Sistemas de compensación de transformadores de medida y protección

Daniel Slomovitz
Instituto de Ingeniería Eléctrica
Facultad de Ingeniería
UNIVERSIDAD DE LA REPÚBLICA

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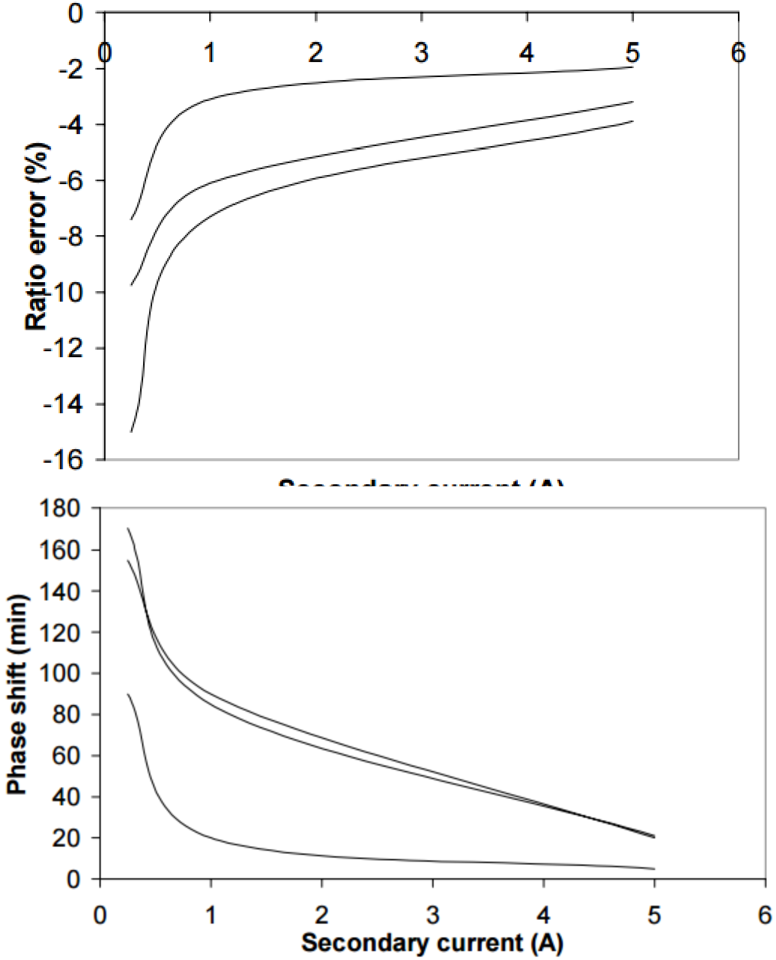
Compensación pasiva de CT

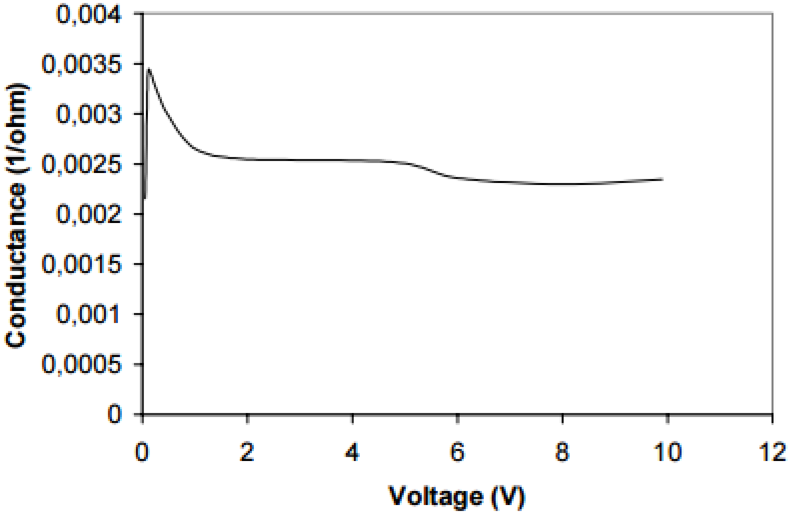


150 A/5 A.

Cargas: 0 VA (curva inferior), 7.5 VA (curva central) y 15 VA (curva superior).

- **Compensación de errores en transformadores de corriente usados en redes de alta tensión**, ALEJANDRO SANTOS , DANIEL SLOMOVITZ, IEEE Revista Latinoamericana, v.: 4 3 , p.:21 - 25, 2006, ISSN: 15480992

