NEURONAL CONTROL STRATEGIES FOR AC-DC CONVERTER WITH POWER FACTOR CORRECTION

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ABSTRACT

This paper deals with the study of two kinds of neuronal controllers applied to a AC-DC converter with power factor correction (Boost PFC): one with an average current mode whose realization is analogical and the other with classic structure whose neuronal controller is numerical. The total harmonic distortion (THD) is taken as criterion of evaluation as well as the regulation speed: the systems must respect standard IEC 61000-3-2. In both cases, the practical project of realization is taken into account. The simulation results showed the effectiveness of the two suggested methods.

Keywords: Nonlinear control, neuronal networks, boost PFC, total harmonic distortion, average current mode, LabView

1. INTRODUCTION

Although of lower cost, the traditional converter with capacitor and diodes generate generate harmonics in the network. These current harmonics can generate problems for the energy distributor (Feld 2009):

- Increase of line losses
- accelerated ageing of the condensers of compensation because of their low impedance: their rated current may be exceeded
- over sizing of the transformers of distribution

The rate of re-injection of these current harmonics can be quantified by the harmonic rate of distortion TDH.
The power-factor fp is defined by:

$$f_p = \frac{P}{S} = \frac{V.I_1.\cos\varphi_1}{V.I} = \frac{I_1.\cos\varphi_1}{I} \qquad (1)$$

With
S, P, indicating respectively, apparent power, active power
I, I_1,φ_1 : the effective value of the AC current, the effective value of fundamental of current, dephasing enters the tension and the fundamental current. The effective value of current is:

$$I = \sqrt{\left(\sum_{k=1} I_k^2\right)} = \sqrt{I_1^2 + \sum_{k=2} I_k^2} \qquad (2)$$

I_k , harmonic of current of rank k

The expression of the THD is also defined as:

$$TDH = \sqrt{\left(\frac{I_2}{I_1}\right)^2 + \left(\frac{I_3}{I_1}\right)^2 \ldots} = \frac{1}{I_1}\sqrt{\sum_{k=2} I_k^2} \qquad (3)$$

So, according to these three relations:

$$f_p = \frac{\cos\varphi_1}{\sqrt{1+TDH^2}} \qquad (4)$$

The power-factor **fp** is thus related to the harmonic rate of distortion TDH. It means that this TDH may be an adapted parameter to quantify the harmonic degree of pollution on the network. In all that follows, it will be taken as index of comparison (in practice TDH expressed in % is used).
With a purely sinusoidal fundamental current and in phase with the voltage, a power-factor approaches the unit value (fp = 1).

To bring solution of this problem, various strategies are proposed whose principal objectives are summarized as follows (Benaïssa 2006), ,(Tédjini 2008), (Singh 2003), (Keraï 2003), (Razafinjaka 2013):

- Obtaining a sinusoidal current network and in phase with the tension
- Or ensuring the smallest possible TDH in order to respect the standard normalizes: IEC-61000-3-2 for example for the systems of class D.
- Ensuring a voltage output constant Vs

There are several methods to obtain these objectives according the adopted model. The system is primarily non-linear because of the presence of the static inverter. However, in several cases, modeling the loop voltage as a system of first order is sufficient to obtain good results. In this case, it is assumed that the current loop is perfect. The basic scheme is given in figure 1.

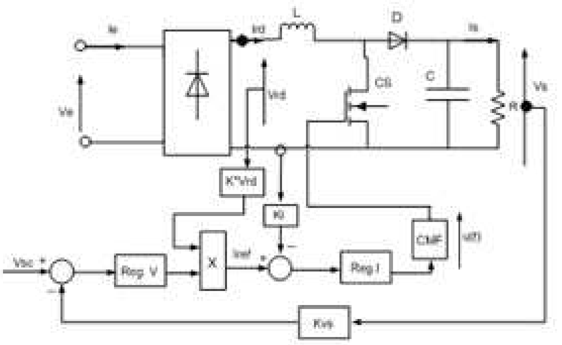

Figure 1: Structure of the boost PFC.

The existence of two loops is highlighted. The reference of the current Iref is obtained by multiplying the output voltage regulator by a party (K*Vrd) of the rectified voltage. The output current regulator is treated in a shaping circuit CMF to obtain the command u(t) used to control the static inverter CS.

