Current Transformers and the Accuracy of Electrical Powers and Energies Measurements

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Abstract: – The measurement of the electrical active and reactive powers and energies in the electrical networks imposes the use of the current transformers. The instrument transformers allow the measurement of the effective value but, in certain cases, one can note errors to the measurement of the electric power and energy. The work presents the explanations of theories and proposes methods of correction of the errors of energy measurement due to the instrument transformers.

Key-Words: – Current transformer, measurement, active power, reactive power, error, correction.

1 Introduction

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

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

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 powers and energies [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 (instrument) transformers. This guide is the work of IEC SC77A. The CIGRE working group 05 of study committee 36 (interference) 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:

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

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

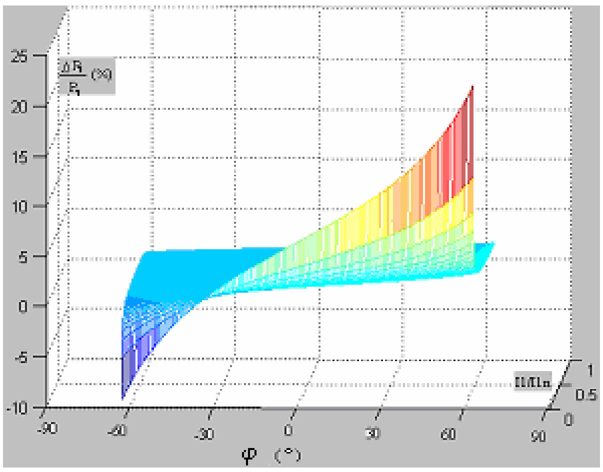
The relative error of active power measurement is:

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

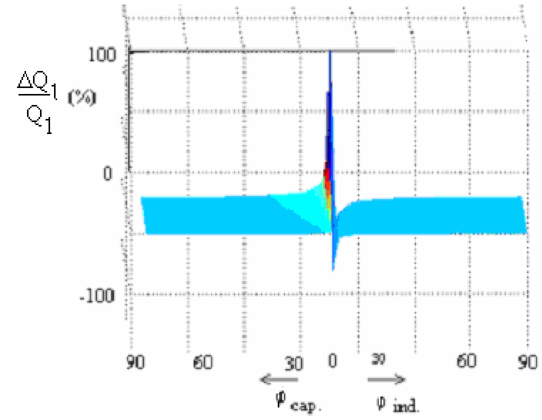
and for the reactive power:

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

The curves of the errors of measurement of active powers are designed on figure 1. For the three-phase systems the total error can be larger, especially in the cases when the phase is significant [10],[11].



a)



b)

Fig. 1. Errors of measurement on the electrical power: a) active; b) reactive.

2 Uncertainty due to the current transformer

The block diagram of the SIMULINK software is presented in figure 2, [12].

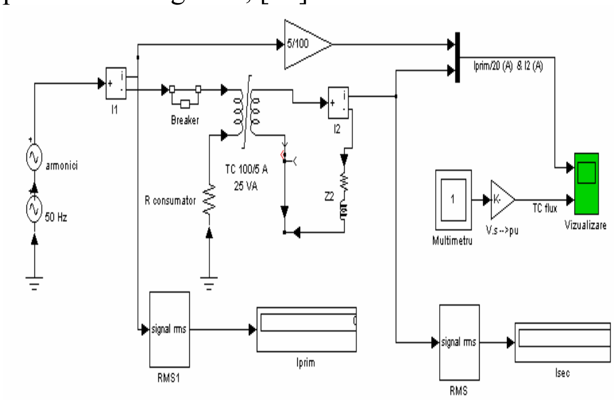
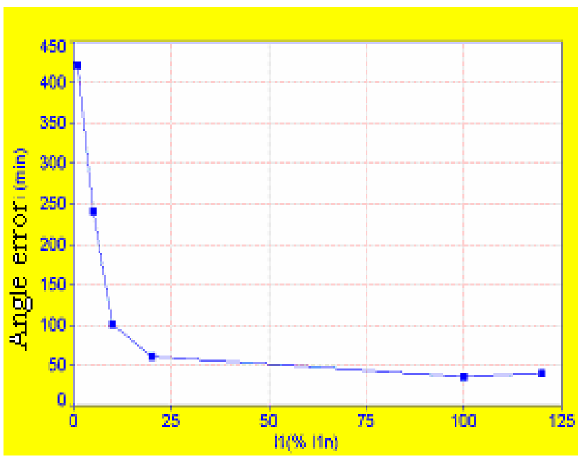


Fig. 2. SIMULINK model for the current transformer.

