Amendment –XVII dated 20.02.2023 on the Request for Proposal Document and Transmission Service Agreement issued for selection of bidder as Transmission Service Provider to establish "Transmission system for evacuation of power from REZ in Rajasthan (20GW) under Phase-III Part C1" through tariff based competitive bidding process

<table>
<tr><th>Sl. No.</th><th>Clause No.</th><th>Existing Provisions</th><th>New / Revised Clause</th></tr>
<tr><td>1.</td><td>2.7.1 of RFP</td><td>The Bidders should submit the Bids online through the electronic bidding platform before the Bid Deadline i.e. on or before 1500 hours (IST) on <u>20.02.2023</u>. In addition to the online submission, the Bidder with lowest Final Offer will be required to submit original hard copies of Annexure 3, Annexure 4 (if applicable), Annexure 6 (if applicable) and Annexure 14 before issuance of LoI</td><td>The Bidders should submit the Bids online through the electronic bidding platform before the Bid Deadline i.e. on or before 1500 hours (IST) on <u>13.03.2023</u>. In addition to the online submission, the Bidder with lowest Final Offer will be required to submit original hard copies of Annexure 3, Annexure 4 (if applicable), Annexure 6 (if applicable) and Annexure 14 before issuance of LoI</td></tr>
<tr><td>2.</td><td>2.7.2 of RFP</td><td>Important timelines are mentioned below:
<table>
<tr><th>Date</th><th>Event</th></tr>
<tr><td>06.02.2023</td><td>Issue of final RFP Project Documents</td></tr>
<tr><td>20.02.2023</td><td>Submission of Bid (Online submission of Bid through electronic bidding portal)</td></tr>
<tr><td>20.02.2023</td><td>Opening of Technical Bid</td></tr>
<tr><td>28.02.2023</td><td>Shortlisting and announcement of Qualified Bidders on bidding portal</td></tr>
<tr><td>01.03.2023</td><td>Opening of Financial Bid - Initial Offer</td></tr>
<tr><td>02.03.2023</td><td>Electronic reverse auction (Financial Bid – Final Offer) for the Qualified Bidders.</td></tr>
<tr><td>07.03.2023</td><td>Submission of original hard copies of Annexure 3, Annexure 4, Annexure 6, as applicable and Annexure 14 by the bidder with lowest Final Offer</td></tr>
<tr><td>10.03.2023</td><td>Selection of Successful Bidder and issue of LOI</td></tr>
<tr><td>20.03.2023</td><td>Signing of RFP Project Documents and transfer of Ramgarh II Transmission Limited</td></tr>
</table></td><td>Important timelines are mentioned below:
<table>
<tr><th>Date</th><th>Event</th></tr>
<tr><td>27.02.2023</td><td>Issue of final RFP Project Documents</td></tr>
<tr><td>13.03.2023</td><td>Submission of Bid (Online submission of Bid through electronic bidding portal)</td></tr>
<tr><td>13.03.2023</td><td>Opening of Technical Bid</td></tr>
<tr><td>21.03.2023</td><td>Shortlisting and announcement of Qualified Bidders on bidding portal</td></tr>
<tr><td>23.03.2023</td><td>Opening of Financial Bid - Initial Offer</td></tr>
<tr><td>24.03.2023</td><td>Electronic reverse auction (Financial Bid – Final Offer) for the Qualified Bidders.</td></tr>
<tr><td>29.03.2023</td><td>Submission of original hard copies of Annexure 3, Annexure 4, Annexure 6, as applicable and Annexure 14 by the bidder with lowest Final Offer</td></tr>
<tr><td>03.04.2023</td><td>Selection of Successful Bidder and issue of LOI</td></tr>
<tr><td>13.04.2023</td><td>Signing of RFP Project Documents and transfer of Ramgarh II Transmission Limited</td></tr>
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Sl. No.	Clause No.	Existing Provisions	New / Revised Clause
3.	2.13.1 of RFP	……. Opening of Envelope (Technical Bid): 1530 hours (IST) on **<u>20.02.2023</u>** ……… Opening of Initial Offer: Initial Offer shall be opened by the Bid Opening Committee in presence of the Bid Evaluation Committee at 1530 hours (IST) on **<u>01.03.2023</u>** in the office of CEA.	……. Opening of Envelope (Technical Bid): 1530 hours (IST) on **<u>13.03.2023</u>** …… Opening of Initial Offer: Initial Offer shall be opened by the Bid Opening Committee in presence of the Bid Evaluation Committee at 1530 hours (IST) on **<u>23.03.2023</u>** in the office of CEA.
4.	**RFP & TSA**		**New Clause Added** **<u>Specific Technical Requirement for STATCOM</u>**

<u>Appendix 1</u>

1. Introduction:

This technical specification for a Static Synchronous Compensator (STATCOM) Station consists of STATCOM, Mechanically Switched Capacitors (MSCs) and Mechanically Switched Reactors (MSRs) (to be installed at MV bus) including associated coupling Transformer (rated 400/xx kV) and other equipment connected to the 400 kV bus. MV voltage level (xx kV) of the coupling Transformer can be chosen by the TSP to optimize the offered solution which meets functional requirement of this Technical Specification.

The STATCOM station shall operate asymmetrically in the leading and lagging MVAR region as applicable to reach the dynamic range specified. The purpose of the STATCOM station is to regulate the voltage of 400 kV Bus [Point of Common Coupling (PCC)]. The Configuration and the nominal rating of the STATCOM station is specified in this document.

The main building block of the STATCOM should be single phase VSC based convertor valve (multi-level) operating in a way to eliminate or minimize ac filter requirement to High pass filter only and connected to the xx kV bus through air core reactors. The STATCOM may comprise of multiple identical STATCOM units (minimum two) operating in parallel.

1.1 Definitions and Abbreviations

For the purpose of this specification, the following definitions / abbreviations are used:

PCC: Point of Common Coupling. The connection point between the STATCOM and the power system at which performance requirements are defined.

Reference Voltage (Vref): The Point on the voltage/current (V/I) characteristic where the static synchronous compensator (STATCOM) is at zero output (i.e. where no reactive power is absorbed from or supplied to the transmission system where the voltage is controlled)

MV: Medium Voltage.

STATCOM Unit: Static Synchronous Compensator based on Multi-Module technology and including air core reactors as needed, Valve cooling, switchgear and its control and protection.

STATCOM: Static Synchronous Compensator consisting of multiple STATCOM Units operating in parallel and connected to a common coupling Transformer. A static synchronous generator operated as a shunt connected compensator, whose capacitive or inductive output current can be controlled independently of the ac system voltage.

MSC: Mechanically Switched Capacitor (Including Switchgear). A shunt-connected circuit containing a mechanical power-switching device in series with a capacitor bank and a current limiting reactor.

MSR: Mechanically Switched Reactor (Including Switchgear). A shunt-connected circuit containing a mechanical power- switching device in series with a reactor.

Sub Module: Basic single power module of a Multi Module STATCOM unit Valve. It is a Part of a STATCOM unit valve comprising controllable switches and diodes connected in full bridge arrangement, together with their immediate auxiliaries, and storage capacitor, if any, where each controllable switch consists of one or more switched valve device(s) connected in series.

Valve: Electrically and mechanically combined assembly comprised of forced commutated devices (for example, IGBT) assembled in levels, complete with all connections, auxiliary components, and mechanical structures, which can be connected in series with each phase of reactor of a STATCOM unit.

Valve Section: Electrical assembly defined for test purposes, comprising one of several sub modules.

Valve Structure: Physical structure holding valve(s), which is insulated to the full system voltage above earth potential.

STATCOM Station: STATCOM Station includes 400 kV Switchgear, Coupling Transformer, STATCOM, MSCs (as applicable), MSRs (as applicable) along with its switchgears and complete integrated control and protection whose outputs are coordinated. (Complete turnkey delivery at site).

CT: Current Transformer.

VT: Voltage Transformer.

SAS: Substation Automation System.

Response Time: the duration from a step change in control signal until the voltage changes by 90% of its final change, before any overshoot.

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

Slope: The ratio of the voltage change to the current change over a defined controlled range of the STATCOM, normally the full (inductive plus capacitive) range at nominal voltage, expressed as percentage.

VSC: Voltage Source Convertor, A forced commutated device (for example, IGBT) based self-commutated convertor that is capable of generating ac voltage from DC capacitor.

Voltage/Current (V/I) Characteristic: The relationship between the current of the STATCOM and the voltage at its point of connection.

Lagging Operation: Inductive operation or reactive power absorption of the STATCOM similar to a shunt reactor.

Leading Operation: Inductive operation or reactive power generation of the STATCOM similar to a shunt Capacitor.

TSP: Transmission Service Provider

2. Relevant Standard:

STATCOM Station shall comply with the following standards (latest edition):

Sl. No.	Description	Standard
1.	Voltage sourced converter (VSC) valves for STATCOM	IEC- 62927 IEEE- 1052 IEC-60747
2.	Control, protection & monitoring	IEC-61000 IEC-60255
3.	Valve Hall for housing the equipments as above comprising of: - wall bushings for connection between converter phases and decoupling reactors, - piping and tubing connections of the cooling system to converter - connection of the control cabinet with the converter through optical fibers - internal lighting, auxiliary power supply (AC and DC) and power socket system - internal HVAC system	IEC-60071 IEC-60270 IEC-60137
4.	X kV, dry insulated, air core and air self-cooled decoupling reactors. Mechanically Switched Reactors, half-reactors stacked on above the other, Outdoor installation, Complete with supporting structures	IEC- 60076
5.	Power Capacitors (MSC etc.)	IEC-60871-1
6.	400 kV Power transformer (Coupling Transformer)	IEC-60076 IEC-60354
7.	CT's and VT's	IEC- 61869
8.	Dis-connectors and Earthing Switches	IEC- 62271
9.	HV & MV Circuit Breakers	IEC- 62271
10.	Surge Arresters	IEC- 60099
11.	Auxiliary & grounding transformer	IEC- 60076 IEEE C57.32 IS- 5553 (Part 6)
12.	Neutral Grounding Resistor, charging resistor	IEEE- C57.32
13.	UPS, SMPS &Other Power supply units	IEC- 62040 IEC- 61558

14.	Others items as per relevant standards specified elsewhere in the specification for substation works.	
15.	Cyber Security	IEC-62243

3. Scope of work

The scope of work with regard to the works associated with the STATCOM comprises of ±2X300 MVAr Modular Multi-level Voltage Source Converter (MMC-VSC) based STATCOM along with 4x125 MVAr MSC (Mechanically Switched Capacitors) and 2x125 MVAr MSR (Mechanically Switched Reactors). 02 Nos. STATCOM shall be distributed in two different 400 kV bus sections of the substation. The TSP shall be responsible for complete installation of STATCOM station along with the substation works as specified in the complete scope of work.

The TSP shall also perform the system studies (steady state and dynamic) according to the requirement mentioned and documentation of the same shall be preserved by TSP & to be submitted to CEA/CTU/GRID-INDIA, as per their request.

The switchgear for connection of STATCOM units, MSCs and MSRs provided on the secondary side of coupling transformer shall be of standard voltage rating as per IEC. The switchgear, structure, control, protection and substation automation on 400 kV side shall be as per applicable Technical Specification of the substation equipment.

Generally, the purpose of STATCOM is to improve system stability, provide damping, and to smooth out the step voltage change associated with MSCs, MSRs and external compensating equipment (i.e. any existing capacitor and reactor banks) switching and provide steady state VARs as needed to support the 400 kV bus voltage.

In order to get optimum control of MVAR, the control of MSCs and MSRs, as well as reactor banks connected on the 400 kV HV side, shall be integrated along with STATCOM control to provide steady state 400 kV bus voltage control in a smooth manner. MSRs and MSCs are to be switched to relieve the STATCOM from high level operation, reduce its continuous losses and maximize its dynamic control potential. The operating functions of the STATCOM Station shall include:

- Steady state voltage control of 400 kV bus,
- Balance steady state voltage at 400 kV bus,
- Dynamic over-voltage control,
- Transient and Dynamic stability control
- Damping of Power Oscillations

It is assumed that the arresters will limit any transient and switching surge over voltages and may also, by design, limit dynamic over voltages.

The requirement of reactive power compensation (as defined above) guaranteed by the TSP shall not be less than the levels specified considering following.

- The total cumulative Capacitive (+) and Inductive (-) MVAR rated Capacity of STATCOM Station as defined above comprising of STATCOM, MSCs (as applicable), MSRs (as applicable) coupling transformer, coupling reactor or any filter (if applicable) shall be rated at 1 p.u. voltage, 1 p.u. frequency and 20^{o} Celsius ambient temperature at 400 kV Bus (Referred to as “Point of Common Coupling” or PCC).

- Capacity of one or more branches of MSC, MSR in STATCOM Station can be included in the offered STATCOM with equivalent capacity. Accordingly, ratings of STATCOM Unit/Branch equipments may be designed.

  Example of equivalent acceptable solutions for each STATCOM Station is given below:

  Option 1: ±300MVAR STATCOM, 2x125MVAr Mechanically switched Shunt Capacitor (MSC), 1x125MVAr Mechanically switched Shunt Reactor (MSR).

  Option 2: +425/-300MVAR STATCOM, 1x125MVAr Mechanically switched Shunt Capacitor (MSC), 1x125MVAr Mechanically switched Shunt Reactor (MSR).

  Option 3: +300/-425MVAR STATCOM, 2x125MVAr Mechanically switched Shunt Capacitor (MSC).

  Option 4: ±425MVAR STATCOM, 1x125MVAr Mechanically switched Shunt Capacitor (MSC)

  Option 5: +550/-425MVAR STATCOM

- The rated capability of STATCOM, MSC (as applicable) & MSR (as applicable) shall be at 400 kV (Referred to as “Point of Common Coupling” or PCC) and in the steady state frequency range of 48.5 Hz-50.5 Hz.

- The STATCOM Station including STATCOM Units, MSCs and MSRs shall be designed to operate continuously under the worst possible combination of steady state voltage and frequency range of 360-440 kV and 47.5 Hz – 52 Hz respectively and transient and temporary over voltages defined in Clause 6.1-f).

- The ac voltage unbalance at fundamental frequency shall be assumed equivalent to a negative phase sequence component of 1.5 % for equipment rating purposes.

- The reactive power compensation levels shall be determined by manufacturing tolerances of the components and measurements carried out using metering accuracy instrumentation at the 400 kV feed points to the STATCOM Station.

- The reactive power capability shall also be determined by calculations based on test values of appropriate quantities at the discretion of the owner.

