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IEEE Std 824-1994)

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IEEE Standard for Series Capacitor Banks in Power Systems

IEEE Power Engineering Society

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IEEE Standard for Series Capacitor Banks in Power Systems

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Abstract: This standard represents a significant update to IEEE 824-1994. Series capacitor bank component and bank duty cycle ratings, equipment insulation levels, protective functions, component testing, instruction books, nameplates, and safety are covered in this standard.

Keywords: bypass gap, capacitor bank, capacitor segment, discharge reactor, metal-oxide varistor, protective level, reactive compensation, series capacitor, series compensation, SSR, trigger circuit, triggered gap, varistor

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Introduction

This introduction is not part of IEEE Std 824-2004, IEEE Standard for Series Capacitor Banks in Power Systems.

The purpose of this revision is to include additional approaches for capacitor fusing and references to new IEEE and IEC standards for related equipment. An additional purpose was to increase the precision and clarity of the wording to make it more consistent with actual industry practice.

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*This standard is dedicated to the memory
of our friend and colleague
Stan Miske*

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IEEE Standard for Series Capacitor Banks in Power Systems

1. Scope

This standard applies to outdoor series capacitor banks and to the major components of a bank that are required to form a complete system for the insertion of capacitors in series with a transmission line. These major components include capacitors, varistors, bypass gaps, bypass switches, discharge current limiting reactors, insulated structures, and protection and control systems. This standard defines the major requirements for the bank and these components. Design and production tests for all of the components are outlined. Disconnect switches associated with the series capacitor bank are not discussed in detail.

This standard applies to fixed series capacitor banks where the inserted reactance is primarily established by the reactance of the capacitors. Not included in this standard are power electronic devices for the insertion or bypassing of the bank. In addition, series capacitor banks applied to distribution circuits are not within the scope of this standard.

2. References

This standard shall be used in conjunction with the following publications. In case of discrepancies between this standard and the referenced standards, this standard takes precedence. Where a specific clause is cited in the text of this document, the following standards should be used. When the following standards are superseded by an approved revision, the revision shall apply, and the reference clauses must be checked for accuracy.

Accredited Standards Committee C2-2002, National Electrical Safety Code[®] (NESC[®]).¹

ANSI C29.8-1985 (Reaff 2002), American National Standard for Wet-Process Porcelain Insulators (Apparatus, Cap, and Pin Type).²

ANSI C29.9-1983 (Reaff 2002), American National Standard for Wet-Process Porcelain Insulators (Apparatus, Post-Type).

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ANSI C37.06–2000, American National Standard for AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis-Preferred Ratings and Related Required Capabilities.

ANSI Z55.1-1967 (Reaff 1973), American National Standard for Gray Finishes for Industrial Apparatus and Equipment.³

IEC 60071-1:1993, Insulation Coordination—Part 1: Definitions, Principles, and Rules.⁴

IEC 60071-2:1996, Insulation Coordination—Part 2: Application Guide.

IEC 60099-4:2004, Surge Arresters—Part 4: Metal-Oxide Surge Arresters without Gaps for AC Systems.

IEC 60694:1996 (Reaff 2002), Common Specifications for High-Voltage Switchgear and Controlgear Standards.

IEC/PAS 62271-100:2003, High-Voltage Switchgear and Controlgear—Part 100: High-Voltage Alternating-Current Circuit Breakers.

IEC 62271-109:2002, High-Voltage Switchgear and Controlgear—Part 109: Alternating-Current Series Capacitor Bypass Switches.

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.^{5,6}

IEEE Std 18™-1992, IEEE Standard for Shunt Power Capacitors.

IEEE Std 693™-1997, IEEE Recommended Practices for Seismic Design of Substations.

IEEE Std 980™-1994, IEEE Guide for Containment and Control of Oil Spills in Substations.

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

IEEE Std 1313.1™-1996, IEEE Standard for Insulation Coordination—Definitions, Principles, and Rules.

IEEE Std 1313.2™-1999, IEEE Guide for the Application of Insulation Coordination.

IEEE Std C37.09™-1999, IEEE Standard Test Procedure for AC High-Voltage Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.1™-1994, IEEE Standard Definition, Specification and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control.

