

# IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications

IEEE Power and Energy Society

Sponsored by the  
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# IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications

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**Transmission and Distribution Committee  
of the  
IEEE Power and Energy Society**

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**Abstract:** General guidelines toward the preparations of a functional specification of transmission fixed-series capacitor (FSC) banks using overvoltage protection based on three technologies are provided. The three technologies are:

- metal oxide varistors
- metal oxide varistors with a forced-triggered bypass gaps, and thyristor protected series capacitors
- thyristor protected series capacitor

This guide does not apply comprehensively to thyristor-controlled series capacitors.

**Keywords:** bypass gap, capacitor bank, capacitor segment, discharge reactor, IEEE 1726™, metal-oxide varistor, protective level, reactive compensation, series capacitor, series compensation, subsynchronous resonance risk (SSR), trigger circuit, triggered gap, varistor

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## Dedication

This document is dedicated to memory of Stan Miske, our friend and colleague.

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## Introduction

This introduction is not part of IEEE Std 1726™-2013, IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications.

The purpose of this guide is to provide general guidelines toward the preparation of a functional specification of transmission fixed-series capacitor banks (FSC) using overvoltage protection based on three technologies: metal oxide varistors, metal oxide varistors with a forced bypass gap, and thyristor valve bypass.

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## 1. Overview

### 1.1 Scope

This guide provides general guidelines toward the preparations of a functional specification of transmission fixed-series capacitor (FSC) banks using overvoltage protection based on three technologies:

- metal oxide varistors
- metal oxide varistors with a forced-triggered bypass gaps
- thyristor valve bypass

The commercial aspects of the specification for a particular project are outside the scope of this guide.

This guide does not apply comprehensively to thyristor-controlled series capacitors. A more complete reference is IEEE Std 1534™-2002.<sup>1</sup> The standard for fixed-series capacitors is IEEE Std 824™-2004.

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<sup>1</sup> Information on references can be found in Clause 2.

## 1.2 Purpose

This guide presents technical clauses that may be used as the basis of a functional FSC specification. The annexes of this guide include related explanatory information. The annexes are cross referenced to the main part of the document.

## 1.3 Application

This guide should be considered a general-purpose resource and does not include all details needed for a specific application. In addition, since transmission FSC banks are typically designed to address a specific application, not every part of this guide may be applicable. The user of this guide should evaluate how and to what extent each clause applies to the development of a specification for a specific application. This guide provides a possible specification that allows the user to fill in information to create a specification.

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 516™-2009, IEEE Guide for Maintenance Methods on Energized Power Lines.<sup>2</sup>

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

IEEE Std 824™-2004, IEEE Standard for Series Capacitor in Power Systems.

IEEE Std 1534™-2002, IEEE Recommended Practice for Specifying Thyristor-Controlled Series Capacitors.

## 3. Definitions, acronyms, and abbreviations

### 3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.<sup>3</sup>

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

**asymmetrical fault current:** Total symmetrical current plus dc component.

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

<sup>2</sup> IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

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[http://www.ieee.org/portal/innovate/products/standard/standards\\_dictionary.html](http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html).

**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. (See Figure 1.)

**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. (See Figure 1.)

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

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

**capacitor unit:** *See power capacitor.*

**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. (See Figure 1.)

**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.

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

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

**fixed-series capacitors (FSC):** A series capacitor bank that has a reactance or reactances that are defined by the discrete reactances of the capacitors and are not variable.

**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 sparkover only during internal faults.

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

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

**insertion current:** The rms (root-mean-square) 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.

**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.

**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 ground, or between platform-mounted equipment and the platform.

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

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

**internally fused capacitor (unit).** A capacitor unit which includes internal fuses.

**MOV assembly:** A group or collection of metal oxide varistors blocks applied to create an arrester.

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

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

**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. *Syn:* **capacitor, capacitor unit.**

**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.

**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.

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

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

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

**segment:** A single-phase assembly of capacitor units and associated protective device, discharge current-limiting reactor, protection and control functions, and one phase of a bypass switch. (See Figure 1.) Segments are not normally separated by isolating disconnect switches. More than one segment can be on the same insulated platform.

**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.

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

**subsegment:** A portion of a segment that includes a single-phase assembly of capacitor units and associated protective device, discharge current-limiting reactor, and selected protection and control functions, but does not have a dedicated bypass switch. (See Figure 1.)

**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. (See Figure 1.) This is sometimes referred to as a *capacitor module*.

**thyristor-protected series capacitor bank (TPSC):** A fixed-series capacitor bank equipped with thyristor valve configured to fast bypass and/or provide capacitor overvoltage protection. (See Annex B.6.2.) The thyristor valve circuit consists of a series of anti-parallel thyristor units 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 bypass switch closes, the thyristor valve is blocked.

**valve element (of a varistor unit):** A single non-linear resistor disc used in a surge arrester or varistor unit.

**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.

**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 to 50  $\mu$ s. The tail of the waveform is not significant in establishing the protective level voltage.

**varistor energy rating:** The maximum energy the varistor can absorb within a short period of time without being damaged due to thermal shock or due to thermal runaway during the subsequent applied voltage. This rating is based on the duty cycle defined by the purchaser. This is the useable 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.

**varistor maximum continuous operating voltage:** The rated rms voltage of the capacitor segment that the varistor is connected across.

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

**voltage-triggered bypass gap:** A bypass gap that is designed to sparkover 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 sparkover during external as well as internal faults.

