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# Studies on the Command of Single-Phase Rectifiers Using the Scalar Control Technique

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***Abstract* - One of the important problems of power supply systems consists in ensuring the quality of energy supplied to consumers. In this issue, the reduction of the harmonic spectrum of the supplied voltage and current has a key role. As electronic power converters are now increasingly used by consumers, the problem of reducing the harmonic spectrum of the current absorbed by the power supply by these consumers is becoming more and more pronounced. For this, there is the problem of using consumers with a power factor as close as possible to the unit, which also ensures the increase of the efficiency of these consumers. The present paper focuses on the study of single-phase rectifier configurations provided with power factor control (PFC) structures. Among the multiple techniques and methods of power factor control, the scalar power factor control technique was applied to a boost type power converter, in two variants. The first variant is that of a single-phase rectifier in fully controlled bridge. The second is that of a single-phase rectifier in uncontrolled bridge. In both cases, the study of the scalar PFC technique was based on the Matlab/Simulink modeling of the two mentioned configurations. Achieving these models allowed the study of the correction mechanism of the power factor under the influence of the various functional parameters of the approached configurations.**

**Cuvinte cheie:** *factor de putere, redresor, convertor static ridicător, control scalar, model Matlab-Simulink.*

**Keywords:** *power factor, rectifier, boost convertor, scalar control technique, Matlab/Simulink model.*

## I. INTRODUCTION

AC-DC, DC-DC or DC-AC power converters are widely used because they provide a variable level voltage at the output, a high efficiency and, in the case of DC - AC converters, a variable output voltage and frequency separately or simultaneously. An important drawback, which is characteristic of these converters connected to the alternating current network, is that they absorb from the power supply a current in the form of pulses on each alternation. Therefore, these converters have a high total harmonic distortion factor (*THD*) and a low power factor.

Typically, these converters are used in various configurations of electronic systems, having the role of controlling the output voltage even under conditions of varying load current and input voltage. More and more applications require the reduction of the *THD* factor of the current consumed from the power supply and a power factor as high as possible. The requirements imposed by ensuring a good power quality, led to sustained researches for the development of some converter structures with power factor control circuits [1]-[8].

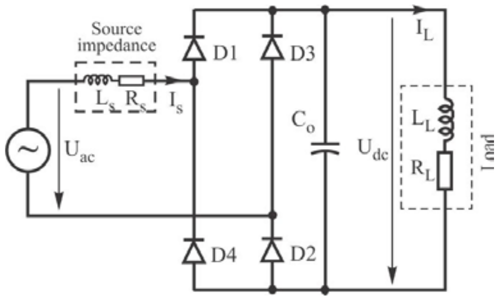


Fig. 1. Schematic of a single-phase uncontrolled bridge rectifier.

The current absorbed by most electronic equipment is non-sinusoidal, discontinuous, with appreciable peaks. This current has a rich content of harmonics, which flows through the mains and the equipment that produced it. Fig. 1 illustrates the diagram of a single-phase uncontrolled bridge rectifier, with filtering capacitor on the DC side, which is suggestive in support of the previous statement.

The configuration illustrated in Fig. 1 was modeled and simulated in Matlab / Simulink. The harmonics contained in the spectrum of the current absorbed from the network circulate both through the rectifier and through the power supply to which the rectifier is connected. The shape of the current absorbed from the power supply, together with that of the supply voltage, are shown in Fig. 2.

The waveforms illustrated in Fig. 2 correspond to the following circuit parameters: $U_{ac}$ = 100 V (RMS), $R_s$ = 0.01 Ω, $L_s = 1\cdot10^{-6}$ H, $C_o = 1000\cdot10^{-6}$ [F], $R_L$ = 50 Ω, $L_L = 1\cdot10^{-4}$ [H], $U_{dc}$ = 131.2 V.

By Matlab / Simulink modeling of the Fig. 1 circuit, it was possible to graphically represent the harmonic spectrum and determine the *THD* factor for the current absorbed from the power supply.

