PASSIVE AND ACTIVE COMPENSATIONS FOR CURRENT TRANSFORMERS

Costin CEPIŞCĂ, Sorin Dan GRIGORESCU*, Stergios GANATSIOS**, Nikolaos G. BARDIS****

*UNIVERSITATEA POLITEHNICA BUCUREŞTI,
** TECHNICAL EDUCATIONAL INSTITUTION OF WEST MACEDONIA, GRECIA,
*** HELLENIC ARMY ACADEMY, GRECIA

Rezumat. *Transformatoarele de curent reprezintă o soluţie tradiţională pentru măsurarea puterii electrice active şi reactive şi a energiei în reţelele electrice. Transformatoarele permit măsurarea valorii rms, dar, în cazul măsurărilor puterii şi energiei, numai valorile mari nu sunt suficiente pentru a susţine şi măsurarea fazei. Se pot observa erori la măsurarea puterii şi energiei electrice şi, de aceea această lucrare prezintă bazele teoretice ale acestor erori şi propune o serie de metode pentru îmbunătăţirea exactităţii de măsurare a puterii şi energiei.*

Cuvinte cheie: *corecţie, transformatoare de current, măsurarea puterii electrice.*

Abstract: *Current transformers represent traditional solution for the measurement of the electrical active and reactive power and energy in the electrical networks. The transformers allow the measurement of the rms value, but, in the case of power and energy measurements, only amplitude values are not sufficient claiming for phase measurements too. One can note errors for electric power and energy measurements, that is why this paper presents the theoretical bases of these errors and proposes a couple of methods for accuracy improvement in the case of energy and power measurement.*

Key words: *Error correction, current transformer, electric power measurements.*

1. INTRODUCTION

In an electric system, the active P and reactive Q powers are written:

$$P = \sum_{k=1}^{n} U_k I_k \cos\varphi_k \qquad Q = \sum_{k=1}^{n} U_k I_k \sin\varphi_k \quad (1)$$

U_k , I_k and φ_k are associated with the harmonics of the tension and current [1].

The errors of measurement of the U, I and φ determines errors of measurement for the P and Q powers and E_P and E_Q energies [2]. The instrument transformers (current/tension) introduced in the measuring equipment, with their errors of amplitude and phase, determine strongly the results of measurements [3], [4].

In certain cases, when the current are small ($I<<I_n$), or a considerable phase between the current and the tension exists, or the current is not sinusoidal, one can note errors of 10-40 % to the measure of power and energy [5], [6].

It is well known that many instrument transformers may have a limited frequency response. In the IEC "General guide on harmonics and interharmonics measurements and instrumentation…" [7], some statements are made on what can be expected of current transformers. This guide is the work of IEC SC77A The CIGRE working group 05 of study committee 36 and the IEEE Power system working group also summarized what was known in the first half of the 1980's. References are frequently made to [8], [9]. One can define the relative errors to the measure of the active power. For a single-phase circuit:

$$\frac{\Delta P}{P} = \frac{k_{In} k_{Un} P_s - P_p}{P_p} \quad (2)$$

where P_s and P_p are the powers (secondary and primary), k_{In}, k_{Un} are the ratios of transformation.

The relative error of active power measurement is:

$$\frac{\Delta P_1}{P_1}(\%) = \varepsilon_I(\%) + \varepsilon_U(\%) - 100(\delta_U - \delta_I)\,\mathrm{tg}\varphi \quad (3)$$

Figure 1 presents the curves of the errors of measurement of active power in function of angle φ and ratio of current.

For the reactive power:

$$\frac{\Delta Q_1}{Q_1}(\%) = \varepsilon_I(\%) + \varepsilon_U(\%) - 100(\delta_U - \delta_I)\,\mathrm{ctg}\varphi \quad (4)$$

and the curves of the errors of measurement of reactive power are designed on Figure 2. For the three-phase systems the total error can be larger, especially in the cases when the phase is significant [10, 11].

