NEW INTERFACE FOR IMPROVING THE HARMONIC CONTENT GENERATED BY THREE-PHASE UNCONTROLLED BRIDGE RECTIFIERS BY MEANS OF THE THIRD HARMONIC INJECTION METHOD

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Abstract – **This paper proposes a new interface for improving the harmonic content of three-phase uncontrolled bridge rectifiers by using an interface composed of a half-bridge converter with complementary drive signals and using capacitors in parallel with the switches. Its operation is proven through simulations and experimental results of a 10kW prototype.**

Keywords **- Harmonic distortion, bridge rectifiers,, third harmonic injection.**

I. INTRODUCTION

Currently most of the electrical system loads are non-linear, behaving as current harmonic sources that cause a poor usage of electrical installations, provoking temperature increases and failures.

Among these non-linear systems are, mainly, adjustable speed drivers that are used to conserve energy and automate processes. These drivers employ three-phase uncontrolled bridge rectifiers as the interface for the converter or inverter that controls the load. This interface causes high line current distortion at the input of the bridge. This problem is aggravated by the use of several similar systems in parallel. The rapid proliferation of these systems with distorted input currents generates adverse effects in the electric systems, degrading the quality of the energy that supplies other loads. In order to lessen these problems, there are many standards and recommendations, such as IEEE-519 and IEC-61000-3-4, that define permissible limits for the harmonic currents of non-linear loads in power electronics equipment.

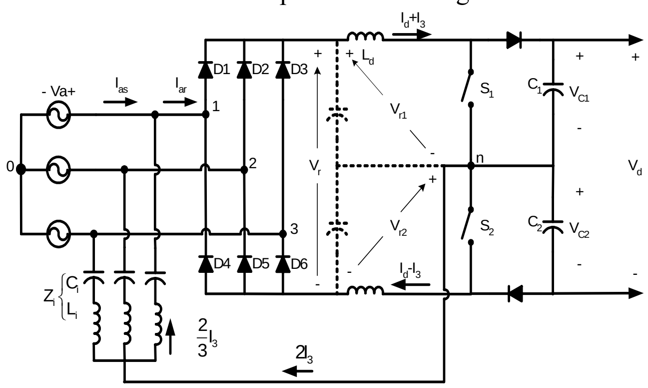
This article presents some existing topologies in the literature, besides proposing a new topology, using a minimum number of switches.

II. EXISTING TOPOLOGIES

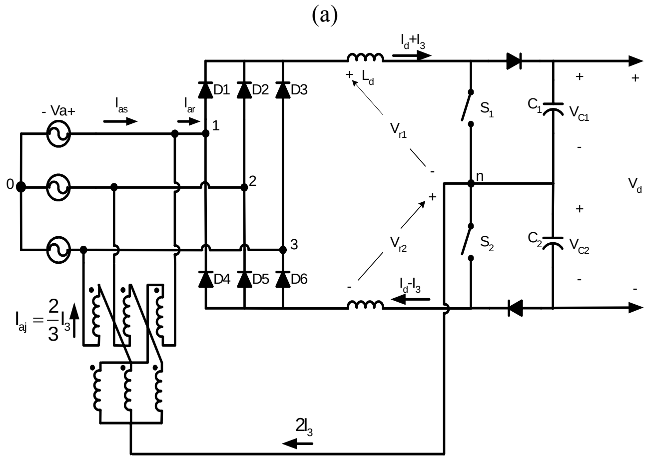
In the bibliography, techniques are proposed to improve the quality of the line currents of bridge rectifiers, considering output voltage regulation.

The techniques developed can be divided into two groups: 1) filters to prevent line current harmonics generated by the power electronics interface used in the system, and 2) improve the current waveform by means of a power electronics interface, thus preventing the generation of harmonic components.

The first group is composed of active and passive filters. The problem with these devices is that they do not regulate the DC voltage at the load. The interface of the second group does not change the topology and it is possible to control the DC output voltage. Figure 1 through figure. 4 presents some of the existing topologies in the literature that reduce the harmonic content of three-phase diode bridge rectifiers.