**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.

### 3.2 Acronyms and abbreviations

|     |                              |
|-----|------------------------------|
| BIL | basic impulse level          |
| CT  | current transformer          |
| DFR | digital fault recorder       |
| EHV | extra-high-voltage           |
| EMI | electromagnetic interference |

|         |                                       |
|---------|---------------------------------------|
| ETT     | electrically triggered thyristors     |
| FACTS   | flexible ac transmission systems      |
| FSC     | fixed-series capacitor                |
| GTO     | gate turn-off                         |
| HV      | high-voltage                          |
| HVDC    | high-voltage direct current           |
| LIWL    | lightning impulse withstand level     |
| LTT     | light-triggered thyristors            |
| LV      | low-voltage                           |
| MOV     | metal oxide varistor                  |
| MSC     | mechanically switched capacitor       |
| MSR     | mechanically switched reactor         |
| Mvar    | megavar                               |
| PCC     | point of common coupling              |
| PMP     | preventative maintenance plan         |
| PT      | potential transformer                 |
| RI      | radio interference                    |
| rms     | root-mean-square                      |
| SCB     | series capacitor bank                 |
| SER     | sequence of events recorder           |
| SSR     | subsynchronous series resonance       |
| STATCOM | static compensator                    |
| SVC     | static var compensator                |
| SVS     | static var system                     |
| SWC     | surge withstand capability            |
| TAG     | triggered air gap                     |
| TCSC    | thyristor-controlled series capacitor |
| TIF     | telephone influence factor            |

|      |                                      |
|------|--------------------------------------|
| TPSC | thyristor-protected series capacitor |
| TNA  | transient network analyzers          |
| TSC  | thyristor-switched capacitor         |
| TSR  | thyristor-switched reactor           |
| TVI  | television interference              |
| TRV  | transient recovery voltage           |
| V/I  | voltage/current                      |

#### 4. Fixed-series capacitor (FSC) project description

This specification is for the design, manufacture, construction, installation, test, commission, warranty, training, and placement into commercial operation of \_\_\_\_ number of FSC bank(s) at \_\_\_\_ substation on the \_\_\_\_ kV transmission line(s) connecting \_\_\_\_ substation to \_\_\_\_ substation. The FSC bank(s) will provide \_\_\_\_% reactive compensation on these lines.

The purpose of the FSC is to:

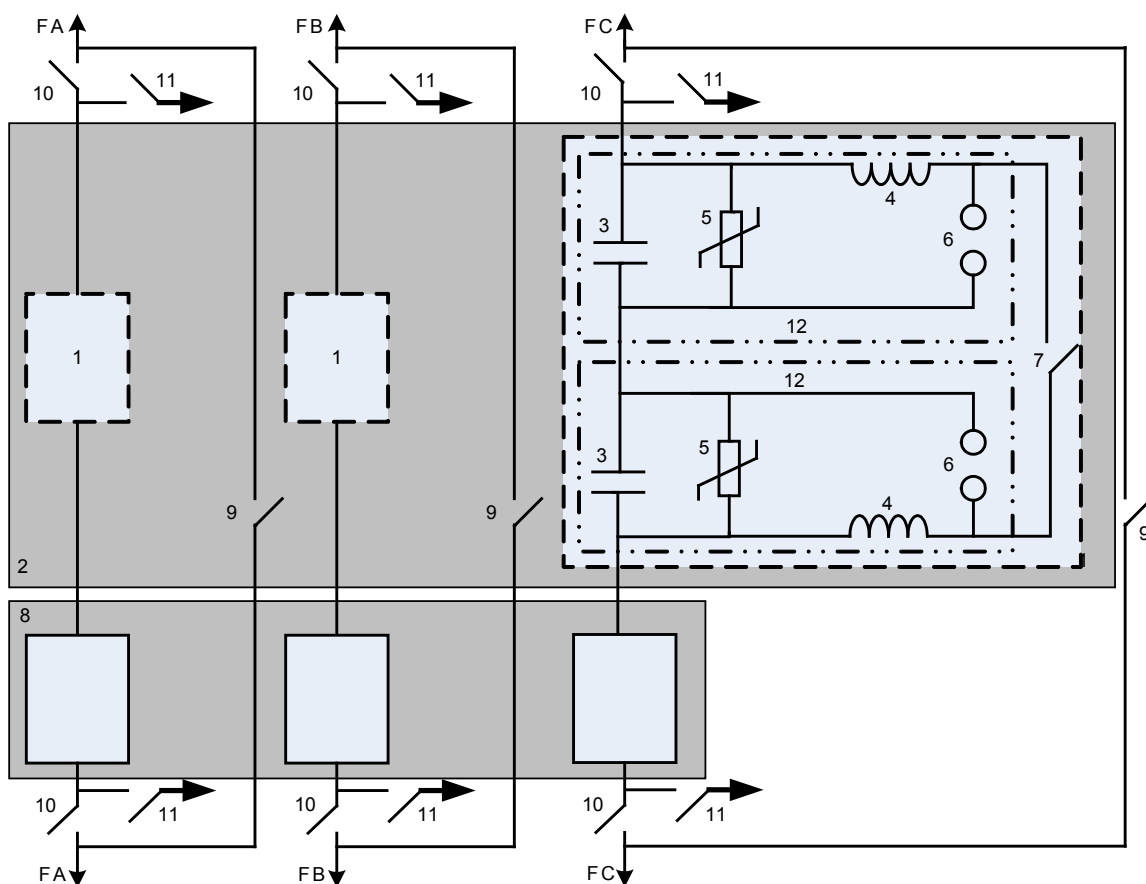
- Increase power flow capacity of \_\_\_\_ kV transmission lines,
- Increase transient stability of \_\_\_\_ kV transmission system,
- Balance and/or control power flow through multiple adjacent lines through the use of FSC banks with multiple switching steps.

