Optimized Fuzzy Variable Structure for a Three-Phase Rectifier with power factor correction

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Abstract:- This paper presents optimized fuzzy variable structure control design in a three phase rectifier to correct the power factor. This control strategy combines fuzzy and sliding mode control algorithms. Few fuzzy rules are used for this scheme. The parameters of the fuzzy controller are adjusted by using the VSC for a better response and robustness. To improve the behavior of the system is applied a gradient optimized method to find better matrix rule values. The simulations of the three-phase rectifier with controlled current are carried out on a DSP. The control scheme presented here offer higher robustness and it is easier to adjust and implement.

Key-Words: - Three-phase Rectifier, Fuzzy Control, Variable Structure Controller, Optimization.

1 Introduction

Three-phase rectifiers have a wide range of use and applications in the industry, from small rectifiers to large one. Basically, they are used to convert an AC input voltage to a DC voltage to feed a load. Three-phase rectifiers have received significant attention in recent years due to lower switch stresses, lower output ripple and better power factor. They are more expensive than single-phase converters but they can be used in high power applications.

There are many techniques for controlling and adjusting line current in three-phase rectifiers. An example is Vector Oriented Control (VOC) which corrects the current line vector direction with respect to voltage supply line vector [1][2][3][4]. Another method is line current indirect control, which is also known as instantaneous active and reactive power control or Direct Power Control (DPC) [5][6][7][8][9][10][11]. This work is based on line current control, where the orientation of line current vector is given by an optimized fuzzy variable structure. This has the advantage that the variable structure control is very simple to implement, rule matrices are given and additionally this kind of control offer higher robustness. The disadvantage is given due to processing that requires the rule matrix values optimization.

The variable structure control systems with sliding mode were introduced by Utkin in 1997 [11], however due to difficulties for its implementation it did not have enough attention at the beginning. Actually sliding mode controllers are used in a wide variety of applications. The main reason for its popularity is the attractive properties that it has; it is good acting in nonlinear systems and applicability to systems of Multiple Inputs and Multiple Outputs (MIMO) [13]. The most important property of the sliding mode control is its robustness and when VSC theory is applied the system becomes more insensitive to the parameters changes and to external disturbances. Control system based on fuzzy logic present similar operation to the variable structure control but it offers bigger robustness because operate under uncertainty and imprecision. However there is not a systematic procedure to design and adjust a controller however it depends of the knowing of the plant and that can be done by trial and error. Recently some researchers have showed the robustness advantage of the sliding mode control introduced into fuzzy controllers [14][15]

In this work it is proposed to carry out the control of the line current of a three-phase rectifier by means of an optimized fuzzy variable structure controller to maintain the rectifier line current in phase with the line voltage. It is used a Takagi-Sugeno fuzzy inference system which is optimized applying a gradient optimized method, this scheme allows a simpler adjustment with more robustness under disturbances and uncertainties.

This implementation is done on a digital signal processor (DSP) from Analog Devices (21061). The variable structure controller is applied to the line current, where the inputs to the fuzzy inference system are the switching function and its derivative.

The paper is structured as follows, in section 2 is described the system and the proposed control strategy, section 3 presents the experiment procedures and the control implementation, in section 4 are showed the results and finally the conclusions are presented in section 5.

2 System Description and Control Strategy

In this section it is described the system to be controlled as well the optimized fuzzy control strategy proposed.

2.1 Three-phase Rectifier

The three-phase rectifier with voltage output is observed in the figure 1, which is composed for three well-defined structures: a filter that consists of inductance in series with AC source, a three-phase bridge IGBT and a DC bus with its associated condenser.

To develop the mathematical model of the rectifier showed in figure 1, it is necessary to suppose that each phase of the rectifier can be represented as the circuit presented in figure 2 [9].

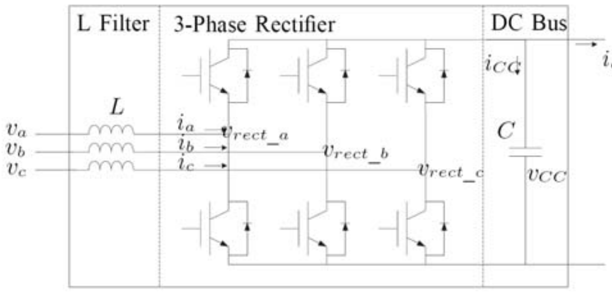

Fig. 1 Three-phase Rectifier

From the circuit in figure 2, it is obtained the equation for its simulation.