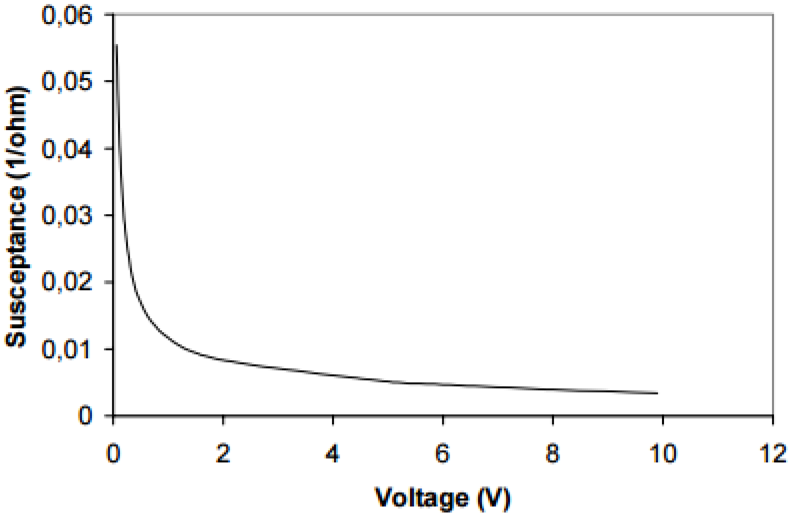
Compensación pasiva de CT

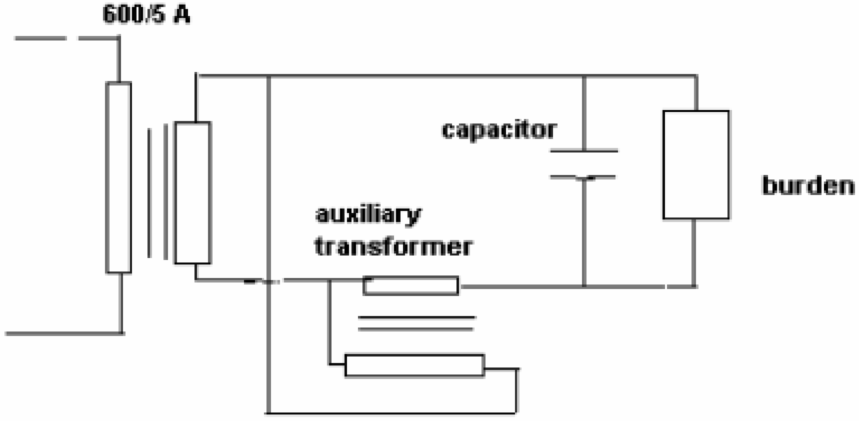


Impedancia magnetizante

Rm: 300 a 400 ohm
Xm: 20 a 100 ohm

Compensación : C=15 uF

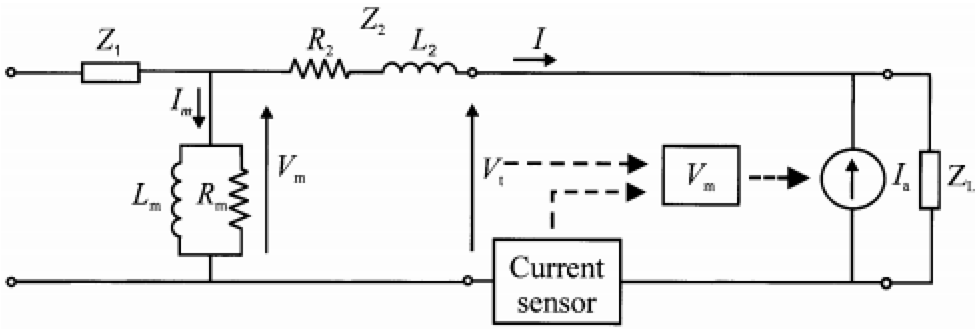




Compensación pasiva de CT

Ratio Burden (VA)	Current (% of IN)	Ratio error (%)	Phase shift (min)
150/5	5	-15	155
	20	-7	90
	100	-4	20
	120	-4	10
600/5	5	-1,6	45
	20	-1	22
	100	-0,6	7
600/5 Compensado	5	-0,2	16
	20	0	9
	100	0,1	9
	120	0,1	6

