

IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators

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of the
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Abstract: General information that should be considered during procurement of a static var compensator (SVC) is provided. The information is intended to assist in the preparation of a procurement specification. Environmental data, power system characteristics, and main characteristics of the SVC are covered.

Keywords: procurement, static var compensators, substations, SVCs

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Foreword

(This foreword is not a part of IEEE Std 1031-1991, IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators.)

This is a new guide developed to provide general information that should be considered during procurement of a static var compensator (SVC). Because SVCs consist of several types of equipment and because each system is specifically designed for an individual application, this guide has listed only the most significant topics for consideration, but not specific quantities.

This guide is not a “tutorial,” and application of its contents in preparing a specification must be done with some degree of understanding. Also, this guide does not include all topics that may be in a contract for an SVC (for example, SVC field testing).

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Introduction

This guide has been written to assist in the preparation of an equipment specification for the procurement of a static var compensator (SVC). Since each SVC is designed for a unique application, not all parts of this guide may be applicable. Also, there may be topics not included in this guide that the user and supplier may wish to discuss (e.g., additional system studies and field testing).

The following is a functional specification for an SVC.

This specification is based on a typical transmission-line application. It is intended that the user of this specification provide required parameter values. Other modifications or additions may also be made as required by the user.

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IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators

1. Scope and Purpose

1.1 Scope

This specification is for the supply of one static var compensator (SVC) with a rating of _____ Mvar lagging to _____ Mvar leading to be installed at the _____ substation.

The SVC and associated transformer are to be connected to a _____ kV bus. A one-line diagram from the user for the proposed SVC location is attached.

1.1.1 Scope of Work of the Supplier

The user should define the equipment, material, and services to be provided by the supplier, as well as the required schedule of supply.

1.1.2 Work Not Included

The user should define the equipment, material, and services to be provided by others.

1.1.3 Applicable Standards

All equipment should comply with the latest relevant standards. Otherwise, design, manufacturer, and test procedures normally carried out on this type of equipment will be followed subject to approval by the users.¹

¹A listing of relevant standards is provided in the appendix.

1.2 Purpose

The primary purpose of the SVC at the _____ substation is to

- 1) Regulate the _____ kV transmission-line voltage by supplying lagging or leading vars within the operating range of the SVC
- 2) Reduce the overvoltages on the transmission line caused by line switching and load rejection
- 3) Provide dynamic voltage support or damping
- 4) Perform other functions as specified by the user

1.3 Types of SVCs

The following types of equipment may be supplied to perform the functions as required in this specification.

- 1) Thyristor-controlled reactor, fixed capacitor (TCR-FC)
- 2) Thyristor-controlled reactor, thyristor-switched capacitor (TCR-TSC)
- 3) Thyristor-controlled reactor, mechanically switched capacitor (TCR-MSC)²
- 4) Others

2. Environmental Data

The following should be provided by the user:

- 1) Elevation above sea level
- 2) Maximum air temperature
- 3) Minimum air temperature
- 4) Humidity conditions
- 5) Ice loading conditions
- 6) Availability and temperature of cooling water
- 7) Maximum wind velocity
- 8) Seismic conditions
- 9) Isokeraunic level
- 10) Cleanliness of atmosphere, according to Sections 9.6, 9.7, 10.2, 10.4, 10.6, and 13.9 of *EPRI EHV Transmission Line Reference Book 345 kV and Above (Second Edition)* and "Application of Insulators in a Contaminated Environment" in *IEEE Power Apparatus and Systems*.
- 11) Audible noise and radio influence voltage (RIV) levels (acceptable levels should be specified for different locations in and around the compensators, such as the control room, the thyristor valve hall, near transformers, etc.)
- 12) Solar radiation level

3. Power System Characteristics

The following system characteristics exist at the _____ substation, and the SVC should be able to operate under the following conditions:

²The addition of a mechanically switched reactive element makes this combination part of a static var system.

3.1 Voltage and Frequency at the High-Voltage (HV) Connection Point

- 1) Nominal voltage line-to-line (L-L) = ____ kV (____ pu)
- 2) Maximum continuous voltage (L-L) = ____ pu
- 3) Minimum continuous voltage (L-L) = ____ pu
- 4) Maximum power frequency overvoltages (specify magnitudes and durations or include simulation results)
- 5) Normal frequency = ____ Hz
 - Minimum continuous frequency = ____ Hz
 - Maximum continuous frequency = ____ Hz
 - Minimum transient frequency = ____ Hz for ____ seconds
 - Maximum transient frequency = ____ Hz for ____ seconds

3.2 Insulation Levels at the HV Connection Point

- 1) Rated basic insulation level, minimum ____ kV
- 2) Rated switching withstand insulation level, minimum ____ kV
- 3) Surge arresters selected must be coordinated to provide the following minimum margins above the protected equipment insulation levels
 - Front of wave ____ %
 - Full wave ____ %
 - Switching surge ____ %

Surge arresters should be capable of withstanding the dynamic overvoltages specified in (4) of 3.1.

3.3 Short-Circuit Levels

Maximum short-circuit level at the SVC connection point is ____ MVA three-phase and ____ MVA line-to-ground (L-G). Minimum short-circuit level at the SVC connection point is ____ MVA three-phase and ____ MVA L-G.

3.4 Network Harmonic Impedances

The complex impedance of the power system under peak and off-peak system conditions for maximum and minimum short-circuit levels should be provided, if available, by the user from the 2nd to the 25th harmonic.

