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# IEEE Guide for Methods of Power Factor Measurement for Low-Voltage Inductive Test Circuits

## IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

IEEE

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**IEEE Std C37.26™-2003**
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# IEEE Guide for Methods of Power Factor Measurement for Low-Voltage Inductive Test Circuits

Sponsor

**Switchgear Committee**
of the
**IEEE Power Engineering Society**

Approved 11 September 2003

**IEEE-SA Standards Board**

Approved 29 December 2003

**American National Standards Institute**

**Abstract:** This guide provides methods for determining the value of power factor for inductive low-voltage (1000 volts ac and below) test circuits. These methods are used in determining power factor during short-circuit current tests in high power laboratories. It is preferred that these methods be used during short-circuit current testing. Alternatively, other methods (including use of computerized or digital techniques) may be used, but the method used must have been validated as producing results equivalent to those obtained using the methods in this guide. The methods described are intended for use in low-voltage test circuits (under 1000 volts ac), but may also be used for higher voltages.
**Keywords:** inductive test circuits, power factor

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# Introduction

(This introduction is not part of IEEE Std C37.26-2003, IEEE Guide for Methods of Power Factor Measurement for Low-Voltage Inductive Test Circuits.)

This guide covers methods used to measure the power factor in low-voltage test circuits. Since the power factor measurement for high capacity test circuits is particularly difficult and different methods may yield different results, the methods that are least likely to yield error are recommended in this guide for any particular circuit condition.

This low-voltage guide was originally created and issued in 1972 as a compatible companion to the high-voltage American National Standard Methods for Determining the RMS Value of a Sinusoidal Current Wave and a Normal-Frequency Recovery Voltage for AC High-Voltage Circuit Breakers, ANSI C37.05-1964 (R1969) and American National Standard Methods for Determining Values of a Sinusoidal Current Wave, Normal-Frequency Recovery Voltage, and a Guide for Calculation of Fault Currents for Application of AC High-Voltage Circuit Breakers Rated on a Total Current Basis, ANSI C37.5-1969.

Use of the methods in this guide over several decades has demonstrated their validity, and this edition of the guide is only a minor editorial update of the material to present format and styles. No significant revisions to the basic technical content have been made.

It is recognized that laboratories may utilize computer-based data acquisition and analysis programs that may calculate values of test power factor. Such programs should be validated to assure that the results obtained are consistent with values obtained using the methods in this guide.

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# IEEE Guide for Methods of Power Factor Measurement for Low-Voltage Inductive Test Circuits

## 1. Overview

### 1.1 Scope

This guide describes three methods used in the measurement of the power factor of inductive low-voltage (1000 volts and below) test circuits. These methods may be used at any frequency; however, the values in the tables are specifically for 60 Hz test circuits. These methods are:

1) Ratio method
2) DC decrement method
3) Phase relationship method

Table 1 lists the preferred method to be used for different levels of test currents and for different levels of power factor. While this guide is primarily intended for use on low-voltage test circuits, the methods discussed are also usable at higher voltages.

**Table 1—Preferred methods of power factor measurement for low-voltage inductive test circuits[a]**

| Test circuit current range (rms symmetrical) | Interrupting time on test device (cycles) | Circuit power factor | |
|---|---|---|---|
| | | 30% or less | Above 30% |
| 20 kA and below | 0.50 or less | Ratio method | Phase relationship method |
| | Above 0.50 | DC decrement method | |
| Above 20 kA to 130 kA, inclusive | 0.50 or less | Ratio method | — |
| | Above 0.50 | DC decrement method | |
| Above 130 kA | Any | Ratio method[b] | — |

[a]Table 1 applies to single-phase or three-phase test circuits, 60 Hz.
[b]For circuits above 130 kA, where asymmetrical closing conditions may jeopardize test plant equipment, the phase relationship method may be used.

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### 1.2 Purpose

The purpose of this guide is to recommend methods of measuring the power factor for inductive test circuits, so that the preferred method giving the greatest accuracy is recommended for any particular circuit.

### 1.3 Alternative methods

The methods in this guide are preferred. Alternatively, other methods (including use of computerized or digital techniques) may be used, but the method used must have been validated as producing results equivalent to those obtained using the methods in this guide.

## 2. References

This guide shall be used in conjunction with the following publication. When the standard referenced in this document is superseded by an approved revision, the revision shall apply.

