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(Revision of IEEE Std 18-1980)

IEEE Standard for Shunt Power Capacitors

Sponsor

Transmission and Distribution Committee
of the
IEEE Power Engineering Society

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Abstract: Capacitors rated 216 V or higher, 2.5 kvar or more, and designed for shunt connection to alternating-current transmission and distribution systems operating at a nominal frequency of 50 or 60 Hz are considered. Service conditions, ratings, manufacturing, and testing are covered. A guide to the application and operation of power capacitors is included.
Keywords: capacitors, shunt connection, transmission and distribution systems

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Introduction

(This introduction is not a part of IEEE Std 18-1992, IEEE Standard for Shunt Power Capacitors.)

This standard was revised in response to a need created by the continuous changes in capacitor technology. Its principal objects are to provide a basis for uniformity in design and testing, and to assist users in the application of shunt capacitors.

This standard was revised by a working group sponsored by the Capacitor Subcommittee of the Transmission and Distribution Committee of the IEEE Power Engineering Society. At the time that this standard was approved, the Capacitor Subcommittee had the following membership:

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Contents

IEEE Standard for Shunt Power Capacitors

1. Scope

This standard applies to capacitors rated 216 V or higher, 2.5 kvar or more, and designed for shunt connection to alternating current transmission and distribution systems operating at a nominal frequency of 50 or 60 Hz.

2. References

This standard shall be used in conjunction with the following publications:

ANSI Z55.1-1967 (withdrawn 1987), Gray Finishes for Industrial Apparatus and Equipment.[1]

ANSI/NFPA 70-1990, National Electrical Code.[2]

IEEE Std 21-1976, General Requirements and Test Procedures for Outdoor Apparatus Bushings.[3]

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors.

IEEE C37.99-1990, IEEE Standard Guide for Protection of Shunt Capacitor Banks (ANSI).

NEMA 107-1987, Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.[4]

NEMA CP1-1988, Shunt Capacitors.

3. Definitions

3.1 ambient temperature: The temperature of the medium, such as air, water, or earth, into which the heat of the equipment is dissipated.

NOTES
1—For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.
2—For air- or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.
3—For self-ventilated enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate neighborhood of the equipment. See 5.7 and table 2.

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[1]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA. ANSI Z55.1-1967 (w1987) is available as an archival document through the same address.

[2]NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[4]NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

3.2 capacitor bank: An assembly at one location of capacitors and all necessary accessories, such as switching equipment, protective equipment, controls, etc., required for a complete operating installation. It may be a collection of components assembled at the operating site or may include one or more piece(s) of factory-assembled equipment.

3.3 capacitor equipment: An assembly of capacitors with associated accessories, such as fuses, switches, etc., all mounted on a common frame for handling, transportation, and operation as a single unit.

3.4 discharge device: An internal or external device intentionally connected in shunt with the terminals of a capacitor for the purpose of reducing the residual voltage after the capacitor is disconnected from an energized line.

3.5 enclosed capacitor: A capacitor having enclosed terminals. The enclosure is provided with means for connection to a rigid or flexible conduit.

3.6 fused capacitor: A capacitor having fuses mounted on its terminals, or inside a terminal enclosure, or inside the capacitor case, for the purpose of interrupting a failed capacitor.

3.7 indoor (prefix): Not suitable for exposure to the weather.

NOTE—For example, an indoor capacitor unit is designed for indoor service or for use in a weatherproof housing. (*See also:* **outdoor.**)

3.8 kilovar (1000 vars): The practical unit of reactive power, equal to the product of the rms voltage in kilovolts (kV), the rms current in amperes (A), and the sine of the angle between them.

3.9 metal-enclosed equipment: A capacitor equipment assembly enclosed in a metal enclosure or metal house, usually grounded, to prevent accidental contact with live parts. *Syn:* **metal-housed equipment.**

3.10 metal-housed equipment: *See:* **metal-enclosed equipment.**

3.11 outdoor (prefix): Designed for use outside buildings and to withstand exposure to the weather.

3.12 power capacitor: An assembly of dielectric and electrodes in a container (case), with terminals brought out, that is intended to introduce capacitance into an electric power circuit.

NOTE—The abbreviated term “capacitor” is used interchangeably with “power capacitor” throughout this standard.

3.13 proof (suffix): An apparatus is designated as dustproof, splashproof, etc., when so constructed, protected, or treated that its successful operation is not interfered with when subjected to the specified material or condition.

The meaning of other terms used in this standard shall be as defined in IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms.

4. Service conditions

NOTE—For additional information on service conditions, see clause 8.

4.1 Normal service conditions

Capacitors shall be suitable for operation at their specified rating when

a) The ambient temperature is within the limits specified in 5.7. (Capacitors may be exposed to the direct rays of the sun.)
b) The altitude does not exceed 6000 ft (1800 m) above sea level. See 6.6.2 and Table 4.
c) The voltage applied between terminals does not exceed the rated voltage by more than the tolerance specified in 5.2.3.
d) The voltage applied between terminals and case does not exceed the insulation class specified in 5.5.
e) The applied voltage does not contain harmonics in excess of the limits specified in 5.2.3(b).
f) The nominal operating frequency is equal to the rated frequency.

4.2 Abnormal service conditions

If capacitors are required to operate under abnormal service conditions, such as the following, the application should be brought to the attention of the manufacturer:

a) Exposure to damaging fumes or vapors
b) Exposure to conducting or explosive dust
c) Exposure to abnormal mechanical shock or vibration, including earthquakes
d) Exposure to radiated heat from surfaces (other than the sun) that are hotter than the ambient temperature limits for capacitors given in 5.7
e) Mounting and/or arrangement that prevents adequate ventilation
f) Operation in ambient temperatures outside the range specified in 5.7
g) Altitude higher than 6000 ft (1800 m) above sea level (see 6.6.2 and Table 4)
h) Momentary duty exceeding that listed in 8.3.2
i) Service conditions other than those listed in 4.1

5. Ratings

5.1 Standard ratings

This standard establishes the following ratings:

a) Voltage, rms (terminal-to-terminal)
b) Terminal-to-case (or ground) insulation class
c) Reactive power
d) Number of phases
e) Frequency

5.2 Tolerances in ratings

5.2.1

Capacitors shall give not less than the rated reactive power at rated sinusoidal voltage and frequency, and not more than 115% of this value, measured at 25 °C uniform case and internal temperature.

5.2.2

Capacitors shall be suitable for continuous operation at 135% of rated reactive power. This maximum reactive power shall include the following factors, the combined effects of which shall not exceed 135%:

a) Reactive power due to voltage in excess of nameplate rating at fundamental frequency but within the permissible voltage limitations described in 5.2.3

b) Reactive power due to harmonic voltages superimposed on the fundamental frequency

c) Reactive power in excess of nameplate rating due to manufacturing tolerance within the limits specified in 5.2.1

5.2.3

Capacitors shall be capable of continuous operation provided that none of the following limitations are exceeded:

a) 135% of nameplate kvar (see 5.2.2)

b) 110% of rated voltage rms, and crest voltage not exceeding $1.2 \cdot \sqrt{2}$ of rated rms voltage, including harmonics but excluding transients (see 8.3.2)

c) 180% of rated current rms, including fundamental and harmonic currents (see 8.5.1 for guidance)

5.3 Momentary ratings

Capacitors shall be capable of withstanding, with full life expectancy, switching transients having peak voltages up to $2 \cdot \sqrt{2}$ times rated voltage rms and other transient disturbances inherent in the operation of power systems. See 8.3.2 for guidance in operating capacitors at overvoltages and overcurrents.

