Fuzzy Model Reference Adaptive Control **of power converter for unity power factor and harmonics minimization**

M.T. Benchouia*,A.Ghamri*, M.E.H. Benbouzid,**, A. Golea*, S.E. Zouzou*
*Laboratory L.G.E.B., Department of Electrical Engineering, Biskra University, Algeria
benchouiat@yahoo.fr
**Laboratory L.I.M.E., Department GEII – IUT, Brest University, France
m.benbouzid@ieee.org

***Abstract*-The absorbed current by the converter is rich in harmonics. This provokes the disruption of the network and influences on the consumers joined to the same node. On the other hand, because of its structure and of the absence of the degree of liberty in the control, the converter consummates a reactive power. In order to minimize the harmonics of side network, several techniques of passive filtering and/or active are used. He is more economical of using some filters set in resonance to the frequency of the harmonic to eliminate. In the exercises, the passive filters have some inconveniences this who renders the delicate conception. For it, we interest us only to the active filtering. The aim of this paper is of understating the harmonics of side network and optimizing the exchange a reactive energy between the network and the converter, including the control of power factor and DC-link voltage using Fuzzy Model Reference Adaptive controller (FMRAC).**

I. Introduction

Industrial and domestic equipments actually use a large variety of power electronic circuits such as switch mode power converters, adjustable speed drives, rectifiers or dimmers. These ones lead to significant energy savings and productivity benefits. But unfortunately, they also present non-linear impedance to the supply network, and therefore generate non-sinusoidal currents. The outcome of these wide-band current harmonics includes substantially higher losses for the transformers and the power lines, possible over voltages and overheating destroying equipments, and disturbances of communication equipments and precision instruments [1], [2]. So, it is necessary to develop techniques to reduce all the harmonics as it is recommended in the CEI-1000-3-2 standard. The first approach consists in the design of LC filters. But, passive filters are not well adapted as they do not take into account the time variation of the loads and the network. They can also lead to resonance phenomena. So, since several years, a more interesting technique is studied: the active filter based either on voltage source or on currents source inverters yielding the harmonic currents needed by the load [3], [4], [5]. However, their control needs to use automatic control theory to improve their efficiency.

Fuzzy control technique has been successfully applied to the control in recent years. This strategy was proposed by Zadeh in 1965 to describe complicated systems which are hard to analyze using traditional mathematics; it's only since the 1970's that fuzzy logic theory has found wide popularity in various applications such as economics, management, medicine, or process control.

Indeed, Mamdani and al. were the first to report on the application of fuzzy set theory to control a small laboratory steam engine. The success of this study led many scientists to attempt to control industrial processes such as chemical reactors, automatic trains, or nuclear reactors using fuzzy algorithms. The results of these experiments showed that fuzzy controllers perform better, or at least well as, adaptive controllers [6], [7]. Moreover, this technique offers the advantage of requiring only a simple mathematical model to formulate the algorithm, which can easily be implemented by a digital computer. These features are appreciated for nonlinear processes for which there is no reliable model and complex systems where the model is useless due to the large number of equations involved. Additionally, fuzzy logic control strategy is used more frequently for the control of electrical machines such as DC or induction motors [7], [8]. Nevertheless, the main problem with fuzzy logic is that there is no systematic procedure for the design of fuzzy controller [9], [10].

In this paper, fuzzy logic theory is applied in regulation loop, in order to minimize harmonics introduced by the line converter, including the control of power factor and DC-link voltage.

