

# A FUZZY LOGIC CONTROLLER OF THREE-PHASE SHUNT ACTIVE FILTER FOR HARMONIC CURRENT COMPENSATION

Kouadria Mohamed Abdeldjabbar, Allaoui Tayeb, Belfedal Cheikh  
Laboratory of Electrical and Computer Engineering (L2GEGI),  
Ibn Khaldun University, Tiaret, Algeria

## ABSTRACT

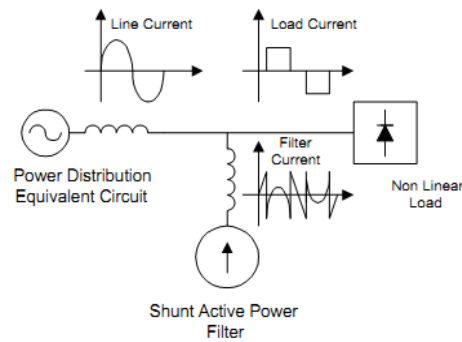
*Performance investigation of Shunt Active Power Filter for harmonic elimination is an interdisciplinary area of interest for many researchers. This paper presents performance improvement of 3-phase Shunt Active Power Filter (SAPF) with Hysteresis Current Control technique for elimination of harmonic in a 3-phase distribution system. The shunt active filter employs a simple method called synchronous detection technique for reference current generation. A proportional-integral (PI) and Fuzzy Logic Controller (FLC) are designed to adjust the parameters of the SAPF system. The proposed system has achieved a low Total Harmonic Distortion (THD) which demonstrates the effectiveness of the presented method. The simulation of global system control and power circuits is performed using Matlab-Simulink and Sim Power System toolbox. The simulation results presented demonstrate improved performance of the SAPF system with the proposed fuzzy logic control approach.*

**KEYWORDS:** Power quality, Shunt active filter, Synchronous Detection Method (SDM), hysteresis control, PI controller, Fuzzy logic controller, total harmonic distortion (THD).

## I. INTRODUCTION

Power Quality is a set of electrical limitations that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy [1]. The harmonics presence in the power lines results in varied problems, like, greater power losses in distribution; problems of electromagnetic interference in communication systems; and operation failures of protection devices, electronic equipments and, industrial processes. The Active filters have been recognized as a valid solution to harmonic and reactive power compensation due to the presence of non-linear loads. The principle of operation of active filters is based on the injection of the harmonics required by the load. An active filter generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling and forces the source current to be pure sinusoidal. As a consequence, the characteristics of the harmonic compensation are strongly dependent on the filtering algorithm employed for the calculation of load current harmonics [2]

The shunt APF is designed to be connected in parallel with the nonlinear load. It detects the harmonic current of nonlinear load and injects into the system a compensating current, identical with the nonlinear load harmonic current but in opposite phase. Therefore, the net current drawn from the distribution network at the point of coupling of filter and the load will be a sinusoidal current of only fundamental frequency[3][4]. The current compensation characteristic of the shunt active power filter is shown in Fig.1.