The results of simulations are presented in figure 3.



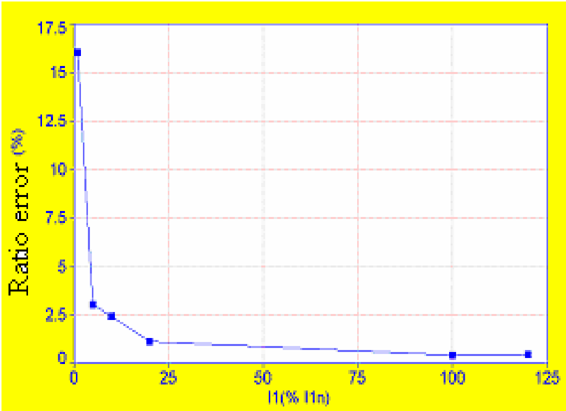


Fig. 3. Errors of the instrument transformer.

To explain the frequency response of ordinary instrument transformers the equivalent circuit diagram of Figure 4 or a similar simplified circuit of Figure 5 are most often used [13].

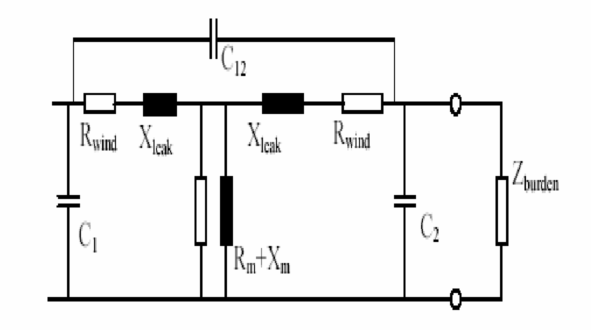


Fig. 4. Model for instrument transformer at medium frequencies.

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 4, 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 4 may be reduced to the circuit diagram according to Figure 5.

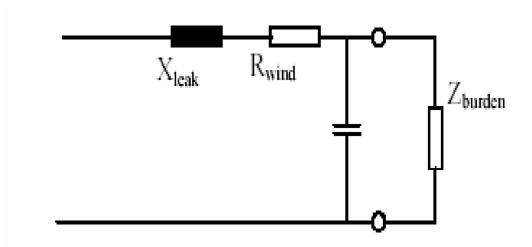


Fig. 5. Simplified model.

Let us analyze the propagation of the errors affecting the measurement of powers and energies one can use a simply model of current transformer- figure 6.

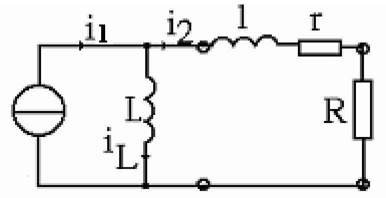


Fig. 6. Model of current transformer.

One can determine easily the frequency response $H(j\omega)$:

- the amplitude response:

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

corresponds to the ratio of real transformation (k_I) and it is related to parameters L, l ,ω, $R' = R+r$, figure 7. The perfect conditions for a current transformer are: inductance L has an infinite value, the values of l and R' negligible.

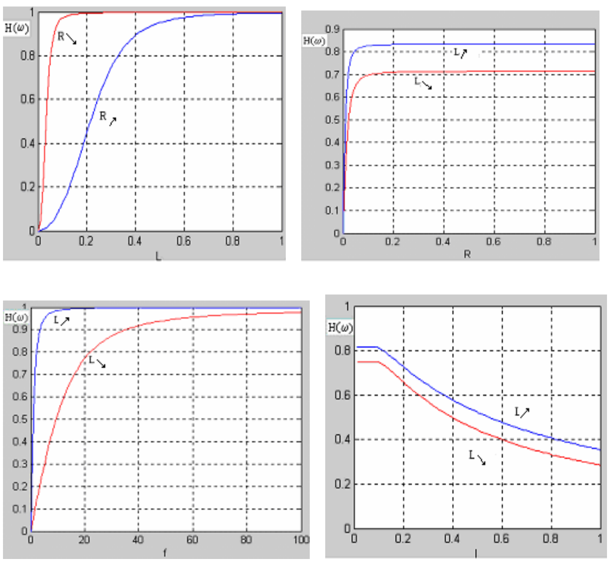


Fig. 7. Errors in the measurement of active power due to $H(\omega)$.

- the phase response:

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

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 8). 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.