In this paper, two kinds of boost PFC are proposed: the ACCM boost PFC and the classic boost PFC. For the study, the loop voltage is calculated assuming that the current loop is perfect.

Neuronal controllers are applied. The training uses the descent of gradient method with Levenberg-Marquardt algorithm. Obtaining simple solutions but effective in both cases is held in account. In all that follows, the structure given by Figure 1 is the reference. The current i_L which is equal to ired in the inductor L must follow in all time the current reference iref and it must not falls in zero as showed by Figure 2.

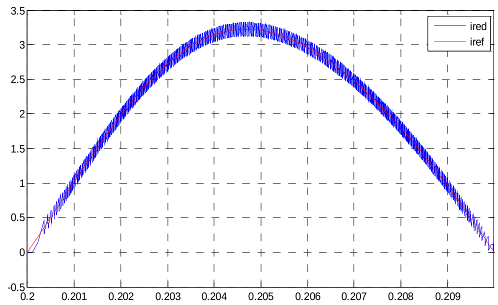

Figure 2: The current in continuous conduction mode

2. BOOST PFC WITH AVERAGE CONTINUOUS CURRENT MODE

Usually, the ACCM Boost PFC is used or high power (Abdel-Rahman 2013), (Dixon 1999) . Here, classic controller as PI is applied for the loop voltage and a neuronal controller is proposed for the current loop. To build the command d(t), several variables are taken in account : iref, Vrd and i_L.

The reference current iref is obtained by multiplying the output controller for the loop voltage with a part of the dressed voltage Vrd. The goal is to have a linear expression for the command u(t):

$$d(t) = a_3 i_L(t) + a_2 iref(t) + a_1 Vrd(t) + a_0 \qquad (5)$$

2.1. Neuronal controller

Here, the classic controller itself it is not to be identified in which case a dynamic network is necessary but the proposition is to identify directly the output d(t). To drive the converter static CS, this output is compared with a signal saw tooth to obtain u(t): it is the role of the shaping circuit CMF (figure 1).

The basic idea starts from a artificial neurons network which the structure is given according to figure 3.

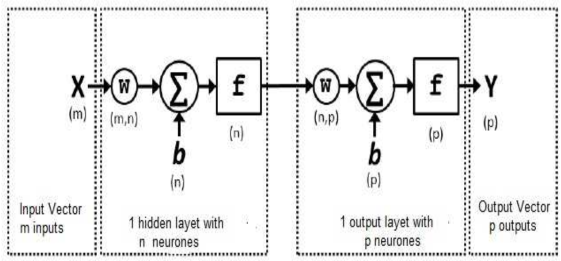

Figure 3: Neuronal network p outputs- m inputs

In our case, there are three inputs and one output. For the study, the followed choice is taken:

- Feed forward network
- Linear function for the activation function
- Type batch training using descent of gradient algorithm as Levenberg-Marquardt

The network used for the identification is so showed according figure 4.

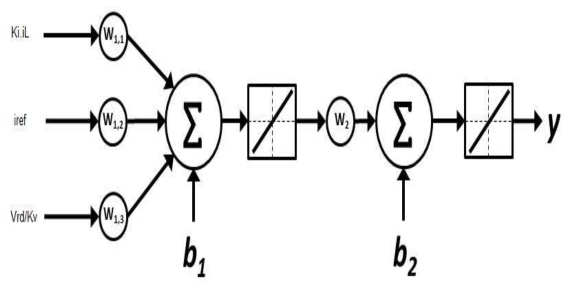

Figure 4: Network used for the identification

After training, a linear neurons network is found which output d(t) is as follow:

$$d(t) = w_2\left(w_{1,1} Ki.i_L(t) + w_{1,2}.i_{ref}(t) + w_{1,3}\frac{V_{rd}(t)}{Kv} + b_1 \right) + b_2 \quad (6)$$

- $w_{i,j}$: synaptic weight of the j^{th} input of the i^{th} neuron
- b_1 : first neuron bias
- w_2 : weight connection between the two neurons
- b_2 : second neuron bias

The relation (6) may be re arranged as:

$$d(t) = w_{iL}.i_L(t) + w_{iref}.i_{ref}(t) + w_{red}\frac{V_{rd}(t)}{Kv} + B \qquad (7)$$

When these different coefficients (weights) are identified, the relation (7) can be translated into analogical diagram using resistances and operational amplifiers as showed by Figure 5.