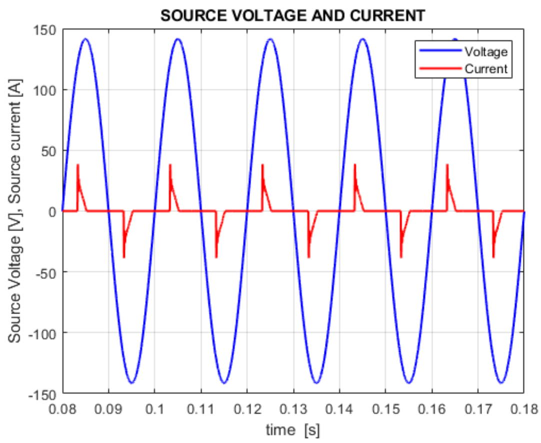


Fig. 2. The evolution in time of the power supply voltage and the current absorbed from the power supply by an uncontrolled bridge rectifier.

Fig. 3 shows the spectrum of harmonics determined by simulating the operation of the single-phase uncontrolled bridge rectifier.

Following the simulations, the parameters were also determined: the fundamental amplitude of the supply current $A_1$ = 9.2 A, *THD* = 1.614 and the power factor *PF* = 0.445.

From the above, it can be concluded that a conventional single-phase full-wave rectifier (uncontrolled) which is provided with filtering capacitor at the output has the following characteristics:

- The absorbed current is non-sinusoidal (Fig. 2), with a rich content of harmonics, especially in the field of harmonics with a rank close to fundamental: 3, 5, 7, 9, as illustrated in Fig. 3.

- It has a low power factor, which reduces the rectifier efficiency.

- The presence of harmonics increases the operating temperature of the transmission lines and other equipment connected to the mains (power supply).

- Reduces the capacity of the power supply to provide maximum power to the load [4].

## II. Scalar Control Technique

Due to the previously mentioned disadvantages, Power Factor Correction (PFC) techniques have been developed, with the role of bringing this important parameter for consumers and power networks to values as close as possible to the unit.

PFC rectifiers have been developed in two basic configurations [2], [8]:

1. Using a fully controlled rectification stage, in which each semiconductor device is controlled according to an algorithm established by a certain power factor control technique.

2. Using an uncontrolled rectifier stage, followed by a controlled buck / boost configuration, in which case the control algorithm applies only to the power contactor belonging to the configuration following the uncontrolled rectifier.

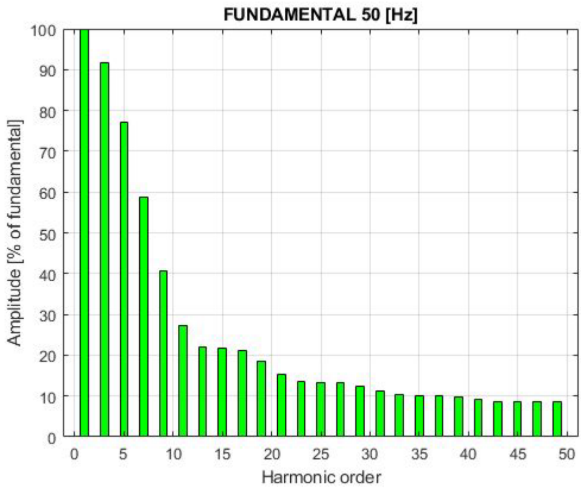


Fig. 3. The harmonic spectrum of the current absorbed from the power supply by a single-phase uncontrolled bridge rectifier.

The first configuration requires the switching operation of a number of four semiconductor devices, while the second configuration requires the switching operation of a single semiconductor device. The choice of one of the two solutions is made primarily based on the converter efficiency at the required power and the characteristics of the semiconductor devices at the required switching frequency.

