IEEE Guide for Static var Compensator Field Tests

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Abstract: General guidelines and criteria for the field testing of static var compensators (SVCs), before they are placed in-service, for the purpose of verifying their specified performance are described. The major elements of a commissioning program are identified so that the user can formulate a specific plan that is most suited for his or her own SVC.
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Introduction

(This introduction is not a part of IEEE Std 1303-1994, IEEE Guide for Static var Compensator Field Tests.)

This guide was prepared by a Task Force of Working Group I_4, Static var Compensators in Substations, of the DC Converter Substations Subcommittee of the Substations Committee of the IEEE Power Engineering Society.

Preparation of this guide began in 1989 with the purpose of establishing SVC field testing guidelines for prospective or first-time users of SVC systems.

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CLAUSE PAGE

IEEE Guide for Static var Compensator Field Tests

1. Overview

1.1 Scope

This document is a guide for field testing and commissioning of static var compensators (SVCs). As such, the document establishes general guidelines and criteria for field testing to verify the specified performance of SVC systems.

This guide does not

— Cover factory and simulator tests of SVC system components (but it assumes that such tests have been performed beforehand).
— Discuss the division of responsibility between user and supplier, since this division is usually defined in the contract between buyer and supplier. Most often, however, the practice is for the equipment, subsystem, and commissioning tests to be performed by the supplier, and the acceptance tests to be performed by the buyer or user.

1.2 Purpose

The purpose of this guide is to help users of SVCs carry out a field test program prior to placing an SVC into service. The major elements of a commissioning program are identified so that the user can formulate a specific plan that is suited to his or her own SVC. Such a test program should cover the following:

— Equipment tests within the SVC system
— Tests of the various subsystems that comprise the SVC system
— Commissioning tests for the complete SVC system
— Acceptance testing of the SVC system

It should be recognized that there are many ways in which a particular SVC may be commissioned, and also that it is not the purpose of this guide to endorse a specific procedure to the exclusion of other methods.

Depending on the purpose of the SVC design (transmission type or smaller size used for other purposes) some tests may not be required. In particular, some control system tests may be included in the factory tests. Also, acceptance tests may be integrated into any of the categories listed above.

2. References

This guide shall be used in conjunction with the following publications.

IEEE Std 18-1992, IEEE Standard for Shunt Power Capacitors (ANSI).

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

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

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

IEEE Std 693-1984 (Reaff 1991), IEEE Recommended Practices for Seismic Design of Substations (ANSI).

IEEE Std 1031-1991, IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators (ANSI).

IEEE Std C37.20.3-1987 (Reaff 1992), IEEE Standard for Metal-Enclosed Interrupter Switchgear (ANSI).

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

3. Definitions

This clause contains definitions for key terms used in this guide. Further clarification of terminology, as needed, is provided at the appropriate points within the text of this guide.

3.1 as-built drawings: A complete set of drawings which, in addition to the original drawings, includes all drawings that accurately record changes made to the equipment or subsystem to indicate the final installation and commissioning.

3.2 derated operation: Use of equipment or a system at a more restricted performance level than that for which the equipment or system was originally designed. Derated operation is usually implemented either to forestall failures or as a result of system component failure.

3.3 energization test: Any test requiring that system voltage be applied to the equipment.

3.4 inspection and test plan (ITP): A summary of prerequisites, system configurations, step-by-step procedures, and evaluation criteria of the tests in one place for permanent record.

3.5 interface test: A test to check interaction among equipment through permanent interconnections.

3.6 ITP: Acronym for **inspection and test plan.** See 3.4.

3.7 IT product: The inductive influence expressed in terms of the product of its root-mean-square magnitude (I), in amperes, times its telephone influence factor (TIF). (Source: IEEE Std 519-1992 .)

3.8 PCC: Acronym for **point of common coupling.** See 3.9.

3.9 point of common coupling (PCC): The connection point between the SVC and the power system at which performance requirements are defined.

3.10 SER: Acronym for **sequence of events recorder.**

3.11 subsystem: An interconnected, interrelated group of equipment intended to serve a single basic purpose within a larger installation or facility.

3.12 TCR: Acronym for **thyristor-controlled reactor.** See 3.15.

3.13 TFR: Acronym for **transient fault recorder.**

3.14 test coordinator: A person typically responsible for organizing and scheduling tests; deciding how, when, and where the system and its components will be tested; and determining the test equipment that is needed.

3.15 thyristor-controlled reactor (TCR): A series connection thyristor controller, typically connected between two halves of a reactor, that forms one leg of the connected circuit. The thyristor controller consists of antiparallel phase angle controlled thyristors for vernier control of the reactor susceptance (current).

3.16 thyristor-switched capacitor (TSC: A series connection thyristor switch, typically connected between a capacitor bank and a current limiting reactor, that forms one leg of the connected circuit. The thyristor switch consists of antiparallel thyristors that are blocked or fired for full conduction (on/off control).

3.17 thyristor-switched reactor (TSR): A series connection thyristor switch, typically connected between two halves of a reactor, that forms one leg of the connected circuit. The thyristor switch consists of antiparallel thyristors that are blocked or fired for full conduction (on/off control).

3.18 TNA: Acronym for **transient network analyzer.** See 3.20.

3.19 TPC: Acronym for **trigger pulse converter.** See 3.22.

3.20 transient network analyzer (TNA): An analog test circuit representing a scaled down version of the pertinent power circuit components, used mainly for control response and performance testing.

3.21 trial operation: A period during which the equipment or system is placed under service conditions and is also monitored for stable, smooth, and reliable performance.

3.22 trigger pulse converter (TPC): A device in the control system that converts the control signal to a signal that can be transmitted to the thyristor valve.

3.23 TSC: Acronym for **thyristor-switched capacitor.** See 3.16.

3.24 TSR: Acronym for **thyristor-switched reactor.** See 3.17.

3.25 valve base electronics (VBE): Electronic circuitry that directs gate pulses into the thyristor valve.

3.26 valve electronics (VE): Electronic circuitry associated with the thyristors and mounted at thyristor level potential.