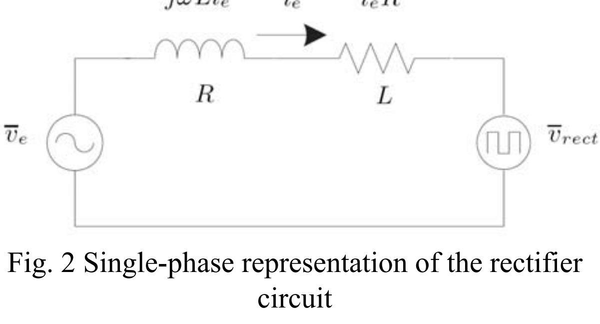

Fig. 2 Single-phase representation of the rectifier circuit

$$\bar{v}_e = R\bar{i}_e + L\frac{d\bar{i}_e}{dt} + \bar{v}_{rect} \tag{1}$$

The model of the rectifier bridge [13] in “abc” coordinates is given by equations (2) and (3).

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = R\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} v_{rect\_a} \\ v_{rect\_b} \\ v_{rect\_c} \end{bmatrix} \tag{2}$$

where the condenser charge equation is:

$$C\frac{dv_{CC}}{dt} = S_a i_a + S_b i_b + S_c i_c - i_o \tag{3}$$

There not a unique equation for the condenser charge [17]. The values of S_a, S_b and S_c can be one or cero, these variables represent the possible switching states.

Applying the Clarke Transformation (5) to the three-phase rectifier system, it is obtained the following differential equation model to be used for the simulations.

$$\begin{bmatrix} v_{ex} \\ v_{ey} \end{bmatrix} = R\begin{bmatrix} i_{ex} \\ i_{ey} \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} i_{ex} \\ i_{ey} \end{bmatrix} + \begin{bmatrix} v_{rect\_ex} \\ v_{rect\_ey} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} v_{ex} \\ v_{ey} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{5}$$

Knowing the voltage equation of the line (2), it is desired to transform the currents into “x-y” coordinates, the same procedure is done and it is represented i_a, i_b and i_c as i_{ex} and i_{ey}.

$$\begin{bmatrix} i_{ex} \\ i_{ey} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{6}$$

The equation of the condenser in “x-y” coordinates is:

$$C\frac{dv_{CC}}{dt} = \left(S_x i_{ex} - S_y i_{ey}\right) - i_o \tag{7}$$

where:

$$\begin{aligned} S_x &= \frac{1}{\sqrt{6}}\left(2S_a - S_b - S_c\right) \\ S_y &= \frac{1}{\sqrt{2}}\left(S_b - S_c\right) \end{aligned} \tag{8}$$

2.2 Variable Structure Control

The general focus of the control is the division of the phase plane, determined by the error and the change of error, in two semi-planes by means of a switching line, denominated sliding surface. The control output magnitude depends on the distance between the state vector and the switching line, being the objective to take the state vector until the switching line in a finite time where the dynamics is insensitive to the system parameters [18][19][20]. Then, let.

$$x^n = f(x,t) + u + d \tag{9}$$

Where x is the state vector, u is the controls variable and d are the disturbances. With:

$$f(x,t) = \hat{f}(x,t) + \Delta f(x,t) \tag{10}$$

A nonlinear function of the state vector, where Δf are uncertainties and $\hat{f}(x,t)$ an estimate of $f(x,t)$. Also it is assumed that the upper bound of the uncertainties is known.

$$|\Delta f| \le F \quad |d| \le D \quad |x_d^n| \le v \tag{11}$$

The function S which defines the sliding surface is given by:

$$S = \left(\frac{d}{dt} + \lambda\right)^{n-1} e \tag{12}$$

The tracking error is given by $e = x_d - x$. With x the state vector, x_d the desired vector and y λ a constant. The surface S=0 is defined as the sliding surface and represents the desired dynamics, which is invariant to parameters variations.

To guarantee that any state e can reach the sliding surface S=0 in a finite time, it is necessary to satisfy the Lyapunov stability criterion (13). Considering a Lyapunov function as:

$$V = \frac{1}{2} S^2 \tag{13}$$

$$\dot{V} = \frac{1}{2}\frac{d}{dt} S^2 \le -\eta |S| \tag{14}$$

Taking its derivate:

$$S \cdot \dot{S} \le -\eta \cdot |S| \tag{15}$$

Knowing that $S = |S| \operatorname{sgn}(S)$ then:

$$\dot{S} \cdot \operatorname{sgn}(S) \le -\eta \tag{16}$$

For a second order system:

$$\ddot{x} = f(x,t) + u + d \tag{17}$$

The surface S, is given by:

$$S = \dot{e} + \lambda e \tag{18}$$

$$\dot{S} = \ddot{e} + \lambda \dot{e} = \ddot{x}_d - \ddot{x} + \lambda \dot{e} \tag{19}$$

then,

$$\left(\ddot{x}_d - f(x,t) - u - d + \lambda e\right).\operatorname{sgn}(S) \le -\eta \tag{20}$$

To satisfy the stability equation and to get a sliding mode, a possible control variable can be given as:

$$u = u_{eq} + K \cdot \operatorname{sgn}(S) \tag{21}$$

where

$$u_{eq} = \lambda e - \hat{f}(x,t) \tag{22}$$

$u_{eq,}$ is the estimated equivalent control used to compensate the unknown system dynamics.

