7º CEDE 1990

MEDICION DEL FACTOR DE POTENCIA EN CARGAS NO LINEALES

Ing. Daniel Slomovitz

U.T.E. LABORATORIO

Paraguay 2385, Montevideo, URUGUAY

Resumen. Se analizan los errores que cometen distintos sistemas de medida, en la evaluación del factor de potencia. En particular son estudiados: los instrumentos analógicos basados en bobinas cruzadas, los sistemas de medida que computan la potencia activa y reactiva tal como sucede en la facturación de empresas eléctricas, y los instrumentos electrónicos basados en la detección de los cruces por cero de las ondas de voltaje y corriente.
Se concluye que muchos de estos sistemas de medida presentan grandes errores cuando la corriente o la tensión no son sinusoidales. En particular, los medidores electrónicos son los más afectados por estas condiciones de trabajo. Se propone el uso de filtros de manera de disminuir sus errores.

1. Introduction

The definition of the power factor PFa, also under nonsinusoidal waveforms, is

$$PFa = \frac{P}{Vrms\ Irms} \qquad (1)$$

where P is the active power, and Vrms and Irms are the RMS values of the voltage and current.

Different types of instruments have been proposed for the measurement of PFa. Millar (1944) carefully studied the behaviour of the crossed-coil meters under sinusoidal conditions. Most of the analog power-factor meters are based on this principle.

There are a lot of papers on electronic phase meters for sinusoidal signals. All of them are based on the use of zero-crossing detectors. A good discussion about the errors of this kind of instrument is given by McKinney (1967). He thoroughly analysed the errors caused by harmonic distortion in the input signals.

The calculation of the cosine of the phase angle value is necessary for calculating the power factor. Bombi et al (1971) have proposed an analog method to do this calculation. This method uses the sinusoidal waveform of the voltage.

Other kinds of instruments use the proper definition of the power factor (see Corney et al. 1967 and Martínez et al. 1987). These instruments measure the active power and the apparent power, and compute the power factor according to equation (1).

We will calculate the errors produced by each of these kinds of instruments when the current or voltage are nonsinusoidal functions. In this error calculation we shall not consider instrument errors such as friction, errors in the detection of zero crossings, limited frequency response, etc. The consideration will be confined to the theoretical errors produced by their operating principles.

2. Analysis under sinusoidal voltage and nonsinusoidal current

Laboratory tests and calibrations of power-factor meters are performed with sinusoidal generators (see Oldham et al. 1981), but in industrial applications they work under nonsinusoidal conditions. In some cases the waveforms are very distorted such as in inverter or rectifier equipment.

For this analysis we will consider a distorted current i, but a sinusoidal voltage v at the measurement location

$$i = \sum_{n=1}^{n} I_n \cos(n\omega t + \Psi_n) \qquad (2)$$

$$v = V \cos(\omega t) \qquad (3)$$

where I_n is the peak value of the nth harmonic of the current, Ψ_n is its phase angle, V is the peak value of the voltage and w is the angular frequency. The sinusoidal-voltage supposition is used because power networks have very low impedances, hence the distortion of the voltage waveform can be neglected in many cases. In this condition the power factor PFa will be

$$PFa = \cos\Psi_1 \cdot (I_1/\sqrt{2})/I_{rms} \qquad (4)$$

hence

$$PFa = \cos\Psi_1 \cdot (1-D^2)^{1/2} \qquad (5)$$

where D is the harmonic distortion of the current

$$D = (1/2 \sum_{n=2}^{n} I_n^2)^{1/2} / I_{rms} \qquad (6)$$

A. Crossed-coil analog meters

It is easy to see that this kind of instrument measures the cosine of the angle between the voltage and the fundamental component of the current (see Appendix). Thus, the error is

$$\frac{PFc}{PFa} = \frac{1}{(1-D^2)^{1/2}} \qquad (7)$$

where PFc is the value of the power factor shown by the crossed-coil meter. The percentage error Ec is Ec=100(PFc/PFa-1). Fig. 1 shows the relation between the percentage error and the distortion D. If D is lower than 10%, the errors will be smaller than 0.5% . Only a large distortion significantly affects this kind of power-factor meter.