Compensación CTs en servicio



$$I_m = \frac{V_m}{R_m} + \frac{V_m}{j\omega L_m}$$

$$V_m = V_t + R_2 I + j\omega L_2 I$$

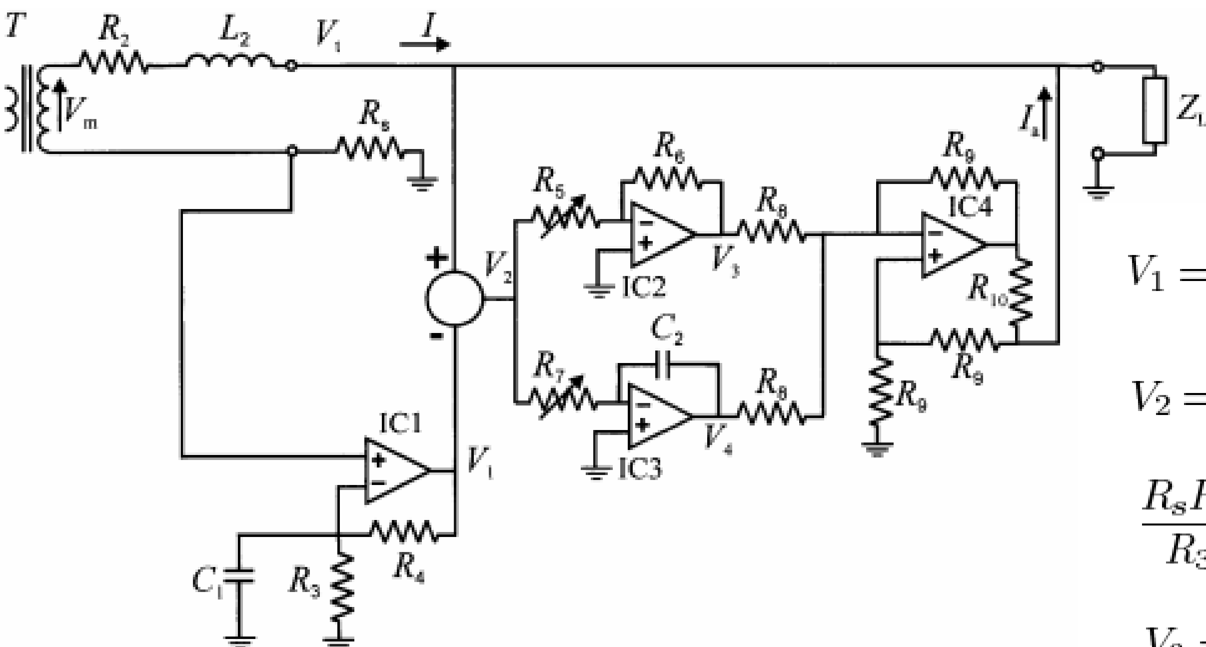
$$I_m = V_t\left(\frac{1}{R_m} - \frac{j}{\omega L_m}\right) + I\left[\frac{R_2}{R_m} + \frac{L_2}{L_m} + j\left(\frac{\omega L_2}{R_m} - \frac{R_2}{\omega L_m}\right)\right]$$

$$I_a = V_t\left(\frac{1}{k_3} - \frac{j}{\omega k_4}\right) + I\left[\frac{k_1}{k_3} + \frac{k_2}{k_4} + j\left(\frac{\omega k_2}{k_3} - \frac{k_1}{\omega k_4}\right)\right]$$

The compensation is automatically achieved if the constants k_i of the electronic control are selected as follows: k_1 is imposed to be equal to R_2, k_2 to L_2, k_3 to R_m, and k_4 to L_m. In this way, the current I_a (amplitude and phase) is equal to the current I_m,

- **Electronic system for increasing the accuracy of in-service instrument-current transformers**, DANIEL SLOMOVITZ, IEEE Transactions on Instrumentation and Measurement, v.: 52 2 , p.:408 - 410, 2003, ISSN: 00189456

Compensación CTs en servicio



$$V_1 = -R_s \left(1 + \frac{R_4}{R_3}\right) I - j\omega R_s R_4 C_1 I$$

$$V_2 = V_t + R_s \left(1 + \frac{R_4}{R_3}\right) I + j\omega R_s R_4 C_1 I.$$

$$\frac{R_s R_4}{R_3} = R_2 \qquad R_s R_4 C_1 = L_2$$

$$V_3 = -V_m \frac{R_6}{\ldots}$$

$$V_4 = V_m \frac{j}{\omega R_7 C_2}.$$

$$I_a = \frac{-V_3 - V_4}{2R_{10}}$$

$$\frac{2R_5 R_{10}}{R_6} = R_m$$

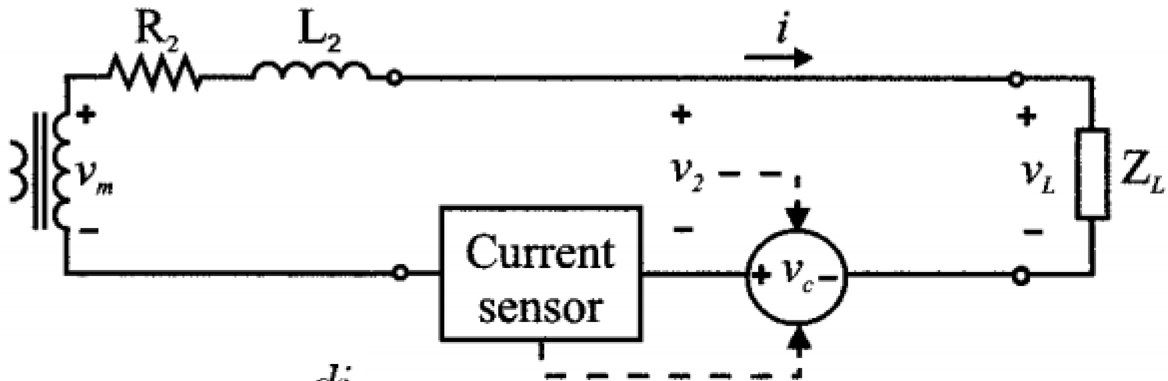
$$2R_7 R_{10} C_2 = L_m.$$

Compensación CTs en servicio

TRANSFORMER EERRORS WITH (COLUMN 3) AND WITHOUT (COLUMN 4) THE COMPENSATING CIRCUIT

Current (A)	Burden (Ω)	Error (compensated)		Error (original)	
		%	crad	%	crad
75	0.3	0.010	0.010	-0.11	0.16
500	0.3	0.005	0.008	-0.08	0.11
1800	0.3	0.002	-0.005	-0.07	0.08
75	1.2	0.010	-0.002	-0.21	0.33
500	1.2	-0.022	0.025	-0.17	0.22
1800	1.2	-0.008	0.010	-0.17	0.12

