



Title: Design, Manufacturing, Factory testing, Delivery, and on-site demonstration of High-Power (500Vdc, 5kA) Thyristor Converter at ITER-India, Institute for Plasma Research, Bhat, Gandhinagar, India

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Abstract:

This document defines the technical requirements for the procurement of 500Vdc, 5kA Full Controlled Thyristor Converter at ITER-India, Institute for Plasma Research, Bhat, Gandhinagar, India, and forms an integral part of the Contract.

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Acronyms

| | |
|-----|--|
| AC | Alternating Current |
| DC | Direct Current |
| DSP | Digital Signal Processor |
| DR | Deviation Report |
| FAT | Factory Acceptance Test |
| HP | Hold Point |
| ISO | International Organization for Standardization |
| LCD | Liquid Crystal Display |
| MIP | Manufacturing and Inspection Plan |
| NCR | Non-conformance Report |
| NP | Notification Point |
| RC | Resistive-Capacitive |
| SAT | Site Acceptance Test |
| SCR | Silicon-Controlled Rectifier |

1 Subject

This specification outlines the requirements for design, manufacture, factory testing at manufacturer's works, secure packaging, supply, transportation, delivery and onsite demonstration of **High-Power (500Vdc, 5kA) Full Controlled Thyristor Converter** at ITER-India, Institute for Plasma Research (IPR), Bhat, Gandhinagar, India.

All documents and information attached to this specification are considered part of it and must be complied by the prospective Supplier.

All deviations from this specification shall be clearly identified as such in a single document entitled "Exceptions to the Technical Specification"

1.1 Responsibilities

The responsibilities between the Parties is summarised in Table 1 (below) and is further detailed in the following sections.

Table 1: Summary of the Responsibilities between the Supplier and ITER-India

| Activity | ITER-India | Supplier |
|---|------------|----------|
| Phase 1 Design | | |
| Submission of design documents/simulations/datasheets | A | R, D |
| Phase 2 Manufacture, FAT and Delivery | | |
| Manufacturing | A | R, D |
| Factory Acceptance Testing | A | R, D |
| Packing and Delivery to the ITER-India, IPR site | A | R, D |
| Unloading at ITER-India, IPR site | R, A | D |
| Phase 3 Receipt & Acceptance | | |
| Receipt and Physical verification | R, A | D |
| Site Acceptance Test at ITER-India, IPR | R, A | D |

R = Responsible for organizing and performing the content

D = Responsible for Demonstration of the content

A = Review/Comment/Accept/Approve

1.2 Contract Execution

1.2.1 Outline of Contract Implementation

The overall procurement cycle is divided into following phases:

- Detailed/manufacture Design
- Manufacture
- Factory Acceptance Testing
- Delivery to the ITER-India, IPR Site
- Receipt and Physical Verification at the ITER-India, IPR Site
- Site Acceptance at the ITER-India, IPR Site

1.2.2 Time Schedule

Refer to ATC document for more details.

2 Scope of Supply

2.1 General

The supplier shall be in charge of the following scopes

2.1.1 Mandatory and Essential Scope and Services

- **Essential equipment and component**
 - 500Vdc, 5kA Full Controlled Thyristor Converter in full accordance with the technical requirements set forth in Section 3.
 - Including supply of following spare parts
 - Thyristor: #10 numbers
 - Gate driver board: #1 number
 - Semiconductor fuses: #3 numbers
- **Essential services**
 - Detailed design confirming the technical specifications, including simulations results.
 - Supplying of the documentation required in section 2.3
 - Performance of the Factory Acceptance Tests indicated in section 5
 - Packing and transport, in accordance with the requirements included in section 4
 - Detailed procedure for Testing, installation and operation and maintenance of thyristor converter
 - Demonstration of site acceptance tests and a session of onsite training for operation of the thyristor converter at the ITER-India, IPR, Bhat, Gandhinagar, India as per section 5

2.2 Equipment and services not included in the Contract

Unless otherwise agreed in future, the followings are out of the scope of the contract.

- Incoming transformer to feed the thyristor converter
- AC Input and load cables/ busbars
- Interconnection-cables for remote connection
- Unloading at site
- All the services, tools and connections needed for site Installation and acceptance Tests (however supplier shall remain responsible for demonstration of site acceptance tests)

2.3 Supply of Documentation

2.3.1 Documentation to be supplied at the start of the contract

D1. Detailed Time schedule

2.3.2 Documentation to be supplied before start of Manufacturing

D2. Detailed Design report including component sizing & thermal calculations, electrical simulation validation preferably on PSIM/MATLAB, detailed DSP control logic flowchart etc.