II. Circuit Configuration

The proposed system configuration is shown in Fig. 1. It's composed by rectifier flowed by nonlinear load. A bridge rectifier made up of six power transistors with inverse parallel diodes is used in the main circuit to achieve bidirectional power flow capability. The left side (input) bridge, connected to supply through impedance Z_s composed of R_s, L_s representing the ac side resistance and inductance is operated to absorb sinusoidal current, in phase with the line voltages. In order to obtain fast response of the input converter, an hysteresis current control technique can be adopted, which ensures that each line current follows its reference with minimum error (within the hysteresis band Δi) and with minimum delay. In order to maintain dc link voltage V_c, irrespective of reference V_{cref} and load variations, a closed loop is introduced. Voltage V_c is filtered by the low pass filter to obtain its average. The output of the filter is compared with its reference V_{cref} and resulting error signal is fed to fuzzy logic controller which provides the control signal I_{ref}. The reference current (I_{ref}) is multiplied by three equilibrates sinusoidal signals, of amplitude unit at the frequency of the network and in phase with the supply voltages. The instantaneous and reference currents are compared and the error signals are generated from which the comparators with hysteresis produce the trigger pulses of the transistors [10].

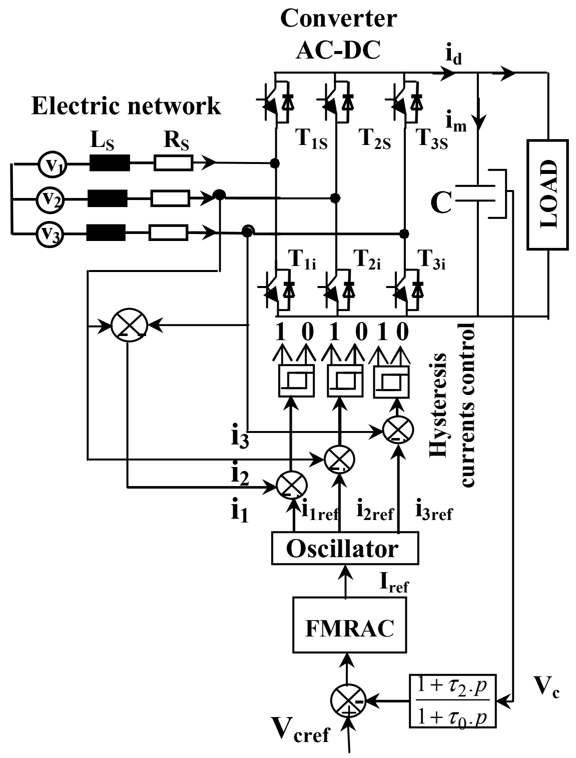

Fig.1. Main circuit with proposed control system.

III. Fuzzy Model Adaptive Controller

A. Classical Fuzzy Control

A typical topology of FMRAC voltage controller is shown in fig.2, [11].The FLC is constituted by three stages: fuzzification, rules execution and defuzzification. The rule base is the principal component of the fuzzy controller; it indicates how the controller behaves to response to any input situation. The rule base is constituted by collection of If-Then rules of the form:

$$\textit{If } e_v(k) \textit{ is } A_j \textit{ and } \Delta e_v(k) \textit{ is } B_j \textit{ Then } I_{ref}(k) \text{ is } C_j \quad j = 1..M \tag{1}$$

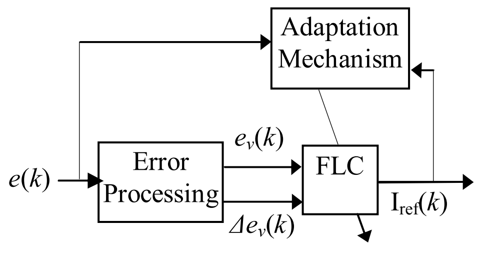

Fig.2. FMRAC structure.

where A_j, B_j and C_j are fuzzy sets such as: NL (negative large), NM (negative medium), etc. defining fuzzy partition on the controller input space (fig. 3), and $e_v(k)$ and $\Delta e_v(k)$ are scaled and normalised version of the error $e(k)$ and the change of error $\Delta e(k)$ given by:

$$e(k) = v_{cf}(k) - v_{cref}(k)$$
$$\Delta e(k) = e(k) - e(k-1) \tag{1}$$

$$e_v(k) = \mathrm{g_e}.e(k)$$
$$\Delta e_v(k) = \mathrm{g_{\Delta e}}.\Delta e(k) \tag{2}$$

The expression "$e_v(k)$ *is* A_j" is implemented by membership function indicating the grade of membership of $e_v(k)$ in the fuzzy set A_j as in fig. 3, this operation is called fuzzification. The shape of the membership function is quite arbitrary and depends on the user's preference. For simplicity, triangular and trapezoidal shapes are usually used. The rules are derived from engineer experience or created automatically by adaptation procedure.