3.27 VBE: Acronym for **valve base electronics.** See 3.25.

3.28 VE: Acronym for **valve electronics.** See 3.26.

4. Preparation of a field test program

The purpose of this clause is to describe how a comprehensive field test program can be applied to SVC systems.

In general, every SVC has been designed and installed for a specific reason and purpose. This reasoning and purpose should be clearly defined for the test program and understood by the participants.

A specific set of inspection and test plans (ITPs) should be prepared for each SVC project. In the field, these ITPs will demonstrate that the specific purposes of that SVC are being met in accordance with the performance specifications.

4.1 Test program phases

A comprehensive field test program includes the following major phases:

a) Overall test planning and organization, including the definition and line of authority for performing the tests
b) Document and data survey, including contract, system study, factory test review, drawing, user's manual availability, and definition of ac system requirements or limitations
c) Preparation of ITPs for equipment, subsystem, commissioning, and acceptance tests of the SVC system
d) Review and approval of, or concurrence with test program by user
e) Schedule, including coordination of installation/test schedule and coordination with system operation
f) Dissemination of information, including as-built drawings

Only phase c), the preparation of ITPs for SVC equipment, subsystem, commissioning, and acceptance tests, is discussed in this guide.

4.2 Inspection and test plans (ITPs)

It is suggested that a format be adopted that breaks down the overall test program into a series of single purpose ITPs.

4.2.1 Contents of the ITP

The ITP should contain at least the following information:

a) Descriptive title and test number. The title should convey the purpose of the test, equipment, and subsystem or system being tested.
b) Person (by title) responsible for directing the test and the person with whom the performance of the test is to be coordinated.
c) List of preceding tests that should have been completed before this test can be attempted.
d) Estimate of time required to complete the test.
e) System configuration prior to the test. This could be in the form of a single-line diagram at the beginning of the test, a table of switch or breaker positions, or other format that describes the pretest configuration.
f) Step-by-step description of the test execution, along with the expected results of each step.
g) Description of the expected final results.
h) Summary of the records required to document successful completion of the test.
i) Identification and description of relevant reference information, such as industry standards, particular requirements from the specifications, or potential impact on the utility.
j) Test equipment used, including type, serial number, calibration, etc.
k) Test sheets with measured data (suitable for future fault diagnosis).

A sample ITP is provided in figure 1. This ITP is for example purposes only, and should be modified to fit the circumstances of the specific project and organization.

TEST DESCRIPTION: TEST NO. 1OB

First energization of TCR valves. (5.3.1.3 in Guide)

TEST DIRECTED BY: Manufacturers test coordinator

PERMISSION TO PROCEED REQUIRED FROM:
a) User's commissioning engineer
b) Utility operating center

PREREQUISITE TESTS AND CONDITIONS:

a) Test 5.1 —Individual equipment tests
b) Test 5.2 —Subsystem tests
c) Test 5.3.1.1—Pre-energization checks
d) Test 5.3.1.2—Low voltage energization tests

ESTIMATED TIME TO PERFORM TEST:

Approximately 8 hrs of actual test time.

SYSTEM CONFIGURATION:

a) Auxiliary power on
b) Both primary and backup protection in-service
c) SVC cooling in-service
d) SVC controls in-service
e) Filter bank switches open or in position required for start-up
f) Power available to line side disconnect of main breaker

TEST OPERATIONS:

a) Clear valve area and reactor area of all personnel, tools, and other apparatus.
b) Test coordinator to make a final inspection and confirm that areas are clear.
c) Close fenced areas (if any) and lock. Remove interlock keys, safety locks, and enable main disconnect.
d) Post observers at safe distance in valve hall and outside reactor yard.
e) Check that all instrumentation (TFR, SER, special recorders) are operational and "ready."
f) Close main disconnect.
g) Carry out the following operation in 1 sec intervals, upon countdown beginning from –3 to +3 sec, as follows:
   –3 sec
   –2 sec—Manually initiate TFR and oscillograph.
   –1 sec
   0 sec—Close main breaker.
   +1 sec—Open main breaker.
   +2 sec—Stop TFR and oscillograph.
   +3 sec

EVALUATION:

a) Check that observers saw no arcs, spitting, or other sign of electrical breakdown.
b) Check that protective relaying did not operate.
c) Check the TFR and special oscillograph records to confirm that all valves withstood voltage without any evidence of breakdown or thyristor gating.

RECORD RETENTION:

Label oscillograph record "Test 1OB" and retain.

CONCLUSION:

At the successful conclusion of this test, the following people, witnessing the test, should acknowledge completion of the test by affixing their signature to the test document.

Manufacturer's test coordinator ______________________

Owner's commissioning engineer ______________________

Figure 1— Sample inspection and test plan

4.2.2 Field test categories covered by the ITP

The field testing of an SVC project should consist of a series of tests documented by individual ITPs, beginning with inspection, installation checks, and mechanical tests of the equipment and progressing through electrical and functional test of equipment, subsystems, and the complete SVC system in accordance with approved drawings, instructions, and user's manual.

In general, the ITP should cover the following field test categories:

a) Inspection verifying the integrity and completeness of the equipment or subsystem
b) Installation check verifying that the equipment or subsystem was installed according to drawings and instructions approved for installation
c) Mechanical tests, when adjustment, calibration, and mechanical (manual) operation of equipment should take place
d) Electrical tests, by using electrical test equipment and ac or dc control potential
e) Functional tests to verify the equipment control circuitry according to schematic drawings and instructions

5. Implementation of a field test program

Field testing is divided into the following groups:

— Equipment tests relating to individual items
— Subsystem tests, where groups of items are operated together to provide a test
— Commissioning tests
— Acceptance tests

All tests of the program should be performed in sequence, progressing to a higher level of tests only after the lower level tests have been completed successfully.

The tests described in 5.1 and 5.2 are known also as pre-commissioning tests, comprising all possible tests without main circuit energization, but with ac or dc control power available for use if required.