3.5 Harmonics

The SVC system should be designed to avoid resonance between shunt capacitor banks, filter branches, and the ac system. The harmonic level on the ____ kV bus should not exceed user system limits as specified below, under worst-case conditions of ambient temperatures; frequency; unbalanced system voltage; and parameters of the SVC such as transformer winding unbalances, valve firing variations, unbalanced reactor, and capacitors.

The maximum voltage distortion should not exceed ____ % for any individual harmonic,³ and should not exceed ____ % for the root-mean-square (rms) sum of all the harmonics from the 2nd to the 25th harmonic.

Users should list their own power-system harmonic levels at the connection point, without the SVC, or provide the ac system harmonic impedance at the point of connection for various maximum and minimum fault cases.

Users should specify a Telephone Interference Factor (TIF) requirement based on acceptance or design criteria.

³See the list of applicable standards in the appendix.

3.6 Loss Evaluation

The evaluated price of the equipment bid will include the cost of losses, which will be evaluated as follows:

(Users to specify their capitalized loss equation)

The SVC losses should include as a minimum the losses of at least the following:

- Thyristor valves
- Thyristor valve cooling
- Control power
- Transformer
- Reactors
- Capacitor banks
- Filters
- Auxiliaries

The entire operating range may be divided into three areas for the loss evaluation. Indicated percentages are a guide only; the user may set other values as appropriate:

- Fully inductive to 25% inductive
- 25% inductive to 25% capacitive
- 25% capacitive to fully capacitive

The mean SVC losses for each area should be given, and the following costs of capitalized losses will be applied. In addition, the supplier should provide a curve for the total operating losses over the entire steady-state operating range.

Expected operating point is ____ Mvar

- Fully inductive to 25% inductive ____ \$/kW
- 25% inductive to 25% capacitive ____ \$/kW
- 25% capacitive to fully capacitive ____ \$/kW

3.7 Availability

The availability of the SVC system for 100% output for either leading or lagging capability should be ____, including any downtime for scheduled maintenance. The supplier should also define the availability of the SVC system at 75% and 50% output, including any downtime for scheduled maintenance.

SVC availability (SVCA) is expressed as a percentage of reactive power that could have been available except for limitations of capacity due to outages. The measure of SVCA is defined as:

$$SVCA = 100 - SVCU \text{ (in \%)} \quad (1)$$

SVC unavailability (SVCU) is the ratio of equivalent outage hours to period hours, expressed as a percentage.

$$SVCU = \frac{EOH}{PH} \times 100 \text{ (in \%)} \quad (2)$$

where

- PH = Period hours or the number of calendar hours in the reporting period
- EOH = Equivalent outage hours or the sum of equivalent outage durations within the reporting period

EOH should be calculated as the sum of forced outage duration (hours) and scheduled outage duration (hours).

4. Main Characteristics of the SVC

4.1 Rated Voltage and MVAR Rating

The nominal rating of the SVC is ____ Mvar lagging (absorption) to ____ Mvar leading (generation) at ____ kV.

The actual rating of the SVC is defined by its voltage-current (V/I) characteristic, as shown in Fig 1.

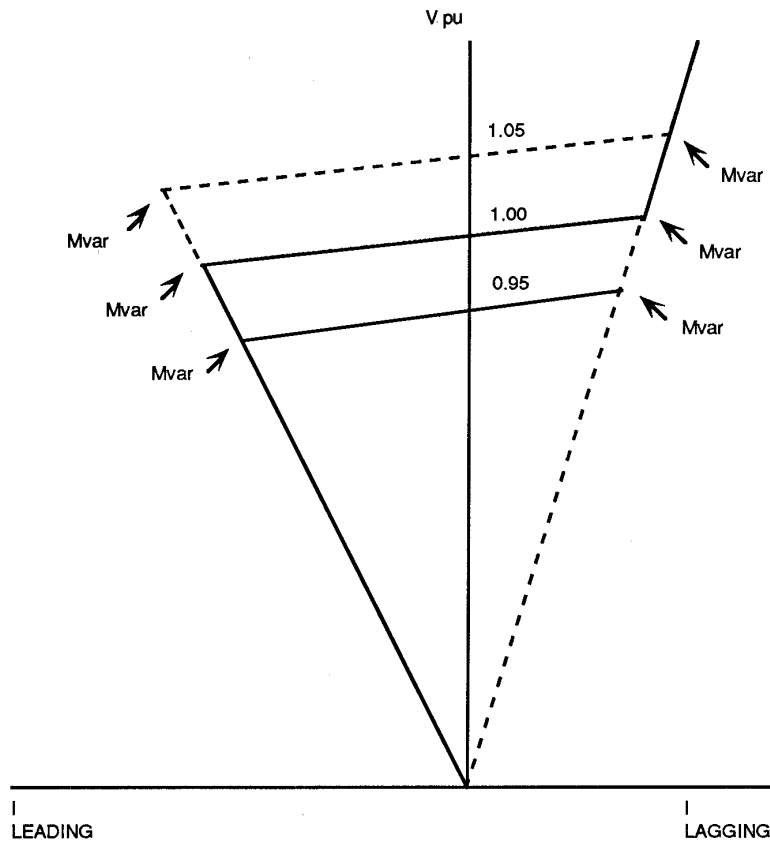


Figure 1— V/I Characteristic of the SVC

Mvar ratings shown are to be measured at the ____ kV bus and with a slope of ____ % on a base of ____ Mvar.