The same error is produced by instruments that use a wattmeter to measure the active power and reactive power (Q) and compute the power factor from the relationship $S^2=P^2+Q^2$, neglecting the distortion power (see Cox et al. 1989). This is the same case than the power utilities, where the power factor is computed from a Watt-hour meter and a var-hour meter.

B. Electronic instruments based on zero-crossing detectors

Low distortion in the input waveforms produces large errors in the power factor measured according to this method. In order to calculate the PF error it is necessary to know the amplitude and phase angle for each harmonic component. Generally, this information is not available, so this error cannot be exactly computed. Notwithstanding, it is possible to limit it, when the distortion of the current is not very high, using the following equation (see McKinney 1967)

$$|\Delta\Psi| \leq \sum_{n=2}^{n} (In/I1) \qquad (8)$$

where $\Delta\Psi$ is the angular difference, in radians, between the angle measured by the instrument and the angle $\Psi 1$.

The difference between cos $\Psi 1$ and PFa must be added to obtain the total error. Equation (7) gives this last amount. The percentage error in the power factor will be Ee=100(PFe/PFa-1), where PFe is the power factor shown by this kind of instrument. The value of the ratio PFe/PFa is

$$\frac{PFe}{PFa} = \frac{\cos(\Psi 1 + \Delta\Psi)}{\cos\Psi 1} \; \frac{1}{(1-D^2)^{1/2}} \qquad (9)$$

Fig. 2 shows the relation between the error Ee and PFa, for currents with 10% (curve b) and 30% (curve a) of harmonic distortion. The errors can be as large as 18% for 10% distortion and PFa=0.5. This shows that these meters cannot be used in measurements where there is some distortion.

Some of the references mentioned the use of low-pass filters in the inputs to avoid these problems, but the effects of filtering have not been analysed.

C. Instruments based on the measurement of active and apparent power

This type of instrument is generally a multipurpose meter. It can measure active and apparent power, voltage and current, and power factor. The power-factor value is computed using (1), so the error generated by its operating principle is zero. Notwithstanding, instruments of this type with small errors in the PF measurement when the waveforms are very distorted, are expensive and difficult to drive in field uses.

3. Analysis under nonsinusoidal current and nonsinusoidal voltage

In order to evaluate the errors of power-factor meters when both waveforms are distorted, it is necessary to know the harmonic content of current and voltage. For the current we will use the general expression shown in (2), but for the voltage we will calculate the harmonic content using a particular Thevenin model of the power network. Fig. 3 shows the proposed model. The resistor R and the inductor L represent the internal-serial impedance of the source. More complex models that take into account the harmonic distortion of the voltage source are refered (see Saleh et al. 1987), but we do not use them because with these conditions it is not possible to arrive to any general conclusion. On the other hand, this harmonic content is usually low.

The harmonic components of the output voltage vo are

$$vo = V \{\cos wt + \sum_{n=1}^{n} [\frac{In}{I1} (En.\cos nwt + Fn.\sin nwt)]\} \qquad (10)$$

The values of the coefficients En and Fn are

$$En = \frac{-R}{V/I1} \cos\Psi n + \frac{nwL}{V/I1} \sin\Psi n \qquad (11)$$

$$Fn = \frac{R}{V/I1} \sin\Psi n + \frac{nwL}{V/I1} \cos\Psi n \qquad (12)$$

The RMS values of vo and i do not differ to much than the values of V and I1. For the most distorted waveform used (#3, Table 1) the ratios are:

V/Vrms = 0.97 and I1/Irms = 0.92. Thus, the per unit values of R and L [R/(Vrms/Irms) and wL/(Vrms/Irms)] practically coincide with R/(V/I1) and wL/(V/I1). For this study we assume R/(V/I1) = 0.03 and wL/(V/I1) = 0.07 which are common values in our distribution networks.

A. Crossed-coil meters

The error produced by this meter is calculated for different shapes of distorted waveforms using (25) which is developed in the Appendix. Table 1 shows the analytical expressions of the current waveforms used. Table 2 shows an extract of the computed percentage errors, with the second column referring to the sinusoidal voltage and the third column to the distorted voltage. The harmonic distortion of the voltage vo is 6% for the waveforms #1 and #2, and 8% for the waveform #3. We may conclude that the error variation caused by the distortion in the voltage waveform can be neglected.