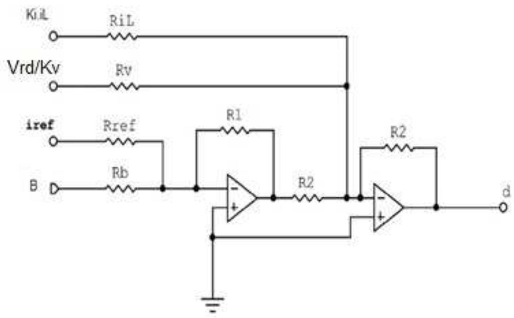

Figure 5: General scheme for a realization

2.1.1 Results

Simulation was made to test the system behaviour following a set value variation and application disturbance materialized by the variation of the load resistance. The total harmonic distortion (THD %) is also used as criterion of appreciation. The results are summarized in figures 6 and 7.

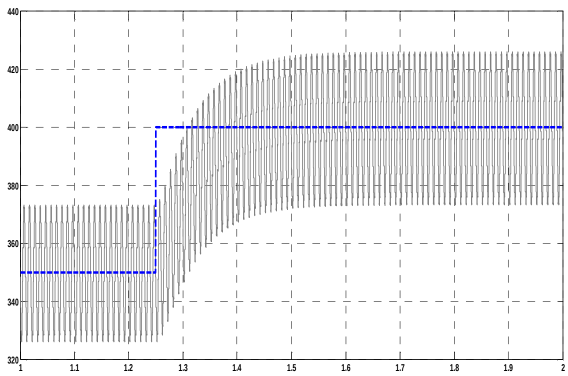

Figure 6: Output Vs response with set point variation

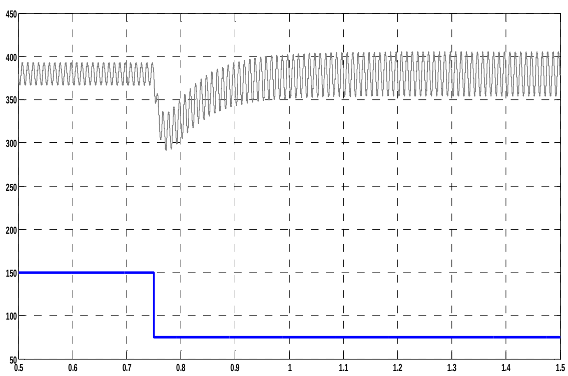

Figure 7: Behaviour by applying load disturbance

In figure 6, the set value is changed from 350[V] to 400[V] and in figure 7, the resistance load R is reduced for its half value (here at t = 0,75[s], R = 30 [Ω] ↓ R=15[Ω]). After Δt = 0,15 [s], the set value is reached and the steady state established.

The input current is sinusoidal and in phase with the input voltage as shown in figure 8. The THD is 5 %.

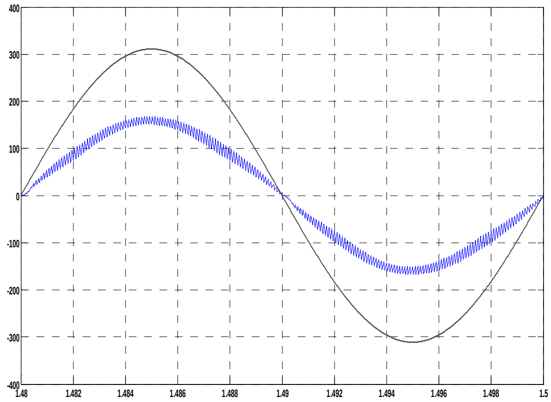

Figure 8: Input current and voltage curves.

2.1.2 Discussion

- The performance of the neural network increases with the number of examples used.
- The ratio of the chopping frequency and the line frequency has effect of the THD. The ratio

  $k = \frac{F_h}{F_L} < 1000$ is adopted ($F_L = 50$ [Hz])
- Changing the weight w_{red} has no effect on the THD. It has effect on the speed regulation.
- More the bias B moves away from the peak of the saw tooth signal, more the THD increases.
- When the absolute value of w_{iref} increases more the THD [%] decreases however, the CS commutation must be taken into account.

This phenomenon is shown in figure 9.