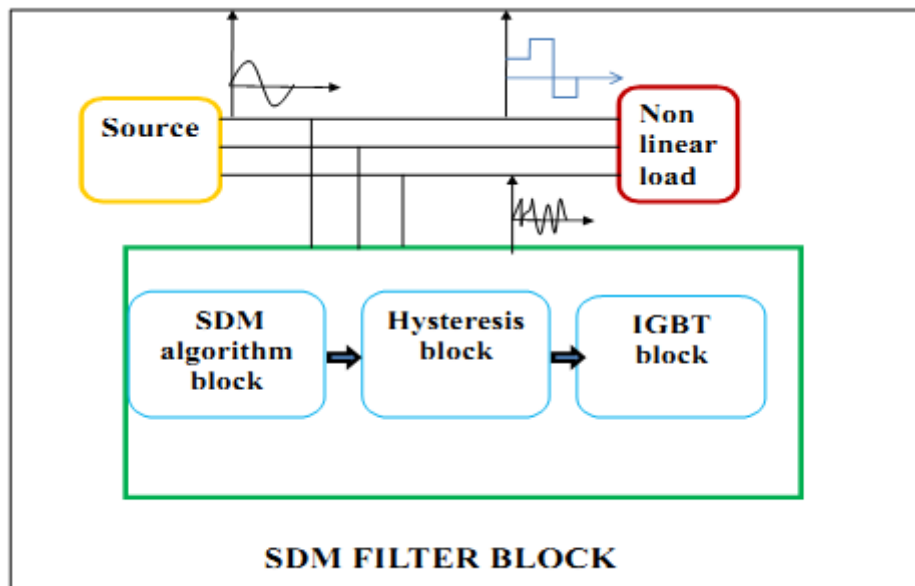


**Figure 1.** Compensation characteristics of a shunt active power filter

In the present paper, the three-phase shunt active filter based on fuzzy logic current controller is proposed to compensate current harmonics. The new controller is designed to improve compensation capability of SAPF by adjusting the DC voltage error using a fuzzy rule. The reference current signals required to compensate current harmonics use the synchronous reference detection method. The performances of the proposed SAPF are evaluated through computer simulations for transient and steady-state conditions with nonlinear loads using Matlab-Simulink program and SimPowerSystem toolbox.

## II. CONTROL STRATEGIES

Different control algorithms are proposed for APF but a Synchronous detection method is used for harmonic detection to calculate reference current for shunt active power filter due to its simplicity. The balanced three phase source currents can be obtained after compensation. The equal current distribution method of this control scheme is implemented in this research work. The following steps are used for generation of reference signal [11].



**Figure 2.** SAPF tuned with SDM method

Hypothesis for this method is

$$I_{sa} = I_{sb} = I_{sc} \quad (1)$$

Where  $I_{sa}$ ,  $I_{sb}$  and  $I_{sc}$  represent the peak values of source current in phase a, b and c respectively.

Voltage and current expression can be written as follows: 3-phase source voltages are given by

$$V_{sa}(t) = V_{ma} \sin wt$$

$$V_{sb}(t) = V_{mb} \sin(wt - 120^\circ) \quad (2)$$

$$V_{sc}(t) = V_{mc} \sin(wt - 240^\circ)$$

3-phase current drawn by load given by

$$I_{La}(t) = \sum_{n=1}^{\infty} I_{an} \sin(wt - \phi_{an})$$

$$I_{Lb}(t) = \sum_{n=1}^{\infty} I_{bn} \sin(wt - \phi_{bn} - 120^\circ) \quad (3)$$

$$I_{Lc}(t) = \sum_{n=1}^{\infty} I_{cn} \sin(wt - \phi_{cn} - 240^\circ)$$

The 3-phase instantaneous power ( $p_{3\phi}$ ) in the proposed system can be written as

$$p_{3\phi} = v_{sa}i_{La} + v_{sb}i_{Lb} + v_{sc}i_{Lc}$$

$$p_{3\phi} = P_a + P_b + P_c$$

$$= V_{ma} \sin wt \sum_{n=1}^{\infty} I_{an} \sin(wt - \phi_{an}) +$$

$$V_{mb} \sin(wt - 120^\circ) \sum_{n=1}^{\infty} I_{bn} \sin(wt - \phi_{bn} - 120^\circ) + \quad (4)$$

$$V_{mc} \sin(wt - 240^\circ) \sum_{n=1}^{\infty} I_{cn} \sin(wt - \phi_{cn} - 240^\circ)$$

The instantaneous power is passed through low pass filter (LPF), which blocks higher order frequency component and only fundamental component is obtained from the output of LPF.

$$p_{fund} = V_{ma} \sin wt I_{a1} \sin(wt - \phi_{a1}) + V_{mb} \sin(wt - 120^\circ) I_{b1} \sin(wt - \phi_{b1} - 120^\circ) +$$

$$V_{mc} \sin(wt - 240^\circ) I_{c1} \sin(wt - \phi_{c1} - 240^\circ)$$

$$= \frac{V_{ma} I_{a1}}{2} [\cos \phi_{a1} - \cos(2wt + \phi_{a1})] + \frac{V_{mb} I_{b1}}{2} [\cos \phi_{b1} - \cos(2wt + \phi_{b1})] +$$

$$\frac{V_{mc} I_{c1}}{2} [\cos \phi_{c1} - \cos(2wt + \phi_{c1})] \quad (5)$$

The average fundamental power in 3-phase is given by

$$p_{av} = \int_0^T p_{fund} dt$$

$$= \frac{V_{ma} I_{a1}}{2} \cos \phi_{a1} + \frac{V_{mb} I_{b1}}{2} \cos \phi_{b1} + \frac{V_{mc} I_{c1}}{2} \cos \phi_{c1} \quad (6)$$