Some meters possess an auxiliary moving coil and a capacitor in the voltage branch to extend the frequency range. This modification increases the errors at low power factors.

B. Zero-crossing meters

The error increase produced by the voltage distortion is given by an equation similar to (8), but changing In/I1 for Vn/V1. For the waveforms analysed this amount is much smaller than the errors shown in Fig. 2, so it can be neglected. Notwithstanding, waveforms generated by inverters have another cause of error generation due to the very fast variation of the current. This variation generates large peaks superposed to the voltage waveform. Electronic power-factor meters that use the voltage waveform to calculate the cosine, are affected by these peaks. On the other hand, the errors generated in the cosine computation may be neglected if the voltage distortion is low.

WAVEFORM NUMBER	ANALYTICAL EXPRESSION
1	cos(wt) + 0.3 cos(3wt)
2	cos(wt+π/2) + 0.3 cos(3wt)
3	cos(wt) + 0.3 cos(2wt) + 0.3 cos(3wt)

Table 1

CURRENT WAVEFORM	PERCENTAGE ERROR (Sinusoidal voltage)	PERCENTAGE ERROR (Distorted voltage)
1	4.4	4.9
2	4.4	4.0
3	8.6	9.5

Table 2

4. New power-factor meter

The first improvement that can be made on zero-crossing meters consists in using two low-pass filters at the inputs. The filters remove the harmonic components of the input voltage and current so the value displayed by this instrument PFf is

$$PFf = \cos\varphi 1 \qquad (13)$$

were $\varphi 1$ is the angle between the fundamental components of voltage and current. Equation (13) shows that under sinusoidal voltage this meter has equal errors than the analog meter. This improvement represents a 100 times error reduction at PF=0.2. Also with distorted voltage we will show that the use of filters significantly improve the behaviour of the zero-crossing meters.

Another error reduction can be achieved measuring the input and output signals on the filters and computing the power factor according to

$$PFp = \cos\varphi 1 \frac{\frac{1}{2}\, V1\ I1}{Vrms\ Irms} \qquad (14)$$

where PFp is the value displayed by this meter, Vrms and Irms are the RMS values of the input voltage and current, and V1 and I1 are the peak values of the fundamental components. Fig. 4 shows the block diagram of this instrument. The low-pass filters remove the harmonic components of v(t) and i(t). The instrument measures Vrms, Irms, V1 and I1. Finally a conventional phase meter measures the phase angle between the sinusoidal waveforms.

Also a digital instrument based on FFT can compute (14). Jain et al. (1979) propose an algorithm to achieve high accuracy measurements of amplitude and phase of the fundamental waves, and RMS values. With this system all measurements and calculations can be done in a digital form.

From (14) and the power-source model proposed in Fig. 3, we will calculate the error produced by this system, when both current and voltage are distorted. The value of power P from the source model to the load is

$$P = \tfrac{1}{2}\, V\ I1 \cos\psi 1 - \tfrac{1}{2}\, R\ I1^2 - \tfrac{1}{2}\, R \sum_{n=2}^{n} In^2 \qquad (15)$$

The 2 first terms evaluate the power related to the fundamental waves of voltage and current. The third term only contents harmonic components ($n \geq 2$). On the other hand, the value of the active power consumed by the load, related to the fundamental components of voltage and current, is $\tfrac{1}{2}.V1.I1.\cos\varphi 1$. The generated and consumed power related to fundamental components, at the same point (load terminals) must be equal, hence

$$\tfrac{1}{2}\, V\ I1 \cos\psi 1 - \tfrac{1}{2}\, R\ I1^2 = \tfrac{1}{2}\, V1\ I1 \cos\varphi 1 \qquad (16)$$

From (1), (14), (15) and (16) we conclude that the value of the error produced by this measuring system is

$$PFp - PFa = \frac{1}{2}\,\frac{R \sum_{n=2}^{n} In^2}{Vrms\ Irms} \qquad (17)$$

Hence

$$PFp - PFa = r\,D^2 \qquad (18)$$

where r=R/(Vrms/Irms) is the per unit value of R. This error is zero if r=0. In this case the voltage can be distorted due to the inductor L. Obviously, if r=0 and L=0 the error is zero. This case corresponds to sinusoidal voltage. The value PFp is always greater than or equal to the actual power factor. The current distortion D is the only parameter of the waveform upon which the error depends.