- In calculations of capability and availability, the owner shall assume the most unfavourable combinations of control, manufacturing and measurement tolerances.

- In case more than one STATCOM Station are installed in a particular substation, each STATCOM Station shall be connected to 400 kV bus individually with complete separate downstream system. Each individual STATCOM station shall have complete independent yet coordinated control system to avoid simultaneous tripping of both STATCOM Stations. The system shall be design in such a way that single common contingency (other than loss of 400 kV voltage, abnormal system events) will not cause tripping of both STATCOM Stations.

- Operation of STATCOM Station shall not excite any resonance condition in connected Power System.

- Control of STATCOM Station shall be designed to prevent hunting between MSRs, MSCs and STATCOM.

3.1 STATCOM building

The STATCOM station shall have independent building including a separate control room different from the main control room building of the Substation. The Building shall comprise of valve halls, cooling system room, control room, LT Switchgear room, Battery room, workshop, Document/Library and general facilities etc.

The STATCOM Building shall comprise of following facilities

1. Control & Relay Panel room
2. AC Distribution Board & DC Distribution Board room

3. Battery room
4. Service Room cum workshop
5. Conference room
6. Valve hall
7. Cooling system room
8. Lobby
9. Corridor with minimum width of 1600 mm
10. Portico
11. Common Toilet
12. Provision of shaft for electrical, sanitary, water supply facilities
13. Other facilities as per functional requirement of building
14. Air Handling Unit (AHU) Room

4. Ambient Condition

STATCOM Station should be designed to perform under the ambient conditions of the site where the STATCOM is required to be installed.

5. Power System Characteristic

The following AC power system characteristics apply at the point of connection i.e. point of common coupling in this case (PCC). STATCOM station operation is required within the parameter value and duration given in following table:

S. No	**Power System Characteristic**	**Value**	**unit**
1.	Nominal ac system voltage, line-to-line	400	kV
2.	Maximum continuous ac system voltage, line-to-line	420	kV
3.	Minimum continuous ac system voltage, line-to-line	380	kV
4.	Maximum short-term ac system voltage, line-to-line	448	kV
5.	Maximum duration of item 4	10	s
6.	Minimum short-term ac system voltage, line-to-line	120	kV
7.	Maximum duration of item 6	5	s
8.	Continuous negative-sequence voltage component (used for performance calculation)	1	%
9.	Continuous negative-sequence voltage component (used for rating calculation)	1.5	%
10.	Continuous zero-sequence voltage component	1	%
11.	Nominal ac system frequency	50	Hz

S. No	**Power System Characteristic**	**Value**	**unit**
12.	Maximum continuous ac system frequency	50.5	Hz
13.	Minimum continuous ac system frequency	48.5	Hz
14.	Maximum short-term ac system frequency	52	Hz
15.	Minimum short-term ac system frequency	48	Hz
16.	Basic Insulation Level (BIL)	1550	kV peak
17.	Switching impulse level (SIL)	1050	kV peak
18.	Power Frequency Withstand voltage	630	kV
19.	1) Maximum three-phase fault current a) for performance requirements b) for rating of STATCOM 2) X/R (Positive/Negative Seq) 3) X/R (Zero Seq) 4) Clearing time - normal 5) Clearing time – backup	 1 a) 63 1 b) 63 2) 33.9 3)8.9 3) 0.10 4) 0.75	 kA kA for 1s s s
20.	Maximum three-phase fault current	63	kA
21.	Existing three-phase fault current	16.8	kA
22.	Minimum three-phase fault current -for performance requirements -for safe operation	 10.7 10.7	 kA kA
23.	Maximum single-phase fault current	63	kA
24.	Existing single-phase fault current	12.4	kA
25.	Minimum single-phase fault current	6.5	kA
26.	Harmonic impedance sectors for each harmonic number up to the 49th harmonic or system impedance data as R-X values with frequency steps not larger than 1 Hz (for performance and/or STATCOM system component rating)	Chapter 7.3 of CIGRE Publication 139	
27.	Background harmonic voltage (or current) spectrum (for STATCOM components rating) (Distortion up to 15th Harmonic	5th Harmonic 1.5% 7th Harmonic 1.0% Other Harmonics 0.5% (each)	
28.	Power System Phase Rotation	CCW	

6. STATCOM Station Characteristics

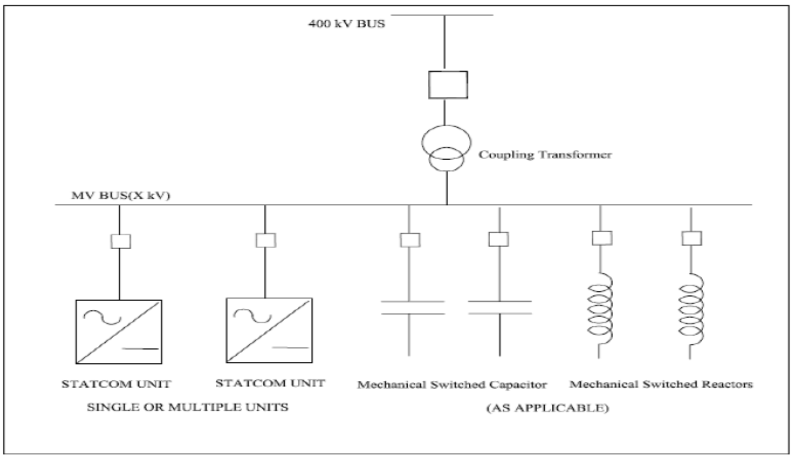

Figure-1: Conceptual Indicative Schematic diagram of STATCOM Station

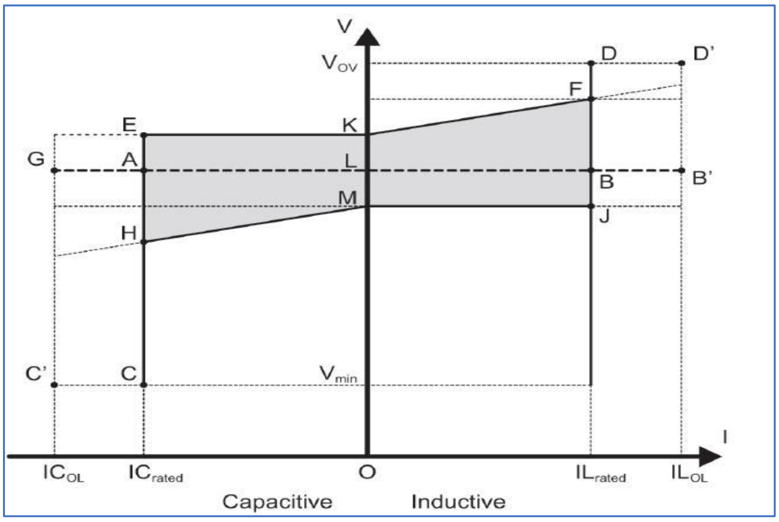

Figure-2: VI Curve of the VSC Portion

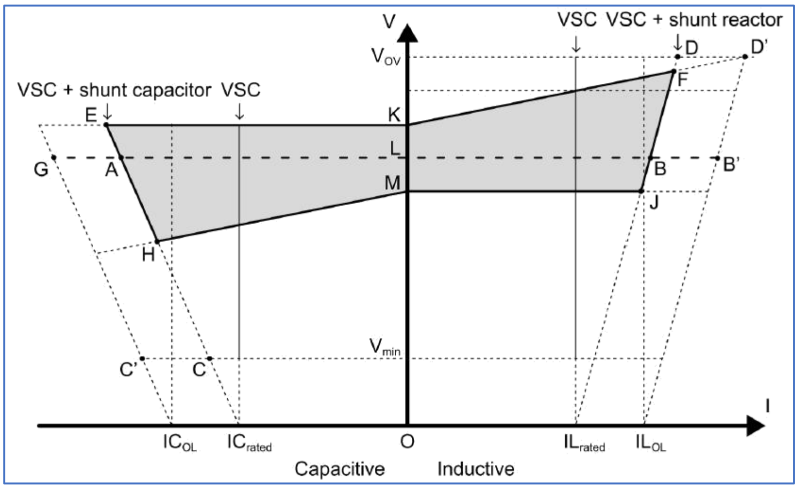

Figure-3: VI Curve of the STATCOM Station

6.1. STATCOM Station Ratings

The output of a STATCOM Station shall be adjusted continuously over the range illustrated in Figure-3.

The following items define the ratings of the STATCOM station equipment.

a) The STATCOM Station should regulate the 400 kV bus voltage to a reference voltage of 400 kV (1.0 per unit, Point L Figure-3), continuously adjustable between 0.95 per unit and 1.05 per unit.

b) The nominal capacitive and inductive reactive power output of the STATCOM should be as defined in the scope, at 1.0 p.u. ac bus voltage and nominal system frequency, and 20°C ambient temperature (Point A and point B of figure-2).

c) The slope of the STATCOM Station characteristic should be adjustable in steps of not greater than 0.5% between 1% and 8%, on a basis of cumulative MVA capacity of STATCOM Station (A+B in Figure-2).

d) The STATCOM Station should continue to generate reactive power during temporary under voltage down to 120 kV (0.3 p.u.) for the duration of 5 seconds (Point C); the STATCOM system may be tripped (or blocked) if the under voltage persists for more than 5 seconds.

e) The STATCOM should continue to absorb reactive power during temporary over voltages in a controlled manner as per the following.

Temporary Overvoltage	Duration
up to 600 kV (1.5 p.u.)	10 seconds
up to 704 kV (1.76 p.u.)	100 milli seconds
up to 800 kV (2.0 p.u.)	50 milli seconds

STATCOM Station may be tripped if the respective temporary over voltages as mentioned above persists for more than its respective mentioned duration.

f) The STATCOM Station should be capable of repeating temporary operation as defined in any one of item (d) and (e) as above for at least 3 charging cycles in 60 minutes.

g) The coupling transformer and all bus equipment, such as filter branches (if applicable), MSC & MSR branches etc. and the MV Bus should be rated to withstand the specified continuous and short-term operation, and to withstand or be protected against voltage and current stresses that exceed these conditions.

h) All equipment in the STATCOM Station should be capable of sustaining, without damage, any fault limited by the maximum design short circuit level of the system and the Coupling transformer impedance.

i) The TSP shall assume the negative sequence voltage of 1% at rated short circuit level and provide control to reduce this unbalance.

j) The injected harmonics by STATCOM Station under the full operating range measured at 400 kV Bus (PCC) in accordance with IEEE-519-2014 and limiting values of individual harmonic distortions and total harmonic distortion shall be 0.5% and 1% respectively.

k) The STATCOM controls should be designed to correct negative sequence voltage during steady state operation.

l) The switching module design should include an appropriate allowance for stray capacitance and component tolerances.

m) The STATCOM should be designed to prevent, or alternatively to withstand, false firing events, i.e., the firing of any valve at an incorrect time in the cycle or when not ordered.

6.2. Control Objectives

The control system shall control the STATCOM, MSCs, MSRs required under this specification, as well as all bus reactors on the 400 kV HV bus of the substation.

Operation logic for the breakers, disconnectors and earth-switches in the STATCOM Station shall also be incorporated in the control system. The control shall be programmable and shall have sufficient scope and flexibility (software programming margin of at least 20%) to permit re-programming according to future changes/addition in the power system. The operator interface must be integrated in a latest version of Windows environment.

6.2.1. STATCOM Station Functions and Applications

6.2.1.1. Voltage Control mode (Automatic and Manual)

Control of the positive sequence component of the fundamental frequency voltage in steady state and dynamic operation, with slope in the range as specified at clause 6.1 c) above.

6.2.1.2. Fixed Reactive Power Mode

In this mode, the reactive power output of the STATCOM as well as switching of MSRs and MSCs, should be manually controlled, by direct operator action. This feature is normally utilized for testing purpose.

6.2.1.3. Steady State Condition

The STATCOM Station shall provide necessary reactive power support to the 400 kV bus (PCC) to compensate for voltage variation under steady state.

6.2.1.4. Dynamic Over-voltage Control Performance

The STATCOM shall be required to provide necessary reactive power support with fast and smooth variation so that over-voltages under dynamic conditions are controlled. STATCOM shall smooth out the step caused by switching of MSCs and MSRs.

The operation of each STATCOM over its range of MVAR from full capacitive to full inductive capacity and vice-versa shall be on the basis of smooth variation.

6.2.1.5. Transient and Dynamic Stability Performances

The STATCOM Station shall provide necessary reactive power so that transient and dynamic stability of the Owner's system are enhanced.

6.2.1.6. Damping of Power Oscillations

The STATCOM shall provide necessary damping to power oscillations by modulating its output in its entire range based on measured rate of change of power/frequency at the 400 kV bus. The damping controller would track local area oscillations as well as wide area oscillations and control would include several loops each focused on different frequency.

6.2.1.7. Facility for compensation of phase imbalance

Provide negative phase sequence voltage control to minimize presence of negative sequence content of the 400 kV bus voltage.

6.2.1.8. Start up and Initial Switching

The operation of STATCOM Station during start-up/initial switching on should not create significant energizing transients causing voltage drop, voltage distortion and swinging of transmission voltage angle at the PCC bus by more than ±5%. TSP shall have to ensure this analytically during design phase and also in the field after commissioning of the facility. TSP shall prepare the design documentation and the same shall be preserved by TSP and to be submitted to CEA/CTU/GRID-INDIA, as per their request.

6.2.1.9. Gain Supervision and Control

To control regulator gain in order to prevent oscillations and excessive overshoot in the STATCOM response, a gain supervision function shall be implemented.

This shall be an essential function for supervision of stability of the closed loop voltage control. The function of this controller is that when the supervision of the gain in the voltage regulator detects oscillations in the voltage controller output, the gain shall gradually be reduced until stability is reached. Normally it is a changed condition 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 change. The control should be adaptive in order to maximize its effectiveness. Gain reductions should be indicated and the reduction of the gain shall be able to be reset to nominal value by means of commands from the operator interface or automatically. A relative gain factor shall also be able to be changed from a gain optimizer.

6.2.1.10. Coordinated reactive power control of external devices

To optimize the use of dynamic vars versus steady state vars, control of externally connected shunt capacitor or reactor banks shall be implemented. Such banks will be connected locally to a HV bus or/and at MV bus. For simultaneous control with the supplementary VSC current controller, coordination for the two functions shall be provided. External devices like MSC/MSR can be switched ON or OFF to position the steady state operating point of the VSC so as to extend its dynamic range.