Compensación pinzas de corriente



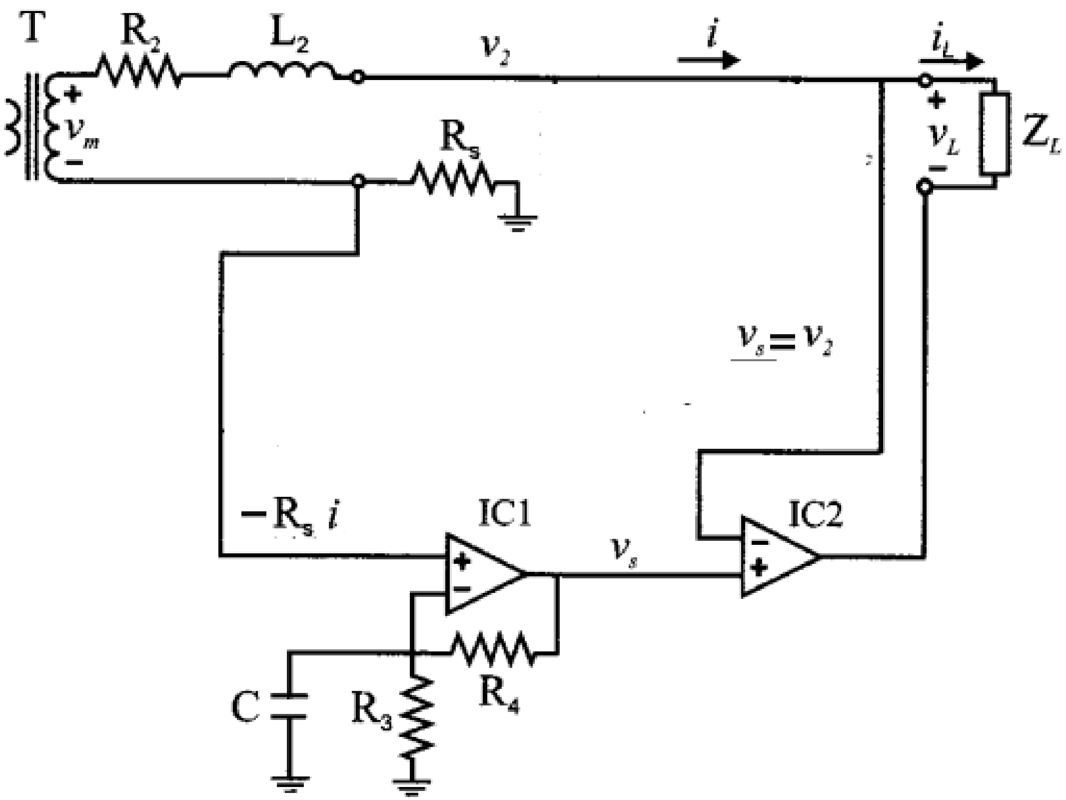
$$v_m = v_2 + R_2 i + L_2 \frac{di}{dt}$$

Si $v_2 = k_1 i + k_2 \frac{di}{dt}$ $\quad v_m = k_1 i + k_2 \frac{di}{dt} + R_2 i + L_2 \frac{di}{dt}$

Para vm=0, k1=-R2, k2=-L2

Electronic error reduction system for clamp-on probes and measuring current transformers. D. Slomovitz, IEEE Transactions on Instrumentation and Measurement Year: 2000 , Volume: 49 , Issue: 6, Pages: 1278 - 1281