IEEE Std C37.30™-1997, IEEE Standard Definitions and Requirements for High-Voltage Switches.

IEEE Std C37.90™-1989 (Reaff 1994), IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus.

³ANSI Z55.1-1967 has been withdrawn; however, copies can be obtained from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

⁴IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

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IEEE Std C37.90.1TM-2002, IEEE Standard Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.2TM-2004, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

IEEE Std C57.12.00TM-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.13TM-1993, IEEE Standard Requirements for Instrument Transformers.

IEEE Std C57.16TM-1996, IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors.

IEEE Std C57.19.00TM-1991 (Reaff 1997), IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings.

IEEE Std C62.11TM-1999, IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits (>1 kV).

3. Definitions

The meaning of other terms used in this standard shall be as defined in *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B4].⁷

3.1 ambient temperature: The temperature of the air into which the heat of the equipment is dissipated.

3.2 bypass current: The current flowing through the bypass switch, protective device, or other devices in parallel with the series capacitor.

3.3 bypass gap: A system of specially designed electrodes arranged with a defined spacing between them, in which an arc is initiated to form a low-impedance path around one segment or a subsegment of the series capacitor bank. The conduction of the bypass gap is typically initiated to limit the voltage across the series capacitors and/or limit the duty to the varistor connected in parallel with the capacitors. The bypass gap includes the electrodes that conduct the bypass current, the triggering circuit (if any), and an enclosure.

NOTE—See Figure 1.⁸

3.4 bypass switch: A device such as a switch or circuit breaker used in parallel with a series capacitor and its protective device to bypass or insert the series capacitor bank for some specified time or continuously. This device shall also have the capability of bypassing the capacitor during specified power system fault conditions. The operation of the device is initiated by the capacitor control, remote control, or an operator. The device may be mounted on the platform or on the ground near the platform.

NOTE—See Figure 1.

3.5 capacitor element: The basic component of a capacitor unit consisting of two electrodes separated by a dielectric.

3.6 capacitor rack: A frame that supports one or more capacitor units.

⁷The numbers in brackets correspond to those of the bibliography in Annex C.

⁸Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

3.7 capacitor unit: *See: power capacitor.*

3.8 discharge current limiting reactor: A reactor to limit the current magnitude and provide damping of the oscillatory discharge of the capacitors during a closing operation of the bypass switch or the start of conduction of the bypass gap.

NOTE—See Figure 1.

3.9 discharge device: An internal or external device permanently connected in parallel with the terminals of a capacitor for the purpose of reducing the trapped charge after the capacitor bank is disconnected from the energized power system.

3.10 external fuse (of a capacitor unit): A fuse located outside of the capacitor unit that is connected in series with the unit.

3.11 external line fault: A fault that occurs on adjacent lines or equipment other than on the transmission line that includes the series capacitor installation.

3.12 forced-triggered bypass gap: A bypass gap that is designed to operate on external command on quantities such as varistor energy, current magnitude, or rate of change of such quantities. The sparkover of the gap is initiated by a trigger circuit. After initiation, an arc is established in the power gap. Forced-triggered gaps typically spark over only during internal faults.

3.13 fuseless capacitor bank: A capacitor bank without any fuses, internal or external, that is constructed of (parallel) strings of capacitor units. Each string consists of capacitor units connected in series.

3.14 insertion: The opening of the capacitor bypass switch to insert the series capacitor bank in series with the line.

3.15 insertion current: The root-mean-square (rms) current that flows through the series capacitor bank after the bypass switch has opened. This current may be at the specified continuous, overload, or swing current magnitudes.

3.16 insertion voltage: The peak voltage appearing across the series capacitor bank upon the interruption of the bypass current with the opening of the bypass switch.

3.17 insulation level: The combination of power frequency and impulse test voltage values that characterize the insulation of the capacitor bank with regard to its capability of withstanding the electric stresses between platform and earth, or between platform-mounted equipment and the platform.

3.18 internal fuse (of a capacitor): A fuse connected inside a capacitor unit, in series with an element or a group of elements.

3.19 internal line fault: A fault that occurs on the transmission line section that includes the series capacitor installation.