IEEE Std C37.100™-1992 (Reaff 2001), IEEE Standard Definitions for Power Switchgear.[1, 2]

## 3. Definitions

The definitions and terms contained in this guide or in other ANSI or IEEE standards referred to in this guide are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this guide.

For definitions of terms used in this guide, refer to IEEE C37.100-1992.

## 4. Ratio method

### 4.1 General

Devices such as current-limiting fuses, fused circuit breakers, and similar fast clearing devices may have total interrupting times of 0.5 cycle or less. The ratio method permits measurement to be made within the operating time of these devices. The ratio method is generally not suitable for use on test circuits with a power factor above 30%.

Since this method requires closing the test circuit to produce the maximum current asymmetry, the resulting high electrical loading and mechanical forces on the bus supports and circuit components may jeopardize the test plant equipment. In such cases, the test laboratory may request to determine the power factor of the test circuit using a reduced current level (such as 50% of the rated test current), with the agreement of the manufacturer and the witnessing test inspector.

### 4.2 Procedures for determining power factor

The power factor of the test circuit is determined at an instant of time one-half cycle (based on the fundamental frequency timing wave) after the initiation of the test current flow by determining the symmetrical

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and asymmetrical (total) currents at this point of time (see Figure 1, Figure 2, and Table 2). Both the rms symmetrical current and the total rms asymmetrical current are to be measured and the ratio $M_A$ (for three-phase test circuits) or $M_M$ (for single-phase test circuits) calculated as follows:

1) Construct the envelope of the test current wave as shown in Figure 1.
2) Construct a vertical line at the one-half cycle time after the initiation of the test current.
3) Measure the deflection of the trace from the zero line to the maximum point of the envelope at the one-half cycle line (this is the value shown as *A*').
4) Measure the deflection of the trace from the zero line to the minimum point of the envelope at the one-half cycle line (this is the value shown as *B*').
5) Calculate the value for the rms symmetrical current, *I*, using Equation (1).
6) Calculate the value for the rms asymmetrical current, *I* ', using Equation (2).
7) Calculate the value for $M_A$ for three-phase test circuit or $M_M$ for single-phase test circuits using Equation (3) or Equation (4), as applicable:

$$I = \text{rms symmetrical current} = \frac{A' + B'}{2.828} = \frac{A}{2.828} \quad (1)$$

$$I' = \text{rms asymmetrical (total) current} = \sqrt{\left(\frac{A}{2.828}\right)^2 + D^2} \quad (2)$$

$$M_M(\text{for single-phase tests}) = \frac{rms\ asymetrical\ current}{rms\ symmetrical\ current} \quad (3)$$

$$M_A(\text{for three-phase tests}) = \frac{average\ of\ the\ rms\ asymmetrical\ curents\ in\ the\ three\ phases}{average\ of\ the\ rms\ symmetrical\ currents\ in\ the\ three\ phases} \quad (4)$$

where

$A'$ = Major ordinate,
$B'$ = Minor ordinate,
$A$ = Peak-to-peak value of alternating component,
= $A' + B'$
$D$ = dc component = $A' - \frac{A}{2}$

Refer to Figure 2 or Table 2 to determine the power factor of the test circuit.

NOTE—The multiplying factors in curve $M_M$ of Figure 2 and the third column of Table 2 are equal to the factors used to determine the rated short-circuit withstand current of an assembly. They are a convenient reference to determine the actual maximum prospective rms asymmetrical current for nonstandard $X/R$ ratios, to which equipment may be sub-

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jected in comparison to the rated value based on an $X/R$ ratio of 6.6 and a multiplier of 1.33 for unfused applications, and an $X/R$ ratio of 5.0 and a multiplier of 1.247 for fused applications (see IEEE C37.20.1-1993, 5.4.4, Note 5).