The scalar control technique can be applied to both variants of PFC rectifiers. The principle diagram of a PFC rectifier from the first category is shown in Fig. 4 [2]. Examining the scheme in Fig. 4 it can be stated that, in the situation where in the analysis of the circuit, it is taken into account own inductance of the power supply $L_s$, the circuit works as a direct boost converter [2].

In Fig. 5 shows the configuration of a PFC boost converter, with scalar control according to the average current value [8].

## III. Modeling the Single Phase Rectifier with PFC System

The diagram of the single-phase PFC rectifier with controlled rectification stage to be modeled is shown in Fig. 4. As it can be seen, there are two cascading feedback loops. The external loop (after the output voltage) provides the value of the reference current $I_{ref}$ for the internal feedback loop (according to the current absorbed from the power supply). In steady state, the reference current is a constant quantity.

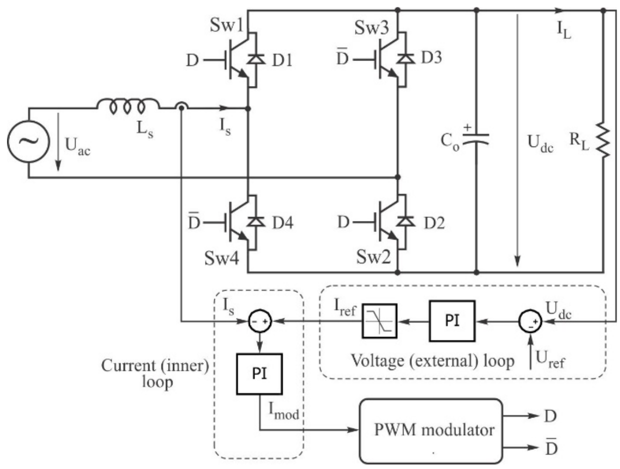


Fig. 4. Configuration of a single-phase rectifier with power factor correction by scalar control technique, with fully controlled bridge [2].

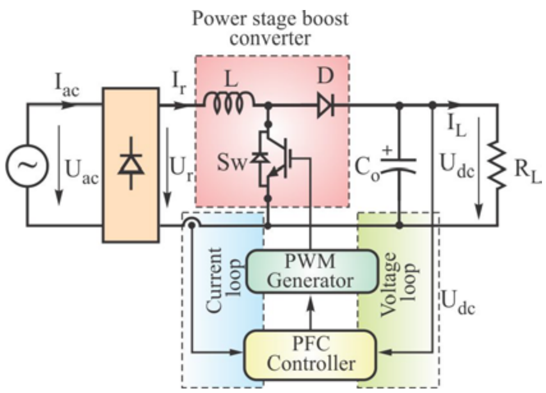


Fig. 5. The principle of PFC control of the boost converter.

In the second feedback loop, the input current is compared with the reference current in order to obtain the modulating current $I_{mod}$.

The PWM modulator contains a triangular wave generator. Switching moments occur by comparing the triangular wave with the modulating current, as it can be seen in Fig. 6. The principle of generating PWM control signals is similar to the SPWM technique used to control voltage-frequency static converters that drive asynchronous motors in variable speed drive schemes.

The circuit configuration shown in Fig. 4, was modeled in the Matlab / Simulink environment, in order to study the possibilities of improving the power factor and determining the amplitude of the fundamental as well as the *THD* factor.

The achieved model is shown in Fig. 7.

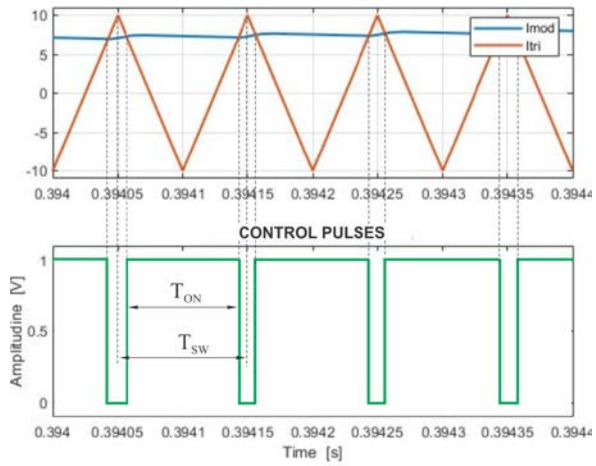


Fig. 6. Control pulses generation (operating cycle).

