# COMPARISON BETWEEN DIFFERENT CONTROL STRATEGIES FOR SHUNT ACTIVE POWER FILTERS

Prof. Eng. **Toader MUNTEANU,** Lecturer Eng. **Gelu GURGUIATU**,
Assis. Eng. **Ciprian BALANUTA**

"Dunarea de Jos" University of Galati

**REZUMAT. În această lucrare este prezentată o comparaţie între trei strategii de comandă utilizate pentru controlul filtrelor active de putere (APF) (Teoria pq, teoria dq, şi controlul indirect). Principalul criteriu de comparaţie este distorsiune armonică totală de curent (THDI) obţinută în reţea şi al-II-lea criteriu este echilibrarea curenţilor absorbiţi din reţea. Curenţii armonici sunt prezenţi în reţea datorită sarcinilor neliniare care sunt din ce în ce mai prezente chiar şi la puteri mici. Filtrul activ de putere studiat este unul de tip shunt trifazat cu conductor de neutru.**

**Cuvinte cheie:** filtre active de putere paralel, strategii de control pentru filtre active de putere

**ABSTRACT. In this paper is presented a comparison between three control strategies used for active power filters (APF) (Instantaneous active and reactive power - PQ, Synchronous reference frame - dq and Indirect control - IC) . The main comparison criterion is the current total harmonic distortion (THDI) obtained in grid and the second is the current balanced. The current harmonics are presented in grid because of non-linear loads which are more and more presented even at low power. The investigated APF is a shunt three phase and four wire APF.**

**Keywords:** shunt active power filters, APF control strategyes.

## 1. INTRODUCTION

Technical evolutions in power electronics have generated many benefits regarding the energy efficiency and power control. Also, the power management has been improved using the power electronics and information technology. Unfortunately, the power quality has become poorer because of non-linear loads connected to grid. A non-linear load is a load which changes the shape of the current waveform from a sine wave to some other form.

To overcome this drawback many solutions have been proposed [1], [2].

The most important solution, with very good results is represented by active power filters (APF). The APF are compound by a power device and a control device which realize the control of the power one. The power device is realized with static switches and can be realized with three legs or four legs. To control the power device many control systems and many control strategy have been proposed [2]. The most popular control strategies presented in the literature are: instant active and reactive power -PQ, synchronous detection-DQ and indirect control - IC.

In the following sections is presented a short description for each type of those control strategies. After the presentation is made, a comparison between the three controls strategies mentioned above is realized where the main criterion is the current harmonic distortion (THDI) and the second is current balanced.

The THDI for the grid current is calculated in each strategy and compared. Also an unbalanced load is conected to grid and it can be seen how each control strategy can handle it.

It must to be mentioned that the load, the APF power device structure and the grid characteristics are maintained the same during all the simulations. The simulations have been made using the models which was implemented in Matlab/SimPowerSystem.

In Fig. 1 is presented the APF connection to grid and generically the four control strategies (PQ, dq, IC) are mentioned.

The theoretical aspects regarding the three control strategies are presented focused on their main characteristics. These strategies are simulated only for a three phase system with neutral wire. The load is a three phase rectifier connected directly to grid with a total power around 5kW and for the unbalanced load is considered a rezistive load connected only to phase *a* to create an unbalance of 54,1%.

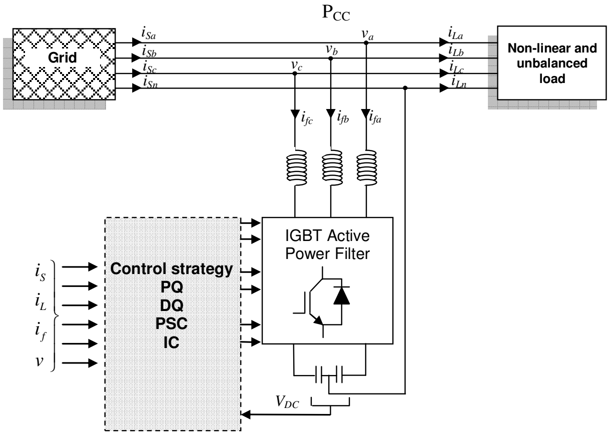


Fig. 1 APF connection

In all the simulations it was used hysteresis controllers because of their good dynamics. The switching frequency is a variable one. Regarding to this, the real implementation have to pay attention to switching frequency control. There are a lot of ways to control the switching frequency presented in literature.