(a)



(b)

Fig. 1. Topologies proposed by Rastogi M., Naik R., Mohan N. [1], [2]

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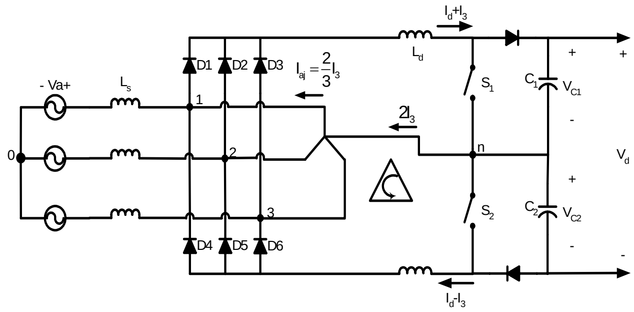


Fig. 2. Topology proposed by Naik R., Rastogi M., Mohan N., Nilssen R., Henze C., [3].

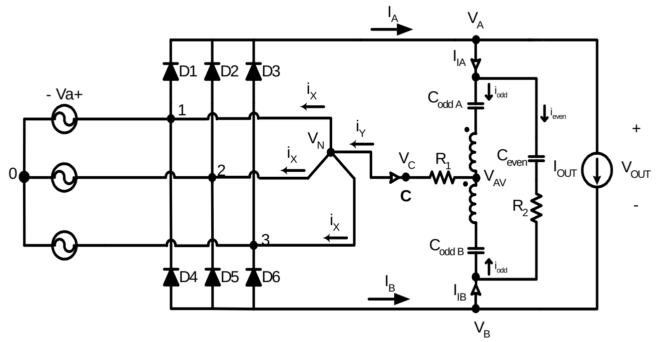


Fig. 3. Topology proposed by Pejović P., Janda Ž., [4].

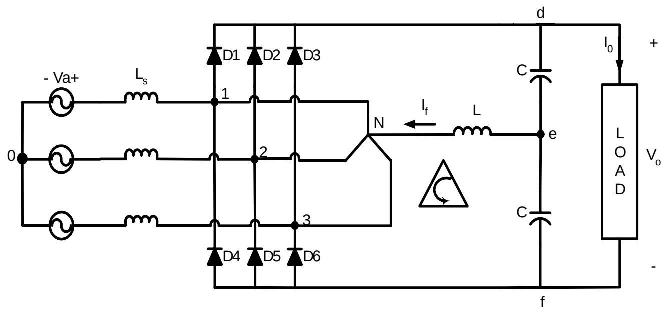


Fig. 4. Topology proposed by Kim S., Enjeti P. N., Packebush P., Pitel I. J., [5].

The use of a greater number of semiconductors is a disadvantage that present the topologies of figure 1 and figure 2. Advantages of these topologies are that they control the output voltage.

The topology of figure 3 presents a greater number of passive components, which are heavy and bulky moreover, it does not control the output voltage.

The proposal of figure 4, does not control the magnitude of the of third harmonic injected in the bridge rectifier.

The topologies proposals in this paper showed in figure 5(a) and 5(b), allow to reduce the semiconductors count and diminish the injected harmonic content in the power system. This does not control the output voltage.

III. THE NEW PROPOSED TOPOLOGY

Seeking a new and better interface that reduces the harmonic content caused by three-phase diode bridge rectifiers, the general idea proposed by Enjeti, [5] is used and to it a transformer and a pair of switches driven by two-level modulation are added, as shown in figure 5(a) and figure 5(b).