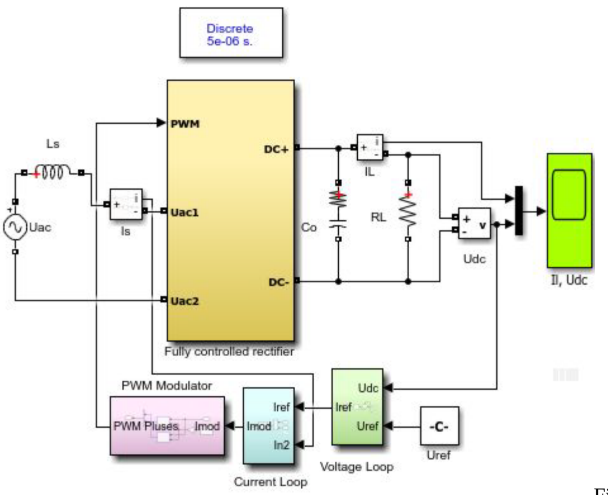


Fig. 7. The rectifier model of  the scheme in Fig. 4.

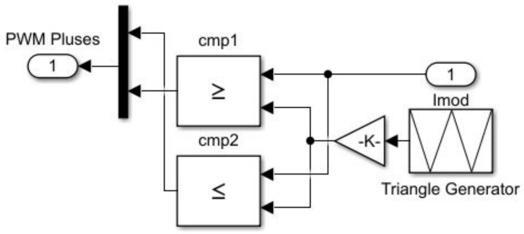


Fig. 8. PWM modulator structure.

The fully controlled single-phase rectifier was implemented with IGBT transistors. This solution was preferred because the switching frequency is not very high, in which case the use of MOSFET transistors would have been recommended. In Fig. 8, the structure of the PWM modulator block is shown. The structure contains a triangular wave generator and two comparators that have the role of detecting the moments of intersection between the modulating current and the triangular wave (according to Fig. 6), thus generating PWM control pulses for IGBT transistors in the rectifier bridge.

The evolution in time of the current absorbed from the power supply, together with the supply voltage, is shown in Fig. 9. The waveforms in Fig. 9 were obtained with the following circuit parameters: $U_{ac}$ = 100 V peak value, $U_{ref}$ = 120 V, $R_L$ = 45Ω, the frequency of the triangular carrier wave $f_{tr}$ = $10^4$ Hz. The harmonic content of the absorbed current is shown in Fig. 10.

1. Harmonics close to the fundamental (low frequency), have aptitudes related to the fundamental, extremely small (less than 2%), as illustrated in Fig. 10. The harmonic of rank 200, corresponding to the carrier frequency of the triangular generator (10 kHz), has a relative to fundamental amplitude of about 3%, as can be seen from Fig. 11, in which the relative to fundamental amplitude of the first 210 harmonics were represented.

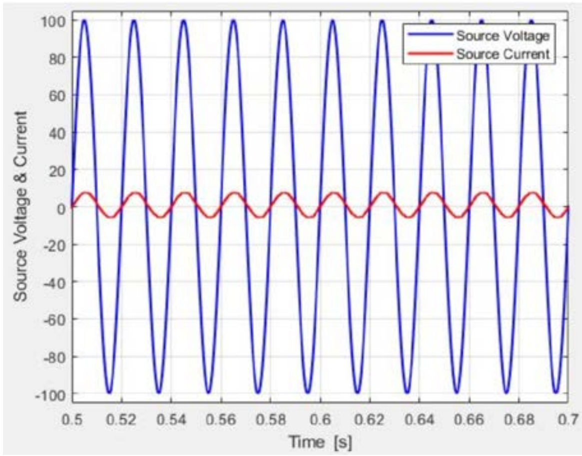


Fig. 9. The evolution in time of the current absorbed from the power supply together with the supply voltage after compensation.