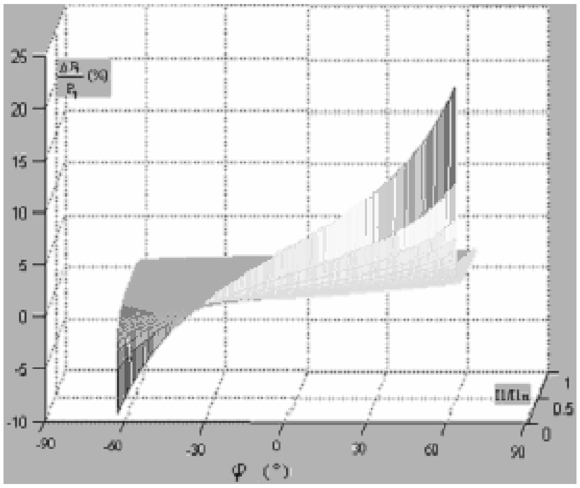


Fig. 1. The relative error of active power measurement.

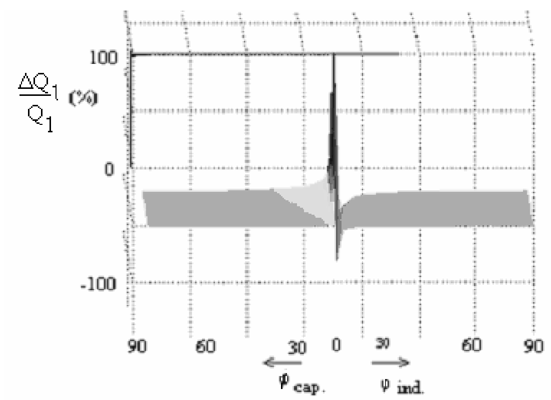


Fig. 2. Errors of measurement on the electrical reactive power.

Presence of errors in various ranges imposes specialized solutions and circuits for error reduction. In the literature are showed different solutions for passive and active compensation of current transformers errors. Passive compensation is related with transformers constructive type and offers limited solutions over the input magnitude range and frequency response. However circuits implied in this case, due to their passive behavior, do not generally reduce the reliability of the system.

The active systems are more responsive for large input value span and frequency, but because of their active principle, they claim an additional energy supply and may reduce the overall stability and reliability.

2. UNCERTAINTY OF THE CURRENT TRANSFORMER. NUMERICAL MODEL STUDY

The block diagram of the MATLAB-SIMULINK software is presented in Figure 3, [12].

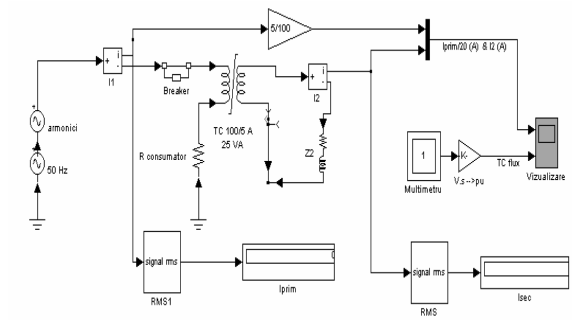
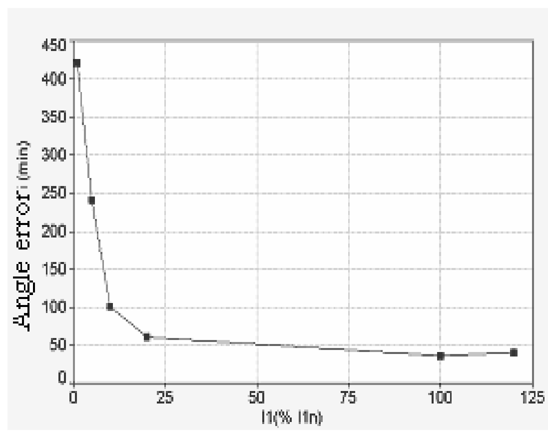
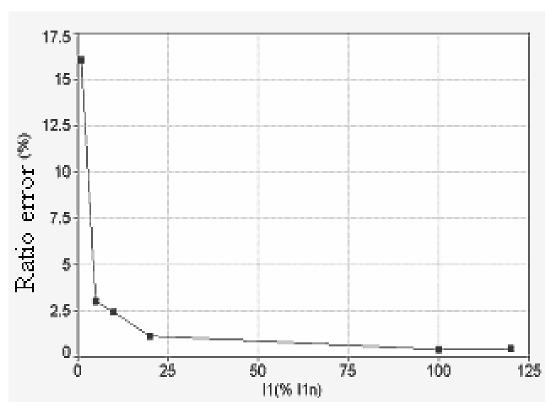


Fig. 3. MATLAB-SIMULINK model for the current transformer.