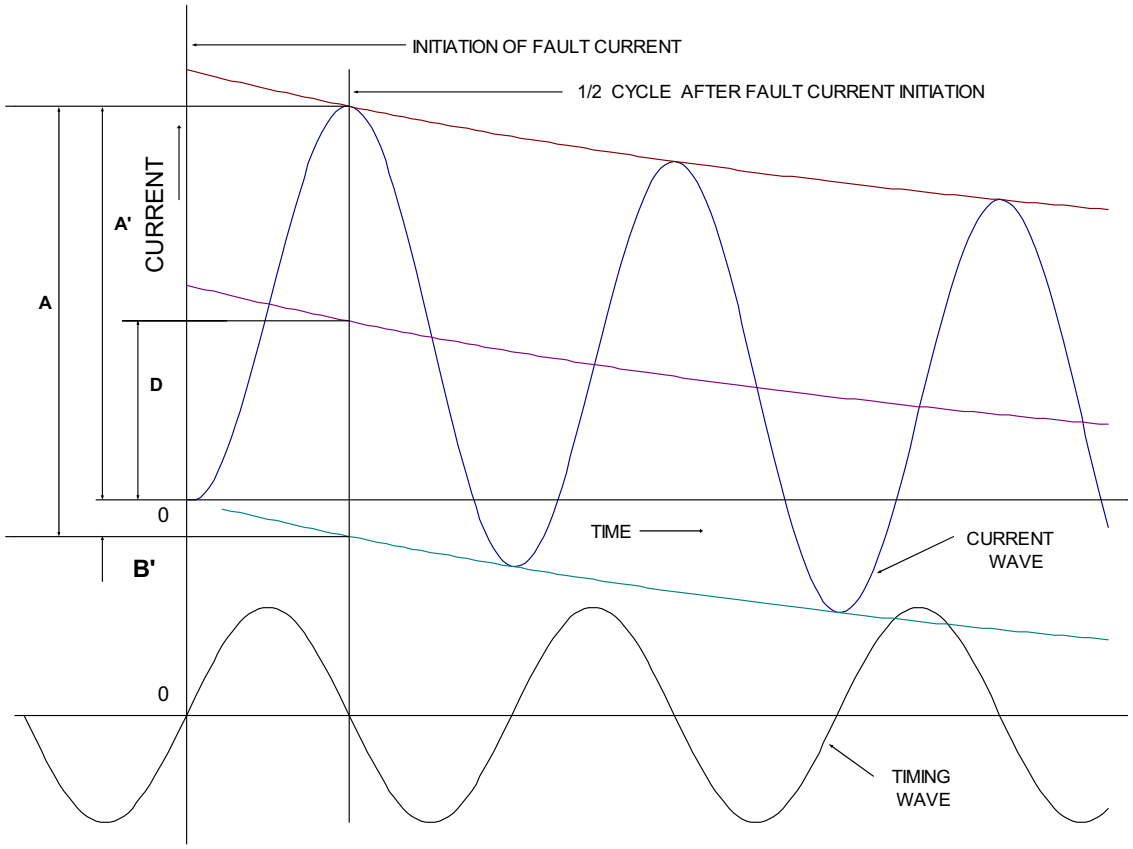



**Figure 1—Ratio method**

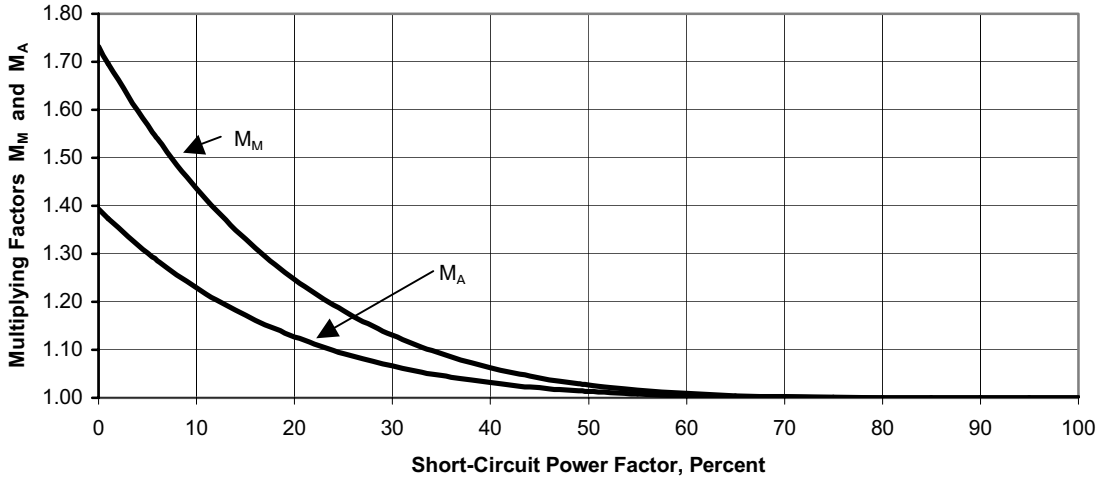



**Figure 2—Multiplying factor versus power factor**


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**Table 2—Multiplying factors for determining circuit power factor at 1/2 cycle**