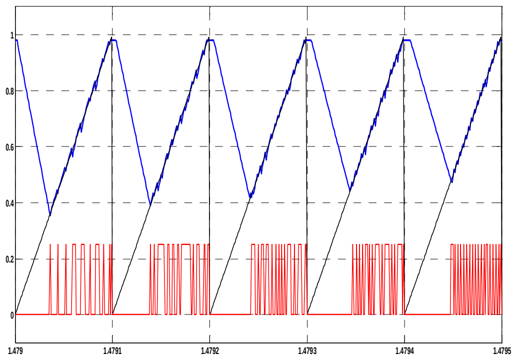

Figure 9: Different signal curves with d(t): blue saw tooth : black u(t): red

In all simulations made, the expression of d(t) according the relation 8:

$$d(t) = -3.K_i.i_L(t) + 5.i_{ref}(t) + \frac{4}{3}.\frac{V_{red}(t)}{Kv} + 12 \qquad (8)$$

Ki and Kv depend of the system.

3. CLASSICAL BOOST PFC

The basic scheme is always given by figure 1. In this case, a hysteresis command is applied for the current loop and an adaptive neuronal controller working as a discrete PI controller for the loop voltage. First, a classic PI controller is applied for the loop voltage. The method consists to design this adaptive neuronal controller by using the measures obtained when classic PI controller is used. It is assumed that the current loop is perfect when this hysteresis command is applied.

3.1. Current loop

The command using sinusoidal band hysteresis is chosen. The current i_L = ired crossing the inductor L is forced to stay in band ±ΔI around the reference as shown in figure 10.

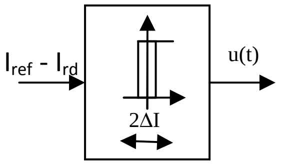

Figure 10: Hysteresis command

Chopping frequency F_H calculation is largely presented in literatures (Razafinjaka 2013), (Feld 2003), (Multon 2003). Its expression is:

$$F_H = \frac{V_M(V_s - V_M)}{2.L.\Delta i.V_s} \tag{9}$$

L, the inductor, V_M, RMS value of input voltage, Vs the output voltage and Δi , the current bandwidth

The inductor L must be designed to respect the chopping frequency F_H according the values of V_M, Vs and Δi. Figure 11 shows curves F_H vs L (V_M= 220V and Vs =400V)

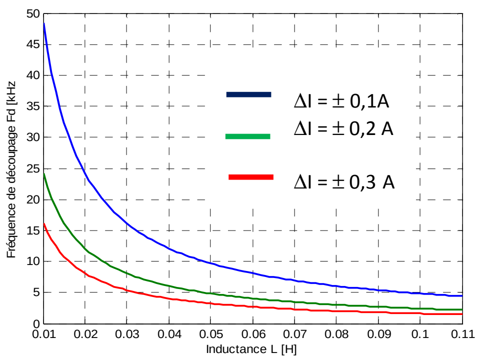

Figure 11: Curves F_H vs L

3.2. Voltage loop

It is assumed that the current loop is perfect (iref = ired). . It is there possible to adopt the following approximation obtained by modelling by assessment of power (Feld 2009), :

$$\frac{V_s(p)}{I_{red}(p)} \simeq \frac{V_s(p)}{I_{ref}(p)} \tag{10}$$

Hence,

$$\frac{V_s(p)}{I_{ref}(p)} = \frac{V_M}{4.V_s} \cdot \frac{R}{1 + p\frac{RC}{2}} \tag{11}$$

The opened loop is defined by a first order transfer function.

$$G(p) = \frac{K}{1 + pT} \tag{12}$$

With $K = \frac{V_M . R}{4 . V_S}$ and $T = \frac{R\ C}{2}$

A PI regulator is sufficient to control such system. Its function transfer may be expressed like followed:

$$G_R(p) = \frac{1 + pA.T_i}{pT_i} \tag{13}$$

The gain A and the constant time Ti can be determined by imposing a frequency Fc for the closed loop. The transfer function for opened loop Go(p) is:

$$G_0(p) = G_R(p).G(p) = \frac{K}{pT_i} \tag{14}$$

By using method compensation:

$$A.Ti = T \tag{15}$$

The transfer function for closed loop is:

$$H(p) = \frac{Go(p)}{1 + Go(p)} = \frac{1}{1 + p\frac{T_i}{K}} \tag{16}$$

Imposing frequency Fc according the relation (16) gives Ti and then the gain A by relation (15).