The controller for the DC voltage of the APF is a PI controller tuned using Ziegler–Nichols method [3].

## 2. CONTROL STREATEGYES

As it was mentioned above the theoretical aspects regarding the three control strategies are presented focused on their main characteristics. These strategies are simulated only for a three phase system with neutral wire. The load current is presented in Fig. 2. The load is a three phase rectifier connected directly to grid with a total power around 5kW and a monophase linear load connected to phase “*a*”with a 900W active power.

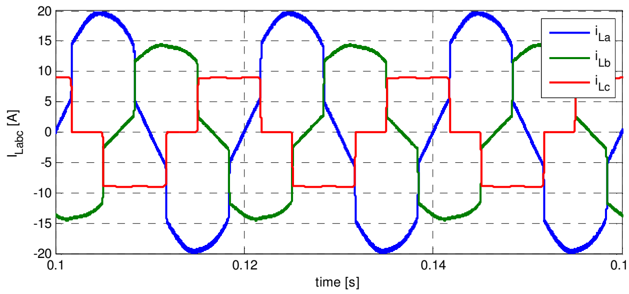
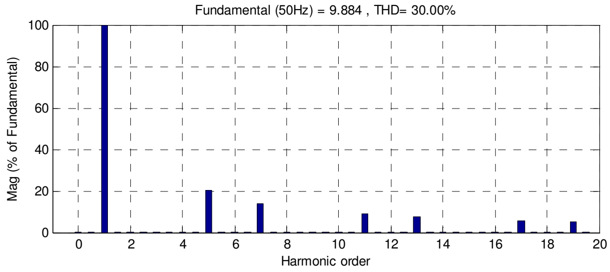


Fig. 2 The non-sinusoidal load current

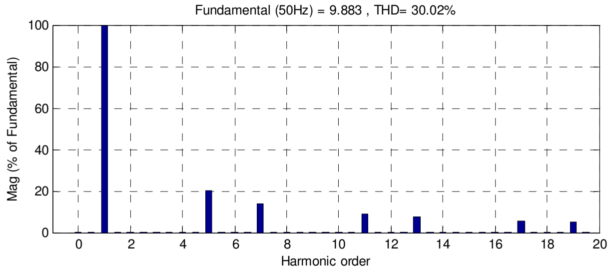
In Fig. 3 is presented the FFT analysis of the load current.

It can be observed that the THD value of the load current is 19,39% for phase *a*, 30.02 for the phase *b* and 30,00% for the phase *c*.

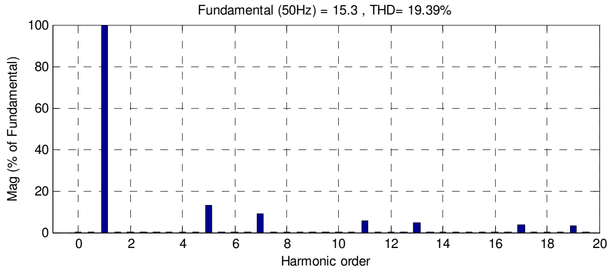
Concerning the unbalanced for the load current it can be observed that the phase *a* have a bigger r.m.s by the other two phases.



a) – phase *a*



b) – phase *b*



c) – phase *c*

Fig. 3 The FFT analysis for load current

The current drawn by the unbalanced load (Fig. 2) have an unbalanced factor $k_L$=54,10%. This factor is calculated using the Fortescue decomposition and the equations (1) where:

$k_I^-$ - the inverse sequence component;

$k_I^0$ - the zero sequence component.

$$k_I^- = \frac{I^-}{I^+} \cdot 100$$

$$k_I^0 = \frac{I^0}{I^+} \cdot 100 \tag{1}$$

$$k = k_I^- + k_I^0$$

In the following sections there are presented the simulations results of the three control strategies proposed for comparation.

The proposed control strategies are: Instantaneous active and reactive power - PQ, Synchronous reference frame - dq, and indirect control – IC.