For 3- phase balanced nonlinear load the followings can be written as

$$V_{ma} = V_{mb} = V_{mc} = V$$

$$I_{a1} = I_{b1} = I_{c1} = I$$

$$\phi_{a1} = \phi_{b1} = \phi_{c1} = \phi_1$$

$$p_{av} = \frac{3VI}{2} \cos \phi_1 \quad (7)$$

Using equation (7), average power per phase can be written as

$$(p_{av})_{ph} = \frac{VI}{2} \cos \phi_1 \quad (8)$$

Let  $I \cos \phi_1 = I_m =$  Maximum amplitude of per phase fundamental current

$$I_m = \frac{2(P_{av})_{ph}}{V} \quad (9)$$

The fundamental current is given by

$$\begin{aligned} I_{Fa}(t) &= I_m \sin \omega t \\ I_{Fb}(t) &= I_m \sin(\omega t - 120^\circ) \end{aligned} \quad (10)$$

$$I_{Fc}(t) = I_m \sin(\omega t - 240^\circ)$$

The expression of reference current for shunt active power filter in each phase ( $i_{ca}^*$ ,  $i_{cb}^*$ ,  $i_{cc}^*$ )

$$i_{ca}^* = I_{La} - I_{Fa}$$

$$i_{cb}^* = I_{Lb} - I_{Fb}$$

$$i_{cc}^* = I_{Lc} - I_{Fc}$$

After getting the reference current, it is compared with the actual current by using hysteresis current comparator to generate six switching pulses, which are used to control the IGBT either by turning ON or OFF.

### III. CONTROLLER DESIGN

#### 3.1. PI Controller

Fig.3 shows the internal structure of the control circuit. The control scheme consists of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals[10]. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value [5].

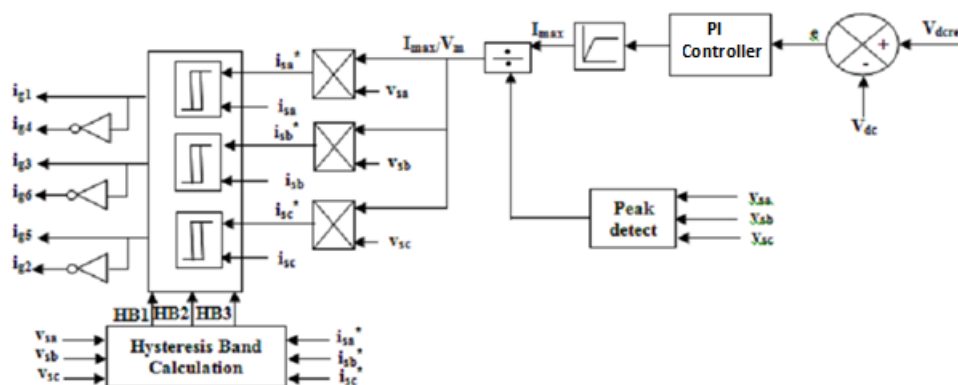


Figure 3 Conventional PI Controller

#### 3.2. fuzzy logic controller

Among the various power filter controller, the most promising is the fuzzy logic control. A fuzzy controller consists of stages: fuzzification, knowledge base, inference mechanisms and defuzzification.

The knowledge bases designed in order to obtain a good dynamic response under uncertainty in process parameters and external disturbances [6][7].

In this study the fuzzy logic controller is used to control the DC capacitor voltage. The capacitor voltage deviation and its derivative are considered as the inputs variables of the FLC and the control voltage vdc present the output as shown in figure.4 [8].