6.2.1.11. Supplementary VSC current controller

To optimize the use of dynamic vars versus steady state vars, a control function that slowly reduces or offsets the STATCOM point of operation shall be implemented. By deliberately adjusting the voltage reference setting within a narrow window the STATCOM system output is pushed toward either a specific point or toward a window to preserve dynamic range. This slow operating function is meant to provide for slower controllers, such as externally connected shunt bank to operate and meet the slower long term voltage variations caused by daily or weekly load variations. Rapid changes in the system voltage that call for dynamic compensation will have priority over this type of controller.

6.2.1.12. Gain optimization

To provide operation at optimal regulator gain, a fully automatic optimizing function shall be implemented. This function operates by inducing a small change in the STATCOM output. The gain is adjusted based on the network response signal.

6.2.1.13. Control of Direct Current

During STATCOM operations, any flow of direct current to transformer MV side must be less than 25% of transformer magnetizing current. DC current flow in the transformer should be minimized by an independent control function which minimizes DC current. For presence of up to 0.2% second harmonic in 400 kV system, the STATCOM control should minimize DC current flow in the transformer.

6.2.2. Under Voltage Strategy

It is essential that the STATCOM Station operates in a robust manner when transmission system under voltages appears. For transmission system voltages down to 0.3 p.u., the STATCOM units must operate unrestricted, producing its rated capacitive current. The STATCOM must be designed to operate at transmission system under voltage, even considering that severe voltage unbalances can appear. The STATCOM must not be restricted by short term negative sequence voltages up to 1.5%, appearing in conjunction with under voltages.

Transmission system under voltages below 0.3 p.u. will appear in conjunction with transmission system faults. The STATCOM must ride through during faults and post fault under voltages. The minimum trip delay for the STATCOM Station, upon complete loss of the transmission system voltage shall not be less than 5 seconds. If station AC auxiliary power distribution is affected, critical loads must be fed from DC station batteries/ UPS without tripping the STATCOM Station. Adequate capacity must be kept in DC station batteries/UPS to feed critical loads for smooth operation of the STATCOM Station facility. There must be redundant station battery system with each station battery system capable of delivering 100% load.

At under voltage conditions for the transmission system voltage, special control strategies are activated which override the normal control modes presented above. Normally if the voltage is low, the output from the STATCOM will be capacitive. If the voltage in all three phases goes below a level, but not greater than 0.3 p.u., a special under voltage strategy may be activated that controls the STATCOM output to 0 Mvar. As soon as the voltage goes higher than 0.3 p.u., the under voltage strategy is deactivated and the normal control will be in operation.

The STATCOM Station must not be tripped or shutdown automatically for under voltages appearing for less than 5 seconds. STATCOM Station must continue to operate at AC system Voltage up to 0.35 p.u. voltage on 2 phases with above 0% on the third phase or above 0.3 p.u.on all three phases until the fault is cleared and line is reclosed. The reclose time shall be up to 2.6 seconds.

6.2.3. Over Voltage Strategy

6.2.1. The TSP shall carry out dynamic stability study upfront in order to assess the dynamic overvoltage requirements. These studies shall include conditions with maximum and minimum short circuit system MVA conditions, single phase and three phase faults as well as stuck breaker, outage of nearby generator and also with outage of parts of the STATCOM Station. It is important that the STATCOM Station rides through temporary over voltages and not trip when it is needed the most.

6.2.3.2. The system should be able to withstand any 3 phase 5 cycle (100 ms) and single phase 10 cycles (200 ms) fault with consequent loss of a 400 kV double circuit line and loss of a 500 MW generator. The fault duration mentioned above correspond to time assumed for persistence of fault. For other system parameters refer clause 5 above (Power System Characteristics). In addition to above requirement, system contingency cases as provided in Annexure-I shall also be withstood.

6.2.3.3. The 400 kV system and equipment to which the STATCOM Station is connected is designed to withstand switching surge overvoltage up to 2.5 p.u. and power frequency over voltages up to 1.5 p.u. with initial value of the temporary overvoltage up to 2.0 p.u. for 1-2 cycles. Based on arrestor coordination and under the worst case scenario the 400 kV system phase to ground peak over voltages may be expected as follows:

i) 650 kVp for 3 peaks
ii) 575 kVp up to 5 cycles
iii) 530 kVp up to 1 second
iv) 475 kVp up to 10 seconds

a) The STATCOM Station shall be designed to withstand these sequential over voltages.

b) If the over voltages greater than 1.1 p.u. are exceeded in magnitude and duration due to any system contingencies, suitable control action shall be taken by STATCOM Station to bear this kind of contingency.

c) The TSP shall evolve the insulation co-ordination of the components of the STATCOM Station after studies have been conducted to determine the over-voltage profile with the STATCOM connected to the system.

d) The TSP shall ensure that STATCOM Station will not excite ferro-resonance and sub-synchronous oscillation in the AC system. The study report in this regard shall be preserved and to be submitted to CEA/CTU/GRID-INDIA, if required.

e) It may also be noted that the tripping action for 400 kV lines is initiated if the overvoltage exceeds 1.12 p.u. for 10 seconds. The tripping of 400 kV lines is initiated if 1.5 p.u. voltage persists for more than 100 milli seconds. The over voltage strategy shall be coordinated with these setting such that the STATCOM Station rides through up to these levels.

6.2.4. STATCOM Station Over load/Over Current

The overvoltage cycles mentioned in clause 6.2.3.3 above create a corresponding current overload in the STATCOM Station components; the STATCOM Station and its components shall be designed to withstand these.

In addition to the above the STATCOM Station and its components shall be designed to withstand overloading caused due to the following eventualities.

i) Short circuits and ground faults in the 400 kV system especially those occurring near to the STATCOM Station and medium voltage bus of the STATCOM Station.

ii) Transient overvoltage due to switching operations and atmospheric effects.

iii) Temporary over voltages.

iv) Short circuits in the transformer secondary circuit such as

- Bushing terminal fault
- Flashover across a reactor, Bus Bar and other connected components/switchgear etc.

v) Protection system faults.

If the rated overvoltage is exceeded as a result of prolonged stressing or for other reasons, the protection specified elsewhere in the specification shall come into effect to prevent damage.

6.2.5. Dynamic Performance Controls of STATCOM Station

The TSP must describe in detail, the dynamic reactive power controls for enhancing stability margin and also damp oscillations of any critical frequencies. The dead band for continuous damping control must be very small so that there no discernible sustained oscillations.

6.2.6. Protective Control Functions

TSP shall provide all necessary protections including Main and Back-up protections for all protective zones and equipments like transformers, STATCOM Units, MSCs (if applicable), MSRs (if applicable), MV Bus Bar etc. TSP shall provide any protective control functions to meet the performance requirement of STATCOM under the scope of the TSP.

a) Overvoltage Protection

TSP shall provide adequate overvoltage protection as a result of any normal operation, mal-operation or system event.

b) Over current Protection

TSP shall provide adequate over-current protection for the STATCOM Station as a result of any abnormal operation, mal-operation or system event.

c) Gate level control Supervision

TSP shall provide adequate Sub module Gate level control supervision.

6.2.7. STATCOM Station Response

STATCOM station response shall be such that the change in measured system voltage to small disturbance should reach 90% of the desired total change within 30 ms of the initiating a 5% step change of voltage reference. The maximum overshoot should not exceed 120% of the total change and the settling time should not exceed 100 ms, after which the voltage should be within ±5% of the final value. This response characteristic within these limits must be respected when the system three-phase fault MVA is between the minimum and maximum value defined in clause-5. The response of the system voltage using the actual controller should be validated on a real time simulator during the Factory Acceptance Test (FAT) at the manufacturer's premises. For the purpose of STATCOM Station response time measurement and signal conversion of the voltage, error should not exceed 0.3%. The voltage response acquisition circuit should have a response time no longer than 10 ms. However, time longer than 10 ms can be allowed provided the requirement of STATCOM response time is met.

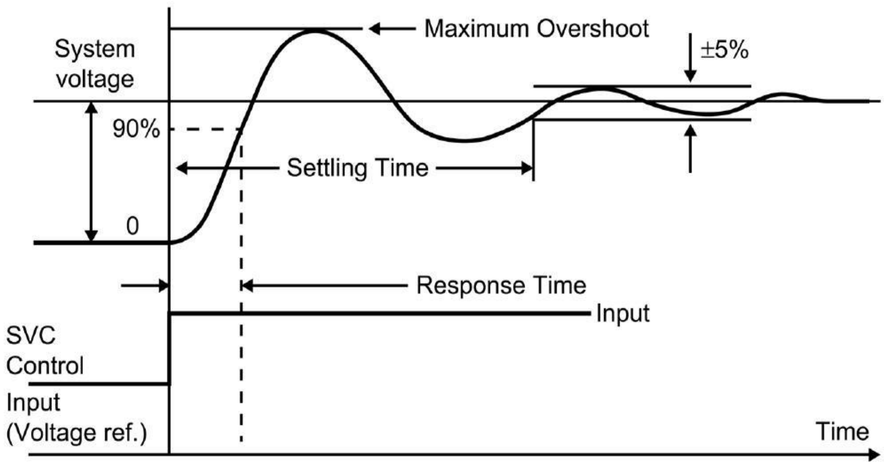

Figure-4 Response and Settling time

6.3. Harmonic performance and AC harmonic filter design

It is likely that with multi-level VSC based technology, no filters or only a small high-pass filter will be needed. The STATCOM shall be operable without AC filters. The STATCOM Station should be designed to eliminate the effects of any harmonic resonance between its MSRs, MSCs banks, filters branches, and the AC system. To limit the harmonic distortion imposed on the 400 kV transmission system, additional contribution of harmonic distortion from the STATCOM Station to 400 kV system (PCC) should not exceed 1% for total and 0.5% for any specific harmonic.

6.3.1. Filter performance

The distortion levels as specified should be met for the following:

a) The continuous range of all system and environmental conditions.

b) Variation in total filter capacitance due to manufacturing tolerance, ambient temperature, aging and changes in capacitance up to alarm level.

c) Variation in tolerance for STATCOM parameters, such as transformer winding unbalances, valve firing variations MSC and MSR unequal reactor and capacitor reactance between phases.

d) System frequency in the range of 48.5 Hz to 50.5 Hz. Calculation should take into account all possible combinations of STATCOMs, MSCs and MSRs.

6.3.2. Filter component rating

The harmonic filter components (and other STATCOM components) should be rated to carry continuously the harmonic currents caused by the background harmonic distortion of the system and the harmonic currents produced by the STATCOM itself. Unless otherwise specified, harmonic currents from the system and the STATCOM of the same order should be added arithmetically. All filter harmonic currents of different order should be added quadratically (root sum of squares).

The rated voltage of capacitors should be derived from the largest arithmetic sum of the power-frequency and individual harmonic voltages obtained from stress calculations in continuous operating conditions (Note: Maximum fundamental voltage and maximum harmonic contributions may not exist at the same time for STATCOM configurations including MSRs or MSCs).

For filter capacitor voltage rating, the loss of capacitor unit or elements should be considered up to the trip level.

The rated voltage of so-called "low voltage" capacitors (e.g. in double or triple tuned filters) should be chosen such as to also withstand imposed transient stresses from faults, energization or other switching events.

6.3.3. Harmonic at PCC

The STATCOM Station contribution to the harmonic distortion levels at the STATCOM Station connection point (PCC) to the transmission system shall not exceed the limits below.

Following are the maximum limits given using denominations according to IEEE STD 519-2019. The 2nd to the 60th harmonics should be considered.

Individual harmonics voltage distortion (Dn) < or = 0.5 %
Total Harmonic voltage distortion factor (THD) < or = 1 %

6.3.4. Harmonic calculation:

Chapter 7.3 of CIGRE Publication 139 together with information in PSSE network files given shall be used for the Network harmonic impedance.

6.4 MV Switchyard

- Medium Voltage (MV) delta bus shall be grounded through a Grounding Transformer (i.e. zig-zag winding Transformer) along with suitable resistor in the neutral.
- MV Switchyard of different STATCOM Station branches shall be fenced with the fence height of 3 meter. Suitable arrangement i.e. electrified fence shall be done to prevent the encroachment of unwanted animal or other to minimize the probability of electrical faults (Ph-E, Ph-Ph). Further bus bar arrangement shall be made in a way to minimize the probability of electrical faults.
- Secondary side of the Coupling Transformer shall be provided with suitable surge capacitors to mitigate transfer surges.
- For MV bus bar, Aluminum conductor (Tube, Rectangular Hollow Section or C Section) may be used, however, suitable bus bar end cover/cap shall be provided to avoid any animal/bird entering the hollow space.

6.5 Broadband Interference

6.5.1 Radio Interference (RI)

The TSP shall take necessary precautions in the form of shielding of valve hall and building or Containers. Further, the following requirements shall also be met:

a) With the STATCOM Station operating at any load upto rated value and within the design range of firing angle, the radio interference level from electromagnetic or electrostatic inductions generated by the STATCOM station shall not exceed 100 micro-volts/m, under fair weather conditions, at any point outside the station fence. The RI criteria shall be achieved at all frequencies within the range of 150 kHz to 300 MHz and with the STATCOM operation at any level up to and including rated value, the design shall provide correcting measures, should the specified design not being realized in the final installation.

b) Measurements of actual RI at STATCOM Station shall be made by the TSP, at points along the above defined contour and at other critical point.

c) RIV (Radio Interference voltage) measured at a phase to ground voltage (266 kV rms) in accordance to NEMA-107 shall not be more than 500 micro-volts for 400 kV system. For other system voltages IEC/NEMA in the order of preference shall be applicable.

6.5.2 Interference with Power Line carrier & open wire carrier system

The TSP shall take the necessary precaution in the form of noise suppression techniques and filtering devices to prevent harmful interferences from STATCOM Station to Power Line Carrier Communication (PLCC) system operating on connected AC transmission network.

The frequency spectra to be protected are:

System	Frequency spectrum
Power Line carrier	30 kHz to 500 kHz
Open wire carrier	5 kHz to 30 kHz

6.6. Audible Noise

The TSP shall limit the audible noise in various areas of the STATCOM Station buildings and Containers to the following values.