The nominal ratings of the FSC bank(s) are \_\_\_\_ A continuous, \_\_\_\_ Ohms capacitive reactance, and \_\_\_\_ Mvar per bank.

The regional and local site location map is shown in attachment # \_\_\_\_\_. A proposed one-line diagram of the substation after installation of the FSC bank is shown in attachment # \_\_\_\_\_. The area for the FSC facility is shown in attachment # \_\_\_\_\_. The points of electrical interconnection of the supplier-furnished FSC facilities are shown in Figure 1, Figure 2, Figure 3, and Figure 4.

Figure 1 describes and defines the individual components typical used to make up a fixed-series capacitor (FSC) bank.

- \_\_\_\_\_ (power system)
- \_\_\_\_\_ (ground grid, soil resistivity)
- \_\_\_\_\_ (station service power)
- \_\_\_\_\_ (control and protection)
- \_\_\_\_\_ (fencing)
- \_\_\_\_\_ (site subsurface and geotechnical data)



# KEY

- |                                      |                                            |
|--------------------------------------|--------------------------------------------|
| 1 Segment (1F)                       | 7 Bypass switch                            |
| 2 Switching step (3F)                | 8 Additional switching steps when required |
| 3 Capacitor units                    | 9 External bypass disconnect switch        |
| 4 Discharge current-limiting reactor | 10 External isolating disconnect switch    |
| 5 Varistor                           | 11 External grounding disconnect switch    |
| 6 Bypass gap                         | 12 Subsegment                              |

**Figure 1—Typical FSC installation nomenclature**

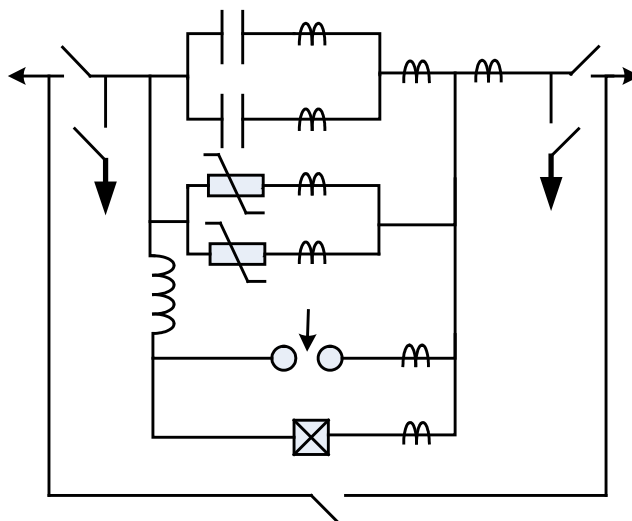


**Figure 2—Example single-line diagram, FSC bank with metal oxide varistor (MOV) plus triggered air gap**

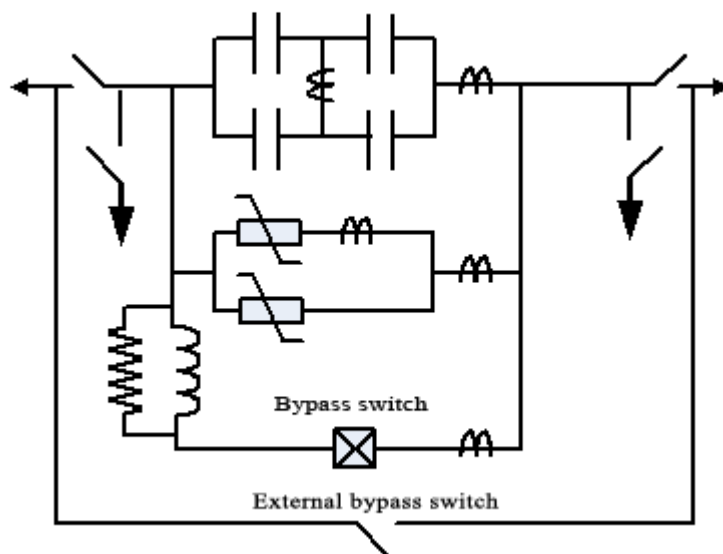


**Figure 3—Example single-line diagram, "gapless" FSC bank with MOV and bypass switch**

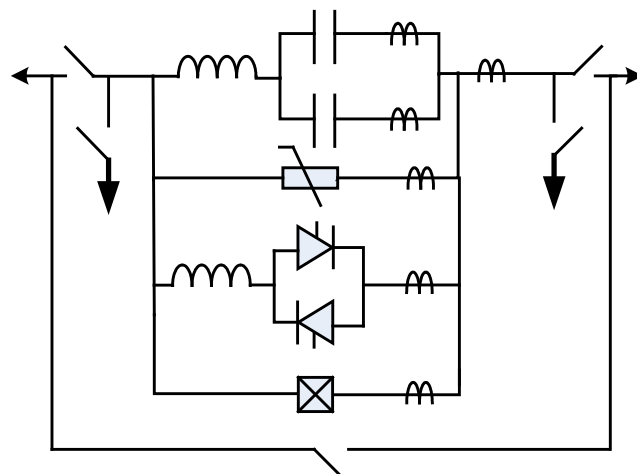


Figure 4—Example single-line diagram, thyristor-protected series capacitor (TPSC)

See Annex B.2 for additional discussion of the FSC specification overall project description.