3.20 internally fused capacitor (unit): A capacitor unit that includes internal fuses.

3.21 main gap: The part of the bypass gap that carries the fault current after sparkover of the bypass gap.

3.22 platform: A structure that supports one or more segments of the bank and is supported on insulators compatible with line-to-ground insulation requirements.

3.23 platform-to-ground communication insulator: An insulator that encloses communication signal paths between platform and ground level.

3.24 power capacitor (capacitor, capacitor unit): 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.

3.25 protective device: A bypass gap, varistor, or other device that limits the voltage on the capacitor segment or subsegment to a predetermined level when overcurrent flows through the series capacitor.

3.26 protective level: The magnitude of the maximum peak of the power-frequency voltage allowed by the protective device during a power system fault. The protective level may be expressed in terms of the actual peak voltage across a segment or subsegment or in terms of the per unit of the peak of the rated voltage across the segment or subsegment.

NOTE—See 5.5.

3.27 reinsertion: The restoration of load current to the series capacitor from the bypass path.

3.28 reinsertion current: The transient current, power-frequency current, or both, flowing through the series capacitor bank after the opening of the bypass path.

3.29 reinsertion voltage: The transient voltage, steady-state voltage, or both, appearing across the series capacitor after the opening of the bypass path.

3.30 series capacitor bank: A three-phase assembly of capacitor units with the associated protective devices, discharge current limiting reactors, protection and control system, bypass switch, and insulated support structure that has the primary purpose of introducing capacitive reactance in series with an electric circuit.

3.31 series capacitor installation: An installed series capacitor bank complete with disconnect switches.

3.32 segment: A single-phase assembly of capacitor units and an associated protective device, discharge current limiting reactor, protection and control functions, and one phase of a bypass switch. Segments are not normally separated by isolating disconnect switches. More than one segment can be on the same insulated platform.

NOTE—See Figure 1.

3.33 subsegment: A portion of a segment that includes a single-phase assembly of capacitor units and an associated protective device, discharge current limiting reactor, and selected protection and control functions, but does not have a dedicated bypass switch.

NOTE—See Figure 1.

3.34 switching step: A three-phase assembly that consists of one segment per phase, with a three-phase operating bypass switch for bypassing or inserting the capacitor segments. This is sometimes referred to as a capacitor module.

NOTE—See Figure 1.

3.35 thyristor protected series capacitor bank (TPSC): A fixed series capacitor bank equipped with thyristor valve configured to fast bypass and/or to provide capacitor overvoltage protection. The thyristor valve circuit consists of a series of anti-parallel thyristor levels and a current-limiting reactor. In a TPSC application, the thyristor is switched to a conductive condition at the specified protection level by the control and

protection system. When the line current returns to nominal value or the bypass switch closes, the thyristor valve is blocked.

NOTE—See A.3.

3.36 trigger circuit: The part of the bypass gap that initiates the sparkover of the bypass gap at a specified voltage level or by external command.

3.37 valve element (of a varistor unit): A single nonlinear resistor disc used in a surge arrester or varistor unit.

3.38 varistor: An assembly of varistor units that limit overvoltages to a given value. In the context of series capacitor banks, the varistor is typically defined by its ability to divert fault current around the series capacitor units, limiting the voltage to a specified protective level while absorbing energy. The varistor is designed to withstand the temporary overvoltages and continuous operating voltage across the series capacitor units.