4.2 Overload

The SVC should be rated to operate safely under the overvoltages specified in (4) in 3.1.

During these overvoltages, the transformer saturation is to be neglected, and the reactor thyristor valves of the TCR should be protected by one of the following means:

- Rated for the expected overvoltage
- To turn on (or conduct) at ____ pu overvoltage
- Protected by a separate zinc oxide (ZnO) voltage limiter with an appropriate protection level (without exceeding the valve current rating)

Also, during these overvoltage conditions as stated in (4) of 3.1, the capacitor thyristor valves of the TSC (if supplied) are to be designed not to turn on (or to conduct), as the addition of capacitive vars during overvoltages will further increase the overvoltages. However, the TSC should be designed to withstand a single mistripping during the overvoltage at the most unfavorable timing without damage and loss of life.

4.3 Reference Voltage

The reference voltage is defined as the point on the VA characteristic where the SVC is at zero output; in other words, where no vars are absorbed from, or supplied to, the transmission system.

The SVC should be capable of continuously adjusting the reference voltage from _____ pu to _____ pu.

4.4 Slope

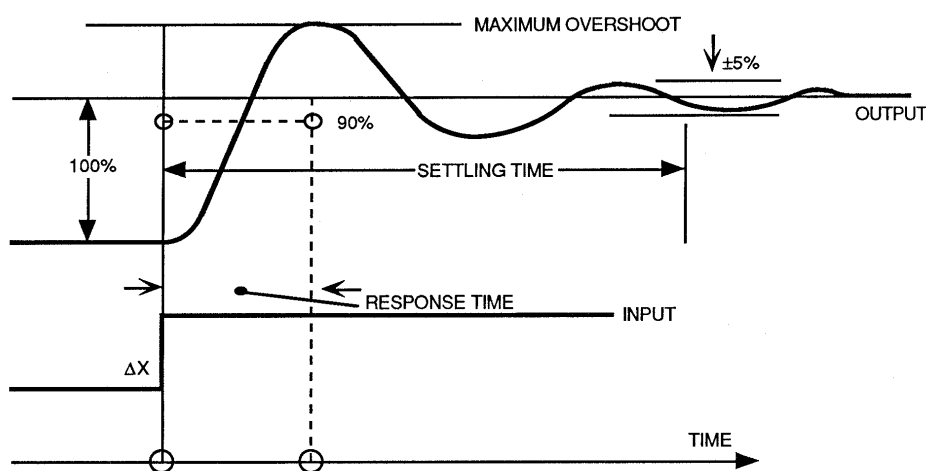
The slope is the ratio of the voltage change of the SVC to the current change (or Mvar output change) over the linearly controlled range of the SVC, in percent. The slope should be continuously adjustable from ___% to ___% on a base of its continuous control range. With a given voltage reference, the compensator output will operate along a linear V/I characteristic defined by a straight line passing through the SVC zero output point.

Example: Assume that the slope is set at 3%, and initially the -50 Mvar to 100 Mvar SVC is at 50 Mvar (lagging) output with a voltage reference of 1.0 pu; if the system voltage then drops 3%, the compensator will supply 100 Mvar (leading).

4.5 Response Time

The response time is the elapsed time required for the SVC output to reach 90% of its final value, following an initial step input of sufficient size to cause an SVC output change from full leading to full lagging; it is dependent upon the system voltage and impedance during a disturbance.

The response characteristic is shown in Fig 2.



KEY:

Response time: Time to achieve 90% of the final value of the output after a small, specified step change in the input
 Settling time: Time to settle within $\pm 5\%$ of the final value

Figure 2— Response of the SVC

In practice, the time of response of an SVC is dependent upon the system voltages and impedances during a disturbance. Therefore, it would be preferable if the user defined the decisive system condition(s) and the associated required time of response(s) of the SVC in terms of the required voltage correction. For example, a user could specify the scenario, "With the power system initially at 1.0 pu voltage and the SVC at 0 Mvar, the SVC shall respond to a system step overvoltage of 1.6 pu and reduce it to 1.1 pu within 50 ms when the system short-circuit MVA is 1000 MVA."

5. Main Components—Required Functions and Features

5.1 Thyristor Valves

5.1.1 Purpose

The purpose of the thyristor valves is to control the ac current in a reactor bank or to switch on or off a capacitor bank (if supplied).

- 1) *Reactor thyristor valves*—The reactor thyristor valves should control the phase current to provide variable amounts of ac current to the reactor bank, thereby controlling variable inductive vars.
- 2) *Capacitor thyristor valves*—The capacitor thyristor valves should switch the ac current by allowing full current conduction or zero current conduction, thereby providing controlled step changes in capacitive vars.

5.1.2 General Description

- 1) The thyristor valves should be designed to ensure satisfactory operation according to the overall performance requirements and including all necessary accessories.
- 2) The design of the thyristor support structure should permit easy access by the user for visual inspection, routine maintenance, and handling of the thyristor.
- 3) Each single-phase thyristor valve should consist of reverse parallel pairs of series-connected thyristors, including all of the necessary heat sinks, snubber circuits, firing circuits, and control-system signal channel equipment.
- 4) *External connections*—Each single-phase thyristor valve should be connected in series with a minimum of two reactive elements. This will limit the current in the thyristor valves in the event of a reactor or capacitor bank flashover. A three-phase assembly should be made by connecting three single-phase valves and reactors or capacitor banks in a delta configuration.

5.1.3 Required Design Parameters

The thyristor valve should be designed with individual thyristors applied in a conservative manner with regard to their basic design parameters.