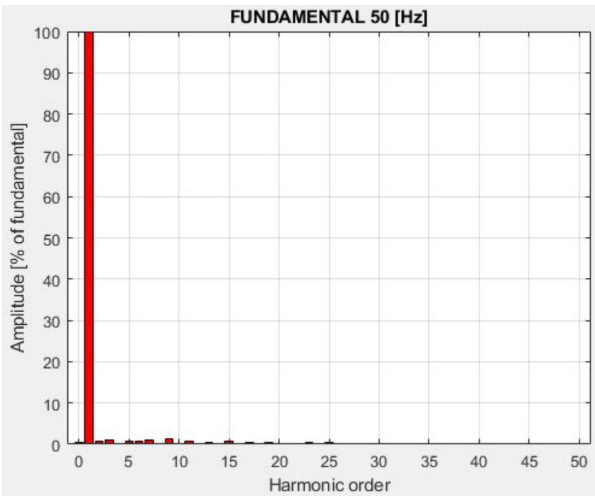


Fig. 10. Harmonic spectrum of the current absorbed from the power supply after compensation.

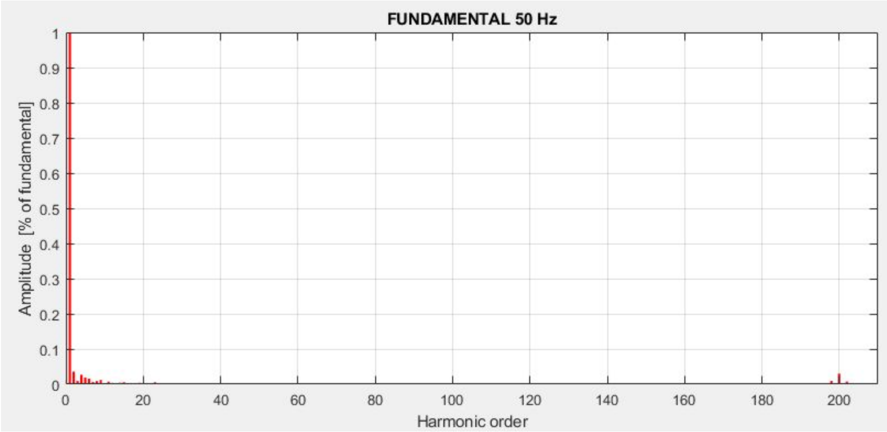


Fig. 11. Spectrum of absorbed current from the power supply (first 210 harmonics relative to the fundamental).

From this point of view, it would be desirable for the frequency of this generator to be as high as possible, but practically it is limited by the switching performance of the electronic devices in the rectifier bridge. Related to these performances, the efficiency of the converter that uses this carrier frequency in order to generate the PWM control pulses can be analysed.

2. The amplitude of the fundamental increased to the value $A_1$ = 6.65 A, which is higher than in the case of the uncontrolled rectifier even if the RMS value of the supply voltage is 70,992 V, and *THD* is of about 0.03.

3. The value of the power factor is *PF* = 0.99, approaching considerably the unit.

## IV. Modeling the Boost Converter with PFC System

The configuration shown in Fig. 4 can be considered a boost converter in a single stage (direct boost). In addition to the qualities highlighted by modeling and simulation, such a rectifier has the disadvantage of a number of four static controlled switches, which operate at a switching frequency much higher than the fundamental frequency. At medium and low powers, the switching losses of static switches do not greatly affect the efficiency of the converter. Instead, at high and very high powers, the switching losses begin to affect the efficiency of the converter. For this reason, two-stage PFC rectifiers, such as the boost converter, are preferred. It has a rectifier stage with uncontrolled power semiconductor devices (diode rectifier) followed by a stage with with a single controlled device that is part of the PFC structure (Fig. 5). Thus, instead of four high frequency switching controlled contactors, there is a single high frequency switching controlled contactor. In this way, the switching losses will be reduced by about a quarter compared to the first case.