5.4 Voltage and reactive power ratings

Voltage and reactive power ratings shall conform to table 1.

5.5 Insulation classes

The basic impulse isolation level (BIL) of standard rating capacitors shall be as shown in table 1.

5.6 Frequency

Power capacitors shall be designed for operation at a rated nominal frequency of either 50 or 60 Hz.

5.7 Ambient temperature

Capacitors shall be designed for switched or continuous operation in outdoor locations with unrestricted ventilation and direct sunlight under the ambient temperatures for each mounting arrangement shown in table 2.

5.7.1 Minimum ambient

Capacitors shall be designed for continuous operation at –40 °C.

5.7.2 Exceptions

For operation under conditions other than those listed above, or in indoor locations or locations with restricted ventilation, see 8.4.

6. Manufacturing

6.1 Thermal stability

Capacitors shall be thermally stable in accordance with the definition and operating conditions outlined in 7.9.

6.2 Internal partial discharge inception level

Capacitors shall not be damaged by partial discharges when energized under any conditions of ambient temperature or continuous voltage permitted by this standard.

Table 1—Common voltage and reactive power ratings

Volts, rms (terminal-to-terminal)	kvar	Number of phases	BIL kV*
216	5, 7 1/2, 13 1/3, 20, and 25	1 and 3	30‡
240	2.5, 5, 7 1/2, 10, 15, 20, 25, and 50	1 and 3	30‡
480	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30‡
600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30‡
2400	50, 100, 150 and 200	1	75
2770	50, 100, 150 and 200	1	75
4160	50, 100, 150 and 200	1	75
4800	50, 100, 150 and 200	1	75
6640	50, 100, 150, 200, 300, and 400	1	95
7200	50, 100, 150, 200, 300, and 400	1	95
7620	50, 100, 150, 200, 300, and 400	1	95
7960	50, 100, 150, 200, 300, and 400	1	95
8320	50, 100, 150, 200, 300, and 400	1	95
9540	50, 100, 150, 200, 300, and 400	1	95
9960	50, 100, 150, 200, 300, and 400	1	95
11 400	50, 100, 150, 200, 300, and 400	1	95
12 470	50, 100, 150, 200, 300, and 400	1	95
13 280	50, 100, 150, 200, 300, and 400	1	95 and 125
13 800	50, 100, 150, 200, 300, and 400	1	95 and 125
14 400	50, 100, 150, 200, 300, and 400	1	95 and 125
15 125	50, 100, 150, 200, 300, and 400	1	125
19 920	100, 150, 200, 300, and 400	1	125
19 920†	100, 150, 200, 300, and 400	1	125 and 150
20 800†	100, 150, 200, 300, and 400	1	150 and 200
21 600†	100, 150, 200, 300, and 400	1	150 and 200
22 800†	100, 150, 200, 300, and 400	1	150 and 200
23 800†	100, 150, 200, 300, and 400	1	150 and 200
24 940†	100, 150, 200, 300, and 400	1	150 and 200

*See 7.7.
†One bushing only.
‡Not applicable to indoor ratings.

6.3 Impulse level

Capacitors shall withstand the impulse levels given in table 3, as demonstrated by the tests outlined in 7.7.

Table 2—Maximum ambient

Mounting arrangement	Ambient air temperature—°C	
	24-h average*	Normal annual†
Isolated capacitor	46	35
Single row of capacitors	46	35
Multiple rows and tiers of capacitors	40	25
Metal-enclosed or -housed equipments	40	25

*The 24-h arithmetic average of hourly readings during the hottest day expected at that location.
†As defined in the reports of the US Weather Bureau.

Table 3—Impulse levels*

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	Impulse level (terminal-to-case, kV peak)
216–1199	30†
1200–5000	75
5001–15 000	95
13 200–25 000	125

*Not applicable to 216–1199 V indoor capacitors.
†See 7.7.

6.4 Internal discharge devices

Capacitors shall be equipped with an internal discharge device that will reduce the residual voltage to 50 V or less within the following time limits after the capacitor is disconnected from rated voltage:

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	Maximum time limit
600 V or less	1 min
Over 600 V	5 min

NOTE—The internal discharge device provided in capacitors should not be considered as a substitute for the recommended practice of manually discharging the residual stored charge before working on capacitors.

6.5 Radio influence voltage

Radio influence voltage generated by a capacitor shall not exceed 250 μV, as determined in accordance with 7.10.

6.6 Bushings

6.6.1 Number of bushings

Single-phase capacitors shall have either one or two bushings. Three-phase capacitors shall have three or four bushings.

6.6.2 Electrical characteristics

The bushings of outdoor capacitors shall have minimum electrical characteristics in accordance with table 4.

Table 4—Electrical characteristics of bushings

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	Minimum insulation creepage distance (in.)†	Withstand test voltage*		
		60 Hz dry 1 min, kV, rms	60 Hz wet 10 s, kV, rms	Impulse 1.2/50 (or 1.5/40) full wave kV crest
216–1199	2 (5.08 cm)	10	6	30‡†
1200–5000	5.5 (13.97 cm)	27	24	75
5001–15 000	10 (25.40 cm)	35	30	95
13 200–25 000	16 (40.64 cm)	42	36	125
15 000–25 000	17 (43.18 cm)	60	50	150
19 920–25 000	26 (66.04 cm)	80	75	200

*NOTE—Withstand test voltages are for standard temperature and humidity at mean sea level.
†At elevations higher than 6000 ft (1800 m) above sea level, additional insulation may be required to prevent bushing flashovers or excessive leakage current.
‡Not applicable to indoor ratings.

6.7 Terminals

6.7.1

Outdoor capacitors shall be provided with either of the following types of terminals, as specified by the user:

a) Clamp connector to accommodate a minimum range of conductor sizes from No 8 solid through No 2 stranded, AWG

b) Threaded stud with 3/8 in (0.95 cm) × 16 or 1/2 in (1.27 cm) × 13 threads suitable for bolting directly to bus bars

6.7.2

Single-bushing outdoor capacitors shall have the bushing terminal as specified under 6.7.1 and the case shall have a suitable connection point as the other terminal.

6.7.3

Indoor capacitors shall be provided with terminals consistent with current-carrying requirements in ANSI/NFPA 70-1990.

6.8 Nameplate marking

Each capacitor shall be provided with a permanent nameplate that includes the following information:

a) Name of manufacturer
b) Unique serial number
c) Manufacturer's type, model, style, or catalog number
d) Year of manufacture
e) Rated reactive power
f) Rated voltage, rms
g) Number of phases
h) Rated frequency
i) BIL (if not in accordance with 6.3)
j) Statement as to whether insulating liquid is or is not flammable (if flammable, amount in gallons shall be shown.)
k) Statement that capacitor contains an internal discharge device

6.8.1 Impregnant identification

Additional marking (decal or stick-on label) shall be visible from the ground. Blue color shall be used to designate non-PCB liquid.

6.9 Mounting hole spacings

The mounting hole spacing for capacitors rated 50 to 400 kvar and 2400 V or higher shall be 15 5/8 in ± 1/16 in (39.70 cm ± 0.16 cm) between centers of 7/16 in (1.11 cm) minimum-diameter holes. Cantilever-mounted capacitors shall accommodate 5/8-in (1.59-cm) mounting bolts at 18 in ± 1/16 in (45.72 cm ± .016 cm) between centers.