### *A. Instantaneous reactive-power control strategy*

In this control strategy, suitable only for three-phase systems, the instantaneous power for the load is calculated [2]. There is calculated a DC component and an oscillating component. The oscillating component is separated over a certain interval of time.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_{an} \\ u_{bn} \\ u_{cn} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_{r\alpha} \\ i_{r\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{ra} \\ i_{rb} \\ i_{rc} \end{bmatrix} \tag{3}$$

The control diagram is presented in Fig. 4.

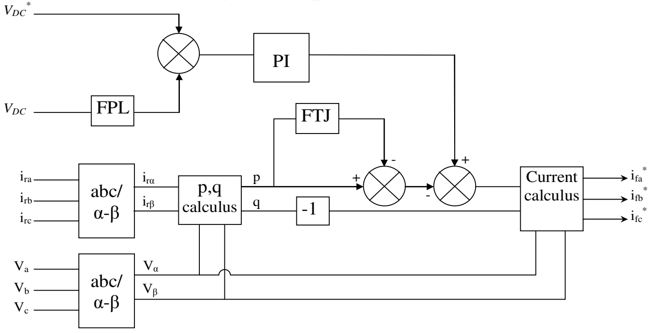


Fig. 4 PQ control strategy

$$\begin{aligned} p_L &= v_\alpha i_{r\alpha} + v_\beta i_{r\beta} \\ q_L &= v_\alpha i_{r\beta} - v_\beta i_{r\alpha} \end{aligned} \tag{4}$$

$$\begin{bmatrix} i_{f\alpha}^* \\ i_{f\beta}^* \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_f \\ q_f \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p_f \\ q_f \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{f\alpha}^* \\ i_{f\beta}^* \end{bmatrix} \tag{6}$$

The grid current obtained with PQ strategy is presented in Fig. 5.

Controlling the APF with PQ control strategy the THD for the grid current obtained is 2,85% for all the three phases.

Regarding the unbalanced factor for the grid current, this is reduced from 54,1% to 2,6% using the PQ contril strategy.

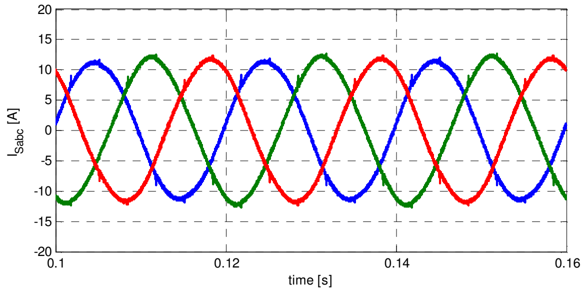


Fig. 5 The grid current in PQ control strategy

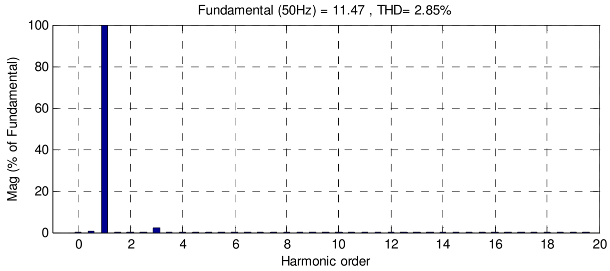


Fig. 6 The FFT analysis for grid current

Using the PQ theory the total harmonic distortion obtained for the grid current is the same for each phase.

### *B. Synchronous-detection control strategy*

The synchronous-detection control strategy is very similar with the PQ strategy [2].

The average power is calculated and divided equally between the three phases. The signal is synchronized with the main voltage signal and is obtained the reference signal. This control strategy is sensible to voltage distortions.