Compensación pinzas de corriente

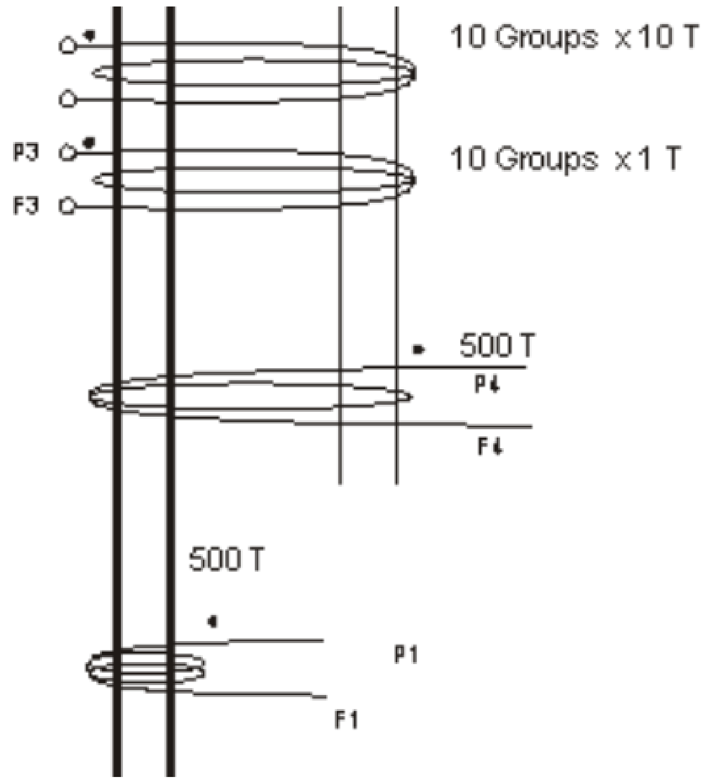


$$v_s = -R_s\left(1+\frac{R_4}{R_3}\right)i - R_sR_4C\frac{di}{dt}$$

$$v_m = R_2 i + L_2\frac{di}{dt} + v_2 + R_s i.$$

$$v_m = \left(R_2 - \frac{R_sR_4}{R_3}\right)i + (L_2 - R_sR_4C)\frac{di}{dt}$$

CT doble etapa



- **Two-Stage Current Transformer with Electronic Compensation**, DANIEL SLOMOVITZ , LEONARDO TRIGO , CARLOS FAVERIO Acta Imeco, v.: 1 1 , p.:85 - 88, 2012

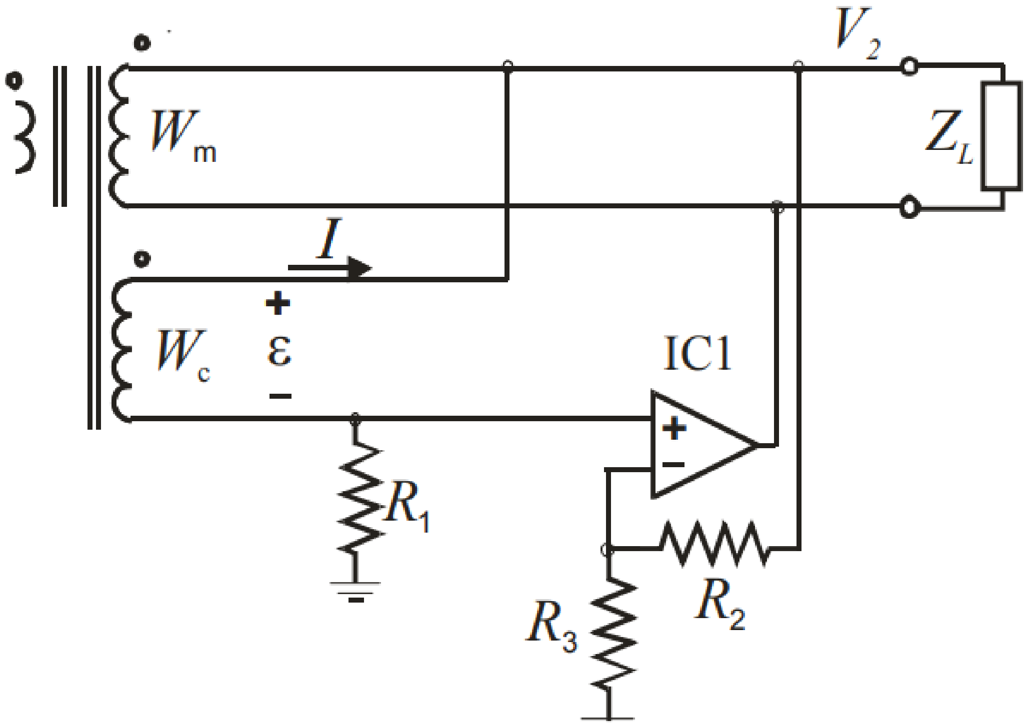
CT doble etapa

Table 1. Available ratios using different series-parallel connections.

Parallel groups	Groups	Turn/Group	Ratio	Input Current (A)
1	10	10	5	1
2	5	10	10	2
5	2	10	25	5
10	1	10	50	10
1	10	1	50	10
2	5	1	100	20
5	2	1	250	50
10	1	1	500	100

Secundario: 0.2 A, 10 ohm

CT doble etapa



$$\varepsilon = I(r + R_1) + V_2$$

$$V_2 = -R_1 I\left(1 + \frac{R_2}{R_3}\right)$$

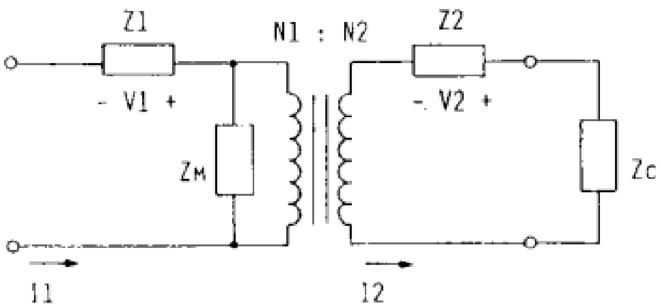
$$\varepsilon = I\left(r - \frac{R_1 R_2}{R_3}\right).$$

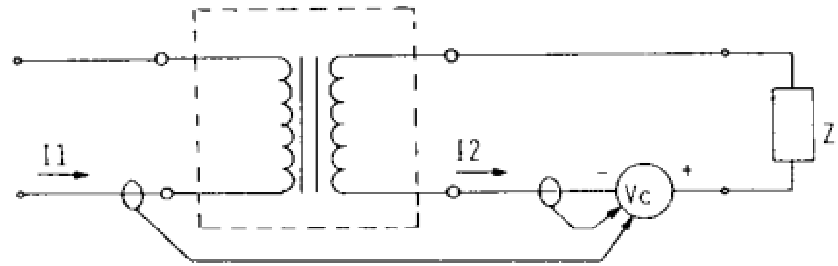
If $r = R_1 R_2 / R_3$, then $\varepsilon = 0$.