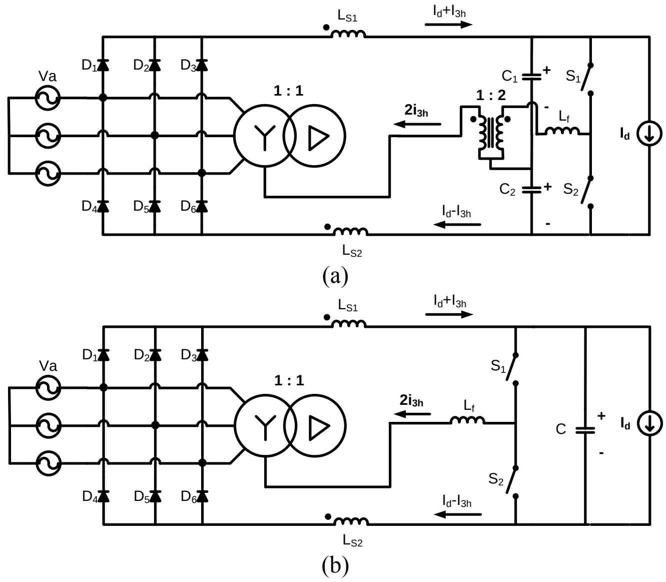


Fig. 5. Circuit of the new proposed topology (a) with transformer, (b) without transformer.

The use of the single-phase transformer is justified because it allows to attenuate the efforts in the semiconductors. The general idea is to reduce the harmonic content that bridge rectifiers generate at the mains without altering the topology of the rectifier. The circuit of figure 5(a) and figure 5(b) shows a pair of capacitors, C_1 and C_2, (figure 5(b), equivalent capacitor, C) who allow the AC component of the current to circulate and operate as a filter. Currents I_d and I_{3h} are, respectively, the load current and the third harmonic current. The load voltage has a ripple at six times the frequency of the input voltage and capacitors C_1 and C_2 (figure 5(b), equivalent capacitor, C) divide this ripple across themselves at three times the frequency of the input voltage. Inductor L_f acts as a filter for the switching current. The transformer controls the amplitude of the third harmonic current that is injected into the power circuit. The three-phase transformer distributes the current into three equal parts by means of the wye connection. The current circulates through the ground wire of the transformer and is distributed among the phases. The secondary side of the transformer is connected in delta without a load. The switches are controlled by the control circuit presented in figure 6, from figure 5 values I_d and $2I_{3h}$ are obtained, which are necessary to control the switches.

The block diagram of figure 6 shows current I_d multiplied by constant K_0, which represents the relation between the load current and the third harmonic current. Considering the first 49 current harmonics, $K_0 \approx 0.74$. Constant $2K_0$ represents the amplitude of the reference signal. The reference is a triangular waveform, with a frequency three times higher them the line frequency. This reference signal is compared to the current that circulates through the ground wire of the three-phase transformer (2_{i3h}). The error is multiplied by H(s), which, in this case, is a proportional-integral compensator, and, afterwards, it is compared to a 20 kHz triangular signal to generate the PWM drive signals of switches S_1 and S_2, which operate in a complementary manner.

In order to prove the operation of the proposed interface by means of simulation, the following electric parameters (see figure 5(a)) were used: two inductors $L_{s1} = L_{s2} = 4mH$, with a series resistance equal to 0.1Ω; two capacitors $C_1 = C_2 = 3.300\mu F$; an inductor $L_f = 3mH$; a single-phase transformer with a turns ratio of 1:2; a three-phase transformer with a turns ratio of 1:1. The input voltage is 220Vrms with a rated power of 10kW at the load.

The parameters listed above were used to perform two simulations. The first simulation does not consider the interface. The second includes the interface proposed in figure 5(a). In this case, a triangular signal is used as the reference current. Using a sinusoidal reference provides a similar result.

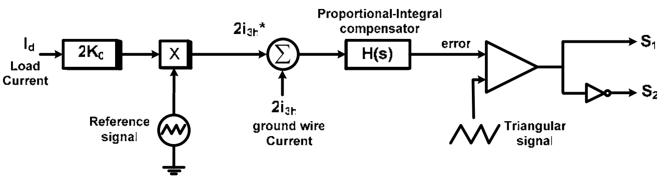
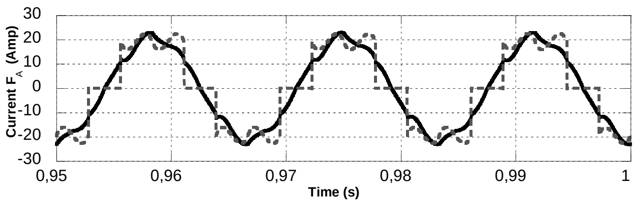


Fig. 6. Control Block diagram of the switches.