By substituting in (20):

$$W.\operatorname{sgn}(S) \le -\eta \tag{23}$$

where:

$$W = \left(\ddot{x}_d - f(x,t) + \hat{f}(x,t) - K \operatorname{sgn}(S) - d\right) \tag{24}$$

$$W = \left(\ddot{x}_d - \Delta f(x,t) - K \operatorname{sgn}(S) - d\right) \tag{25}$$

then

$$\left(\ddot{x}_d - \Delta f(x,t) - d\right).\operatorname{sgn}(S) - K \le -\eta \tag{26}$$

Then.

$$K \ge |\ddot{x}_d| + |\Delta f(x,t)| + |d| + \eta \tag{27}$$

Finally, taking the upper bound value.

$$K \ge F + D + v + \eta \tag{28}$$

The constant K is the maximum value of the control output and (28) indicates that if K is bigger than the addition of all the uncertainties, the system reaches the sliding surface and remains invariant to parameters variations and disturbances.

The sign function causes discontinuities to the control function, to avoid this change to the control signal, a boundary layer that contains the sliding surface is used, this introduce a smooth discontinuity to the control signal.

$$u = u_{eq} + K.sat\left(\frac{S}{\phi}\right) \tag{29}$$

where:

$$sat\left(\frac{S}{\phi}\right) = \begin{cases} \operatorname{sgn}(S) & |S| \ge \phi \\ \dfrac{S}{\phi} & |S| \le \phi \end{cases} \tag{30}$$

where ϕ the thickness as is shown in Figure 3 [19].

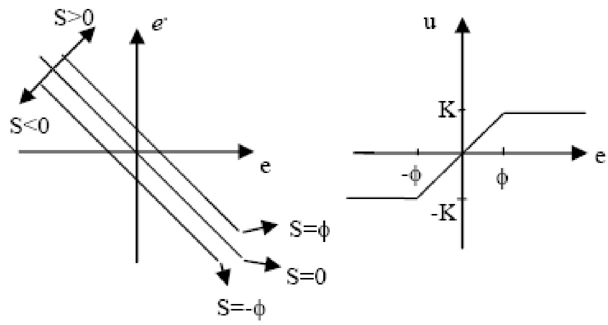

Fig. 3. Boundary layer and sliding control law.

The switching surface for an n order system is:

$$\sigma_{n-1} = \left(\frac{d}{dt} + \lambda \right)^{n-1} e \qquad (31)$$

This switching surface can be generated by a hierarchical method [19][20].

$$\begin{aligned} \sigma_1 &= \dot{e} + \lambda e \\ \sigma_2 &= \dot{\sigma}_1 + \lambda \sigma_1 \\ &\vdots \\ \sigma_{n-1} &= \dot{\sigma}_{n-2} + \lambda \sigma_{n-2} \end{aligned} \qquad (32)$$

Then the control law can be expressed by using the switching function $S_{n-1} = K\sigma_{n-1}$, as:

$$u = u_{eq} + K.\mathrm{sgn}\left(\frac{S_{n-1}}{\phi} \right) \qquad (33)$$

2.3 Fuzzy Variable Structure Control

Fuzzy controllers can be considered as variable structure controller due its similarity [19]. To observe this characteristic, it can be considered a fuzzy controller with an input S, output *u* and with a set of rules given as:

If (S is NL) Then (u is Nb)
If (S is NS) Then (u is Nm)
If (S is Z) Then (u is Zz)
If (S is PS) Then (u is Pm)
If (S is PL) Then (u is Pb)

Where NL Negative Large, NS Negative Small, Z Zero, PS Positive Small, PL Positive Large. And Nb Negative big, Nm Negative medium, Zz Zero, Pm Positive medium and Pb Positive big.

The membership function for S and its derivatives is given in Figure 4.

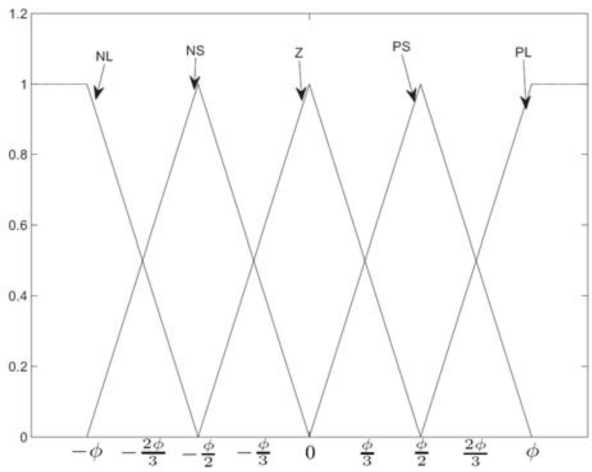

Fig. 4. Membership function of S

The input set S is mapped into an output set *u* by a fuzzy inference system. The relation between the output *u* and the input S is given as in Figure 5. This function is similar to a saturation function used by classical variable structure systems, but is generally a linear function by intervals as is shown in figure 3 If the number of membership functions is increased this becomes more linear [23]:

$$u = f\left(S\right) \qquad (34)$$

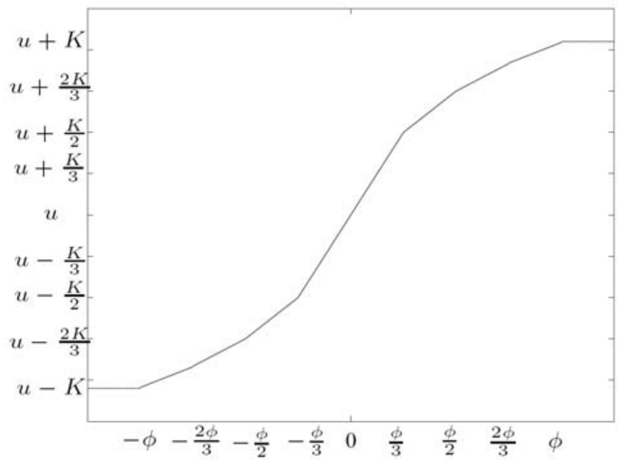

Fig. 5. Sliding control law.

The numbers of rules are defined from the input variable S, the error and its derivate can be variables to be used. The switching function can be defined as:

$$\begin{aligned} S\left(E,R\right) &= K_d(\lambda e + \dot{e}) = E + R \\ E &= K_d \lambda e = K_e e \\ R &= K_d \dot{e} \end{aligned} \qquad (35)$$

A representation of the fuzzy system is showed in Figure 6 and the rule-base is given in Table 1.

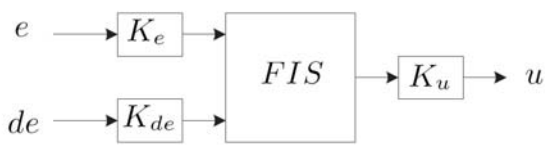

Fig.6. Block diagram of a fuzzy inference system.

Table 1. Rule-base for the fuzzy system.

$e\backslash\Delta e$	NL	NS	Z	PS	PGL
NL	Nb	Nm	Nm	Nm	Zz
NS	Nm	Nm	Nm	Zz	Pm
Z	Nm	Nm	Zz	Pm	Pm
PS	Nm	Zz	Pm	Pm	Pm
PL	Zz	Pm	Pm	Pm	Pb

Figure 7 shows the block diagram of a hierarchical method for a third order system as:

$$\sigma_1 = \dot{e} + \lambda e$$
$$\sigma_2 = \dot{\sigma}_1 + \lambda \sigma_1$$
$$S_2 = K_d \sigma_2 = K_d \left(\dot{\sigma}_1 + \lambda \sigma_1 \right) = E + R \quad (36)$$
$$E + K_d \lambda \sigma_1$$
$$R = K_d \dot{\sigma}_1$$

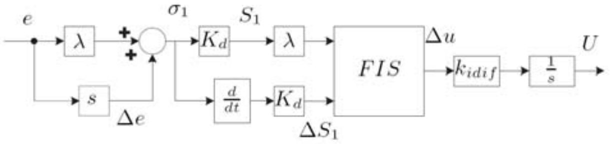

Fig. 7 Block Diagram of the Fuzzy Variable Structure

2.4 Gradient-based descent method

Gradient optimization methods search for a good one moving on the function in direction of the local gradient. The adjustment is carried out minimizing the error function between the answer and the wanted answer. The search of the minimum is carried out starting from the input-output data and minimizing the function of the error. But these methods based on the calculation have certain lack of robustness, due mainly of two causes. First, the exploration is carried out locally, this means that is searching to improve inside an environment of the current state and then in many cases can drift in a good local minimum. Second, it is necessary that the functions to optimize are derivable [23].

For a Takagi-Sugeno inference system the rules are given as:

$$R^i : If\ x_1^i\ is\ A_1^i \cdots x_n^i\ es\ A_n^i\ then\ y\ is\ b^i \quad (37)$$

where i=1…m.

The output is given by:

$$\alpha^i = \prod_{j=1}^{n} \mu A_j^i(x_j)$$
$$y = \frac{\sum_{i=1}^{m} \alpha^i \cdot b^i}{\sum_{i=1}^{m} \alpha^i} \quad (38)$$

The gradient method can optimize the consequent numbers b^i by using input-output data. This method adjust the values of b^i to minimize the objective function, this can be expressed as:

$$E = \frac{1}{2}(y_d - y)^2 \quad (39)$$

y_d: wished output.

