

# IEEE Guide for the Functional Specification of Transmission Static Var Compensators

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**Abstract:** This guide documents an approach to preparing a specification for a transmission static var compensator. The document is intended to serve as a base specification with an informative annex provided to allow users to modify or develop specific clauses to meet a particular application.

**Keywords:** filters, harmonics, static var compensators, static var system, TCR, thyristor valves, TSC, TSR

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# Introduction

(This introduction is not a part of IEEE Std 1031-2000, IEEE Guide for the Functional Specification of Transmission Static Var Compensators.)

This document is a revision of IEEE Std 1031-1991, Guide for a Detailed Functional Specification and Application of Static Var Compensators. The guide has been renamed and provides an example and general information that may be considered when developing a technical specification for a transmission static var compensator (SVC).

This guide is not a tutorial, and application of its contents in preparing a technical specification shall be done with sufficient technical knowledge and understanding. This guide may not include all topics necessary for every SVC application and does not address any commercial conditions applicable to specific projects.

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# IEEE Guide for the Functional Specification of Transmission Static Var Compensators

## 1. Overview

### 1.1 Scope

This document provides general guidelines toward the preparation of a functional specification of transmission static var compensators (SVCs) using conventional thyristor technology. Many clauses will be useful for compensator systems using gate turn-off (GTO) thyristor technology [static compensator (STATCOM)] or other semiconductor devices, or SVCs associated with high-voltage dc (HVDC) converter stations, or industrial and distribution applications.

General terms and conditions forming the commercial part of a specification for a particular project are outside the scope of this document.

### 1.2 Purpose

Starting at Clause 4, this document presents technical clauses that may be used as the basis of a functional SVC specification. The wording deliberately uses “should” rather than “shall” because this document is a guide, not a specification. The user of this guide might wish to make this adjustment when converting clauses into a specification. Annex B of this document contains supplemental information intended to further develop specific clauses. Further information is referenced by the same subdivision numbering used in the main text.

### 1.3 Application

The guide should be considered a general purpose resource and does not include all details needed for a specific application. Likewise, because transmission SVCs 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 an SVC specification.

Clause 3 gives definitions such as a static var compensator (SVC), a static var system (SVS), and associated other reactive elements. This guide applies to the SVC.

## 2. References

This guide should be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

Accredited Standards Committee C2-1997, National Electrical Safety Code<sup>®</sup>, NESC<sup>®</sup>.<sup>1, 2</sup>

ANSI Std C63.16-1993, American National Standard Guide for Electrostatic Discharge Tests Methodologies and Criteria for Electronic Equipment.

BS EN 61803: 1999, Determination of power losses in high-voltage direct current (HVDC) convertor stations.<sup>3</sup>

IEC 60815-05: 1986, Guide for the selection of insulators in respect of polluted conditions.<sup>4</sup>

IEC 61954-09: 1999, Power electronics for electrical transmission and distribution systems—Testing of thyristor valves for static VAR compensators.

IEEE Std 18-1992, IEEE Standard for Shunt Power Capacitors.<sup>5</sup>

IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in AC Substation Grounding.

IEEE Std 139-1988 (Reaff 1999), IEEE Recommended Practice for the Measurement of Radio Frequency Emission from Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises.

IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

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

IEEE Std 1303-1994, IEEE Guide for Static Var Compensator Field Tests.

IEEE Std C37.90.1-1989 (Reaff 1994), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.

## 3. Definitions, acronyms, and abbreviations

### 3.1 Definitions

For the purposes of this guide the following technical terms and definitions apply. The IEEE Standard Dictionary of Electrical and Electronics Terms shall be referenced for terms not defined in this clause.

<sup>1</sup>The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

<sup>2</sup>National Electrical Safety Code<sup>®</sup> and NESC<sup>®</sup> are both registered trademarks and service marks of the Institute of Electrical and Electronics Engineers, Inc.

<sup>3</sup>EN publications are available from the European Committee for Standardization (CEN), 36, rue de Stassart, B-1050 Brussels, Belgium (<http://www.cenorm.be>).

<sup>4</sup>IEC 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, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

<sup>5</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 (<http://standards.ieee.org/>).