The results of simulations are presented in Figure 4 which shoes the predicted results proving large increase of errors, bought in phase angle and ratio, for currents less than a quarter of the nominal value.



a)



b)

Fig. 4. Errors of the current transformer: *a* – angle error; *b* – ratio error.

To explain the frequency response of ordinary current transformers the equivalent circuit diagram of Figure 5 are most often used [13].

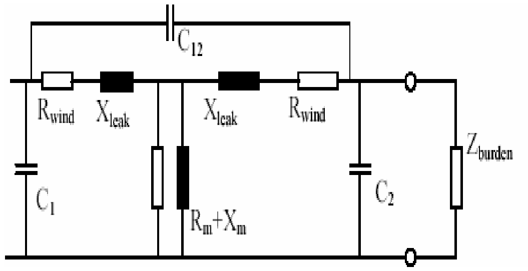


Fig. 5. Model for current transformer at medium frequencies.

These are common equivalent diagrams of a transformer except for the capacitors. The capacitors C_1 and C_2 are the lumped stray capacitance of the primary and secondary winding, respectively, and C_{12} is the stray capacitance between the windings. At low frequencies such as 50 Hz they may be negligible but for higher frequencies they may form several resonance circuits, together with the leakage and burden reactance, at various frequencies.

From Figure 5, it can further be deducted that grounding (that affects the voltage across C_{12}) as well as the loading (including long cables), especially inductive or capacitive loading, may well affect the frequency response.

In some situations, the equivalent circuit diagram of Figure 5 may be reduced to the circuit diagram according to Figure 6.

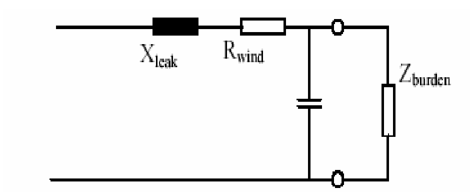


Fig. 6. Simplified model.

Let us analyze the propagation of the errors affecting the measurement of power and energy one can use a simply model of current transformer-Figure 7.

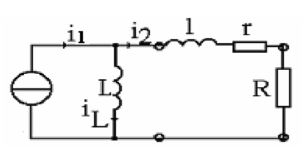


Fig. 7. Model of current transformer.

One can determine easily the frequency response *H(jω)*:

– the amplitude response:

$$H(\omega)=\frac{\omega L\sqrt{(R+r)^2+(\omega L+\omega l)^2}}{(R+r)^2+(\omega L+\omega l)^2} \qquad (5)$$

corresponds to the ratio of real transformation (k_I) and it is related to parameters L, l, ω, $R' = R + r$ (Figure 8). The perfect conditions for a current transformer are: inductance L has an infinite value, the values of l and R' negligible.

– the phase response:

$$\Theta = \arctan\frac{R+r}{\omega L+\omega l} \qquad (6)$$

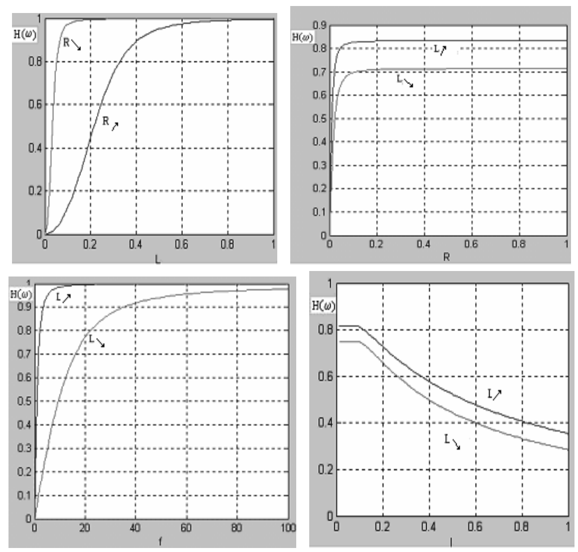


Fig. 8. Errors in the measurement of active power due to $H(\omega)$.

The phase Θ is the image of the phase between the primary current and the current on resistance R'. The evolution of Θ according to L, l, ω and R' has paces obtained by calculation (Figure 9). Inductance L influences much more the phase; a low value increases Θ. The inductance l must be limited. The resistance of the shunt R must be low.