5.1 Equipment tests

This subclause covers pre-commissioning tests for equipment items peculiar to SVC. It is assumed that for each item of equipment, a manufacturer's checklist of inspection is available and has been completed satisfactorily after installation and prior to the start of these equipment tests. This checklist should include, for example, the following:

— Inspection of equipment upon arrival to site
— Installation checks (including, but not limited to, proving that all fastenings are tight, connections, and ground connections are correct, and insulators are clean and undamaged)
— Mechanical tests and adjustments

5.1.1 General

Contract specifications or existing standards apply to field tests of the following equipment: transformers, disconnecting and grounding switches, circuit breakers, instrument transformers, arresters, capacitors, reactors, resistors, auxiliary supplies, wall bushings, insulators, busbar, cables (power and control), and HVAC (heating, ventilating, and air conditioning) equipment. The fire protection and detection system should be verified to be in an operational state. Specific recommendations for these items of equipment is not provided.

5.1.2 Thyristor valve

5.1.2.1 Power supply to valve electronics

- Check the power supply (voltage and current) at the valve electronic units.
- Check the corresponding output.
- Check the alarm signals on loss of power.

5.1.2.2 Fiber optic

- Measure the attenuation of each fiber from ground level control equipment to gate unit, and reverse, where applicable.
- Check the correct connection per drawings.
- Verify the pulses received by thyristor gate unit in correct sequence and the firing pulse shape.
- Verify the monitoring signal that is sent and received.

5.1.2.3 Coolant circuit

- Check the unobstructed coolant circuits in all parallel paths.
- Check the coolant circuit connections.
- Verify the leak detection and alarm signals.

5.1.2.4 Contact resistance

- Confirm spring compression securing thyristors to assure contact resistances between thyristor and heat sink.
- Measure resistance between each interconnecting busbar on the valve, or confirm bolt torque values of busbar connections.

5.1.2.5 Grading network impedance

- Measure each total phase resistance (R) and capacitance (C), or check for continuity of the RC damping circuit.

5.1.3 Valve cooling equipment (skid or package)

5.1.3.1 Installation verification

Valve cooling systems are normally premounted, factory tested (to a certain degree), and interconnected at the site. The completeness and correctness of the overall system installation at the site should be verified visually with the aid of checklists, diagrams, drawings, and instructions. The checking process should include the immediate environment of the cooling system (such as mounting bolts), clearances (to allow for vibration, thermal expansion, exhaust air, etc.), openings, automatic shutters, walking and maintenance space, warning and instruction signs, lighting, leak-water collection, floors, and others.

The completeness and quality of the cooling media and supplies (such as water, filters, deionizing resin, and chemicals), as well as replacement and spare quantities, should be verified.

For water cooling systems, instructions regarding the water quality (pH number, etc.) of the first fill should be followed. This process should include running the flushing operation in bypass (i.e., without thyristor valves) over several hours, including all branches, heat exchangers, deionizers, etc.; turning pumps on and off repeatedly; and operating valves repeatedly, until no more particles accumulate in the filters.

5.1.3.2 Cooling power supplies

- Record the power supply input voltage.
- Observe the alarm signal on loss of input voltage.

5.1.3.3 Cooling auxiliary equipment

- Verify action and position of all automatically operated valves, louvers, doors, etc.
- Verify backup, standby, and spare equipment.

5.1.3.4 Pumps and fans

- Verify rotation direction.
- Verify start-up.
- Verify start-up of backup pump on loss of supply to running pump.
- Record starting and running motor current.
- Verify overload trip time of all motors by artificial single-phasing of all three-phase motors.
- Check noise and vibration.

5.1.3.5 Deionizer

- Check the conductivity measurement of the coolant to see that it drops below alarm level when raw water is circulated.

5.1.3.6 Measurement

- Verify conductivity meters.
- Observe pressure and temperature meters and check calibrations.

5.1.3.7 Heat exchangers (where applicable)

- Pressure test all piping, welds, and connections during subsystem tests.

5.1.3.8 Flow meters

- Verify correct installation of flow meters.
- Verify proper operation of flow meters.

5.1.4 Control equipment

5.1.4.1 Power supplies

- Record power supply input voltage and check to ensure that the subunit supply indication is healthy.
- Observe that changeover on loss of input voltage causes no voltage dip in control equipment.
- Observe correct alarm signal on loss of power supply.
- Confirm that controls perform at highest and lowest specified voltages.

5.1.4.2 Monitoring system

- Verify that the correct status and alarm signals (e.g., primary and secondary voltages, loss of supply, circuit breakers or disconnecting switches open, thyristor redundancy used) are sent to the monitoring system.

5.1.4.3 Control settings

- Check to see that all settings correspond to design values.
- Check to see that monitoring signals show correct values or correctly indicate alarms in response to injected signals.

5.1.5 Grounding transformer (if used)

- Verify phase connections.
- Verify oil levels and pressures.
- If secondary or tertiary winding of transformer are used for the auxiliary power, apply the full set of normal transformer tests.

5.1.6 Grounding capacitor (if used)

- Measure capacitance by suitable meter, or measure impedance at nominal frequency and some other reference frequency and derive capacitance.
- List and compare measured capacitance to nameplate.
- Apply the high potential test.

5.2 Subsystem test

5.2.1 General

Subsystems should be identified and subsystem tests designed in such a way that all components, connections, and interfaces are included with related software installed and operating. Subsystem tests involve ac/dc control circuit energization, interface, and operational and performance tests that are executed after equipment tests have been successfully performed. Sufficient overlap of testing should exist at all interfaces with other subsystems.

5.2.2 Thyristor valve system

The subsystem covered under this clause includes the complete valve structures, connected indoor buswork, wall bushings, instrument transformers, cooling ducts and pipes, firing and monitoring signal transmission systems, and trigger pulse converters (TPC) or valve base electronics (VBE) and valve electronics (VE) for any one three-phase thyristor-switched capacitor (TSC), thyristor-switched reactor (TSR), or thyristor-controlled reactor (TCR).

All individual equipment tests and installation checks described in 5.1 shall be completed successfully. Pertinent documentation (drawing lists, drawings, manuals, test plans, checklists, software listings, functional block diagrams, etc.) should be available and used.