**3.1.1 commercial operation:** The acceptance, by the user, of the static var compensator (SVC) from the supplier.

**3.1.2 contract start:** The date a contract to supply a static var compensator (SVC) becomes effective, and the user has given notice to proceed.

**3.1.3 control range:** The total inductive plus capacitive range of reactive current or megavar variation of the static var compensator (SVC), at the point of connection.

**3.1.4 lagging operation:** Inductive megavars absorption of the static var compensator (SVC), similar to a shunt reactor.

**3.1.5 leading operation:** Capacitive megavars generation of the static var compensator (SVC), similar to a shunt capacitor.

**3.1.6 mechanically switched capacitor (MSC):** A shunt-connected circuit containing a mechanical power-switching device in series with a capacitor bank and sometimes also a damping reactor.

**3.1.7 mechanically switched reactor (MSR):** A shunt-connected circuit containing a mechanical power switching device in series with a reactor.

**3.1.8 point of common coupling (PCC):** The busbar from which other loads sensitive to voltage may be connected as well as the static var compensator (SVC) and any disturbing load it is required to compensate.

**3.1.9 point of connection:** For a static var compensator (SVC) with a dedicated transformer, the high-voltage (HV) bus to which the whole is connected. For an SVC connected to an existing transformer, or direct connected at low voltage, the busbar to which it is connected.

**3.1.10 reference voltage:** The point on the voltage/current (V/I) characteristic where the static var compensator (SVC) is at zero output (i.e., where no vars are absorbed from, or supplied to, the transmission system at the point of connection).

**3.1.11 response time:** The duration from a step change in control signal input until the static var compensator (SVC) output reaches 90% of required output, before any overshoot.

**3.1.12 settling time:** The duration from a step change in control signal input until the static var compensator (SVC) output settles to within  $\pm 5\%$  of the required output.

**3.1.13 slope:** The ratio of the voltage change to the current change over the full (inductive plus capacitive) linearly controlled range of the static var compensator (SVC) at nominal voltage, expressed as a percentage.

**3.1.14 STATCOM (static compensator):** A static synchronous generator operated as a shunt-connected static var compensator (SVC), whose capacitive or inductive output current can be controlled independently of the ac system voltage.

**3.1.15 static var compensator (SVC):** A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current to maintain or control specific parameters of the electrical power system (typically bus voltage).

**3.1.16 static var system (SVS):** A combination of different static and mechanically switched var compensators whose outputs are coordinated.

**3.1.17 thyristor-controlled reactor (TCR):** A shunt-connected thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial conduction of the thyristor valve.

**3.1.18 thyristor-switched capacitor (TSC):** A shunt-connected thyristor-switched capacitor whose effective reactance is varied in a stepwise manner by full- or zero-conduction operation of the thyristor valve.

**3.1.19 thyristor-switched reactor (TSR):** A shunt-connected thyristor-switched inductor whose effective reactance is varied in a stepwise manner by full- or zero-conduction operation of the thyristor valve.

**3.1.20 voltage/current (V/I) characteristic:** The relationship between the steady-state current of the static var compensator (SVC) and the voltage at its point of connection.

## 3.2 Acronyms and abbreviations

|         |                                   |
|---------|-----------------------------------|
| BIL     | basic impulse level               |
| CT      | current transformer               |
| EMI     | electromagnetic interference      |
| ETT     | electrically triggered thyristors |
| FACTS   | flexible AC transmission systems  |
| GTO     | gate turn-off                     |
| HV      | high-voltage                      |
| HVDC    | high-voltage direct current       |
| LTT     | light-triggered thyristors        |
| LV      | low-voltage                       |
| MSC     | mechanically switched capacitor   |
| MSR     | mechanically switched reactor     |
| PCC     | point of common coupling          |
| PT      | potential transformer             |
| RI      | radio interference                |
| RMS     | root-mean-square                  |
| STATCOM | static compensator                |
| SVC     | static var compensator            |
| SVS     | static var system                 |
| SWC     | surge withstand capability        |
| TIF     | telephone influence factor        |
| TNA     | transient network analyzers       |
| TSC     | thyristor-switched capacitor      |
| TSR     | thyristor-switched reactor        |
| TVI     | television interference           |
| V/I     | voltage/current                   |

## 4. SVC project description

This specification is for the design, manufacture of equipment, construction, installation, test, commission, warranty, training, and placement into commercial operation of an SVC at \_\_\_\_\_ substation connected to the \_\_\_\_\_ busbar.

