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An American National Standard

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

Sponsor

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IEEE Power Engineering Society

Secretariat

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Foreword

(This Foreword is not a part of American National Standard and IEEE Standard Guide for Power Factor Measurement for Low-Voltage Inductive Test Circuits, ANSI C37.26-1972, IEEE Std 330-1972.)

This standard 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 standard guide for any particular circuit condition.

This low-voltage standard guide has been written 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, 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, C37.5-1969.

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An American National Standard

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

1. Scope

This standard describes three methods used to measure the power factor in 60 Hz inductive low-voltage (1000 volts and below) test circuits. Similar methods may apply at other frequencies. These methods are:

(1) Ratio method
(2) dc decrement method
(3) Phase relationship method

These preferred methods are shown in Table 1.

2. Purpose

The purpose of this standard is to recommend methods of measuring power factor for inductive test circuits by such means as oscillographic records, so that the preferred method, giving the greatest accuracy, is recommended for any particular circuit.

3. Definitions

The definitions and terms contained in this document or in other American National Standards referred to in this document, are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this standard.

For additional definitions of terms used in this standard, refer to American National Standard Definitions for Power Switchgear, C37.100-1972.

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 and generally

Table 1
Preferred Methods of Power Factor Measurement for Low-Voltage Inductive Test Circuits (See Note 1)

Test Circuit Current Range (rms symmetrical)	Interrupting Time on Test Device (Cycles)	Circuit Power Factor	
		0-30 Percent	Above 30 Percent
20 kA and below	0.5 or less	Ratio Method	Phase relationship method
	Above 0.5	dc Decrement Method	
Above 20 kA to 130 kA, inclusive	0.5 or less	Ratio Method	—
	Above 0.5	dc Decrement Method	
Above 130 kA	Any	Ratio Method (Note 2)	—

Notes:

(1) Table 1 applies to single-phase or three-phase test circuit, 60 Hz.
(2) For circuits above 130 kA, where asymmetrical closing conditions may jeopardize equipment or instrumentation, the phase relationship may be used.

is not suitable on circuits with power factors above 30 percent.

Since this method requires closing the circuit to produce maximum current asymmetry, the resulting high mechanical forces on bus supports and circuit components may jeopardize the test equipment or instrumentation. When there is a question of jeopardy, the phase relationship method may be used.

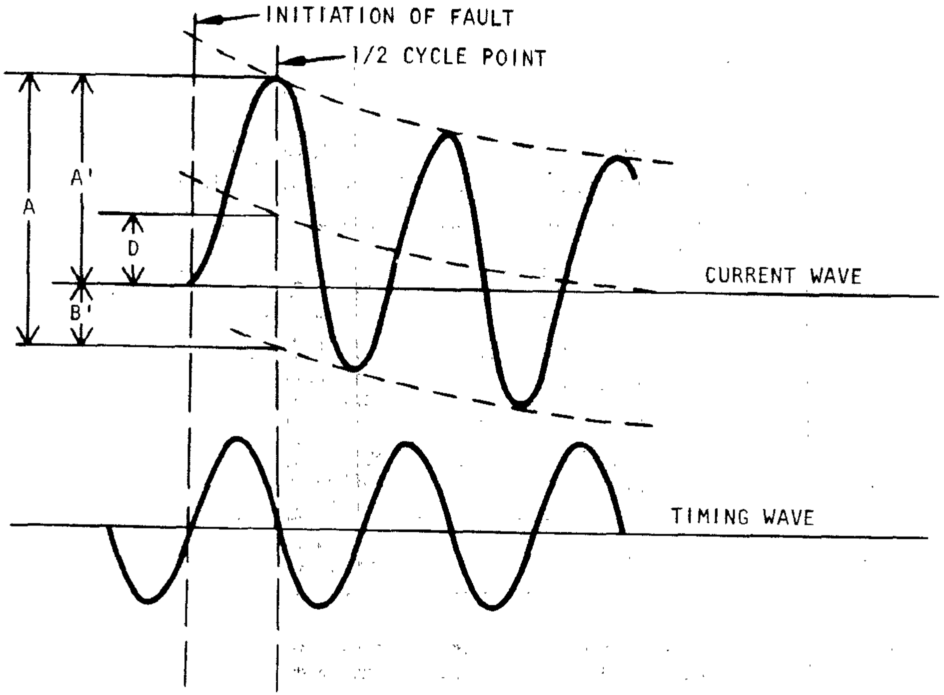
4.2 Procedure for Determining Power Factor. The power factor is determined at an instant one-half cycle (based on the fundamental frequency timing wave) after the initiation of current flow by determining the asymmetrical and symmetrical currents at this point. (See Figs. 1 and 2, and Table 2.) Both total rms asymmetrical current and rms symmetrical current are to be measured and the ratio M_A or M_M calculated as follows: Construct the envelope of the wave as shown in Fig. 1. The rms symmetrical and rms asymmetrical currents shall be determined as indicated in the equations of Fig. 1. Having determined these values, the M_A for three-phase circuits and M_M for single-phase circuits are determined from the following:

$$\text{Ratio } M_A \text{ (for Three-Phase Tests) } \frac{\text{Average of the rms Asymmetrical Current in the Phases}}{\text{Average of the rms Symmetrical Current in the Phases}}$$

$$\text{Ratio } M_M \text{ (for Single-Phase Tests) } \frac{\text{rms Asymmetrical Current}}{\text{rms Symmetrical Current}}$$

Fig. 1
Ratio Method

A' = major ordinate
B' = minor ordinate
A = peak-to-peak value of alternating component $= A' + B'$
D = dc component $= A' - \dfrac{A}{2}$
I = rms symmetrical current $= \dfrac{A' + B'}{2.828} = \dfrac{A}{2.828}$
I' = rms asymmetrical current $= \sqrt{\left(\dfrac{A}{2.828}\right)^2 + D^2}$



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

5. DC Decrement Method

5.1 General. This method is recommended for circuits of 30 percent power factor or less where the device to be tested interrupts at a point in time more than one-half cycle from the initiation of the current. This method relates power factor to the rate of decay of the dc component. The current measuring method used should not introduce distortion into the dc component. Use noninductive shunts since current transformers may introduce significant error.

5.2 Procedure for Determining Power Factor. The power factor may be determined from the curve of the dc component of the asymmetrical current wave. See Fig. 3.

5.2.1 The equation for the dc component is:

$$i_d = I_{d0}\, e^{-(Rt/L)}$$

where

i_d = value of the dc component at time t

I_{d0} = initial value of the dc component

L/R = time constant of the circuit in seconds

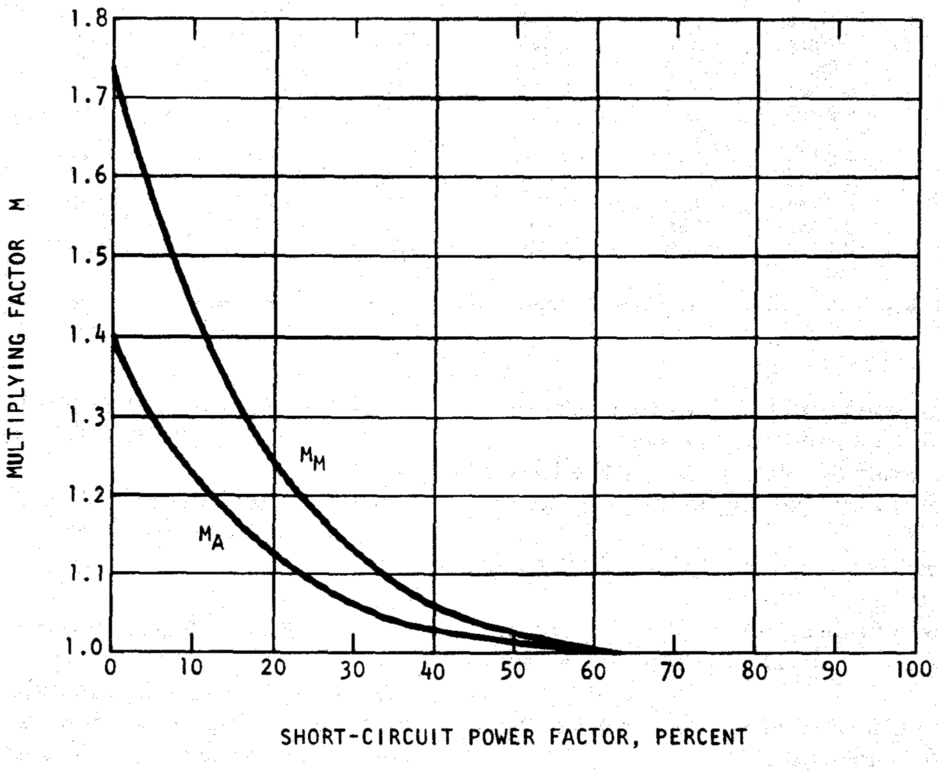
t = time interval, in seconds, between i_d and I_{d0}