5.2.2.1 Interface testing

Verify all equipment interconnections progressively from terminal to terminal, according to the pertinent drawings. A suitable method is provided in IEEE Std C37.20.3-1987 .[1]

CAUTION — Where sensitive electronic devices are connected to terminals, electrical circuit testers should be used with caution. Include, as applicable, verification of mechanic, magnetic, fiberoptic, hydraulic, and pneumatic interconnections. Verify electric clearances and interfaces with other contractor-supplied and owner-supplied subsystems.

The use of checklists and suitable markings on system schematic diagrams is a convenient method of record keeping.

[1]Information on references can be found in clause 2.

5.2.2.2 Coordination of valve and valve firing circuits

A separate TPC or VBE unit for converting control signals to suitable signals that can be transmitted to the thyristor valves is often located next to each three-phase valve unit. This TPC or VBE should be included in this subsystem.

a) Firing pulse phase correlation check: The control and protection equipment subsystem testing (see 5.2.4), including the TPC or VBE, should be completed for this test. The purpose of this test is to assure the proper timing of the valve firing signals for each phase and current polarity. The boundaries of this test should overlap the valve equipment tests and the control subsystem tests (i.e., the peripheral signal measuring points should be chosen accordingly). Details of the test can differ greatly from manufacturer to manufacturer. The following basic procedure applies.
   Magnetic or optical pulses arriving at the thyristors for all phases and current polarities should be compared to the related control signals with an oscilloscope. The test can be expanded to include the control system by using valve terminal ac voltage signals as applied to the control. Opto-electric converters may be used as appropriate.
b) Monitoring (check-back) pulse test: This test should verify the integrity and proper correlation of any thyristor and thyristor electronics status monitoring scheme (to the extent to which this is possible without voltage across the thyristor).

5.2.3 Valve cooling system

The thyristor valve cooling subsystem includes the entire cooling circuit outside the valves (i.e., pipes, ducts, pumps, heat exchangers, filters, purifiers, controls, meters, valves, flaps, and gauges). The interface on the valve side consists of flanges or air duct connections. The valve internal portion of the cooling system should be included in at least some of the tests.

Different types of valve cooling exist. For example

- Single or double circuit water cooling with dry or evaporative water/air heat exchanger or water/water heat exchanger
- Closed loop or open loop air cooling with or without intermediate water circuit
- Other media and combinations

The test plan for the thyristor valve cooling subsystem depends on the type of system under test. The plan should lean heavily on the supplier's documentation and instructions. Only general guidelines are included here.

5.2.3.1 Installation verification

After installation verification of the cooling equipment (see 5.1.3.1) has been performed, and flushing in bypass operation shows no particle accumulation, the bypass is removed, the thyristor valves are connected to the cooling circuit, and in the case of liquid cooling, filled with coolant. A first check for leaks is done under static pressure only. A static overpressure test is required. Details of actual pressure and time should be determined in coordination with the manufacturer and stated in the ITP.

Installation verification of the cooling system power supply, as well as cooling system control and protection equipment should follow. This should include protective relay settings, sensors, instrument readings, and alarms. The leak water detection system, atmospheric pressure relays, room thermostats, and other related systems should be checked.

5.2.3.2 Cold test run

After successful completion of all checks, the valve cooling system is started according to the supplier's instructions. With liquid cooling systems, the pumps are turned on and operated for several hours to remove all residual air from pipes, heat sinks, resistors, etc. For air cooling, the same idea applies. Fans, ducts, flaps, heat exchangers, and components are submitted to a test run. Electric currents, auxiliary power consumption, coolant flow and pressure, conductivity, temperatures, noise, and other parameters of importance are measured and recorded according to the ITP. All possible faults are simulated in order to test the related sensors, alarms, and trips. In this way, the correct alarm and trip levels, as well as the proper reaction of the control and protection system, are verified.

With liquid cooling, thorough checking for leaks is required and should be repeated during heat-run tests. Since the valves are not energized during these tests, no thermal tests can be performed at this time. A list of thermal tests to be completed during commissioning or acceptance tests should be maintained.

Transfer to standby units (from one power supply to another, from one pump to the other, from cooler to cooler, fan to fan, and control to control) should be tested as applicable. The transfer or loss of auxiliary power should either alarm or trip-off the unit, respectively.

5.2.4 Control system

SVC control equipment in this context includes open-loop and closed-loop control. Equipment testing, including testing by TNA or other suitable methods, is assumed to be performed in the manufacturer's test facility. Field tests of the control equipment will emphasize interface checks and tests of settings to verify that no transport damage has occurred. These tests include the following:

— Receiving tests
— Instrument transformer interface testing
— System control interface testing
— TPC, VBE, and VE interface testing

5.2.4.1 Receiving tests

— Visual check of control
— Check of power supply (connect supply voltage and measure auxiliary voltages at different locations in control)
— Test of settings (voltage and current testers are connected directly to the controller terminals)

5.2.4.2 Instrument transformer interface testing

All instrument transformers are to be checked for proper ratio and phasing, especially with respect to the SVC controls. One method is to excite the secondaries of these transformers directly from the instrument transformer terminals with the appropriate test equipment. The corresponding signals are then checked inside the control cubicle(s). This verifies the cable and terminal connections. The following instrument transformers are typically included in the above procedure:

— Primary potential transformer (PT)
— Primary current transformer (CT)
— Secondary ground reference transformer with PTs
— PTs for shunt capacitor banks
— CTs in valve branches
— Bushing CTs

CAUTION — If a PT is energized from the low voltage secondary side, safety procedures shall be observed on the high voltage side.

5.2.4.3 System control interface testing

If the design is such that the system control sends and receives signals to and from the SVC control, then the related interfaces, as well as the interfaces between the open-loop and closed-loop control portions, shall be tested by injecting and measuring signals as appropriate. This procedure should include signal connections to substation components such as breakers and switches.

5.2.4.4 TPC or VBE and VE interface testing

It is necessary (although not always easy) to test all firing signal paths, possibly including individual thyristor locations. Some of this testing is included in 5.2.2. Synchronized firing pulses should be released by the control system or generated by auxiliary test equipment (to overcome interlocking mechanisms).

5.2.5 Capacitor/filter bank

There are two basic types of harmonic filters.