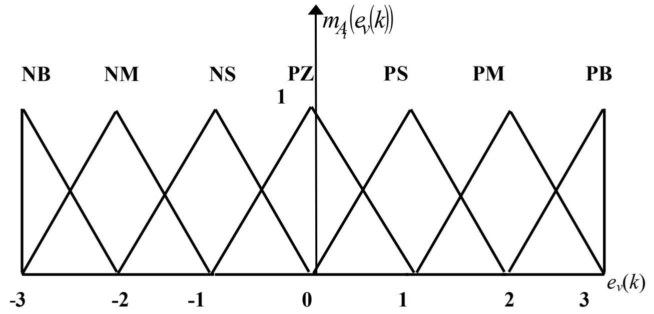

Fig.3. Membership functions.

The logical operators "*and*" and "*Then*" can be interpreted as *min* or algebraic product, and various inference and defuzzification algorithms can be used to produce crisp output value [8], [9]. If the operators "*and*" and "*Then*" are implemented as algebraic product, the max-product inference and the centroid defuzzification algorithms are used, then the crisp value of the controller output is:

$$I_{ref}(k) = \frac{\sum_{j=1}^{M} m_{A_j}(e_v(k)).m_{B_j}(\Delta e_v(k)).c_{0j}}{\sum_{j=1}^{M} m_{A_j}(e_v(k)).m_{B_j}(\Delta e_v(k))} \tag{4}$$

where c_{0j} is the centre of the membership function of the fuzzy set C_j, such that $m_{C_j}(c_{0j}) = 1$. The above equation can be written as:

$$I_{ref}(k) = \sum_{j=1}^{M} m_j(k).c_{0j} \tag{5}$$

where $m_j(k)$ is the normalised degree of contribution of the jth rule to the controller output given by:

$$m_j(k) = \frac{m_{A_j}(e_v(k)).m_{B_j}(\Delta e_v(k))}{\sum_{j=1}^{M} m_{A_j}(e_v(k)).m_{B_j}(\Delta e_v(k))} \tag{6}$$

then (6) can formulated in the following matrix form:

$$I_{ref}(k) = \mathrm{m}(k).\theta \tag{7}$$

where

$$\mathrm{m}(k) = [m_1(k) \quad m_2(k) \quad \cdots \quad m_M(k)] \tag{8}$$

and

$$\theta = [c_{01} \quad c_{02} \quad \cdots \quad c_{0M}]^T \tag{9}$$

B. Adaptation Mechanism

When the qualitative knowledge used to construct the rule base is false or incomplete, and then the controller can't drive correctly the machine to the desired performance. More if the rule base is static (i.e, fixed rules), the controller can't cope with variations of the environment and the parameters of the machine. In those cases a mechanism of adaptation must be added to correct and complete the rules. In the FMRAC, the adaptation mechanism adjusts at each sample t the fuzzy controller output (i,e. the rules consequences parameters θ)to move them in the direction that minimises the following criterion[11]:

$$J(t) = e^2(t) \tag{10}$$

Then the gradient algorithm can be used to move the parameters values in the direction of the minimum of J(t). The parameters adaptation can be done using the following usual formula:

$$\theta(t+1) = \theta(t) - \gamma \frac{\partial J(t)}{\partial \theta(t)} \tag{11}$$

where γ is the learning step size.