| Power factor % | $X/R$ ratio | Multiply factor $M_M$ | Multiply factor $M_A$ |
|---|---|---|---|
| 0 | ∞ | 1.732 | 1.394 |
| 1 | 99.995 | 1.696 | 1.374 |
| 2 | 49.990 | 1.662 | 1.354 |
| 3 | 33.318 | 1.629 | 1.336 |
| 4 | 24.980 | 1.598 | 1.318 |
| 5 | 19.975 | 1.568 | 1.302 |
| 5.87 | 17.000 | 1.543 | 1.288 |
| 6 | 16.637 | 1.539 | 1.286 |
| 7 | 14.251 | 1.512 | 1.271 |
| 8 | 12.460 | 1.486 | 1.256 |
| 9 | 11.066 | 1.460 | 1.242 |
| 10 | 9.950 | 1.436 | 1.229 |
| 11 | 9.036 | 1.413 | 1.216 |
| 12 | 8.273 | 1.391 | 1.204 |
| 13 | 7.627 | 1.370 | 1.193 |
| 14 | 7.073 | 1.350 | 1.182 |
| 15 | 6.591 | 1.331 | 1.172 |
| 16 | 6.169 | 1.312 | 1.162 |
| 17 | 5.797 | 1.295 | 1.152 |
| 18 | 5.465 | 1.278 | 1.144 |
| 19 | 5.167 | 1.262 | 1.135 |
| 20 | 4.899 | 1.247 | 1.127 |
| 21 | 4.656 | 1.232 | 1.119 |
| 22 | 4.434 | 1.218 | 1.112 |
| 23 | 4.231 | 1.205 | 1.105 |
| 24 | 4.045 | 1.193 | 1.099 |
| 25 | 3.873 | 1.181 | 1.092 |
| 26 | 3.714 | 1.170 | 1.087 |
| 27 | 3.566 | 1.159 | 1.081 |
| 28 | 3.429 | 1.149 | 1.076 |
| 29 | 3.300 | 1.139 | 1.071 |

| Power factor % | $X/R$ ratio | Multiply factor $M_M$ | Multiply factor $M_A$ |
|---|---|---|---|
| 30 | 3.180 | 1.130 | 1.066 |
| 31 | 3.067 | 1.121 | 1.062 |
| 32 | 2.961 | 1.113 | 1.057 |
| 33 | 2.861 | 1.106 | 1.053 |
| 34 | 2.766 | 1.098 | 1.050 |
| 35 | 2.676 | 1.091 | 1.046 |
| 36 | 2.592 | 1.085 | 1.043 |
| 37 | 2.511 | 1.079 | 1.040 |
| 38 | 2.434 | 1.073 | 1.037 |
| 39 | 2.361 | 1.068 | 1.034 |
| 40 | 2.291 | 1.062 | 1.031 |
| 41 | 2.225 | 1.058 | 1.029 |
| 42 | 2.161 | 1.053 | 1.027 |
| 43 | 2.100 | 1.049 | 1.025 |
| 44 | 2.041 | 1.045 | 1.023 |
| 45 | 1.985 | 1.041 | 1.021 |
| 46 | 1.930 | 1.038 | 1.019 |
| 47 | 1.878 | 1.035 | 1.017 |
| 48 | 1.828 | 1.032 | 1.016 |
| 49 | 1.779 | 1.029 | 1.014 |
| 50 | 1.732 | 1.026 | 1.013 |
| 55 | 1.518 | 1.016 | 1.008 |
| 60 | 1.333 | 1.009 | 1.004 |
| 65 | 1.169 | 1.005 | 1.002 |
| 70 | 1.020 | 1.002 | 1.001 |
| 75 | 0.882 | 1.0008 | 1.0004 |
| 80 | 0.750 | 1.0002 | 1.0001 |
| 85 | 0.620 | 1.0000 | 1.0000 |
| 90 | 0.484 | 1.0000 | 1.0000 |
| 95 | 0.329 | 1.0000 | 1.0000 |
| 100 | 0.000 | 1.0000 | 1.0000 |

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# 5. DC decrement method

## 5.1 General

This method is recommended for test circuits with a power factor of 30% or less, where the device to be tested interrupts at a point in time more than one-half cycle after the initiation of the test current. This method relates the power factor to the rate of decay of the dc component of test current. The current measuring method used should not introduce distortion into the dc component of current. The use of noninductive current measuring shunts is recommended, as current transformers may introduce significant errors into the measurements unless additional precautions are taken.