The purpose of the SVC is to regulate the voltage of the \_\_\_\_\_ kV busbar. The nominal ratings of the SVC are \_\_\_\_\_ Mvar leading at \_\_\_\_\_ kV to \_\_\_\_\_ Mvar lagging at \_\_\_\_\_ kV.

A regional and local site location map is shown in Figure \_\_\_\_\_. A proposed one-line diagram of the \_\_\_\_\_ substation after installation of the SVC is shown in Figure \_\_\_\_\_. The area for the SVC facility is shown in Figure \_\_\_\_\_. The points of electrical interconnection of the supplier-furnished SVC and the user-furnished facilities are shown on the following figures:

Figure \_\_\_\_

\_\_\_\_ (power circuit)  
\_\_\_\_ (grounding)  
\_\_\_\_ (station service)  
\_\_\_\_ (control and protection)

and, for turnkey projects

\_\_\_\_ (fencing)  
\_\_\_\_ (site sub-surface and geotechnical data)  
\_\_\_\_ (other)

The design and layout of the SVC facility should provide for future expansion requirements as shown in Figure \_\_\_\_.

See Annex B for additional discussion of the SVC specification.

## 5. Scope of supply and schedule

### 5.1 Scope of supply

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

- a) SVC thyristor valve and valve cooling equipment
- b) High-voltage (HV) ac equipment, transformer, switchgear, circuit breaker, disconnects, potential transformers (PTs), current transformers (CTs), surge arresters, and grounding transformers
- c) Reactors, capacitors, and harmonic filters
- d) SVC station services
- e) SVC yard control, protection, alarm and monitoring systems
- f) Special maintenance equipment and tools
- g) Training program for operation and maintenance personnel
- h) Spare parts
- i) Testing and commissioning services
- j) Documentation including instruction manuals

For turnkey supply, the following are added:

- k) Civil works for the SVC, including the switchyard, fencing, drainage, access, and parking
- l) SVC building, including grounding
- m) SVC foundations and structures to mount busbars, including grounding and ground mat connections

## 5.2 Equipment, materials, and services furnished by the user

The nonelectrical data to be supplied by the user is given in Clause 6; the electrical data is in Clause 7, Clause 8, and Clause 9.

The user should furnish the following equipment, materials, and services:

- a) Site for the SVC available \_\_\_\_ calendar days after contract start
- b) Source of water for construction
- c) Source of temporary station service power for construction at \_\_\_\_\_ kV, available \_\_\_\_ calendar days after contract start
- d) \_\_\_\_\_ sources of permanent station service power for the SVC at \_\_\_\_\_ kV, available \_\_\_\_ calendar days after contract start
- e) Existing facilities and equipment

## 5.3 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 controlling features of the project, dates for user-furnished services, dates on which supplier-furnished drawings will be provided and approval given, 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 SVC. 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 SVC should be designed to meet all rating and performance requirements specified in this document while operating in the following site and environmental conditions:

- |    |                                                                |       |                    |
|----|----------------------------------------------------------------|-------|--------------------|
| a) | Site elevation above sea level                                 | _____ | m                  |
| b) | Maximum ambient dry-bulb temperature                           | _____ | °C                 |
| c) | Maximum ambient wet-bulb temperature                           | _____ | °C                 |
| d) | Minimum ambient air temperature                                | _____ | °C                 |
| e) | Maximum daily average ambient air temperature                  | _____ | °C                 |
| f) | Minimum daily average ambient air temperature                  | _____ | °C                 |
| g) | Ice loading conditions                                         | _____ | kg/m <sup>2</sup>  |
| h) | Maximum ground snow depth                                      | _____ | m                  |
| i) | Maximum frost depth                                            | _____ | m                  |
| j) | Maximum steady wind velocity                                   | _____ | m/s                |
| k) | Wind gust factor or maximum wind gust                          | _____ | m/s                |
| l) | Seismic zone and withstand data                                | _____ |                    |
| m) | Isokeraunic level                                              | _____ | days/yr            |
| n) | Dust concentration (or pollution level per IEC 60815-05: 1986) | _____ | mg/cm <sup>2</sup> |
| o) | Salt concentration                                             | _____ | mg/cm <sup>2</sup> |
| p) | Solar radiation level                                          | _____ | W/cm <sup>2</sup>  |
| q) | Earth resistivity                                              | _____ | Ohm-m              |