For the implementation of the scalar method in this case, two reaction loops are used as in the previous case: a reaction loop according to the output voltage and a reaction loop according to the current absorbed from the power supply.

PFCs with the implementation of feedback loops are used to ensure stable operation and acceptable dynamic behavior, regardless of the load variation mode [3].

The scalar control method according to the average value of the current leads to a better waveform of the absorbed current. The current error amplifier used in Fig. 12 filters the measured rectified current. The output of this error amplifier controls the PWM modulator. The current loop tends to reduce the error between the mean value of the rectified current $I_r$ and its reference. [3].

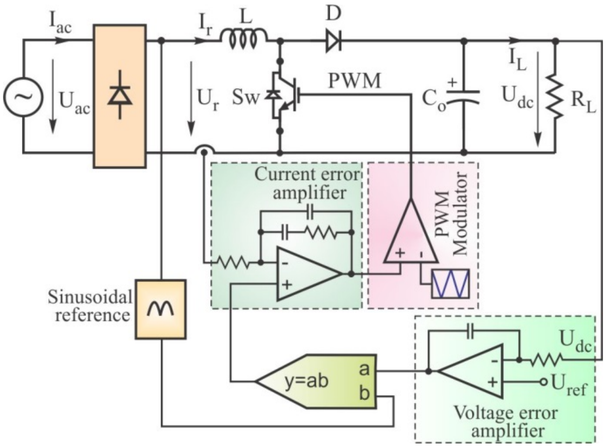


Fig. 12. Block diagram of the PFC boost converter controlled by the average current value ([3]).

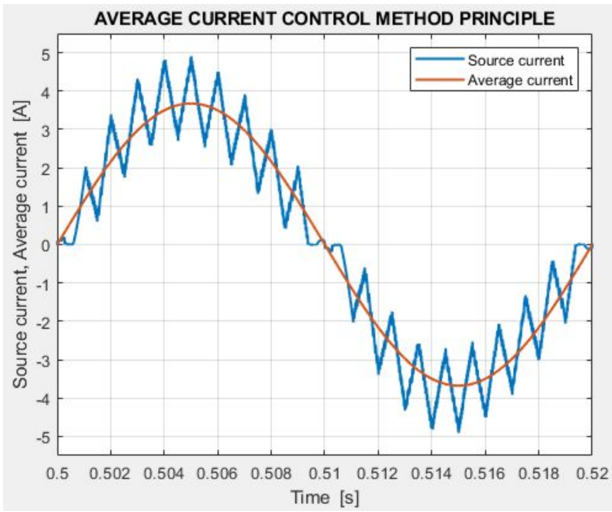


Fig. 13. Waveforms for control by average current value.