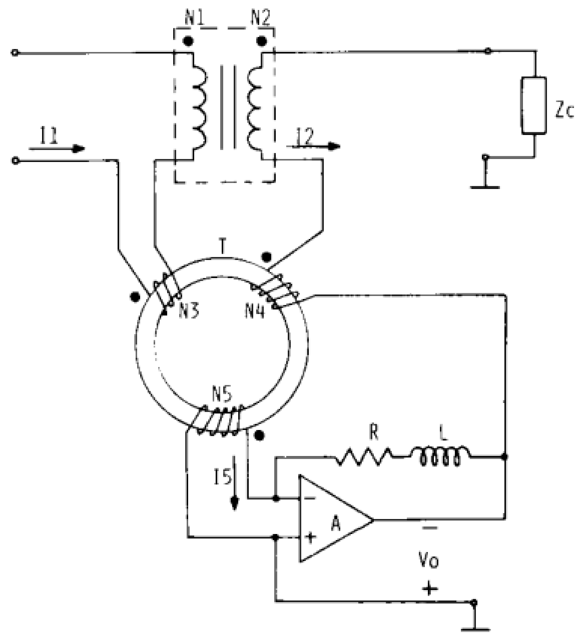
Table 2. Calibration of the proposed transformer.

Ratio	Primary current (A)	Error in phase x10^{-6}	Error in quadrature x10^{-6}
10	2	-0.6	-0.8
5	1	-0.4	-0.6

Compensación de VTs







$$R = Rt \cdot (N5/N3)/(N2/N1 + N4/N3)$$

$$L = Lt \cdot (N5/N3)/(N2/N1 + N4/N3)$$

• **Electronic compensation of voltage transformer**, DANIEL SLOMOVITZ, IEEE Transactions on Instrumentation and Measurement, v.: 37 Diciembre , p.:652 - 654, 1988, ISSN: 00189456

Compensación de VTs

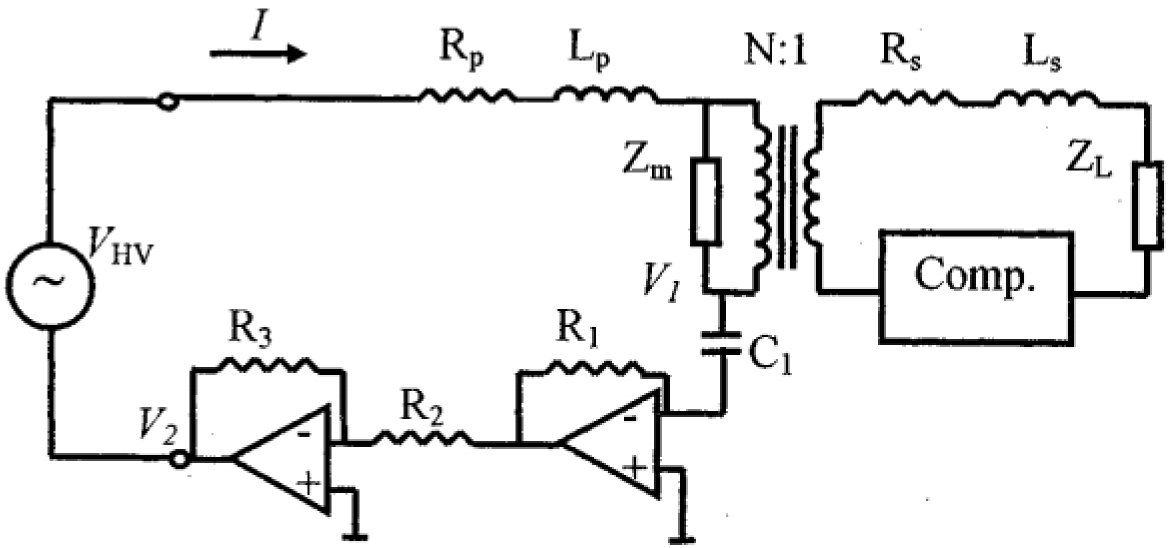
TRANSFORMER ERRORS WITHOUT COMPENSATION

LOAD	INPUT VOLTAGE (V)	RATIO ERROR (%)	PHASE DISPLACEMENT (absolute) (minute)
10VA @ Vn cos phi=0.8	60	-0.56	10
	100	-0.57	11
	130	-0.57	11
	150	-0.61	14

TRANSFORMER ERRORS WITH THE PROPOSED COMPENSATION

LOAD	INPUT VOLTAGE (V)	RATIO ERROR (%)	PHASE DISPLACEMENT (absolute) (minute)
10VA @ Vn cos phi=0.8	60	0.00	0.3
	100	0.00	0.4
	130	0.00	0.5
	150	-0.01	0.7