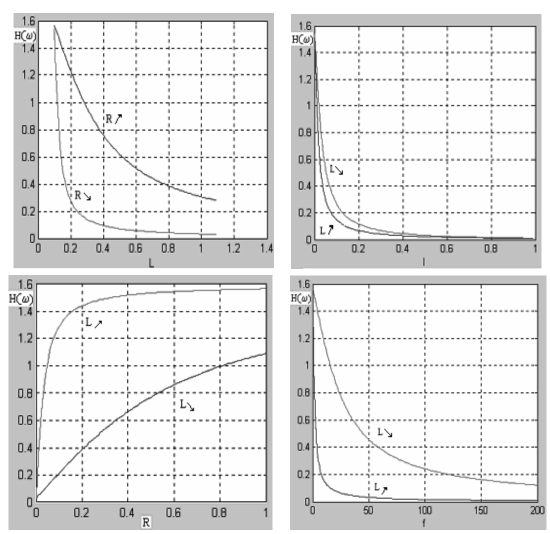


Fig. 9. Errors occurring in the measurement of active power due to Θ.

The effects of internal parameters of current transformer in the power measurement are presented in the Figure 10.

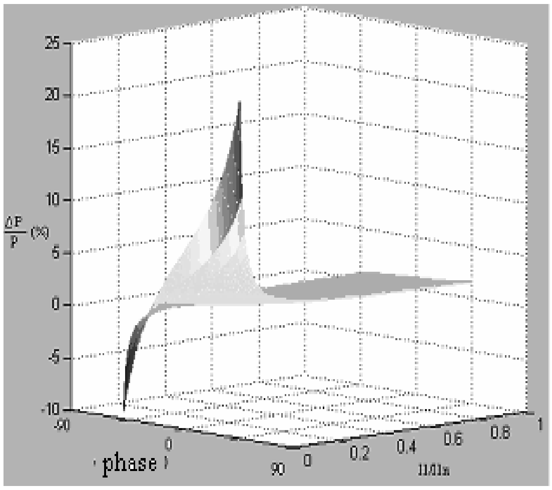


Fig. 10. Effects of internal parameters of current transformer in the power measurement.

3. PASSIVE COMPENSATION METHOD

A correct compensation is carried out only for one fixed configuration: type of transformer, wiring and measuring apparatus [14].

Use a passive network (Fig. 11) compensate errors caused by the inductance transformer *L* by adding a capacitor *C*.

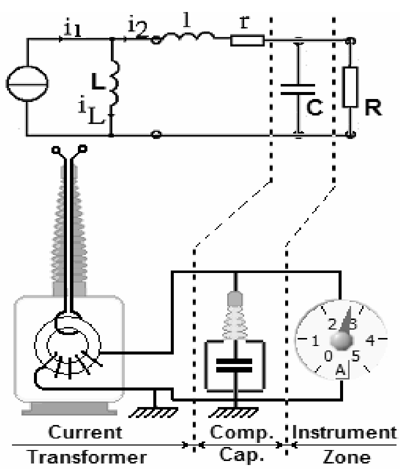


Fig. 11. In circuit passive compensation basics.

In Figure 12 is shown the MATLAB-SIMULINK model for the circuit in Figure 11. The results of compensation for small current are presented in Figure 13. One may see that errors reduction in small bought for ratio and phase angle. No shortage in reliability, due of the insertion of the capacitor, is the main schematic advantage, but the chance of unwanted resonance may be considered a drawback for this simple arrangement.

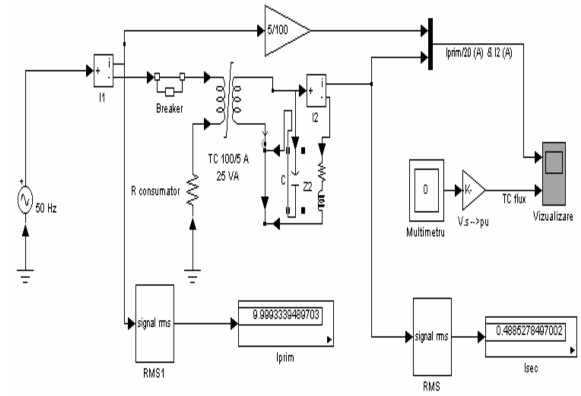
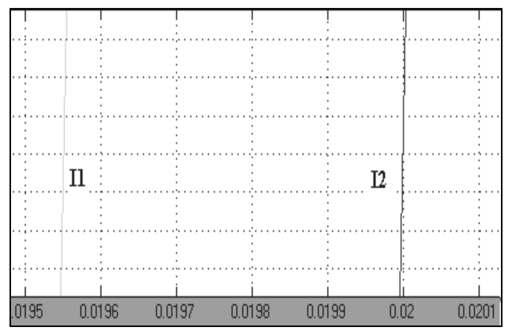
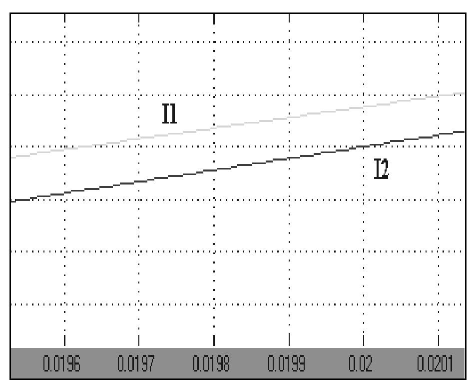