e = base of Napierian logarithms (2.7183)

Fig. 2
Multiplying Factor vs Power Factor

$$M_A = \frac{\text{Average of the rms Asymmetrical Current in the Phases}}{\text{Average of the rms Symmetrical Current in the Phases}}$$

$$M_M = \frac{\text{rms Asymmetrical Current}}{\text{rms Symmetrical Current}}$$



Multiplying Factors

Table 2

Power Factor Percent	X/R Ratio	Multiplying Factor: Maximum Single Phase rms Current at ½ Cycle (Curve M_M)	Multiplying Factor: Average Three Phase rms Current at ½ Cycle (Curve M_A)	Power Factor Percent	X/R Ratio	Multiplying Factor: Maximum Single Phase rms Current at ½ Cycle (Curve M_M)	Multiplying Factor: Average Three Phase rms Current at ½ Cycle (Curve M_A)
0	∞	1.732	1.394	29	3.3001	1.139	1.070
1	100.00	1.696	1.374	30	3.1798	1.130	1.066
2	49.993	1.665	1.355	31	3.0669	1.121	1.062
3	33.322	1.630	1.336	32	2.9608	1.113	1.057
4	24.979	1.598	1.318	33	2.8606	1.105	1.053
5	19.974	1.568	1.301	34	2.7660	1.098	1.049
6	16.623	1.540	1.285	35	2.6764	1.091	1.046
7	14.251	1.511	1.270	36	2.5916	1.084	1.043
8	12.460	1.485	1.256	37	2.5109	1.078	1.039
8.5	11.723	1.473	1.248	38	2.4341	1.073	1.036
9	11.066	1.460	1.241	39	2.3611	1.068	1.033
10	9.9501	1.436	1.229	40	2.2913	1.062	1.031
11	9.0354	1.413	1.216	41	2.2246	1.057	1.028
12	8.2733	1.391	1.204	42	2.1608	1.053	1.026
13	7.6271	1.372	1.193	43	2.0996	1.049	1.024
14	7.0721	1.350	1.182	44	2.0409	1.045	1.022
15	6.5912	1.330	1.171	45	1.9845	1.041	1.020
16	6.1695	1.312	1.161	46	1.9303	1.038	1.019
17	5.7967	1.294	1.152	47	1.8780	1.034	1.017
18	5.4649	1.277	1.143	48	1.8277	1.031	1.016
19	5.1672	1.262	1.135	49	1.7791	1.029	1.014
20	4.8990	1.247	1.127	50	1.7321	1.026	1.013
21	4.6557	1.232	1.119	55	1.5185	1.015	1.008
22	4.4341	1.218	1.112	60	1.3333	1.009	1.004
23	4.2313	1.205	1.105	65	1.1691	1.004	1.002
24	4.0450	1.192	1.099	70	1.0202	1.002	1.001
25	3.8730	1.181	1.093	75	0.8819	1.0008	1.0004
26	3.7138	1.170	1.087	80	0.7500	1.0002	1.00005
27	3.5661	1.159	1.081	85	0.6128	1.00004	1.00002
28	3.4286	1.149	1.075	100	0.0000	1.00000	1.00000