- 1) The thyristor valve should be designed for maximum overvoltage and overcurrent stresses due to system faults and switching. These maximum stress values are as specified in Section 3.
- 2) The thyristor valve design should include an appropriate allowance for unequal voltage distribution across individual thyristors in the thyristor valve. A minimum of 10% redundant series thyristors (but no less than one redundant series thyristor) are required in each single-phase thyristor valve.
- 3) *Thyristor Triggering Means*—For fiber-optic systems, two independent triggering systems should be provided.
- 4) *Thyristor Failure Indication*—A monitoring means to determine the number of thyristors that have failed should be provided.

- 5) *Replacement of a Failed Thyristor*—The thyristor valves should be designed to allow easy replacement of failed thyristors. If they are liquid cooled, no cooling connections should be broken to replace a failed thyristor.
- 6) *Thyristor Ratings*—The suppliers should provide a standard data sheet of ratings for thyristors to be supplied.

5.1.4 Required Valve Protection

Minimum valve protection should include the following protective functions:

- 1) *Reactor Valves*—Automatic overvoltage protection of thyristor valves should be provided. The minimum level at which this protective system operates should be specified by the supplier in per unit of rating.
- 2) *Reactor and Capacitor Valve*—Independent emergency firing of each thyristor should be provided. This could be back-up protection for the thyristor if the automatic overvoltage protection scheme fails or if only part of the series string of thyristors turns on or off.
- 3) *Capacitor Valves*—A ZnO voltage limiter may be included with the thyristor valves for overvoltage protection.

NOTE — The individual emergency firing protection of the capacitor valves must be coordinated with the ZnO protection so that the ZnO protection will operate before the individual emergency firing operates.

5.1.5 Testing

As a minimum, the supplier should submit a test program for the thyristor valves, including type and routine tests in the factory.

5.2 Thyristor-Valve Cooling System

5.2.1 Purpose

The purpose of the thyristor-valve cooling system is to remove the heat produced by the thyristor valve and to transmit this heat to the outside ambient air or to a medium other than the valve ambient.

5.2.2 System Types

Generally, two types of cooling systems are possible: water cooled or air cooled. In either case, the cooling system should be completely furnished with all necessary interconnecting piping, ductwork, circulating pumps, blowers, heaters, make-up reservoirs, heat exchangers, filters, water treatment plants, instrumentation, automatic controls, alarms, control power systems, and other necessary equipment.

5.2.3 Water Cooling (If Applicable)

- 1) A closed, deionized, recirculating water system should be used.
- 2) The high-purity (high-resistivity) water in the closed loop system should be circulated through the heat-producing electrical equipment at a constant flow rate. A purifying loop to maintain the high purity (high resistivity) of the water in the closed system should be provided.
- 3) The heat transfer from the closed water system to the ambient air should take place in a water-to-air or water-to-water heat exchanger.
- 4) Required design functions and features
 - a) *Dual Pumps*—Dual pumps should be provided, with one pump normally operating and the second pump standing by. Should a pump failure occur, the second pump should automatically switch in without shutting down the equipment. An alarm should be displayed at the control cabinets to alert the operator that a pump problem exists.
The cooling system should be constructed to permit work on the defective pump unit without shutting down the system.
The pumps should have mechanical seals, and makeup water should not be required.

- b) *Fully Rated Capacity Pumps*—The cooling system should use motor-driven pumps (two are required, one is redundant) that are normally capable of supplying 100% of the required maximum water flow.
- c) *Dual Purification System*—The cooling system should contain dual purifying loops, one operating and a second standing by. When the ion-exchange material is depleted in the operating loop, the standby loop should automatically switch in and display an alarm at the control cabinet indicating maintenance is needed. The purification system should be designed to maintain the resistivity of the water above 1 MΩ/cm. A resistivity cell located in the outgoing water from the deionizer should detect the depletion of the material. The second purifying loop will continue to operate in the presence of a primary-loop alarm until its deionizer is depleted.
Filters and deionizer material should be designed to allow replacements in minutes without shutdown of the cooling unit. (Normal replacement should not be required more than once every three months.)
- d) *Redundant Fans*—Each water-to-air heat exchanger should have at least one standby fan. This fan should come into operation if any of the operating fan(s) fail. For systems requiring more than one fan normally operating, a single fan failure should cause an alarm to be given. Successive fan failures should activate a system shutdown when the water temperature exceeds the safe design level of the manufacturer.

5.2.4 Air Cooling (If Applicable)

- 1) A nonrecirculating (once-through) or recirculating air system should be provided, depending on the requirement of the thyristor selected by the manufacturer and on specific site conditions. A once-through air system is one in which outside air is drawn through a filter and then through the thyristor valve, and the heated air is then exhausted to the outside. A recirculated air system is one in which the air is recirculated within the SVC building, and the heated air is cooled with a heat exchanger.
- 2) Required design functions and features
 - a) Dual blowers should be provided, with one blower normally operating and the second standing by. Should a blower failure occur, the second blower should automatically switch in without shutting down the equipment. An alarm should be displayed at the control cabinets to alert the operator that a blower problem exists.
The cooling system should be constructed to permit work on the defective unit without shutting down the system.
 - b) *Fully Rated Capacity*—The cooling system should use motor-driven blowers (two are required, one is redundant), each of which are normally capable of supplying 100% of the required maximum air flow.
 - c) *Dual Filtering Systems (Nonrecirculated Systems)*—The cooling system should include a two-stage filter system: one stationary air filter and one moving filter. The moving filter will automatically insert a clean section of filter into the air stream as it becomes used. It will display an alarm at the control cabinet when maintenance is needed. The filter should be designed such that replacement under normal conditions should not be required more than once every six months.
 - d) *Monitoring*—The cooling system should have sufficient gauges and indicators to indicate the status of any part of the unit for both normal operations and for maintenance.