6.10 Grounding provisions

Capacitors shall have provision for effective electrical bonding of the case to capacitor hangers or mounting frame.

6.11 Color

Colors for capacitor cases and bushings shall be as defined in ANSI Z55.1-1967, unless otherwise specified.

7. Testing

7.1 General

Capacitor tests are designated as either production tests or design tests.

7.1.1 Production tests

Production tests shall be performed by the manufacturer on each capacitor and shall include the following:

a) Short-time overvoltage test (see 7.2)
b) Capacitance test (see 7.3)
c) Leak test (see 7.4)
d) Discharge resistor test (see 7.5)
e) Loss determination test (see 7.6)

7.1.2 Design tests

Design tests shall be performed by the manufacturer on a sufficient number of capacitors to demonstrate compliance of the design with various parts of this standard. Capacitors shall first meet production test requirements before being subjected to design tests. The design tests shall include the following:

a) Impulse withstand test (see 7.7)
b) Bushing tests (see 7.8)
c) Thermal stability test (see 7.9)
d) Radio influence voltage test (see 7.10)
e) Voltage decay test (see 7.11)

7.1.3 Test practices

The following conditions for testing shall be used:

a) New and clean capacitors shall be used for each test.
b) Ambient temperature shall be 25 °C ± 5 °C.
c) All alternating-current voltages shall have a frequency of 50 or 60 Hz and be approximately sinusoidal in wave shape.

7.2 Short-time overvoltage tests (production test)

Each capacitor shall withstand the following test voltages for at least 10 s. Test voltages shall be applied in such a manner as to avoid transients.

7.2.1 Terminal-to-terminal test

Each capacitor shall, with its case and internal temperature at 25 °C ± 5 °C, withstand for at least 10 s a terminal-to-terminal insulation test using a direct current test voltage of 4.3 times rated voltage rms or an alternating sinusoidal voltage of two times rated voltage rms.

For those systems with higher than normal overvoltages, a special design for capacitors rated 2 400 V rms or higher may be used, for which this test will be increased to a dc test voltage of 6.25 × rated voltage rms in accordance with agreement between manufacturer and purchaser.

The capacitance shall be measured on each unit both before and after the application of the test voltage. The initial capacitance measurement shall be at low voltage. The change in capacitance, as a result of the test voltage, shall be less than either a value of 2% or that caused by failure of a single roll of the particular design. For three-phase Y-connected units, the above testing for terminal-to-neutral shall be followed by a test at $\sqrt{3}$ times above values between each outside bushing to the center bushing to test the phase insulation.

7.2.2 Terminal-to-case test (not applicable to capacitors having one terminal common to the case)

Terminal-to-case tests shall be made on capacitors having all terminals insulated from the case. The appropriate test voltage from table 5 shall be applied between all insulated terminals connected together and the case.

7.3 Capacitance test (production test)

Capacitance tests shall be made on each capacitor to demonstrate that it will deliver not less than rated reactive power and not more than 115% of rated reactive power at rated voltage and frequency, corrected to a capacitor case and internal temperature of 25 °C. Measurements made at other than 25 °C are corrected by adjusting for temperature difference according to the established temperature relationship for the capacitor tested. Capacitance measurements shall be traceable to the National Institute of Standards and Technology.

7.4 Leak test (production test)

A suitable test shall be made on each capacitor to ensure that it is free from leaks.

7.5 Discharge resistor tests (production test)

A suitable test shall be performed on each capacitor to ensure that the internal discharge device will reduce an initial residual voltage equal to $\sqrt{2}$ times rated voltage rms to 50 V or less in the time limits specified in 6.4.

7.6 Loss determination test (production test)

Loss measurement shall be made by the manufacturer on each capacitor to demonstrate that the capacitor losses are equal to or less than W_M as defined in 7.9.2.3.

7.7 Impulse withstand test (design test)

Impulse tests shall be applied between terminals and case, with the terminals connected together.

NOTE—Single bushing capacitors, of which the case forms one electrode, shall not be subjected to the impulse withstand test. When one principal terminal of the capacitor is connected to the case, the BIL requirements shall not apply to the internal insulation assembly. The internal insulation assembly shall assure that the capacitor will meet the requirements of 7.2.1. However, the bushing shall meet all the requirements of 6.6 and the nameplate shall carry the applicable BIL.

7.7.1

The capacitor shall successfully withstand three consecutive positive impulses.

Table 5—Test voltages

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	Impulse 1.2/50 (or 1.5/40) full wave kVcrest	Terminal-to-case test voltage alternating current V, rms	
		Indoor	Outdoor
216–300	30*	3000	10 000
301–1199	30*	5000	10 000
1200–5000	75	—	26 000
5001–15 000	95	—	34 000
13 200–25 000	125	—	40 000

*Outdoor units only.

7.7.2

The impulse voltage shall be 1.2/50 (or 1.5/40) full wave, as described in 7.7.3, with a crest value given in table 5. The tolerance on the crest value shall be ± 3%.

7.7.3

The time to crest of a 1.2/50 impulse wave shall be measured as 1.67 times the time for the voltage to rise from 30 to 90% of crest value. The tolerance on the time to crest shall be ± 30%. The time to 0.5 crest value point on the tail of the wave shall be measured from the virtual time zero and shall be 40 to 50 µs. The virtual time zero shall be taken at the intersection of the zero voltage line and a line drawn through points on the front of the wave at 30 and 90% of the crest value.

The time to crest of a 1.5/40 impulse wave shall be measured from the virtual time zero and shall not exceed 2.0 µs. The time to 0.5 crest value point on the tail of the wave shall be measured from the virtual time zero and shall not be less than 40 µs. The virtual time zero shall be taken as the intersection of the zero voltage line and a line drawn through points on the front of the wave at 30% and 90% of the crest value.

7.8 Bushing test (design test)

Bushing test voltages shall be applied in accordance with the test procedures specified in IEEE Std 21-1976.

7.8.1 Fifty- or 60-Hz withstand test

If no flashover occurs, the bushings shall be considered as having passed the test successfully.

7.8.2 Impulse withstand test

If any one, but not more than one, of three applications of the test voltage causes flashover, three additional impulses shall be applied. If no additional flashover occurs, the bushings shall be considered as having passed the test successfully.

7.9 Thermal stability test (design test)

The test capacitor shall be considered thermally stable if the hot-spot case temperature reaches and maintains a constant value within a variation of 3 °C for 24 h, under the following test conditions.

7.9.1 Selection of samples

One sample shall be selected as the test capacitor. Two other capacitors of the same ratings and having approximately the same power factor and capacitance (at rated voltage, rated frequency, and case and internal temperatures at t_S) as the capacitor test shall be selected for barrier capacitors. Resistor models having the same power loss, thermal characteristics, and physical dimensions as the test capacitor may be substituted for the barrier capacitors.

7.9.2 Test method

7.9.2.1 Mounting conditions

The test capacitor, selected as above, shall be mounted in an enclosure between the two barrier capacitors at the manufacturer's minimum recommended center-to-center spacing. The mounting position selected shall be the recommended operating position that produces the highest internal temperatures.

7.9.2.2 Ambient temperature

The air inside the test enclosure shall be maintained at an average temperature of 46 °C and shall not be force-circulated. The inside wall temperature of the enclosure shall be within ± 5 °C of the ambient temperature in the enclosure. The ambient temperature shall be measured by means of a thermocouple on the case or within the dielectric of an isolated unenergized capacitor, supported and positioned so that it is subjected to the minimum possible thermal radiation from the three energized samples.