Figures 12, 13 and 14 show the simulation results when frequency at closed loop are Fc= 5 [Hz] and Fc=15[Hz]

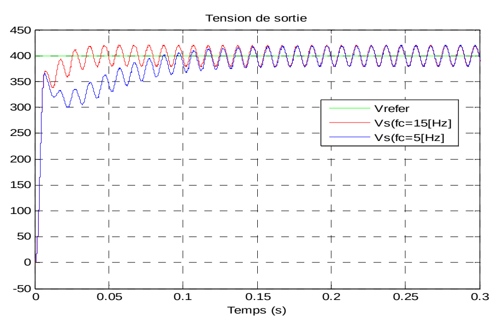

Figure 12: Curves giving Vs at Fc=5[Hz]- Fc=15[Hz]

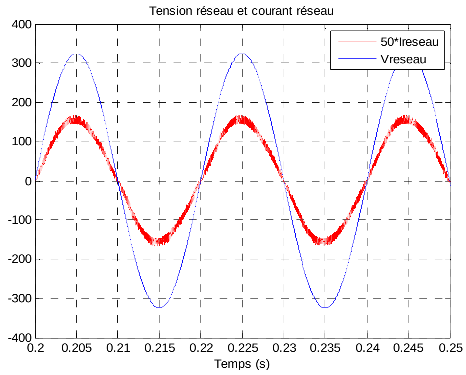

Figure 13: Current and voltage input at Fc = 5[Hz]

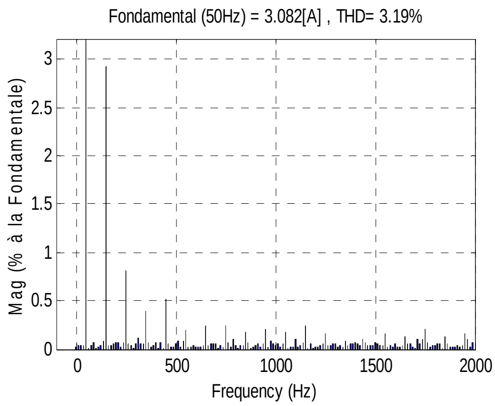

Figure 14: Spectrum current analysis at Fc = 5[Hz] THD= 3,19%

Following conclusions can be expressed:

- The current is sinusoidal and in phase with the voltage
- More the frequency loop is higher more the regulation is faster but the harmonic rate distortion of the current is higher
- F_c= 5 [Hz] TDH = 3,19%
  F_c = 15 [Hz] TDH = 7,62 %

In all that follows, the results obtained with Fc =5 [Hz] are chosen.

3.3. Neuronal controller for the loop voltage

As said below, an adaptive neuronal controller working as a PI controller is designed using the results obtained by the classic PI controller. In this context, an ADALINE network is chosen for the identification of the parameters using retro propagation algorithm with direct action. A structure of such network is given in figure 15.

The objective consists to identify the different values of the synaptic weights and bias. These values are stored as vectors to determine the two parameters K and Ki for the discrete PI controller (Nampoina 2010).

$$G_R(z) = K + \frac{Ki}{z-1} \qquad (17)$$

Figure 16 shows the structure of the adaptive neuronal controller built around the values of the weights and bias.

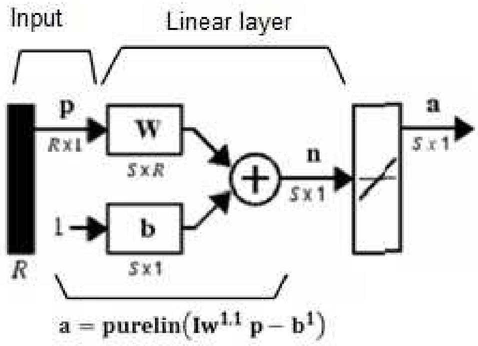

Figure 15: Structure of an ADALINE network

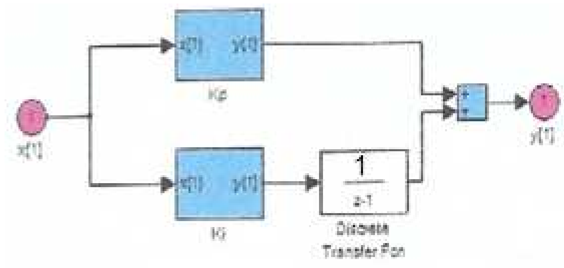

Figure 16: Adaptive neuronal controller implantation

3.3.1 Results

The values of different weights and bias are stored and used in all simulations. The results are presented in Figures 17, 18, 19 and 20.

