NATIONAL TRANSMISSION AND DESPATCH COMPANY (NTDC)

SPECIFICATION P- : 2009

STATIC VAR COMPENSATORS

Prepared by
DESIGN DEPARTMENT (NTDC)

CONTENTS

STATIC VAR COMPENSATORS

1. FOREWORD

1.1 This specification has been prepared by Design Department, Services Division, NTDC.

1.2 This is a turnkey specification for a Contractor to connect a complete Static VAR Compensator (SVC) system to a substation. The specification does not include all the necessary terms & conditions of the contract.

1.3 The specification is subject to revision as and when required.

2. INTRODUCTION & PURPOSE

2.1 **Background**

2.1.1 The reactive power demand from the Company' system is escalating drastically but the sources to cope with such a huge reactive power requirement are limited especially during disturbances/contingencies.

2.1.2 The reactive power demand is maximum during summer due to air-conditioning and refrigeration loads. When system faces voltage dip due to any fault followed by trip of a 500kV circuit, the voltage recovery gets very slow resulting in voltage collapse. In order to meet the reactive power demand for steady state conditions, there is an ongoing program of installation of shunt capacitor banks at 11 kV, 66 kV and 132 kV levels by all the Distribution Companies (DISCOs) in their respective areas. However, these capacitor banks do not contribute much in voltage recovery under dynamic conditions when motor load is dominant in the system during summer. The motor stalling phenomena causes to draw huge reactive current which leads the voltage to drop down further and this vicious cycle causes the system to face voltage-instability leading to wide spread voltage-collapse and blackout. This phenomenon was studied by carrying out the transient voltage stability studies using dynamic load models and the results indicated that installation of SVC would be a remedy to overcome this problem.

2.2 **SVC Project Description**

2.2.1 For SVC site and system descriptions, please refer to Annexure-A.

2.2.2 The design of SVC shall meet the operational and system dynamic requirements specified in his specification using any configuration of Thyristor Controlled Reactors (TCR), Thyristor Switched Capacitors (TSC), fixed capacitors (FC) and harmonic filter circuits. The full dynamic range shall consist of thyristor controlled reactors and/or thyristor switched capacitors except FC. Temporary overload of specific components shall also be considered. The harmonic filter requirements have to be fulfilled over the whole reactive power range for harmonic emission from the grid as well as SVC system.

2.2.3 Each bidder shall provide a detailed design of the SVC being offered, showing all the equipments in the Contractor's scope of supply, control & protection schemes, cooling system arrangement, reliability and availability calculations etc.

2.2.4 The bidder shall declare safety hazards including hazardous materials associated with equipments being supplied and the design shall include suitable protection measures complying with the international standards.

3. REFERENCE STANDARDS

3.1 **Documentation, Language & Units**

3.1.1 All documents, drawings, instructions, manuals, technical information and test certificates shall use SI units and shall be in English.

3.2 **Standards/Specifications**

3.2.1 All work connected with the supply of the SVC system shall be in accordance with the requirements of appropriate latest International/Company standards and regulations such as IEC & IEEE. Where no International/Company standard exists, the SVC system shall comply with recognised standards and design practices. If the requirements of this specification conflict with any of the reference standards or practices, the Company's specification(s) shall prevail in particular to those items/requirements. The bidder shall state and furnish a list of all standards used for the specific type of equipment/material with the bid.

3.2.2 For the major SVC components, the latest version of the following standards in particular shall apply:

General

ISO 1000	Metric Standards
ISO 9001	Quality Assurance
ISO 1459, 1461	Hot-dip Galvanisation
IEC 60060	High Voltage Testing Techniques
IEC 60071	Insulation Co-ordination
IEEE 1031	IEEE Guide for the Functional Specification of Transmission Static Var Compensators

Thyristors

IEC 60146	Semiconductor Converters
IEC 60147	Essential Ratings and x-tics of Semiconductor Devices and General Principles of Measuring Methods
IEC 60747-1	Semiconductor Devices - Discrete Devices - Part 1: General
IEC 60747-2	Semiconductor Devices - Discrete Devices - Part 2: Rectifier Diodes
IEC 60747-6	Semiconductor Devices - Discrete Devices - Part 6: Thyristors
IEC 61954	Testing of Thyristor Valves for Static VAR Compensators
IEEE 1303	Guide for Static VAR Compensation Field Tests

Capacitors

IEC 61070-11, IEC/TR 600871-1;-4	Shunt Power Capacitors

Transformers

IEC 60076, P-46	Transformers

Reactors

IEC 60289	Reactors

Arrestors

IEC 60099, P-181	Surge Arrestors

Circuit Breakers

IEC 62271-100, P-193	Circuit breakers

Disconnectors

IIEC 62271-102, P-128	Disconnectors and Earthing Switches

Insulators & Bushings

IEC 60137	Bushings above 1000V
IEC 60168	Insulators of Ceramic or Glass
IEC 60815	Guide for Selection of Insulators in respect of Polluted Conditions

Instrument Transformers

IEC 60044-1, P-90	Current Transformers
IEC 60044-2, P-129	Voltage Transformers

Switch gear & Control gear

IEC 60694	Common clauses for HV Switchgear and Control gears
IEC 62271	High-voltage switchgear & control gear

Harmonics & Filter Banks

IEEE 519	Guide for Harmonic Control and Reactive Compensation of Static Power Converters
IEC PAS 62001	Specification and Design Evaluation of AC Filters for HVDC Systems

Measurements

IEC 60688	Transducer for Electrical measurements

Optical fibre

IEC 60794	Optical fibre cables

Relays

IEC 60255	Electrical Protective Relays

EMC

IEC 61000-4-2,3,4,5	Control System EMC (immunity)

3.2.3 The above stated list does not claim to be complete. Some additional standards are also referred under specific clauses. Additionally, all general laws and regulations have to be followed regarding Health and Safety.

3.3 **Definitions**

3.3.1 For the purposes of this specification, the following technical terms and definitions shall apply. IEC 60050 & IEEE International Electro technical Vocabulary shall be referred for terms not defined in this clause.

i) Control range:
The total inductive plus capacitive range of reactive current or megavar variation of the static VAR compensator (SVC) at the point of connection during normal voltage (±5% of the nominal value) and contingency voltage (±10 % of the nominal value) range.

a) Lagging operation:
Inductive megaVARs absorption of the static VAR compensator (SVC).

b) Leading operation:
Capacitive megavars generation of the static var compensator (SVC).

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

iii) Point of connection:
For a static var compensator (SVC) with a dedicated transformer, the high-voltage (HV) bus to which the whole system is connected.

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

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

vi) Settling time:
The duration from a step change in control signal input until the SVC output settles to within ±5% of the required output.

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

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

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

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

xi) Voltage/current (V/I) characteristic:
The relationship between the current of the static var compensator (SVC) and the voltage at its point of connection.

3.4 **Acronyms & Abbreviations**

BIL	Basic Insulation Level
EMI	Electromagnetic Interference
ETT	Electrically Triggered Thyristors
PCC	Point of Common Coupling
RI	Radio Interference
SVC	Static var Compensator
SWC	Surge Withstand Capability
TIF	Telephone Influence Factor
TNA	Transient Network Analyzers
TSC	Thyristor-Switched Capacitor
TVI	Television Interference
V/I	Voltage/Current
CT	Current Transformer
PT	Potential Transformer
HMI	Human Machine Interface
DFR	Digital Fault Recorder
DSM	Dynamic System Monitor
VQR	Voltage Quality Recorder
SOE	Sequence of Event Recorder

4. ENVIRONMENTAL DATA

4.1 **Ambient Conditions**

4.1.1 The SVC shall be designed to meet all ratings and performance requirements specified in this document while operating in the following environmental conditions:

Maximum temperature (under the Sun)	55°C
Maximum mean over any 24 hours	45°C
Mean temperature in any year	30°C
Minimum temperature	-10°C

4.2 **Relative Humidity**

4.2.1 The relative humidity may range up to 100%. The maximum values of the ambient temperature and humidity, however, do not occur simultaneously. During monsoons high humidity may persist for many days at a time with temperature ranging from 30°C to 40°C.

4.3 **Altitude**

4.3.1 Installations may be upto 1000 m above sea level.

4.4 **Atmospheric Conditions**

4.4.1 It may be assumed that the air is not, normally, heavily polluted by dust, smoke, aggressive gases, vapors or salt spray. However, at certain times of the year severe dust storms may be experienced.

4.4.2 Certain areas are subject to heavily polluted atmosphere and insulation or bushings for installation in such areas shall have an extended creepage distance from line to earthed parts.

5. SCOPE OF WORK

5.1 **General Requirements**

5.1.1 The Contractor shall be responsible for all the specified studies, design, engineering, furnishing of all equipments, delivery, civil works, erection, installation, testing, commissioning and field verification of the complete SVC system. The Contractor may also be required to provide all information for independent design verification and system modelling.

5.1.2 The Contractor shall be responsible for design, construction, site improvements and determining the final dimensions based on detailed design study.

5.1.3 All equipment shall be designed as needed to meet the requirements in this specification. Any equipment and/or function of the SVC not specifically mentioned herein shall be designed as required by the overall design of the SVC system in order to ensure the satisfactory operation of the system even after installation and operation of SVC.

5.2 Equipment/Material

5.2.1 The Contractor’s scope of works also includes but not limited to the followings. For additional/special requirements, refer Annexure - D.

i) All engineering, fabrication, supply, installation, testing and commissioning of the SVC components, their assemblies and accessories.

ii) 132 kV/MV transformer, ONAN/ONAF cooling, 3 single-phase units, oil immersed, outdoor type with HV & MV insulated bushings, control & auxiliary cubicles and all other allied accessories. One single-phase unit shall be supplied as spare in addition.

iii) Complete TCR & TSC units including thyristor valves for reactive power control with their protection, control, monitoring and cooling system.

iv) Harmonic filters as required by the specified harmonic performance levels.

v) All transformer bay equipment on the primary side of the step-down transformer including circuit breakers, disconnect switches, instrument transformers, surge arrestors, a motor-driven earthing switch, etc.

vi) All bus work on secondary side of the transformer including tubular bus bars, steel support structures, insulators, circuit breakers, disconnectors, earth switches, surge arresters, connectors, joints, fittings etc.

vii) Bushings to the SVC valve building.

viii) SVC MV Auxiliary transformer.

ix) Control and Protection equipment of the SVC, including measurement, monitoring, indication etc.

x) SVC MV Surge capacitors and SVC Control HMI.

xi) MV Current and Voltage transformers.

xii) Separate SVC auxiliary supplies (AC and DC) complete with automatic changeover, cable laying, protection, batteries and battery chargers with charger coupler arrangement.

xiii) Ring main unit (RMU) arrangement for the AC supplies shall be applied to ensure uninterruptible supply.

xiv) Surge protection and overhead lightning protection of the SVC yard and supporting structure.

xv) SVC yard lighting.

xvi) All equipment's support structures, foundations and trenches.

xvii) SVC control and power cabling.

xviii) Three each, 132kV air insulated Surge Arresters mounted in close proximity to the SVC HV transformer bushings.

xix) Three each, MV Transformer mounted Surge Arresters.

xx) Complete SVC buildings including thyrister valve hall, control/relay/protection rooms as per design requirements and according to Company standards with foundation, plumbing, lighting, fire protection and electrical outlets as well as facilities for ambient temperature & humidity control.

xxi) The Contractor shall design and construct a room for the storage of the recommended spare parts and one maintenance room for the local repair/maintenance of the SVC equipment/parts.

xxii) All delivered equipment shall be adequately protected and anti-corrosive in nature.

xxiii) Any other equipment and engineering required for the proper functioning, operation and maintenance of the SVC.

xxiv) Single Line and Layout Drawings of the substation where SVC is to be installed, are presented in Annexure-C.

5.3 Services

5.3.1 The following services shall be part of the Contractor's scope of work:

i) Site civil works including site preparation.

ii) SVC yard and associated substation civil work i.e. sub-soil investigation, site development, clearing, grading, access roads, site fences, gates, surface treatment, drainage, drainage materials, filling, footings, foundations, trenches, ducts, site security during construction etc as per site requirements.

iii) Delivery, receiving and handling at the site of all materials and equipment under scope of work.

iv) Supply and installation of interconnecting cables or fibre optics from the SVC equipment to the SVC control building and to the substation control building.

v) Assembly, erection and installation of all equipment on site. Wiring and connection of all equipment, apparatus, components, and equipment frames, racks and switchboard panels, etc.

vi) Supervision and performance of field verification, final checkout, start up and commissioning tests of all SVC apparatus and controls connected to the grid including all interfaces, and verification of proper operation and functioning of the same.

vii) Training of the Company's personnel, which will enable them to operate and maintain the SVC and modify its control parameters if so required.

viii) Arrangement of testing facilities and witnessing of routine/type tests, trainings etc. to the Company engineers, as required.

ix) Any other services and engineering required for the proper functioning of the SVC.

5.4 Interfaces

5.4.1 Connection to the Substation

5.4.1.1 The existing 132 kV outdoor switchgear in double bus single breaker configuration shall be expanded by a complete 132 kV bay for making interconnection to the SVC.

5.4.1.2 The SVC shall be connected to the specified bus bar at the substation through a coupling transformer and outdoor bay. The bay shall comprise of circuit breakers, disconnectors, earthing switches, arresters, current and voltage transformers etc. as per SVC overall operation and design requirements.

5.4.1.3 132kV tubular bus bar arrangement and its connections from the SVC 132 kV bay in the existing 132kV switchyard to the SVC transformer air insulated outdoor bushing.

5.4.2 Earthing, Grounding Mat

5.4.2.1 The grounding mat is to be connected to the existing grounding system in the substation. The Contractor shall perform earth measurements and care shall be taken when providing new grounding system that it shall not form closed loops to ensure that induced current from the TCRs is not circulated in the grounding loops.

5.4.3 SCADA & Communication Systems Interfacing

5.4.3.1 Interface to the Company's communication and SCADA system shall be provided including RTUs in SVC control room, substation control room etc. and all necessary cables for interfacing. The interfaces shall match with the existing RTUs. The SVC shall also be remotely controlled through SCADA interface by the Company's control centre.

5.4.3.2 The 132 kV connection bay shall be included in the remote control system of substation.

5.4.3.3 Alarms shall be grouped locally in a rational way and be exchanged with the remote control centre.

5.4.3.4 The Contractor's responsibility includes the provision of potential free contacts at the SCADA terminal box at the site for exchanging the data but excludes the communication links.

5.4.4 Water supply, Sewage and Drainage

5.4.4.1 In the substation, the water supply has to be arranged by the Contractor. The connection for the SVC cooling system has to be investigated by the Contractor. The connection for the drainage of the SVC and the rainwater is also included in the Contractor's scope of work.