To minimize the objective function:

$$\Delta b_k^i = -\eta \frac{\partial E}{\partial b^i}$$
$$\Delta b_k^i = -\eta (y_{dk} - y_k) \frac{\alpha_k^i}{\sum_{j=1}^{m} \alpha_k^j} \quad (40)$$

k=*1…K* (input-output data). The final value of b^i is given by:

$$b^i = b^i + \Delta b^i \quad (41)$$

3 Experimental Procedures

The parameters of the system to be simulated are shown in Table 2. The values used for these simulations are actual values used in a testing platform which is located in the SIEP laboratory at the "Universidad Simón Bolívar". The inductance value was designed for maximum power transmission between the supply line and the rectifier. The capacitance value is difficult to calculate for set DC voltage. The criterion to set the DC voltage is based on controlling the DC voltage to twice the voltage without controller. In other words, twice DC voltage in the diode bridge rectifier. In this work DC voltage is not controlled but it is checked in order to avoid it to increase without control.

To implement the control strategy it is necessary to make a rotational transformation (Park Transformation) with angle in which the three-phase system rotates. With $\omega t = 2\pi f t = 377t$ the current equation (5) is written as:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_{ex} \\ i_{ey} \end{bmatrix} \quad (42)$$

Table 2. Value of the rectifier parameters used for the simulation

Componentes	Valores
v_e	$120V$
R_L	100Ω
C	$4700\mu F$
L	$11{,}5mH$

It is known that the line voltage is given as:

$$v_a = K_e \sin(\omega t)$$
$$v_b = K_e \sin(\omega t - \frac{2\pi}{3}) \quad (43)$$
$$v_c = K_e \sin(\omega t - \frac{4\pi}{3})$$

Therefore the generation of the reference source currents [24] are:

$$i_a = k_{iref}\sin(\omega t)$$
$$i_b = k_{iref}\sin(\omega t - \frac{2\pi}{3}) \tag{44}$$
$$i_c = k_{iref}\sin(\omega t - \frac{4\pi}{3})$$

with, $k_{iref} = \frac{A}{K_e}$, this means that the power supply vector is normalized and then multiplied by a constant A, that is the current magnitude of the rectifier line. This current will limit the amount of power that the rectifier can supply. Also currents i_{d_ref} and i_{q_ref} are obtained by using expressions similar to equation (42).

The current components in "dq" coordinates are constants, this makes easier to implement any control strategy.

3.1 Fuzzy Variable Structure Controller for Current

In this case the variable structure scheme is shown in figure 7, where the value of K_d is 5 and λ is 2.

From this variable structure are obtained the input variables of the fuzzy inference system. These inputs variables are the switching function and its derivative which are calculated from the direct and quadrature component. The algorithm to implement the fuzzy inference system to the plant is done in 3 steps.

Step 1: Here are defined the inputs membership functions, each one are divided in 5 subsets: NL, NS, Z, PS and PL, this is shown in figure 8.

Step 2: Fuzzy rules are defined in Table 1.

Both fuzzy inference system use the same rules, where Nb=-10, Nm=-1, Zz=0, Pm=1 and Pb=10.

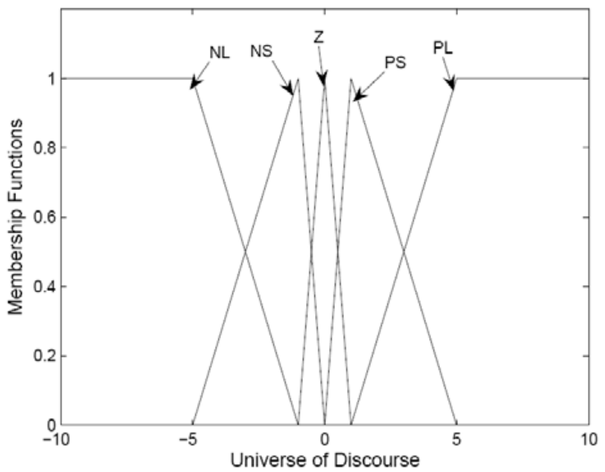

Fig. 8 Input Membership Functions

Step 3: The fuzzy inference system is chosen; in this case Takagi-Sugeno is used. Then the output is given as:

$$u = \frac{\sum_{i=1}^{N} \omega_i z_i}{\sum_{i=1}^{N} \omega_i} \tag{45}$$

with

$$\omega_i = \mu_{A_i}(e)\mu_{B_i}(\Delta e) \tag{46}$$

The output of the fuzzy inference system is integrated in order eliminate transient response:

$$u(t+1) = \left(u(t) + \Delta u(t)\right) * k_{idif} \tag{47}$$

where k_{idif} = 1 y a integral constant.