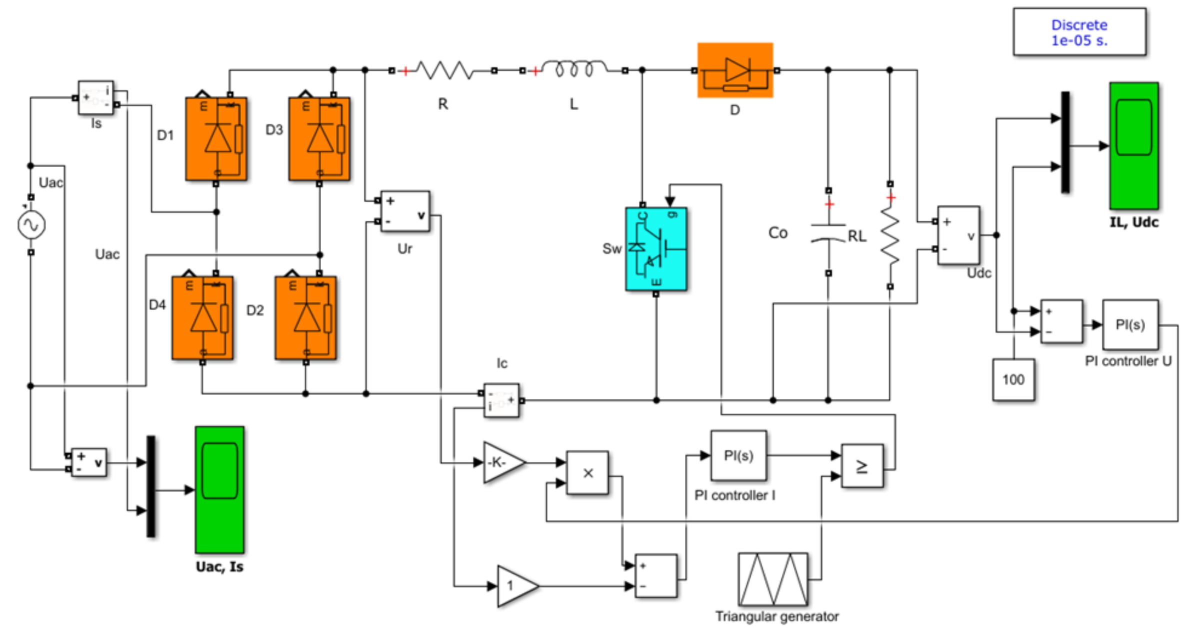


Fig. 14. The Matlab / Simulink model of the circuit shown in Fig. 5.The average current control method avoids the complications of the peak current control method by using a high gain integrative amplifier in the current feedback loop [3].

The waveforms illustrating the application of this method can be seen in Fig. 13.

The method has the following important advantages [3]:

a) The switching frequency is constant;

b) It does not require compensation ramp;

c) There is lower sensitivity to telecommunication noises, due to current filtering.

In addition to these advantages, the method also highlights some disadvantages, such as [3]:

1) The need to measure the current flowing through the inductance L;

2) It is necessary to use a current amplifier, whose compensation circuit must be designed so as to take into account the operating conditions of the converter.

For the study of the configuration of the PFC boost converter controlled by the average current method, the Matlab / Simulink model of the circuit in Fig. 5 has been conceived. The structure of this model is presented in Fig. 14.

The parameters for which the study was done by simulation on the above model of this PFC boost converter are: $U_{ac}$ = 40 V (RMS), $L$ = 3 mH, $C_o$ = 10,000 μF, $U_{ref}$ = 100 V, $R_L$ = 100 Ω. The resistor $R$ in the model is the ohmic resistance of the inductance $L$. The frequency of the triangular wave generator is $f_{tr}$ = 10 kHz. With these parameters, the shape of the current absorbed from the power supply is shown in Fig. 15.

Following the Fourier analysis of this current, it was possible to graphically represent the harmonic spectrum of this current, which is presented in Fig. 16.

The amplitude of the fundamental is, in this case, $A_1$ = 3.714 A. Harmonics of order higher than 50 are insignificant, up to around 200, a value that corresponds to the triangular carrier frequency (10 kHz).

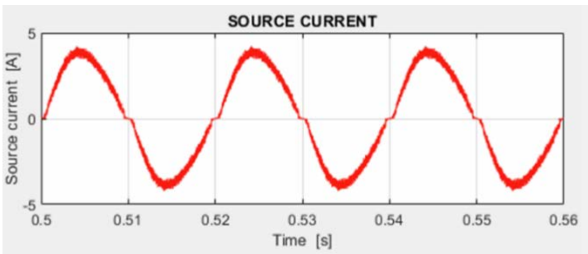


Fig. 15. The evolution over time of the current absorbed from the power supply by the PFC boost converter.