5.2.5 Cooling System Protection

- 1) The cooling system should monitor its own operation and the condition of the cooling water.
- 2) For water-cooled systems, the protection system should include as a minimum the following warning alarms:
 - a) Depleted demineralizer (deionizing) cell
 - b) Low water resistivity
 - c) Low water tank level
 - d) Primary pump stopped
 - e) Primary fan stopped
 - f) Abnormal water flow (partial blockage)
 - g) Abnormally high coolant temperature
- 3) For water-cooled systems, the protection system should include as a minimum the following shutdown alarms:

- a) Excessively low water resistivity
 - b) Excessively high water temperature
 - c) Excessively low water tank level
 - d) Both pumps stopped
 - e) Blocked water flow
- 4) For air-cooled systems, the protection system should include as a minimum the following warning alarms:
- a) Blower transfer
 - b) High exhaust air temperature
 - c) High differential pressure across the filter
- 5) For air-cooled systems, the protection system should include as a minimum the following shutdown alarms:
- a) Exhaust air over temperature
 - b) Loss of pressure

5.3 Control Equipment

5.3.1 Purpose

- 1) The primary purpose of the control of the SVC is to control system voltage. This is accomplished by having the SVC supply leading or lagging reactive power in response to measured system variables or operator inputs.
- 2) The desired benefit(s) of controlled reactive power flow should be specified. These may include the following:
 - a) Three-phase average or positive sequence voltage control
 - b) Phase voltage control based on
 - Individual phase voltages
 - Positive and negative sequence voltages
 - Negative sequence voltages (phase balancing)
 - c) Voltage control with superimposed reactive power control based on reactive power measurements to control system power flow
 - 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 (stability or system subsynchronous enhancement)

5.3.2 Control System Description

- 1) The structure and function of an active SVC control should consist of one or more of the following:
 - a) Voltage, current, and reactive power measurement (M)
 - b) SVC control (C) by generation of the appropriate firing pulses to the thyristor valves
 - c) Supplementary control modules for damping and var control (SC)
 - d) Monitoring and protection of the control itself and the components it controls
 - e) Orderly startup-shutdown sequencing
 - f) Automatic voltage control, operative during start-up to prevent unnecessary switching of the reactive elements

The control structure is illustrated in Fig 3.

- 2) SVC control characteristics
 - a) The *operating characteristic* of the SVC control is illustrated in Fig 4. To define the characteristic properly, the user should include:
 - The reference voltage (V_{ref}) and minimum/maximum values ($V_{ref\ min}$ and $V_{ref\ max}$) with complete adjustment capability of the voltage reference setpoint (which equals zero SVC output) at any value within the specified range
 - The slope (SL) of the voltage control characteristic, including minimum and maximum values (SL_{min}/SL_{max})
 The slope of the V/I characteristic should be continuously adjustable between 0.5% and 10%, based on total Mvar continuous operating range.

- Range of control
 - Overall accuracy of the controlled voltage ($\pm 1\%$) and the linearity of the maximum slope with the control range ($\pm 10\%$)
 - The static characteristic with a bandwidth V_{ref} , found in SVCs with stepwise control based on TSC or SC. The step size should be selected such that the controlled voltage can be kept within the bandwidth.
- b) The *dynamic characteristic* of the SVC control is the response (SVC current I) to a small step change (linear range of control) in the voltage reference value or in any input quantity "X" at defined system conditions.