To compare with the errors produced by the other kinds of instruments, we assume r=0.03, as was established previously. The percentage error Ep of the proposed meter is [Ep=100(PFp/PFa-1)]. Fig. 5 shows the calculated error values for 2 current distortions: 10% (curve b) and 30% (curve a).

Fig. 1 shows that crossed-coil meters have an error of 5% if D=30% . Under these conditions the proposed meter has errors between 0.3% and 3% when the PF varies between 1 and 0.1 respectively. This represents an error decrease of between 17 and 1.7 times.

The ratio between PFf and PFp is

$$\frac{PFf}{PFp} = \frac{Vrms\ Irms}{\frac{1}{2}\ V1\ I1} \qquad (19)$$

If Dv is the voltage harmonic distortion

$$\frac{PFf}{PFp} = \left(\frac{1}{1-D^2}\right)^{\frac{1}{2}} \left(\frac{1}{1-Dv^2}\right)^{\frac{1}{2}} \qquad (20)$$

The value of the last term, for the most distorted waveform analysed (#3, Table 1) is 1.003. This shows that in the zero-crossing meter with filters, previously mentioned, the error increase due to the voltage distortion can be neglected.

5. Experimental evaluation

An instrument was developed according to the proposed system. Fig. 6 shows its block diagram. It is similar to the diagram shown in Fig. 4, but it only has one filter and one voltmeter. The 2 filters of Fig. 4 must have equal performance in the pass band. Also the 2 voltmeters and 2 ammeters should be of high precision. These conditions are difficult to achieve and imply high costs. On the other hand, the system shown in Fig. 6 uses only one filter and one voltmeter, which must be changed between the input and output port of the filter. The voltmeter error and the errors due to the filter are greatly cancelled with this system. The phase shift produced by the filter is the same for both channels, so it does not change the measured angle $\varphi 1$. The voltmeter error affects in a similar way the input and output voltages of the filter, so the voltage and current ratios shown in (14) remain unchanged.

As an angular reference, it uses the voltage input signal. The commutation of the switches and the computation of the measured values can be done automatically. This is easy to achieve if the phase meter has a microprocessor. However, for evaluating the proposed system we used manual commutation and calculation. With S1 in the upper position the voltmeter measures Vrms when S2 is in the left side, and $V1/\sqrt{2}$ when it is in the right side. With S2 in the lower position the voltmeter measures a proportional value of Irms and $I1/\sqrt{2}$ when S2 is in the left and right sides, respectively. The angle 1 results as the difference between the 2 angles measured by the phasemeter.

The filter used is a 6th order Tchebyscheff type with a 70 Hz cut-off frequency. The attenuation at the 3rd harmonic (150 Hz) is 200 times. The voltmeter used is an RMS-responding 4 ½-digit instrument. The phase meter used has 0.01 degree of precision.

For the comparison, a class 1 crossed-coil meter, a zero-crossing electronic power-factor meter, the same meter but with filters in the inputs, and the proposed system were tested. We also measured the active power, voltage and current to compute the actual value of PF. We used a 0.05 class digital wattmeter and digital voltmeter and ammeter with errors smaller than 0.03% . To be sure about the errors that this set of instruments has under nonsinusoidal waveforms, we compared the calculated PF with the PF measured by an AC-DC thermal transfer instrument (see Goffin et al. 1946). Unfortunately the measurement technique with this system is very cumbersome. We have used this method only to be sure that the measurement system composed of a wattmeter, voltmeter and ammeter has errors smaller than 0.1% .

A microprocessor-based waveform generator produces the nonsinusoidal waveforms, which are amplified to drive the current circuits of the meters under test. A sinusoidal source synchronized with the current generator acts as the sinusoidal voltage source. The synchronism circuit can change the power factor value. The circuit shown in Fig. 7 was used to obtain a distorted voltage source. This circuit simulates the voltage waveform vo produced by the circuit of Fig. 3.