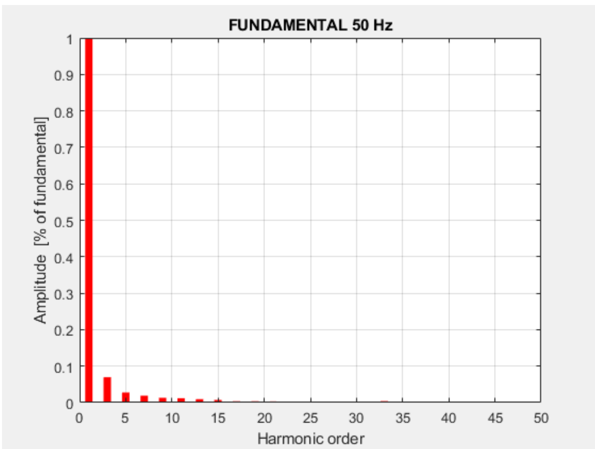


Fig. 16. Harmonic spectrum of the current in Fig.15.

Following the simulation study on the model in Fig.14, the following values were determined: $PF$ = 0.9925 and $THD$ = 0.095. The higher $THD$ factor value in this case is explained by the fact that the amplitude of the higher order harmonics is higher in the case of the boost converter, compared to the direct converter.

In order to highlight the importance of tuning the reaction loops, Fig. 17 illustrates the voltage $U_{dc}$ obtained at the output of the rectifier, in comparison with the imposed reference voltage.

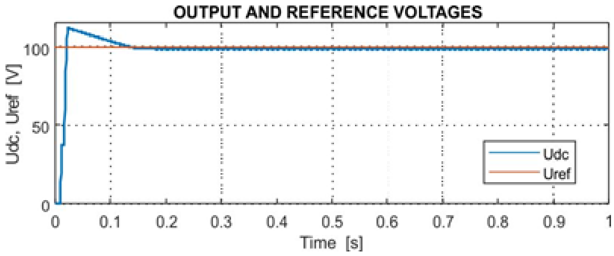


Fig. 17. $U_{dc}$ and $U_{ref}$ voltages.

According to this figure, the parameters of the feedback loops also determine the duration of the transient regime of the output voltage until reaching the prescribed value (in this case, the duration of the transient regime is about 0.15 s). During this transient regime, the output voltage is higher than the prescribed value.

## V. CONCLUSION

The comparative results of the study of the scalar control techniques applied to the single-phase rectifiers provided with PFC structures, can be summarized in Table I.

TABLE I

COMPARISON BETWEEN DIFFERENT PARAMETERS

| | Power Factor | THD | Current shape |
|---|---|---|---|
| Single Phase rectifier without PFC control | 0.445 | 1.614 | Pulsating |
| Single Phase full bridge PFC controlled | 0.99 | 0.03 | Sinusoidal |
| Single phase boost PFC controlled rectifier | 0.9925 | 0.095 | Sinusoidal |

By applying scalar control methods for power factor correction, it is possible for the value of the power factor to approach the unit, and in cases where the feedback loops are designed correctly, it can even reach the value of 1. Both scalar control variants are relatively simple to be implemented.

The first variant does not require the measurement of the input voltage $U_{ac}$, it requires the measurement of only the current flowing through the inductance of the power supply. The control method can also be applied to three-phase rectifiers. Following the study on the model, it was found that the method has the disadvantage of a certain degree of instability in various operating conditions.

The second method of scalar control, applied to a classic boost converter structure has the advantage of better stability when changing the operating parameters (especially the load value), of adjusting the $U_{dc}$ output voltage level according to the prescribed reference values, a spectrum of harmonics and a power factor comparable to those obtained by using the first method.

The disadvantage of implementing the second method is that the input voltage and current values in the boost converter circuit must be measured.

These drawbacks are offset by the fact that the switching losses of static switch are lower than in the first case, because instead of four contactors (which make up the rectifier bridge), only one switching device is used, the one that belongs to the boost structure, that is to the second stage of the converter.

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