## 7. Power system characteristics

The following ac power system characteristics apply at the point of connection prior to SVC installation. Normal SVC operation is required within the parameter values and durations given.

|    |                                                                                  |                  |         |
|----|----------------------------------------------------------------------------------|------------------|---------|
| a) | Nominal ac system voltage, line-to-line                                          | _____            | kV      |
| b) | Maximum continuous ac system voltage, line-to-line                               | _____            | kV      |
| c) | Minimum continuous ac system voltage, line-to-line                               | _____            | kV      |
| d) | Maximum short-term ac system voltage, line-to-line                               | _____            | kV      |
| e) | Maximum duration of item d)                                                      | _____            | s       |
| f) | Minimum short-term ac system voltage, line-to-line                               | _____            | kV      |
| g) | Maximum duration of item f)                                                      | _____            | s       |
| h) | Continuous negative-sequence voltage component                                   | _____            | %       |
| i) | Continuous zero-sequence voltage component                                       | _____            | %       |
| j) | Nominal ac system frequency                                                      | _____            | Hz      |
| k) | Maximum continuous ac system frequency                                           | _____            | Hz      |
| l) | Minimum continuous ac system frequency                                           | _____            | Hz      |
| m) | Maximum short-term ac system frequency                                           | _____            | Hz      |
| n) | Maximum duration of item m)                                                      | _____            | s       |
| o) | Maximum rate of change of frequency (df/dt)                                      | _____            | Hz/s    |
| p) | Minimum short-term ac system frequency                                           | _____            | Hz      |
| q) | Maximum duration of item p)                                                      | _____            | s       |
| r) | Lightning impulse protective level (BIL)                                         | _____            | kV peak |
| s) | Switching impulse protective level                                               | _____            | kV peak |
| t) | Maximum three-phase fault current                                                | _____            | kA      |
| u) | Minimum three-phase fault current                                                | _____            | kA      |
| v) | Maximum single-phase fault current                                               | _____            | kA      |
| w) | Minimum single-phase fault current                                               | _____            | kA      |
| x) | Harmonic impedance sectors (for performance)                                     | See Figure _____ |         |
| y) | Harmonic impedance sectors (for rating filter components)                        | See Figure _____ |         |
| z) | Background harmonic voltage (or current) spectrum (for rating filter components) | See Figure _____ |         |

## 8. Main SVC characteristics

### 8.1 SVC rating

These clauses define the ratings of the compensator equipment.

- The SVC should regulate the \_\_\_\_\_ kV bus voltage to a reference voltage of \_\_\_\_\_ kV (1.0 per unit), continuously adjustable between \_\_\_\_\_ per unit and \_\_\_\_\_ per unit.
- The nominal capacitive reactive power output of the SVC at point A should be \_\_\_\_\_ per unit on 100 MVA base at 1.0 per unit ac bus voltage and nominal system frequency, and 20 °C ambient temperature. Refer to the voltage/current (V/I) characteristic on Figure 1.
- The nominal inductive reactive power output of the SVC at point B should be \_\_\_\_\_ per unit on 100 MVA base at 1.0 per unit ac bus voltage (see Figure 1).
- The nominal slope of the characteristic should be adjustable in steps of not greater than \_\_\_\_\_% between \_\_\_\_\_% and \_\_\_\_\_%, on a basis of \_\_\_\_\_ MVA (see Figure 2).

- e) The SVC should continue to generate reactive power during a temporary undervoltage down to the value given in Clause 7 f) for the duration given in Clause 7 g) (point C on Figure 1); the SVC may be tripped if the undervoltage persists for more than \_\_\_\_\_ s.
- f) The SVC should continue to absorb reactive power during a temporary overvoltage in a controlled manner up to the value given in Clause 7 d) for the duration given in Clause 7 e) (point D on Figure 1); the SVC may be tripped if the overvoltage persists for more than \_\_\_\_\_ s.