Tables 3 and 4 show the measured percentage errors, generated by the crossed-coil meter (Ec), the zero-crossing meter (Ee), the zero-crossing meter with filters (Ef), and the proposed PF meter (Ep). These errors are related to the current waveforms shown in Table 1, for power factors varying from 0.1 to 1. Table 3 refers to a sinusoidal voltage and Table 4 to a distorted voltage. The measured values are in accordance with the previous theoretical conclusions. In this way, the percentage error of crossed-coil meters is practically independent of the PF value, according to (7) and Table 2. Only around PF=0.1 is this value slightly increased, because the actual percentage error of the instrument increases as the power factor approaches to zero. There are no significant differences using sinusoidal or distorted voltages. This fact supports the conclusions of Section 3.

CURRENT WAVEFORM	PF	Ec %	Ee %	Ef %	Ep %
1	0.15	7.2	-60	5.5	0.7
1	0.3	4.0	-27	5.0	0.2
1	0.5	3.8	-9	4.9	0.1
1	0.8	3.7	-2	4.8	0.0
1	1	4.2	2	4.7	-0.1
2	0.1	5.1	220	6.0	1.2
2	0.2	3.1	120	5.5	0.7
2	0.5	3.9	40	5.1	0.3
2	0.8	4.4	19	4.9	0.1
2	1	4.3	3	4.8	0.0
3	0.15	8.6	360	8.7	-0.4
3	0.3	8.2	190	9.5	0.4
3	0.5	7.6	80	9.4	0.3
3	0.8	8.1	-37	9.2	0.1
3	1	8.5	-4	9.0	-0.1

Table 3

CURRENT WAVEFORM	PF	Ec %	Ef %	Ep %
1	0.15	8.2	7.4	2.1
1	0.3	4.7	6.2	0.9
1	0.5	4.0	5.9	0.6
1	0.8	4.1	5.7	0.4
1	1	4.4	5.7	0.4
2	0.15	4.8	7.8	2.5
2	0.3	3.2	6.5	1.2
2	0.5	5.0	6.0	0.7
2	0.8	4.8	5.8	0.5
2	1	4.6	5.7	0.4
3	0.15	6.6	15	5.1
3	0.3	7.1	13	2.6
3	0.5	8.5	11	1.6
3	0.8	9.1	11	0.9
3	1	8.8	10	0.6

Table 4

The zero-crossing meters have huge errors in the examples shown. For the current waveform #2 of Table 3 (worse case for D=30%), the measured errors are similar to those calculated, shown in Fig. 2 (curve a). These errors are so large that there is no interest in evaluating them under nonsinusoidal voltage.

The errors of zero-crossing meters with filters (Ef) are practically the same as the analog-meter errors under sinusoidal voltage (Table 3) and slightly greater when the voltage is distorted (Table 4).

The proposed system has very small errors under sinusoidal voltage. Also with distorted voltage the errors are about 10 times smaller than crossed-coil meters at PF=1. This agrees very well with the theoretical error reduction, considering the actual errors of these instruments.

6. Conclusions

Crossed-coil meters have errors of 0.5% when the current harmonic distortion is 10% . This shows that only high distortion significantly affects this kind of PF meter.

The electronic zero-crossing meters have huge errors even at low distortion levels. With a 10% distortion, the error can be as large as 20% around PF=0.5 . This shows that this meter cannot be used in measurements where there is some harmonic distortion.

A great improvement is achieved using low-pass filters in the inputs. Such an instrument has errors similar to analog meters.

To diminish the errors coming from the cancellation of the harmonic components, it is proposed to measure the RMS and the peak values in the input and output ports of the filter and computes these values according to (14). The error of this measuring system is zero when the voltage is sinusoidal. Under nonsinusoidal voltage the error is about 100 times smaller than conventional electronic-zero-crossing meters and about 10 times smaller than crossed-coil meters.