## 5.2 Procedure for determining power factor

The power factor may be determined from the curve of the dc component of the asymmetrical test current wave. See Figure 3.

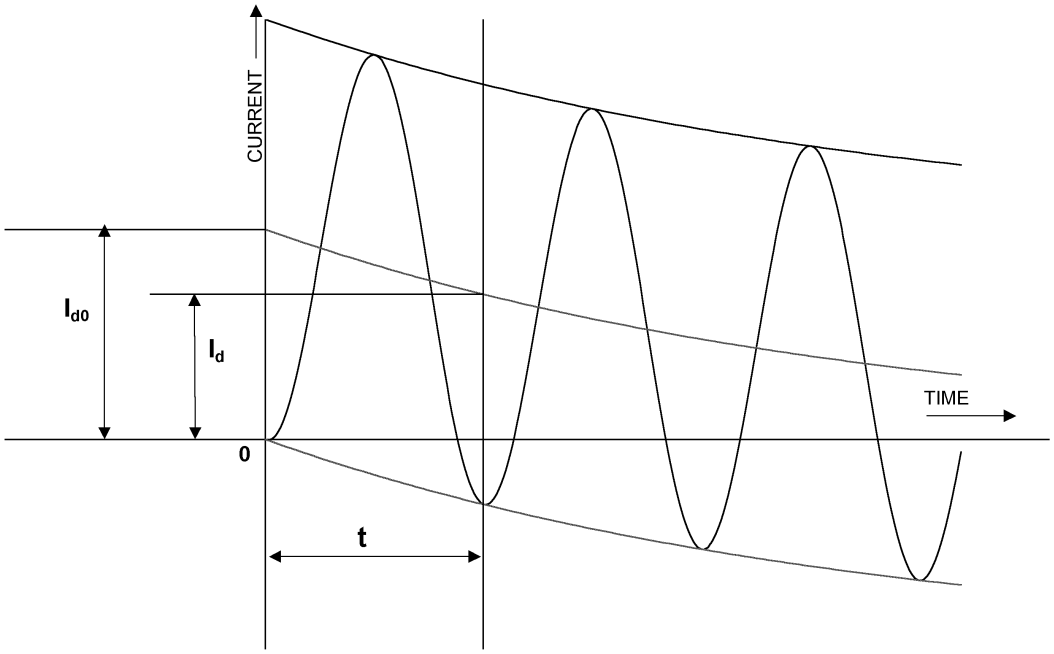



**Figure 3—DC decrement method**

### 5.2.1 Determination of time constant

The formula for the dc component of test current is shown in Equation (5):

$$i_d = I_{do} e^{-(Rt/L)} \tag{5}$$

where

$i_d$ = Value of the dc component of the test current at the time $t$,
$I_{do}$ = Initial value of the dc component of the test current,
$L/R$ = Time constant of the test circuit in seconds,
$t$ = Time interval, in seconds, between $i_d$ and $I_{do}$,
$e$ = Base of the natural logarithms (≈2.7183).


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The procedure to determine the test circuit time constant, using Equation (5), is as follows:

1) Measure the value of $I_{do}$ at the time of the current initiation.
2) Measure the value of $i_d$ at any later time $t$.
3) Determine the value of $e^{-(Rt/L)}$ by dividing $i_d$ by $I_{do}$.
4) Using a calculator, calculate the natural logarithm (ln) of $e^{-(Rt/L)}$ to obtain the value for $-Rt/L$.
5) Calculate the value for the time constant, $L/R$, by dividing the value of $t$ by the value of $-Rt/L$.

### 5.2.2 Determination of power factor angle

Calculate the value of the angle $\phi$ from Equation (6):

$$\phi = \arctan(\omega L/R) \quad (6)$$

where

$\omega$ = $2\pi F$ and $F$ is the actual test frequency in Hz.

### 5.2.3 Determination of power factor

The test circuit power factor then is calculated as shown in Equation (7):

$$\text{Power factor} = \cos\phi \quad (7)$$

$$M_A = \frac{average\ of\ the\ rms\ asymmetrical\ currents\ in\ the\ phases}{average\ of\ the\ rms\ symmetrical\ currents\ in\ the\ phases}$$

$$M_M = \frac{rms\ asymmetrical\ current}{rms\ symmetrical\ current}$$

## 6. Phase relationship method

### 6.1 General

The methods of determining the test circuit power factor dependent upon asymmetrical values of test current (see Clause 4) or the decay of the dc component of test current (see Clause 5) generally are not suitable for the measurement of the power factor of circuits above 30% power factor, where the dc component is severely reduced. This method can also be used for tests with lower power factor if the test current is symmetrical or nearly symmetrical. The phase relationship method, using the time relationship of the current and the voltage waves, is the recommended method on test circuits having power factors above 30%.