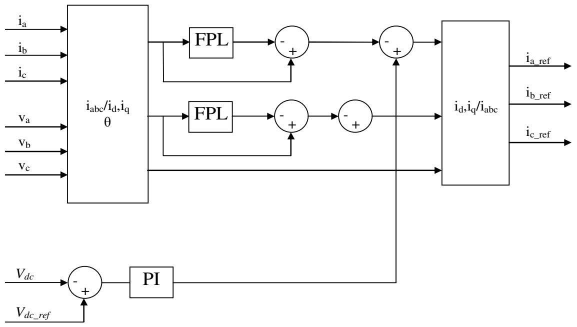


Fig. 7 Synchronous-detection control strategy

There are calculated $i_{Ld}$ and $i_{Lq}$ using the following equations:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) \\ \sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{7}$$

Also the powers are calculated:

$$\begin{cases} p_L(t) = i_{Ld}v_d + i_{Lq}v_q = v_\alpha i_{L\alpha} + v_\beta i_{L\beta} \\ q_L(t) = i_{Ld}v_d - i_{Lq}v_q = v_\alpha i_{L\beta} - v_\beta i_{L\alpha} \end{cases} \quad (8)$$

Using the invers transformation there are obtained the reference currents for the APF.

The grid currents in these conditions are presented in Fig. 8.

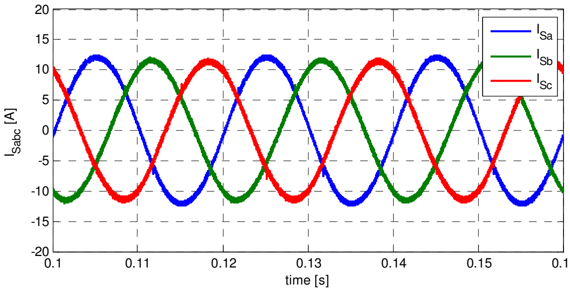
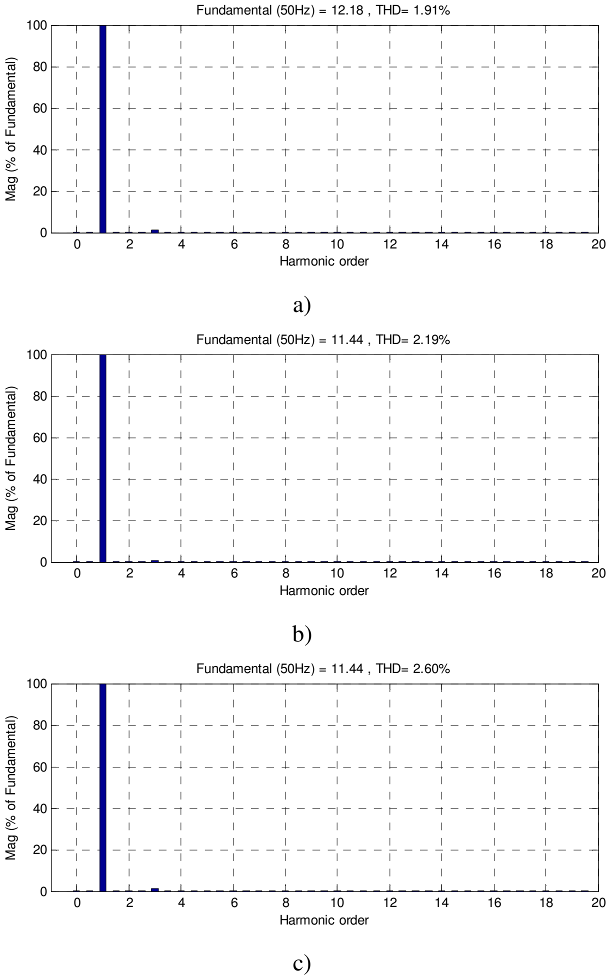


Fig. 8 The grid current in dq control strategy



a)

b)

c)

Fig. 9 The FFT analysis for grid current in dq control; a) phase *a*,b) phase *b*; c) phase *c*

Using the DQ theory the total harmonic distortion obtained for the grid current have different values for the three phases.

The unbalanced factor is reduced from 54.1% to 6% by using the DQ control strategy in a shunt active power filter.

## *C. Indirect control strategy*

The indirect control strategy does not need to know the load current spectrum or the reactive load current [4], [5]. This control strategy is intended to impose that the grid current to be harmonics free. In Fig. 10 is presented the indirect control strategy.