- Sharply tuned, band-pass filters
- Very broadly tuned, high-pass filters

Each filter type is composed of capacitors, reactors, and in some cases, resistors. In general, the procedure for testing the filter types is the same, except for the tuning requirement of the tuned filter.

Test the protection and alarm functioning. One method is to perform primary and secondary injection tests.

If the filters are the tuned type

- Measure capacitance, inductance, and resistance of each phase component.
- Plot the impedance vs. frequency characteristics.
- Check the initial tuning using a frequency generator and oscilloscope, or digital multimeter (DMM), to find the resonant point.
- If necessary, tune the filter to designated value.

For broadly tuned filters, the factory-certified test data for capacitors, reactors, and resistors can be used to confirm the tuning of the filters.

5.3 System commissioning tests

Commissioning tests are those tests performed at the job site to verify the performance of the SVC as specified.

Test procedures should contain safety, communication, authorization, and energization instructions to be followed by the system operating center. These procedures should accomplish the following:

- Establish the system test coordinator’s role, authority, and obligations.
- Contain emergency procedures and tagging requirements.
- Contain instructions consistent with the purchaser’s practice.

It is advisable to prepare switching instructions with associated switching diagrams for each test showing the SVC system single-line diagram. All controllable switching devices should be specifically marked in the desired open or closed position for the given test. These steps will enhance communication with the purchaser’s system operators.

Upon successful completion of the equipment and subsystem tests, the SVC system can be declared “ready for commissioning tests.”

System commissioning tests can be divided into

- Energization tests
- Operational and performance tests
- Trial operation

5.3.1 Energization tests

Major phases of energization tests include

- Pre-energization checks
- Low voltage energization tests (optional)
- Initial energization tests
- Operational start-up tests

5.3.1.1 Pre-energization tests

A final inspection and visual check should be made to assure that all ground switches are open, safety grounds are removed, and removable bus links are reinstalled. Appropriate checks should be made to assure that all previously disabled interlocks and permissive circuits are reactivated. All safety rules should be reemphasized prior to energization.

Prior to energization, a specific inspection concentrating on system grounding should be performed. This inspection will ensure that all equipment grounds, grounding transformers, and system grounds are installed and connected in accordance with construction drawings.

5.3.1.2 Low voltage energization tests (optional)

Prior to energizing the SVC at full system voltage it may be advantageous to carry out a low voltage energization. At this low level of voltage, any installation or prior testing errors can be safely detected with minimum risk of damaging the equipment. SVC control, synchronization, and controller stability can be verified at a safer, scaled-down voltage. However, low voltage energization tests involve considerable effort, and it should be evaluated, on a case-to-case basis, as to whether or not this extra effort is justifiable.

This test will assure that the overall phase relation of the power circuit, firing pulse circuit, proper monitoring, and fault annunciation for all thyristors and thyristor electronic circuits is correct. Generally, this test is the most comprehensive check of the entire system prior to full voltage energization.

Differential relay protection polarity also can be checked during this test. The scaled-down voltage operation of the SVC will allow for vital control function checks without undue risk to the system.

Use test voltages and currents to do the following:

- Operate each protective relay.
- Check relay logic and verify that the trip contacts operate the correct devices.
- Check or set relay calibration.

It is important to treat this test as a full voltage test from the point of view of safety procedures and final trip testing. Systematic detailed trip testing should have been performed prior to this. All necessary safety procedures shall be observed the same as with full voltage energization.

As much of the SVC installation as is possible (in a practical sense) should be energized. If possible, a medium voltage should be applied to the SVC transformer primary. Alternatively, a low voltage can be applied to the SVC bus.

CAUTION — If the SVC transformer is energized from the low voltage side, safety procedures shall be observed on the high voltage side.

Some parts of the SVC will require adjustments to operate in the low voltage environment (i.e., synchronizing PT outputs may have to be stepped-up using auxiliary PTs). If this is not possible, the PTs can be substituted with three-phase variable ac voltages in phase with the PT outputs. Voltage measuring units on TSCs may need to be shunted to increase their sensitivities. Thyristor valves will require some thyristors to be shunted to obtain a sufficient minimum voltage per thyristor. These shunts should be rotated during the test to ensure that all thyristors are energized and controlled.

For the purpose of this test, the current rating of the test supply can be calculated as:

$$I_{test} = Q_{max} \cdot \frac{V_{test}}{(V_{nominal})^2}$$

where

Q_{max} is the larger of the following:
Q_{max_L}, maximum inductive output of the SVC
Q_{max_C}, maximum capacitive output of the SVC

During this test, as many functions of the SVC as possible should be tested. TCR, TSC, and filter currents, as well as their unbalance currents, should be measured and extrapolated to full voltage level.

If possible, basic step response tests of the controller can be performed using suitable low voltage loads or response voltage steps. A “hands-on” practice may be conducted during this low voltage test with minimum effect on the power system.

5.3.1.3 Initial energization test

In preparation for initial energization tests, arrangements should be made with system operators to assure that the ac network can absorb or generate the desired Mvars. The ac network configuration may need to be changed to accommodate anticipated Mvar swings. As a last resort, testing may need to be limited to the allowable levels, which may be lower than rated.

The first high voltage energization may be performed in steps not necessarily in agreement with the normal operating start-up sequence. The steps could be as follows:

- Energize the power transformer with no load.
- Energize the bus with all load-side disconnect switches open.
- Energize the harmonic filters.

Typically, the lowest order filter should be energized first to avoid resonant overvoltages. If the system conditions allow it, ultimately energize all filters simultaneously. During filter energization, bus voltage changes should be monitored to obtain an indication of the relative strength (short circuit capacity) of the ac system.

To isolate potential problem areas, each branch of the SVC system should be energized one at a time.

The system operator should be informed of possible malfunctioning that could produce Mvar swings equal to the TCR or TSC ratings.

Initial energization tests should be performed according to the supplier’s recommendations.

The TCR or TSR branch should be energized first, without issuing firing pulses (i.e., blocked, to verify the integrity and voltage withstand capability of thyristors). Depending on the valve design, the absence of firing pulses can be assured by different methods. In some valve design, it may be adequate to simply leave the branch blocked, whereas for other designs, the complete disabling of valve firing may be required (for example, by disconnecting the firing pulses but leaving the monitoring connections, or by disabling the firing pulse generator).