### 6.2 Procedure for determining power factor

This method involves the closely controlled closing of the test circuit and determines the power factor of the test circuit under essentially symmetrical current conditions.

1) Determine the “zero point” of the “true” axis of the test current at the end of the first major half cycle by constructing the current waveform envelope and a line midway between the two envelope lines.
2) Determine the open circuit voltage zero that occurs just prior to the current zero of interest by extension in time of 360 degrees from the second voltage zero before the initiation of the test current.

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3) The power factor of the test circuit will be the represented by the time in degrees (or in milliseconds) between the extended open circuit test voltage zero and the current zero at the time of measurement (end of the first major half cycle of test current).

4) This procedure must be repeated on each phase of a three-phase test circuit and the current zero of each phase must be related to the phase-to-neutral voltage for that phase. Greater accuracy will result if the power factor of each phase is determined with the test circuit closed to produce a symmetrical current for the phase under investigation. The test circuit power factor is considered as the average of the individual phase power factors.

5) If the voltage wave is subject to measurement phase shift upon closure of the test circuit (as shown in Figure 4), it is necessary to determine and use the voltage zero point which would have existed (indicated by the dashed line) if the phase shift in the voltage wave had not occurred.

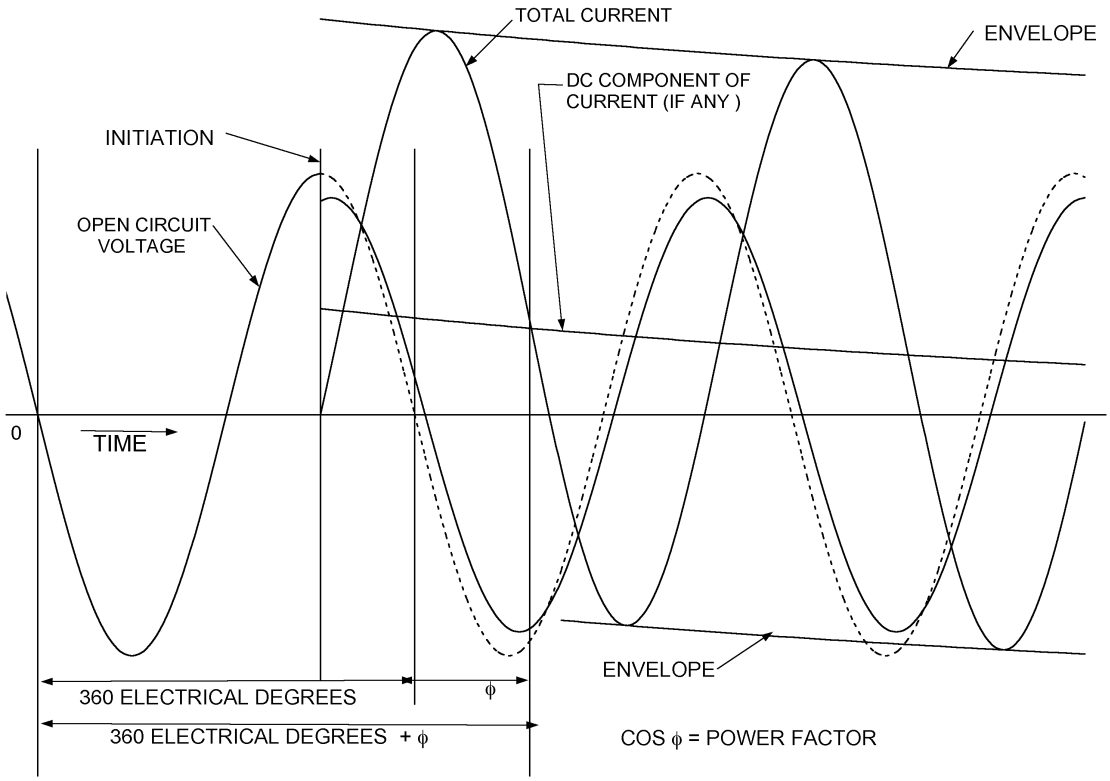



**Figure 4—Phase relationship method**


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# Annex A

(informative)

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