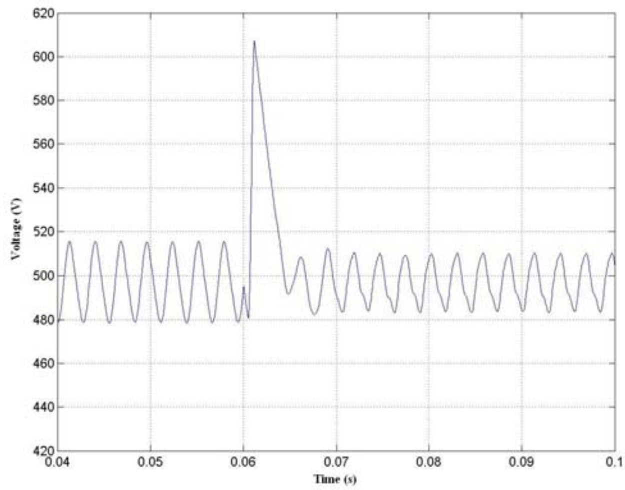


Figure 8 – Voltage on the Three Phases Rectifier at the Switching of the Capacitors Bank.

IV. CONCLUSION

The figures 9, 10 and 11 show the values of the current harmonic components on the secondary of the transformer, current and voltage THD, respectively.

Although the nonlinear loads represent just 16% of the total installed load, the 5th harmonic currents represent 27% on the primary of the transformer, figure 9, and 27,2% on the secondary.

The current peaks must be observed, because they will circulate in all electric installation.

With the installation of capacitors bank it can be observed that the RMS current on the secondary of the transformer decreases. This occurred due to the decrement of the reactive component.

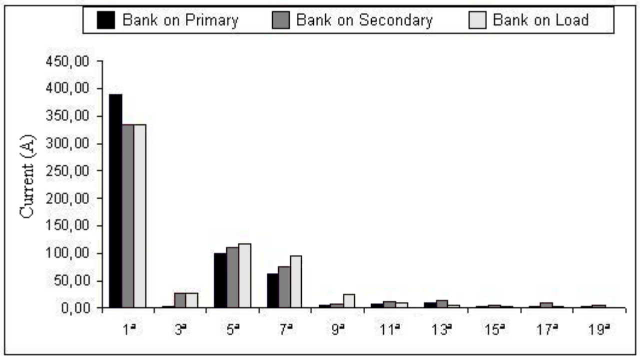


Figure 9 – Harmonic Currents on the Secondary of the Transformer.

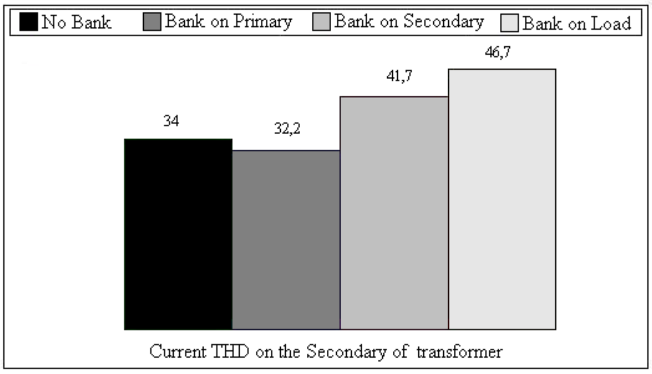


Figure 10 – Current THD (%).

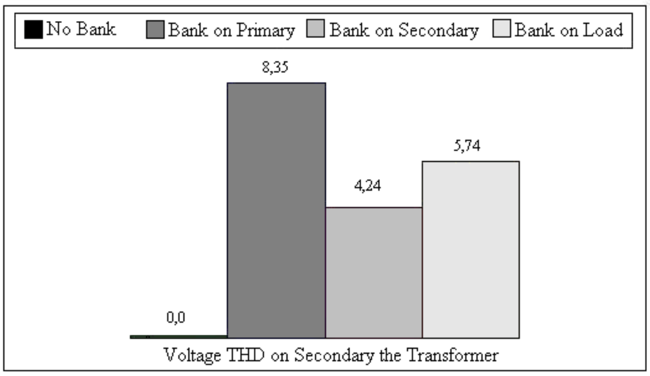


Figure 11 – Voltage THD (%).

The switching of capacitors bank always causes voltage peak, they are higher or smaller depending on the location installed. These overvoltages cause deterioration of the equipments sources, figure 8. The cost of this source is related directly to the level of voltage that its components support, the power supplies are designed for an over-voltage of 20%. One example of this is computer power supplies that have electrolytic capacitors with working voltage of 250V.

On the figure 10 it can be observed that the current THD increases, when the installation of capacitors bank is located near of the load. Figure 11 shows that the highest voltage THD is for the bank installed on the primary of the transformer.

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