Figure 7 presents the input currents of the bridge rectifier. It can be observed that the current waveform is corrected by including the interface. Figure 8 shows the harmonic spectrum of the current of phase A, with and without the interface. A zoom of the harmonic content is also shown in order to better observe the spectrum. Figure 9 presents the voltages and currents at the three-phases of the supply. It can be seen that the displacement factor is approximately unitary.



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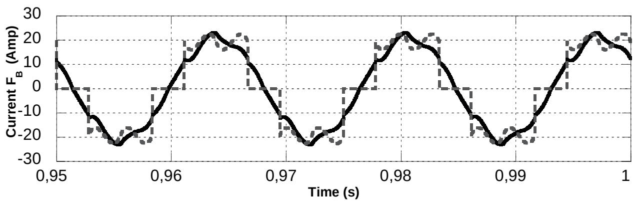

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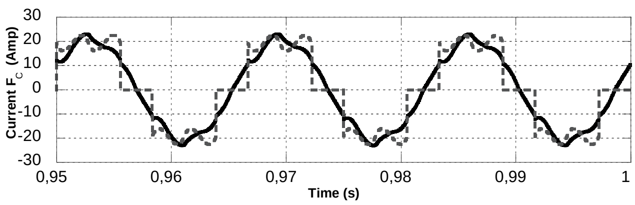
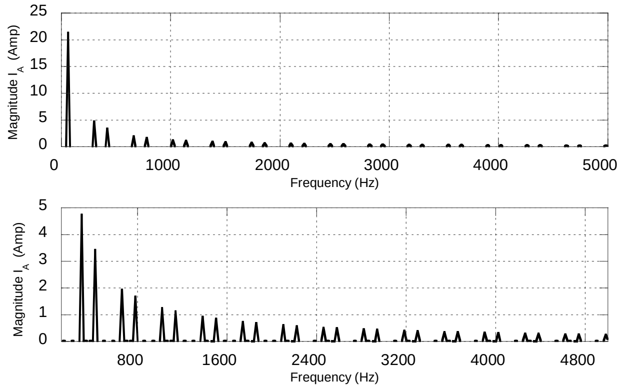


(c)

Fig. 7. Currents, with and without the interface, at the three-phase input of the diode bridge rectifier (a) Phase A, (b) Phase B e (c) Phase C.



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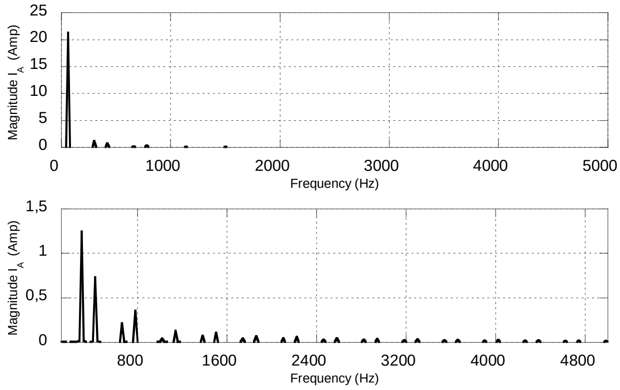

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Fig. 8. Harmonic spectrum of the current of phase A with zoom, (a) without the interface, (b) with the interface.

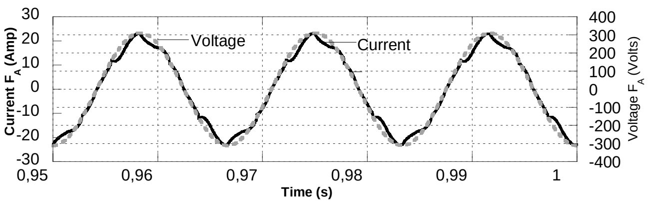


Fig. 9. Voltage and current at the input of the bridge rectifier, phase A.

IV. EXPERIMENTAL RESULTS

To verify feasibility of the proposed system, a rectifier was designed to operate at 10 kW rated power, with 220 V of RMS input voltage, 60 Hz mains frequency and 510 V of output voltage. Circuit diagram of the rectifier is presented in figure 5(b). The table I present the effort in the semiconductors with and without the use of the transformer.