The time constant L/R can be ascertained from the above formula as follows:

(1) Measure the value of I_{d0} at the time of current initiation and the value of i_d at any other time t

(2) Determine the value of $e^{-Rt/L}$ by dividing i_d by I_{d0}

(3) From a table of values of e^{-x} determine the value of $-x$ corresponding to the ratio i_d/I_{d0}

(4) The value x then represents Rt/L, from which L/R is determined

5.2.2 Determine the angle ϕ from:

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

where

$\omega = 2\pi$ times the actual frequency

5.2.3 Power Factor = $\cos \phi$

6. Phase Relationship Method

6.1 General. Methods dependent upon asymmetrical values of current or the decay of the dc component generally are not suitable

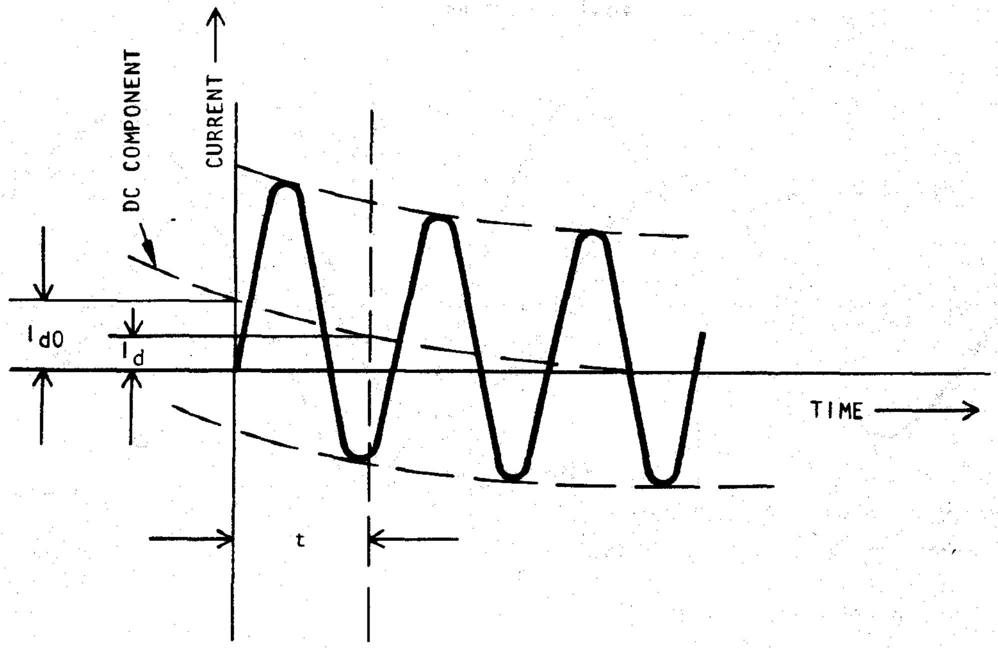


Fig. 3
DC Decrement Method

for the measurement of power factor circuits above 30 percent where the dc component is severely reduced. Therefore, the phase relationship method, using current and voltage waves, is the recommended method on circuits having power factors over 30 percent.

6.2 Procedure for Determining Power Factor. This method involves controlled closing and determines the power factor of the test circuit under essentially symmetrical closing conditions. Construct suitable straight, parallel wave envelope lines and a line midway between them to determine the "zero point" of the "true" axis of the current wave at the end of the first major half cycle. By relating this point to the open circuit voltage wave "zero point," the power factor can be determined from the difference in electrical degrees between the "zero point" of the current at the end of the first major half cycle and the corresponding "zero point" position of the circuit voltage wave. For three-phase circuits, each phase current must be related to its own phase-to-neutral voltage. Greater accuracy will result if each power factor is determined when the circuit is closed so that the phase under consideration has symmetrical characteristics. The average of the phase power factors is considered as the circuit power factor. If the voltage wave is subject to measurable phase shift upon closure of the test circuit (as shown in Fig. 4), it is necessary to determine and use the voltage zero (0) point which would have existed (indicated dash line) if the phase shift in the voltage wave had not occurred.