5.5 Documents

5.5.1 Supply of the following documentation shall be made by the successful bidder:

i) All drawings/data, instructions/service/trouble shooting manuals necessary to operate and maintain the SVC and associated equipments with complete drawings in triplicate. The drawings shall include the complete set of plans, elevations, sections, wiring, schematics, piping, etc. of the whole SVC system. The scope of spare parts and special tools must be co-ordinated with the requirements/guarantees of reliability and availability requirements mentioned in sub-clause 7.9.

5.6 Spare Parts & Special Tools

5.6.1 The bidder shall furnish recommended spare parts for the SVC system as well as all special tools needed for the maintenance/operation of the SVC. A detailed list of the spare parts/special tools including all necessary information regarding manufacture, supplier, equipment specification, calibration intervals, etc. shall be furnished with the bid. Refer to sub-clause 8.15 of this specification as well.

5.7 Equipment, Material & Services Furnished by the Company

5.7.1 A dedicated piece of land where the SVC system shall be installed.

5.7.2 Water, one or two (independent) auxiliary AC feeders (230/400V) for temporary use, as required for installation of the equipment and to facilitate reasonable working conditions for the Contractor's personnel.

5.7.3 Available as-built reference data and drawings for the Contractor's use for design and interconnection of the SVC system.

6. POWER SYSTEM CHARACTERISTICS

6.1 The power system AC characteristics at the point of connection prior to SVC installation are mentioned in Annexure - B. SVC operation is required within the specified parameter values and durations.

7. SVC CHARACTERISTICS

7.1 **<u>Voltage & Reactive Output Ratings</u>**

7.1.1 <u>Continuous Ratings</u>

7.1.1.1 The discussion under this clause is based on the V/I characteristics mentioned in clause 8 of IEEE Std 1031 and are indicated in Fig 1 below:

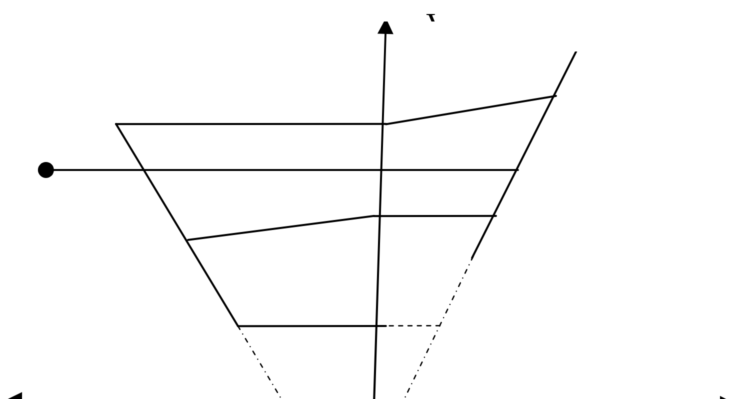


Figure 1 – SVC V/I Characteristics

7.1.1.1 The nominal continuous operating capacitive and inductive capability shall not be less than the values specified in Annexure-A at PCC. Component tolerances and frequency deviations shall be considered while designing SVC requirement for continuous rating.

7.1.1.2 The reactive power range specified in the preceding sub-clause is the minimum requirement at SVC HV bus after allowing for the combined effect of all component and control tolerances including that of the transformer. These tolerances shall be stated by the bidder in the bid and be guaranteed.

7.1.1.3 The SVC shall be capable of and continuously controllable over the voltage range from 0.9 p.u. to 1.1 p.u. of the primary voltage and full nominal reactive (inductive & capacitive) range specified in Annexure-A.

7.1.1.4 The nominal slope of the characteristic shall be adjustable in steps of not greater than 0.5% between 0 % and 3 % on 100 MVA base.

7.1.1.5 The SVC shall be capable of continuous operation for system frequencies specified in Annexure-B.

7.1.1.6 The nominal operating voltage for the low voltage side of step-down transformer is to be determined by the Contractor in order to optimize the SVC design.

7.1.1.7 The SVC configuration must ensure that under normal steady state operation, including operation with partial rating, the SVC output must not exhibit any over-voltages (due to switching of non-controlled reactive elements within the SVC) larger than 5 % of the operating voltage at minimum short circuit power.

7.1.2 Short-time Ratings

7.1.2.1 The SVC shall be capable of short-time overloads and over- voltage operation which may occur during system disturbances and contingencies.

7.1.2.2 The SVC shall continue to generate maximum capacitive reactive power during a temporary under-voltage down to a value and duration specified in Annexure-A (point C on Fig. 1). The SVC may be blocked if the under-voltage persists for more than the specified duration.

7.1.2.3 The SVC shall continue to absorb reactive power during a temporary over -voltage in a controlled manner up to a value and duration specified in Annexure-A (point D on Figure 1). This is the minimum requirement and the Contractor shall determine the maximum overload and over- voltage requirements based on the network data. The SVC shall be rated and designed to withstand these over-voltages.

7.1.2.4 The compensator transformer and all bus equipment such as filter branches, thyristor-controlled reactor (TCR) branches, thyristor-switched capacitor (TSC) branches, capacitor bank branches, and reactor bank branches whether at high-voltage or medium-voltage shall be rated to withstand the specified continuous and short-time operation and be protected against voltage and current stresses that exceed these conditions. All components of the SVC, such as the filter and capacitor bank branches shall not trip during the overload period. The control and protection of the SVC shall not trip the equipment during transient over-voltages caused by network contingencies like fault clearances.

7.1.2.5 The SVC reactive output current shall not be limited while within the specified range setting and operating modes. The SVC controller shall be capable of controlling (switching and blocking) the TCR's, TSC's and switching the external devices such as bus reactors and capacitors at any time during the transient disturbance.

7.1.2.6 The SVC shall be designed to be able to operate at the temporary frequencies deviations specified in Annexure-B.

7.1.2.7 The SVC shall not increase the voltage unbalance at the SVC HV terminals by more than 0.1 % due to component, measurement, control system and thyristor firing unbalance tolerances when the voltage balancing control is out of operation or not required.

7.1.2.8 The components of the SVC shall be designed for operation consistent with the V-I characteristic defined in the presence of power frequency surges and dips at the SVC HV bus corresponding to the overload cycles specified. The SVC shall not be tripped or prevented from operation during these network conditions. The duration between consecutive overload cycles will not be less than 60 minutes.

7.1.2.9 The SVC shall be able to operate in degraded modes with respect to any of the TCR/TSC being out of service and/or any single filter branch being out of service and any combination thereof. The reactive power output of the SVC will be adjusted to the allowable range. SVC is required to operate in degraded mode when at least 50% of the specified capacity (inductive or capacitive) is not available. The bidders are required to describe the degraded modes of their system with the bid.

7.2 Control Objectives

7.2.1 Control of phase voltage based on

i) Individual phase voltages
ii) Positive and negative sequence voltages

7.2.2 Control of three-phase average or positive sequence of the fundamental voltage in steady state, during and after faults, over the full slope range is required. The SVC voltage controller shall be optimized to rapidly control the HV voltage to prevent large induction load stalling and the associated delayed voltage recovery phenomenon during and after single phase, phase to phase and three phase faults on the Company's system.

7.2.3 Control of voltage with superimposed reactive power control. The controller returns SVC output slowly to a preset steady-state value, so that its megavar capacity to support voltage is held in reserve for disturbed conditions.

7.2.4 Voltage control with superimposed damping control based on active power, speed, or frequency measurements to damp oscillations or to enhance the power transfer capability.

7.2.5 The SVC shall not trip during the dead time of 350 ms during automatic reclosing operations.

7.2.6 The SVC shall have provision to control at least three shunt capacitors and/or shunt reactors located on remote/SVC substations.

7.2.7 The SVC shall not trip during the under-voltage conditions and the controller shall:

i) Prevent harmonic instability due to network resonances
ii) Not limit the dynamic performance of the SVC
iii) Not limit the voltage and reactive power control range

7.2.8 The control system must function such that under normal operation including operation with partial rating, the SVC output must not exhibit any over-voltages (due to switching of non-controlled reactive elements within the SVC) larger than 5% of the operating voltage at minimum short circuit power.

7.2.9 The control system shall co-ordinate the operation of the SVC to regulate the primary voltage and the reactive power consumption. Operation logics for the breakers, disconnectors and earth-switches in the SVC shall also be incorporated in the control system. The control shall be fully computerised and programmable and have sufficient scope and flexibility to permit re-programming to accommodate future changes in the power system.

7.2.10 A comprehensive control strategy would be devised for voltage control, reactive power control, over-voltage/under-voltage strategies and restoration of output to pre-disturbance level through slow-susceptance control or any other strategy.

7.2.11 The performance of OLTC on 220kV/132kV transformer for steady state voltage regulation shall also be brought under this controller.

7.3 Control System Description

7.3.1 The Controller for the SVC system shall be housed in a newly built SVC control room. The control system shall be HMI based integrated with the SVC protection system having the following minimum features:

i) As a minimum, a digital programmable controller shall be supplied to control the SVC completely. Programmable means numerically accessible to the Company to change or modify the control parameters of the SVC.

ii) The controller shall have diagnostic and self-checking features for both itself, and for valves, gate firing & drive circuits, interface hardware/software and transducers. The controller shall be re-programmable.

iii) It shall have excess capacity to allow future program upgrades to satisfy the changing requirements of the power systems or future extensions to the SVC. The re-programmability shall include:

a) Ability to control up to 3 shunt devices (reactors or capacitors)

b) Ability to control the SVC with an additional signal for stability or system damping i.e. Power Oscillation Damping (POD).

iv) The SVC controller shall have programmable filtering and dynamic compensation for input signals to ensure proper dynamic performance. The control system shall be insensitive for all harmonics. It shall be programmable for all parameters.

v) The accuracy of voltage shall be within ± 0.005 p.u. of the reference voltage. The accuracy of linearity of the slope delivered by the SVC shall be ± 1 % of the slope setting of current, expressed as a percentage of nominal current at maximum output.

7.4 Major Control Functions

7.4.1 There shall be two major control strategies for the output control of the SVC:

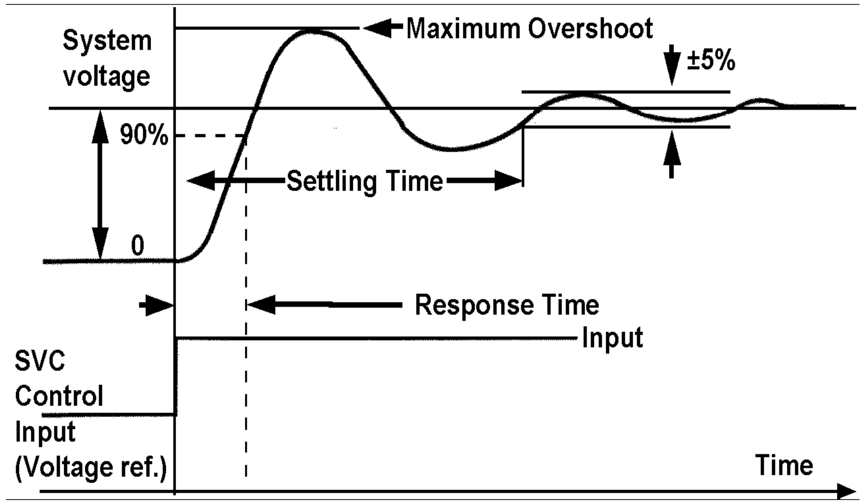
7.4.1.1 Voltage Control Mode (VCM)

7.4.1.1.1 In this mode, the control system shall perform a three phase voltage regulation based on a voltage error and using a slope correction for stationary output control. The error shall be determined by the difference between a set voltage reference and the positive sequence voltage response from the primary side of the step-down transformer. The voltage reference and slope shall be controllable in the interval specified in sub-clause 7.1

7.4.1.1.2 Measurement and signal conversion of the voltage error shall not exceed 0.3%.

7.4.1.1.3 When in voltage control mode, the SVC shall meet the following requirements on speed of response time to a step change:

i) The change of measured system voltage shall reach 90% of desired total change in less than 40 ms of the initially control signal of voltage reference with a maximum overshoot of 10 %. The settling time of the HV bus bar voltage to reach within 5% of the final value shall be less than 200 msec. During this change, the SVC output shall not reach its limits. The response is required when the system 3-phase fault MVA is at the minimum value mentioned in Annexure-B. (Refer Figure 2 below)



7.4.1.2 Fixed Susceptance Mode (FSM) OR Constant Q-Mode

7.4.1.2.1 In this mode, the susceptance of the SVC shall be manually controllable by direct operator action. The operator shall set the susceptance reference and the MVAR output is then given by the product of the value of this reference and the square of the primary voltage. The susceptance reference shall be continuously variable within an interval that corresponds to the output interval specified in sub-clause 7.1.

7.4.1.2.2 In this mode a system voltage limiting controller is active and prevents over-/under voltages by limiting the reactive output of the SVC.

7.4.2 It shall be possible to change between the two strategies above without any transients in the reactive output from the SVC. Changeover of the control facility from one mode of operation to the other in both directions shall not subject the system to any bumps.

7.4.3 In Fixed Susceptance Mode (FSM) operation the controller is blocked and the switchover facility accepts the manual susceptance set point. Bumpless changeover from FSM operation to VCM operation is ensured by automatic set point correction and with an update function of the controller to the actual susceptance value at the changeover instant.

7.4.4 In VCM operation, the output of the manual susceptance set point is blocked and the switchover facility accepts the output of the PI-controller.

7.4.5 On changeover from VCM operation to FSM operation the last susceptance output of the controller is stored by the manual susceptance set point setter. After switchover, the manual susceptance set point can be adjusted to the required value by the operator.

7.5 Supplementary Control Functions

7.5.1 Slow Reactive Power Regulator Function

7.5.1.1 When the SVC is in voltage control mode it shall be possible to activate a slow susceptance regulator (slow-Q regulator). This is normal operation mode. When this regulator is activated the stationary output from the SVC is controlled to a specific susceptance as long as the difference between the line voltage and the voltage reference stays within a certain band. If the difference is larger than the band the stationary output from the SVC will automatically follow the slope in order to keep the voltage at a certain level (VCM).

7.5.1.2 The transient response from the SVC will still follow the slope even when the susceptance regulator is activated.

7.5.1.3 The susceptance reference shall be continuously variable within an interval that corresponds to the output interval specified in sub-clause 7.1 and the size of the band in the interval 0-10%.

7.5.1.4 changeover/activation & deactivation of the slow susceptance regulator from one mode of operation to the other in both directions shall be possible without transients in the output in the reactive output from the SVC. Hunting between the controls modes has to be avoided.

7.5.2 <u>Gain Supervision</u>

7.5.2.1 A gain supervisor which shall be a function for supervision of the stability of the closed loop voltage control, shall be included.

7.5.2.2 The function of the supervisor is that when the supervision of the gain in the voltage regulator detects oscillations in the susceptance reference, the gain shall gradually be reduced until stability is reached.

7.5.2.3 The reduction of the gain shall only be in the open loop gain of the voltage regulator. The closed loop gain shall remain the same. Normally, it is an increase in the transmission system contribution to the closed loop gain that results in the instability. The reduction in the voltage regulator gain shall only balance the external increase.