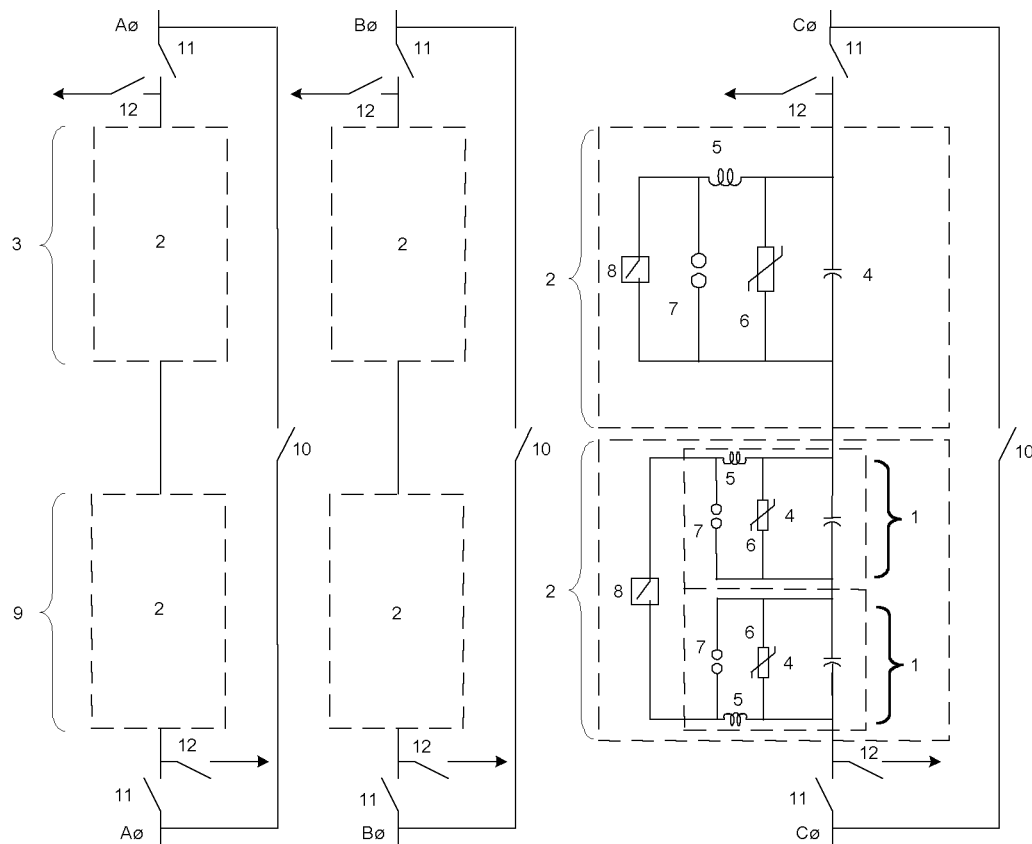
3.39 varistor coordinating current: The varistor current magnitude associated with the protective level. The varistor coordinating current waveform is considered to have a virtual front time of 30 μ s to 50 μ s. The tail of the waveform is not significant in establishing the protective level voltage.

3.40 varistor energy rating: The maximum energy the varistor can absorb within a short period of time without being damaged due to thermal shock or thermal runaway during the subsequent applied voltage. This rating is based on the duty cycle defined by the purchaser. This is the usable rating after taking into account factors such as current sharing among parallel columns. The additional energy absorption capability of the spare units is not normally included in this rating.

3.41 varistor maximum continuous operating voltage (MCOV): The rated rms voltage of the capacitor segment that the varistor is connected across.

3.42 varistor unit: A single insulated enclosure containing one or more valve elements in series and possibly in parallel.

3.43 voltage-triggered bypass gap: A bypass gap that is designed to spark over on the voltage that appears across the gap terminals. The sparkover of the gap is normally initiated by a trigger circuit set at a specified voltage level. A voltage-triggered bypass gap may be used for the primary protection of the capacitor and may spark over during external as well as internal faults.



- 1—Subsegment (1ø)
- 2—Segment (1ø)
- 3—Switching step (3ø) or module (3ø)
- 4—Capacitor units
- 5—Discharge current limiting reactor
- 6—Varistor
- 7—Bypass gap
- 8—Bypass switch
- 9—Additional switching steps when required
- 10—External bypass disconnect switch
- 11—External isolating disconnect switch
- 12—External grounding disconnect switch
- 3, 9—Included in a series capacitor bank
- 3, 9, 10, 11, 12—Included in a series capacitor installation

Figure 1—Typical series capacitor installation nomenclature

4. Service conditions

4.1 Normal service conditions

Series capacitor banks shall be suitable for operation at the specified bank and equipment ratings and duty cycle sequence under the following conditions:

- a) The elevation does not exceed 1000 m above sea level.