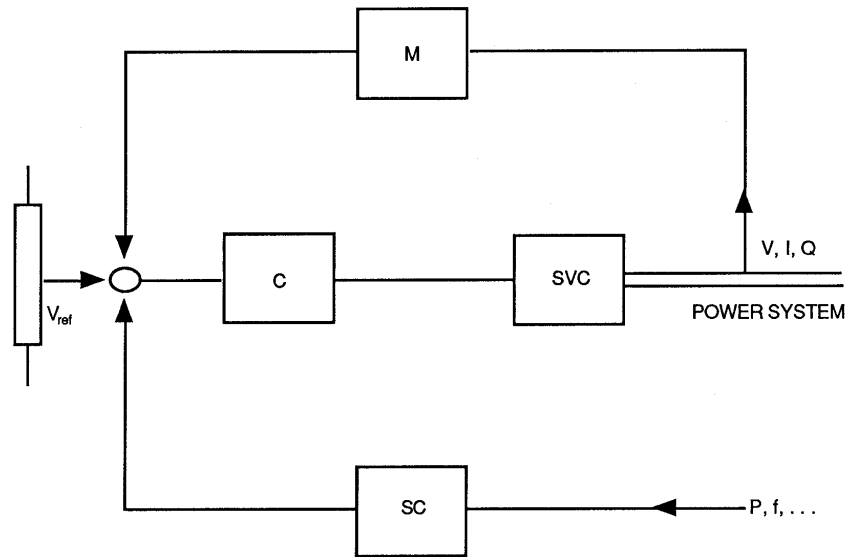


Figure 3— SVC Control Structure

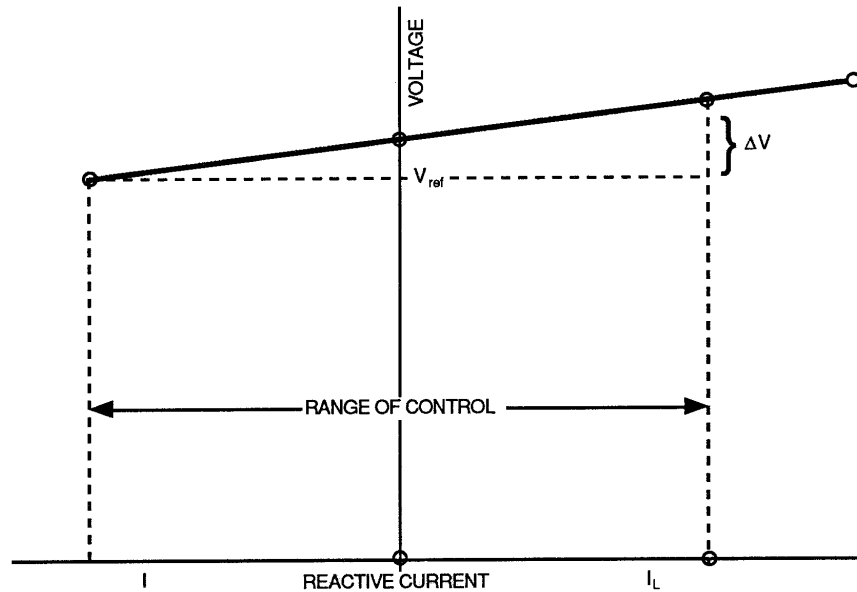


Figure 4— SVC Control Characteristic

5.3.3 General

- 1) *General Construction*—The control system components should be mounted in free-standing, indoor, metal-clad cabinets.
- 2) *Cooling and Operating Environment*—The equipment within should be designed to operate properly at a maximum allowable ambient air temperature of _____ °C. Supplemental cooling may be provided.
- 3) *Circuitry*—The logic control circuitry should employ solid-state components mounted on plug-in printed circuit cards. The printed circuit cards should have built-in test points and indicating lights to facilitate testing and maintenance.

5.3.4 Control System Protection

The central control unit should monitor its own operation and the operations of the various SVC components. Two levels of protection should be provided: warning and shutdown. The first-level alarm (warning) should indicate that a problem exists but that the equipment or its proper operation is not in immediate danger. The second-level alarm (shutdown) should initiate a shutdown of the SVC due to equipment problems that might cause damage if left uncorrected.

- 1) The control system protection should include (as a minimum) the following warning alarms:
 - a) Power supply failure
 - b) Cooling system fan or pump failure
 - c) Cooling system problems (example: low water resistivity, primary pump stopped, etc.)
 - d) Capacitor can failure within an acceptable level
- 2) The control system protection should include (as a minimum) the following shut-down alarms:
 - a) Loss of all control power
 - b) Loss of cooling system rated capabilities
 - c) Loss of synchronism with the system voltage
 - d) Excessive number of capacitor can failures
 - e) Excessive overcurrent in a thyristor valve
- 3) The central control unit should also have a built-in protective system for self-monitoring.

5.4 Protection Equipment

5.4.1 Purpose

In addition to the protective features provided as part of the thyristor valves and control, a complete protection system based on conventional relaying techniques should also be provided to protect the compensator components against all abnormal operating conditions that may occur.

5.4.2 Description

- 1) The protection relays and equipment should be mounted in a cabinet(s) separate from the SVC control and interface cabinets.
- 2) The protection relays and equipment should receive their sensing from current transformers, potential transformers, etc. that are either supplied as part of the SVC equipment or, where indicated, provided by the user.

5.4.3 Design Features/Requirements

- 1) A general feature is that all equipment in the SVC system should be self-protecting.
- 2) All protection equipment and systems are to be properly coordinated to prevent incorrect operations of the protection equipment or systems during normal SVC operation, including anticipated abnormal conditions on the transmission system of the user, as specified.

- 3) The user should identify and provide information regarding the methods of line and system protection and reclosing at the point of SVC connection to the transmission system. The protection equipment or systems provided with the SVC should also coordinate with the system of the user.

5.4.4 Required Protection

The following is a list of the minimum required protection. The supplier should provide any additional protection that he or she deems is necessary. Final requirements will be determined by mutual agreement between the user and the supplier.

- 1) Main transformer
 - Overcurrent
 - Overtemperature
 - Differential
 - Ground fault
 - Gas accumulation
 - Sudden pressure relay
 - Overexcitation
- 2) Main reactors
 - Overcurrent
- 3) Capacitor banks (or filters)
 - Overcurrent
 - Unbalance
- 4) Bus
 - Ground fault

5.5 Meter and Control Switches

- 1) Control of the SVC should be possible from a local control panel, with provisions made for remote data acquisition, monitoring, and supervisory control.
- 2) The local control and indication panel should contain as a minimum the following items:
 - a) "On" switch
 - b) "Trip" switch
 - c) SVC "on" indication
 - d) SVC "off" indication
 - e) Three-phase high-side line currents of the main transformer
 - f) Total reactive power generated or absorbed by the compensator
 - g) Three-phase currents of each thyristor valve
 - h) Primary voltage, single phase
 - i) Secondary voltage, single phase
 - j) Voltage reference setting
 - k) Slope setting

5.6 Reactors

5.6.1 Purpose

The purpose of the main shunt reactors is to provide the required lagging var supply. The purpose of the filter reactors (if required) is to tune the capacitor banks to provide the necessary reduction of harmonics.