Appendix

Fig. 8 shows the diagram of a single phase crossed-coil meter. θ is the deflection angle. ia, ib and i are the instantaneous values of the currents of each coil. The values of the average torques [1] of each coil Ta and Tb are

$$Ta = Ka \sin \theta \frac{1}{Ra} \frac{1}{T} \int_0^T i \, v \, dt \qquad (21)$$

$$Tb = Kb \sin(\theta+\alpha) \frac{1}{Lb} \frac{1}{T} \int_0^T i \left(\int_{to}^{t} v\, dt \right) dt \qquad (22)$$

where Ka and Kb are constants that depend on the physical configuration of the coils. The integral between the parenthesis, in (22), must have an average value of zero, thus "to" must be fixed according to this criterion. The value of the angle α between coils is 90 degrees in most cases.

The two torques must be equal, thus

$$tg\ \theta = \frac{-Kb}{Ka} \frac{Ra}{Lb} \frac{\frac{1}{T}\int_0^T i \left(\int_{to}^{t} v\, dt \right) dt}{\frac{1}{T}\int_0^T i\, v\, dt} \qquad (23)$$

Generally, the ratio between the constants of this meter may be expressed by the following equation

$$\frac{Kb}{Ka} = \frac{w\, Lb}{Ra} \qquad (24)$$

Where w is the angular frequency of period T. Thus

$$tg\ \theta = -w \frac{\frac{1}{T}\int_0^T i \left(\int_{to}^{t} v\, dt \right) dt}{\frac{1}{T}\int_0^T i\, v\, dt} \qquad (25)$$

It is easy to see that when the current i and voltage v are sinusoidal functions, the value of the second term of (25) is equal to the tangent of the angle between those magnitudes.

This equation permits the calculation of θ for any current and voltage waveforms. We will calculate this angle, supposing a distorted current and sinusoidal voltage according to (2) and (3). The numerator of (25) is

$$\frac{1}{T}\int_0^T i \left(\int_{to}^{t} v\, dt \right) dt = \frac{1}{T}\int_0^T \frac{V}{w} \sin(wt)\{I1 \cos(wt+\Psi 1) + \sum_{n=2}^{n} [In \cos(nwt+\Psi n)]\} dt \qquad (26)$$

Only the fundamental component will have influence on the integral because the integral value of the other terms is zero. Hence

$$\frac{1}{T}\int_0^T i \left(\int_{to}^{t} v \, dt\right) dt = \frac{-1}{2} \frac{I1 \; V}{w} \sin \Psi 1 \tag{27}$$

On the other hand, the denominator of (25) represents the active power. Its value is

$$\frac{1}{T}\int_0^T i \, v \, dt = \tfrac{1}{2} \, I1 \, V \cos \Psi 1 \tag{28}$$

Finally, the value of tg θ is

$$tg\, \theta = tg\, \Psi 1 \tag{29}$$

This equation shows that only the fundamental component of the current has influence on this kind of instrument, when distorted current and sinusoidal voltage are applied.

References

Bombi,F. and Ciscato, D., Feb. 1971, Digital power-factor meter has high order of accuracy, Elec. Engin.,55-58.

Corney, A.C. and Pullman,R.T.,1987, Digital sampling laboratory wattmeter. IEEE Trans. Instrum. Meas., IM-36, 54-59.

Cox, M.D. and Williams, T.B., 1989, Induction varhour and solid-state varhour meters performances on nonlinear loads. Paper Nº 89 WM 049-8 PWRD presented at IEEE/PES 1989 Winter Meeting.

Goffin, G. and Marchal, G., 1946, Etude théorique de l'emploi du thermocouple pour la mesure de précision de la puissance en courant alternatif. Bull. Assoc. Suisse des Elect., 20, 595-600.

Jain, V.K. and Collins, W.L. and Davis, D.C.,1979, High-accuracy analog measurements via interpolated FFT. IEEE Trans. Instrum. Meas., IM-28, 113-122.

Martinez, P.M. and Celis, F.N. and Ruiz, E.O. and Gutierrez, J.M.D., 1987, A digital power factor meter (in Spanish). Mundo Electrónico, 170, 107-113.