7.5.2.4 The reduction of the gain shall be able to be reset to nominal value by means of commands from the operator interface. A relative gain factor shall also be able to be changed from a gain optimizer.

7.5.3 <u>Gain Optimisation</u>

7.5.3.1 To adjust the gain in the closed voltage control loop for varying short-circuit power conditions, a special optimisation function shall be included. The action of the Gain Optimiser must not produce large changes in the SVC output. By adjusting the gain, fast voltage response shall be obtained with stable SVC output at the short circuit power interval specified in Annexure-B.

7.5.4 <u>TCR Direct Current Control</u>

7.5.4.1 Second harmonic interaction, e.g. between the TCR and the step-down transformer, can take the transformer into saturation. This condition shall be barred by a control function which eliminates DC currents in the TCR.

7.5.5 <u>Under and Over-voltage Strategies</u>

7.5.5.1 At under or over-voltage conditions for the primary voltage, special control strategies shall be activated that overrides the normal control modes presented above.

7.5.5.1.1 <u>Under-voltage Strategies</u>

i) Usually, if the voltage is low the output from the SVC will be capacitive. If the voltage in all three phases goes below a certain value (0.3 pu), a special under-voltage strategy shall be activated that blocks the firing pulses to the TSC valves and controls the SVC output to a settable reference. As soon as the voltage in one of the phases goes higher than a certain value (0.3 pu) the under-voltage strategy is de-activated and the normal control will be in operation.

7.5.5.1.2 Over-voltage Strategies

i) The TCR valves shall be controllable up to 1.3 pu primary voltage. If the voltage increases above this limit continuous firing pulses shall be given to the TCR valve and the firing pulses to the TSCs may be blocked when the voltage exceeds 1.3 pu. The continuous firing of the TCR valves is retained until the voltage is again below 1.3 pu when the normal control takes over. The settings for an over-voltage trip have to be co-ordinated with the existing over-voltage protection of the grid.

7.5.6 Protection

7.5.6.1 The control and protection of the SVC shall not trip the equipment during transient over-voltages and by network contingencies like fault clearances.

7.5.6.2 The thyristors, TSCs & TCRs shall be protected against transient stresses like overvoltage & overcurrent during system contingencies - the details of which shall be furnished in the bid.

7.5.6.3 There shall be a (phase-wise operating) supervision of the correlation between the triggering pulses to the thyristor valves and the measured valve currents.

7.5.6.4 For further details, please refer sub-clause 8.13.

7.6 Harmonic Performance

7.6.1 The SVC system shall be designed to avoid resonance condition between its shunt capacitor banks, shunt reactors, filter branches, and the ac system. In addition to that it shall limit the harmonic distortion imposed on the connected transmission system.

7.6.2 Filter Performance

7.6.2.1 The SVC contribution to the harmonic distortion levels at the SVC connection point to the transmission system shall not exceed the limits described in Annexure-B according to IEC and/or IEEE, under worst case of:

i) The continuous range of system and environmental conditions stated in this specification.
ii) Variation in tolerance of total filter capacitance, including permissible fuse failures.
iii) Variation in tolerance for SVC parameters such as transformer winding unbalances valve firing variations and unequal reactor and capacitor reactance between phases.

7.6.3 Filter Component Rating

7.6.3.1 The harmonic filter components including SVC components shall be rated to carry the harmonic currents generated by the background harmonic distortion of the system and the harmonic currents produced by SVC itself. The rated voltage of capacitors shall not be less than the arithmetic sum of the normal continuous power frequency voltage and the largest of the individual harmonic voltages.

7.7 Audible Noise

7.7.1 The Contractor shall design and construct the SVC to limit the audible noise interior and exterior to the facilities.

7.7.2 The level of the audible noise inside the SVC building shall not exceed 80 dB (A) in areas where personnel are permitted during SVC operation. Audible sound shall be further limited not to exceed 50 dB (A) in the control room.

7.7.3 The Contractor shall also be responsible for establishing existing audible noise levels prior to the construction of the facilities and for preparation of a report. The final report shall record audible noise levels prior to and after construction to verify the compliance with the specified requirements. Post-commissioning audible test be carried out to ensure requirements of noise level limits.

7.8 **Description & Evaluation of Losses**

7.8.1 The bidder shall provide a summarized loss evaluation of the total proposed SVC system. The summarized losses shall include losses on all SVC components up to the main bus connection and shall, in particular, include the followings:

i) Main Step-down transformer including harmonics
  a) Core losses
  b) Copper losses at upper rating including fan consumption (converted to 75°C)

ii) Auxiliary transformer (s)
  a) Core losses
  b) Copper losses at upper rating including consumption (converted to 75°C)

iii) Thyristor valves and associated equipment
  a) Thyristors, diode, voltage damping & grading losses etc.
  b) Auxiliary power for controls and cooling system etc.

iv) Reactor banks

v) AC Filters
  a) Fundamental frequency Losses
  b) Harmonic losses

vi) Shunt Capacitor Banks (Filter, TSCs, shunt)

vii) Control and protection equipment

viii) Station Service Equipment

ix) Miscellaneous (details shall be provided by the bidder)

x) SVC auxiliary equipment

xi) Heating, cooling and air conditioning for all equipment, enclosures and outdoor cabinets

7.8.2 Losses in switchgear, bus bars, cables, clamps, connectors, etc., are excluded. The applicable tolerance, if any, shall be stated clearly for all the equipments.

7.8.3 The total system fundamental frequency losses excluding transformer no-load loss shall be calculated and submitted by the bidder with the bid assuming an outside temperature of 50 deg. C with bus voltage of 1.0 p.u., at maximum slope setting and at the following operating points:

i) Total system losses (excluding transformer no-load loss), P_1 (kW), at 100% inductive output at **10**% of the system total operating time, T_1.

ii) Total system losses (excluding transformer no-load loss), P_2 (kW), at 50% inductive output at **15**% of the system operating time, T_2.

iii) Total system losses (excluding transformer no-load loss), P_3 (kW), at 0 Mvar output at **10**% of the system operating time, T_3.

iv) Total system losses (excluding transformer no-load loss), P_4(kW), at 50% capacitive output at **45**% of the system operating time, T_4.

v) Total system losses (excluding transformer no-load loss), P_5(kW), at 100% capacitive output at **20**% of the system operating time, T_5.

7.8.4 In addition to above, the bidder shall submit a description of the calculation methodology for total system losses with break-up details. As-built SVC losses shall be based both on factory measurements and calculations and shall be furnished with the bid. The bidder shall also quote and submit, at the time of bidding, the guaranteed losses at maximum capacitive and maximum inductive MVAR output from the SVC and a graph of losses in kW against Mvar output for the entire output range of the SVC at nominal system reference voltage, frequency, slope settings at ambient temperature of 50°C, shall be submitted by the bidders. This shall include losses in all components, all hysteresis effects and any increased losses due to any thyristor switching and all auxiliary plant loads. The bidder shall describe the method that will be used to verify all guaranteed losses and summarize the comparison between guaranteed and as-built losses in a report.

7.8.5 For each operating point, losses are calculated for the parts of the SVC in operation or connected, weather conducting current or not. If more than one combination of SVC parts might operate at a given output, both values shall be given and separately summed with explanation.

7.8.6 Capitalization of Losses

7.8.6.1 The SVC system bid prices shall, as part of the bid evaluation process, be adjusted to take into account the present value of the total SVC system losses over a 25 year period in order to determine comparable prices between proposed systems. The tolerance in component losses, if any, shall clearly be stated in the bid by the bidder.

7.8.6.2 For transformers, the following rate shall be applicable for the capitalization of losses:

- Capital cost of no-load loss US$ **5200** per kW

The capitalized cost of no-load losses at 100% voltage and load losses at principal tap corresponding to 100% upper rated power at reference temperature of 75°C including corresponding consumption of fan motors shall be considered.

7.8.6.3 The losses will be verified/measured during SVC system factory testing in the presence of engineers and in case the measured values exceed the guaranteed values, a penalty at twice the rate of the capital cost stated above shall be payable by the Contractor in excess of guaranteed values.

7.8.6.4 The total cost for losses used in the evaluation will be calculated by the Company using the following formulas:

i) Total evaluated loss, $=[P_1 \times T_1 + P_2 \times T_2 + P_3 \times T_3 + P_4 \times T_4 + P_5 \times T_5]$

7.8.6.5 The total evaluated cost of the complete SVC system losses in USD is given by:

$$\text{Ceq} = \left(\sum P \times \text{Co}\right) \times \left[\frac{1-(1+i)^{-n}}{i}\right]$$

Where

Co = Cost per year per kW of losse

i = Interest Rate = 14%

Note: The operating life of the plant is considered as 25 years.

7.9 **SVC Availability and Reliability**

7.9.1 The SVC system is being installed to provide steady state and transient voltage support, in order to improve the stability margins of the transmission system to avoid voltage sags leading to voltage collapse under disturbed condition thus enhancing the reliability and quality of power delivery. The entire SVC system shall be designed for a life time of at least 30 years.

7.9.2 Definitions

i) **Forced outages** are outages caused by the SVC equipment which result in loss of the essential function of the SVC. These outages are initiated by protective devices.

ii) **Scheduled outages** are outages necessary for preventive maintenance to assure continued and reliable operation of the SVC.

iii) **Outage duration** is the elapsed time from the instant the SVC is out of service to the instant it is returned to service.

iv) **Forced outage rate (FOR)** is the number of forced outages per year.

v) **Forced outage unavailability (FOU)** is the unavailability caused by forced outages in percent per year.

vi) **Availability** is defined as 1-FOU in percent per year.

vii) The following shall be included in outage duration:

a) The time required to determine the cause of an outage or to determine which equipment or units of equipment must be repaired or replaced.

b) The time required to repair or replace the relevant equipment.

c) The time required by system operators/ technicians for disconnection and grounding of equipment in preparation for repair work and for removal of grounds and reconnection of equipment after repairs is complete.

7.9.3 Partial Outage

7.9.3.1 If partial SVC output is available, the duration of equivalent outage shall be calculated as the product of the derated condition duration and the proportion of the nominal output range (capacitive or inductive as applicable) which cannot be achieved during this period.

7.9.4 **Annual Availability**

7.9.4.1 The annual equivalent availability for forced outages in % is defined as:

$$\left[1 - \sum \frac{\text{Duration of equivalent outage}}{8760}\right] \times 100$$

7.9.4.2 Guaranteed Availability and Reliability

i) The annual equivalent availability (1-FOU) for forced outages for the SVC system shall be at least 98 %.

ii) The guaranteed forced outage rate (FOR) shall be ≤ 4.

iii) The bidder shall provide a preliminary reliability/availability study with the bid demonstrating compliance with these requirements.

iv) Routine maintenance shall not be required more than once per year. All plant items which require regular inspection shall be listed in the bid together with the recommended service intervals to achieve the required service life of 30 years. The bidder shall list in full details, all those components which have a life of less than 30 years and shall provide detailed proposals for overcoming this deficiency.

v) The bidder shall guarantee the quoted availability performance for applicable warranty period. The Contractor shall be notified of major outages. During the guarantee period, the Company shall maintain records of the number and duration of forced and scheduled outages, hours of operation, and any other relevant data and shall make those records available to the Contractor upon request.

vi) The bidder shall provide data, detailed calculations and results to Company that supports the availability performance estimate. The availability of spare parts, as recommended shall be included in the availability calculations. If the actual performance is below the values stated in items (i) and (ii) above, the Contractor shall provide corrections and modifications to meet the availability guarantees at his own cost and responsibility.

vii) The bidder shall suggest the maintenance interval suitable for its equipment and shall describe any monitoring condition offered.

8. SVC MAIN COMPONENTS & REQUIRED FUNCTIONS

8.1 <u>General</u>

8.1.1 The specification clauses regarding thyristor valves and other main components are intended to be general, i.e., not prescribing the precise form, rating, or quantity of the components, but allowing the bidder to propose an optimum solution. All the offered equipments shall be type tested in accordance with the latest issue of the relevant IEC/Company standards.

8.1.2 All components of the SVC shall be rated taking in to account the following parameters:

i) Any harmonic generated by SVC

ii) The supply system harmonic impedance loci for the system as defined in Annexure-B.

iii) The levels of pre-existing harmonic on the system as defined in Annexure-B and any potential magnification of these harmonics.

iv) The AC system voltage and AC system frequency ranges as given in Annexure-B.

v) The maximum level of negative phase sequence component as given in Annexure-B.

vi) The environmental conditions mentioned under sub-clause 4.1.

8.2 Step-down Transformer

8.2.1 <u>General Requirements</u>

8.2.1.1 The transformer winding configuration shall be determined by the Contractor, as required by the proposed SVC design and Company network requirements.

8.2.1.2 The design of the transformer shall be single-phase and one spare unit shall be provided with the bank. The installation shall be designed to facilitate the connection of the spare transformer into the system and isolation of the failed unit. The spare unit shall normally be energized from the primary side. The transformers shall not be equipped with OLTC. The protection schemes shall also be arranged to facilitate rapid reconnection to the spare transformer CTs. This reconnection shall not require rewiring or reconnection of CT wires.

8.2.2 <u>Rating</u>

8.2.2.1 The transformer shall be designed to comply with the continuous and short-time MVAR requirements mentioned in sub-clause 7.1. The capacity of the transformer (MVA) must be designed to meet these requirements without exceeding normal loss of life or increase in the level of internal partial discharges.

8.2.2.2 The offered transformers shall be ONAN/ONAF cooled. Sufficient reserve capacity shall be provided, so that SVC capacity is not reduced upon loss of a cooling pump, fan, etc.

8.2.3 Impedances

8.2.3.1 The transformer impedance shall be determined by the Bidder as required by the SVC design and shall be chosen so that the transformer will withstand all fault currents at the maximum fault level current specified in Annexure-B.

8.2.4 Voltage Rating and BIL

8.2.4.1 The transformers voltage rating shall be as required by the SVC design. The BIL rating shall be determined by the bidder as required by the SVC design and in accordance with the IEC standards and requirements mentioned under Annexure-B.

8.2.4 Audible Noise

8.2.5.1 Audible noise levels from the step-down transformer shall be coordinated to meet the requirements for the SVC installation in sub-clause 7.7 and applicable IEC standards.

8.2.5 Direct Current Capability

8.2.5.1 The flux density shall be appropriate for the excitation conditions under the voltage range specified.

8.2.5.2 The transformer shall be designed to carry direct current consistent with the SVC design or suitable means shall be incorporated within the SVC to limit this current to a level satisfactory for the transformer. To ensure minimum harmonic generation, the saturation flux density of the transformer shall be higher than the maximum flux density reached during normal operation, and the bidder shall state the margin by which it is exceeded. This maximum flux density is obtained at the highest secondary voltage during any reactive power generation, highest reference voltage, minimum slope, and minimum continuous frequency.