3.2 Conclusion Optimization

To carry out the optimization of the consequence, the following algorithm is applied to the fuzzy inference system for the direct and quadrature current.

$$\begin{aligned} b_d(i,j,t+1) &= b_d(i,j,t) + \Delta b_d(i,j,t) \\ \Delta b_d(i,j,t) &= -\eta\left(u_{dif\_d}(t) - u_{PI\_d}(t)\right)\alpha(i,j,t) \\ b_q(i,j,t+1) &= b_q(i,j,t) + \Delta b_q(i,j,t) \\ \Delta b_q(i,j,t) &= -\eta\left(u_{dif\_q}(t) - u_{PI\_q}(t)\right)\alpha(i,j,t) \end{aligned} \tag{48}$$

where η= 0.01, $i \in [0,4]$, $j \in [0,4]$, sub indexes i and j indicates the rule at the rule matrix due the switching function and its derivative.

Signals $u_{dif\_d}(t)$ and $u_{dif\_q}(t)$ are the integrated control signals for each one of the fuzzy inference system. Signals $u_{PI\_d}(t)$ and $u_{PI\_q}(t)$ are the output of a classic PI control used as a teaching signal. The control signals are given as:

$$\begin{aligned} u_{dif\_d}(t) &= v_{rect\_d}(t) \\ u_{dif\_q}(t) &= v_{rect\_q}(t) \\ u_{PI\_d}(t) &= v_{PI\_d}(t) \\ u_{PI\_q}(t) &= v_{PI\_q}(t) \end{aligned} \tag{49}$$

Figure 9 shows then the overall control scheme for the three-phase rectifier with the fuzzy variable structure controller and the optimizer.

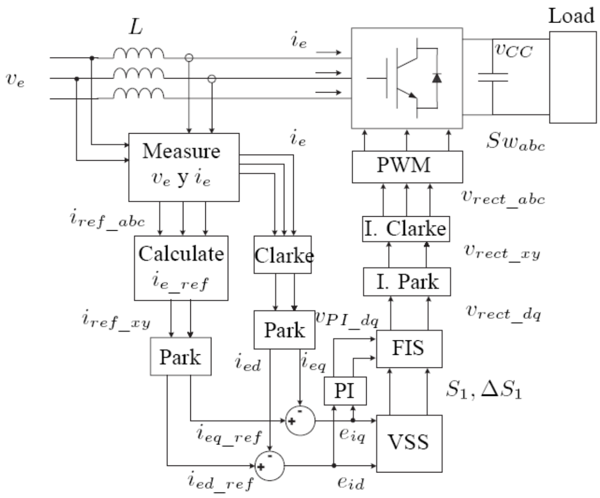

Fig. 9 Control Scheme for the Current

The look-up table after the optimization is showed in table 3.

Table 3. Rule Base Table for the PI Fuzzy Controller.

$e\backslash\Delta e$	NL	NS	Z	PS	PL
NL	-29.01	-17.00	-17.01	-14.09	-0.01
NS	-16.04	-16.01	-14.01	-0.009	14.91
Z	-15.00	-13.09	0.01	14.01	15.01
PS	-13.01	0.009	14.09	15.00	16.19
PL	0.01	15.01	15.07	16.10	31.09

The values were taken Nb=-30, Nm=-15, Zz=0, Pm=15 and Pb=30.

4 Results

As it was indicated before, this work proposes the current control of a three-phase rectifier. The source current that is presented in "abc" coordinates must be changed to "xy" coordinates using Clarke transformation method and then to "dq" coordinates by Park transformation. After this transformation the current reference is constant due the system is rotating at ωt.

The amplitude of the reference current is set to K_{iref}=15A, which is changed at t=0.1sec to K_{iref}=30A, as it is noticed the reference change is 100% to test the system response. Then:

$$i_a = 15\sin(\omega t)$$
$$i_b = 15\sin(\omega t - \frac{2\pi}{3}) \qquad (50)$$
$$i_c = 15\sin(\omega t - \frac{4\pi}{3})$$

After, using Park transformation i_{ex} and i_{ey} are transformed to i_d and i_q, where $i_d = 18A$ and $i_q = 0A$ for $k_{iref} = 15A$. For $k_{iref} = 30A$ the currents have the following values, $i_d = 37A$ e $i_q = 0A$.

This simulation is carried out with the fuzzy variable structure controller optimized and non optimized.

In figure 10 is shown the line current waveform when the system has a capacitive load. It is shown the line current from phase A and the desired reference current.

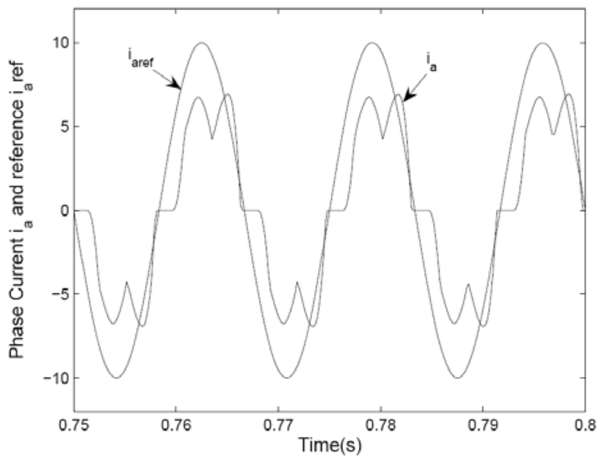

Fig. 10 Line Current from phase A and its reference

4.1 Fuzzy Variable Structure Controller

In this case the results of the simulations are presented in figure 11, where direct current and the reference are showed.