7. References

[1] *NEMA Standard for Molded Case Circuit Breakers,* Publication AB 1-1969.

[2] *IEC Specification for Alternating-Current Circuit Breakers,* IEC Publication 56-1-1971.

[3] Underwriters' Laboratories, Inc. *High-Interrupting-Capacity Fuses; Current-Limiting Types,* UL198.2-1970.

[4] Harder, J. E. A method of power factor measurement for circuit interrupter testing. *IEEE Transactions on Power Apparatus and Systems,* vol PAS-87, no 10, Oct 1968, TP21 PWR.

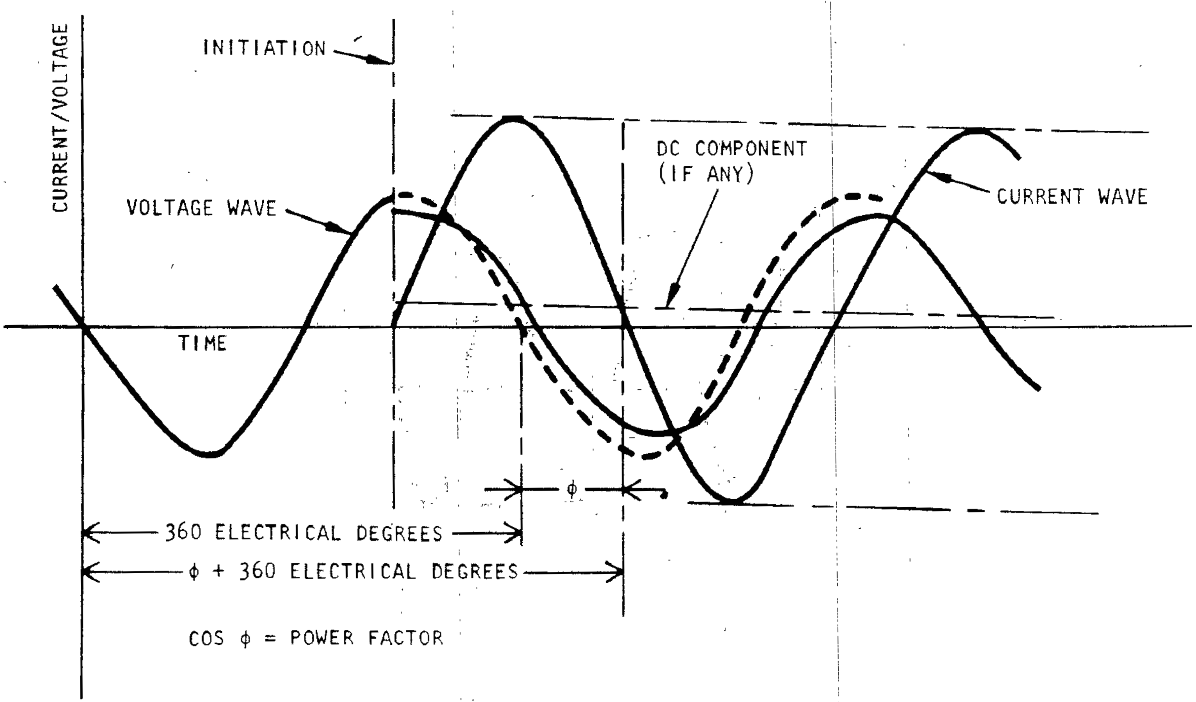


Fig. 4
Phase Relationship Method

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[6] Brandt, T. F., Jr, *Test Procedure for Determining Short-Circuit Power Factor.* Presented at IEEE Winter Power Meeting New York, N. Y., Jan 29, 1968, 68CP20-PWR.

[7] Withers, J. S. *Ammeter-Voltmeter-Wattmeter Method of Determining Short-Circuit Power Factor in a Short-Circuit Laboratory.* Presented at IEEE Winter Power Meeting, New York, N. Y., Jan 29, 1968, 68CP82-PWR.