7.9.2.3 Test voltage

All three sample capacitors shall be energized at a test voltage to be determined as follows:

$$V_T = 1.1\ V_R \sqrt{\frac{W_M}{W_A}}$$

where

V_T is the test voltage

V_R is the capacitor rated voltage rms

W_M is the manufacturer's maximum allowable power loss. This loss shall be calculated using 110% of rated voltage rms and the manufacturer's established maximum product of measured capacitance and power factor, at rated voltage and frequency and at a stated case and internal temperature t_S.

NOTE—W_M does not correspond to an exact limit on either capacitance or power factor but does correspond to an exact limit on their product. The quantity W_M/W_A reduces to a ratio of

(Maximum product of capacitance and power factor):(Measured product of capacitance and power factor)

W_A is the actual power loss of the test capacitor. This loss shall be calculated using 110% of rated voltage rms and the actual capacitance and power factor of the test capacitor measured at rated voltage and frequency and at a stated case and internal temperature t_S.

t_S is the manufacturer's dielectric temperature limit under the conditions of this thermal stability test.

The test voltage (V_T) calculated for this test shall be limited to a value that will result in operation of the test capacitor at a maximum of 140% of its kvar rating. This voltage shall be maintained constant, within ±2% throughout the last 24 h of the test period.

7.9.2.4 Temperature measurement

The temperature of the test capacitor shall be measured by means of thermocouples attached to the case sidewall and cover. All temperature measurements shall be accurate to within ± 1 °C.

7.10 Radio influence voltage test (design test)

Radio influence voltage tests on capacitors shall be conducted in accordance with the following.

7.10.1 Equipment

The equipment and general method used in determining the radio influence voltage shall be in accordance with the recommendations of the Joint Coordination Committee on Radio Reception of EEI, EIA, and NEMA as set forth in NEMA 107-1987.

7.10.2 Test voltage

The test voltage shall be of rated frequency and 115% of rated voltage rms of the capacitor.

7.10.3 Method

Capacitors having two or more bushings with the windings fully insulated from the case shall be tested with the case grounded and with the voltage specified in 7.10.2 applied between all bushings connected together and the case. Capacitors having only one bushing per phase with the case as the other terminal should not be tested, as this type of contruction precludes any meaningful radio influence voltage (RIV) measurement due to the high capacitance.

7.10.4 Precautions

The following precautions should be observed when measuring the radio influence voltage of capacitors:

a) The capacitor shall be at approximately the same temperature as the room in which the tests are made.
b) The capacitor bushings shall be dry and clean.
c) The capacitor shall be mounted in its recommended position with recommended clearance.

7.10.5 RIV limits

The radio influence voltage when measured in accordance with the foregoing at a frequency of 1 MHz, shall not exceed 250 μV.

7.11 Voltage decay test (design test)

The capacitor shall be energized at rated alternating current voltage rms or direct current voltage of 1.1 $\sqrt{2}$ times rated voltage rms. The decay of the voltage, when de-energized, shall be measured by suitable means. The time for decay of residual voltage to 50 V or less shall not exceed 5 min for capacitors rated higher than 600 V or 1 min for capacitors rated 600 V or less.

7.12 Performance test

The manufacturer shall provide the user with performance test data to substantiate the design.

8. Guide for the application and operation of power capacitors

8.1 General

This subclause presents a brief summary of some of the more important principles involved in the successful application and operation of power capacitors. It is general in nature and is intended to supplement the specific recommendations of the manufacturer.

NOTE—When capacitors are operated at frequencies lower than rated, both reactive power and current ratings are reduced in direct proportion to the operating frequency.

8.2 Life

The life of a capacitor is shortened by overstressing, overheating, chemical change, physical damage, or repeated temperature changes. Life to 90% survival should exceed 20 years.

8.3 Overvoltage limits and protection

8.3.1

Shunt capacitors cause a voltage rise at the point where they are located and are therefore more likely to operate at overvoltages than other types of equipment. Recognizing this factor, the nameplate voltage ratings of capacitors and permissible overvoltage operation are generally higher than those established for motors and most other equipment. Capacitors conforming to this standard may be operated continuously up to 110% of rated voltage rms, provided that the crest voltage, including all harmonics, does not exceed $1.2\sqrt{2}$ times rated voltage rms and provided that the maximum permissible 135% of rated kvar is not exceeded (see 5.2.3). Operation at terminal voltages in excess of rated or in ambient temperatures higher than the maximums listed in 5.7 may shorten the life of a capacitor.

Shunt capacitors are frequently connected directly in parallel with induction motors and switches by means of the motor switching device. Overvoltage may result when the motor and capacitor combination is disconnected from the line, since the inertia of the motor and its mechanical load will keep the motor rotating and the motor will operate as an induction generator. The voltage of self-excitation for a given motor and capacitor combination will depend upon the intersection of the capacitor volt ampere line and the motor magnetization curve. Article 460 of ANSI/NFPA 70-1990 states that the total kvar rating of capacitors connected on the load side of a motor controller shall not exceed that which is required to correct the no-load power factor of the motor to unity in order to avoid overvoltages due to self-excitation.

If a larger capacitor (or capacitor bank) is used, it is recommended that a separate switch, controlled by the motor switch, be installed to automatically disconnect the capacitor(s) from the motor when the motor is disconnected from the source voltage.

When a motor can be rapidly de-energized and re-energized, the possibility of high transient torques should be considered. Capacitors switched with motors prolong the duration of residual voltage in the motor as it comes to rest after de-energization. In general, capacitors applied in conformance with Article 460 of ANSI/NFPA 70-1990 will not create excessively high transient torques. In cases where motors are connected to high-inertia loads, the motor manufacturer should be consulted.

8.3.2

Capacitors may be subjected to both high voltage and high current under certain conditions associated with switching. The magnitude of the permissible current and voltage peaks depends on the frequency of occurrence. In the case of a frequently switched capacitor, current and voltage peaks must be held to relatively low values. Comparatively high values may be tolerated on a bank switched infrequently. The tables in 8.3.2.1, 8.3.2.2, and 8.3.2.3 provide a guide for the evaluation of service conditions from the standpoint of peak currents and voltage.

NOTE—The limitations shown in these tables are based on the occurrence of overvoltages when internal temperatures of the capacitor are less than 0 °C.

The multiplying factors shown in these tables may be increased, upon recommendation by the manufacturer, when fewer overvoltages are expected or when less severe temperature conditions exist.

Capacitors meeting the tests specified in clause 7 may reasonably be expected to withstand the overvoltages and overcurrents shown in the tables of 8.3.2.1, 8.3.2.2, and 8.3.2.3.

8.3.2.1 Momentary power frequency overvoltage

A capacitor may reasonably be expected to withstand, during normal service life, a combined total of 300 applications of power frequency terminal-to-terminal overvoltages without superimposed transients or harmonic content, of the magnitudes and durations in the following table:

Duration	Maximum permissible voltage (multiplying factor to be applied to rated voltage rms)
6 cycles	2.20
15 cycles	2.00
1 s	1.70
15 s	1.40
1 min	1.30
30 min	1.25

8.3.2.2 Transient overcurrent

A capacitor may reasonably be expected to withstand the peak discharge currents listed in the following table:

Probable number of transients per year	Permissible peak transient current (multiplying factor to be applied to rated current rms)
4	1500
40	1150
400	800
4000	400

8.3.2.3 Transient overvoltage

A capacitor may reasonably be expected to withstand the transient overvoltages listed in the following table:

Probable number of transients per year	Permissible peak transient voltage (multiplying factor to be applied to rated voltage rms)
4	5.0
40	4.0
400	3.4
4000	2.9

8.3.3

Capacitors connected to exposed lines may require surge protection by station-type or intermediate-type surge arresters located as closely as possible to the capacitor bank. If capacitors are located indoors, the arresters may be located at the line entrance to the building. Installation should be made in accordance with the latest industry standards for surge arresters. Capacitors connected between the line and grounded neutral are effective in reducing the slope of a traveling wave front. However, the available energy will sometimes be sufficient to damage unprotected capacitors.