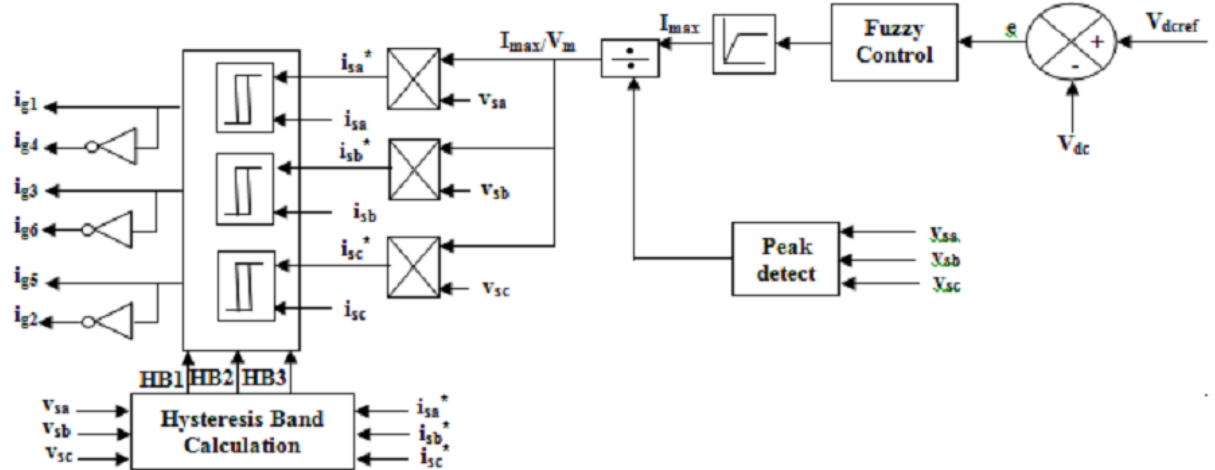


Figure 4 Conventional Fuzzy Logic Controller

The input and output variables are converted into linguistic variables. We have chosen seven Fuzzy subsets, NL (Negative), EZ (Environ Zero) and P (Positive). In this paper, we have applied min-max inference method to get implied fuzzy set of the turning rules and the “centroid” method was used to defuzzify the implied fuzzy control variables.

The membership functions used for the input and output variables are shown in figure.5, the Fuzzy rule base is given in the table.1 [9].

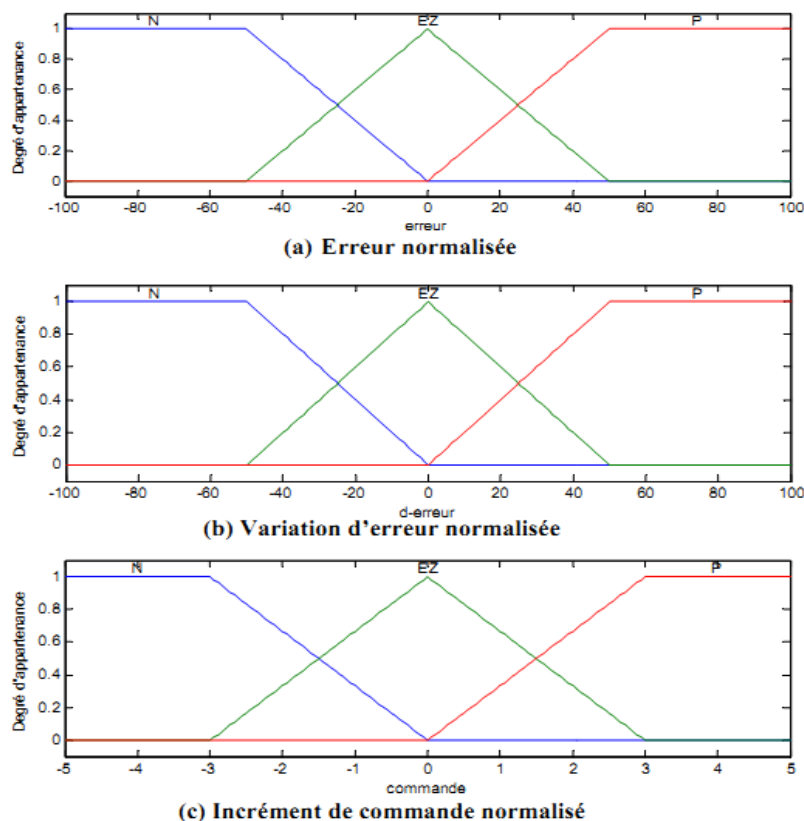


Figure 5 Membership function for the input and output variables

Table.1 Fuzzy control rule:

$E_i$	N	EZ	P
$\Delta E_i$			
N	N	N	EZ
EZ	N	EZ	P
P	EZ	P	P

#### IV. SIMULATION RESULTS AND DISCUSSION

The simulation results are provided to verify the performance and effectiveness of the proposed control scheme based on fuzzy current controller for the shunt active power filter compared to conventional PI controller. The parameters of the simulation are:  $L_f = 3 \text{ mH}$ ,  $C_1 = 2200 \text{ }\mu\text{F}$ ,  $V_s = 220 \text{ V/50 Hz}$ , and  $V_{dc-ref} = 700 \text{ V}$ .