D3. Native simulation files for check and approval

D4. Manufacturing Inspection Plan (MIP)

D5. Schematic, Single Line Diagrams and detailed wiring diagrams

D6. Components Data Sheets

D7. Engineering Drawings and layout

D8. Bill of material

2.3.3 Documentation to be supplied before start of FAT

D9. Factory Acceptance Test Procedure at least one-week prior FAT

2.3.4 Documentation to be supplied before Shipment

D10. Factory Acceptance Test Report

D11. Final DSP code along with updated control logic flow charts

D12. Final As-built manufacturing Dossier (D3-D9)

D13. Installation, Operation and maintenance manuals

2.3.5 Documentation to be supplied along with Shipment

D14. 1 set of hard and 1 set of soft copy of all the above final as-built documents

D15. Records of approved Non-Conformances (NCR) and Deviation Requests (DR), if any

3 Technical Requirements

3.1 Design Requirements

The detailed design report shall include calculations confirming the selection of each component used in the equipment. Appropriate safety margin shall be considered for selection of components as per applicable standards.

The equipment design, manufacturing and test procedures shall of thyristor converter shall conform with IEC 60146. All components shall be able to support electromagnetic and mechanical forces during normal operation and fault conditions.

The equipment shall be designed considering standard industrial practice for Electromagnetic Compatibility.

3.2 Manufacturing Requirements

Manufacturing and Inspection Plan (MIP) shall be developed by the Supplier and submitted to ITER-India for review and approval/acceptance.

The thyristors shall be selected from following reputed manufacturers only. Use of thyristor from any other manufacturer is subject to prior approval by ITER-India on the grounds of detailed justification and technical evaluation of offered make.

- ABB,
- Dynex
- Infineon,
- Powerex
- Ruttonsha

3.3 Technical Specifications

The Thyristor Converter shall consist of 3 Phase, full wave, full controlled thyristor bridge generating up to **500Vdc, 5kA** on inductive load as shown in block level schematic in Figure 1.

Two parallel thyristors shall be provided in each arm of the bridge. Each SCR shall be mounted on adequately rated heatsink and protected against voltage surges and hole storage effect by means of R-C snubber circuit and device fuses. The SCR shall also be protected for high di/dt.

Thyristorized Bypass circuit shall be implemented at the output of the controlled rectifier with following function.

- The output of converter shall be equipped with bypass capability, which shall be capable of carrying the full load current. The bypass shall be controlled by an external command (such as a quench command) and/or internal fault response logic, as applicable.
- In event of external quench command, the converter shall turn-off main thyristors and trigger the bypass thyristors to isolate source, and freewheel output current flowing through coil.
- The external Bypass of the converter is one-way and shall be of continuous rating

DSP based controller shall be integrated with the thyristor converter panel for control of the output voltage/current by providing synchronous firing signals to the thyristors. The controller shall also provide soft start feature along with other protection functions. Controller shall also have soft-start bypass feature. Following minimum protections shall be provided.

- Fast acting Semiconductor fuses for each SCR of Rectifier Bridge for protection against overloads and short circuit.
- RC network for protection against transient voltage surges.
- Protection against over temperature.
- DC Over current and short circuit

The delivery of thyristor converter at ITER-India Lab, IPR, Bhat is under responsibility of supplier, while the unloading at IPR is not included in the scope.

Load parameters for the site acceptance tests are highlighted in detailed specification Table 2. The arrangements for factory testing are supplier's scope.

Block level Schematic of the required thyristor converter panel is shown in Figure 1.