Valve hall (Inside)	90 dBA
Mechanical equipment areas indoor (measured at 2 metre distance)	75 dBA
Mechanical equipment outdoor (Measured at 15 m distance)	75 dBA
Control Room Building*	60 dBA
At the limits of STATCOM STATION perimeter fence	80 dBA

**This is the background noise from the ventilation system adjacent rooms, control cubicles etc. Printers, recorders may be switched off during measurement.*

6.7. Loss Requirements

6.7.1. The TSP must guarantee the total losses of STATCOM Station, be less than 1% of the reactive power output individually at its inductive limit (STATCOM+MSRs) and capacitive limit (STATCOM+MSCs) for the cumulative highest reactive power output of STATCOM Station at PCC with worse combination of manufacturing tolerances. For the purpose of total loss measurements, it should be assumed that ambient temperature is 20°C, the PCC voltage is 1 per unit, and the slope setting is 1 %. The STATCOM system may not operate at these conditions, but they provide a common base.

6.7.2. The total losses shall include all components, as well as different parts or subsystems of complete STATCOM Station such as coupling transformer, All VSC systems and components, MSC Capacitors and Reactors, MSR Reactors, Control and protection systems, including ancillary devices such as HMI, fault recorders, and SCADA, Auxiliary Power supply systems, cooling systems, Building ancillary services such as lighting, air conditioning, heating, and ventilation. It may be noted that for the redundant VSC valve levels and dual/redundant control and protection systems, the losses of redundant VSC valve levels and dual control and protection systems shall be considered during loss measurement.

6.7.3. For the dual or redundant systems design of STATCOM Station, such as dual pumps or redundant fans, dual systems losses to be excluded, if the dual system is not in service during the normal operation of the STATCOM Station. However, dual systems should be included if they are required to be in service under the defined operating conditions. The same methodology shall be applied for HVAC (heating ventilation and air conditioning systems).

6.7.4. The TSP is required to prepare documentation for the detailed calculation of total losses based on measurement during Factory Acceptance Tests of major equipment and systems mentioned above as per relevant IS/IEC/IEEE standards & same shall be preserved and to be submitted to CEA/CTU/GRID-INDIA, as per their request. Further for equipment/systems, whose loss measurement cannot be done during Factory Acceptance Test, the same can be measured at site, and a combination of calculation and measurement shall be used to derive the total losses as specified above. During Loss measurement, all fans and pumps; valve room and control room air-conditioning system shall be switched on. However, redundant fans, pumps & air-conditioners shall be kept off during loss measurement.

6.7.5. During the factory tests the losses for the following equipment shall be measured/ assessed as detailed below:

Coupling transformer:

Losses shall be measured at factory/lab at the maximum rating, at power frequency as per relevant

IEC/IS under below conditions:

i. No load loss (Iron loss) at rated voltage and fundamental frequency.

ii. Load loss (copper loss) at rating corresponding to maximum continuous current and at 75°C.

iii. Transformer cooling equipment's loss (Auxiliary loss) at rated voltage and fundamental frequency.

Reactors:

The losses shall be measured at factory/lab at the maximum rating at power frequency as per relevant IEC/IS.

VSC Valves: Converter losses are composed of losses in power electronic switches [Insulated Gate Bipolar Transistor (IGBT) or equivalent], made up of conduction and switching losses, and the losses in DC capacitors, resistors, and inductors used within the converter system. Refer IEEE-1052 for calculating VSC losses.

Capacitor:

The capacitor losses shall be measured at manufacturer's works at power frequency as well as calculated to obtain the losses in the complete bank on the basis of factory measurement.

Auxiliary System:

Auxiliary power losses shall be calculated from the KW and efficiency of all motors (name plate rating) of the cooling system, air conditioning, ventilation etc. The higher of the total losses for the entire auxiliary systems occurring at full capacitive capacity MVAR or full Inductive MVAR as the case may be shall be considered for arriving at the total losses.

Harmonic Filters, if any:

The losses shall be calculated at the maximum STATCOM Station loading at 400 kV and 50 Hz.

The calculations shall be on the basis of tested results of the components.

6.8. Selection of Insulation levels

6.8.1. Arrestors:

Protective levels of arresters connected to the 400 kV AC Bus Bars of the STATCOM Station shall be coordinated with the insulation and surge arrester Characteristics of the 400 kV AC systems to which the STATCOM Station is to be connected. The specification and characteristics of the surge arresters installed in 400 kV AC system is given in Substation specification. The Front of Wave Withstand Level (FWWL), Lightning Impulse Withstand Level (LIWL) and Switching Impulse Withstand Level (SIWL) shall be determined by the following margins:

a) A SIWL at least 1.15 times the switching impulse protection level.

b) A LIWL which is an IEC standard level corresponding to the SIWL and shall be at least 1.25 times the lightning impulse protection level.

c) A FWWL which is at least 1.25 times the front of wave protection level.

In addition to above minimum basic requirement the various insulations level of 400 kV equipment shall be as below. The STATCOM Station equipment, coupling transformers etc. shall be co- ordinated accordingly.

	SIWL	LIWL
All equipment including Transformer Bushing and winding	1050 kVp	1425 kVp

6.8.2. Valves

The requirement of insulation levels of the valves shall be as per the design requirement.

6.8.3. Air clearances

The air clearances shall be determined by the TSP based on the required withstand levels for all waveforms in order to limit the probability of flashover within the STATCOM Station to a target value of one flashover in 15 years.

6.8.4. Switchyard

The air clearances for switchyard equipment shall be equal to or greater than minimum values as specified in IEC-60071. Altitude correction factor (if any) shall also be considered as per IEC.

6.8.5. Leakage distances

The Creepage/leakage distance across insulation shall be determined by the TSP and shall be adequate to ensure that under condition of heavy pollution, the probability of a flash over of an insulator does not exceed one in 15 years. However, the leakage distance for all AC insulators for outdoor installation shall not be less than 25 mm/kV of the maximum operating phase to earth rms voltage at the insulator. The leakage distance of equipment connected to 400 kV systems shall not be less than 10500 mm.

Specific creepage distance for outdoor bushings, insulator strings and long rod insulators shall be minimum 31mm/kV.

6.9. STATCOM Station availability and reliability

The following definitions apply:

6.9.1. Outage terms:

a) Outage

The stage in which an equipment is unavailable for normal operation due to an event directly related to the equipment which results in reduction in STATCOM Station capacity.

b) Scheduled Outage

An outage which can be scheduled at least one week in advance

c) Forced outage

The stage in which the equipment is unavailable for normal operation but is not in the scheduled outage stage and which results in reduction in STATCOM Station capacity i.e. an outage which is not scheduled outage.

6.9.2. Capacity terms

Maximum Continuous Capacity (Pm)

The maximum STATCOM Station capacity (MVAR) for which continuous operation under normal condition is possible.

6.9.3. Outage duration terms

Actual Outage Duration (AOD)
The time elapsed in hours between the start and end of an outage.

6.9.4. Time Categories

a) The number of hours in the reporting period in a full year, the period year is 8760 hours. If the equipment is commissioned, part way through a year, the period hours will be proportionately less than 8760 hours.

b) Total Outage hour (TOH)

The sum of all outage duration within the reporting period. TOH = AOD

6.9.5. Availability & Reliability Terms

Unavailability:

Unavailability is the duration for which the STATCOM Station is not available with specified rating due to forced outages per year. If part of the station is unavailable, then the unavailability duration shall be counted proportionally. However, if STATCOM is out then its duration shall count as fully unavailable STATCOM Station. However, If STATCOM unit is out then the STATCOM Station unavailability shall be counted proportionally STATCOM capacity. STATCOM Station Control system outage shall count as full STATCOM Station unavailability. 'OF' is the outage frequency which will be the number of forced outages per year.

The period basis for availability and reliability calculations shall be 12 months. The TSP shall ensure that the design will meet the specified guaranteed and design target value of availability and reliability.

Outage times for repair, maintenance and replacement of components shall be based on the premises that all items in the list of recommended spare parts are on hand, that all maintenance schedule of recommended maintenance are adhered to. Reliability calculations shall be made and shall be presented as the expected frequency of unscheduled loss of STATCOM Station capacity. For simultaneous occurrence of events, for either of which a loss of capacity would result, the longer repair time shall be counted.

The facilities shall be assumed to be utilized 100% of the time at 100% load, regardless of the actual reactive power generated/absorbed by the STATCOM Station. Hence the availability and reliability assessment will be based on the capability of STATCOM Station to generate/absorb the rated reactive power regardless of whether, it is in service or not.

6.9.6. Availability Requirement

The calculated availability of the system considered on the annual basis shall be equal to or exceed the following target values.

Minimum availability requirement of each complete STATCOM Station

- Guaranteed for STATCOM Station - 98%

The outages of STATCOM Station capacity caused by the failure of equipment outside the scope of the TSP shall not be considered for calculation of availability and reliability guarantee. However, such outage shall be restricted to

1) Complete loss to 400 kV supply (at PCC)
2) Human Error.

Circumstances causing curtailment of STATCOM Station capacity that will be included in reliability and availability assessment and which can lead to forced outages shall include but not be limited to the following:

a) Failure of equipment
b) Mal-operation of control and protection system
c) Failure to start
d) Reduction in capacity.

6.9.7. Reliability Requirement

a) Reliability

In the assessment of reliability, the following events shall also be considered to constitute a STATCOM Station outage:

i) A STATCOM Station shut down.
ii) A reduction of STATCOM Station capacity due to outage of any component of STATCOM Station

The calculated reliability of the complete STATCOM Station shall be equal to or exceed the following design target values.

The average outage frequency per year for each STATCOM Station shall not exceed the following values:

	Design target for STATCOM Station	Max acceptable Guaranteed value for STATCOM Station
Total Numbers of Forced Outage	3 x Nos. of STATCOM Station	5 x Nos. of STATCOM Station

6.9.8. Guaranteed Failure Rate of Sub modules (including all component and electronic): The maximum annual guaranteed failure rate of sub module (including all component and electronic) shall not exceed 1.0% per STATCOM. The failure rate shall not include failures directly attributable to operation and maintenance errors

6.9.9. GUARANTEED OF FAILURE RATE AC POWER CAPACITOR

The maximum guaranteed annual capacitor failure rate shall not exceed 0.15% except first unit failure. The capacitor shall be considered as failed if its Capacitance value varies more than ±5% of the (actual measured) name plate value. Leakage of oil from the capacitor and deformation of the capacitor unit shall be considered as a failure even if the capacitance value is within the tolerance limits.

7. Design Principles

The objective for the design of the STATCOM Station shall be to achieve high level of availability and reliability as specified. Special attention shall be given to design the STATCOM Station to avoid forced outages. The TSP shall conduct thorough design reviews to ensure minimum risk of such outages. The TSP shall give careful attention to related factors affecting STATCOM Station performance such as subsystem & system testing, protective relays co-ordination and proper setting of relays.

Except where greater reliability requirements are specified in these specifications, the design basis for STATCOM Station shall be such that no single contingency downstream from the medium voltage bus shall cause a total outage of the STATCOM Station. The following general criteria shall be followed for the design of the control system:

a) Use of components similar to those whose reliability has already been proved in use.

b) Use of good design practices, surge protection, filtering and interference buffers to assure Immunity to sensitive component and circuits against damage and interference by induced voltages and currents in the external cabling and cubicle wiring.

c) Use of fail safe and self-checking design features.

d) Use of component and equipment redundancy, by means of either duplication or triplication with automatic transfer facilities wherever necessary to meet the requirement of these specifications.

e) Design which in the event of component failures, provide for transfer to a less complex operating mode.

f) Provision of alarm, fault diagnosis & indication

8. STATCOM Station Main Components

8.1. STATCOM Unit

The main electrical data of the STATCOM Units are the following:

o Rated voltage	20 kV Minimum
o Rated frequency	50 Hz
o Redundancy (Sub Module)	2 Nos. or 5% whichever is higher
o Rated Power of each STATCOM unit/Branch	± 50MVAR Minimum
o Valve Cooling	Deionized/Demineralized water

In general, the STATCOM units shall equally share the load however under contingency condition it should be possible to run the units with unequal load. Charging of the DC capacitors of Sub module during initial start-up shall be achieved by means of Resistors and bypass breaker arrangement. The charging resistor for DC capacitor of STATCOM Sub module should be designed for three charges per hour followed by appropriate cooling time. Power for the gate level control shall be derived internally from Sub module. The offered STATCOM Units with its Control system shall be suitably located inside the STATCOM Station Building.

8.1.1. STATCOM Valve

The valve shall be designed to meet the performance requirements described in this specification and as described below.

In order to ensure a modern low loss and reliable solution, the STATCOM valve assembly shall use the multi-module (including redundant sub modules) approach.
The valves shall be designed to ensure satisfactory operation according to the overall performance requirements and include all necessary auxiliary equipment required for smooth and reliable operation. The valves shall be indoor air-insulated and cooled by de-mineralized water. The valves shall be of modular design and have removable Sub-Module for ease of maintenance. The valves shall be mounted to allow easy access for visual inspection, routine maintenance and replacement, and facilities shall be provided to enable the easy access.

8.1.2. Semiconductor Switches

The electronic switches should be designed with the aim to achieve operation according to the overall performance requirements of the STATCOM Station. The valve shall be designed with individual semiconductor switches applied in a conservative manner with regard to their basic design parameters. The semiconductor switch shall meet the requirements of IEC 60747 except where otherwise specified herein. The proposed semiconductor switch shall be of a type which is in, or ready for, commercial operation with characteristics fully proven by recorded years of operation in other installations.

The semiconductor switches shall be designed to withstand all stresses expected under steady state, transient and temporary overvoltage conditions. Basic semiconductor devices shall be of the Press Pack type, or packaged to provide short circuit means in case of device failure such that the STATCOM can continue to operate without interruption. The adjacent sub module should be protected against possible explosion of semiconductor switch.

Under the restriction of redundancy (minimum two or 5% whichever is higher) i.e. the failure of any semiconductor switch or sub module or monitoring device etc. shall not prevent continued system operation. In the event of any of the above failure, the STATCOM shall annunciate and identify the specific location of the failed device and continue operation until such time as repairs can be scheduled. During such time the next shutdown can be availed, the STATCOM must continue to operate without downgrading STATCOM capability.

The switching device’s design should include an appropriate allowance for unequal voltage distribution across individual devices in the valve due to stray capacitor and component tolerances.

The switching device’s design should include an appropriate allowance for unequal voltage distribution across individual devices in the valve due to stray capacitor and component tolerances.

Each switching device should be able to operate within component ratings, generally with at least two failed sub-module or level. The number of possible failed sub-modules or levels as specified shall be consistent with the availability requirements of the STATCOM system.