It can be noticed that the current reaches the set point in less than t=0.02 sec and with an overshoot of 7A. After, the set point is changed and the system is able to follow it with no overshoot and a settling time of 0.02 sec.

In figure 12 is showed the quadrature current and its reference. At the beginning an undershoot of 2.2A and an overshoot of 1A with a settling time less than 0.025 sec and a small steady state error. Then at t=0.1 sec it is applied the reference change, but it can be observed that the quadrature current has almost no variation, less than 0.05A during a period of 0.02 seconds.

Finally, in figure 13 is presented the line current from the phase A and its reference. The line current is completely synchronized with its reference and reach the same magnitude at t=0.02 sec. This is due to the small error that the direct and quadrature current presents at this time.

When the reference is changed, there is not overshoot in the response because the direct current did have not either, but it takes also 0.02 sec to reach the reference value.

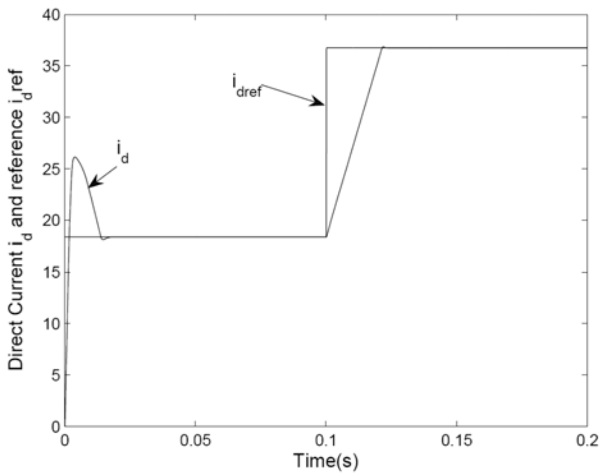

Fig. 11 Direct Current (i_d) and Reference Current (i_{ref})

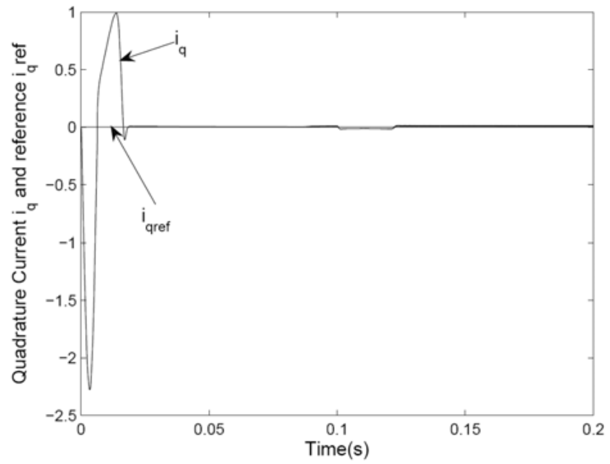

Fig. 12 Quadrature Current (i_q) and its Reference (i_{qref})

4.1 Optimized Fuzzy Variable Structure Controller

The direct line current and its reference are shown at figure 14. The current response presents an overshoot of 4A without oscillations. The settling time is less than 0.01 sec and it does not show steady state error. It is applied the change at the reference and the system can follow the reference without overshoot. The response is faster than the precedent experiment and without steady state error.

Figure 15 show the quadrature current and its reference, it presents an undershoot of -0.25A with a settling time less than 0.01 sec. At t=0.01 is introduced the reference change and the quadrature current shows a small error of 0.1A which it is not to significant.

The line current from phase A and its reference are shown in figure 16. The line current is in completely in phase with the reference having the same magnitude of the reference at t=0.01 sec.