The adaptation algorithm (11) involve the computation of the partial derivatives of $J(t)$ with respect to θ, which is given by:

$$\frac{\partial J(t)}{\partial \theta} = -2e(t)\frac{\partial V(t)}{\partial \theta(t)} \tag{12}$$

Because, no direct relation exists between $V(t)$ and $\theta(t)$, the expression (12) can be transformed as:

$$\frac{\partial J(t)}{\partial \theta} = -2e(t)\frac{\partial V(t)}{\partial I_{ref}(t)}\frac{\partial I_{ref}(t)}{\partial \theta(t)} \tag{13}$$

where

$$\frac{\partial I_{ref}(t)}{\partial \theta(t)} = (\mathrm{m}(t))^T \tag{14}$$

The expression (14) involves the computation of the gradient of $V(t)$ with respect to $I_{ref}(t)$. From the engineering qualitative experience, it is known that speed and torque vary in the same sense. Thus, this gradient can be approximated by some positive constant value. Because only the sign of the gradient is critical to the iterative algorithm convergence, the gradient value can be set simply to (+1). In this work, the gradient is approximated between tow samples by:

$$\frac{\partial V(t)}{\partial I_{ref}(t)} \approx \frac{V(t) - V(t-1)}{I_{ref}(t) - I_{ref}(t-1)} = \frac{\Delta V(t)}{\Delta I_{ref}(t)} \tag{15}$$

thus, the adaptation algorithm can be written as:

$$\theta(t+1) = \theta(t) + \gamma 2e(t)\frac{\Delta V(t)}{\Delta I_{ref}(t)}(\mathrm{m}(t))^T \tag{16}$$

Because the relation between the error and the parameters θ is linear, the mean squared error surface is quadratic. Then, the gradient algorithm is guaranteed to converge rapidly to the single global minimum. The implementation of the gradient algorithm is the same for each parameter and does not change as rules are added or removed from the FLC rule base. This means that the algorithm scales easily and the computational cost increases linearly with the number of rules.

IV. SIMULATION RESULTS

Simulation results for the control of DC output voltage and minimization of the line current harmonics with adaptive fuzzy controller are represented. The following parameters: V_{RMS} =220 V, Ls = 0.006 mH, C = 200 µF, Vcref = 440 V, τ_0 = 0.00025 s, τ_2 = 0.005 s, Δi = 0.5 A and sampling time Ts = 0.1 ms are used in simulation. Switch delay, dead times, on state voltages and snubbed network were neglected, unless the on-off behaviour of all semiconductors.

The results show: that the input current has a sinusoidal form and in phase with supply voltage (Fig.4.), witch minimizes the reactive power consumed by the rectifier (see Fig.5.). Fig.6. shows that the power factor is near unity (P.F = 0.98). Fig.7. and fig.8, illustrate respectively the spectrum of input current and supply voltage. It can be observed that the minimization of the current harmonics by FMRAC is achieved.

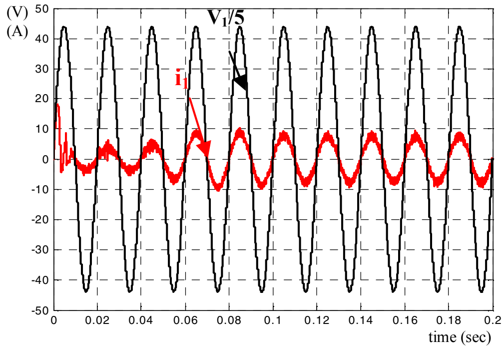

Fig. 4. Line voltage and supply current.

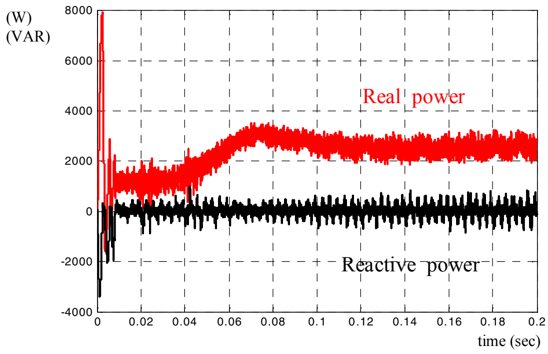

Fig.5. Input real and reactive powers.