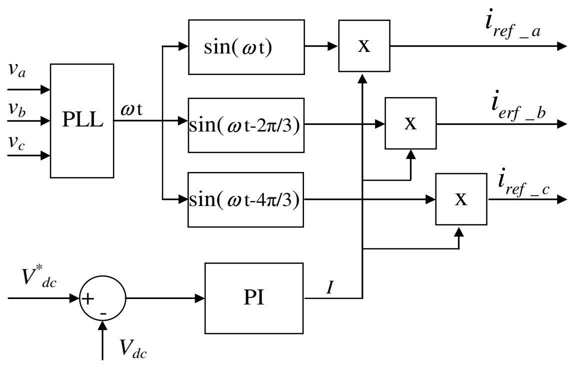


Fig. 10 The indirect control strategy

For the phase a the current in Pcc (Common coupling point) have the following equations:

$$i_{sa}(t) = i_{La}(t) + i_{fa}(t) \quad (9)$$

where the load current is:

$$i_{La}(t) = i^1_{La}(t) + i_{Lak}(t) + i_{Laq}(t) \quad (10)$$

where:

$i^1_{La}$ - the fundamental current component through the load in phase with the voltage;

$i_{Lak}$ - the reactive current component through load;

$i_{Laq}$ - the deforming current component through load.

The current through APF:

$$i_{fa}(t) = i^1_{fa}(t) + \tilde{i}_{fa}(t) \quad (11)$$

where:

$i^1_{fa}(t)$ - fundamental current by APF;

$\tilde{i}_{fa}(t)$ - deforming component.

The APF is controlled in such way that:

$$\tilde{i}_{fa}(t) + i_{Lak}(t) + i_{Laq}(t) = i_{\sin} \quad (12)$$

The reference currents are:

$$i^*_a = I \cdot \sin(\omega t) \quad (13)$$

$$i_b^* = I \cdot \sin\left(\omega t - \frac{2\pi}{3}\right) \qquad (14)$$

$$i_c^* = I \cdot \sin\left(\omega t - \frac{4\pi}{3}\right) \qquad (15)$$

I – the current magnitude, needed to realize sin wave of $i_x$ and in phase with corresponding voltage.

The grid currents obtained using indirect control strategy is presented in Fig. 11.

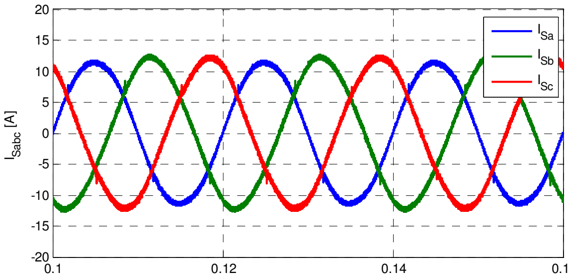
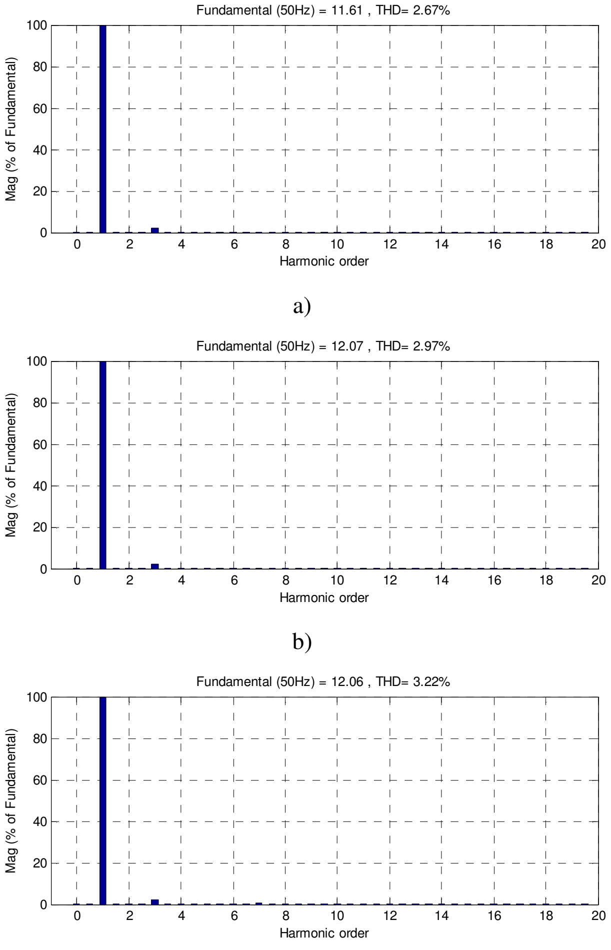


Fig. 11 The current from grid in indirect control strategy



a)

b)

c)

Fig. 12 The FFT analysis for grid current in indirect control: a) – phase *a*; b) phase *b*; c) phase *c*

Using the CI control strategy the total harmonic distortion obtained for the grid current have different values for the three phases respectively 2,67% for phase *a,* 2,97% for phase *b,* 3,22% for phase *c,* .