8.1.3. Sub module for Multi-Module Topology

The key element of the Multi-Module topology shall be the Sub module. By increasing the number of these sub modules, it is possible to obtain high voltage with extremely low harmonic distortion and very low dv/dt using low switching frequency that reduces power losses. Sub module shall have the following characteristics:

Sub module shall be designed to guarantee high maintainability with self-sealing type hydraulic valves and electrical plugs for ease of installation or un-installation.

VSC sub-modules should be protected against overvoltages with appropriate strategies. Description of the failure mode of the switching device and the strategies used following failure should be provided.

In each fiber optic cable (having multiple fiber cores) used for control/communication purpose of sub-module at least two fiber cores shall remain available as spare for future use.

8.1.4. The STATCOM sub module has DC capacitors that require a charge to allow full functionality and performance. At the startup of the STATCOM Station, the capacitors are discharged. During the energization sequence of the STATCOM, Capacitors are charged from the main power grid via resistor operated in series to the main connection circuits. Once the desired charging voltages are reached, the charging resistor circuit is bypassed using bypass switch/breaker.

The Type and Rating of the charging resistor and associated bypass switch shall be designed with the aim to achieve operation according to the overall performance requirements of the STATCOM Station and shall conform to relevant Standard.

8.1.5. STATCOM Valve Cooling system

A closed-loop recirculating system shall be provided with full heat rejection capacity with redundancy for pumps, heat exchangers, and fans, appropriate to the STATCOM Station availability requirements. The cooling system should be able to maintain full capacity at maximum ambient temperature and maximum STATCOM reactive power output. The cooling system should be able to operate at the lowest ambient temperature and zero output specified. The Valve cooling system shall have black start capability and necessary UPS/UMD shall be provided separately for each STATCOM Unit.

The valve cooling system shall be designed to meet the performance requirements described in this specification and as described below.

a) Each STATCOM Unit shall have its own de-ionized water valve cooling system with redundant pumps.

b) For cooling the STATCOM valves, a deionized re-circulating (closed loop) water system shall be used.

c) Water to air heat exchanger shall be used for cooling of this de-ionized water. Water to water heat exchanger shall not be employed.

d) System shall be designed such that no shut down of STATCOM be resorted to for making up the deionized water in the system. The make-up water should comply with the recommended PH and purity.

e) Cooling water shall have a constant flow rate irrespective of loading. The flow rate shall be decided on the basis of extreme operating conditions.

f) The control system for cooling system shall be redundant type including the provision of redundant control supply and main power supply. However, in place of redundant control system for cooling system, suitable alternate mode is also acceptable meeting the requirement of fulfilling cooling system operation even if failure of cooling control.

g) 2x100% pumps with one as standby shall be provided for the primary. Should a pump failure occur, the second pump should automatically switch in without shutting down the STATCOM. An alarm shall be displayed at the control panel for failure of first pump and standby pump in operation.

h) Each cooling system shall be provided with independent/dedicated UMD supply however common battery for both UMD power supply may be accepted. A UMD system will provide an extended capability of the STATCOM Station to deliver reactive power without any interruption, adding a buffer against the system faults or during events such as delayed voltage recovery or TOV.

i) The secondary cooling system shall be redundant type such that it shall be possible to take out 10% (minimum one number) of the cooler module (fan unit) of secondary cooling system without affecting the rated performance of STATCOM).

j) The cooling system should be designed and provided to permit work on faulty pump / faulty fan without shutting down the system.

k) Normally no make-up water shall be required however in case of expansion vessel level going low; same shall be replenished automatically by means of make-up water tank and make up water pump to be supplied with the system.

l) TSP shall provide water treatment plant of sufficient capacity. The purification (treatment) system shall be designed to maintain the conductivity below 1 micro siemens. A resistivity cell in the outgoing water from deionizer should detect the depletion of ionized material. Filters and deionizers shall be designed to allow replacement during operation. Normal replacement shall not be required more than once every year.

m) Filters and deionizer/deoxidizer material shall be designed to allow replacement within minutes without shutdown of the cooling unit. (Normal replacement should not be required more than once/year).

n) Primary cooling system shall monitor its own operation and condition of cooling water.

o) The protection system of cooling cycle shall have minimum following alarms:

p) Depleted deionizing cell

   i) Depleted deionizing cell

   ii) Low water resistivity

   iii) High water temperature

iv) Primary pump stopped

v) Fan stopped

vi) Primary pump or fan interlock circuits faulty

vii) Primary cycle (Make-up water) tank level low

viii) Failure of control supply.

ix) UMD/UPS fault.

q) Following shutdown alarms / TRIP shall be provided with cooling system protection. Excessive low water resistivity Excessive high water temperature, complete loss of auxiliary supply to primary pumps, low flow, Low Pressure etc.

r) The dissipative components of the converter are cooled with deionized water.

s) The power losses are transferred to the external ambient by means of a deionized water /air heat exchanger. All the piping and other components Complete instrumentation set has been mounted on board in order to check the status of the cooling system:

- Conductivity gauge system.
- Flow meter equipped with two set points (alarm and trip).
- Pressure meter
- Two thermometers for inlet and two thermometers for outlet (two set points for alarm and trip)
- Thermostat

t) The status of the cooling system is monitored by means of the control system.

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

8.1.6. Tests on STATCOM Unit Valve

All applicable tests i.e. Operational Type Tests (except Short-circuit test), Dielectric Type Tests & Test for valve insensitivity to electromagnetic disturbance shall be done as per latest edition of IEC 62927. Partial Discharge test shall be done during routine test of each sub module without DC Capacitor in addition to other routine/production tests specified in IEC 62927.

8.2. STATCOM Station Control equipment and operator interface

8.2.1. Control Equipment

The control systems should achieve the functional objectives given in Clause 6.2. The accuracy of voltage should be within ± 1% of the reference voltage. The accuracy of the gradient and linearity of the slope delivered by the STATCOM Station should be defined in relation to the current deviation from the theoretical slope defined in Clause 3.1. The maximum deviation should be less than ± 5% of nominal current.

The control system design shall be based on single fail criterion i.e. failure of any one component in the system should not result in to outage of the complete system. As a minimum, a dual (hot standby) digital programmable controller shall be supplied for each STATCOM unit/branch and STATCOM Station to control the STATCOM, MSRs and MSCs completely including the functions listed as mentioned below:

a. The controller shall have diagnostic and self-checking features for both itself, and for valves, gate firing and drive circuits, interface hardware and software. This is required to reduce outage times and to facilitate fault finding.

b. The Controller shall be reprogrammable. The Owner shall have at least the following possibility for changing the following reference and limit values via HMI:

c. Closed loop Controllers:

   The STATCOM Station controller shall have means to modify the reference set points. This refers to the functionality that will allow all the control parameters to be adjustable within selectable limits and is inclusive of, but not limited to following:

   - Voltage controller
   - Q controller (reactive power controller).
   - Supplementary VSC current controller.
   - Other supplementary control functions.

d. Sequence Controllers:

   The sequence control and open-loop controllers shall include the control of all switchgears and associated control gear and external devices.

e. The Controller shall have at least 10% excess I/O capacity to allow future program upgrades to satisfy the changing requirements of the power systems or future extensions to the STATCOM Stations. As a minimum a control of up to 4 future HV shunt devices (reactors or capacitors) shall be included in the offer.

f. All control signals available for remote control must also be available locally so as to ensure that a local operator can operate the STATCOM Station if the communications link between STATCOM Station and remote control centers is lost.

g. A changeover switch shall be provided for control the selection of local or remote control.

h. Tsp shall provide the equipment necessary for the purpose of control, protection and interlocking of all equipments within the scope of supply.

i. TSP shall be responsible for design and coordination of control, protection and interlocking system and switching sequences within the STATCOM Station. All necessary interfacing required between AC switchyard equipment and STATCOM Station for the above purpose shall also be included in the scope of TSP.

j. It is proposed to control STATCOM through a Supervisory Control and Data Acquisition (SCADA) System. All the data shall be acquired through suitable means from field and various components and control is executed through the redundant HMI. The local STATCOM Station Control system shall consist of Redundant STATCOM Station controller, redundant HMI workstation, Gateway, STATCOM Station Control System Engineering cum Disturbance Recorder (DR), PC which can also be used as standby HMI workstations in case of emergency with associated peripheral equipment such as color laser log Printers, Color laser jet fault record printer, GPS System, Inverter / UPS etc. all interconnected via redundant Ethernet based Station LAN Network. Each work-stations and PCs at STATCOM Station shall have at least 19" LED display.

k. In addition to above, HMI workstation (identical to HMI Workstation provided in STATCOM Station control room) should also be provided in control room of main 400 kV substation. This HMI workstation should be powered from an independent UPS system sufficient enough to provide power to HMI workstation for minimum two hour in case of auxiliary power failure.

l. The control equipments shall satisfy the reliability and availability requirements specified in this specification

m. All necessary measures shall be taken to ensure satisfactory operation in presence of harmonic current and voltage, noise and radio interference signals. The equipments shall be designed to operate in the environmental conditions specified in the specification.

8.2.2. Operator Interface

a) Each STATCOM Station shall have a SCADA consisting of an HMI which shall provide a Centralized (local) operator control of the STATCOM Station functions. All human interface operations necessary for the control and monitoring of the STATCOM shall be provided at this point.

b) Any abnormal condition requiring operator action or intervention or maintenance on any of the STATCOM Station subsystems shall be annunciated at the STATCOM Station control room and the Substation control room.

c) The local HMI shall include the following diagrams as different screens in the display system:

   i. Complete STATCOM Units and STATCOM Station single line diagram including EHV and MV busses
   ii. AC Auxiliary supply and distribution
   iii. DC Auxiliary supply and distribution
   iv. STATCOM Valve cooling systems
   v. Interlocking system.

d) These diagrams shall indicate status, alarms, voltages, currents, etc. The HMI shall provide complete diagnostics on alarm and trip indications as required and discussed in this specification, including SER information.

e) A facility shall be provided whereby the local HMI features and functions shall be accessible from remote. A remote user shall be able to view screens and change STATCOM Station parameter settings.

f) As the substation where STATCOM Station shall be installed, will be equipped with Sub-station Automation System (SAS) conforming to IEC 61850, it is required that STATCOM Station control and monitoring shall be integrated with SAS already provided at main 400 kV Sub-station by the TSP. It is proposed to connect STATCOM Station SCADA with SAS through a Gateway and the database, configuration etc. of main substation SAS shall be upgraded to incorporate STATCOM Station events, alarms, Controls (both switchgear and control functions of STATCOM Station like setting of parameters etc.) so that STATCOM Station can be effectively monitored and controlled from main substation SAS and shall be monitored from Load Dispatch Center (NRLDC).

8.3. STATCOM Station Protection System

8.3.1 Protection system Design

a) To ensure that faults are cleared within stability critical clearing time, to minimize damage to plant, and to avoid voltage collapse, loss of load or load limitations, TSP shall provide a high speed main protection scheme. An independent (having separate measurement system) back-up protection scheme shall be provided in the event of the main protection scheme failing or switched out for maintenance.

b) The STATCOM Station shall be completely self-protecting (unit protection). STATCOM Station shall be protected from damage for all conditions of overcurrent, overvoltage, excessive reactive power loading, unbalance due to loss of capacitor elements, phase-to-phase and phase-to-ground faults, three phase faults, loss of cooling, semiconductor valve or control malfunction, faults (STATCOM, MV system) in individual primary connected components of the STATCOM, HV system faults, etc. The STATCOM Station shall withstand the maximum fault current for a period of the maximum fault clearing time as specified, considering second contingency cases due to the previously mentioned conditions.

c) All protection equipment and systems should be properly co-ordinated to prevent incorrect operations of the protection equipment or systems during normal STATCOM Station operation, including anticipated abnormal conditions on the transmission system, as specified. Fail-safe principles should be applied throughout.

8.3.2. The basic principle and order of precedence for the control and protection shall be, to take care of following:

- Correctly identify a fault, problem or error condition,
- Only if necessary, isolate the minimum number of components, subsystems whenever possible,
- Utilize degraded modes to the maximum extent possible either directly (no interruption of the STATCOM Station operation) or indirectly (by tripping the STATCOM Station momentarily in order to isolate the branch and re-energisation of the STATCOM Station).
- Trip STATCOM Station and Block.

a) Failure of the STATCOM Station Interface (SCADA interface) shall not result in a Protection trip of the STATCOM Station. A fail-safe philosophy shall be implemented to allow the STATCOM Station to operate safely and independently from the STATCOM Station Interface (SCADA interface).

b) Protection equipment shall be designed and applied to provide maximum discrimination between faulty and healthy circuits.

c) The Protection shall be sufficiently sensitive to cater for the full range from maximum to minimum fault level condition. The Protection shall also be suitable for a system fault level equal to the maximum short circuit capacity of the substation. All current transformer design shall be based on these fault levels.

d) All required protective, control devices, etc. including auxiliary instrument transformers and panels, relays, cabling, wiring, indication, and all other associated plant and material necessary for the effective operation of the protection systems shall be supplied and installed by TSP.

e) The protective relays shall be microprocessor based. Relays shall have approved characteristics and mounted in dust and moisture proof cases. The protective relays shall be provided with visual indication for starting, tripping and failure of the protective function. The LEDs shall be reset without opening the covers. The protection relays shall also be equipped with HMI facilities suitable for manual parameter settings and viewing of the settings. Relays with provision for manual operation from outside the case, other than for resetting, are not acceptable. Relay settings shall be visible and readable without having to remove the relay cover. Relays shall be of approved construction and shall be arranged so that adjustments, testing and replacement can be effected with the minimum of time and labor. Auxiliary Relays of the hand reset type if provided shall be capable of being reset without opening the case. Electrically reset tripping relays shall be provided as necessitated by the system of control, such as for those circuits subject to remote supervisory control.

f) Relay contacts shall be suitable for making and breaking the maximum currents which they may be required to control in normal service but where contacts of the protective relays are unable to deal directly with the tripping currents, approved Auxiliary tripping relays shall be provided. In such cases, the number of auxiliary tripping relays operating in tandem shall be kept to a minimum in order to achieve fast and reliable fault clearance times. Separate contacts shall be provided for alarm and tripping functions. Relay contacts shall make firmly without bounce and the whole of the relay mechanisms shall be as far as possible unaffected by vibration or external magnetic fields

g) Steps shall be taken to protect the circuitry from externally impressed transient voltages which could reach the circuitry via connections to instrument transformers or the station battery. The outing of cables should be such as to limit interference to a minimum. Any auxiliary supplies necessary to power solid state circuits shall be derived from the main station battery and not from batteries internal to the protection.

h) **Relay communication**

The Relays shall also have a communication port provided on the front of the relay for configuration and parameter settings as well as downloading of data. A direct port suitable for remote communication shall also be provided at the back of the Relay. This port shall conform to IEC - 61850.

i) **Tripping schemes**

- Tripping of MV circuit breakers shall be done by means of two separated trip signals.