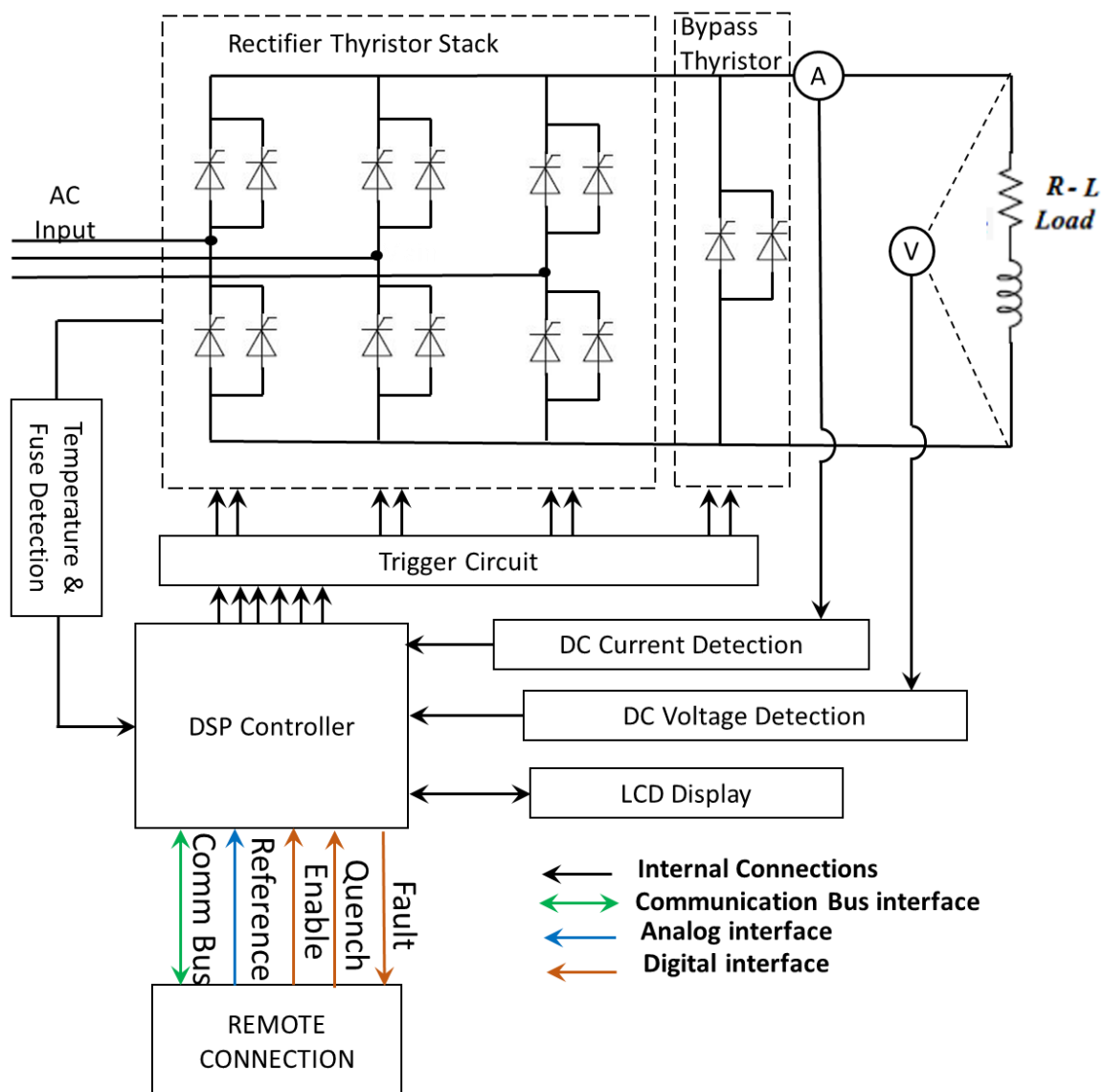


Figure 1 : Block level schematic representation of 500Vdc, 5kA Full Controlled Thyristor Converter

Following Table 2 summarizes the technical specifications for **500Vdc, 5kA Full Controlled Thyristor Converter**.

Table 2: Technical specifications for 500Vdc, 5kA Full Controlled Thyristor Converter