- b) The indoor and outdoor ambient temperatures are within the limits specified by the purchaser (see 5.2).
- c) The ice load does not exceed 19 mm (if applicable).
- d) Wind velocities are no greater than 128 km/h.
- e) The horizontal seismic acceleration (if applicable) of the equipment does not exceed 0.2 g, and the vertical acceleration does not exceed 0.16 g, when applied simultaneously at the base of the support insulators. For the purposes of this standard, the values of acceleration are static. This is the *low seismic level* defined in IEEE Std 693-1997.⁹ The seismic acceleration and the maximum wind do not have to be considered to occur simultaneously.
- f) The snow depth (if applicable) does not exceed the height of the foundations for the platform support insulators. (A typical maximum height is 1 m.)
- g) Maximum solar radiation in watts per square meter as specified by the purchaser.

4.2 Abnormal service conditions

The application of series capacitor banks at other than the normal service conditions shall be considered as special and should be identified in the purchaser's specification. Examples of such conditions are as follows:

- a) Service conditions other than those listed in 4.1
- b) Exposure to excessively abrasive and conducting dust
- c) Exposure to salt, damaging fumes, or vapors
- d) Swarming insects
- e) Flocking birds
- f) Conditions requiring over-insulation or extra leakage distance on insulators
- g) Unusual transportation or storage conditions
- h) Seismic accelerations at the *moderate or high seismic qualification levels* as defined in IEEE Std 693-1997

4.3 Abnormal power system conditions

Examples of abnormal power system conditions are as follows:

- a) Significant continuous harmonic currents in the transmission line
- b) The transmission line on which the series capacitor bank is located does not have phase transpositions, so the reactances of each phase of the line are not approximately equal.

5. Ratings

5.1 Fundamental bank ratings

The following items are the fundamental ratings for a series capacitor bank for a specific application:

- a) *Rated system voltage*—The maximum continuous power system phase-to-phase rms voltage for which the phase-to-ground insulation system is designed.
- b) *Rated frequency*—The frequency (measured in Hz) of the power system for which the capacitor bank is designed.

⁹Information on references can be found in Clause 2.

- c) *Rated reactance (X_C)*—The capacitive reactance for each phase of the series capacitor bank at its rated frequency with internal dielectric temperature of 25 °C. The maximum tolerance for this reactance is shown in Table 1.

Table 1—Maximum tolerances

Bank three-phase Mvar	Maximum difference of any phase from rated reactance	Maximum reactance difference among phases
Less than 30 Mvar	±5%	3%
30 Mvar or more	±3%	1%

The reactance change with ambient temperature at rated frequency shall be less than 0.1% per °C.

The total reactance per phase shall be divided among the number of segments as defined by the purchaser.

- d) *Rated continuous current (I_R)*—The rms current that the capacitor or capacitor bank shall be capable of carrying continuously at rated frequency and rated ambient temperature range.
- e) *Rated segment voltage (V_R)*—The rated rms voltage across a segment when the segment is carrying rated current.
- f) *Reactive power rating (Q_R)*—The reactive power rating for the bank, as determined from rated reactance and rated current per phase, may be calculated using Equation (1):

$$Q_R = 3 I_R^2 X_C \quad (1)$$

where

Q_R is the reactive power rating in Mvar,
 I_R is the rated current (kA),
 X_C is the rated reactance of each phase (ohms).

5.2 Ambient temperature

The series capacitor equipment shall be designed for energization, continuous operation, and short-time overloads in an outdoor environment with an ambient temperature range as specified by the purchaser. This shall apply to all equipment that is associated with the series capacitor bank located outdoors. The heating caused by the close proximity of some of the series capacitor bank equipment and by exposure to sunlight shall be accounted for in the design.

In the case of series capacitor bank equipment such as the ground-level protection and control that is to be located in a control building, the design of that indoor equipment shall be consistent with the temperature range within the building. IEEE Std C37.1-1994 provides guidance for buildings with different types of heating and cooling.

5.3 Component current ratings

The series capacitor bank shall be capable of withstanding continuous rated current, system swing currents, emergency loading, power system faults, and in some applications, harmonic currents. Some of these