5. Scope of supply and schedule

5.1 Scope of supply

5.1.1 Supplier- and user-furnished scope of supply (division of responsibility)

The equipment, materials, and services to be furnished by the supplier and user include, but are not limited to, the following:

|                                                                            | Not applicable, or by other | Supplier, bid stage      | Supplier, project stage  | User, bid stage          | User, project stage      |
|----------------------------------------------------------------------------|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Documentation (Clause 14)                                                  |                             |                          |                          |                          |                          |
| Power system studies (11.1)                                                |                             |                          |                          |                          |                          |
| Power system analysis, MOV requirements, preliminary calculations (11.1.2) | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Power system analysis, MOV requirements, final calculations (11.1.2)       | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| System dynamic stability analysis, swing currents (11.1.3)                 | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

|                                                                  | Not applicable, or by other | Supplier, bid stage      | Supplier, project stage  | User, bid stage          | User, project stage      |
|------------------------------------------------------------------|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Line breaker transient recovery voltage (TRV) studies (11.1.4)   | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Subsynchronous resonance (SSR) screening studies (11.1.5)        | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Line protection relaying coordination studies (11.1.6)           | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Insulation coordination study, line-to-ground (11.1.7)           | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| <u>Equipment design studies (11.2)</u>                           |                             |                          |                          |                          |                          |
| MOV rating study (11.2.2)                                        | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Capacitor unit design study (11.2.3)                             | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Capacitor discharge current-limiting and damping study (11.2.4)  | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Insulation coordination study, on-platform (11.2.5)              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Structural design and verification analysis (11.2.6)             | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Reliability, availability, and maintainability calculation (8.3) | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| <u>Other documentation</u>                                       |                             |                          |                          |                          |                          |
| Instruction books                                                | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Training material                                                | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Type test reports for all major components (Clause 12)           | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Production test reports (Clause 12)                              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Field installation test plan and report (Clause 12)              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Commissioning test plan and report (Clause 12)                   | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Special testing plan and report                                  | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

|                                                                                       | Not<br>applicable,<br>or by other | Supplier,<br>bid stage   | Supplier,<br>project<br>stage | User, bid<br>stage       | User,<br>project<br>stage |
|---------------------------------------------------------------------------------------|-----------------------------------|--------------------------|-------------------------------|--------------------------|---------------------------|
| <b>Equipment supply</b>                                                               |                                   |                          |                               |                          |                           |
| Capacitor units and mounting racks (9.1)                                              | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Capacitor protective fusing (if required, 9.1)                                        | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Metal oxide varistors (9.2)                                                           | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Discharge current-limiting reactors (9.6)                                             | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Parallel damping resistors (if required, 9.6)                                         | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Triggered bypass gaps (if required, 9.3)                                              | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Thyristor valves (if required, 9.4.1)                                                 | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Thyristor valve reactors (if required, 9.4.2)                                         | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Bypass switches (9.7)                                                                 | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Bypass switch interpole wire and cable                                                | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Wire and cable from bypass switch to ground-based control systems                     | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| On-platform equipment support insulators (9.5)                                        | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Removable maintenance ladders for each platform                                       | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Current transformers and optical (A/D) converters and transmitters (9.8.1)            | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Fiber optic signal columns                                                            | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Fiber optic cabling from signal column to ground-based protection and control systems | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Ground-based protection and control systems (9.8)                                     | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |
| Human-machine interface (HMI) to ground-based protection and control system           | <input type="checkbox"/>          | <input type="checkbox"/> | <input type="checkbox"/>      | <input type="checkbox"/> | <input type="checkbox"/>  |

|                                                                                                                                                                          | Not applicable, or by other | Supplier, bid stage      | Supplier, project stage  | User, bid stage          | User, project stage      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Remote terminal unit (RTU) to interface ground-based protection and control system and HMI to substation/utility SCADA (supervisory control and data acquisition) system | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Set of external motor operated disconnect switches including a bypass disconnect and two isolating disconnect switches with grounding blades                             | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Wire and cable from disconnect switches to ground-based control systems                                                                                                  | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Electrical buswork, fittings, and connectors                                                                                                                             | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Digital fault recorder                                                                                                                                                   | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Sequence of events recorder                                                                                                                                              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Special maintenance equipment and tools                                                                                                                                  | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Spare parts                                                                                                                                                              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Ground grid                                                                                                                                                              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| FSC bank foundations and structures to mount bus support insulation and disconnect switches, including grounding and ground-grid connections                             | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Dead-end towers and other substation structures such as ladders, decking                                                                                                 | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Protection and control building (Clause 16)                                                                                                                              | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Auxiliary power for protection and control systems and switch power (Clause 16)                                                                                          | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| <b>Site services, turnkey services (if required)</b>                                                                                                                     |                             |                          |                          |                          |                          |
| Technical direction by factory representative during installation                                                                                                        | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Training program for operation and maintenance personnel (Clause 15)                                                                                                     | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

|                                                                                                                                             | Not applicable, or by other | Supplier, bid stage      | Supplier, project stage  | User, bid stage          | User, project stage      |
|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Site pre-commissioning testing and representation during commissioning                                                                      | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Construction and erection of all equipment up to, but not including, line drops (connections from disconnect switches to transmission line) | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Civil works for the FSC bank, including the cable trenching, fencing, drainage, access, rock coverings, and lighting                        | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Line drop connection services                                                                                                               | <input type="checkbox"/>    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