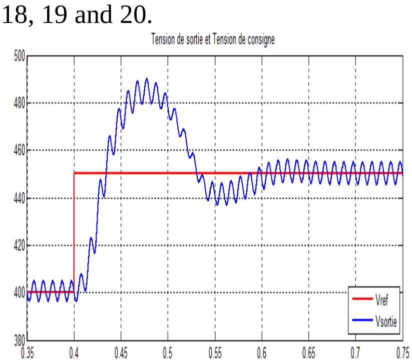

Figure 17: Response Vs with set point variation

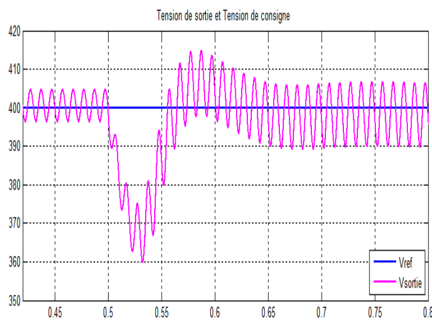

Figure 18: Behavior with load disturbance

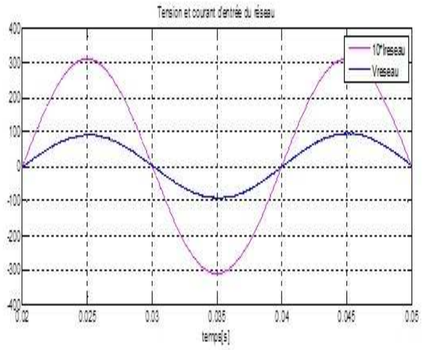

Figure 19: Current and voltage curves

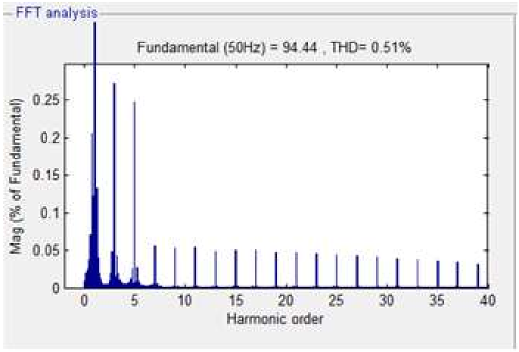

Figure 20: Spectrum current analysis

It is here highlighted that an overshoot D1= 8,9% appears with set point variation (Vsc = 400V → 450V). At t = 0,5 [s], a load disturbance is applied (R = 328 [Ω] → R = 164 [Ω]), the steady state is reached after Δt = 0,2 [s].

The regulation performances regulation is less than the classic one but the THD is largely improved. By the same method of calculation, here the total harmonic distortion is THD = 0, 51%.

3.4. Discussion

At first time, the training has generated N = 2, number of hidden layers. Several simulations are then adopted to find an optimal value of this number N by taking THD % as criterion. Figure 21 gives the variation of the THD vs N.

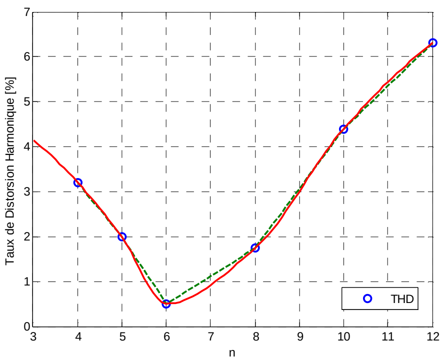

Figure 21: THD (%) vs. the number N

An optimal value $\hat{N} = 6$ is found and applied in the identification of the parameters.

CONCLUSION

In this paper, two kinds of neuronal controller are proposed. For the ACCM Boost PFC, the command d(t) is directly built for the current loop. For the classical Boost PFC, the hysteresis command is applied for the current loop and an adaptive neuronal controller is chosen for the voltage loop. Simplicity of realization are taken into account in both cases. The simulations show the feasibility of the methods and the efficiency of the neuronal controllers.

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