Fig. 12. SIMULINK model for passive compensation of current transformer.



a) without *C*: $\varepsilon_I = 8{,}2$ % $\delta_I = 7{,}5°$;



b) *C*= 100µF : $\varepsilon_I = 8{,}0$ % $\delta_I = 6{,}5°$

Fig. 13. Passive compensation results, $I_1 = 1\% \; I_{1n}$.

4. ACTIVE COMPENSATION METHOD

The active compensation uses active circuits, i.e. operational amplifier based, in various schematics.

The principle proposed in this article is illustrated in Figure 13, [15]. No additional windings on the current transformer are used, making the circuit an add on device for the actual field transformers.

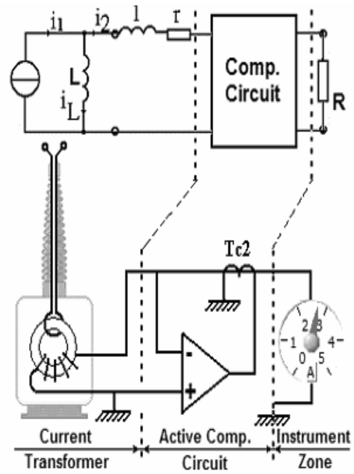
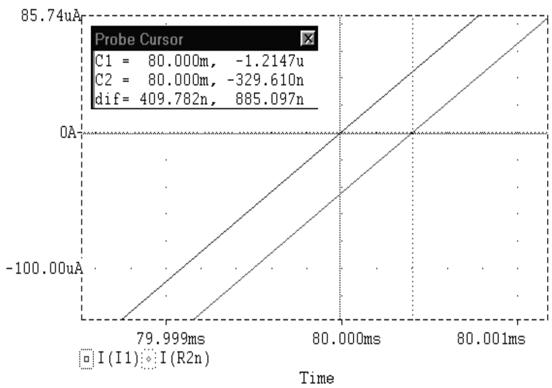
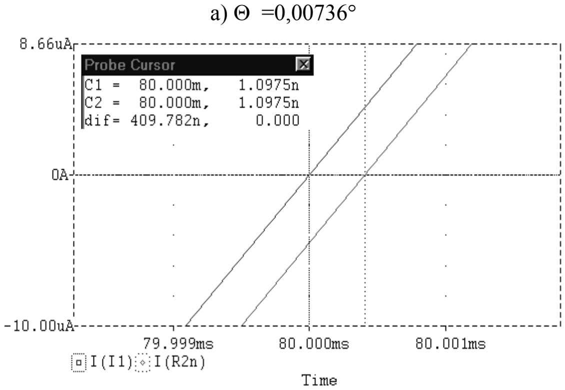


Fig. 14. Active compensation schematic.

Using SPICE simulation of the electronic circuit in Figure 14, angle error results are presented in Figure 15.a for nominal current I_{1n} and Figure 15.b for a current as low as 5% I_{1n}.



a) Θ =0,00736°



b) Θ =0,00738°

Fig. 15. Angle error for simulated circuit in Figure 14.

5. EXPERIMENTAL ASPECTS FOR ACTIVE COMPENSATION

The implemented instrument using transformers active compensation is illustrated in Figure 16 for a 100 A/5 A ratio transformer and $S_n = 5$ VA.

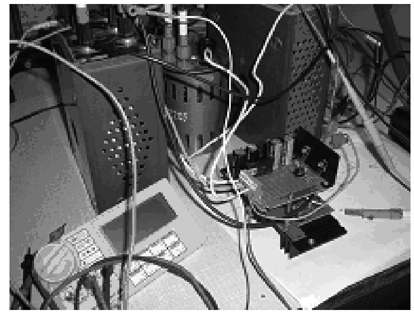


Fig. 16. Experimental rig.