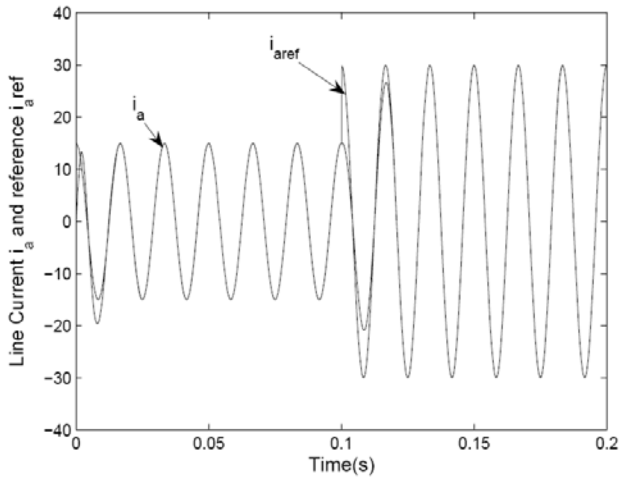

Fig. 13 Line Current from phase A and its reference

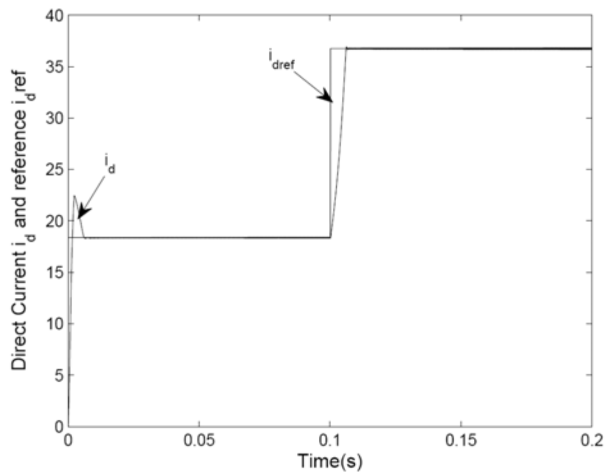

Fig. 14 Direct Current (i_d) and its Reference (i_{ref})

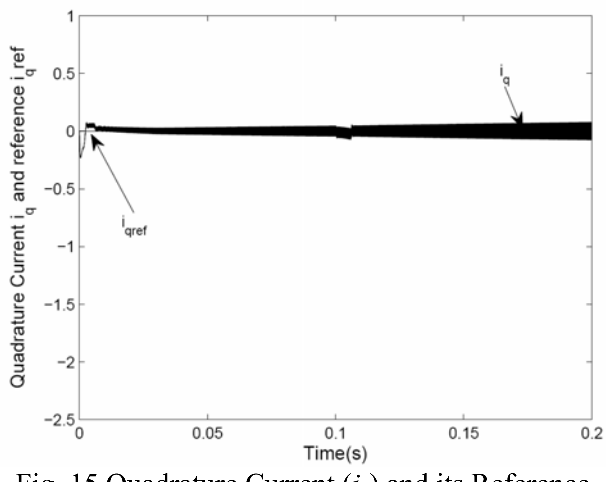

Fig. 15 Quadrature Current (i_q) and its Reference (i_{qref})

Is easy to see that the fuzzy optimized variable system achieved better results than the fuzzy variable structure one.

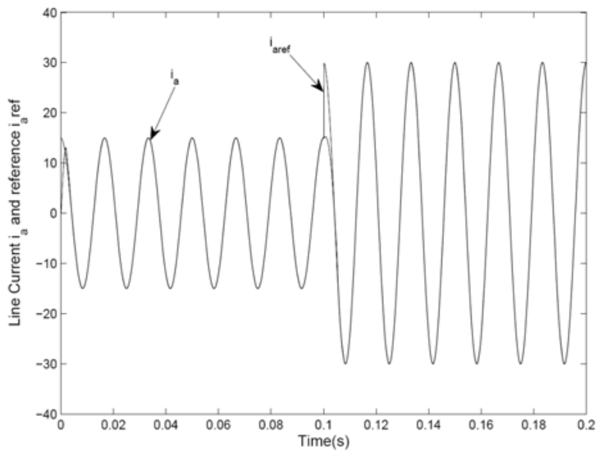

Fig. 16 Line Current from phase A and its reference

5 Conclusions

There were carried out the simulations of a three-phase rectifier system with current control using a variable structure controller scheme. It was shown that it is possible to control the currents by using a "dq" transformation and then controlling the direct and quadrature components as if were independent components. What happens, it is that although they are orthogonal components the variation of the direct current affects indirectly to the quadrature current and vice versa.

Additionally to this, it was implemented an optimization algorithm of the consequences based on the stochastic gradient method to the variable structure controller.

It was shown that a second order system can be controlled with a third order variable structure controller to obtain improvements due to that presents a higher degree of liberty that allows to carry out a better tuning of the controller.

It was showed that the simulations carried out optimized rules present an improvement to the rules obtained by the knowledge and the experience of the designer. It was possible to reduce the overshoot almost in a 50% and the response time was quickly.

Finally, it can be observed that both, the optimized control algorithm and the non optimized one were able to compensate the displacement factor to one. Either there were applied changes to the line current reference, in both cases the line current and voltage remained in phase.

Among other advantages the control processing is performed on a DSP, which is dedicated only to perform the operations of the control strategy proposed, being this faster. In addition, the way that system has been modeled and simulated is easy to implement in SIEP platform. It is not necessary to make any changes to the control, just some changes to sensing signals and output signals (control variable). The DSP must only be connected to the platform to perform the experimental testes.

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