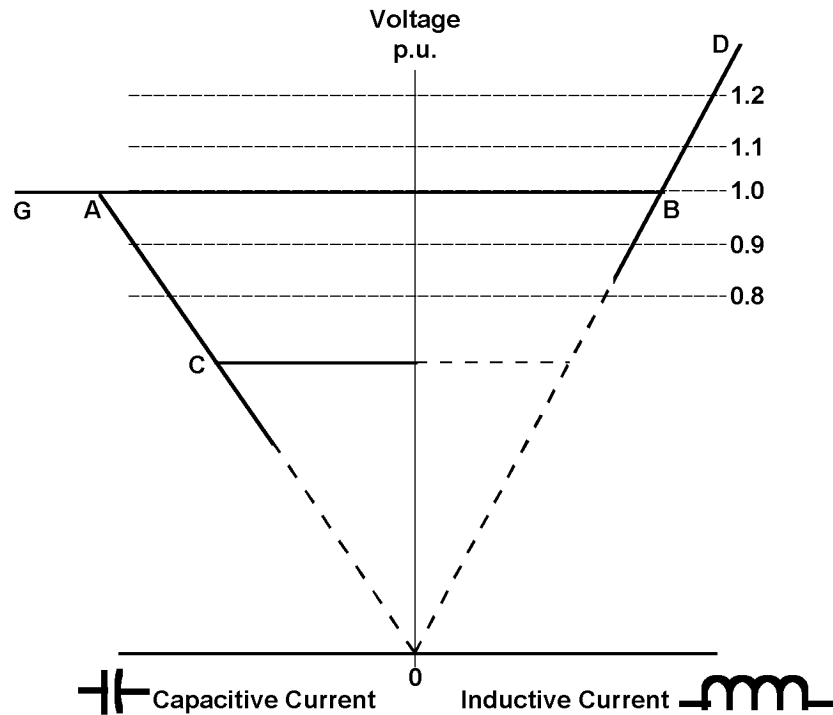
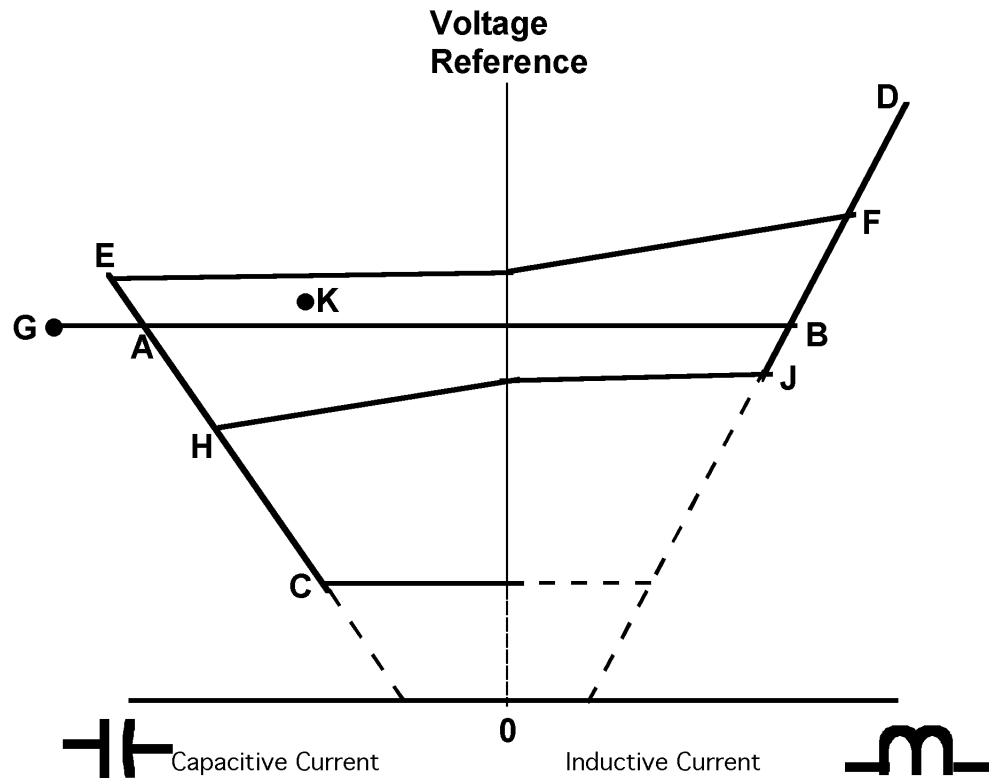