Compensación VTs



$$V_1 - V_2 = \left(- \frac{R_1 R_3}{R_2} - j \frac{1}{\omega C} \right) I$$

Rp=R1R3/R2, wL=1/(wC)

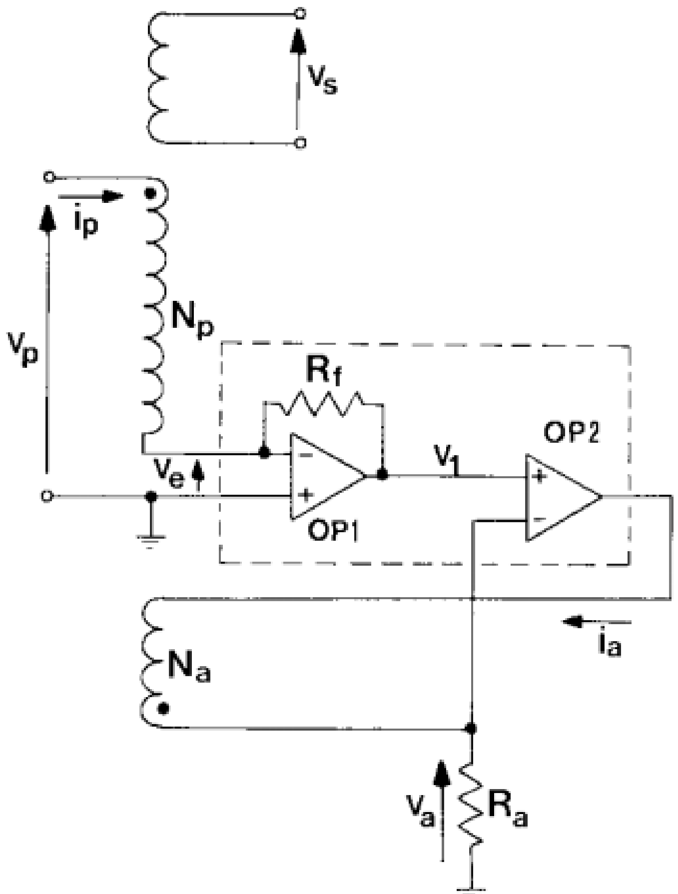
• **Electronic based high-voltage measuring transformers**, DANIEL SLOMOVITZ, IEEE Transactions on Power Delivery, v.: 17 2 , p.:359 - 361, 2002, ISSN: 08858977

Compensación VTs

30 kV/100 V, 15 VA, class 0.1

CONDITIONS		WITHOUT COMPENSATION		WITH COMPENSATION	
Voltage (kV)	Load (VA)	Ratio Error (μV/V)	Phase (μrad)	Ratio Error (μV/V)	Phase (μrad)
12	0	1200	-520	-12	8
24	0	1260	-450	-1	-11
36	0	900	-270	15	-11
36	15	-240	-550	10	-20

Reducción de corriente magnetizante en VT



$$i_a = -Ki_p \quad K = R_f/R_a$$

magnetomotive force, A, is

$$A \text{ (in ampere-turns)} = N_p i_p - N_a i_a$$

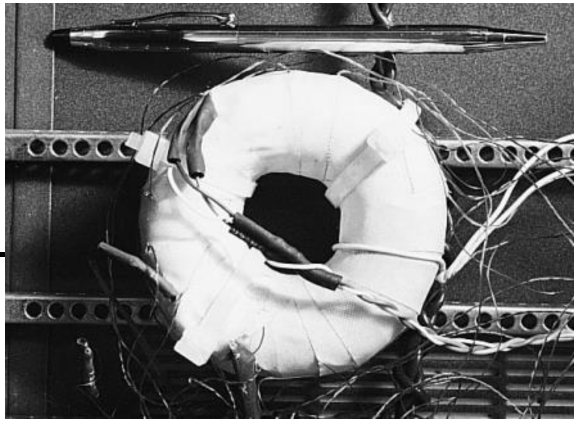
$$i_p = A/[N_p(1 + KN_a/N_p)]$$

- **Electronic compensation of inductive voltage dividers and standard voltage transformers**, DANIEL SLOMOVITZ, IEEE Transactions on Instrumentation and Measurement, v.: 47 2 , p.:465 - 468, 1999, ISSN: 00189456