The TSC branch can be energized in a similar manner.

The symmetry of the power circuit phases will be determined by measuring the SVC bus voltages and the phase currents in each branch. Measured voltage and current values can be used to calculate actual impedances.

If phase balancing circuits are used in the TCR branches, they should be adjusted to ensure that currents in each of the three phases are equal.

For the TCR, the impedance will vary for different thyristor firing angles. For the TSC, TSR, and harmonic filters, the branch impedance values will be nearly constant.

Differences measured among phases in the same branch will indicate that there can be irregularities in inductance or capacitance values. For the TCR, the difference in phase impedance values also can be an indication of thyristor firing angle asymmetry.

5.3.1.4 Operational start-up tests

All manual and automatic start-up and shutdown sequences should be tested separately on each of the SVC branches. This will demonstrate the controllability and the de-block and block capabilities of the thyristor valves in each branch.

The emergency stop function should be tested early in the test sequence to verify correct operation.

5.3.2 Operational and performance tests

To gain flexibility for testing performance across the total operating range, system adjustment may be necessary.

5.3.2.1 SVC continuous operating range

The test of continuous operating range should verify that the SVC is capable of operating up to its specified limits in the continuous operating mode, from maximum Mvar capacitive to maximum Mvar inductive.

The actual reactive power, Q (Mvar), output from the SVC system at nominal voltage can be determined by direct measurements at the point of common coupling (PCC) through use of the following formula:

$$Q_{\text{actual}} = Q_{\text{measured}} \cdot \left(\frac{V_{\text{nominal}}}{V_{\text{measured}}}\right)^2$$

5.3.2.2 Verification of the SVC voltage characteristics

If the SVC installation is intended to control the system voltage, the slope characteristic of the SVC should be verified by measurements and calculations. In the voltage control operating mode, the reactive power output of the SVC should be adjusted by means of altering V_{ref}, such that the SVC just obtains maximum inductive output. The overall slope of the voltage characteristic for maximum inductive output should be taken to be

$$\%V_{\text{slope}} = \left[\frac{V_{\text{measured}} - V_{\text{ref}}}{V_{\text{ref}}}\right]100$$

Similarly the overall slope of the voltage characteristic for maximum capacitive output should be taken to be

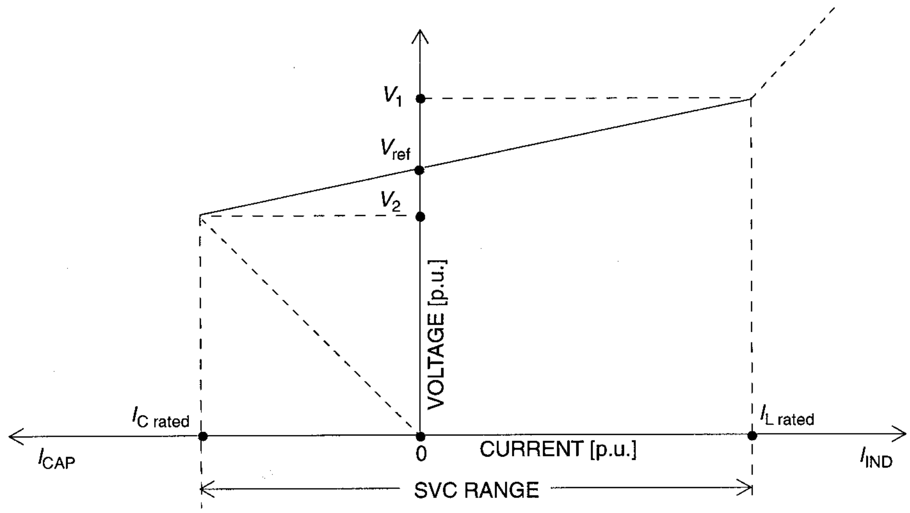
$$\%V_{\text{slope}} = \left[\frac{V_{\text{ref}} - V_{\text{measured}}}{V_{\text{ref}}}\right]100$$

where

$\%V_{\text{slope}}$ is the percentage of slope per base MVA

$V_{measured}$	is the measured bus voltage in per-unit (p.u.) of base voltage at the PCC
V_{ref}	is the reference voltage in p.u. of base voltage

The slope of the SVC is the ratio of p.u. voltage change to p.u. current change over the controlled range of the SVC system (see figure 2).



$$\%V_{slope\,(inductive)} = \frac{(V_1 - V_{ref})\,100}{V_{ref}}$$

$$\%V_{slope\,(capacitive)} = \frac{(V_{ref} - V_2)\,100}{V_{ref}}$$

where

$I_{C\ rated}$	is the rated capacitive current
$I_{L\ rated}$	is the rated inductive current
V_1	is the controlled V at inductive current rating
V_2	is the controlled V at capacitive current rating

$$\text{TOTAL slope} = \%V_{slope\,(inductive)} + \%V_{slope\,(capacitive)}$$

Figure 2— Slope of static var compensator system

In each case, the overall slope is expressed as a percentage voltage change per base MVA. The value of % V_{slope} should be adjusted between the values specified in the contract document.

5.3.2.3 Verification of load characteristics

The setting of the SVC should be varied over its entire range to verify its output, in particular over the switching point of TSC or TSR branches. Oscillographic recordings of system voltages, SVC (transformer primary) currents, and the Mvar control signal should be used to verify the output of the SVC, including branch switching. The output of the SVC should be within the specified parameters.

5.3.2.4 Dynamic system tests

To verify the SVC system dynamic characteristics, steps in the reference values should be applied to test the response of the SVC. For installations that are intended for voltage control, step changes in V_{ref} should beapplied. If possible, records should be kept of SVC response to the lowest system short circuit levels. In particular, the SVC should not become unstable during minimum short circuit level conditions while maintaining good response during maximum short circuit level conditions.