**Figure 1—V/I characteristics of the SVC to define ratings at nominal voltage**

- g) (Optional) The short-time capacitive reactive power output of the SVC should be \_\_\_\_\_ Mvar at \_\_\_\_\_ per unit ac bus voltage for \_\_\_\_\_ s (Figure 2, point G), following 1 h operation at or below the level specified under 8.1 b).
- h) (Optional) Continued controllable conduction of the SVC to absorb reactive power should be possible up to \_\_\_\_\_ per unit ac bus voltage for \_\_\_\_\_ s, following 1 h operation at or below the level specified under item 8.1 c).
- i) The SVC should be capable of repeating short-term operation as defined in any one of 8.1 e), 8.1 f), or 8.1 g) every \_\_\_\_\_ min.
- j) The compensator transformer and all bus equipment such as filter branches, thyristor-switched capacitor (TSC) branches, thyristor-switched reactor (TSR) branches, thyristor-controlled reactor (TCR) branches, capacitor bank branches, and reactor bank branches [whether at HV or low-voltage (LV)] should be rated to withstand the specified continuous and short-term operation, and to withstand or be protected against voltage and current stresses that exceed these conditions.
- k) All equipment in the SVC system should be capable of sustaining a fault unconstrained by the transformer impedance. Taken with its normally connected transformer, all SVC equipment should sustain, without damage, any internal fault no matter what fault level is available on the HV system(s).



A is defined by 8.1 b), giving the nominal capacitive susceptance, OA.

B is defined by 8.1 c), giving the nominal inductive susceptance, OB.

C is defined by Clause 7 f).

Below point C the SVC should normally block TSC branches and await a recovery of voltage before resuming normal action.

D is defined by Clause 7 d). It is on an extension of line OB.

E is an extension of line OA at maximum voltage reference and minimum slope.

F is an extension of line OB at maximum voltage reference and maximum slope.

G is defined by 8.1 g).

H and J give minimum voltage settings for continuous operation at maximum and minimum slope, respectively.

K is a most severe operating condition, chosen to define filter component ratings.

**Figure 2—Detail of SVC characteristic (exaggerated scale)**

## 8.2 Control objectives

### 8.2.1 SVC functions, with priority

The desired function(s) and the priority in which the SVC should respond to them are

- Control of three-phase average or positive sequence of the fundamental voltage in steady state and post fault, with slope in the range of \_\_\_\_\_% to \_\_\_\_\_%.

- b) Control of phase voltage based on
  - 1) Individual phase voltages
  - 2) Positive and negative sequence voltages
- c) Control of voltage with superimposed reactive power control. The reactive power returns SVC output slowly to a preset steady-state value, so that its megavar capacity to support voltage is held in reserve.
- d) Voltage control with superimposed damping control based on active power, speed, or frequency measurements to damp oscillations or to enhance the power transfer capability.
- e) The SVC should not trip during the dead time of \_\_\_\_\_ ms during automatic reclosing operations.

### 8.2.2 Response

The change of measured system voltage should reach 90% of the desired total change within \_\_\_\_\_ ms of the initiating control signal of voltage reference. The maximum overshoot should not exceed \_\_\_\_\_% of the ordered change and the settling time should not exceed \_\_\_\_\_ ms, after which the voltage should be within \_\_\_\_\_% of the ordered value. This response is required when the system three-phase fault MVA is at the minimum value defined in Clause 7 (see Figure 3).