The unbalanced factor is reduced from 54.1% to 4,1% by using the CI control strategy in a shunt active power filter.

## 5. CONCLUSIONS

✓ Using a shunt active power filter, the harmonic distortion for grid current can be reduced considerable. Also the unbalanced current can be improved. These mean that the losses in feeding line and power transformer are reduced also.

✓ In this paper it was analyzed three control strategies for active power filters. It was presented how the three control strategies can improve the current harmonic distortion and the current unbalanced.

✓ The PQ strategy can achieve a THD of 2.85%, the DQ strategy can achieve different THD for each phase respectively 1.91% on phase *a*, 2.19% on phase *b*, 2.60% on phase *c*, and the CI control strategy also can achieve different THD for each phase respectively 2.67% on phase *a*, 2.97% on phase *b*, 3.22% on phase *c.*

✓ The unbalanced factor for the grid current is reduced from 54.1% to 2.6% in PQ strategy, to 6% in DQ strategy and to 4.1% in CI Strategy.

✓ This paper cans recommend to use the adequate control strategy depending on the predominant power quality problem to be solved.

## BIBLIOGRAPHY

[1] M. Montero, E.R. Cadaval, F. Gonzalez, "*Comparison of control strategies for shunt active power filters in three-phase four-wire systems*", IEEE Transactions on Power Electronics, vol. 22, pp. 229–236, January 2007.

[2] M. El-Habrouk, M.K.Darwish and PMehta (2000) *Active power filters: A review* -IEE Proceedings online no. 2000O522

[3] E. Ceanga, C. Nichita, L. Protin, N. Antonio Cutululis, "Theorie de la commande des systemes" Ed. Tehnica Bucuresti, 2001, ISBN: 973-31-2103-7

[4] Gurguiatu, Gelu, Vechiu, Ionel, Toader Munteanu; "*Power quality improvement using renewable energy*" - International Conference on Renewable Energies and Power Quality, Las-Palmas, 13-15 april 2011, ISBN: 978-84-616-7527-8;

[5] Vechiu, Ionel; Gurguiatu, Gelu; Rosu, Emil*;"Advanced active power conditioner to improve power quality in microgrids*"**,** - IPEC, 2010

Conference Proceedings Digital Object Identifier: 10.1109/IPECON.2010.5697021; Publication Year: 2010 , Page(s): 728 – 733

## About the authors

Prof. Eng. **Toader MUNTEANU**, PhD.
"Dunarea de Jos" University of Galati
email:toader.munteanu@ugal.ro

Toader MUNTEANU was born in Isaccea - Tulcea, Romania year 1956. He graduated the faculty of Electrotechnics in the year 1982 to Iasi, the specialization Electrotechnics. Ph.D. graduated at "Dunarea de Jos" University of Galati in 1996 in Electrical Engineering.

Lecturer . Eng. **Gelu GURGUIATU,** PhD
"Dunarea de Jos" University of Galati
email: gelu.gurguiatu@ugal.ro

Gelu GURGUIATU was born in Focsani, Romania year 1980. He graduated the faculty of Electrical Engineering and Computer Science in the year 2003 to Galati, the specialization Electrical Drives with surrender in the French language. The work of graduate was achieved in Le Havre, France as part as laboratory GREAH from Le Havre University. Master – graduated S.I.C.T.E.E. Control in Electrical Energy Transport and Conversion in 2004. Power Quality Expert graduated in 2006. Ph.D. graduated at "Dunarea de Jos" University of Galati in 2011 in Electrical Engineering.

Assis. Eng. **Ciprian BALANUTA**, PhD student. ,
"Dunarea de Jos" University of Galati
email: daniel.balanuta@ugal.ro