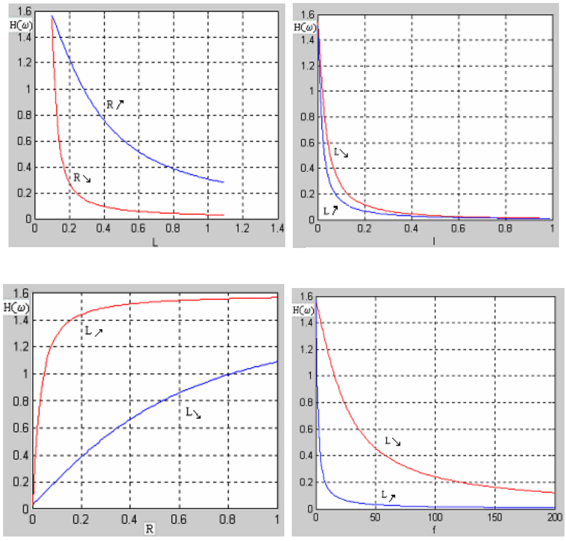


Fig. 8. Errors occurring in the measurement of active power due to Θ.

The effects of internal parameters of current transformer in the power measurement is presented in the figure 9.

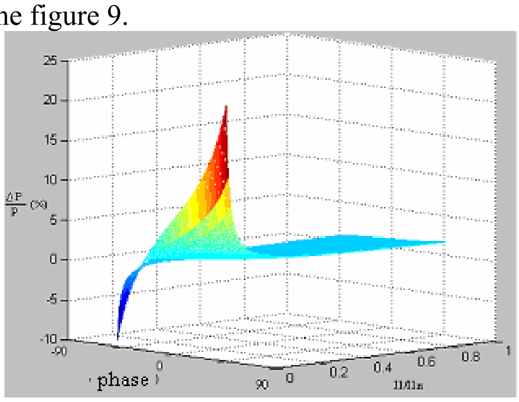


Fig. 9. Effects of internal parameters of current transformer in the power measurement.

3 Methods for compensation

A correct compensation is carried out only for one fixed configuration: type of transformer, wiring and measuring apparatus [14]. Another correction has to use a passive network – figure 10 - or an active circuit in order to compensate for errors caused by the transformer. As the phase is well informed inductance *L*, one can cancel this current with a capacity component.

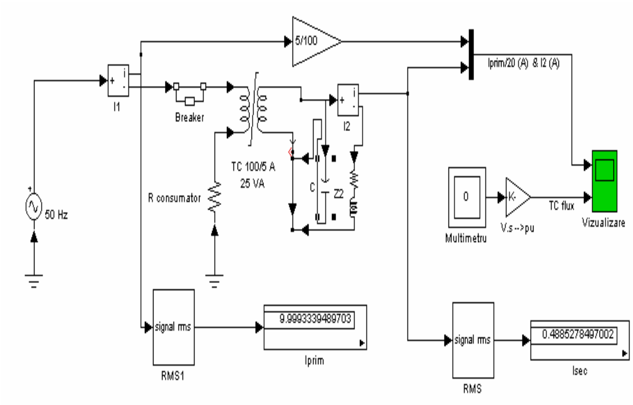
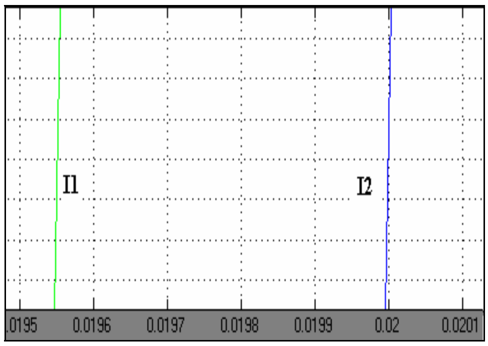
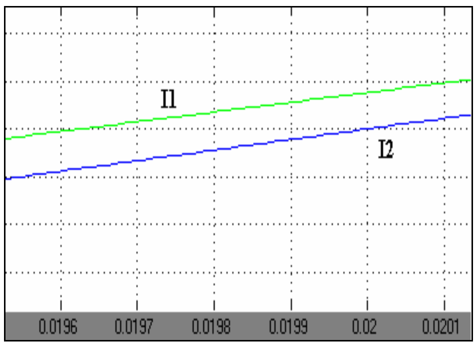


Fig. 10. SIMULINK model for passive compensation of current transformer.

The results of compensation for small current are presented in figure 11.



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



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

Fig. 11. Passive compensation, I_1 = 1 % I_{1n}.

4 Conclusions

The measuring equipment of the electric power, with instrument 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.

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