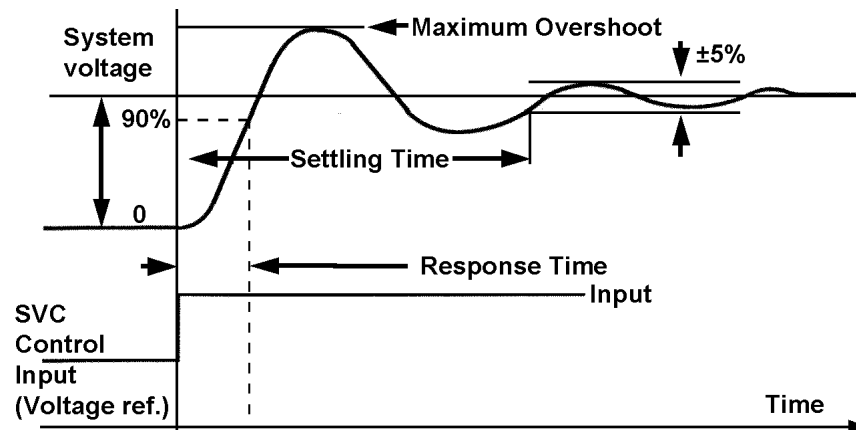


Figure 3—Response of the SVC

## 8.3 Harmonic performance

The SVC system should be designed to avoid resonance between its shunt capacitor banks, filter branches, and the ac system, and to limit the harmonic distortion imposed on the connected transmission system.

### 8.3.1 Filter performance

The maximum voltage distortion generated by the SVC should not cause the values shown in Table 11.1 of IEEE Std 519-1992 to be exceeded.

These requirements should be met for the following:

- The continuous range of system and environmental conditions stated in Clause 6 and Clause 7
- Variation in tolerance of total filter capacitance, including permissible fuse failures
- Variation in tolerance for SVC parameters, such as transformer winding unbalances, valve firing variations, and unequal reactor and capacitor reactance between phases

These performance requirements may be exceeded for system conditions outside the continuous normal envelope specified in Clause 7.

### 8.3.2 Filter component rating

The harmonic filter components (and other SVC components) should be rated to carry the harmonic currents caused by the background harmonic distortion of the system and the harmonic currents produced by the SVC itself. Unless otherwise specified, individual harmonic currents from the system and the SVC should be added quadratically (root sum of squares).

The rated voltage of capacitors should be not less than the arithmetic sum of the normal continuous power-frequency voltage and the largest of the individual harmonic voltages.

## 8.4 Telephone and radio interference

### 8.4.1 Telephone interference

Limits for telephone interference should be given, where applicable, as follows:

- The  $I \times T$  product should be less than \_\_\_\_\_, where  $I \times T$  is defined as the square root of the sum of the squares of harmonic current ( $I_n$ ) and the corresponding weighting factor from the “C-message” weighting factors established by subclause 6.9.1 of IEEE Std 519-1992.
- The  $kV \times T$  product, otherwise known as telephone influence factor (TIF), should be less than \_\_\_\_\_, where  $kV \times T$  is defined as the square root of the sum of the squares of harmonic voltage ( $V_n$ ) and the corresponding weighting factor from the “C-message” weighting factors established by subclause 6.9.1 of IEEE Std 519-1992.

### 8.4.2 Radio interference

The potential for higher frequency emissions should be limited to avoid interference with any properly licensed or authorized radio, television, microwave, or other equipment in service. In addition, the radio frequency emissions produced by the SVC should not exceed \_\_\_\_\_  $\mu\text{V/m}$  over the range of 150 kHz to 1 MHz, when measured 500 m from the SVC station perimeter, except where overhead lines leave the station. The measurements should be made in accordance with IEEE Std 139-1988, based on quasi-peak detector readings.

## 8.5 Audible noise

The supplier should design and construct the SVC to limit the audible noise interior and exterior to the facilities. Audible noise limits outside the SVC building typically apply at the substation fence line. Inside the building, they apply at a specified distance (typically 3 m) from the emitting source and include the following:

- |    |                                                                  |             |
|----|------------------------------------------------------------------|-------------|
| a) | Station fence                                                    | _____ dB(A) |
| b) | Within compressor areas                                          | _____ dB(A) |
| c) | At a distance of _____ m outside of compressor area enclosure(s) | _____ dB(A) |
| d) | At a distance of _____ m outside of mechanical equipment areas   | _____ dB(A) |
| e) | Maintenance workshop                                             | _____ dB(A) |
| f) | Control rooms                                                    | _____ dB(A) |
| g) | Relay rooms                                                      | _____ dB(A) |
| h) | Other accessible rooms                                           | _____ dB(A) |

The supplier should also be responsible for establishing existing audible noise levels prior to construction of the facilities and for preparation of a report. The final report should record audible noise levels prior to and after construction.

## 8.6 Loss evaluation

The bidder should supply the estimated or warranted total losses (kW) calculated in accordance with the equations in 8.6.1 through 8.6.7. It should be assumed that ambient temperature is \_\_\_\_\_ °C, the busbar voltage is \_\_\_\_\_ per unit, and the slope setting is \_\_\_\_\_ %. The SVC may not operate at these conditions, but they provide a common base for evaluation.