- Duplicate high security tripping circuits for MV Circuit Breaker shall comprise two independent high speed (less than 10 ms) high burden (greater than 150 W) tripping relays for each circuit, each with its own independent DC supply. The trip circuits for all circuit breakers need to be equipped with a "lockout" function and it shall be possible for this to be reset manually and remotely by the operator.

j) The protection for the power system is based on a normal switching state and an occurrence of a single fault. This means that faults resulting from maintenance as well as the simultaneous occurrence of two or more faults are not taken into account.

k) The input circuits of the digital protections shall be monitored by means of a plausibility check. If any incorrect information is found, the protection function shall be blocked by the protection. All protection relays shall have facilities for monitoring trip circuits. Detection of an interruption in the case of a switched on circuit breaker shall be signaled.

l) **Test facilities**

- It shall be possible to test the protective device during operation without causing trips. Links shall be provided for isolation of individual protection trip circuits and the common protection trip circuit to each circuit breaker trip coil.

- Separate test facilities shall be provided for each current and voltage transformer secondary circuit so as to give access for testing of protection relays and associated circuits. The Test facility to be supplied shall have two selectable positions, a Service and a Test position. In the service Position, the test switch connects CTs and VTs signals to the Relays and trip commands to the circuit breaker trip coils. In the Test Position, the test switch applies a short-circuit to the CT secondary windings and open circuits the VT secondary cores and allow injection of secondary current and voltage into the relay. At the same time, the Trip commands to the Circuit Breaker Trip Coils are Isolated. The test Switch supplied shall be to the Approval of the Owner.

m) The protection of the electrical system shall be designed and installed in such a way that the failed equipment is disconnected selectively and automatically. All equipment are to remain operative during transient phenomena, which may arise during switching or other disturbances to the system.

n) **Auxiliary DC Supplies**

- The protection concept has to be designed in a way so that back-up protection is provided at all times. All protection relays shall be configured in a way that failure of one Auxiliary DC system will not affect the relay. If all DC supplies to the controllers are lost, the STATCOM Station breaker must be tripped via the protection panel.

o) **Electromagnetic Compatibility**

- Electronic Relays and other electronic devices and the ancillary circuits connected to them, such as power supplies, current and voltage transformer secondaries, status or tripping or alarm circuits shall be designed to ensure that they are compatible for use in the hostile electrical environment found in an MV or HV substation.
- Adequate steps by means of suitable design, shall be taken to prevent Electromagnetic Interference (EMI), (generated by sources such as circuit breakers, disconnectors, lightning, radio or radar emissions, switching contactors in dc circuits etc.) or Electrostatic Discharges (ESD) from affecting relay performance or causing damage to components.
- All relays offered shall therefore have been type-tested to meet the current requirements of IEC Standards with respect to High Frequency disturbance, Fast Transients, Electrostatic Discharge, Radio Frequency Interference testing etc.

p) List of Protection functions for STATCOM Station

Coupling Transformer Protection:

i) Biased Differential protection (87T)
ii) REF protection (64T)
iii) Overcurrent protection (50, 51)
iv) Ground Overcurrent (51N)
v) Overflux protection (HV and MV)
vi) Transformer mechanical trips

STATCOM MV Bus Protection:

i) Bus Differential protection (87)
ii) Ground over current protection (51N), used with neutral Grounding Transformer
iii) Under / Over Voltage (59 Ph-Ph) protection
iv) Over voltage (Open Delta) protection

STATCOM Branch Protection:

i) Differential protection (87)
ii) Overload protection (49)
iii) Overcurrent protection inside delta (50, 51)
iv) Negative phase sequence protection (46)
v) STATCOM branch overcurrent protection (50, 51, 50N, 51N)

MSR Branch Protection:

i) Differential protection (87)
ii) Ground over current protection (51N)
iii) Reactor branch unbalance protection (Negative Phase Sequence)
iv) Thermal Overload protection

MSC Branch Protection:

i) Ground over current protection (51N)
ii) Capacitor Overvoltage (Using current signal) protection.
iii) Capacitor unbalance protection (60C)
iv) Over current protection (50, 51)

- The protection functions listed above are minimum set of function to be provided, any additional protection required to fulfill the requirement of protection system shall also be provided.
- Further protection function of individual branch (STATCOM, MSC, MSR) shall trip the respective branch MV CB.
- All CBs shall be provided with individual Breaker Failure protection relay. Breaker Failure relay shall have the logic based on current signal or CB close open status.
- Any fault on MV bus will trip the 400 kV breaker. However, any branch fault shall be cleared by respective MV branch Circuit Breaker.
- Protection System for the STATCOM valve portion of the STATCOM station shall be provided in the redundant controllers to isolate the STACOM valve during internal overload/overvoltage, ground fault etc.

8.4. STATCOM Station Fault Recording System

An integrated Transient Fault Recording (TFR) System shall be supplied, installed & commissioned. This shall include trigger level settings for analog, etc. subject to review and comment. Disturbance and event recording facilities are required for local monitoring of the STATCOM following a disturbance on the power system or the STATCOM System. The following inputs are required:

- All analogue signals (output signals)
- All digital signals (control outputs, status indications, commands, alarms and trip indications). Internal STATCOM Station control signals/variables to be selectable.
- The accuracy of the TFR for event inputs shall be at least 100 µs (sampling rate of minimum 10 kHz).
- The TFR shall have provision for remote access and retrieval of recorded information on to a PC. For this purpose, a communication link to the Substation LAN shall be implemented.
- The remote software application for the data retrieval shall be included.

8.5. Mechanically Switched Reactor (MSR)

MSR is a fixed source of inductive reactive power connected in shunt to the MV bus of STATCOM Station and switched by means of Circuit breaker (with control switching device) based on the command from STATCOM Station control system. The rated capability of MSRs shall be at 400 kV (Referred to as “Point of Common Coupling” or PCC) and in the steady state frequency range of 48.5 Hz-50.5 Hz. However, The MSR Components shall be designed with the aim to achieve operation according to the overall performance requirements of the STATCOM Station. The individual components of MSR shall be able to withstand the onerous condition imposed by system overvoltage and harmonics. The MSR consists of 3-ph Air Core Reactor, 3-ph MV Circuit breaker (SF6/Vaccum type), associated current transformer, 3-ph Disconnector and associated safety grounding switch. The MSR area shall be fenced and castle key interlock with safety grounding switch shall be provided for human safety.

Specification for individual components like Air core reactors etc. is provided in the subsequent clause.

8.6. Mechanically switched capacitor (MSC)

MSC is a switched 3-phase capacitor bank connected in shunt to the MV bus of STATCOM station and switched automatically by means of Circuit breaker (with control switching device) based on the command from STATCOM Station control system. The rated capability of MSCs shall be at 400 kV (Referred to as “Point of Common Coupling” or PCC) and in the steady state frequency range of 48.5 Hz-50.5 Hz. However, TSP will ensure the corresponding values at PCC (400 kV) for possible operating condition measured at PCC. The MSC Components shall be designed with the aim to achieve operation according to the overall performance requirements of the STATCOM Station. The individual components of MSC shall be able to withstand the onerous condition imposed by system overvoltages and harmonics. The MSC consists of 3-ph AC power capacitor bank, current limiting air core reactor as required, 3-ph MV

Circuit breaker (SF6/Vaccum type), associated current transformer, 3-ph Disconnector and associated safety grounding switch. The MSC area shall be fenced and castle key interlock with safety grounding switch shall be provided for human safety. Specification for individual components like Capacitors, Air core reactors etc. is provided in the subsequent clauses.

8.7. Air Core Reactors

a) Reactors shall be air core, dry type, be suitable for outdoor installation and there shall be no tapping on the reactors. The insulation level shall be adequate and TSP has to ensure proper insulation coordination.

b) The insulation of the reactor shall be class F and hot spot temperature rise shall not exceed 105°C above ambient temperature. Winding temperature rise shall not exceed 80°C above ambient temperature.

c) The reactor shall be designed to withstand thermal dynamic shocks and mechanical shocks while in service and during erection.

d) The reactor shall fully conform to the relevant IEC standard.

e) The reactor shall be designed to withstand overloading due to over voltage as specified and shall also be subjected to excitation by harmonics; the reactor must be able to withstand such events without deterioration in normal life.

f) All internal (with in a reactor coil) current carrying connections shall be welded/brazed or compressed joint.

g) All terminals shall be either tin plated or silver plated.

h) Lifting lugs shall be provided for handling of the reactor.

i) The reactor shall be vertically mounted.

j) The reactors shall be subjected to type and routine tests in accordance with the latest issue of IEC-60076 as appropriate to the type of reactor provided.

k) Tests on Reactors: The reactors shall be subjected to type and routine tests in accordance with the latest issue of IEC-60076 as appropriate to the type of reactor provided.

8.8. AC POWER CAPACITORS

i) General

a) The capacitor banks shall comprise of capacitor units, discharge devices, protection equipment, series reactor as required, earthing switches, suitably connected in series and parallel, mounted at ground level with protected fencing all round. The number, arrangement and connection of capacitor banks shall be designed to suit the requirement of compensator as a whole. If convenient, the capacitor banks may be used in conjunction with reactors. In this event the rating of capacitor shall be adequate to cope up with the harmonic loading. The frequency variations shall also be considered. To limit the peak in rush current for switching in the capacitors, current limiting reactors with parallel connected damping resistors if required shall be connected in series with shunt capacitor banks.

b) The capacitors shall be provided with internal type fuses. Alternatively, fuseless capacitor is also acceptable.

c) Fuses shall not melt nor shall deteriorate when subjected to the inrush current during the life of the bank.

d) With the capacitor charged to a peak voltage, the fuses associated with the healthy elements shall not melt when carrying the discharge current resulting from a breakdown of an element or from an external short circuit.

e) Fuses shall be capable of disconnecting a faulty element over a range of voltage across the unit terminals from 0.9 times rated unit voltage (Un) to 2.0 Un. In addition, if all the elements in same row of an internally fused capacitor were to fail as a result of a cascading action, the last fuse element to melt shall be capable of successful disconnection with a voltage of not less than 1.5 times.

f) After fuse operation the fuse assembly shall be able to withstand continuously at least 1.5 times rated unit voltage Un across the gap for 10 Seconds.

g) Fuses shall be preferably of the current limiting type but fuse system shall in any event be designed to ensure that energy released into a faulty capacitor unit is less than the valve that will cause rupture or bursting of the container.

h) The capacitor units shall be outdoor type. The container of the capacitor shall be of stainless steel.

i) Each capacitor unit shall be readily accessible and replaceable without disturbing any other unit. The supporting frames shall be designed to provide adequate ventilation to the units.

j) The dielectric fluid used in capacitor unit shall be environmentally safe & bio-degradable, non-toxic. Polychlorinated biphenyle (PCB) type dielectric or any of its derivatives shall not be acceptable.

ii) Construction & Design Requirement

a) The capacitors shall conform to IEC-60871. The capacitors shall be provided with internally mounted discharge resisters with characteristics in accordance with IEC-60871.

b) The current limiting reactors (as required) shall be dry type and connected in series with the capacitor bank. Suitable lifting lugs shall be provided.

c) The capacitor enclosure shall have sufficient strength to withstand without damage or loss of life, mechanical load, both in operation and during erection. The loads shall include electromagnetic forces including those during faults external or internal to the capacitor bank, wind loading, forces due to expansion and contraction caused by ambient temperature and load variation and seismic effects all as specified.

d) The capacitor units shall be interchangeable in order to reduce the spare requirements and simplify maintenance procedures.

e) The capacitor stack shall be vibration free. Stack shall have a fixed potential, that is connected to one electrical points in the bank. The stack shall be of galvanized structural steel.

f) The capacitor racks shall be supplied complete with all capacitor units, insulators, and connection and shall be equipped with lifting lugs/eyes to facilitate assembly into the stacks. The racks shall be constructed of galvanized structural steel. No drilling of galvanized steel shall be allowed. Each rack shall be labeled with the weight of the fully equipped racks, the phase and bank of which it forms a part. The maximum and minimum capacitor unit capacitance which may be substituted into the racks as spares shall be suitably identified. Suitable warning labels shall be affixed.

g) The capacitor shall be specially designed to be suitable for intermittent duty to which they are suitable to.

h) The capacitors should comply with the overload capacity as per NEMA.

i) The capacitor elements shall be vacuum dried inside the case prior to impregnation with dielectric fluid. After impregnation, the capacitor unit shall be sealed immediately upon removal of the impregnated reservoir.

j) The discharge register shall discharge the unit from peak operating voltage to less than 75 Volts within 10 minutes.

k) The capacitor case shall be made from type 409 stainless steel or equivalent stainless steel with all joints welded and tested for leaks.

l) All racks and bus insulators as well as the insulators used to insulate each stack of capacitor from ground level shall be pincap or post type. The minimum voltage rating shall be 15 kV and low frequency wet withstand voltage of all insulator used to insulate within or between the capacitor racks of a stack shall not be less than three times the actual voltage stress across the insulators. The insulator shall be outdoor type manufactured from wet porcelain. The insulators shall be bolted to the top members of the frame to support electric grade aluminum buses.

m) The size and groupings of the individual capacitor units shall be such that a single blown fuse will not cause the voltage across parallel group to rise by more than 10%.

n) The redundancy to be provided, shall be as per requirement specified regarding reliability and availability in clause mentioned elsewhere.

iii) Capacitor Unit Failure Detection

The stages of capacitor units or element failure detection shall be provided as below.

a) A three-step unbalanced current protection shall be provided in each capacitor bank to initially generate an alarm when the unbalance limit is reached and finally to trip the bank in case of limit being exceeded.

b) The first stage shall generate an alarm and the capacitor unit shall continue in service. It may be assumed that the bank shall be disconnected for maintenance within 2 weeks.

c) The second stage shall generate a separate alarm and a delayed trip signal which will disconnect the bank after two hours.

d) The third stage shall cause immediate disconnection of Capacitor Bank.

iv) Tests on Capacitors

All the tests on capacitor units shall be generally in accordance with the latest issue of IEC publication 60871.