8.2.5.3 The bidder shall clearly indicate the Harmonic content (HV and MV) that the transformer shall be subjected to under the worst case conditions.

8.2.6 Other Requirements

8.2.6.1 As per Company specification P-46.

8.2.7 Standards and Testing Requirements

8.2.7.1 A s per IEC & Company Standards.

8.2.8 Information to be Supplied with the Bid

8.2.8.1 Complete data/drawings, ratings, dimensions, test reports etc as per relevant Company/IEC standards including the following:

i) Type, make & designation
ii) Continuous and short-time MVA and voltage ratings.
iii) Insulation levels.
iv) Number, accuracy and ratio of all bushing current transformers.
v) Type of cooling.

vi) Audible sound level
vii) Direct current capability
viii) Weights and physical dimensions

8.3 **Thyristor Valves**

8.3.1 General Requirements

8.3.1.1 The thyristor valves shall comply with the requirements of Standards/specifications mentioned under clause 3.2.

8.3.1.2 The thyristor valves shall be made up of a number of thyristor levels, electrically connected in series. The number and rating of thyristors used to form each valve shall meet the overall performance requirements. The valves shall have sufficient margin to enable rated output to be maintained continuously with one (1) thyristor level redundant.

8.3.1.3 The voltage rating of the thyristors shall be such that no cascading failure shall result in the event of failure of all redundant thyristors (+1). The bidder shall demonstrate compliance with this redundancy requirement in the bid. Automatic disconnection of the TCR/TSC branch is permissible after the failure of a thyristor with redundancy already used up. The thyristor valve shall be supplied complete with cooling plant & material, all auxiliaries for gating, monitoring and grading. Parallel mounting of unidirectional thyristors is not acceptable.

8.3.1.4 The thyristor valves shall be designed to withstand all stresses expected under steady state, transient and temporary over-voltage conditions specified in this specification including but not limited to the followings:

i) Transient over-voltages due to AC system fault application and fault clearing.

ii) Temporary over-voltages originating in the AC or caused by AC system faults (such faults which result in combined over-current and over-voltage stresses).

iii) Resonant voltage oscillations on the medium voltage side of the SVC transformer excited by system disturbances such as fault application, fault clearing, line switching and transformer energization.

iv) Fast surges transferred from the AC system.

v) Over-voltages due to control malfunction such as false firing of the valve, loss of firing signal, maloperation of the voltage control loop and loss of synchronization.

vi) Transient over-voltages due to partial blocking caused by, i.e, improper firing, forward recovery protection or VBO firing.

8.3.1.5 Transformer saturation shall not be considered in calculating the above stresses except where it increases those stresses.

8.3.1.6 Voltage grading shall be provided to uniformly distribute the voltage across each thyristor level within the valve and together with the over-voltage protection devices to protect the thyristors against forward and reverse blocking voltages above the thyristor rating.

8.3.1.7 The thyristor valve components which are the main heat-generating components (e.g. thyristors, damping and grading components, valve reactors, gating circuits and current carrying connections within the valve) shall be designed to withstand the thermal stresses which affect their operating characteristics.

8.3.1.8 The thyristor valves shall be capable of withstanding the highest over currents expected in service and be capable of blocking corresponding voltages at the highest thyristor junction temperature reached. It shall be possible to replace faulty thyristors without interruption to the cooling circuit and with minimum disturbance to other plant and material.

8.3.1.9 The valve firing must be robust. Misfiring due to control system maloperation, or power grid disturbances, shall be prevented. The thyristor valve arrangements shall permit easy access for visual inspection, routine maintenance, removal, replacement and handling of the thyristor. Such work shall result in minimal loss of coolant and the bidder shall provide means of retaining any coolant. For liquid cooled valves it shall not be necessary to open any cooling water connections to replace a thyristor or other electrical component. Any special tools required for replacement of thyristors or other valve component shall be provided. Each single phase thyristor stack (or equivalent) shall consist of anti-parallel series connected thyristor, including all necessary heat sinks, snubber circuits, voltage grading circuits and firing circuits.

8.3.1.10 In each phase of a TSC branch, the thyristor valve shall be connected in series with a capacitor bank and a current limiting reactor. The current limiting reactor shall be designed to limit the inrush-current during fault conditions and misfiring. In each phase of TCR branch, the single phase thyristor valve shall be connected in series between two reactors.

8.3.1.11 Thyristor valve design shall include a minimum of 10% redundant series thyristors, but not less than one redundant series thyristor, in each single-phase thyristor valve. All rating, performance and protection requirements shall be met with all redundant thyristors short-circuited.

8.3.1.12 The bidder shall guarantee the annual failure rate of thyristors stated in its Availability Evaluation report. The guaranteed annual failure rate of thyristors shall include failures caused by malfunction of the firing system and of auxiliary components associated with a thyristor.

8.3.1.13 The failure of thyristors shall be monitored by the Company. The annual failure rate of the thyristors will be calculated during the availability guaranteed period commencing after the start of commercial operation of the SVC system and will not include failures directly attributable to operating and maintenance error and other incidents unrelated to the system.

8.3.1.14 The bidder shall provide full details of the complete thyristor valve, including control and protection circuitry, valve cooling facilities, including their means of control, temperature and flow monitoring and alarms, etc. This shall be included in the thyristor valve design report.

8.3.2 <u>Valve Maintenance & Monitoring</u>

8.3.2.1 Thyristor monitoring and maintenance requirements are as follows:

i) A monitoring means to identify any thyristors that have failed shall be provided. A continuous monitoring system shall be provided to detect failed thyristors and provide indication of each failure and its location in the valve. The SVC shall be automatically tripped if the number of failed thyristors and associated electronics is more than the number of redundant thyristors.

ii) The thyristor valves shall be designed to allow easy replacement of failed thyristors. Other TSC, TCR, etc., or filter branches shall be capable of continued service while a thyristor is being changed or during similar maintenance.

8.3.3 Valve protection

8.3.3.1 The bidder shall state the methods of over-voltage protection of the valves and the voltage levels at which these protections operate, as follows:

i) TCR valves shall be protected against over-voltage by a forced-firing system.

ii) TSC valves shall not be fired under over-voltage, and interlocks and latches shall be provided to avoid false firing.

8.3.3.2 The individual emergency firing protection of TCR valves can be coordinated with the valve surge arrester. If so, the latter shall operate first.

8.3.3.3 Light-triggered thyristors (LTT) and electrically triggered thyristors (ETT) shall have built-in over-voltage protection, or the bidder shall explain how the consequences of a faulted light source or light guide are handled.

8.3.4 Thyristor Valve Cooling System

8.3.4.1 General Requirements

8.3.4.1.1 The purpose of the thyristor valve cooling system is to remove the heat produced by the thyristor valve operation and transfer this heat to the outside ambient air. In either cooling systems i.e. water cooled or air cooled, the system shall be completely furnished with all necessary interconnecting piping, ductwork, circulating pumps, blowers, heaters, make-up reservoirs, heat exchangers, filters, water treatment plant, instrumentation, automatic controls, alarms, control power systems, and other necessary equipment. The redundancy for the cooling equipments shall be appropriate to the SVC availability requirements and shall be stated by the bidder.

8.3.4.1.2 The cooling system shall provide adequate cooling for operation under all conditions up to and including maximum specified rated loads and extreme ambient conditions.

8.3.4.1.3 Replacements of thyristors shall be possible without the need for opening the cooling circuit and the cooling system shall be designed to permit work on the defective pump unit without restricting the SVC operation.

8.3.4.1.4 Maintenance of the cooling system shall not be required more than once per year.

8.3.4.1.5 The audible noise of the outdoor heat exchanger shall be co-ordinated to meet the requirements for SVC installation mentioned in sub-clause 7.7.

8.3.4.2 Liquid Cooling

i) A closed-loop recirculating system shall provide full heat rejection capacity with redundancy for pumps, heat exchangers, and fans, appropriate to the SVC availability requirements. The cooling system shall be able to maintain full capacity at maximum ambient temperature and maximum SVC reactive power output. The cooling system shall be able to operate at the lowest ambient temperature and with SVC in floating condition. The bidder shall describe how this operation is done.

ii) Replacement of certain cooling equipment (e.g., pumps, fans, cooler unit), if defective, shall be possible while the cooling system still operates.

iii) A purifying loop to maintain liquid resistivity shall be provided. The bidder shall state the design value of liquid resistivity and describe methods of detecting and responding to abnormal conditions.

iv) The quantity of deionising material shall be sufficient for a period longer than the specified maintenance interval operation without replacement. Deionising materials shall be replaceable without cooling system shut down. Instructions for frequency of inspection and change shall be given. The bidder shall describe the necessary maintenance actions and their frequency.

v) Maintenance of closed loop systems and make up for loss of liquid shall not be required more than once a year.

xxv) The cooling system shall use two motor driven pumps that each are normally capable of supplying 100% of the required maximum cooling medium flow. One pump will be in operation while the other pump is standing by. It shall be possible to operate either pump as primary operating pump. In case of single pump failure, the second pump shall automatically be switched in without the necessity of blocking the firing of the thyristors. The cooling system specific to thyristor valves shall be installed with complete redundancy with no chance of failure of cooling system. It shall always be available irrespective of SVC switched OFF/stopped/AC supply failure i.e. sufficient ride-through shall be provided so that SVC must remain available to regulate voltage under all circumstances.

vi) Make up scheme shall be described and submitted to the Company by the manufacturer at design stage.

vii) All valves, strainers, pumps, tubes and piping in the cooling system shall be made of stainless steel and designed for high reliability.

viii) Make-up for loss of liquid shall be done automatically without SVC shutdown. A make-up tank for supply of additional cooling medium shall be supplied together with a pump unit.

ix) The liquid to air heat exchangers shall have at least one standby fan.

x) An automatic control system shall regulate and sequence the operation of the cooling equipment to maintain the temperature within the design limits. The control system will allow for a transfer from main to standby pumps without a cooling system or SVC system shutdown. Each pump, cooling fan and/or mixing valve shall have both automatic and manual control modes.

8.3.4.2 Gauges of the following properties shall be included in the cooling system as a minimum:

i) Expansion tank fluid level
ii) Cooling medium resistivity
iii) Cooling medium temperature
iv) Cooling medium pressure
v) Cooling medium flow in each thyristor branch

8.3.4.3 Air cooling

i) Either a non-recirculating (i.e., once through) or a recirculating air system may be provided, depending on the requirement of the thyristor selected by the Contractor and on specific site conditions.
ii) An air cooling system shall provide full heat rejection with redundancy in blowers, filtering, monitoring, and heat exchangers. The cooling system shall permit work on a defective unit without shutting down the system.
iii) The bidder shall describe the air filtering system and details of monitoring status of blowers, filters, and other components.
iv) Sufficient gauges and indicators shall indicate the status of any part of the unit for both normal operations and maintenance.

8.3.5 Cooling System Protection

8.3.5.1 For Liquid Cooled System

8.3.5.1.1 The redundant cooling control and protection system shall provide for the necessary cooling of the SVC system valves and shall monitor its own operation and the condition of cooling water. An automatic control system shall regulate and sequence the operation of the cooling equipment to maintain the temperature within the design limits. The control system will allow for a transfer from main to standby pumps without a cooling system or SVC system shutdown. Each pump, cooling fan and/or mixing valve shall have both automatic and manual control modes. The cooling system control shall have sufficient indication of status, temperature, pressure and flow to allow for safe manual operation of the cooling system in the event of the automatic cooling system control failure. The control system shall include as a minimum the following alarm signals:

i) Pump stopped, failure
ii) Low cooling medium resistivity
iii) Low expansion tank level
iv) Abnormal liquid flow
v) High coolant temperature
vi) High coolant pressure
vii) Fan stopped, failure
viii) Leakage

8.3.5.1.2 The protection system shall include as a minimum the following shutdown signals:

i) Low expansion tank level.
ii) Abnormal liquid flow.
iii) High coolant temperature.

8.3.5.1.3 All alarms, indications and measured values shall be displayed in the local control system.

8.3.5.1.4 The control and protection of the cooling system shall be supplied from the dc station battery. Loss of the dc supply to the cooling controls shall not result in damage to the cooling equipment or the SVC valves. Pumps and fans shall be supplied from the station service (AC).

8.3.5.2 For Air-cooled System

8.3.5.2.1 For air-cooled systems, the protection system shall include, as a minimum, the following warning alarms:

i) Blower transfer
ii) High exhaust air temperature
iii) High differential pressure across the filter
iv) Low air flow.

8.3.5.2.2 For air-cooled systems, the protection system shall include, as a minimum, the following shutdown alarms:

i) Excessive exhaust air temperature
ii) Loss of air flow

8.3.6 Standards & Testing Requirements

8.3.6.1 The design and testing shall comply with the relevant standards specified in sub-clause 3.2 of the specification.

8.3.7 Information to be Supplied with the Bid

8.3.7.1 Complete data/drawings, ratings, dimensions, test reports, etc as per relevant standards including the followings:

i) Overall diagram of the cooling system and its components including gauges.
ii) Rated values on flow, temperature, pressure drop and liquid volume.
iii) Cooling medium.
iv) Ratings of pumps and fans.
v) Alarm and trip signals from the control system

8.4 Thyristor Switched Capacitors (TSCs)

8.4.1 The oscillations occurring at TSC energization with the capacitor voltage differing from the system voltage shall be efficiently suppressed. In case of operation without harmonic filters the oscillations must be practically damped out in not more than 5 cycles.

8.4.2 The thyristors shall have the ability to be switched off and successfully block the applied voltage at 1.5 p.u primary voltage.

8.4.3 The control and valve firing system shall be designed to minimize the risk for generation of false firing pulses at normal or disturbed mode operation. The system shall be insensitive to variations in or complete loss of station auxiliary AC supply voltage.

8.4.4 The thyristors must be protected against harmful voltage during their recovery period at partial turn off situations, i.e. recovery protection.

8.4.5 In case of severe power grid disturbances resulting in difficulties to maintain proper firing pulse synchronization, the valve must not misfire to such a degree that thermal valve overload leading to reduced thyristor blocking capability are caused. Voltage build up on the capacitors exceeding 2.0 times of their voltage rating is not allowed.

8.4.6 In case the misfiring itself cannot be prevented, the negative effects thereof shall be limited by suitable state of the art methods and the system must be designed to handle multiple misfirings on the worst point of wave at 1.5 p.u primary voltage. The buildup of the capacitor voltage at each misfiring must be accounted for.

8.5 **Thyristor Controlled Reactors (TCRs)**

8.5.1 Each thyristor level in the TCR valve shall be protected by over-voltage protection. This protection shall provide emergency firing of thyristors in event of an over-voltage or failure to deliver firing pulses to one or more individual thyristors.

8.5.2 The thyristors shall be fully phase angle controllable for primary over-voltages up to 1.3 p.u. without operation of voltage break-over devices.