McKinney, J.E., 1967, Digitized low-frequency phasemeter assembled from logic modules. Jour. Resea. Nat. Bureau Stand.-C, **71C**, 227-238.

Millar, N.P., 1944, Crossed-coil power-factor meters. Trans. Elect. Engineering, **63**, 294-301.

Oldham, N.M. and Turgel, R.S., 1981, A power factor standard using digital waveform generation. IEEE Trans. Power App. Syst., **PAS-100**, 4435-4438.

Saleh, R.T. and Emanuel, A.E., 1987, Optimum shunt capacitor for power factor correction at busses with lightly distorted voltage. IEEE Trans. on Power Deliv., **PWRD-2**, 165-173.

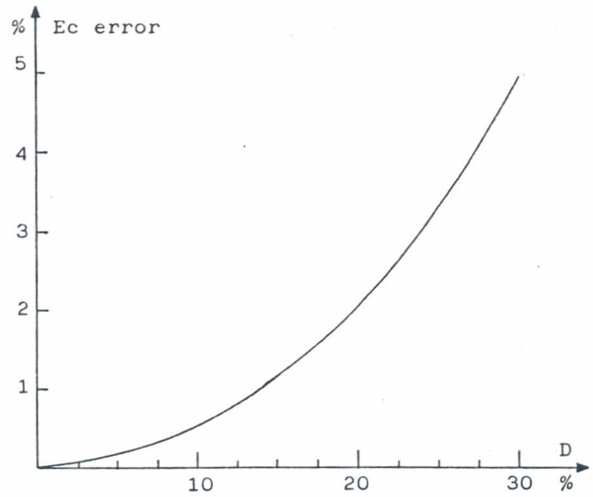

FIGURA 1

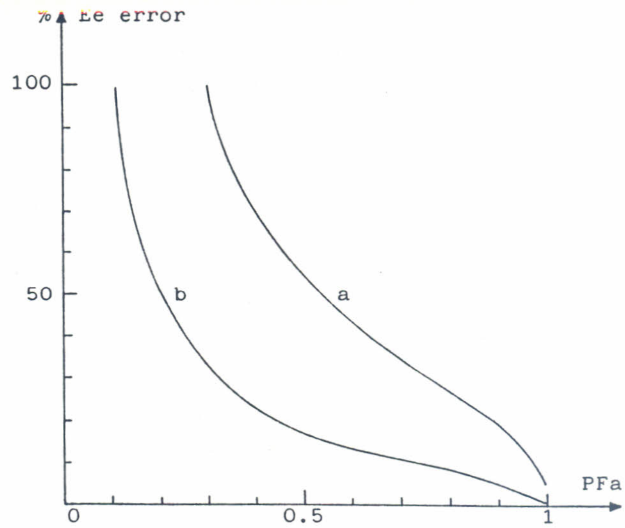

FIGURA 2

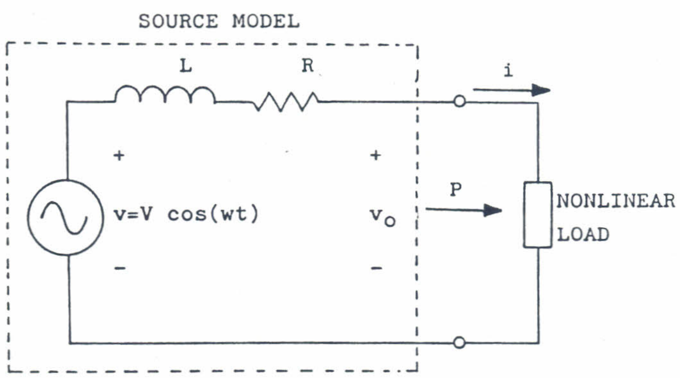

FIGURA 3

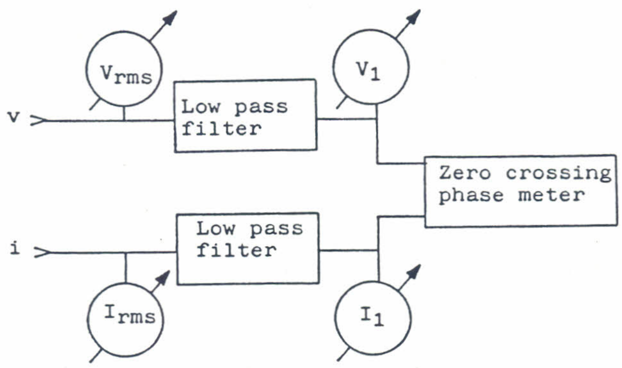

FIGURA 4

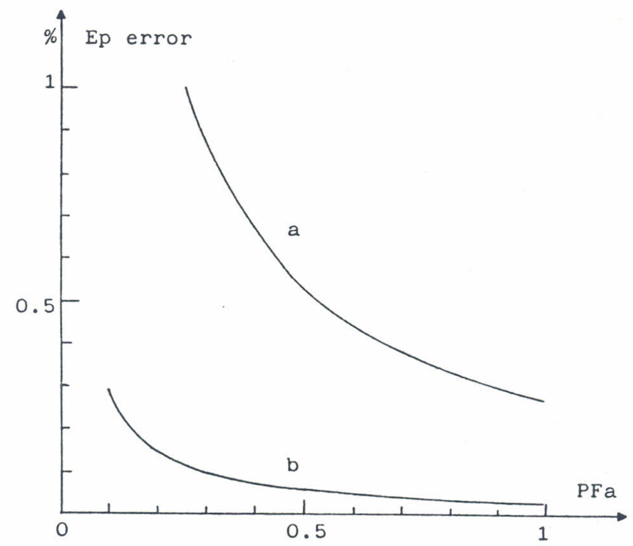

FIGURA 5

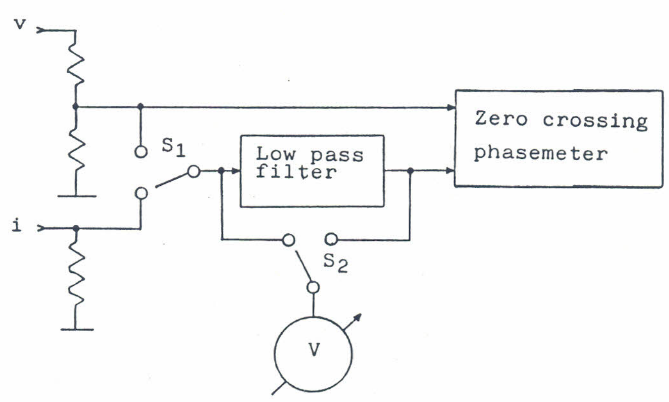

FIGURA 6

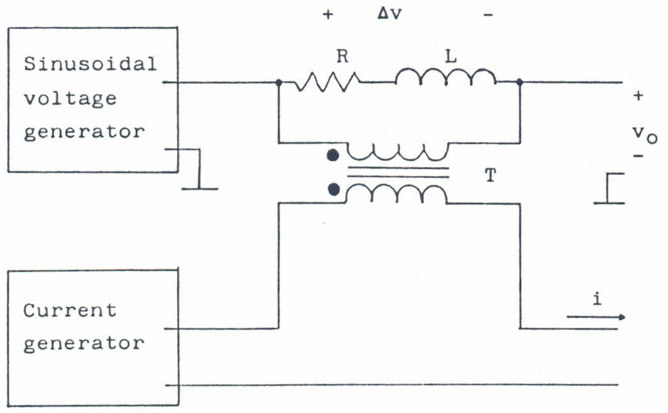

FIGURA 7

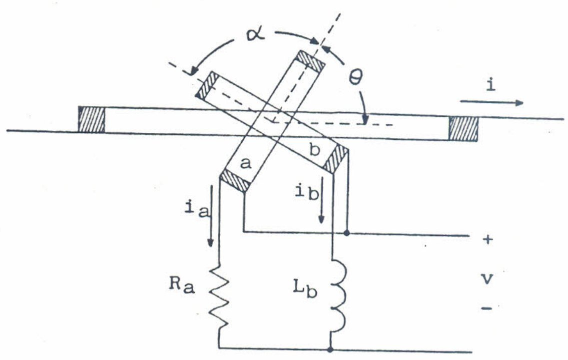

FIGURA 8