8.9. Coupling Transformer

The TSP shall provide 04 Nos. single phase coupling transformer to operate as 3- ph bank with one unit as spare for stepping down the voltage from 400 kV system to a suitable medium voltage value as required. The Medium Voltage side of the coupling transformer to couple with the STATCOM shall not be less than 20 kV to ensure optimum power transformation.

The Coupling Transformer shall be designed with the aim to achieve operation according to the overall performance requirements of the STATCOM Station. The transformer should be designed & rated to carry complete capacitive and inductive reactive loading as specified for STATCOM Station including that of mechanically switched capacitor and Reactors etc.), as well as harmonic currents associated with the most onerous operating conditions of STATCOM Station, without loss of life.

The coupling transformer shall be designed in accordance with the most upto date experience in STATCOM application and shall incorporate the latest improvements of design currently employed in the industry. The Comprehensive design review of Coupling Transformer of STATCOM Station shall be carried out by the TSP.

8.9.1. General Requirements

The coupling transformer shall be designed electrically and mechanically for operating conditions peculiar to STATCOM Station operation, which shall include, but not be limited to the following:

a) Electrical insulation problems resulting from the transformer being subjected to voltages of distorted sinusoidal wave shape because of saturation, harmonics, trapped DC. in capacitors etc.

b) The cumulative effect of electro-dynamic forces produced during valve commutation or other short circuit conditions imposed by valve design limitation and valve group operation.

c) Harmonic currents due to STATCOM operation, with particular reference to additional stray losses resulting from these harmonic currents.

d) No generation of uncharacteristic harmonics by the transformers.

e) Stresses due to normal control operation and other onerous operations such as blocking and de-blocking.

f) Stress due to fast response requirement of STATCOM for loading from 100% inductive to 100% capacitive and vice-versa.

g) Overvoltage stresses for which STATCOM shall be designed as per specification would apply for transformer also.

h) All other stresses for which STATCOM Station shall be designed as per specification would apply for transformer also.

i) The transformer and all its accessories like Bushings, CTs etc. shall be designed to withstand without damage, the thermal and mechanical effects of any external short circuit to earth and of short circuit across the terminals of any winding for a period of 3 seconds. The short circuit level of 400 kV system to which the transformer shall be connected as per the maximum short circuit level of main substation. Short Circuit level of the Coupling Transformer shall be as per Short Circuit level of the respective Substation. Short circuit level for HV bushing shall be 63 kA for 1 Sec**.**

j) The transformer shall be capable of being loaded in accordance with IEC-60076 or the overload conditions as specified which is worst. There shall be no limitation imposed by bushings during its terminal fault.

k) The transformer shall be capable of withstanding the mechanical stresses caused by symmetrical or asymmetrical faults on any winding.

l) The transformer should be designed to carry a certain level of direct current consistent with the STATCOM design. To ensure minimum harmonic generation, the saturation flux density of the transformer should be higher than the maximum flux density reached over the full steady state (continuous operating) range; this margin shall be at least 10%. This maximum flux density (over the full steady state range) is obtained at the highest secondary voltage during any reactive power generation, highest reference voltage, minimum slope, and minimum continuous frequency. The flux density at the highest secondary voltage shall lie in the linear portion of the B-H curve. Any harmonic generated by the transformer should be considered by the design of the STATCOM.

m) All protection class Current Transformers in coupling transformer shall be of PX/PS type. Other details of these Current Transformers shall be as per protection/metering requirement and shall be decided during detailed engineering. However, the parameters of WTI Current Transformer for each winding shall be as per Coupling Transformer manufacturer.

n) Transformers shall be capable of operating under natural cooled condition up to the specified load. The forced cooling equipment shall come into operation by pre-set contacts of winding temperature indicator and the transformer shall operate as a forced cooling unit initially as ONAF up to specified load and then as OFAF. Cooling shall be so designed that during total failure of power supply to cooling fans and oil pumps, the transformer shall be able to operate at full load for at least ten (10) minutes without the calculated winding hot spot temperature exceeding 140 deg C. Transformers fitted with two coolers, each capable of dissipating 50 per cent of the loss at continuous maximum rating, shall be capable of operating for 20 minutes in the event of failure of the oil circulating pump or blowers associated with one cooler without the calculated winding hot spot temperature exceeding 140 deg C at continuous max rating.

o) The transformer shall be free from any electrostatic charging tendency (ECT) under all operating conditions when all oil circulation systems are in operation. In general, oil flow speed shall not exceed 1.0 m/sec within winding in the oil flow system of the transformers. The manufacturer shall ensure that there is no electrostatic charging tendency in the design.

The Technical Parameters of Transformer shall be as below

Sl. No.	Description	Unit	Technical Parameters
1.1	Rated Capacity		
	HV	MVA	To meet the performance requirement & ratings of STATCOM. The transformer shall be suitable for 100% reactive loading
	MV	MVA	
1.2	Voltage ratio (Line to Line)		400 / XX (*)
1.3	Single / Three Phase Design		Single phase
1.4	Applicable Standard		IEC 60076
1.5	Rated Frequency	Hz	50
1.6	Cooling & Percentage Rating at different cooling		ONAN/ONAF/(OFAF or ODAF): 60% / 80%/100% OR ONAN/ONAF1/ONAF2: 60% /80%/100% OR OFAF (with 5 x 25% unit cooler if required)
1.7	Impedance at 75 Deg C		

Sl. No.	Description	Unit	Technical Parameters
	HV–MV		To suit the design requirements.
1.8	Tolerance on Impedance (HV-MV)	%	As per IEC
1.9	Service		Outdoor
1.10	Duty		Continuous Reactive loading
1.11	Overload Capacity		IEC-60076-7
1.12	Temperature rise over 50 deg C ambient Temp		
i)	Top oil measured by thermometer	^{0}C	45
ii)	Average winding measured by resistance Method	^{0}C	50
1.13	Windings		
i)	System Fault level		
	HV	kA	63
	MV	kA	To suit the design requirements.
ii)	Lightning Impulse withstand Voltage		
	HV	kVp	1300
	MV	kVp	*
	Neutral	kVp	170
iii)	Switching Impulse withstand Voltage		
	HV	kVp	1050
iv)	One Minute Power Frequency withstand Voltage		
	HV	kVrms	570
	MV	kVrms	*
	Neutral	kVrms	70
v)	Neutral Grounding		Solidly grounded
vi)	Insulation		
	HV		Graded
	MV		Uniform
vii)	Tan delta of winding	%	< 0.5
1.14	Vector Group (3 – ph) (unless specified differently elsewhere)		YNd*
1.15	Tap Changer		Not Applicable
1.16	Bushing		
i)	Rated voltage		
	HV	kV	420

Sl. No.	Description	Unit	Technical Parameters
	MV	kV	*
	Neutral	kV	36
ii)	Rated current (Min.)		
	HV	A	*
	MV	A	*
	Neutral	A	*
iii)	Lightning Impulse withstand Voltage		
	HV	kVp	1425
	MV	kVp	*
	Neutral	kVp	170
iv)	Switching Impulse withstand Voltage		
	HV	kVp	1050
v)	One Minute Power Frequency withstand		
	Voltage		
	HV	kVrms	695
	MV	kVrms	*
	Neutral	kVrms	77
vi)	Minimum total creepage distances		
	HV	mm/kV	31mm / kV
	MV	mm/kV	31mm / kV
	Neutral	mm/kV	31mm / kV
vii)	Tan delta of bushings		
	HV	%	Refer Note 2
	MV	%	Refer Note 2
viii)	Max Partial discharge level at Um		
	HV	pC	10
	MV	pC	10
	Neutral		-
1.17	Max Partial discharge level at 1.58 * Ur /√3	pC	100
1.18	Max Noise level at rated voltage and at principal tap at no load and all cooling Active	dB	80
1.19	**Maximum Permissible Losses of**		
	Transformers		
i)	Max. No Load Loss at rated voltage and Frequency	kW	To suit the design requirements.
ii)	Max. Load Loss at maximum continuous current and at 75^{O} C	kW	To suit the design requirements.

Sl. No.	Description	Unit	Technical Parameters
iii)	Max. Auxiliary Loss at rated voltage and Frequency	kW	To suit the design requirements.

Notes:

1. *No external or internal Transformers / Reactors are to be used to achieve the specified HV/MV impedances.*
2. *The criteria for Transformer losses shall be **"Copper Loss (Load Loss) > Iron Loss (No Load Loss) > Cooler Loss (Auxiliary Loss)"**.*
4. ***(*) marked parameters shall be decided based on STATCOM manufacturer's requirement***

8.10. STATCOM Station MV Switchgear

The MV Switchgear shall be designed with the aim to achieve operation according to the overall performance requirements of the STATCOM Station.

8.10.1. MV Circuit Breaker

The MV Circuit Breaker shall comply with the IEC and all other relevant Standards, and as specified in this specification. They shall satisfy the General Technical Requirements and shall be designed to operate in the environmental conditions specified in this specification.

The Circuit Breaker offered should be of SF6 type /Vacuum type only and of class C2, M2 as per IEC

i) The circuit breaker shall be complete with terminal connectors, operating mechanism, control cabinets, piping, interpole cable, cable accessories like glands, terminal blocks, marking ferrules, lugs, pressure gauges, density monitors (with graduated scale), galvanised support structure for CB and control cabinets, their foundation bolts and all other circuit breaker accessories required for carrying out all the functions the CB is required to perform.

ii) All necessary parts to provide a complete and operable circuit breaker installation such as main equipment, terminals, control parts, connectors and other devices whether specifically called for herein or not shall be provided.

iii) The support structure of circuit breaker shall be hot dip galvanised. Exposed hardware items shall be hot dip galvanised or Electro-galvanised.

iv) MV Circuit Breaker shall be equipped with controlled switching with consequent optimization of switching behavior, when used in:

- Switching of Capacitor Bank
- Switching of shunt Reactor Bank

v) Reactor Switching Duty test shall be conducted on MV Circuit Breaker in line with latest edition of IEC 62271-110.

vi) Type Tested for Back-to-Back Capacitor Bank Switching as per latest edition of IEC 62271-100.

vii) Routine tests as per IEC: 62271-100 shall be performed on all circuit breakers.

viii) The medium voltage circuit breakers in any of the branches shall be designed to switch off metallic three phase short circuits limited only by the transformer impedance of the STATCOM System (Coupling transformer) with the initial short circuit current and DC component according to IEC 60909-0. Thereby the worst case time constant where the maximum short circuit peak and DC component occur shall be considered. The network shall be considered to deliver the maximum short circuit power of the substation.

8.10.2. MV Isolator and Earth Switch

The isolators and earth switches shall comply with the IEC and all other relevant Standards, and as specified in this specification. They shall satisfy the General Technical Requirements and shall be designed to operate in the environmental conditions specified in this specification.

i) The isolators and accessories shall conform in general to IEC-62271 series as per relevance (or IS:9921) except to the extent explicitly modified in specification.

ii) Earth switches shall be provided on isolators wherever called for.

iii) Switches shall be motor operated with local & remote operation feature and local manual operation feature. Remote operation of Earth Switch is not required.

iv) Disconnections and earth switches shall electrically and mechanically be interlocked. Castle Key interlocking facilities shall be provided to mechanically interlock the earth switch and Isolator to the doors of valve rooms.

8.10.3. Instrument Transformers for STATCOM Station

The instrument transformers shall comply with the relevant IEC Standards. They shall satisfy the general Technical Requirement specified in specification and shall be designed to operate in the environmental conditions specified in this Specification. The instrument transformers provided for control, metering and protective relaying functions shall have voltage & current ratings, accuracy ratings and burden capabilities adequate to provide their designated functions within the overall accuracy requirement of the systems.

Voltage Transformers

Voltage transformers shall comply with the relevant IEC standards IEC 61869 (Part-1, Part-3 and Part-5).

Current Transformers

Current transformers shall comply with 61869 (Part-1 and Part-2). Type tests and routine tests as per relevant IEC.

8.10.4. Surge Arrester

TSP shall install the surge arresters necessary for the protection of the equipment associated with STATCOM Station in accordance with the requirements as per insulation coordination study. The surge arresters shall give consistent protection to their associated equipment against overvoltages produced by lightning or switching surges, internal or external station faults, and other system disturbances.

The surge arresters shall be rated such that they are able to discharge a specified maximum energy due to the application of lightning, switching surges, temporary over voltages and faults as determined by insulation coordination studies, without coming into the temperature region where thermal runaway could result upon subsequent application of maximum transient and steady state voltage conditions.

The arrester housing shall be porcelain/composite type. The end fittings shall be made of non-magnetic and corrosion proof material.

Internal components shall be designed to eliminate internal corona and also to ensure minimal capacitive coupling with any conducting layer of pollutant on the outside of the porcelain housing Particular attention shall be given to the high discharge currents which some of the arresters may experience in service due to discharge of stored energy of the ac filter and reactive compensating equipment, tripping of STATCOM etc.

8.11. STATCOM Station Auxiliary Power Supply

The auxiliary supply of STATCOM Station shall conform with the system requirements relating to reliability, availability, and redundancy, performing continuously to help ensure that the complete STATCOM Station operates as per the requirements. STATCOM station Auxiliary supply including all necessary switchgear (viz. AC/DC, lighting boards etc.) shall be completely separate from the main substation auxiliary supply, all loads of STATCOM station shall be fed from this supply. The auxiliary supply provides power to the controllers, cooling system, station supplies, and various other essential and non-essential loads. With the exception of the cooling system, all other essential loads are also connected to the DC system of the STATCOM Station which is also to be provided separately from the DC system of the main substation.

The auxiliary supply system shall be able to provide a stable supply for the STATCOM Station during system faults such as single-phase faults, phase-to-phase faults, and three-phase faults and LVRT (Low Voltage Ride Through) to allow continuous operation of the STATCOM Station during these transient events.

The auxiliary supply system of each STATCOM Station shall consist of two main incomers and one emergency incomer from DG set. The two main incomers shall be required to be paired to act redundantly to help ensure a certain degree of reliability and availability. One of the main incomer shall be supplied from 33 kV tertiary winding of ICT at the main substation. The other main incomer can be supplied from any one of the following three options:

- Supplied from Tertiary/Yoke winding of STATCOM coupling Transformer.
- Supplied from MV Bus Bar of STATCOM Station.
- Supplied from Power PT on HV side of coupling Transformer.

Wherever the Voltage variation on the incomer is very high, a solid state AVR (Automatic Voltage Regulator) shall be provided to control the auxiliary supply voltage.

All MV incomers shall be provided with suitable CB, disconnector, instrument Transformer etc. along with necessary protection system.