8.3.4

Capacitors may be used on circuits of higher voltage than the terminal-to-case insulation class, provided the cases are supported on external insulation suitable for the circuit voltage and provided the terminal-to-terminal voltage limits stated in 5.2.3, 8.3.2.1, and 8.3.2.3 are not exceeded.

8.3.5

Capacitor banks installed on three-phase, four-wire multigrounded neutral distribution feeder circuits are frequently connected in Y with the neutral of the capacitor bank connected to the system multigrounded neutral conductor. Under certain conditions, the neutral of the capacitor bank is disconnected from the system neutral conductor to reduce the harmonic currents in the system. With the neutral of the capacitor bank floating to reduce harmonic currents, or if the bank is normally installed in the ungrounded Y configuration, a fault in one phase of the bank will subject the capacitors in the unfaulted phases to overvoltage. A completely faulted phase of a capacitor bank will subject the capacitors in the unfaulted phases to $\sqrt{3}$ times system line-to-neutral voltage. With typical fusing practices, the time that the capacitors are subjected to the overvoltage will usually exceed the stated overvoltage capability of the capacitor as defined in 8.3.2. The user should recognize that high overvoltages can be impressed on capacitors in ungrounded Y capacitor banks if only fuses are employed for protection.

8.4 Operating and ambient temperatures

8.4.1

It is essential that consideration be given to the arrangement of capacitors and complete equipment as an installation to provide adequate ventilation and dissipation of heat. Capacitors are designed to operate at a lower temperature rise than most other types of apparatus for the following specific reasons:

a) Unlike most other power apparatus, shunt capacitors (whether unswitched or switched) normally operate for relatively long periods of time at full load and, therefore, do not benefit from the lower average temperature rise characteristic of typical daily load cycles.
b) For reasons of economy, capacitors are designed to operate at comparatively high dielectric stresses. The combination of these stresses with operation at high temperature for extensive periods of time will result in gradual deterioration and shortened life.

8.4.2

Capacitor ratings are based on maximum ambients with an allowance for heat dissipation by radiation and convection. The arrangement and mounting of capacitors and the conditions of installation will affect the heat dissipation and thereby limit the ambient temperature in which capacitors may be operated. Capacitors and capacitor equipments operating outdoors in direct sunlight and with unrestricted ventilation will normally operate with lower temperature rise than those operating indoors in still air. The following points are important in relating the operating temperature of a capacitor to the conditions of installation.

a) An individual nonenclosed capacitor, such as is mounted on an outdoor pole, will dissipate heat with the least temperature rise (the heat dissipation being approximately 45% by radiation and 55% by convection).
b) The mounting of capacitors in rows side by side or in tiers, or both, increases the temperature rise because of heating of the air stream and because of reduced radiation.
c) The enclosing of capacitors in a housing or room without forced air ventilation increases the temperature rise because of reduced radiation and restriction of the natural circulation of air.
d) Capacitors having relatively large physical size for their reactive power rating relative to similarly shaped capacitors using the same dielectric system will ordinarily have less than normal temperature rise and may be suitable for operation at ambient temperatures higher than those given in 5.7 or in indoor ambients without forced ventilation.
e) Capacitors subjected to radiation from the sun or from any surface, the temperature of which is above the ambient, show a higher temperature rise.

8.4.3

Where ambient air temperatures higher than those listed in 5.7.1 are expected in service, the manufacturer should be consulted.

8.5 Abnormal capacitor overload current

8.5.1

Capacitor overload currents due to excessive fundamental voltage or to harmonic voltages added to the fundamental voltage may occasionally be encountered. Currents due to fundamental and harmonic voltages should be limited to a maximum of 1.8 times the normal 50 or 60 Hz rating of capacitors rated 2400 V and higher. The blowing of fuses for excessive temperature rise may be the first noticeable indication of an overload condition. Capacitors and auxiliary devices are designed for continuous operation up to 1.35 time rated kvar, including the kvar due to the fundamental voltage and all harmonic voltages provided that the capacitor voltage does not exceed an rms value of 1.1 times rated or a peak value of $1.2\sqrt{2}$ times rated voltage rms. Where currents with substantial harmonic components are likely to be encountered, provision should be made for additional current-carrying capacity in the circuit breakers, fuses, and other auxiliary devices.

8.5.2

If harmonic currents are above the allowable limits, one or more of the following remedies should be undertaken:

a) Relocation of the capacitors to other parts of the circuit may reduce overcurrent due to partial resonance.
b) Capacitors may be switched off the circuit during periods in which overcurrents are likely to occur. Automatic control actuated by change in current, change in voltage, change in reactive kVA, or by time switch may be used.
c) Removal of neutral ground, if present.

CAUTION—Bank insulation and switch load interrupting rating may be inadequate if neutral is disconnected.

d) If these remedies fail, it may be necessary to resort to the use of reactors of a selected rating. These may be connected in series or shunt with all or a part of the capacitor bank to reduce the harmonic current. The use of reactors necessitates the determination of the exact harmonic causing excessive current, which may be done with a harmonic voltmeter, oscillograph, or harmonic analyzer. Careful consideration must be given to allowing for increased voltage or current loading on a capacitor as the result of adding a reactor.

8.6 Inspection and maintenance

8.6.1

Inspection should be made within 8 to 24 h after the installation of shunt capacitors and during the first periods of light load on the circuit when maximum overvoltage will be obtained. Readings of voltage and current in each phase should be made to determine that

a) Phase voltages are balanced within the limits of the capacitor rating.
b) Operating kvar (that is, the sum of the fundamental frequency kvar and any harmonic frequency kvar that may be present) does not exceed 135% of the rated value.

CAUTION

It is recommended that after de-energization at least 5 min be allowed for discharge and that the capacitor terminals be connected together and grounded before touching any live parts.

8.6.2

Regular inspection of the capacitor installation on an established schedule should include a check of ventilation, fuses, temperature, and voltage conditions. In contaminated areas, capacitor bushings and insulating surfaces should be cleaned periodically, the interval between servicing depending on the severity of conditions to which the insulators are exposed. Capacitors or equipments exposed to weathering may require repainting periodically to prevent excessive corrosion and to maintain a good radiating surface.

8.6.3

Handling and disposal of capacitor insulating fluid should follow the methods required by federal, state, and local regulations.

8.7 Field test of capacitors

Field tests on capacitors may include voltage tests for insulation strength (both terminal-to-terminal and terminal-to-case), capacitance or current tests, insulation resistance tests, power factor or loss measurements, and seal test for liquid tightness. Field tests may be divided into two classes (see 8.7.1 and 8.7.2).