##### 4.1. Simulation results using PI controller

Fig. 6 shows the simulated waveforms of three-phase ac source voltages and source current before compensation.

The waveforms of source voltage and source current after compensation are simultaneously shown in Fig. 7. The DC voltage is presented in Fig. 8.

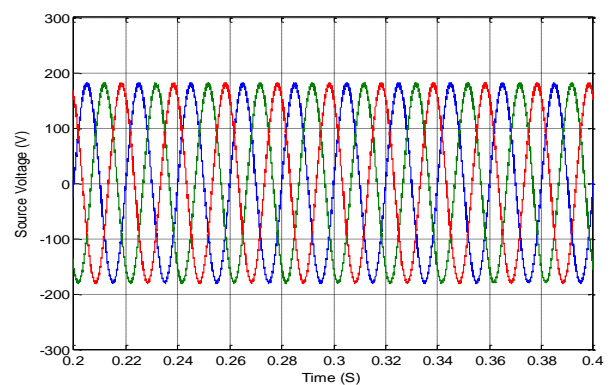
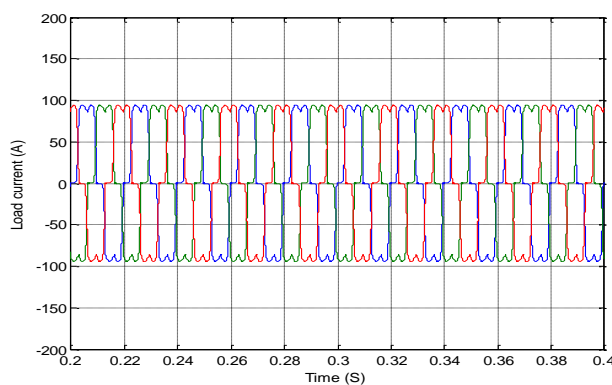


Figure 6. Source voltages and source current without APF

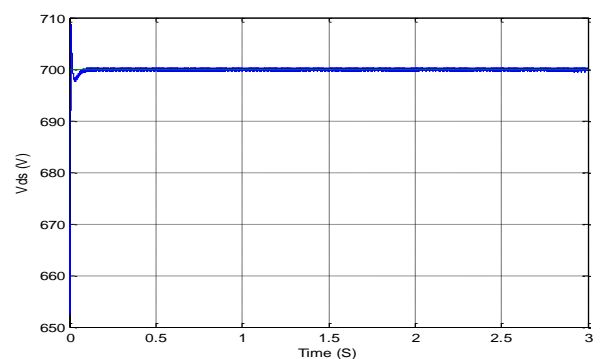
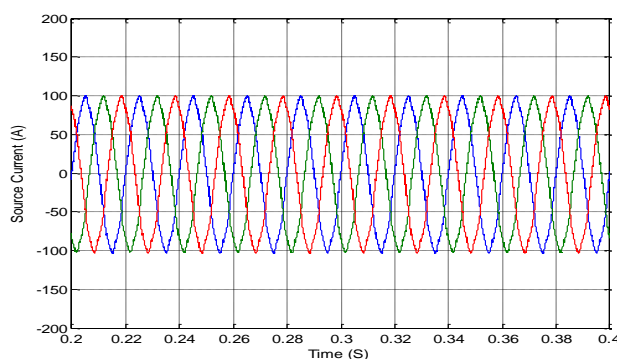


Figure 7. Source current after compensation using PI controller

Figure 8. DC side capacitor voltage

##### 4.2. Simulation results using fuzzy controller

The source current before APF application using fuzzy controller is shown in Fig. 9.

The waveforms of source current after compensation is shown in Fig. 18. Lastly, the output DC capacitor voltage is presented in Fig. 11.