8.5.3 All components in the TCR shall be designed to allow for the trapped decaying component of current caused by a three phase zero impedance fault on the primary side of the step-down transformer which is cleared in 5 cycles and followed by temporary over-voltage specified in sub-clause 7.1. The fault shall be assumed to occur at the peak of the current waveform in the TCR.

8.5.4 The thyristors must be protected against harmful voltage during their recovery period at partial turn off situations, i.e. recovery protection.

8.5.5 The control and valve firing system shall be designed to minimize the risk for generation of false firing pulses at normal or disturbed mode operation. The system shall be insensitive to variations in or complete loss of the auxiliary AC supply voltage.

8.5.6 In case of severe power grid disturbances resulting in difficulties to maintain proper firing pulse synchronization, the valve must not misfire to such a degree that thermal valve overload leading to reduced thyristor blocking capability are caused.

8.5.7 Standards and Testing Requirements

8.5.7.1 The design and testing requirements of the thyrister valves shall comply with the standards specified in sub-clause 3.2 of the specification.

8.5.8 Information to be Supplied with the Bid

8.5.8.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant standards including the followings:

i) Continuous and short-time current and voltage ratings of thyristor valve.
ii) Voltage and current capability of thyristors.
iii) Number of thyristors in series and number of redundant thyristors.
iv) Insulation level.
v) Principles of Firing system and Monitoring system
vi) Weights and physical dimensions.
vii) Valve overvoltage, overcurrent and misfiring protection scheme.

8.6 **Reactors**

8.6.1 The reactors are utilised in the TCR branches to provide the inductive MVAR output and in the TSC branches to limit inrush currents. Reactors are also used as tuning elements of the harmonic filters.

8.6.2 Design requirements for TCRs shall include but not limited to the followings:

i) The reactors used for TCR branch and filter components shall be of single phase, air-cored, self-cooled and suitable for outdoor installation.
ii) All structural and fence metalwork, including foundations, shall be designed to avoid metallic loops and parallel circuits in which induced currents can run.
iii) The purpose of the filter reactors is to tune the capacitor banks to provide the necessary reduction of harmonics.
iv) Reactors shall be capable of withstanding short circuit forces based on maximum design fault levels.
v) The reactor voltage rating shall be as required by the SVC design. The BIL and BSL rating shall be determined by the Bidder as required by the SVC design and the insulation requirements specified in Annexure-B.

vi) Audible noise levels from the reactors shall be co-ordinated to meet the requirements for the SVC installation in sub-clause 7.7 and the applicable IEC standards.

vii) The magnetic field strength at any point where personnel have access during operation shall not exceed 2 mT.

8.6.4 Standards and Testing Requirements

8.6.4.1 The design and testing requirement shall comply with the relevant standards specified in sub-clause 3.2 of this specification.

8.6.5 Information to be Supplied with the Bid

8.6.5.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant standards including the followings:

i) Inductance including manufacturing tolerances

ii) Continuous and short-time current and voltage ratings, indicating contribution from the harmonic currents

iii) Design criteria for maximum temperature

iv) Insulation level

v) Weight and physical dimensions

8.7 **Capacitor Banks**

8.7.1 The capacitors are utilised in the TSCs to provide capacitive MVAR output, and in harmonic filters.

8.7.2 The capacitor banks shall be designed to avoid resonance with other SVC branches as well as the network on the primary side of the step-down transformer. Possible resonance phenomena shall be included for in the design.

8.7.3 Reactors for limiting of inrush currents shall be connected in series with the capacitor banks in the TSCs.

8.7.4 The capacitor units shall be constructed with materials resulting in minimum losses and maximum reliability. Each unit shall be free of PCB.

8.7.5 The capacitor units shall be identical and interchangeable among all capacitor.

8.7.6 The capacitor voltage rating shall be as required by the SVC design. The rated voltage shall be based on an arithmetical addition of individual harmonic voltages that will appear across the capacitors. The harmonic currents generated by TCRs and pre-existing harmonic voltages (Annexure-B) applied on PCC has to be simultaneously taken into account in SVC component design. The BIL and BSL rating shall be determined by the Bidder as required by the SVC design and the insulation requirements specified in Annexure-B. The bidder shall show how the protection system matches the capability of the capacitors with full regard to the harmonic content of the currents and voltages.

8.7.7 The individual capacitor units shall be individually fused. Anyhow, either internally or externally fused capacitors can be used. For the dimensioning of the capacitor fuses parallel charged elements must be considered.

8.7.8 Audible noise levels from the capacitor banks shall be co-ordinate to meet the requirements for the SVC installation and the applicable IEC standards.

8.7.9 All conduction within the capacitor bank shall be insulated and insulating caps shall be provided for all capacitor units bushing terminals or conducting mounting points.

8.7.10 Capacitor dielectric losses shall clearly be stated by the bidder in the bid.

8.7.11 The capacitor units shall reduce the residual voltage by suitable state of the art methods.

8.7.12 The Bidder shall guarantee the filter and AC shunt capacitor unit maximum annual failure rates. The capacitor unit annual failure rate in service shall be calculated based on the actual level of capacitor unit or element failures during the availability guaranteed period mentioned under sub-clause 7.9, commencing after the start of commercial operation of the SVC system. The above shall apply to each type of capacitor unit supplied individually where type refers to the unit capacitance & voltage, current, and kVAr rating.

8.7.13 The configuration of the individual units shall be determined by Contractor. The kVAr and voltage ratings of the individual capacitor units are not specified herein and shall be determined by the Contractor.

8.7.14 The units shall be identical within each branch vertically or edge mounted, and suitable for mounting in open type structure racks for outdoor use with the service conditions and system ratings given in this Specification.

8.7.15 Any capacitor unit found leaking during the warranty period shall be replaced with a new one by the Contractor at its own cost and responsibility. Repair of leaking units will not be accepted.

8.7.16 The capacitor racks shall be designed to allow the change-out of any capacitor unit without disassembly of the rack or disturbance of any other capacitor unit.

8.7.17 The structural members of the racks shall not be used as electrical buses. To ensure safe earthing of all parts, all structural members of the rack shall be electrical connected together and earthed with a provision of earthing to all structure members during maintenance.

8.7.18 <u>Standards & Testing Requirements</u>

8.7.18.1 The design, manufacturing and testing requirements of the relevant latest IEC standards shall be met with.

8.7.18.2 A suitable capacitor bank test device shall be delivered as part of the contract which will facilitate the testing of the bank without removal of any connections.

8.7.19 <u>Information to be Supplied with the Bid</u>

8.7.19.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant standards including the following:

- i) Capacitance including manufacturing tolerances and redundancy.
- ii) Rated voltage of capacitor units
- iii) Insulation level.
- iv) Description of fuse system.
- v) Weights and physical dimensions.
- vi) Losses.
- vii) Bank configuration, including number of series and parallel units.

8.8 **Circuit Breakers**

8.8.1 The circuit breakers shall be of SF6 type. The breaker shall be rated for the switching and current carrying duty imposed upon them in their intended location.

8.8.2 The breakers shall be capable of the amount of operations expected, considering the SVC application with both inductive and capacitive loads.

8.8.3 Interrupting units shall have flags, visible from ground level to indicate open/ closed position.

8.8.4 There shall be auxiliary contacts for indication of low gas pressure.

8.8.5 Operating mechanism shall have electrically operated trip circuits. There shall be two parallel trip coils.

8.8.6 Thermostatically operated heaters shall be supplied for temperature control and prevention of condensation build-up.

8.8.7 Mechanically or electrically operated non-resettable operation counters shall be provided.

8.8.8 All operating equipment, including auxiliary switches shall be housed in a weather/water/vermin proof cabinet.

8.8.9 All other general requirements of Company's specification P-193 shall be compliance with.

8.8.10 Standards and Testing Requirements

8.8.10.1 The design and testing of the main SVC breaker shall comply with relevant latest editions Company specifications and relevant International standards mentioned under sub-clause 3.2 of the specification.

8.8.11 Information to be Supplied with the Bid

8.8.11.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant Company/International standards including the following:

i) Continuous current and voltage rating.
ii) Making and breaking current capability.
iii) Insulation level.
iv) Creepage distances.
v) Weights and physical dimensions.

8.9 **Disconnectors & Earthing Switches**

8.9.1 The switches shall be adequately sized to carry the maximum steady-state and overload currents including fault, inrush, harmonic currents and over-voltages.

8.9.2 The switches shall meet the insulation requirements specified in this specification.

8.9.3 Thermostatically operated heaters shall be supplied for temperature control and prevention of condensation. All cabinets shall have sufficient ventilation ducts.

8.9.4 Disconnectors & earthing switches shall be designed and constructed to operate satisfactorily in the environmental conditions described in this specification.

8.9.5 All operating equipment, including auxiliary switches, shall be housed in a weather/water/vermin proof cabinet.

8.9.6 Disconnectors shall be both manual and motor operated. Disconnectors shall electrically and mechanically be interlocked. Earth switches shall mechanically be interlocked.

8.9.7 Grounding equipment for maintenance and repair shall be supplied with each separate circuit that can be out of service while the remainders are in continuous operation. Grounding equipment for the SVC secondary bus system/transformer shall also be supplied.

8.9.8 The disconnectors and earth switches shall be positioned to enable maintenance work to be carried out in complete safety on the whole SVC and, where appropriate, on its component parts when any depleted mode operation is adopted.

8.9.9 For the secondary side of the SVC transformer the disconnect switches are required to isolate any apparatus for which maintenance is needed. At a minimum the following major components shall have disconnect and earthing switches:

i) Each thyristor controlled reactor branch
ii) Each thyristor switched capacitor bank
iii) Each fixed capacitor bank
iv) Filter branches

8.9.10 The disconnectors shall be used to isolate an affected filter, TCR or TSC branches when a fault is developed. The disconnectors and earth switches shall be fitted with safety interlocks. This isolation shall be carried out through either of the following methods described below:

i) TCR and TSC: Tripping of the HV circuit breaker either locally or from remote and switching the SVC off the system before the disconnector is opened. After successful isolation of the affected branch, the SVC shall be available to be immediately switched back on again.

ii) TCR only: Blocking of the thyristor valves of the affected TCR branch before opening the disconnector. The normal operation of the SVC shall remain unaffected except for the loss of reactive power range resulting from the isolation of the affected TCR branch.

iii) Filter branches only: Tripping of the affected filter branch circuit breaker before isolation of this branch, The SVC HV circuit breaker shall not operate during this sequence.

iv) Auxiliary transformer branch: Tripping of the auxiliary branch circuit breaker before isolation of this branch, the SVC HV circuit breaker shall not operate during this sequence.

8.9.11 All disconnect and earthing switches shall be indicated on the SVC Single Line Diagram provided by the Bidder.

8.9.12 <u>Standards and Testing Requirements</u>

8.9.12.1 The design and testing of the disconnectors/earthing switches shall comply with relevant latest editions of Company specification P-128 and standards mentioned under sub-clause 3.2 of the specification.

8.9.13 <u>Information to be Supplied with the Bid</u>

8.9.13.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant Company/International standards including the following:
Type and rating.
i) Insulation level.
ii) Creepage distances.

8.10 **Surge Arrester**

8.10.1 All necessary surge arresters shall be supplied by the Contractor for the protection of the equipment particularly the main SVC transformer, thyristor valves, reactors and filter banks. The surge arresters shall be properly designed to meet the insulation co-ordination and discharge requirements in accordance with IEC & Company Standards.

8.10.2 Only gap-less arresters of the Zinc oxide type shall be accepted. The arrester shall have sufficient pressure relief capability in order to make them explosion free and to sure that personnel and equipment safety is guaranteed. On the primary side of the step-down transformer, it is recommended that the arresters shall be of class 4 or better. On the low voltage side of the transformer the arresters shall be of class 3 or better referring to IEC 60099.

8.10.3 All arresters placed on the high voltage side of the transformer shall be equipped with surge counters. Filter energisation shall not activate any surge counter.

8.10.4 The activation of a surge arrester on the primary side shall be indicated to remote centre also.

8.10.5 The surge arresters supplied for the SVC shall comply with the Company Standard selection/sizing taking also into account future shunt capacitors to be located in the nearby substations and over-voltages due to switching, ferro-resonance etc.

8.10.6 <u>Standards and Testing Requirements</u>

8.10.6.1 The design and testing of the surge arresters shall comply with relevant latest editions of Company specification P-181 and standards mentioned under sub-clause 3.2 of the specification.

8.10.7 Information to be Supplied with Bid

8.10.7.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant Company/International standards including the following:

i) Type and Rating.
ii) Energy discharge capability
iii) Insulation level
iv) Creepage distances
v) Weights and physical dimensions

8.10.7.2 All surge arresters shall be indicated on the SVC Single Line Diagram provided by the Bidder.

8.11 **Instrument Transformers**

8.11.1 The successful Bidder shall supply all necessary voltage and current transformers on the high voltage as well as on the low voltage side of the step-down transformer. These instrument transformers shall be manufactured and tested according to IEC and Company standards. The quantity of instrument transformers and corresponding current and voltage rating shall be calculated and designed by the bidder. The Bidder shall provide description, rating, performance, dimension and proposed tests for the instrument transformers.

8.11.2 All the insulation, minimum creepage and strike distance and local environmental conditions shall be met.

8.11.3 Current Transformers

8.11.3.1 CTs shall be suitably rated to match the full capabilities of the SVC. CT transformation ratios, outputs, and accuracy classes within the SVC scheme shall be selected by bidder to meet the requirements of the specific CT application. Full details of all the CTs being offered shall be provided by bidder.

8.11.3.2 All the current transformers for SVC component protection, indication, measurement and control purposes shall comply with the latest IEC & Company Standards.

8.11.3.3 The CT secondary's which are used for measurement; indications or control devices shall not be used for protection purposes.

8.11.4 Standards and Testing Requirements

8.11.4.1 The design and testing of the CTs shall comply with relevant latest editions of Company specification P-90 and standards mentioned
under clause 3 of the specification.

8.11.5 Information to be Supplied with Bid

8.11.5.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant Company/International standards shall be furnished with the bid. The numbers of current transformer and corresponding ratings shall be indicated on the Protection Block Diagram-to be provided with the bid.

8.11.6 Voltage Transformers

8.11.6.1 VT transformation ratios, outputs, and accuracy classes within the SVC scheme shall be selected by the bidder to meet the requirements of the specific VT application. Full details of all the VTs being offered shall be provided by the bidder.

8.11.6.2 All the voltage transformers included in the bid for SVC component protection, indication, measurement and control purposes shall comply with latest IEC & Company Standards.

8.11.6.3 The voltage transformers shall be designed to avoid saturation at voltages up to at least 1.3 p.u. Further, no ferro-resonance conditions shall occur between voltage transformers and capacitors including stray capacitances.

8.11.7 Standards and Testing Requirements

8.11.7.1 The design and testing of the VTs shall comply with relevant latest editions of Company specification P-129 and standards mentioned under clause 3 of the specification.