CAUTION

Capacitors may rupture during the tests in 8.7.1 and 8.7.2. Adequate safeguards should be provided to prevent injury to personnel or damage to adjacent equipment in the event of violent failure of a capacitor during test. Testing should be done at or near room temperature to avoid damage to the dielectric. The capacitor may be damaged if discharged by short-circuiting its terminals before five minutes after the test potential is removed. Before any tests are initiated, the manufacturer's instructions should be carefully studied and followed.

8.7.1 Tests to check the condition of new capacitors before being placed in service

Field tests on new capacitors may be made by applying voltages for 10 s not in excess of 75% of the factory test voltages given in 7.2.1 and 7.2.2. Experience has shown that these tests are not necessary on all capacitors. In applying low-frequency tests, it is recommended that the capacitors be energized at a voltage not in excess of the nameplate rating, then the voltage raised to 75% of the factory test value. To de-energize the capacitors, the voltage should be reduced to a value not in excess of rated voltage before opening the circuit.

CAUTION

Adequate safeguards should be provided to prevent injury to personnel or damage to adjacent equipment in event of violent failure of a capacitor during test.

Testing should be done at or near room temperature to avoid damage to the dielectric.

It may be more convenient to use direct current in testing. Again, the terminal-to-terminal test should be made by applying voltages for 10 not in excess of 75% of the direct-current factory test voltages given in 7.2.1.

The total duration of the test, including time to charge the capacitor to the required value, should not exceed 1 min to avoid the possibility of overheating the built-in discharge resistors.

The test voltage from short-circuited terminals-to-case should be as follows:

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	BIL	Direct current field test voltage (terminal-to-case) V dc
216–1199	30*	15 000†
1200–5000	75	28 500
5001–15 000	95	39 000
13 200–25 000	125	45 000

*For outdoor units only.
†Test voltage for indoor capacitors should be reduced to 7500 V.

In direct-current testing, the charging rate should be limited to a value not in excess of 1 A. This can be conveniently accomplished by connecting in series with the capacitor a resistance in ohms not less than the value of the testing potential in volts. A 50-W resistor rating will be satisfactory. A similar resistor of 50 000 to 100 000 ¾ should be connected across the capacitor to drain the charge after the test potential is removed.

CAUTION

Adequate safeguards should be provided to prevent injury to personnel or damage to adjacent equipment in event of violent failure of a capacitor during test.

Testing should be done at or near room temperature to avoid damage to the dielectric.

The capacitor may be damaged if discharged by short-circuiting its terminals before 5 min after the test potential is removed.

8.7.2 Tests to check the condition of a capacitor after it has been in service

Field tests may be made to ascertain the operating condition of a capacitor. Such tests are necessary only in case of indication of trouble or after exposure to possible damage. The service ability of a capacitor may be determined by one or more of the following simple tests.

CAUTION

Adequate safeguards should be provided to prevent injury to personnel or damage to adjacent equipment in event of violent failure of a capacitor during test.

8.7.2.1 Dielectric strength

The condition and insulation strength of the terminal-to-terminal dielectric or between shorted line terminals and the case may be tested by applying an overvoltage not exceeding 75% of the factory test voltages given in 7.2.1 and 7.2.2.

8.7.2.2 Capacitance

Capacitance may be satisfactorily determined by measuring the current while applying a known voltage and frequency (preferably rated voltage and frequency) of a good wave shape undistorted by voltage control devices. This test will also indicate short-circuited or open-circuited capacitors. See 5.2.1 and the nameplate rating for the determination of nominal capacitance values.

8.7.2.3 Terminal-to-terminal resistance

Terminal-to-terminal insulation resistance measurements may be made on two-bushing capacitors with a suitable bridge, or calculated from the direct-current voltage and current readings. When internal discharge resistors are included, as indicated on the nameplate, the terminal-to-terminal resistance reading obtained will be the value of the discharge resistor that is much lower than the normal insulation resistance of the dielectric. Refer to 6.4 for the basis on which nominal resistance values are selected.

When values of insulation resistance of the dielectric are needed, they should be obtained from the manufacturer.

8.7.2.4 Terminal-to-case resistance

Terminal-to-case insulation resistance measurements may be made on two-bushing capacitors to determine the condition of the line insulating terminals and dielectric insulation to case. (If the capacitor has a single bushing and internal discharge resistors, the resistance reading obtained will be the value of the discharge resistors that is much lower than the normal insulation resistance.) Refer to 6.4 for the basis on which nominal resistance values are selected. When values of insulation resistance of the dielectric are needed, they should be obtained from the manufacturer.

8.7.2.5 Leak test

Liquid tightness of a capacitor may be checked by increasing the internal pressure and inspecting for leaks at elevated pressure. This may be done effectively by thoroughly cleaning the case, heating the capacitor a minimum of 4 h in an oven, and then placing it horizontally on clean paper with the suspected point of leakage on the bottom.

NOTE—The temperature of the capacitor case should not be allowed to exceed the manufacturer's recommendations.

8.7.2.6 Power factor (dielectric loss)

Measuring the terminal-to-case power factor or dielectric loss is another means of determining the condition of the line insulating terminals and insulation to case. This measurement is more difficult and has no advantage over the resistance test described in 8.7.2.4.

Measuring the terminal-to-terminal power factor or dielectric loss provides another means of determining the operating condition of the terminal-to-terminal dielectric but is not necessary as an addition to the tests described in 8.7.2.1 through 8.7.2.5. Such measurements should be made at rated frequency where applicable and at test voltages of not less than 25% of rated voltage to obtain accurate results.

8.7.3 Interval between tests

Periodic testing of capacitors at short intervals is unnecessary. Since they are hermetically sealed, their measurable characteristics should remain relatively constant under normal operating conditions. However, operating conditions are subject to change. Therefore, it is recommended that periodic inspections and checks be made to detect operating conditions liable to cause damage or reduced life.

8.8 Fusing

Occasional failures should be anticipated and a protective scheme should be provided that will reliably detect and clear a faulted capacitor before

a) A major fault develops that jeopardizes the circuit.
b) Gas pressure inside the faulted capacitor increases to the point where it becomes hazardous to personnel, adjacent capacitors, or other equipment.
c) The remaining capacitors are damaged by overvoltage (in ungrounded Y banks or in banks with more than one series group per phase).

The two most commonly used protective schemes are primary group fusing and individual capacitor fusing. Primary group fusing is more often used on small distribution banks. Ratings of group fuses should be selected that will

a) Withstand the relatively high inrush current.
b) Carry the continuous bank current with adequate allowance for normal overloads caused by voltage regulation, harmonics, plus tolerances in capacitance, etc.
c) Detect and isolate the faulted phase before the internal gas pressure causes violent rupture of a failed capacitor and, in the case of ungrounded Y banks, before the remaining capacitors in the unfaulted phases are damaged by overvoltages.

Individual capacitor fusing is commonly used on relatively large capacitor banks. In general, the operation of the individual fuses in banks involving more than one series group per phase and in all ungrounded Y banks, irrespective of the number of series groups per phase, will increase the voltage on the capacitors remaining in service. Figures 1, 2, and 3 show the magnitude of overvoltages resulting from removal of various numbers of capacitors from the more common bank connections. The protective scheme should include provision for disconnecting the entire bank before the voltage on the remaining capacitors exceeds the values recommended in 8.3.

In general, the smallest fuse should be used that has adequate capacity to withstand the inrush currents and to carry the maximum continuous current expected at the capacitor bank location. For a given fuse type, the smaller the ampere rating used, the smaller the probability of case rupture.

Recommendations for fusing to provide a satisfactory probability against case rupture should be obtained from the manufacturer.