Depending on application, additional tests may be performed. For example

- For installations that are intended to respond to active and reactive power demands, a step change in Q_{ref} should be applied. Step inputs to Q_{ref} should be made to obtain records of SVC response to varying disturbances.
- If the load to be compensated consists of fast changing dc loads, consideration should be given to applying a sinusoidal input to Q_{ref} of equivalent frequencies and magnitudes of the expected sub-harmonic currents caused by the load. The SVC should provide stable and adequate compensation as specified.
  It is worth noting that the ac network might be able to absorb the full capacitive-to full inductive-and back Mvar swing (typically within 1 sec) better than it can absorb it in incremental steps.

5.3.2.5 Special control function tests

All specified special control functions should be tested. Tests of any special switching or sequencing operation (such as fixed capacitor or reactor bank switching) should be performed. Automatic inhibits should be simulated for the particular operating or system conditions for which they were designed.

5.3.2.6 Tests of redundancy

All redundant systems should be tested. To verify transfer times and disturbance-free operation, transfer operations shall be performed under energized, in-service conditions.

Power circuit transfer and, if provided, cooling and auxiliary system transfer shall be evaluated and compared to specified reliability requirements.

Testing, by simulated failure of redundant systems, should be performed at this time to ensure that double contingencies result in an orderly shutdown or emergency stop.

5.3.2.7 Derated operation

Derated operating modes should be tested with SVC branch or harmonic filters taken out-of-service. The reduced Mvar capabilities should be recorded and evaluated.

Interlocking for various out-of-service conditions should be verified.

5.3.2.8 Measurements of harmonics and distortion

Individual and total harmonic distortion factors should be obtained or calculated from actual voltage and current harmonic measurements. Individual harmonic distortion, total harmonic distortion (THD), telephone influence factor (TIF), and IT product factors should include all harmonics specified in IEEE Std 1031-1991 .

Harmonic and distortion measurements should be made at the PCC under the following conditions:

a) *SVC system off.* Under typical ac system operating conditions, these measurements will give the background or reference values.

b) *SVC system on.* Under the above typical conditions, measurements should be made at several TCR operating levels producing the highest single harmonic and highest THD.

During these tests, harmonic filter current magnitudes will indicate the effectiveness of filters and whether loading is within safe design values.

For capacitor banks with external fuses, the unbalance protection steps are tested by simulating capacitor fuse blowing with opening fuse links or terminal post connections. Alarm levels and subsequent trip conditions should be verified and relay currents should be monitored to confirm calculations of relay settings.

Where capacitors with internal fuses are used, the function of unbalance protection steps are tested by introducing additional capacitance to create unbalance.

For both types of capacitors, secondary injection to the unbalance relay can be used to create an unbalance current corresponding to calculations. Verification of alarm and trip condition is directly possible.

5.3.2.9 Measurements of noise interference

To verify compliance with the specification requirement, other optional tests, such as the system interference measurements for the following, can be performed (with and without the SVC in-service):

— audible noise (AN)
— radio interference (RI)
— television interference (TVI)
— power line carrier (PLC)
— telephone line carrier (TLC)

5.3.2.10 Heat run test

This test is performed to verify the loading conditions of the system components and to identify potential hot-spots, either in the equipment or the connecting buswork.

The SVC should be adjusted manually to the point where maximum losses of the system are encountered. Cooling system, individual equipment, and ambient temperatures should be recorded along with associated electrical quantities over the period of the beat run. The test should continue until temperature equilibrium is reached and maintained in the equipment and cooling system. Readings should be corrected for maximum ambient temperature as indicated in the user’s specifications.

Particular attention should be given to the effectiveness of the valve cooling system. Maximum SVC losses should be generated; redundant units should remain turned off (as applicable); equilibrium should be achieved and maintained; and coolant input and output temperatures, pressures, and flow rates should be monitored. The heat run should be verified with each of the redundant cooling components substituted one at a time.

These tests should cover dynamic heat run tests to verify short time overload capabilities during cooling system component failures.

The heat run tests should be repeated under derated conditions and load. This may include, for example, tests at the maximum load allowed without spray water for an SVC with evaporative cooler.

Since maximum losses of the different components do not necessarily occur at the same working point, the heat run should be repeated for maximum stress in the various components.

Careful infrared scanning of the equipment, buswork, ground connections, and fences can provide useful information for potential hot-spots that may reveal loose connections or inductive heating.

5.3.2.11 SVC loss determination

The SVC losses are typically in the range of 0.5–0.75% of the total Mvar output. Total losses are best determined by calculations using data from factory test reports and direct measurements in the field, where such measurements are practical (such as auxiliary, cooling system, and building services).

Loss should be determined at various operating points, including normal, zero Mvar, maximum capacitive, and maximum inductive output at the PCC. All equipment required to be in-service at the particular operating point should be included in the calculations.

The equipment losses listed below, as applicable, should be part of the loss determination at various load levels. The loss determination for items a)–e) is based on factory measurements and additional calculations considering harmonics and ambient conditions. The loss determination for items f)–h) can be determined in the field by direct measurement at the auxiliary distribution breakers or at the equipment terminals. To verify guaranteed losses, calculations may be required to derive the losses incurred at the specified ambient temperature from those measured in the field at the actual ambient.

a) Power transformer
   - No load losses
   - Load loss
   - Harmonic losses
b) TCR/TSR branches
   - Thyristor valve losses
   - Reactor losses
c) TSC branches
   - Thyristor valve losses
   - Capacitor losses
   - Reactor losses
d) Mechanically switched (MS) capacitors or reactors
   - Capacitor or reactor losses
   - Resistor losses (if any)
e) Harmonic filters
   - Reactor losses, including harmonic losses
   - Capacitor losses, including harmonic losses
   - Resistor losses, including harmonic losses
f) Cooling system
   - Pump power consumption
   - Fan power consumption
   - Cooling medium treatment power consumption
g) Control system
   - Control power
h) Auxiliary system
   - Building services power consumption
   - Auxiliary transformer losses
   - Grounding transformer losses

5.3.3 Trial operation

A period of time designated as “trial operation” should precede the final acceptance tests. The accepted running time is usually 5–10 days, with the SVC system functioning as intended in the design and performance specifications, and without intentional disconnection from the ac network. Any interruption should be analyzed.