8.11.8 Information to be Supplied with Bid

8.11.8.1 Complete data/drawings, ratings, dimensions, test reports etc. as per relevant Company/International standards shall be furnished with the bid. The numbers of voltage transformers and corresponding ratings shall be indicated on the Protection Block Diagram-to be provided with the bid.

8.12 **Control & Monitoring System**

8.12.1 General Requirements

8.12.1.1 The Contractor shall provide the necessary systems for the purpose of control, protection, operation, interlocking, indication and alarms for all equipment supplied as part of this contract. The Contractor shall also be responsible for defining and providing the co-ordination of the controls, protection, interlocking and switching sequences required for equipment during operation, testing and maintenance of the equipment. Reliability of operating equipment, availability of SVC system and safety of the personnel shall all be considered in the design.

8.12.1.2 The design and testing of all control and protection equipment shall comply with the latest applicable IEC Standards.

8.12.1.3 All events and alarms generated by the control system and external input signals (events and alarms) to the control system shall be stored in the control and protection system. It shall also be possible to analyze retrieved events and to print out these messages. All recordings and messages shall be given with a real time stamp. Correct time tagging must be ensured. The accuracy and resolution of the time tagging must at least be 1 ms. The station master clocks of the SVC must be synchronized. In case of loss of synchronization, the station master clocks must continue operation with the internal crystal with an accuracy of 1 ppm.

8.12.1.4 Software in the control system determines to a great extent the performance of the SVC system. Software quality assurance is therefore essential. In this respect the entire life cycle of the software shall be considered:

i) Experience with compareable system
ii) Planning and design of software
iii) Implementation of software
iv) Testing of software during commissioning
v) Maintenance of software after commissioning
vi) Possible future extension of software

8.12.1.5 The design, quality requirements, testing and documentation of all software for the control system shall comply with the latest revision of relevant IEC standards. The application software shall be written and documented in a high level language, using graphical symbols for functional blocks, logic circuits and numerical elements.

8.12.1.6 Dedicated software for debugging of existing software as well as for the maintenance of existing software and development of additional software shall be part of the supplied package.

i) The software shall be designed if possible for standard hardware. Later upgrades of the hardware shall not necessarily result in major software changes.
ii) The software may be benchmarked with the results of RTDS studies performed in the factory before delivering of the SVC.

8.12.2 SVC Control - General Requirements

8.12.2.1 The control systems shall achieve the functional objectives given in clause 7. The primary purpose of the control of the SVC is to control system voltage in response to measured system variables, auxiliary inputs for supplementary control, or operator inputs. The voltage and current measurements are included in the SVC scope of supply in order to ensure that they are compatible for the required response of controls.

8.12.2.2 A digital programmable controller shall be supplied to regulate the reactive output from the SVC. All necessary equipment for control, protection, monitoring, alarms and indications shall be housed in a relay panel provided by the Contractor. The controller shall have diagnostics and self-checking features for both itself and interface circuits. The control and monitoring equipment shall be used to implement the functional requirements in this specification. Complete redundancy of control system must be ensured to meet the requirements of sub-clause 7.9 – SVC Availability and Reliability.

8.12.2.3 The accuracy of voltage shall be within ±1% of the reference voltage. The accuracy of linearity of the slope delivered by the SVC shall be ±5% of the slope setting of current, expressed as a percentage of nominal current at maximum output.

8.12.2.4 The valves and controls shall be designed to avoid any “cross-talk” interference between anti-parallel thyristor pairs.

8.12.2.5 When TSC switching is included, the bidder shall detail the method of coordination between TCR and TSC switching in and out in order to achieve vernier control on smooth net output change.

8.12.3 Operator Interface

8.12.3.1 The control interface shall provide for local and remote control points. Only one control point shall be active at any one time and as determined by a master control point, but it shall be possible to view plant status, control settings, and other SVC parameters at all control points.

8.12.3.2 The local control point shall be near the SVC control hardware. It shall permit the following control functions to be carried out:

i) Sensing and regulation of 132kV bus voltage.

ii) Alternate modes of operation, as required, including a manual mode for site testing and emergency shutdown by the operator.

iii) Voltage, current and reactive power measurements.

iv) SVC control by generation of appropriate firing pulses to the thyristor valves.

v) Orderly start-up and shutdown sequencing of the SVC to facilitate smooth SVC energization and de-energization.Monitoring and protecting the control itself in progress and the components it controls.

vi) Coordinating and controlling opening and closing of circuit breakers and disconnect switches.

vii) Performing certain protective functions.

viii) Change of reference voltage and slope settings.

ix) Alarm acceptance and where appropriate reset them.

x) The control and monitoring system shall be designed to meet the demands for availability and reliability specified.

8.12.3.3 A synchronizing scheme shall be used to produce properly spaced timing pulses synchronized to the AC system. The synchronizing function shall be designed to:

i) Be immune to severe harmonic distortion of voltage wave form.

ii) Be immune to large phase shifts in voltage wave form.

iii) Continue to operate during and following large voltage & frequency excursions.

8.12.3.4 The controls may also contain one or more of the followings:

i) Automatic return to manual mode of operation at the most recent voltage setting on the loss of input voltage measurement signal.

ii) Automatic voltage control, operative during start-up to prevent unnecessary switching of the reactive elements.

iii) Self-check facility at regular intervals which operates equipment to verify its correct operation.

iv) Supplementary control modules for damping and var control.

v) Control system damping with gain supervisor and gain optimizer. On gain supervision, details shall be given especially in the context of instability. This function shall also include an adjustable emergency gain. The criteria for detection of instability includes:

a) Frequency range of the oscillation
b) Amplitude of the oscillation
c) Number of consecutive oscillations above an adjustable threshold

8.12.4 Control System Construction Requirements

8.12.4.1 Possible requirements of control system construction are as follows:

i) The control system components shall be mounted in free-standing, indoor, metal-clad cabinets with appropriate rating, where necessary.

ii) Control equipment shall be designed to operate properly at the expected maximum allowable ambient indoor air temperature. Supplemental cooling may be provided.

iii) Printed circuit cards shall have built-in test points indicating lights to facilitate testing and maintenance. Microprocessor-based systems shall have self-checking and fault diagnosis features to be described by the bidder.

8.12.5 **Station Control and Monitoring Requirements**

8.12.5.1 The Contractor shall submit a local digital station control and monitoring system with the following minimum capabilities and features:

i) The system shall give the operator detailed information regarding the status of the equipment. Functional overview of the SVC, displays for the control of the SVC, status lists, measured values, indications, alarms etc. shall be present on the screen. Setting/adjustment of certain control parameters/protection settings and command of operating equipment (breakers, disconnectors etc.) shall be given from this system. Interlocking for safety of equipment and personnel shall be included.

ii) The control desk shall be equipped with a monitor for the current control of the SVC. The operator can freely select which information is to be shown on the monitor. All features of the local Station Control and Monitoring system shall be precisely identified to enable proper use by the system operators. The operator interface shall be realised using the standard Windows environment. Different levels (at least three) of access shall be distinguished, using passwords.

iii) The Contractors solution shall use two monitors. One being for local and the second for either local or remote control. In the commissioning phase both monitors are located at the local control location. Both monitors can be used for monitoring functions however only one for controlling the SVC.

iv) Supervision and recording of events, internal and external. Resolution shall be 1 ms or better. The event information shall be stored on recoverable data media in a standard format, for later access. In case of disturbances of the SVC, the system shall handle all the events without losing information.

v) All alarm, event and help texts presented to the operators in the local station shall be in English. All messages must be identified by a unique index. The structure of one event line shall at least include date, time, alarm number, source, text, status.

vi) The system shall be equipped with a powerful on-line help function to advise local operators in the actions that have to be taken in any fault situation within the SVC.

vii) There shall be a possibility for a remote dialled up connection to the local control system for maintenance purposes (PC anywhere). Measures to prevent unauthorised system access must be taken. There must be different levels of user access available for a dialled up connection.

8.12.5.2 A power quality measurement system shall continuously acquire, store and present information with respect to the quality of the AC voltages and currents.. At a minimum the following measured values shall be determined:

i) True RMS measurement of the phase voltages and currents
ii) Reactive and apparent power per phase and total
iii) Voltage and current unbalance
iv) Voltage sags and swells
v) Current sags and swells
vi) Individual harmonic distortion in the currents and voltages up to the 40^{th} harmonic
vii) Total harmonic distortion
viii) Voltage dips ($\Delta U/\Delta t$)

8.12.5.3 The device for power quality supervision shall automatically supervise the limits of voltages and currents according to IEC and register any violation of these limits. It must be possible for Company to define their own limitations which shall then be supervised accordingly.

8.12.5.4 The monitoring/recording of the AC harmonics shall comply with the latest applicable IEC standard.

8.12.5.5 The stored information in the recording equipment shall be accessible for later evaluation. Dedicated software to present all measured values and to allow for additional mathematical processing of the data shall be included.

8.12.5.6 The Contractor shall present the proposed system to the Company.

8.12.5.7 SCADA RTU will be required to accommodate all the SVC SCADA system requirements including 20% spare capacity without using the existing spare capacity. Communication of SVC analogue, status and alarm points to the substation operator via SCS Human Machine Interface in the line terminal substations.

8.12.5.8 A state of the art sequence of event recorder will be required. Resolution shall be 1ms or better. To the maximum extent practical, the SOE functionality shall monitor internal variables in the SVC_Control and Protection System. It will monitor to the maximum extent possible, signals on an individual phase basis and identify each as such.

8.12.5.9 A state of the art Transient Fault recorder (TFR)/ DFR (or equivalent) will be included to monitor the status of various SVC parameters. The TFR/DFR Device shall have a pre-fault capture and a post-fault capture. The TFR/DFR Device shall have a variable sampling rate for short and long duration power system disturbance events. Disturbance and event recording facilities are required for local monitoring of the SVC following a disturbance on the power system or on the SVC. SVC voltages, currents, thyristors, TSC/TCR and filter currents will be monitored by the Transient Fault Recorder in addition to various other control and protective variables.

8.12.5.10 A state of the art Voltage Quality Recorder (VQR) shall be provided which shall monitor the SVC HV voltage (three phases) and current (three phases). The VQR shall be set up to measure power quality parameters in accordance with international standards from IEC/IEEE.

8.12.5.11 A state of the art DSM shall monitor all the main 220 kV and 132 kV circuits' voltages and currents – incoming and outgoing lines and transformers. It shall include all three phases of each circuit. The DSM shall also monitor the system frequency.

8.12.5.12 The integrated SVC controller together with the HMI, SOE, TFR, DSM and VQR shall be designed and configured that will allow future connection/interfacing to a network via Ethernet TCP/IP protocol, for remote access, fault diagnostics, data download and viewing. This is inclusive of all the hardware and software requirements for the SVC site and remote site but excludes the communication cabling/links.

8.12.6 <u>Local/Remote Control</u>

8.12.6.1 SVC may be controlled either locally or remotely.

8.12.6.2 In case of remote control, the control system must spontaneously prepare all signals and changes in analogue values from the SVC control system for transmission to the control centre without delay.

8.12.6.3 Details of the response time of the signals shall be provided by the bidder in the bid.

8.12.6.4 There shall be no limitations in the transmission capacity to the control centre other than the limitations given by the available communication speed and the communication protocol.

8.12.6.5 <u>Control selection</u>

i) The control system shall be designed to permit a free choice between necessary setting and monitoring of the system from the local control room at the substation or from the control centre. Switching between local and remote control is to be carried out in the local control room.

ii) The "Switch" between local and remote control has to be placed locally in the SVC control room. It shall only be possible to control the SVC either from remote or from local. A key switch will be installed locally in the SVC control room.

iii) The switch "LOCAL" - "REMOTE" shall have two positions:

a) **LOCAL:** only local control shall be possible. The operator in the SVC station can select whether all signals and measurements shall be transmitted to the remote control centre or not. Alarms and measurements shall be registered locally and presented on the HMI.

b) **REMOTE:** only remote control shall be possible. All local audible functions shall be blocked. Alarms and measurements shall be registered locally and presented on the HMI.

iv) A switch between local and remote control shall neither result in an unintentional jump in the power exchange nor in any electrical disturbances or unintended control actions.

8.12.7 Telecommunication Failure

8.12.7.1 Any telecommunication failure must not cause any unintentional operation of the control system. If the telecommunication link between SVC control system and corresponding remote control centre breaks down during remote operation, the settings shall be frozen at the value at the time of the loss of the telecommunication link or a predefined status should be achieved. Any active control actions shall be terminated in a safe state.

8.12.7.2 When the telecommunication link is re-established, the remote control of SVC shall automatically be re-established. All alarms and indications issued in the SVC during the failure shall be transmitted in chronological order to the control centre.

8.12.8 Indications

8.12.8.1 Each control point shall indicate as a minimum:

i) Starting or stopping sequence in progress
ii) Reference voltage and slope settings
iii) The control point selected
iv) Any other settings such as supplementary stabilizing signals
v) SVC “on” indication
vi) SVC “off” indication
vii) Three-phase high-side line currents of the main transformer
viii) Total reactive power generated or absorbed by the compensator
ix) Primary voltage, single phase
x) Secondary voltage, single phase
xi) SVC branches in/out (where applicable)

8.12.9 Annunciations/Alarms

8.12.9.1 The central control unit shall monitor its own operation and the operations of the various SVC components. Two levels of protection i.e. warning and shutdown shall be provided. The first-level alarm (warning) indicates that a problem exists, but the equipment itself or its proper operation is not in immediate danger. The second-level alarm (shutdown) initiates a reduction in output range or a shutdown of the SVC due to equipment problems that might cause damage if left unattended.

8.12.9.2 The first-level alarms include the following as a minimum:

i) Auxiliary power supply failure; back-up supply in use
ii) Cooling system fan or pump failure; back-up pump or fan is available
iii) Cooling system problems (e.g., low water resistivity, primary pump stopped)

iv) Capacitor failures can exist, but within an acceptable quantity
v) Loss of redundant thyristors
vi) Branch availability
vii) Loss of signal-measuring controlled bus bar voltage, with the control continuing to maintain the last SVC operating point unless the regulated bus bar voltage is also the source of synchronizing voltage.

8.12.9.3 The second-level alarms include the following as a minimum:

i) Loss of all control power
ii) Loss of cooling system rated capabilities
iii) Loss of source of synchronizing voltage
iv) Excessive number of capacitor failures
v) Excessive over-current in a thyristor valve
vi) Loss of thyristors in excess of redundancy margin

8.12.9.4 The central control unit shall also have a built-in protective system for self-monitoring.

8.12.9.5 It shall be possible to transfer alarms to the remote control centers as individual alarms and as combined alarms. The control system shall contain software that makes it possible to create combined alarms on the basis of detailed alarms of the SVC. Combined alarms shall be able to function as detail alarms at the creation of new combined alarms. Both detailed and combined alarms shall be stored in an archive in the local control system. On request from the HMI the alarms can be retrieved, displayed and sorted.