Due the rated levels of the semiconductor, the topology without transformer was implemented. For higher power levels, the use of transformer is a good alternative to attenuate the losses and efforts in the semiconductors.

The magnetic components were designed according the numerical simulation.

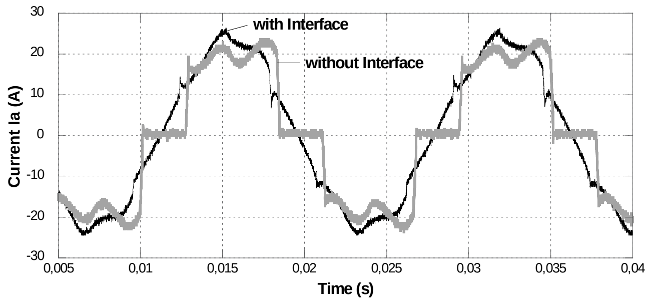
The input inductors are L_{s1}=L_{s2}=4 mH, with 2.1 kVA of apparent power. The filtering inductor is L_f=3 mH with 0.7 kVA of apparent power. Three phase transformer is with a turns ratio 1:1 with 5 kVA of apparent power.

TABLE I
Current of the semiconductors with and without the use of the transformer

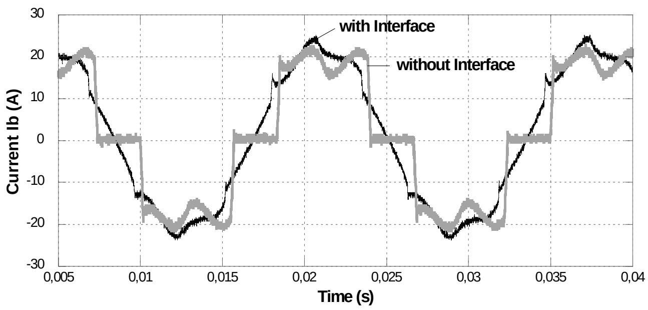
Currents	Currents without Transformer (A)	Currents with Transformer (A)
Maximum current in the diodes	34.6	21.9
RMS current in the diodes	11.8	7.6
Average current in the diodes	6.0	4.0
Maximum current in the IGBT	33.7	9.8
RMS current in the IGBT	8.3	2.0
Average current in the IGBT	3.3	0.7

Two Capacitors, C_1 e C_2, are connected in series with C= 3330 μF of capacitance and 350 V rate voltage. IGBT modulate and bridge rectifier are manufacture by Semikron, model SKM 50 GB 063 D and model SKD 50/04A3, respectively. IGBT modulate processes about 40 % of output rated power.

It is possible to observe in the figures 10(a), 10(b) and 10(c) the improvement of the diode bridge input currents. To quantify this improvement a Fourier analysis of the input current presented in the figures 11(a), 11(b) and 11(c). The THD of input currents are about 7 % in all three phases.



(a)



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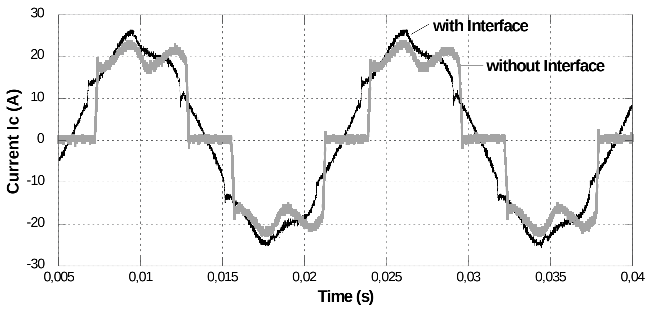
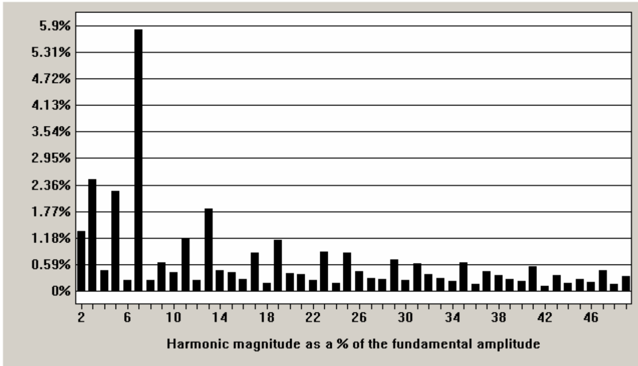