### 5.1.2 User-furnished scope of supply

The equipment, materials, information, and services to be furnished by the user include, but are not limited to, the following:

- The non-electrical data to be supplied by the user is given in Clause 6; the electrical data is in Clause 7, Clause 8, and Clause 9.
- Site for the FSC bank will be available \_\_\_\_\_ calendar days after contract start.
- Source of water for construction.
- Source of temporary station service power for construction at \_\_\_\_\_ V, available \_\_\_\_\_ calendar days after contract start.
- \_\_\_\_\_ sources of permanent station service power for the FSC bank equipment at \_\_\_\_\_ kV, available \_\_\_\_\_ calendar days after contract start.
- Existing facilities and equipment.

With the exception of the equipment, materials, and services furnished by the user, the supplier shall be responsible for the design, engineering, manufacturing, delivery, civil works, erection, installation, testing, commissioning, and field verification of the series capacitor (SC).

Any equipment and/or function of the SC not specifically specified herein should be designed as required by the overall design of the SC system in order to ensure the satisfactory operation of the same.

See B.3.1 for guidance on developing a scope split section to the specification.

## 5.2 Schedule

Project completion is \_\_\_\_\_ calendar days after contract start. The supplier's project schedule is due \_\_\_\_\_ calendar days after contract start and should include such details as dates for commencement and completion of work on several key features of the project, dates for user-furnished services, dates on which supplier-furnished drawings will be provided and approval given, dates for any required design and production testing of all major equipment, and dates and length of time of any required power outages.

Design review meetings should be held between the user and supplier to review and discuss progress of the design and supply of the FSC bank(s). The first design review should be held within \_\_\_\_\_ calendar days after contract start. Subsequent design reviews should be held every \_\_\_\_\_ calendar days.

## 6. Site and environmental data

The FSC bank(s) should be designed to meet all rating and performance requirements specified in this document while operating in the following site and environmental conditions:

|                                               |       |                    |
|-----------------------------------------------|-------|--------------------|
| Site elevation above sea level                | _____ | m                  |
| Maximum ambient dry-bulb temperature          | _____ | °C                 |
| Maximum ambient wet-bulb temperature          | _____ | °C                 |
| Minimum ambient air temperature               | _____ | °C                 |
| Maximum daily average ambient air temperature | _____ | °C                 |
| Minimum daily average ambient air temperature | _____ | °C                 |
| Ice loading conditions                        | _____ | kg/m <sup>2</sup>  |
| Maximum ground snow depth                     | _____ | m                  |
| Maximum frost depth                           | _____ | m                  |
| Maximum steady wind velocity                  | _____ | m/s                |
| Maximum wind gust                             | _____ | m/s                |
| Seismic zone and withstand data               | _____ |                    |
| Dust concentration level or pollution level   | _____ | mg/cm <sup>2</sup> |
| Salt concentration                            | _____ | mg/cm <sup>2</sup> |
| Solar radiation level                         | _____ | W/cm <sup>2</sup>  |
| Earth resistivity                             | _____ | Ohm-m              |

## 7. Power system characteristics

The following ac power system characteristics apply:

|                                                                                                      |       |         |
|------------------------------------------------------------------------------------------------------|-------|---------|
| Nominal ac system voltage, line-to-line                                                              | _____ | kV      |
| Maximum continuous ac system voltage, line-to-line                                                   | _____ | kV      |
| Maximum short-term ac system voltage, line-to-line                                                   | _____ | kV      |
| Lightning impulse protective level for line-to-ground insulation                                     | _____ | kV peak |
| Switching surge withstand insulation level for line-to-ground insulation                             | _____ | kV peak |
| Wet-withstand (10-s ac) insulation level for line-to-ground insulation                               | _____ | kV      |
| Creepage distance requirement for insulators                                                         | _____ | mm/kV   |
| System power frequency                                                                               | _____ | Hz      |
| Maximum fault clearing time including breaker failure                                                | _____ | sec     |
| Maximum three-phase symmetrical fault current                                                        | _____ | kA      |
| Maximum three-phase asymmetrical fault current                                                       | _____ | kA peak |
| Maximum single-phase symmetrical fault current                                                       | _____ | kA      |
| Maximum single-phase asymmetrical fault current                                                      | _____ | kA peak |
| Maximum three-phase short-circuit strength at terminals of FSC bank. With other end of the line open | _____ | MVA     |
| Impedance angle of above short-circuit strength                                                      | _____ | degrees |
| Significant system harmonic current magnitude                                                        | _____ | A       |
| Frequencies of significant harmonic currents                                                         | _____ | Hz      |