8.12.9.6 It shall be easy to block any erroneous detail alarm from being part of a combined alarm. It shall be possible to use logical operators without restrictions in the creation of combined alarms.

8.12.9.7 The SVC plant indications and alarm system shall register all real changes and shall ensure that the changes are also transferred to the remote control interface. Multiple alarms, for instance due to contact bouncing shall be prevented. False indications and alarms shall be avoided.

8.12.9.8 The alarms shall always show the real current status of the SVC equipment. Alarms shall not be pulsed. They shall disappear by themselves, once the activation criterion has disappeared, without having to be acknowledged in the station.

8.12.9.9 It will be considered as advantage if this selection is made by parameter definition or with graphical tools.

8.12.10 Standard and Testing Requirements

8.12.10.1 All control plant and material shall be type tested for Surge Withstand Capability according to IEC 1000-4-5, Electrostatic Discharge according to IEC 1000-4-2, Electrical Fast Transient Burst according to IEC 1000-4-4 and Radio Freq. Interference according to IEC 1000-4-3.

8.12.11 Information to be supplied with the Bid

8.12.11.1 An overall description of the structure of the control and monitoring system shall be supplied in the bid. Key performance data (e.g. resolution in voltage control, resolution and symmetry in triggering angle, response time in voltage acquisition, intrinsic filtering of voltage harmonics etc.) shall be given and explained.

8.13 **SVC Protection**

8.13.1 Depending on the technical specifications, operational requirements of the SVC as well as technical specifications of the existing protection system of the substation, the Contractor will be responsible for providing the appropriate protection solutions. The following solutions, but not limited, shall be provided/performed by the Contractor:

i) The SVC system supplied by Contractor shall be self-protecting.

ii) The protection relays and equipment shall be mounted separate from the SVC control and interface cabinets.

iii) The protection system shall, to the extent applicable, be built on the principle of a main and a back-up protection, for each protected zone/object. The two independent protection schemes, each capable of detecting all faults segregated to the extent that each uses separate secondaries of common current transformers, independently fused supplies from common voltage transformers, separate DC supplies and each tripping a separate circuit breaker trip coil through its own latching tripping relay, are required. The system must enable easy and clear identification of fault location and faulted element. The functionality of the protection system shall be given in a protection matrix.

iv) The functional requirements for the protection system are:

a) Protection equipment and personnel from damage and injury

b) Determination of the faulted zone

c) Protections shall be arranged in overlapping protective zones. A fast main protection shall be available for each fault type. This main protection shall be supported by a back-up protection function, preferably based on a different measuring principle, that may be part of another main protection

d) Testing of protections shall be possible on-line without affecting the operation of the SVC

v) The protection relays and equipment shall receive their primary input from CTs, VTs etc., that will be supplied as part of the SVC equipments by the Contractor. Redundant protective functions shall be included and demonstrated.

vi) All protection equipment and systems shall 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 Company, as specified. Fail-safe principles shall be applied throughout. The protection system shall be selective and the total protection time shall never exceed 100 ms in any case (including circuit-breaker time).

vii) Single point of failures in the protection system shall be avoided by a complete physical subdivision of the protection system (incl. analogue and digital input signals) in two parts. Both subsystems shall be connected to a separate auxiliary supply. Tripping paths to circuit breakers shall be redundant.

viii) There must be no possibility that working/programming in the control system can influence the function on the protective devices.

ix) The Bidder shall provide a report on the protection system and protection co-ordination with detailed drawings. This report shall provide a description of each type of protection, the co-ordination of the protective devices and the recommended protective settings. The rating and performance of the instrument transformers as well as the co-ordination with the protective relays is also part of this report.

x) The Contractor shall supply a comprehensive electrical interlocking scheme to permit safe manual or automatic sequential connection and isolation of equipment. The interlocking scheme shall be designed to provide complete safety to personnel, hazard free equipment operation, failsafe operation in the event of component failure and maximum flexibility in operating the equipment.

xi) During on-line testing of the SVC, 100% protection of the SVC and the associated AC equipment must be ensured.

xii) The power supply for the control and protection equipment and the trip paths shall be designed redundant.

8.13.2 Component Protection

8.13.2.1 The following is a list of the possible required protection. Additional protection may be provided if deemed necessary.

i) Transformer and 132kV Bus

a) Transformer and SVC bus differential
b) SVC primary bus over-current
c) Ground Over-current
d) Breaker failure function
e) Low oil-level
f) Sudden pressure relay/Buchholz relay
g) Over temperature (oil and windings)
h) Cooling circuit supervision

ii) SVC Low Voltage Bus

a) Over-voltage
b) Under-voltage
c) Residual voltage
d) Differential
e) Voltage zero-sequence
f) Over current
g) Overvoltage

h) Ground over current

iii) Thyristor Controlled Reactors (TCRs)

a) Three phase over-current
b) Three single-phase differential
c) Thermal overload protection of reactors.

iv) Thyristor Switched Capacitors (TSCs)

a) Three phase over-current
b) Three single-phase differential
c) Capacitor bank unbalance protection for the TSC delta
d) Negative phase sequence
e) Zero phase sequence
f) Overload
g) Ground over current

v) Thyristor Valves in TCRs/TSCs

a) Over-voltage
b) Overcurrent
c) Thyristor failure
d) Thermal overload

vi) Harmonic Filters

a) Neutral voltage shift
b) Unbalance
c) Overvoltage
d) Differential
e) Ground Over current
f) Three phase over-current
g) Overload protection

vii) Master control

a) Loss of control power
b) Loss of synchronization signal

viii) Cooling media

a) Temperature
b) Flow
c) Resistivity
d) Leakage
e) Transfer failure or power loss

8.13.3 **Accessories**

8.13.3.1 The term "hardware" is understood to cover both the central processing unit and the directly connected subsystems, e.g. the power supply, I/O-gates, communication equipment and terminal equipment.

8.13.3.2 Only components of a high quality shall be used in the equipment. The Contractor shall use standard components. Connecting equipment for the terminal equipment shall be of a standard type.

8.13.3.3 The redundancy in the control and protection system shall be so arranged that loss of one auxiliary power source does not result in loss of control, cooling system or protection system. Two independent auxiliary power supplies shall be available. The design shall be such that the stand-by control system and cooling system can be tested and maintained during normal operation of the SVC.

8.13.3.4 Electronic components which are designed to be operated between 0% and 100% of rated voltage, current or power shall not be operated long-term at more than 70% of their rated voltage, current or power. Resistors shall be operated at not more than 50% of their rated power. Integrated digital and analogue circuits and others such as electronic components designed to be operated between a minimum voltage not equal to zero and a maximum voltage shall be operated approx. at the midpoint of their designed voltage range.

8.13.3.5 All cables between control cubicles, control desk etc. shall be terminated in terminals in the cubicles etc. The cubicles shall be of IP class 21 or higher. All components in the cubicles which have to be read or adjusted shall be located at a height above the floor of between 70 and 180 cm.

8.13.3.6 It is not permitted to fix more than one wire under a terminal. Multithread wires must be terminated with multicore cable ends.

8.13.3.7 Binary inputs of protective systems shall not operate on capacitive charge currents caused by earth faults in the DC-auxiliary voltage.

8.13.3.8 Design of cubicles has to be according to IEC standards. Terminals and all electrical connections must be of such a type that accidental contact with voltage is impossible.

8.13.3.9 The cross section of cables shall be determined according to the requirements of the detailed engineering phase. However the lowest permissible cross section is:

i) For secondary circuits of current transformers - 4 mm² (1 A rated current)
ii) For secondary circuits of voltage transformers – 2.5 mm²
iii) For trip circuits – 2.5 mm²
iv) For control circuits – 1.5 mm²

8.13.3.10 Current inputs of protective relays have to be designed for $100*I_N$ for 1 sec.

8.13.4 Standards and Testing Requirements

8.13.4.1 The design and testing of the protection equipments shall comply with relevant latest version of IEC standards.

8.13.5 Information to be Supplied with the Bid

8.13.5.1 A detailed preliminary protection block diagram shall be included in the bid. Details of protection equipment including type, make, rating etc shall also be furnished with the bid.

8.14 **Auxiliary Power Supplies**

8.14.1 The SVC equipment shall include all the power supplies necessary for its operation, including step-down transformer, AC distribution boards, batteries, battery chargers, etc. The power supplies shall be sufficient to supply all pumps, fans, valves, valve cooling system and controls, building cooling and heating systems.

8.14.2 The SVC auxiliary power distribution shall include both AC & DC distributions. The following principle requirements shall be met:

i) Two independent sources (one from SVC MV bus bar and other from the existing 11kV panel) shall be installed for the AC auxiliary supply. The power quality of the supply and the required load from the SVC shall be specified by the Contractor. The redundant feeders from the existing 400V distribution of the substation will be used for the auxiliary supply of the SVC. The connection cables shall be provided and installed including end termination by the Contractor.

ii) An automatic switching sequence, for selection of input AC feeder shall be provided. Switching must not cause significant disturbances in the MVAR output of the SVC.

iii) Auxiliary supplies must provide LVRT (Low Voltage Ride through Capability) and Fault Ride through Capability for at least 10 sec.

iv) The SVC control and protection equipment shall be supplied from the DC distribution. This is specifically valid for the subsystems being critical for continuous operation of the SVC. Certain more peripheral parts of the control system, e.g. subsystems and components related to the operator interfaces, can have AC supply, in these cases a non-interruptible source (type UPS) has to be used.

v) The DC distribution for the control and protection equipment, concerning batteries, shall be divided into two independent circuits. Each battery shall be rated for the full load in order to assure unrestricted SVC operation in case of battery failure. The requirements regarding availability and reliability have to be considered.

vi) All required rectifiers and inverters shall be supplied by the Contractor.

vii) The capacity of the batteries shall be chosen for at least 10 hours operation without charging.

viii) All AC and DC sub-distributions shall be built with at least 20% spare outgoing circuits for possible extension.

ix) The design and testing of the AC and DC distribution, the batteries, the rectifiers and the inverters shall comply with all relevant NTDC Specification and IEC standards.

x) Control & Auxiliary Voltages

a)	Type of System	3-phase,4wire,neutral
b)	Nominal voltage	230/400 V
c)	Limits of supply voltage which an AC operating device or auxiliary equipment shall be capable of operating correctly within the tolerance	+10% -15%
d)	Rated frequency	50 Hz
e)	Frequency limits	48-51 Hz
f)	Initial symmetrical three phase short circuit current	15kA
g)	One minute Power frequency withstand voltage for the auxiliary circuits	2kV
h)	DC Voltage	
i)	Tolerance	+10%, -15%

8.15 **Spares**

8.15.1 General Requirements

8.15.1.1 The basic supply of the SVC shall include a full complement of essential spare parts, which are to be furnished at the same time and as part of the SVC supply. It is the Contractor's responsibility, based on the particular design for the SVC to provide adequate spare parts to meet the specified reliability and availability requirements.

8.15.1.2 All spare parts offered must be of the same quality and completely interchangeable with the original parts.

8.15.1.3 The Bidder shall submit a complete list of spare parts to be supplied for the SVC system including information regarding type, make, rating etc.

8.15.1.4 The Contractor shall allow enough room for storage of the recommended spare parts.

8.15.1.5 The Bidder shall guarantee that sufficient spare parts shall be available from the bidder for purchase by the Company after acceptance of the system for a sufficient period of time stated by the bidder.

8.15.1.6 If any items which are necessary for safe operation and maintenance fail during the guarantee period, they have to be replaced by the Contractor at his expense and new spare (s) has to be delivered.

8.15.2 Spares Strategy

8.15.2.1 A strategy for spare parts shall be developed to demonstrate that the complement of spare parts will be adequate to meet the specified reliability requirements.

8.15.2.2 The spares strategy shall be based on a tabulation of all of the components in the SVC, down to the level of the lowest replaceable module i.e. all components suitable for unit replacement at the first level of maintenance shall be included in the tabulation but individual devices that would not be replaced except as part of a shop or bench repair of a replaceable component shall not be in this tabulation.

8.15.2.3 Each component in the tabulation shall be identified for its importance to the operation of the SVC, according to the following classification:

i) Category A: SVC operation is not possible until this component has been repaired or replaced (e.g., main step-down transformer, shunt reactor).

ii) Category B: SVC operation can continue (or resume) at reduced rating but further failures may lead to an SVC outage (e.g., TCR, TSC, MSR, MSC).

iii) Category C: SVC operation can continue on an emergency basis, but a critical function has been lost or bypassed. Some risk of further complications or equipment damage exists until the function is restored (e.g., one of two pumps out of service, protective relaying, UPS, or cooling alarm sensors not in service).

iv) Category D: Operation can continue without serious impairment (e.g., building services such as lighting or heating).

v) The tabulation shall include the failure rate or the expected replacement rate of the component over a 15 year period.

vi) The tabulation shall include the information regarding manufacturer, type, make, ratings and estimated delivery cycle etc.

vii) Each device shall either be:

a) Included on an inventory list of all site spares. The inventory list shall show the description, quantity, and storage location of each spare, assuming that any time that a spare is used, the item is reordered.

b) Provided with a contingency plan to obtain a replacement on short notice, if a spare is not being kept on hand.

8.16 Engineering Studies

8.16.1 The Contractor shall perform studies to determine the design ratings and requirements of all plant and material to be supplied under this contract. The CONTRACTOR shall confirm the design ratings and requirements of all plant and material to be supplied under the contract. Engineering studies shall be performed within the scope of supply. Studies are required to demonstrate that the SVC meets all specified performance criteria. The bid must contain a list of all engineering studies.

8.16.2 Prior to manufacture of the SVC, the Contractor shall perform simulation studies within agreed time frames for review, comment and participation by the Company. The Company reserves the right to perform parallel verification studies on its own or by a third party. The Contractor shall provide all required information for independent design verification and system modelling. The Contractor will be utilizing the system analysis software of PSS/E and electromagnetic transient simulation package (PSCAD/EMTDC) for verification and require the data to be either in the correct format or available EMTDC data format. The results will be verified by performing studies on Real Time Digital Simulator (RTDS) as well, before delivery of the SVC.

8.16.3 Transient and stability studies using PSS/E (version 30) to verify the SVC control system performance, evaluate SVC control system function and optimize the control of SVC during system disturbances, such as major faults and load rejection in the Company network. The design shall investigate the adequacy of the SVC to ensure stability and prevent under-voltages & over-voltages during system transient, dynamic and fault conditions. This is inclusive of degraded modes for the SVC system.

8.16.4 Detailed harmonic impedance, impact design and measurements to verify the filter design. The detailed filter configuration shall be supplied. This is to verify the adequacy of the SVC harmonic filter design through simulation of the Company's equivalent network response to SVC harmonics. It shall include evaluating maximum harmonic levels at the SVC point of common coupling (PCC).