At the request of the user, the manufacturer will provide the user with case rupture curves for the manufacturer's capacitors.

Typical curves indicating regions of high and low probabilities of case ruptures for capacitors with paper, paper-film, or all-film dielectrics are illustrated in figure 4.

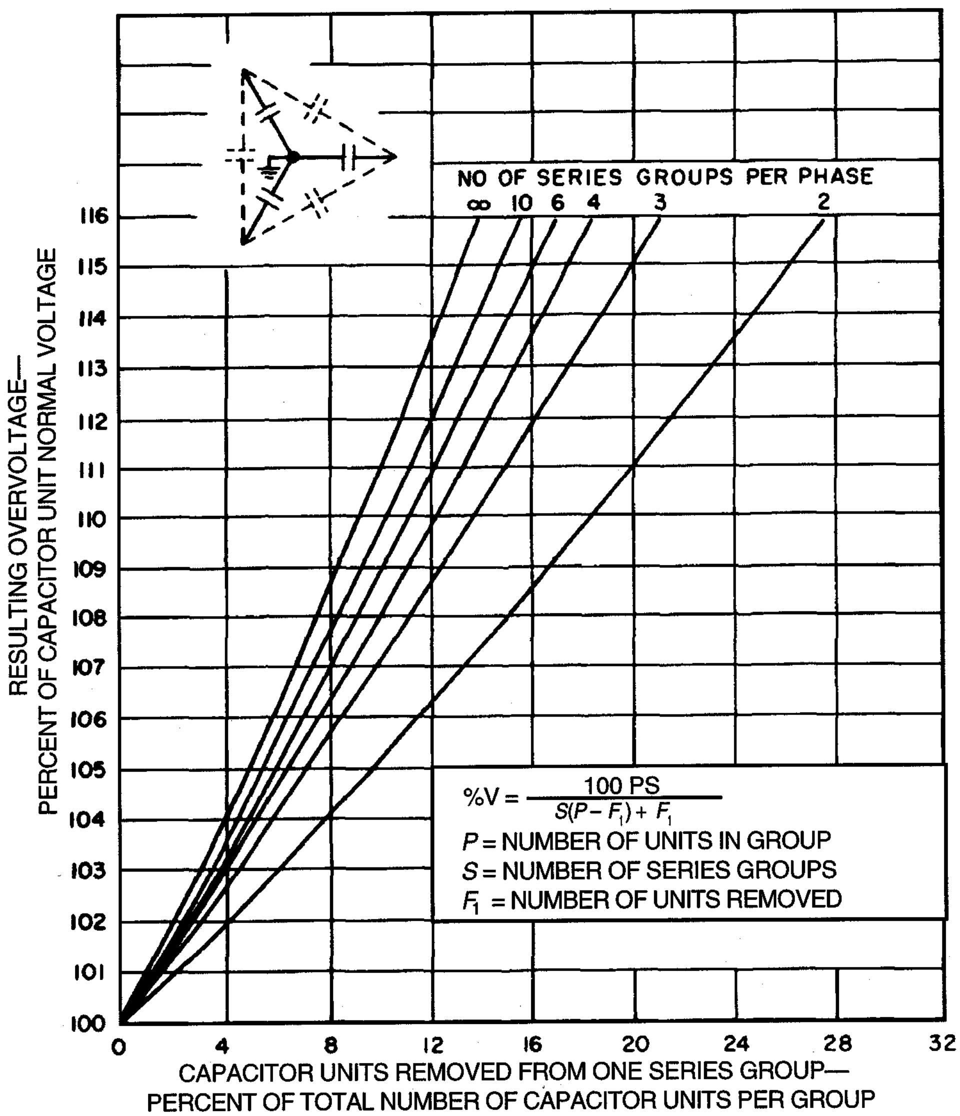

Figure 1—Grounded Y-connected, Δ, or grounded double Y-connected capacitor bank: Voltage on remaining capacitor units in series group vs. percentage of capacitor units removed from series group

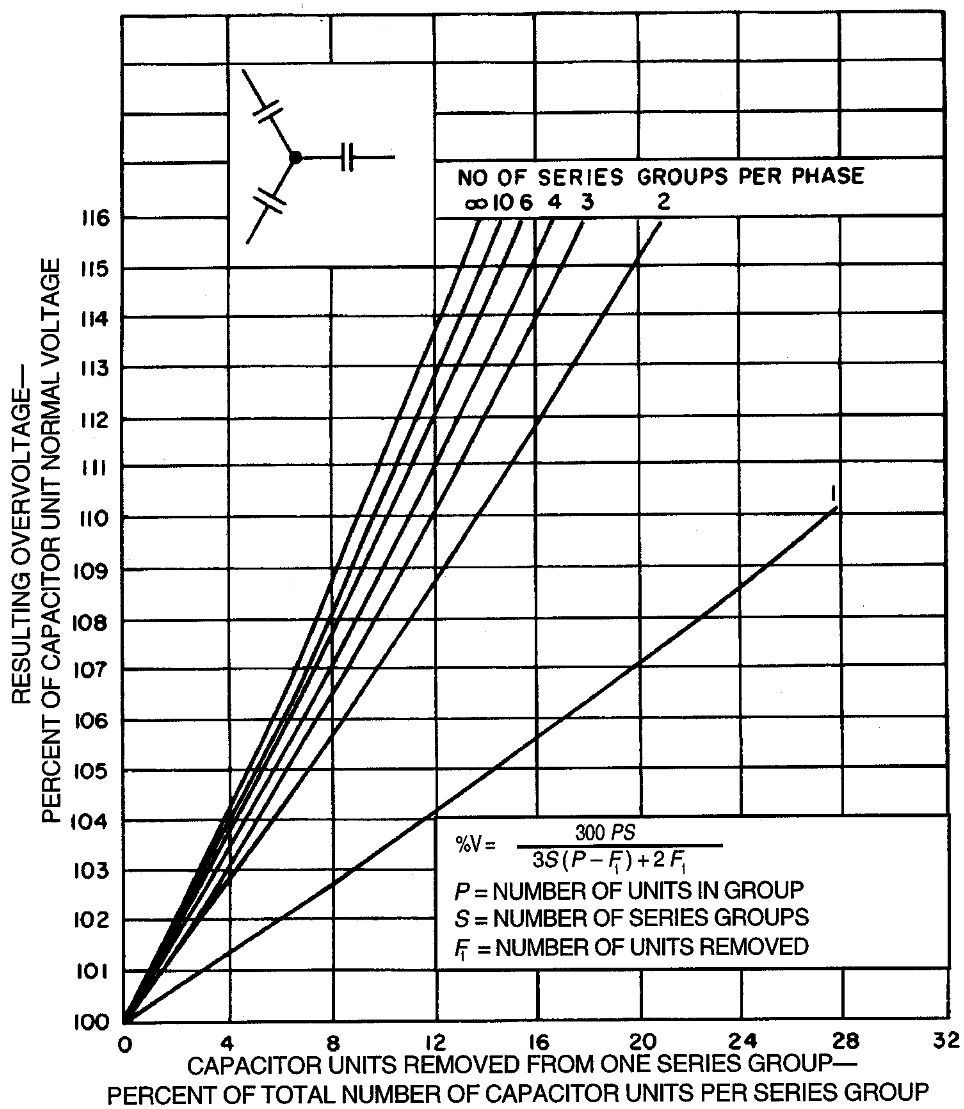

Figure 2—Ungrounded Y-connected or ungrounded double Y-connected (neutrals isolated) capacitor bank: Voltage on remaining capacitor units in series group vs. percentage of capacitor units removed from series group