## 8. Main FSC characteristics

### 8.1 Overall FSC bank ratings

The following overall FSC bank ratings shall apply:

|                                                                 |       |                           |
|-----------------------------------------------------------------|-------|---------------------------|
| Power frequency                                                 | _____ | Hz                        |
| Nominal capacitive reactance at power frequency, per-phase      | _____ | Ohms                      |
| Nominal phase capacitance                                       | _____ | $\mu\text{F}$             |
| Nominal phase current rating (1.0 pu)                           | _____ | $\text{A}_{\text{rms}}$   |
| Nominal phase voltage rating (1.0 pu)                           | _____ | $\text{kV}_{\text{rms}}$  |
| Three-phase reactive power rating                               | _____ | Mvar                      |
| Protective level voltage range, pu                              | _____ | pu                        |
| Protective level voltage range, peak volts across phase         | _____ | $\text{kV}_{\text{PEAK}}$ |
| Number of segments/switching steps (see Figure 1)               | _____ | n/a                       |
| Segment/switching step reactance split (if more than 1 segment) | _____ | Ohms                      |
| MOV energy capacity per phase                                   | _____ | MJ                        |
| 8-h overload/working current                                    | _____ | pu                        |
| 30-min overload/working current                                 | _____ | pu                        |
| 10-min overload/working current                                 | _____ | pu                        |
| 1-min overload/working current                                  | _____ | pu                        |
| 10-s swing current                                              | _____ | pu                        |

### 8.2 Protection and control philosophy

#### 8.2.1 Protection and control functions

The purchaser should include in his specification that the following functions be provided for the bank. Further discussion is included in IEEE Std C37.116™-2007. In addition the purchaser should indicate if automatic reinsertion should be provided.

- Protection functions against overstress from system conditions
  - Capacitor overload protection: This is a function of the specified overload current requirements for the bank and utility practices.
  - Varistor high-current protection: This function is achieved by measuring varistor current and deducing varistor energy. This function may also include monitoring the magnitude of the varistor current.

- Varistor over-temperature protection: This function is achieved by measuring varistor current and deducing varistor temperature.
- Bypass gap protections: Bypass gap protections typically include detection of prolonged gap conduction.
- Discharge current-limiting reactor harmonic overcurrent protection (optional): This function detects excessive harmonic current in the reactor.
- Protection functions associated with equipment failure or malfunction
  - Capacitor unbalance
  - Platform fault
  - Bypass gap failure
  - Varistor failure
  - Bypass switch failure
  - Pole disagreement
  - Protection and control system failure
- Control functions
  - Bypassing
  - Insertion (automatic or manual) and reinsertion
  - Lockout
  - Temporary block insertion
  - Operation of disconnect switches

### 8.2.2 Degree of redundancy

It is important that the purchaser carefully specify the desired level of redundancy. Items that may be specified to have redundancy are shown in the following list. It may also be specified by the purchaser that the two protection systems be physically separate, each in its own cabinet. The purchaser may specify if the protection system is to be operated from one or two station batteries and the degree of separation between the supplies that is required within the series capacitor bank protection and control system.

- Digital controllers and relays
- Power supplies
- Platform-to-ground signal columns and fiber optical cabling
- Current transformers and current sensors
- Circuits to trigger the forced-triggered gap
- Closing coils for the bypass switch

### 8.2.3 Control of the external disconnect switches

The disconnect switches associated with the series capacitor bank can be controlled by the series capacitor control system or by the control system of the associated substation. If these switches are to be controlled by the series capacitor bank control system, that desire should be stated in the specification. The following additional functions are often provided and should be specified if desired.

- Interlocking so that the bypass switch and the isolation switches will only operate in the proper sequences.
- Automatic isolation of the bank via the disconnect switches for certain equipment contingencies for which the bank should be isolated from the power system.

### 8.2.4 Monitoring requirements (DFR, SER)

In general a digital fault recorder (DFR) and or sequence of events recorder (SER) are installed as an integral part of the series capacitor control and monitoring system. The only ability to monitor and assure the proper operation and maintenance remotely is to install monitoring and recording capability. A DFR and SER device are supplied during commissioning to confirm proper design and operation of controlled components. The inclusion of these devices makes commissioning, operation, and maintenance simpler and more economic.

The purchaser should select a device that has an adequate number of channels to observe system conditions and monitor all necessary functions. Remote contact and communications with DFR and SER should be reviewed to determine the necessity. The DFR and SER must be configurable for remote communication which will comply with government or critical infrastructure standard requirements.

## 8.3 Reliability, availability, and maintainability

### 8.3.1 Background

The purchaser will have to specify the level of redundancy that is expected. Many specifications only list a value, for example 98%. This is a calculated statistical value based on the number and type of components. It is helpful to understand that this is a theoretical number that may make the tender difficult or confusing. The user should understand the availability of the unit for maintenance and appropriately specify the level of component redundancy necessary to maintain the series capacitor bank.

### 8.3.2 Objectives

The design of reliable industrial and commercial power distribution systems is important because of the high costs associated with power outages. There is a need to be able to consider the cost of power outages when making design decisions for new power distribution systems and to be able to make quantitative cost versus reliability trade-off studies.

A quantitative reliability analysis includes making a disciplined evaluation of alternate power distribution system design choices. When costs of power outages are factored into the evaluation, the decisions can be based upon total owning cost over the useful life of the equipment rather than simply first cost of the system.

### 8.3.3 Fundamentals of power system reliability evaluation

Fundamentals necessary for a quantitative reliability evaluation of electric power systems include definitions of basic terms, discussions of useful measures of system reliability and the basic data needed to compute these indexes, and a description of the procedure for system reliability analysis including computation of quantitative reliability indexes.