Acceptance tests should be allowed to commence only after successful completion of the trial operation period.

5.4 Acceptance tests

Acceptance tests are those tests that the user reserves the right to re-perform or verify after the supplier performs the commissioning tests and submits the test reports. Acceptance tests should not commence until all commissioning tests at the site are completed and test reports are submitted to the satisfaction of the user.

The acceptance test program may need to be modified based on the results of the commissioning tests and interim test reports. New tests may need to be added or certain tests re-performed to address problems brought out during commissioning.

Acceptance tests may include the following categories of tests:

- Static (steady state) tests
- Dynamic tests
- Control tests
- Staged fault tests

5.4.1 Static (steady state) tests

Acceptance tests of SVC systems are based on the preceding tests, witnessed and documented, as applicable. The final adjustment, trimming, and debugging should have taken place during commissioning tests.

During the acceptance period, a formal demonstration of the working system will be made. Operation should be performed (typically by user's personnel and with the supplier's supervision) according to the following suggested program.

5.4.1.1 Test of control functioning

a) Control sequences
   1) Start/stop
      - manual
      - automatic
   2) Emergency stop
   3) Protection initiated stop
      - isolation
      - restart
   4) Control mode selection
      - constant Mvar output
      - constant system voltage
      - float (zero Mvar output)
   5) Transfer of operation
      - local/remote
      - manual/automatic
b) Control range capability sequences. In each control mode, demonstrate possible control over the entire operating range by testing the following:
   1) SVC Mvar capability (local/remote)
   2) Voltage reference adjustment capability (local/remote)
   3) Slope adjustment capability (local/remote)
   4) Slope linearity
   5) Current limiting action
c) Demonstration of control modes:
   1) Set reference *Q* and verify constant Mvar output
   2) Set reference voltage and verify constant system voltage
   3) Maintain zero Mvar output

5.4.1.2 Load tests

Verify compensator operation at rated load in both rated capacitive and inductive loads (subject to system limitations).

a) Verify system parameters, such as voltage, current, and Mvar at PCC
b) Verify SVC performance values
   1) Losses (SVC efficiency)
   2) Harmonic filter performance factors, such as individual and total harmonic distortion and TIF
   3) Audible noise (indoor/outdoor)
   4) Interference levels (optional)
   5) Temperature rise

5.4.1.3 Redundancy test

Verify the functioning of redundant circuits. In each case, the functioning of signaling circuit, monitoring, blocking, and disconnecting sequences should be demonstrated clearly following the loss of various redundant systems.

a) Verify disturbance-free operation of SVC with the following:
   1) Simulated single-thyristor failure
   2) Simulated capacitor unit failure
b) Verify disturbance-free operation of SVC upon transfer to redundant circuit
   1) Transfer of valve cooling system to standby unit
   2) Transfer of auxiliary ac/dc services
   3) Transfer to uninterruptable power supply (UPS) operation (if furnished)
c) Verify derated operation or orderly shutdown
   1) Multiple thyristor failure
   2) Multiple capacitor failure
   3) Loss of any one SVC branch
   4) Double failure of auxiliary system
   5) Unavailability of redundant circuit when called upon

5.4.1.4 Test of protection schemes

Protection scheme tests can be performed by simulating faults to verify the effectiveness of protection at various points in the SVC system. However, it is advisable to limit the number of breaker tripping to one from each of the following typical groups of protection:

a) Power circuit fault simulation
   1) Trip main breaker
   2) Verify relay redundancy
   3) Verify breaker failure protection
   4) Valve fault
   5) High voltage bus fault
   6) Power transformer fault
   7) SVC bus fault
   8) SVC branch fault (per branch)
   9) Harmonic filter fault
   10) Capacitor bank fault
   11) Reactor fault
b) Control system failure simulation
   The method of simulation should be worked out with the manufacturer.
c) Valve failure simulation
   1) Simulated single-thyristor failure
   2) Simulated multiple-thyristor failure

d) Cooling system failure
   Multiple cooling system component failure
e) Auxiliary power system failure
   1) Multiple auxiliary power system failure
   2) DC control power failure
   3) UPS failure during transfer
f) Support system failure
   1) Monitoring system fault
   2) Alarm system fault
   3) Fault recording system failure
   4) Sequence of events recorder failure

5.4.2 Dynamic tests

To verify the behavior of the SVC, system disturbances should be applied. These disturbances will try to displace the operating point within the normal control range of regulation without excursions outside the limits, but exercising both TSC and TCR. Response time of the SVC should be monitored.

The following actual operating conditions can provide valuable test data for system performance:

a) Transmission line(s) switched into and out of service, energization of nearby capacitor banks, or loading of transformer bank.
b) Placing SVC into service, taking SVC out of service.
c) System response when SVC is operated across the whole range by step change of reference point (V_{ref}, Q_{ref}) subject to system limitation.
d) In order to assess transient and possible resonance phenomena, current waveforms in each filter branch and voltage waveforms across each filter branch element should be recorded during the following SVC operating conditions:
   1) Normal SVC start-up and shutdown sequences, at least three consecutive occasions.
   2) Normal load switching sequences should be performed at least three times.
   3) Sample measurements made across the normal operating range.

It is recommended that measurements of the above switching events be made with high resolution (kHz range) recorders that can trace the actual transients. These records can be used to determine the magnitude of dynamic voltages and currents that are seen by the filter elements. The records should be kept as reference for future measurements to verify that filter effectiveness and system operating conditions have not changed.

5.4.3 Control tests

Special control functions specified in the contract, such as capacitor bank switching, special regulator functions, automatic testing of standby equipment, etc., should be demonstrated under realistic operating conditions.

5.4.4 Staged fault tests

Actual staged fault tests should be implemented only after a thorough study of their effects on the ac system. Staged faults should be completely under utility (user) management.

To gain the maximum amount of useful data, exact procedures should be prepared and carried out with extreme precision of measurement sequence and duration. Personnel and equipment safety shall be maintained at all times. Special backup protection may be considered for added ac system security.

NOTE — Due to ac system configuration or loading condition during the period of commissioning, it may not be possible to perform these tests.

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