5.6.2 General Description

Dry-type, air-core reactors for outdoor use are preferred.

5.6.3 Design Requirements

- 1) Each phase reactor should be divided into two reactors, one on each side of the thyristor valve, in order to limit short-circuit currents resulting when one reactor is shorted.
- 2) Detailed reactor specifications are included as an attachment. (The user is to attach his or her standard specification.)

5.6.4 Tests

Tests should be made in accordance with the latest revision of of IEEE standards for current-limiting reactors and shunt reactors.⁴

5.7 Capacitor Banks

5.7.1 Purpose

The purpose of the capacitor bank(s) is to provide the required leading var supply and also to provide sufficient reduction of harmonic voltages and currents that may be generated by the SVC system. The banks (shunt capacitors and filter banks) should be designed to avoid resonance with the ac power system.

5.7.2 General Description

Shunt capacitor banks should include capacitor units and protective fuses, suitably connected in series and parallel, and an unbalanced protection scheme in each capacitor bank to indicate possible capacitor failure.

5.7.3 Design Requirements

- 1) Capacitors should be capable of continuous operation at maximum working voltage up to 110% of rated voltage, as specified in IEEE Std 18-1980 .
- 2) The capacitor banks may be used in conjunction with reactors for the purpose of harmonic filtering. In this event, the bank rating should be designed with adequate margins for the anticipated harmonic loading and the increased voltage stress due to the voltage rise across the filter reactor.
- 3) Series reactors to limit the peak inrush/outrush currents should be supplied where necessary to stay within the rating of new and existing switching devices.
- 4) The supplier should submit information about the transformer and the reactor impedances, as well as the harmonic overvoltage factor, that have been used for calculating rated voltage and reactive power for the capacitor banks.
- 5) Detailed capacitor-bank specifications are included as an attachment. (The user is to attach his or her standard specification.)

5.7.4 Tests

Tests should be made in accordance with the latest revision of IEEE standards for power capacitors.⁵

5.8 Power Transformers

5.8.1 Purpose

The purpose of the step-up power transformer (where applicable) is to couple the SVC components to the high-voltage transmission system.

⁴See the list of applicable standards in the appendix.

⁵See the list of applicable standards in the appendix.

5.8.2 General Description

The power transformer is a standard transformer, except that it must be designed to handle a 100% reactive load. It also must be able to function with the secondary voltage variations caused by the operation of the SVC reactive components.

5.8.3 Requirements and Features

- 1) The insulation levels of low-voltage windings should be stated by the supplier, together with information on the intended overvoltage protection. All bushings of the transformers should be furnished with the necessary current transformers for relay protection of the power transformer.
- 2) The transformer should be either three single-phase or one three-phase design.
- 3) The nominal transformer capacity rating should be _____ MVA with a (*specify FOA, FA/FA, etc.*) cooling rating.
- 4) Detailed transformer specifications are included as an attachment. (The user is to attach his or her standard specification.)

5.8.4 Tests

Tests should be made in accordance with the latest revision of IEEE standards for power transformers.⁶

5.9 Disconnect Switches

5.9.1

The SVC is made up of several major components. As a minimum, the SVC should have a means of being visibly disconnected from the power system for maintenance or repair. A manual disconnect switch or a removable, metal-clad circuit breaker can provide this function. Grounding devices or provisions for grounding should be provided if specified by the user. In addition, individual components should be able to be disconnected by switches, removable links, or other means to facilitate testing (see 5.9.3).

5.9.2

Disconnect switches and links should be adequately sized to carry the maximum steady-state current that can flow in it (rms of fundamental and harmonics), as well as the momentary currents due to faults.

A detailed specification is included as an attachment. (The user is to attach his or her standard specification.)

5.9.3

As a minimum, each of the following major components should have as a disconnecting device

- 1) Thyristor-controlled reactors and associated three-phase thyristor valves
- 2) A thyristor-switched capacitor bank and associated three-phase thyristor valves
- 3) A fixed and mechanically switched capacitor bank
- 4) Harmonic filters

5.9.4 Tests

Tests should be made in accordance with the latest revision of IEEE standards for disconnect switches.⁷

⁶See the list of applicable standards in the appendix.

⁷See the list of applicable standards in the appendix.

6. Spares

The supplier should provide a list of recommended spare parts to cover unforeseen equipment failures and estimated annual replacements due to maintenance. The supplier should identify the spare parts required to meet the availability requirements.

7. Engineering Studies

The following engineering studies should be provided after the award to the vendor to verify the SVC performance for all possible system operating conditions. Load flow studies should be performed in the initial stage to determine the optimal SVC operating point for different system conditions.

7.1 Dynamic Performance Studies

Transient and dynamic stability studies should evaluate SVC control system performance during system disturbances such as major faults and load rejection.

The operation of auxiliary controls, if specified, designed to damp power oscillations following system disturbances should be verified.

The interaction of the SVC controls with the other nearby control systems should be evaluated. These include high-voltage direct-current (HVDC) controls, generator controls, and other SVC controls.

The effect of system harmonics under transient and steady-state conditions on the SVC control system performance should be evaluated.

7.2 Harmonic Performance Studies

The adequacy of the SVC harmonic filter design should be verified through detailed simulations of the power system response to SVC harmonics. The studies should evaluate maximum harmonic levels at the SVC point of common coupling and the potential for magnification at other system locations.