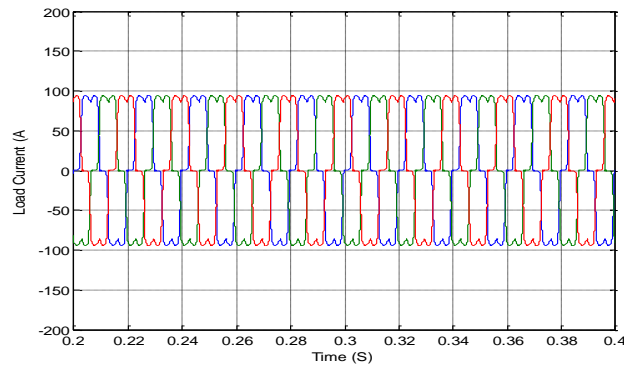


Figure 9. source current without APF

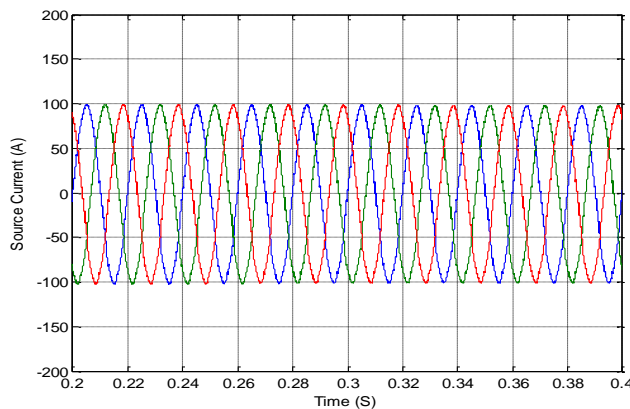


Figure 10. Source current after compensation using Fuzzy controller voltage

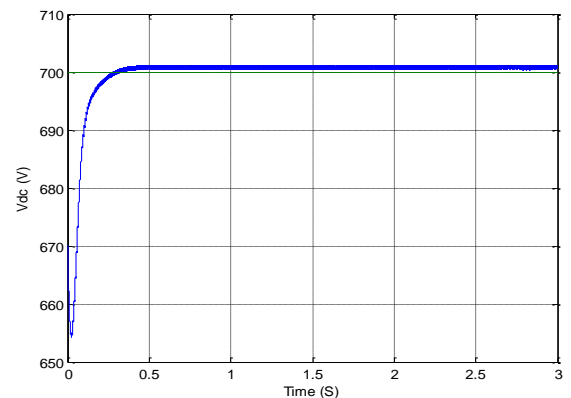


Figure 11. DC side capacitor voltage

## V. CONCLUSION

In the present paper, a three-phase three-level shunt active filter with neutral-point diode clamped inverter based on fuzzy logic current controller is presented. Use of the filter is aimed at achieving the elimination of harmonics introduced by nonlinear loads. Several simulations with various nonlinear loads (AC/DC converter with R,L) under different conditions are performed using the conventional PI and fuzzy current controllers. The results show the superiority and effectiveness of the proposed fuzzy controller in terms of eliminating harmonics and response time, The THD is significantly reduced from 23.74% to 4.12% by conventional PI controller and to 3.26% for fuzzy controller (with APF) in conformity with the IEEE standard norms. The current source for the two controllers after compensation is sinusoidal. Hence, the proposed fuzzy logic current controller is an excellent candidate to control shunt active filters based on inverter topology to eliminate the harmonic currents without scarifying performance tracking as compared to PI controller.

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## AUTHORS

**KOUADRIA Mohamed abdeldjabbar** is PhD student in the Department of Electrical Engineering in at the Ibn Khaldoun University of Tiaret, ALGERIA. He received a MASTER degree in Automation and control of industrial systems from the UIK of Tiaret. His research activities include the Renewable Energies and the Control of Electrical Systems. He is a member in Energetic Engineering and Computer Engineering Laboratory (L2GEGI)



**ALLAOUI Tayeb** received his engineer degree in electrical engineering from the Ibn Khaldoun University of Tiaret in 1996 and his master degree from the University of Science and Technology of Oran in 2002. His research interests includes intelligent control of power systems and FACTS, Active filter and renewable energies. He is a Director of Energetic Engineering and Computer Engineering Laboratory (L2GEGI).



**BELFEDAL Cheikh** received the Magister degree in electrical engineering from Tiaret University, Algeria, in 1996. Currently he is with the Department of Electrical Engineering, Tiaret University. His fields of interest are control of electrical machines, power converters, modelling and control of wind turbines. He is a member in Energetic Engineering and Computer Engineering Laboratory (L2GEGI)