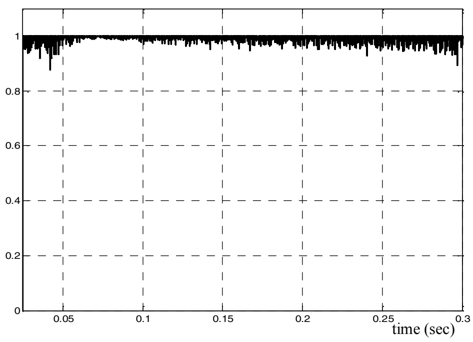

Fig. 6. Power factor.

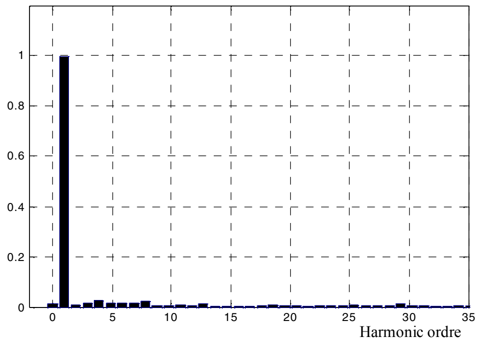

Fig. 7. Spectrum input current.

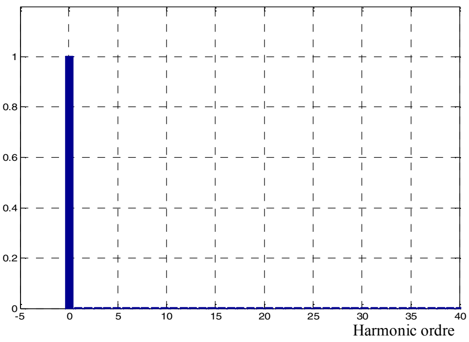

Fig. 8. Spectrum DC voltage.

To confirm the effectiveness of the proposed control, a step load torque has been applied between 0,15s and 0,25s (from 10 Nm to 15 Nm).Fig.9 shows that the line current is approximately sinusoidal. The rapid change of the line current shows that the system has a very good dynamic response to load variation, The reactive power is not affected by this external disturbance and input real power peaks are observed with a sign depending on the increasing or decreasing of step load torque (see Fig. 10).

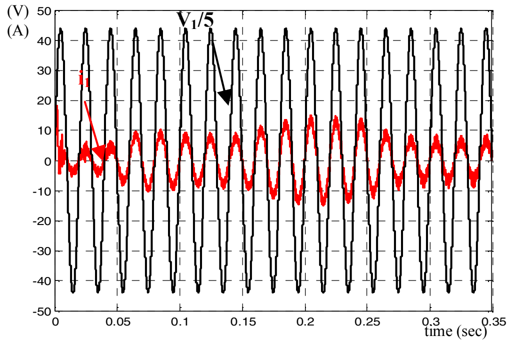

Fig. 9. Line voltage and supply current.

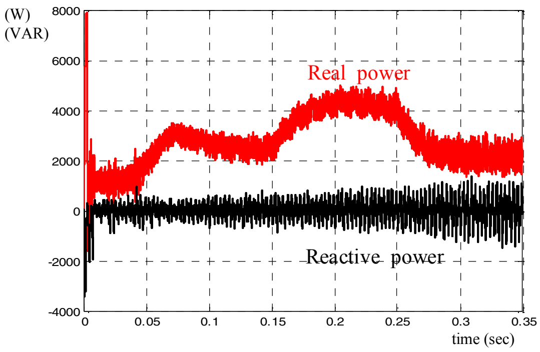

Fig.10. Input real and reactive powers.

V. Conclusion

In this paper, the Fuzzy Model Reference Adaptive controller is used to minimize harmonics of side network introduced by the converter, including the control of power factor and DC-link voltage. Several tests have been performed in order to prove the efficiency of the type of the control. Simulation results confirm the validity of this control technique. An experimental study on the proposed converter system is left for future studies.

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