Determination of maximum system harmonic levels should be based on:

- 1) Evaluation of all possible system operating conditions
- 2) Evaluation with maximum filter component tolerances
- 3) Evaluation with maximum system voltage unbalance and firing angle unbalance for noncharacteristic harmonic generation
- 4) Evaluation of possible resonant overvoltages
- 5) Evaluation of the filter thermal ratings based on specified operating conditions

7.3 Transient Overvoltage Studies

Transient overvoltage studies should be performed with the actual controls modelled to verify that the SVC equipment is adequately protected against overvoltages and overcurrents (including excessive valve recovery voltages) resulting from power system transients and SVC system misoperations. Concerns to be evaluated include

- 1) Faults on the high-voltage and low-voltage bus (single line-to-ground, phase-to-phase, and three-phase)
- 2) Faults across TCR or TSC
- 3) Valve misfiring under the most severe system conditions

Annex Relevant Documents for Major Components

(Informative)

(This appendix is not a part of IEEE Std 1031-1991, IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators, but is included for information only.)

The following documents are provided for information purposes.

Harmonic Control

IEEE Std 519-1981 , IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters (ANSI).⁸

Insulation Coordination

IEC Pub 71-1 (1976), Insulation co-ordination—Part 1: Terms, definitions, principles and rules (sixth edition).⁹

IEC Pub 71-2 (1976), Insulation co-ordination—Part 2: Application guide (second edition).

IEEE C62.2-1987 , IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating-Current Systems (ANSI).

Power Transformers and Reactors

CAN/CSA C88-1990, Power Transformers and Reactors.

IEC Pub 76, Power transformers.

IEC Pub 289 (1988), Reactors.

IEC Pub 354 (1972), Loading guide for oil-immersed transformers.

IEEE C57.12.00-1987 , IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (ANSI).

IEEE C57.12.90-1987 , IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers; and Guide for Short-Circuit Testing of Distribution and Power Transformers (ANSI).

IEEE C57.21-1990 , IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA.

IEEE C57 Standards Collection, 1990 Edition: Distribution, Power, and Regulating Transformers.

⁸IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁹IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembe, CH 1211, Genève 20, Switzerland/Suisse. 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.

Relay Protection and Control

IEEE C37.91-1985 (Reaff. 1991), IEEE Guide for Protective Relay Applications to Power Transformers (ANSI).

IEEE C37.90-1989, IEEE Standard for Relays and Relay Systems Associated With Electric Power Apparatus (ANSI).

IEEE C37.90.1-1989 (Reaff. 1991), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (ANSI).

IEEE Guides and Standards for Protective Relaying Systems, Spring 1991 Edition.

Power Capacitors

CSA CAN3-C155-1984, Shunt Capacitors for AC Power Systems.¹⁰

IEC Pub 70 (1967), Power capacitors.

IEC Pub 871-1 (1987) Amendment No. 1 (1991), Shunt capacitors for a.c. power systems having a rated voltage above 660 V—Part 1.: General—Performance, testing and rating—Safety requirements—Guide for installations and operation.

IEEE Std 18-1980, IEEE Standard for Shunt Power Capacitors (ANSI).

Surge Arresters

IEEE C62.11-1987, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (ANSI).

Thyristors

IEC Pub 146, Semiconductor convertors.

IEC Pub 147, Essential ratings and characteristics of semiconductor devices and general principles of measuring methods.

IEC Pub 700, Testing of semiconductor valves for high-voltage d.c. power transmission.

IEEE Std 857-1990, IEEE Guide for Test Procedures for HVDC Thyristor Valves.

Disconnect Switches

IEC Pub 129 (1984), Alternating current disconnectors (isolators) and earthing switches.

IEC Pub 265, High-voltage switches.

IEC Pub 947-3 (1990), Low-voltage switchgear and controlgear—Part 3.: Switches, disconnectors, switch-disconnectors and fuse-combination units.

IEEE C37.30-1971 (Reaff. 1987), IEEE Standard Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports (ANSI) (includes IEEE C37.30a-1975).

¹⁰CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Rexdale, Ontario, Canada M9W 1R3.

IEEE C37.34-1971 (Reaff. 1987), IEEE Standard Test Code for High-Voltage Air Switches (ANSI).

IEEE C37.34a-1978 (Reaff. 1988), IEEE Standard Corona Test Supplement to IEEE C37.34-1971, IEEE Standard Test Code for High-Voltage Air Switches (ANSI).

IEEE C37.35-1976 (Reaff. 1987), IEEE Guide for the Application, Installation, Operation, and Maintenance of High-Voltage Air Disconnecting and Load Interrupter Switches (ANSI).

IEEE C37.37-1979 (Reaff. 1987), IEEE Standard Loading Guide for AC High-Voltage Switches (in excess of 1000 volts) (ANSI).

IEEE C37 Standards Collection, Spring 1991 Edition: Circuit Breakers, Switchgear, Relays, Substations, and Fuses.

Control Systems

ANSI/IPC D300G-1984, Printed Board Dimensions and Tolerances.¹¹

ANSI/IPC A600D-1989, Acceptability of Printed Boards.

General Definition of Terms

IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

Environmental Data

EPRI EHV Transmission Line Reference Book 345 kV and Above, 2nd ed. Palo Alto, CA: Electric Power Research Institute, 1987.

Holte, K. C. et al., "Application of Insulators in a Contaminated Environment," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, no. 5, pp. 1676–1690, Sept./Oct. 1979.

¹¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.