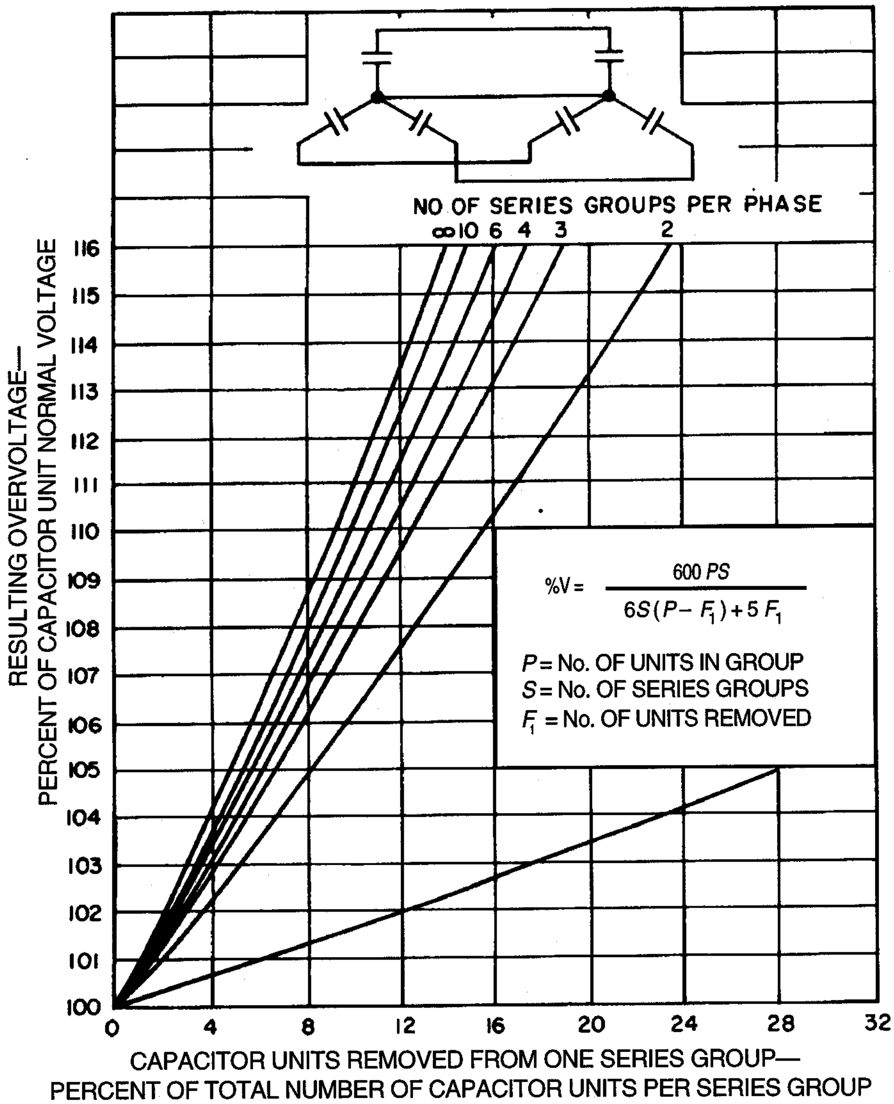

Figure 3—Ungrounded double Y-connected (neutrals tied together) capacitor bank: Voltage on remaining capacitor units in series group vs. percentage of capacitor units removed from series group

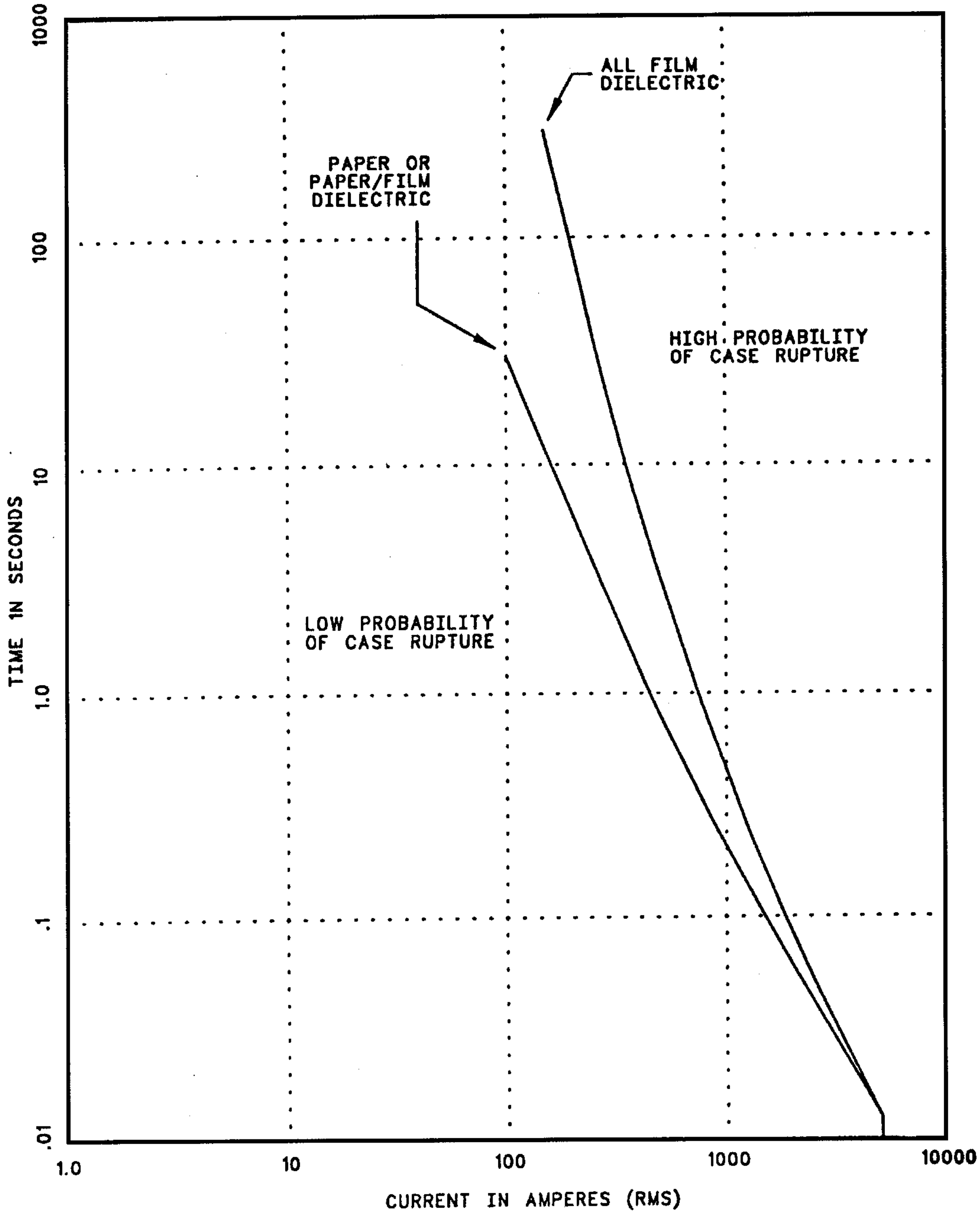

Figure 4—Typical case rupture curves for approximately 1800 in^3 case volume