8.16.5 The Contractor shall provide the following digital models to enable simulation of the SVC and its control and protective functions during steady-state operation, dynamic, and transient conditions in different timeframes:

i) PSCAD/EMTDC (latest version) model for time simulations from 1.0 ms up to 10.0 s.

ii) PSS/E (version 30) model for time simulations from 1.0 ms up to 60 s.

8.16.6 If the Company's or third party's studies indicate disagreement with the Contractor's results, the Contractor shall be required to work with the Company or his representatives to reach an agreement on the controversial issues and/or to make the required design corrections, in accordance with this specification.

8.16.7 The studies made by the Contractor shall result in a report which shall be submitted to the Company for information. The reports shall include but not be limited to:

i) <u>Main Component Design</u>

In this report, the analysis for the SVC equipment rating required to cover all modes of the SVC operation, considering the worst possible combination of manufacturing tolerances and frequency deviations, shall be presented. Power system characteristics shall be clearly stated and a summary of the rating of the SVC components shall be given including the calculation of fault currents for thermal and mechanical design.

ii) <u>Insulation Coordination</u>

In this report, analysis for the insulation levels shall be presented.

iii) Thyristor Valve Design and Protection

In this report, the calculations for the rating of the thyristor valves shall be presented. Coordination of break over device levels and other protective functions shall be described. Control strategies for possible misfirings shall be specified in detail and cooling requirements shall also be stated in this report.

iv) Control System Strategy

In this report, the control strategies implemented in the control system shall be described in detail. The verification of the main strategies shall be done by running the real control system together with a simulator implementing a network equivalent together with the SVC high voltage components. The verification can be done during the factory validation test of the control system

v) Protective Relay Coordination

In this report, the calculation of relay protection setting levels shall be presented together with the principles for protection coordination. A summarized list of the protection settings shall be given.

vi) Loss Evaluation

In this report, the total SVC losses shall be calculated and compared with guaranteed values. Explanations to discrepancies, if any, shall be given. The Loss Evaluation report shall be based on component loss data obtained from factory tests and from calculations. Refer to sub-clause 7.8 of this specification as well.

vii) Harmonic Filter Design and Performance

In this report, the harmonic filter design shall be described and the resulting maximum harmonic distortion generated by the SVC shall be presented.

viii) Reliability Study

The Contractor shall be required to demonstrate that the SVC design will achieve availability specified in sub-clause 7.9. The Contractor shall resubmit during the SVC design phase, the Reliability Study updated to reflect the performance of actual components used in the SVC.

ix) Site Noise Level Study

The Contractor shall submit the details/data indicating how the noise limits of sub-clause 7.7 shall be meet with. During the SVC design phase the Contractor shall perform a detailed site noise level study to confirm compliance with the noise limit specified. This study shall also determine site noise levels at extreme operating points and indicate how SVC generated noise varies across the full operating range (MVAR and voltage).

8.17 **Documents and Drawings**

8.17.1 In addition to the detailed information requested elsewhere in this specification, the Bidder shall submit all technical documentation necessary to give a detailed and clear picture of the proposed delivery. The bid documentation shall further provide ample proof of the Bidder's compliance with all aspects of this specification.

8.17.2 Drawings, technical descriptions, instruction, manuals etc shall be in English.

8.17.3 The following guidelines apply for the presentation of technical documentation being part of the bid:

i) A descriptive document shall be included, which shall present the proposed SVC configuration, and its compliance with the rating and functional requirements. Assumptions and methodology used for calculation of fundamental frequency and harmonic stresses and performance, shall be presented within this document.

ii) A single-line diagram of the SVC shall be included.

iii) A protection block diagram of the SVC shall be included.

iv) The losses of the proposed SVC, as a function of reactive power output, shall be presented as described in sub-clause 7.8.

v) The audible noise levels, with consideration the Company requirements, and the proposed SVC layout shall be presented. This description shall also give the principles of the methodology used for calculation of noise levels.

vi) The reliability and availability of the proposed SVC shall be addressed. Results of availability calculations shall be presented, along with the assumptions taken and methodology used.

vii) Layout drawing showing the proposed SVC site and the location of the main components shall be included. Also a 3-D plan of the SVC installations and building shall be provided.

viii) Preliminary inspection and test plans shall be provided for the factory tests of thyristor valves and SVC control system & allied equipment/material alongwith the commissioning tests, and the field verification tests.

8.17.4 The following documentation is, typically, required to be furnished by the bidder:

i) Technical reports
ii) Equipment specifications
iii) Quality assurance documentation
iv) Equipment test reports, if any
v) Control elementary drawings
vi) Plan and profile drawings, as built
vii) Civil/mechanical/architecture
viii) As built drawings

8.17.5 Plant Documentation

8.17.5.1 The Contractor's plant documentation for the delivered SVC system shall contain documents, drawings, instructions and manuals necessary to operate and maintain the SVC system. As a minimum the following documentation (divided into groups) shall be provided:

i) System Description

This group shall provide overall system related information such as SVC system descriptions, single-line diagrams, function block diagrams and plant circuit diagrams. The design reports in sub-clause 8.16 of this specification shall be provided as part of this group.

ii) Operation and Maintenance

This group shall provide information on the operation, fault tracing and maintenance of the plant, such as operation instructions, general maintenance instructions, list of alarms and spare parts, etc.

iii) Equipment Documentation

This group shall provide information on the equipment included in the SVC system. The information shall include circuit diagrams, dimension prints, technical descriptions, assembly drawings etc.

iv) Plant Construction

This group shall provide information on items such as civil works, erection and installation, cabling and inter-connection. The information shall include architectural drawings, station layouts, bills of materials, installation manuals and lists of cables.

v) Factory Testing:

This group shall include Inspection and test plans, and factory test records.

vi) Commissioning Documentation

This group shall contain field test records created and logged during the testing and commissioning of the SVC system.

vii) Field Verification Test report

The Field Verification Tests shall be documented in a report. This document shall include appropriate references to the performance requirements and to the performed design studies.

8.17.5.2 All drawings and documentation shall be in accordance with relevant International/IEC Standards.

8.18 **Trainings**

8.18.5 The Contractor shall arrange following training courses for the Company's Engineers:

8.18.5.1 Basic Engineering and Studies Regarding SVC Technology

i) The Contractor shall provide courses from operational aspects with respect to hardware and software as well as training of the Engineers who will be responsible for operation, maintenance and repair. Appropriate training documentation shall be included. All the training shall be given in the English language.

ii) The courses shall also include training in the factory during the testing of the complete SVC control system and allied equipments to Ten Company's Engineers on design, operation maintenance and repair of the system.

iii) The Contractor shall arrange/provide courses from system analysis, planning and design aspects to verify and modify, if required, some control parameters of the SVC.

8.18.5.2 On-site Training

i) A comprehensive training programme including complete system design and function, operational aspects and preventive maintenance shall be arranged by the Contractor for Ten Company's Engineers.

8.18.5.3 Site Visits

i) The Contractor shall arrange at his expense/cost the study tours/visits for five engineers of NTDC on at least two sites of SVCs, similar in size and performance as of this project within 3 months after award of contract.

9. TESTING REQUIREMENTS

9.1 General Requirements

9.1.1 The Contractor shall be responsible for organizing and performing all tests in accordance with the applicable standards and any additional requirements in this specification. Where standards are not suitable or applicable, other common industry procedures and mutually acceptable methods shall be used.

9.1.2 All equipment included as part of the SVC system shall be tested before being placed in final operation. The bidder shall furnish the test plan/procedures.

9.1.3 The bidder shall submit a list of tests clearly stating the type tests that will be carried out for this project, and stating the type tests where instead a report from a previously performed test shall be considered in lieu of actual test performance. The list of tests shall also include routine tests and factory acceptance tests to be performed for this project.

9.1.4 The results obtained from type tests must demonstrate that the equipment conforms to the requirements of this specification and the latest applicable standards.

9.1.5 The results obtained from tests must be compiled and organized in writing. All test results must contain the appropriate signature of the Contractor.

9.1.6 Company reserves the right for itself and/or its nominated representatives to be present and witness all tests.

9.1.7 The Contractor shall furnish all labour, materials, instrumentation, testing facilities and inspection test plan (ITP) for all tests.

9.1.8 If any piece of equipment provided as a part of the SVC does not pass a test or is damaged, the Contractor must replace or repair the failed or damaged equipment and modify the equipment design, if necessary. The Contractor may be required to repeat the tests previously done on any equipment which is replaced, repaired or modified. All expenses for the material, re-installation and re-testing will be borne by the Contractor.

9.1.9 The Contractor, at all times, must obtain permission from Company to perform field verification tests when the SVC is connected to the power system.

9.2 **SVC Control System Testing**

9.2.1 A Factory Simulator Test shall be performed for the original control and protection system. The Contractor shall thoroughly test all control and protection functions on RTDS in the factory in the presence of Company's Engineers. These tests shall provide an initial verification of performance before the control and protection equipment is shipped to site. These tests shall include but are not limited to:

i) Verification of each control function
ii) Verification of control linearity
iii) Verification of the monitoring system
iv) Verification of the protection system
v) Verification of overall system performance for minor and major system disturbances
vi) Verification of processor loading of all digital controllers

9.3 **SVC Sub-system Testing Before Energization**

9.3.1 The SVC subsystem tests are those tests to be performed at the site on the fully assembled SVC subsystems in the presence of Company's Engineers, without having the SVC connected to the power system. The Contractor shall submit a list of these tests. Company reserves the rights to approve the test plan.

9.4 **SVC Commissioning Test & Field verification**

9.4.1 Upon satisfactory completion of the subsystem tests, energization of the SVC and field verification tests shall be performed in the presence of Company's Engineers. These tests are performed at the site on the fully assembled SVC with the SVC operating and connected to the power system. These tests need close co-operation with the responsible remote control centre from the Company. The Contractor shall submit a list of these tests. Company reserves the rights to approve the test plan.

9.5 **<u>Schedule of Testing</u>**

9.5.1 The Contractor shall give the Company **an** advance notice of type, routine and factory acceptance tests 2 months before the actual testing date.

9.5.2 Inspection and test plans shall be submitted for the Company's information prior to commencement of the test.

9.5.3 Company reserves the right to approve inspection and test plans.

9.6 **Trial Operation**

9.6.1 As soon as commissioning and field verification tests have been completed, the Contractor shall advise Company in writing that the equipment is ready for service.

9.6.2 After successful commissioning and field verification tests of the SVC itself, the SVC will be part of the scope of testing within the grid reinforcement project of the Company.

9.6.3 A trial operation shall start according to the time schedule agreed upon. It lasts for a period of 3 months as a minimum extendable to another 3 months in case of maloperation during initial trail period. The Contractor will be responsible for the operation of the plant until it is formally taken over by Company. This applies even if operating periods fall outside normal working hours. During the trial operation Company's operating procedures shall be followed regarding switching, dispatching and access to high voltage areas. The Company will provide the staff necessary for taking care of these safety precaution tasks.

9.6.4 During trial operation the Contractor shall provide the agreed number of supervising engineers and service personnel on Site. The supervising engineers shall supervise the equipment on site, instruct the personnel of the Company and at the same time assist during testing etc.

Annexure-A

SVC & Power System Description

A-I The SVC system is to be installed at 220/132 kV New Kot Lakhpat AIS, outdoor manned substation situated in Lahore, Pakistan.

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

i) The nominal capacitive reactive power output of the SVC at point A in Figure 1 (sub-clause 7.1) shall be 450 MVAR at 1.0 per unit AC bus voltage, nominal system frequency and at 50 °C ambient temperature.

ii) The nominal inductive reactive power output of the SVC at point B of Figure 1 (sub-clause 7.1) shall be 50MVAR at 1.0 per unit AC bus voltage, nominal system frequency and at 50 °C ambient temperature.

iii) The nominal slope of the characteristic shall be adjustable in steps of not greater than 0.5% between 0% and 3%, on a basis of 100 MVA (sub-clause 7.1, Figure 1).

iv) The SVC shall continue to generate reactive power during a temporary under voltage down to a value of 0.3 per unit for duration of 10s (point C in Figure 1). The SVC may be tripped if the under voltage persists for more than 10s.

v) The SVC shall continue to absorb reactive power during a temporary overvoltage in a controlled manner up to the value of 1.3 per unit for duration of 3s (point D on Figure 1). The SVC may be tripped if the overvoltage persists for more than 3s.

vi) These are the minimum requirements and the Contractor shall determine the maximum overload and over voltage requirement based on the network data provided in the specification. The SVC shall be rated and designed to withstand these over voltages.

A-III SVC Configuration

i) The SVC shall consist of either six-pulse or twelve-pulse topology. The inductive part of the SVC system shall consist of TCR(s) branch. In case of more than one TCR branch, TCR branches shall be of equal size. The capacitive thyristor switched part of the SVC system shall be implemented by means of TSC branch. In case of more than one TSC branch, TSC branches shall be of equal size. Multi TCRs and/or TSCs shall operate on the principle of a master-follower.

ii) The SVC system design has to allow partial operation in case of any single branch (TCR, TSC and FC) out of service.

iv) The fixed capacitive part of the SVC will consist of filter branches of equal size, rating and configuration. Each one of the filter branches will consist of either a group of (3 single tuned LC filters) or a double tuned filter group. Damping on the filters may be needed.

Annexure-B

B-I **Frequency**

i)	Nominal AC system frequency	50 Hz
ii)	Maximum continuous AC system frequency	49.8 Hz
iii)	Minimum continuous AC system frequency	50.2 Hz
iv)	Maximum short-term AC system frequency	50.5 Hz
v)	Minimum short-term AC system frequency	49.4 Hz
vi)	Network earthing	Directly earth

B-II **Insulation Co-ordination**

	Parameters Based on prevailing Standards	132kV	220kV	500kV
	Lightning impulse level (1.2/50µSec)			
a)	To earth and between phases, kV peak	650	1050	1550
b)	Between open isolator contacts, kV Peak	750	1200	1865
	One minute power frequency withstand test			
a)	To earth and between phases, kV rms	275	460	620
b)	Between open isolator contacts, kV rms	315	530	800

B-III **Short Circuit Levels**

Parameters	132kV	220kV	500kV
Three phase symmetrical short circuit current, kA rms	31.5/40	40	40
Three phase symmetrical peak withstand current, kA peak	80/100	100/125	100/125

B-IV **Transmission Data for Harmonic Studies (To be provided Later on)**

i) Harmonic impedance sectors or performance)	See Figure ____________
ii) Harmonic impedance sectors for rating filter components	See Figure ____________
iii) Background harmonic voltage (or current) spectrum (for rating filter components)	See Figure ____________
iv) Harmonic requirement Existing single harmonic distortion value v) Total harmonic distortion value	$U_v \leq$ %; THD ≤ %
vi) Permissible single harmonic distortion value from 2nd to 25th harmonics vii) Maximum allowed total harmonic distortion value	$U_v \leq$ 1.5% THD ≤2.5%
viii) TIF	≤
ix) Total Harmonic current factor (IT)	≤ 2.0 %
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