The following waveforms were acquired using an acquisition system based on a HP- digital sampling oscilloscope, and prove predicted results into the DSO error limits. An example of input/output currents is illustrated on the DSO – Figure 17.

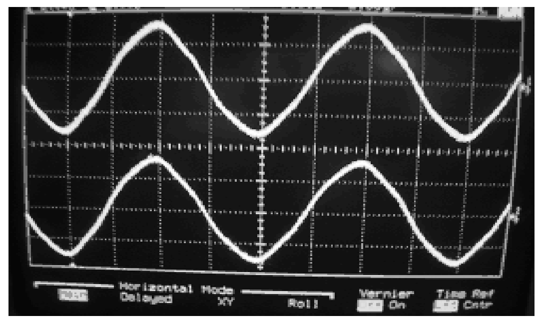


Fig. 17. Input and output waveforms acquired by the DSO.

In practice low currents, with respect to I_{1n}, errors behavior is important, that this domain was extensively explored. The following results are obtained for a primary current of 20%I_{1n}. In Figure 18 are illustrated the waveforms in the actual case of a burden reduced with 50%, and in Figure 19 are the correspondent results for a burden increased ten times. No actual differences may be observed in the bought limit cases for the aspect of the main waveforms.

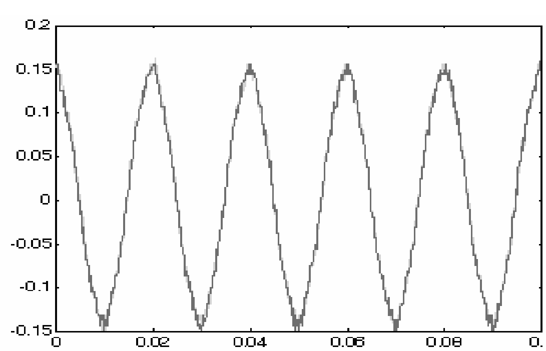


Fig. 18. Current waveforms in the case of I1=20%I1n, Z2=50%Z2n.

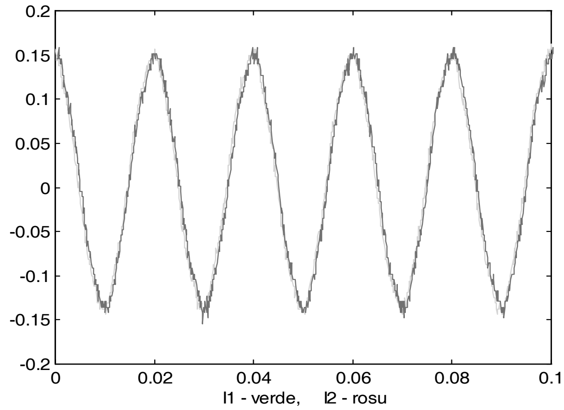


Fig. 19. Current waveforms in the case of $I_1=20\%I_{1n}$, $Z_2=10Z_{2n}$,

The experimental results indicate an accurate behavior of the proposed circuit even on edge conditions of extra large burden values.

6. CONCLUSIONS

The measuring equipment of the electric power, with current transformers presents errors due to the specific condition (phase, the shape of the current, amplitude of the current). This analysis explains the sources of errors and the possibilities of compensation of uncertainties.

Two methods of passive and active errors compensation are proposed in this article. Each method presents advantages for the metrological characteristics and drawbacks from the point of view of global reliability and functional side effects. The active compensation has superior metrological performances, but implying the use of additional electronics and power supplies may eventually reduce the overall reliability of the system.

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Scientific revue:

Ion M. POPESCU, professor, Politehnica University Bucharest.

About authors:

Costin CEPIŞCĂ, professor, doctor at Politehnica University Bucharest, e-mail: costin@wing.ro

Sorin Dan GRIGORESCU, professor, doctor at Politehnica University Bucharest, e-mail: sgrig@electro.masuri.pub.ro

Stergios GANATSIOS, professor, doctor, at Technical Educational Institution of West Macedonia, e-mail: ganatsio@teikoz.gr

Nikolaos G. BARDIS, doctor at Hellenic Army Academy, e-mail: bardis@ieee.org