System reliability assessment and evaluation methods based on probability theory that allow the reliability of a proposed system to be assessed quantitatively are finding wide application today. Such methods permit consistent, defensible, and unbiased assessments of system reliability that are not otherwise possible.

The quantitative reliability evaluation methods permit reliability indexes for any electric power system to be computed from knowledge of the reliability performance of the constituent components of the system. Thus, alternative system designs can be studied to evaluate the impact on reliability and cost of changes in component reliability, system configuration, protection and switching scheme, or system operating policy including maintenance practice.

### 8.3.4 Data needed for system reliability evaluations

The data needed for quantitative evaluations of system reliability depend to some extent on the nature of the system being studied and the detail of the study. In general, however, data on the performance of individual components together with the times required to perform various switching operations are required. System component data that are generally required are summarized as follows:

- Failure rates (forced outage rates) associated with different modes of component failure
- Expected (average) time to repair or replace failed component
- Scheduled (maintenance) outage rate of component
- Expected (average) duration of scheduled outage event

If possible, component data should be based on the historical performance of components in the same environment as those in the proposed system being studied.

### 8.3.5 Method for system reliability evaluation

The method for system reliability evaluation that is recommended has evolved over a number of years. The method, called the *minimal cut-set method*, is believed to be particularly well suited to the study and analysis of electric power distribution systems as found in industrial plants. The method is systematic and straightforward and lends itself to either manual or computer computation. An important feature of the method is that system weak points can be readily identified both numerically and non-numerically, thereby focusing design attention on those sections of the system that contribute most to unreliability.

## 9. FSC main component requirements

### 9.1 Capacitors

#### 9.1.1 Capacitor banks and units

Capacitor unit specification requirements include the following:

- a) The capacitance variation of any two phases of the same three-phase series compensation bank must not exceed \_\_\_% of the arithmetic mean capacitance of the three phases. Such shall be true for the complete ambient temperature range specified under Clause 6.
- b) The series compensation bank capacitance must not vary by more than  $\pm$  \_\_\_% of the nominal capacitance specified under Clause 4, for a capacitor unit internal temperature of \_\_\_°C
- c) Only one type of capacitor unit must be used for the complete series compensation bank. A second type of unit is accepted, if required to feed the triggered air gap (TAG) circuits.
- d) The capacitor unit series-parallel arrangement is left up to the supplier. However, their physical arrangement must be such that an individual units replacement has no effect on the other units.
- e) The power frequency withstand voltage between the series compensation bank terminals must be at least \_\_\_% higher than the varistor protection (60Hz) for the internal fault current indicated in Clause 7.
- f) The capacitor units must be designed for outdoor installation and for a series compensation application.
- g) The individual unit capacitance must not vary by more than  $\pm$  \_\_\_% of the nominal value.
- h) The external radio interference must not exceed \_\_\_V pu (per unit). The test voltage must be equal to \_\_\_ times the unit's nominal voltage. The measurement frequency being \_\_\_ MHz.
- i) The capacitor units may be fuseless, internally fused, or externally fused.
- j) Internally fused capacitors must be designed in order to function with a number of elements in parallel lost just below the threshold of capacitor unbalance current protection trigger. Also, in the case of units without fuses, the design must take into consideration the amount of short-circuit elements, in the same unit, just below the capacitor protection trigger.

#### 9.1.2 Fuseless capacitors

Fuseless capacitors must have protection scheme that will detect the shorting of an entire series group. This is a requirement for detecting a ruptured can. Bushing basic impulse level (BIL) should be coordinated to be consistent with design protective level.

#### 9.1.3 Internally fused capacitors

Each element of the capacitor unit must be protected by a fuse having the following characteristics:

- Must only operate in the event that a fault occurs with the associated unit; must not operate when the series compensation bank is subjected to internal or external faults
- Must not operate for the specified overload cycle.

The supplier must include in his proposal:

- Calculations of constraints to which the capacitor unit is subjected
- The fuse's time-current coordination curve

#### 9.1.4 Externally fused capacitors

The fuse associated with a particular capacitor unit must be coordinated so as to sustain the current constraints arising from the following conditions:

- Overload cycle
- Fault internal or external to the series compensation bank
- Discharge current resulting from the spark gap striking

The capacitor unit associated fuse must be able to isolate the defective unit at the maximum terminal voltage, assuming that the series compensation bank terminal voltage is equal to the varistor protection level.

Following a fuse operation, there must not be any excessive leakage current nor any risk of sparking when a full voltage is permanently applied between the bus bar and the defective capacitor unit terminal, and such for all specified atmospheric conditions.

The supplier must include in the proposal:

- Calculations of constraints subjected to the capacitor unit
- The fuse's time-current coordination curve

## 9.2 Varistors

Varistor specification requirements include the following:

- a) The number of varistor columns must be determined in order to meet the installed energy absorption.
- b) The minimum number of varistor columns (excluding installed spare columns) must be chosen to withstand the worst internal or external fault, taking into consideration the uneven current sharing between columns.
- c) An installed spare quantity of at least \_\_\_\_% of the total number of varistors per phase, rounded up to the next whole number, must be supplied and be operational on the platform. A varistor may contain one or more varistor columns in parallel within the same housing.
- d) After 1 min of rest delay, the varistors must be capable of absorbing a second time of the nominal energy absorption. The varistor protection strategy must allow for such utilization of this additional energy absorption capability.
- e) The varistor unit must be designed such as to prevent explosive breakage of the housing (per most-recent IEEE Std 824™-2004, see pressure relief design test requirements) in the event of a short-circuit failure of one or more varistor columns. Failures caused by a series compensation bank discharge current at a voltage corresponding to the varistor protection level defined in 8.1 superimposed on a \_\_\_\_ kA<sub>rms</sub> fault of \_\_\_\_ cycle duration in the unit itself. It can be assumed that the fault current has an asymmetrical component with ratio X/R = \_\_\_\_.