8.12. Fire Protection System for STATCOM Station:

Necessary fire protection for STATCOM units, Coupling Transformer, MSC, MCR and Harmonic filter (if any) shall be required. Fire-fighting system shall conform to CEA (Measures Relating to Safety & Electric Supply) Regulations.

Suitable fire detection system using smoke detectors and/or heat detectors shall be provided in STATCOM Station for all room and areas. These smoke fire detection system shall be connected to a separate Fire annunciation system clearly identifying the zone.

The hydrant system shall be extended from fire fighting system of the substation in the yard. Suitable no. of hydrant shall be provided for protection of STATCOM Station equipment in the yard namely Coupling Transformer, MSCs, MSRs and Harmonic Filter (if required) etc. as applicable for the station. Further suitable nos. of hydrant shall also be provided for STATCOM Station building.

If HVW (High Velocity Water) Spray system is provided for transformers and reactors of main substation, the same may be extended for coupling transformer.

8.13. Air-conditioning and ventilation system for STATCOM station

The STATCOM Station shall be provided with Air conditioning system as per requirement.

1) AC System (Except Valve Hall):

Air condition system shall be provided for the following rooms in the STATCOM Building:

a. Control and Relay room
b. Battery room
c. Conference Room
d. Store cum workshop
e. Cooling system room
f. Lobby

Capacity and quantity of the AC units shall be decided based on heat load calculation and redundancy requirement.

2) Air-Conditioning System for Valve hall:

Air-Conditioning shall be provided for each Valve room for maintaining the following inside conditions round the year:

Dry Bulb Temperature (DBT): 35 ^{o}C (Maximum)

Relative Humidity (RH) - 60% (Maximum)

The system shall be designed for an outside ambient temperature of 50 ^{o}C. Based on the above system design & parameters for valve room the AC system shall comprise of "AHU & Air-cooled DX Condensing units" with one Main & one Standby unit for each room. The system shall be designed for 24 Hours, 365 Days of the year operation to maintain the inside temperatures of the Valve Hall for proper operation of the critical equipment. The air-cooled condensing unit shall be designed for continuous duty.

9. Engineering studies

The TSP shall carry out studies as brought out in this section with a model of the STATCOM in PSSE and PSCAD and documentation of the same shall be preserved and to be submitted to CEA/CTU, as per their request. The objective of these studies is to verify the steady state requirement of reactive power under normal and contingent operating conditions for peak and light loads conditions in the network.

The studies shall have to be carried out for

- Peak Load
- Light Load
- Contingency Conditions

The load flow and dynamic file available with CTU shall be provided to the TSP in PSSE version 34 format. If data is not available typical data shall be assumed by TSP.

The studies should demonstrate that the STATCOM system meets all system and equipment specified performance criteria as per the specification. Engineering studies should include, but not be limited to, the studies described in subsequent subsections.

9.1. System dynamic performance studies

Dynamic performance studies should verify that the STATCOM system controls the system's dynamic performance during system disturbances. Dynamic performance studies include the following:

a. Studies verifying that the STATCOM provides adequate dynamic control to meet the system and STATCOM system performance criteria for the system conditions.

b. Study of response time and of the STATCOM system's behavior and contribution to the system's recovery from faults.

c. Studies to verify the operation of any supplementary controls designed to damp power oscillations following system disturbances.

d. Studies to evaluate the interaction of the STATCOM controls with the other nearby control systems, including High Voltage Direct Current (HVDC) controls, generator controls, and controls of other Flexible AC Transmission System (FACTS) devices.

In addition to the above, relevant studies shall include the cases stated as mentioned in Annexure-I

9.2. Harmonic performance

The studies should evaluate resultant maximum harmonic levels at the STATCOM system Point of Common Coupling (PCC), and determine maximum stresses on all

STATCOM system components. The study report should include the following:

a. Evaluation of specified system and operating conditions (refer to Clause 5) under all possible STATCOM operating conditions.

b. Evaluation within maximum ranges of STATCOM system component tolerances (worst performance values may not occur at detuning extremes).

c. Evaluation with maximum system voltage unbalance (refers to item 8 and item 9 in Table 3 of Clause 5).

d. Evaluation of worst case resonance condition between STATCOM system and overall system.

e. Evaluation of possible resonant overvoltages.

f. Transformer saturation induced harmonics for component rating calculation only.

g. Evaluation of impact considering single phase auto reclose deadtime.

9.3. Electromagnetic transients, control performance, and overvoltage studies

Transient overvoltage studies should be performed with the actual controls modeled to verify that the STATCOM system equipment is adequately protected against overvoltages and overcurrents (including excessive valve recovery voltages) from power system transients resulting from switching, fault clearing events, and credible STATCOM system misoperations. Evaluation shall include the following:

a. Study of start-up, including transformer energization, shutdown, switching coordination, and other local area network switching events

b. Study of STATCOM system protection and protection coordination

c. Faults on the HV and MV bus (single line-to-ground, phase-to-phase, and three-phase)

d. Faults across the VSC, capacitors, and other equipment if used

e. Control interaction

9.4. Insulation coordination study

Overall insulation coordination should be verified by considering the results of studies (dynamic overvoltages, and fault and switching transients), including the impacts of lightning surges on the STATCOM equipment. This study should determine and verify insulation levels, clearances, and arrester placement and ratings.

9.5. Other Studies

a) Grounding Study

b) Protection coordination

c) PLC/radio interference

d) Magnetic field strength

e) Other studies as applicable

9.6. Software simulation models

The TSP shall provide the latest following PSCAD and PSSE simulation model(s) and parameters to CEA/CTU/GRID-INDIA alongwith detailed documentation for the purpose of future simulation to adequately represent and model the proposed STATCOM system in the respective software:

a. **Stability model**. TSP should provide a detailed STATCOM system dynamics model for use in (PSCAD and PSSE) powerflow and stability simulation software. The model detail should be appropriate and complete for positive-sequence power system simulation and analysis that is typically performed with powerflow and transient stability programs. All appropriate control features for such analysis will be modeled, and necessary documentation on the theory and use of model should be provided. Stability model should be non-proprietary and freely available for distribution.

b. **Transients model**. TSP should provide a detailed STATCOM transients model for use in PSCAD. The model detail should be appropriate and complete for transient response calculation of the STATCOM system. All appropriate control features for such analysis will be modeled, and necessary documentation on the theory and use of model should be provided.

10. Factory tests of controls

The integrated nature of the performance of the STATCOM in an electrical grid requires the following tests:

a. The TSP should perform factory simulator system tests for integrated control and protection system to ensure the proper operation of the same. The control system should be connected to a digital simulator with adequate representation of the electrical network for various conditions. The STATCOM system controller needs to be representative of control functions, including basic controllers but inclusive of supplementary controls, firing controls, and protective functions integrated into the controllers.

b. The simulator should provide an accurate network representation including network harmonic behavior, as well as synchronous condensers, power stations, generators (with AVRs), and pump storage schemes, existing HVDC, SVCs and STATCOMs, future SVCs and STATCOMs, FSC (fixed series capacitors), and shunt reactors/capacitors/filters.

STATCOM system control function type tests on a simulator should include the following:

- Verification of each control function.
- Verification of control linearity.
- Verification of control redundancy.
- Verification of the monitoring system.
- Verification of the protection system with reference to integrated protective functions included in the Controllers and firing controllers.
- Verification of overall system performance for minor and major system disturbances.
- Verification of processor loading of all digital controllers.
- Verification of STATCOM system parallel operation with other controls in the system and control Stability.
- Verification of control equipment performance for auxiliary power supply voltage (AC and DC) and frequency variations (AC).
- Routine production tests of all control functions, and separately of all protection functions.

11. VISUAL MONITORING SYSTEM FOR WATCH AND WARD OF STATCOM STATION

Visual monitoring system (VMS) for effective watch and ward of STACOM station premises covering the areas of entire switchyard, STATCOM building, Coupling Transformer, Cooling Towers and main gate, shall be provided. The TSP shall design, supply, erect, test and commission the complete system including cameras, Digital video recorder system, mounting arrangement for cameras, cables, LAN Switches, UPS and any other items/accessories required to complete the system.

Features of VMS system shall be as those specified for main substation.

The number of cameras and their locations shall be decided in such a way that any location covered in the area can be scanned. The cameras shall be located in such a way to monitor at least:

a) Coupling Transformer, Mechanically Switched Reactors (if any) and Mechanically Switched Capacitors (if any), AC filter banks (if any).

b) STATCOM Valve hall, Cooling System, Electrical and Mechanical Auxiliary area.

c) Entrance to STATCOM Station.

d) All other Major Equipments (such as CB, CT, VT, SA etc.)

The cameras can be mounted on structures, buildings or any other suitable mounting arrangement.

12. Spares, Special Tools and Tackles

Considering high technology proprietary equipment of the STATCOM TSP shall ensure necessary spares are procured to maintain the necessary reliability and availability of STATCOM station. Further all necessary special tools and tackles required for erection, testing, commissioning and maintenance of equipment shall also be taken.

Annexure-I

Contingency Cases for Ramgarh STATCOM

A) N-1 Contingency

Contingency at 765 kV level

1. Three Phase Fault close to 765 kV bus of Ramgarh S/s followed by tripping of one circuit of Ramgarh- Bhadla-III 765 kV D/c line (fault persist for 100 ms)
2. Single Phase to Ground Fault close to 765 kV bus of Ramgarh S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Ramgarh-Bhadla-III 765 kV D/c line
3. Three Phase Fault close to 765 kV bus of Bhadla-III S/s followed by tripping of one circuit of Ramgarh- Bhadla-III 765 kV D/c line (fault persist for 100 ms)
4. Single Phase to Ground Fault close to 765 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Ramgarh-Bhadla-III 765 kV D/c line
5. Three Phase Fault close to 765 kV bus of Bhadla-III S/s followed by tripping of one circuit of Bhadla-III -Sikar-II 765 kV D/c line (fault persist for 100 ms)
6. Single Phase to Ground Fault close to 765 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Bhadla-III -Sikar-II 765 kV D/c line
7. Three Phase Fault close to 765 kV bus of Sikar-II S/s followed by tripping of one circuit of Bhadla-III -Sikar-II 765 kV D/c line (fault persist for 100 ms)
8. Single Phase to Ground Fault close to 765 kV bus of Sikar-II S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Bhadla-III -Sikar-II 765 kV D/c line

Contingency at 400 kV level

9. Three Phase Fault close to 400 kV bus of Fatehgarh-III S/s (Section-2) followed by tripping of one circuit of Fatehgarh-III S/s (Section-2) –Bhadla-III 400 kV D/c line (fault persist for 100 ms)
10. Single Phase to Ground Fault close to 400 kV bus of Fatehgarh-III S/s (Section-2) followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1

second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Fatehgarh-III S/s (Section-2) –Bhadla-III 400 kV D/c line

11. Three Phase Fault close to 400 kV bus of Bhadla-III S/s (Section-2) followed by tripping of one circuit of Fatehgarh-III S/s (Section-2) –Bhadla-III 400 kV D/c line (fault persist for 100 ms)
12. Single Phase to Ground Fault close to 400 kV bus of Bhadla-III S/s (Section-2) followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Fatehgarh-III S/s (Section-2) –Bhadla-III 400 kV D/c line
13. Three Phase Fault close to 400 kV bus of Bhadla-III S/s followed by tripping of one ckt of Bhadla-III–Fatehgarh-II 400 kV D/c line (fault persist for 100 ms)
14. Single Phase to Ground Fault close to 400 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Bhadla-III–Fatehgarh-II 400 kV D/c line
15. Three Phase Fault close to 400 kV bus Fatehgarh-II S/s followed by tripping of one ckt of Bhadla-III–Fatehgarh-II 400 kV D/c line (fault persist for 100 ms)
16. Single Phase to Ground Fault close to 400 kV bus of Fatehgarh-II S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. tripping of one circuit of Bhadla-III–Fatehgarh-II 400 kV D/c line

<u>Contingency at 220kV level</u>

17. Three phase fault close to 220KV Ramgarh PS bus with Tripping of one ckt of 220KV Adani Renewable Energy Holding Four Ltd. (600MW) - Ramgarh PS D/c line
18. Case 17+ Three phase fault close to 220KV Ramgarh PS bus with Tripping of other ckt (2^{nd}) of 220KV Adani Renewable Energy Holding Four Ltd. (600MW) - Ramgarh PS D/c line
19. Three phase fault close to 400KV Ramgarh PS bus, with Tripping of 400 kV Adani Renewable Energy Holding Four Ltd. (900MW) - Ramgarh PS line

B) N-1-1 Contingency

<u>Contingency at 765 kV level</u>

1. Case 1 & 2 (consider as separate cases) + Single Phase Fault close to 765 kV bus of Ramgarh S/s followed by single pole opening (100 ms) of the faulted phase (2^{nd} ckt of Ramgarh- Bhadla-III 765 kV D/c line) and successful re-closure (dead time 1 second)

2. Case 3 & 4 (consider as separate cases) + Single Phase Fault close to 765 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase (2nd ckt of Ramgarh- Bhadla-III 765 kV D/c line) and successful re-closure (dead time 1 second)
3. Case 5 & 6 (consider as separate cases) + Single Phase Fault close to 765 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase (2nd ckt of Bhadla-III -Sikar-II 765 kV D/c line) and successful re-closure (dead time 1 second)
4. Case 7 & 8 (consider as separate cases) + Single Phase Fault close to 765 kV bus of Sikar-II S/s followed by single pole opening (100 ms) of the faulted phase (2nd ckt of Bhadla-III -Sikar-II 765 kV D/c line) and successful re-closure (dead time 1 second)

<u>Contingency at 400 kV level</u>

5. Case 9 & 10 (consider as separate cases)+ Single Phase Fault close to 400 kV bus of Fatehgarh-III S/s (Section-2) followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. 2nd circuit of Fatehgarh-III S/s (Section-2) –Bhadla-III 400 kV D/c line
6. Case 11 & 12 (consider as separate cases)+ Single Phase Fault close to 400 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. 2nd circuit of Fatehgarh-III S/s (Section-2) –Bhadla-III 400 kV D/c line
7. Case 13 & 14 (consider as separate cases)+ Single Phase Fault close to 400 kV bus of Bhadla-III S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. 2nd circuit of Bhadla-III–Fatehgarh-II 400 kV D/c line
8. Case 15 & 16 (consider as separate cases)+ Single Phase Fault close to 400 kV bus of Fatehgarh -II S/s followed by single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line i.e. 2nd circuit of Bhadla-III–Fatehgarh-II 400 kV D/c line