For each operating point, losses are calculated for the parts of the SVC in operation or connected, whether conducting current or not. If more than one combination of SVC parts might operate at a given output, both values should be given and separately summated, with explanation, and the average taken forward to the summation.

Losses in switchgear, busbars, cables, clamps, connectors, etc., are excluded. Losses associated with harmonic currents are also omitted from loss calculations for evaluation (though they should be considered to determine ratings of cooling plant and the like).

Losses in the equipment described in 8.6.1 through 8.6.7 should be included in the calculations.

### 8.6.1 Thyristor valves

See Annex C.

### 8.6.2 Transformer losses

The transformer losses are a function of the transformer resistance and the root-mean-square (RMS) fundamental current in the transformer and core and stray losses.

Transformer losses are normally measured on test at full load and no load. The no load losses should be stated at nominal voltage and no load, and should be taken as being consumed at all times.

The full load losses should be used to calculate an equivalent resistance of the transformer. Losses of the transformer at each SVC operating point required in 8.6.7 should then be calculated using this resistance and the predicted transformer current for that SVC output.

### 8.6.3 Reactor losses

The reactor losses are calculated from the rms fundamental phase current  $I$ .

$$P_{\text{reac}} = 3 \times R_{\text{reac}} \times I^2 \quad (1)$$

$R_{\text{reac}}$  is the fundamental frequency resistance. The reactor resistance values should be verified from the test report for the reactors. Tests of quality factor,  $Q$ , should be made with as many connections, clamps, shields, etc., as possible in position.

This calculation applies to TSC and filter reactors, TCRs, mechanically switched reactors (MSRs), and TSR reactors.

### 8.6.4 Capacitor bank losses (TSC, MSC, and filters)

In the test reports for each capacitor unit, the dissipation factors (tan delta) are given. An average value for all capacitor units is used to calculate the capacitor bank losses. The formula used is

$$P_{\text{cap}} = Q_{\text{cap}} \times DF \quad (2)$$

where

$Q_{\text{cap}}$  is the actual capacitor kvar, and

$DF$  is the capacitor dissipation factor, which should include the losses in capacitor fuses.

### 8.6.5 Resistor losses

The resistor losses are calculated

$$P_{\text{res}} = 3 \times R_{\text{res}} \times I^2 \quad (3)$$

where

$R_{\text{res}}$  is the resistor resistance, and

$I$  is the fundamental RMS phase current through the resistor.

### 8.6.6 Auxiliary system power

The power used by the auxiliary systems for pumps, fans, and building cooling and heating systems together with the power needed by each thyristor level is deduced for each specified condition of the ambient temperature and reactive power flow. Nominal auxiliary supply voltage is assumed.

### 8.6.7 Total loss evaluation

The losses for each equipment in operation (8.6.1 through 8.6.6) are summed for each load level (state whether capacitive or inductive) required and should be evaluated as follows:

|                                       |   |       |                   |                           |               |     |
|---------------------------------------|---|-------|-------------------|---------------------------|---------------|-----|
| Point 1                               | - | _____ | Mvar: \$ _____/kW | × Calculated losses _____ | kW = \$ _____ |     |
| Point 2                               | - | _____ | Mvar: \$ _____/kW | × Calculated losses _____ | kW = \$ _____ |     |
| ⋮                                     | - | _____ | ⋮                 | ⋮                         | ⋮             |     |
| ⋮                                     | - | _____ | ⋮                 | ⋮                         | ⋮             |     |
| ⋮                                     | - | _____ | ⋮                 | ⋮                         | ⋮             |     |
| Point n                               | - | _____ | Mvar: \$ _____/kW | × Calculated losses _____ | kW = \$ _____ |     |
| Total evaluation of losses = \$ _____ |   |       |                   |                           |               | (4) |

The \$/kW values take into account the percentage of time the SVC is expected to operate at or near that Mvar output. The sum of the above loss values should be added to the first cost of the equipment to determine the total evaluated cost.

In addition, the supplier should provide a curve for the total operating losses over the entire steady-state operating range at a system voltage of \_\_\_\_\_ per unit.