### 9.3 Triggered bypass gaps

Triggered bypass requirements include the following:

- a) The triggered air gap (TAG) must be designed to protect the MOV by quickly bypassing the capacitors and MOV when, under internal fault conditions, the absorbed energy would exceed the energy absorption capacity without TAG protection. The maximum time delay from the point at which the MOV high-current and/or high-energy bypass threshold is exceeded until TAG conduction shall not exceed \_\_\_\_ ms.
- b) The supplier must ensure in the design of the TAG that the meteorological conditions specific to the substation (see Clause 6) are considered when calculating minimum non-triggered sparkover voltage of the TAG electrode assemblies.
- c) The spark gap must be able to sustain at least \_\_\_\_ conductions with a capacitor discharge current at a voltage corresponding to the varistor protection level defined in 8.1 superimposed on a \_\_\_\_ kA<sub>rms</sub> fault of \_\_\_\_ cycle duration before the main electrodes contact surfaces require maintenance.
- d) Following a series of discharges, the minimum non-triggered sparkover voltage of the TAG electrode assemblies must not be reduced more than \_\_\_\_% of the guaranteed value.
- e) If the FSC bank voltage is greater than \_\_\_\_ pu of the nominal voltage, the TAG triggering mechanism must reliably cause conduction.
- f) The minimum non-triggered sparkover voltage of the TAG electrode assemblies must be greater than the MOV residual voltage at the MOV high-current bypass threshold, taking into consideration the meteorological conditions specific to the substation (see Clause 6).
- g) After each operation, the spark gap must be able to recover its full self-striking dielectric strength within \_\_\_\_ seconds.
- h) The spark gaps must be physically protected against snow, ice, and moisture.

### 9.4 Thyristors and thyristor reactors

#### 9.4.1 Thyristor valves

A bistable semi-conducting device composed of three or more junctions that can be switched from the OFF state to the ON state or vice versa. Such switching occurs in at least one quadrant of the principle voltage-current characteristic. The inclusion of thyristors for fast bypass and reinsertion is a reasonable solution in cases where multiple faults occur and stability of single-pole reinsertion are necessary.

#### 9.4.2 Thyristor valve reactors

A wound iron core device used to dampen or limit the rate of rise current when a thyristor is triggered. This device limits current inrush and improves thyristor operation and longevity.

### 9.5 Insulation and air clearances

Fixed-series capacitors (FSCs) for three-phase systems are, with a few exceptions (e.g., FSCs for distribution networks), built up by single-phase units. A three-phase extra-high-voltage (EHV) series capacitor bank consists of three single-phase units. Each single-phase unit is connected in series with the

corresponding phase of the compensated three-phase circuit. Each single-phase unit is normally erected on an individual platform. The platforms need to be insulated from ground and from each other. In addition, the FSC equipment mounted on each platform needs to be insulated from the platform.

In summary, the following insulation systems need to be specified for a series capacitor:

- Insulation between each FSC platform and ground
- Insulation between the FSC platforms
- Insulation on top of each FSC platform

## 9.5.1 Selection and test of insulation system voltages

### 9.5.1.1 Standard values

The insulation withstand voltages of the FSC installation shall be chosen from the standard values prescribed in IEEE Std 1313-1™ [B10], IEEE Std 1313-2™ [B11], or IEC 60071-1 [B6] and IEC 60071-2 [B7]. See Table B.3, Table B.4, and Table B.5.

### 9.5.1.2 Insulation between platform and ground

The phase-to-ground insulation for the series capacitor bank shall meet the withstand levels specified by the purchaser. These levels should be consistent with the standard practice for nearby substations taking into account that the voltage on the platform support insulators **may be higher** than the voltage at the substation. This is due to the voltage step in the voltage profile along the transmission line produced by the FSC. In addition, for line located FSCs, the voltage rise at the FSC location due to the curved or higher voltage profile of a long transmission line must be added.

Listed in Table B.2, Table B.3, and Table B.4 are various possible insulation levels that are consistent with ANSI and IEC standards. The test voltages for the platform to ground insulation (phase-to-ground insulation) shall be selected among the standard values according to Table B.2, Table B.3, and Table B.4.

For installations at elevations significantly above 1000 m, an increased insulation may be required.

The leakage distance (creepage distance) for the phase-to-ground insulators shall meet that specified by the purchaser.

NOTE—The values specified shall apply not only to the platform-to-ground insulators, but also to other series capacitor devices connected between phase and ground such as the line-to-ground insulator(s) of the bypass switch, the platform-to-ground communication equipment insulator(s), and the line-to-ground insulator(s) of the disconnectors.

### 9.5.1.3 Insulation between platforms (phases)

The test voltages for the platform-to-platform insulation (phase-to-phase insulation) shall be selected among the standard values of Table B.3.

Otherwise applicable parts of B.7.5.1.1 apply to the phase-to-phase insulation.