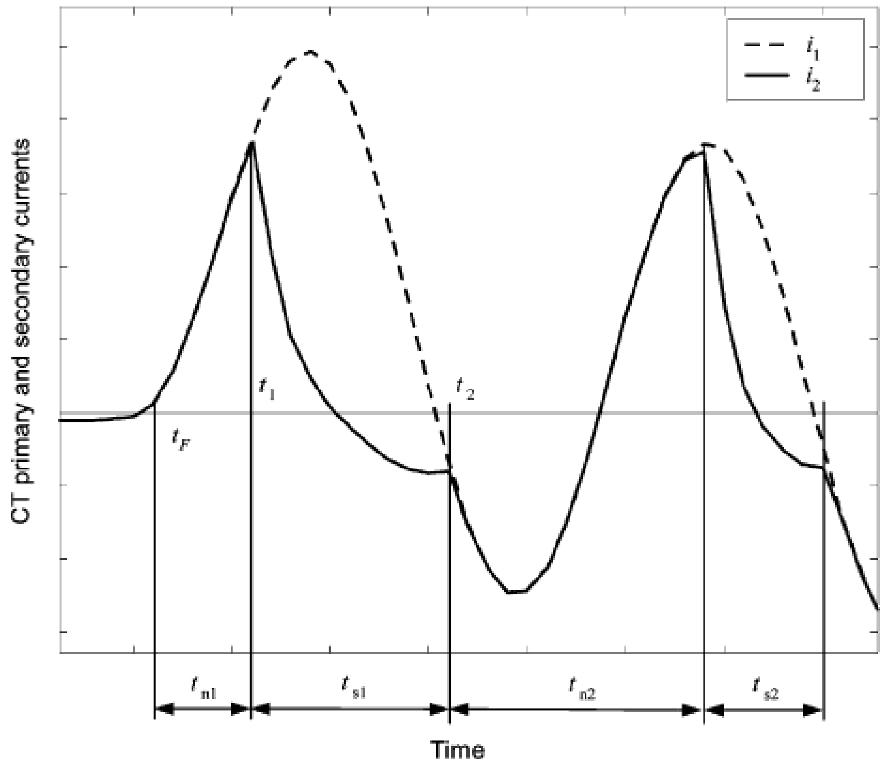
Reducción de corriente magnetizante en VT

TABLE I
PRIMARY CURRENT AGAINST PRIMARY VOLTAGE. FIRST COLUMN: PRIMARY VOLTAGE. SECOND COLUMN: ELECTRONIC COMPENSATION CIRCUIT CONNECTED. THIRD COLUMN: WITHOUT COMPENSATION

Voltage (V)	Cureent with Compensation (μA)	Current withour Compensation (mA)
5	3	0.6
10	5	0.9
20	8	1.4
40	17	2.5
70	24	3.8



Problema de saturación de CTs



Correction of Current Transformer Transient Performance, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 23, NO. 2, APRIL 2008
Andrzej Wiszniewski, Waldemar Rebizant,*, and Ludwig Schiel*

Posibles soluciones

Several approaches may be found in the literature

- determination of CT saturation based on normative recommendations [1] or CT model equations [2];
- detection of CT saturation with the use of algorithmic methods (measurement of certain signal features) (e.g., [3]);
- use of artificial-intelligence techniques [including artificial neural networks (ANNs)] for CT saturation detection and compensation (e.g., [4] and [5]).

[1] *IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes, **ANSI/IEEE C37.110** Std.*
[2] W. Rebizant, K. Feser, T. Hayder, and L. Schiel, “**Differential relay with adaptation during saturation period of current transformers**,” in *Proc. 14th Power System Protection Conf., Bled, Slovenia, Sep./Oct.* 1, 2004, pp. 124–129.

[3] Y. Kang, S. Kang, and P. Crossley, "**An algorithm for detecting CT saturation using the secondary current third-derivative function**," in *Proc.*
IEEE Bologna PowerTech Conf., Jun. 23–26, 2003, pp. 320–326.
[4] M. M. Saha, J. Izykowski, M. Lukowicz, and E. Rosolowski, "**Application of ANN methods for instrument transformer correction in transmission line protection**," in *Proc. 7th Int. Conf. Developments in Power System Protection, Amsterdam, The Netherlands, Apr. 9–12, 2001, pp.* 303–306.
[5] W. Rebizant and D. Bejmert, "**Current transformer saturation detection with genetically optimized neural networks**," presented at the IEEE PowerTech Conf., St. Petersburg, Russia, Jun. 27–30, 2005, paper 220.
[6] Y. C. Kang, U. J. Lim, S. H. Kang, and P. A. Crossley, "**Compensation of the distortion in the secondary current caused by saturation and remanence in a CT**," *IEEE Trans. Power Del., vol. 19, no. 4, pp.* 1642–1649, Oct. 2004.
[7] F. M. Arguelles, M. A. Z. Arrieta, J. L. Dominigues, B. L. Jaurrieta, and M. S. Benito, "**A new method for dc offset removal for digital protective relays**," *Elect. Power Syst. Res., vol. 76, pp. 194–199, 2006.*

Estimación de momento de saturación y predicción

II. Determination of the Instant of Saturation

The time of saturation may be determined by means of comparison of the predicted (estimated) value of the current sample and the real sample of the secondary current. If the secondary current sample $i_2(n)$ is substantially smaller than the estimated value of the current $i_{2e}(n)$, then one may conclude that the saturation took place some time between the samples $(n-1)$ and (n) (see Fig. 2).

To predict the sample $i_{2e}(n)$, which is unknown, one has to use previous samples taken during the undistorted section. The simplest and, at the same time, least accurate method of estimation is based on the assumption that during the time between the samples $(n-1)$ and (n), the first derivative of the primary current is the same as in the previous sampling period between the samples $(n-2)$ and $(n-1)$. This leads to the formula (see Appendix)

$$i_{2e}(n) = 2 * i_2(n-1) - i_2(n-2). \qquad (1)$$

Fin