(c)

Fig. 10. Currents, with and without the interface, at the three-phase input of the diode bridge rectifier (a) Phase A, (b) Phase B e (c) Phase C.



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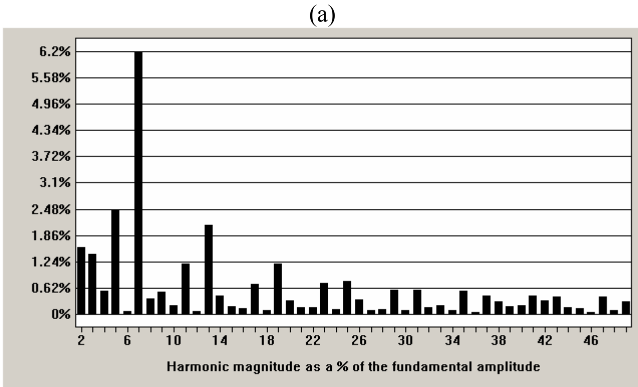

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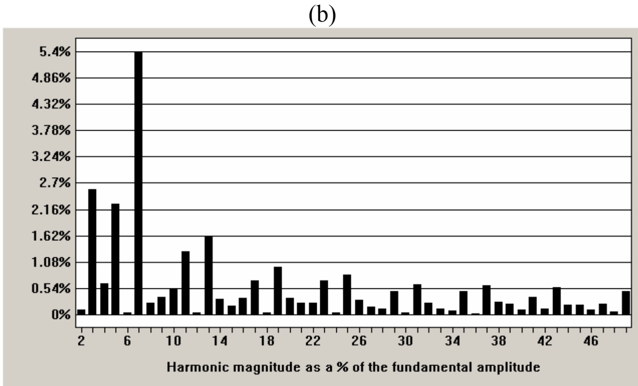

(c)

Fig. 11. Fourier analysis (a) Phase A, THD = 7,7%, (b) Phase B, THD = 7,8%, (c) Phase C, THD = 7,2%.

It is used norm IEC 61000-3-4 (Table II) to know the limit of percentages harmonic current for equipment.

TABLE II
Limit of percentages harmonic current, of Norm IEC 61000-3-4, for equipment

Harmonic Number (h)	Admissible harmonic current I_h/I_1 %	Harmonic Number (h)	Admissible harmonic current I_h/I_1 %
3	21,6	19	1,1
5	10,7	21	0,6
7	7,2	23	0,9
9	3,8	25	0,8
11	3,1	27	0,6
13	2	29	0,7
15	0,7	31	0,7
17	1,2	≥33	≤0,6

Figure 12 presents the line voltage and current, of phase A. The system presents high power factor.

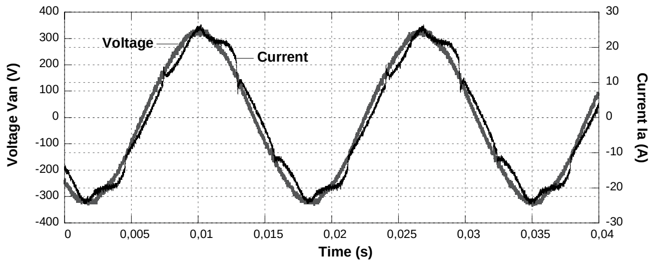

Fig. 12. Line current and line voltage, Phase A.

Figure 13 presents the behavior of the power factor versus the output power.

Figure 14 presents the experimental curve of efficiency of the three-phase uncontrolled bridge rectifier with the circuit of third harmonic injection. It is observed that the presence of the circuits that form the interface does not contribute significantly for the degradation of the efficiency.

Figure 15 presents the behavior of the THD of the line current. It is verified that the THD of the current is reduced with the increase of the power, being minimum for the rated power.

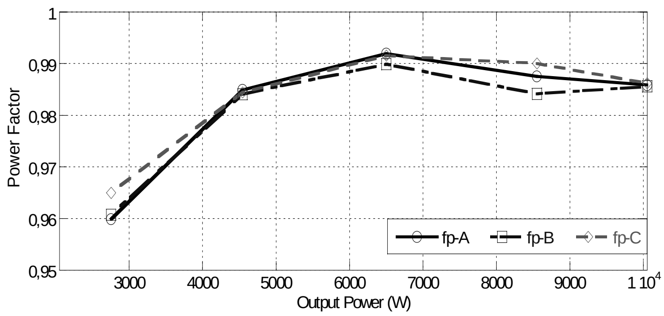

Fig. 13. Power factor versus output power.

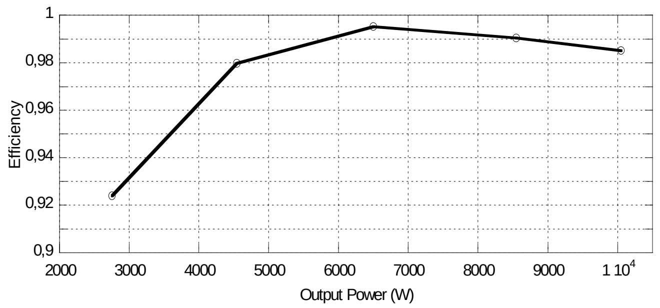

Fig. 14. Efficiency versus output power.

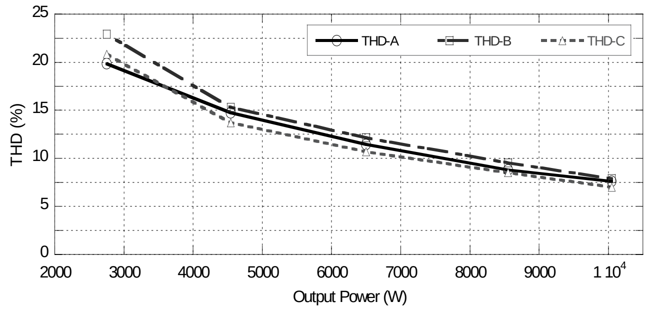

Fig. 15. THD versus output power.

V. CONCLUSIONS

In this work a new topology was presented to reduce current harmonic content provoked by the three-phase uncontrolled rectifier bridges, besides achieve a high power factor in the input of the bridge rectifier. From represented the theoretical and experimental studies in this work it can be concluded what it follows:

- The number of semiconductors added to the three-phase bridge rectifier is minimum in comparison with other presented interfaces;
- By means of the convenient choice of the value of the inductance to be used in the inductors of entrance and filtering, power factor is practically equal to the unit in rated power. It is observed that, taking in account the simplicity of the circuit, such result is notable, since the alternatives topologies only get high power factor using high frequency commutation what generates high losses.
- Although optimized for a determined power, the circuit presents high power factor and high efficiency in an wide range of output power;
- The used inductors in output bridge rectifier and the filtering operate in the triple of the frequency of the power system, being able themselves to use for the construction of its cores usually used steel-silicon plates of the same type in industrials transformer. Even being necessary high value inductors, the high magnetic flow density, characteristic of these magnetic plates, reduces the inductors volume. The cost of such material is also insignificant front the cost of the ferrites, that are necessary in inductors of high frequency;
- The current added diodes rectifier, due to inclusion of the interface, are very small;
- The tests in the prototype demonstrate the viability of the use of the interface presented in this work. In a similar way, the tests demonstrate that the implementation of the considered control also acts in way favorable in the moving one to the power factor and the THD of the input current of the rectifier;
- The three-phase transformer used is specified, approximately, for 40% of the output power.

The new interface, for simplicity of circuit implementation for the reduced cost associate, for the easiness of its practical assembly and for the important presented characteristics consists in an excellent contribution to the subject.

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