| Sr. No. | Descriptions | Ratings |
|---------|--|---|
| 1 | AC Input | 433V AC, $\pm 10\%$; 50Hz $\pm 3\%$; 3 Phase, 3 Wire. |
| 2 | Output current | 5000 A dc (<i>Programmable</i>) |
| 3 | Output voltage | Up to 500 V dc |
| 4 | Configuration | 3 phase 6 pulse full controlled thyristor bridge |
| 5 | Device Specification | <p>This thyristor converter is also planned to be used for validation of future high current requirements. Hence higher device margin is considered in the present requirement.</p> <p>Two parallel thyristors shall be provided in each arm of the bridge, with following minimum specifications for each thyristor</p> <p>Max average on-state current $I_{T(AV)} > 4000A$</p> <p>Max non-repetitive surge current $I_{TSM} > 50kA$</p> <p>Max on state voltage $V_{TM} < 1.8V$ at T_j max</p> <p>Max repetitive peak forward V_{DRM} & reverse blocking voltage $V_{RRM} > 3000V$</p> <p>Max deviation of on-stage voltage between thyristors $< 50mV$</p> |
| 6 | Duty | Continuous |
| 7 | Control Type | <p>Closed-loop Current Control</p> <p>Open-loop Voltage Control</p> |
| 8 | Output current di/dt to be supported | $> 1kA/ms$ |
| 9 | Current Adjustment | 10-100% |
| 10 | Accuracy (Full Scale) | $< \pm 1\%$ |
| 11 | Installation | Indoor |
| 12 | Operating Condition | <p>5- 50 deg C,</p> <p>RH $< 95\%$ non-condensing</p> |
| 13 | Cooling | Forced Air cooled |
| 14 | Degree of Protection | IP 20 |

| | | |
|----|---|---|
| 15 | Applicable Codes and Standard | IEC 60146 |
| 16 | Load Parameters (for site acceptance test) | Inductive Load L= 350 μ H \pm 10%, R= 17 mohms \pm 10% |
| 17 | Input Transformer for onsite testing purpose at pulsed duty (out of supplier scope) | Power=1000kVA Primary Voltage = 11000V Secondary Voltage = 433V Primary current = 52.49A Secondary current = 1333.37A Transformer Impedance at nominal secondary current (1.33kA) = 4.75%, Vector Group = Dyn-11 |
| 18 | Dimensions | Footprint of ~ 1.5 m x 1 m |
| 19 | Controller | <ul style="list-style-type: none"> 32-bit DSP based controller preferably from Texas TMS320 series with clock speed better than 100MHz. Local operation and monitoring shall be planned using LCD display Output voltage, output current and bypass current shall be measured and displayed on the LCD display. Moreover, it shall be possible to insert CT through device to measure current through each thyristor Emergency Push button shall be available on the cabinet to safely turn OFF the converter Controller shall have soft-start bypass feature INDICATORS: LEDs shall be provided for indication of following <ul style="list-style-type: none"> Mains ON (R, Y, B) – on Incomer cabinet Rectifier ON Control ON Rectifier Healthy Cooling Fan Fail SCR Over Temperature SCR Fuse fail. Phase fail/phase reversal Gate drive PS failure ALARMS: Audio Visual Alarm along with fault status shall be provided for following failures. <ul style="list-style-type: none"> SCR Fuse Failure. SCR over Temperature. Cooling Fan Fail DC Over Voltage. DC Over Load. Phase Fail/phase reversal Gate drive PS failure Following protections shall be provided for thyristors <ul style="list-style-type: none"> Fast acting Semiconductor fuses for each SCR of Rectifier RC network for protection against transient voltage surges. Protection against over temperature. |

| | | |
|----|--------------------------|---|
| 19 | Remote Control Interface | <ul style="list-style-type: none"> Remote control operation and monitoring using standard communication interface such as RS232/485 MODBUS/LAN etc. from remote connection All the alarms, faults and status shall also be transferred to remote connection via communication interface The "Reference" Analog signal (0- 10V) shall be used to control the thyristor converter in the full range (from 0 to nominal voltage/current) The "Enable" digital signal (0-24V) is used to switch on and off the thyristor converter. When the Enable signal is high, output voltage/current follows the reference voltage/current. While the Enable signal is low, the analogue reference is not considered by the PS controller, for this reason the output voltage/current is always zero. External "Quench" digital signal (0-24V) shall enable the bypass thyristor when condition permits. In case of faults inside thyristor converter, it shall first turnoff the thyristors. Also, "Fault" signal shall be sent to remote connection, which could further trip the incoming breaker. |
| 21 | Other requirements | <ul style="list-style-type: none"> Busbars: Electrical grade Copper busbars of suitable capacity shall be used. Wires and Cables: Multistrand Insulated copper conductor cables /wires of suitable cross section shall be used. The wires /cable shall be conforming to IS 694 /1554. Construction: All components shall be mounted in vermin proof cabinets. Cabinets shall be made of M.S. sheet with suitable iron angle structure. The cabinets shall be powder coated preferably with Grey RAL-7035 and confirming to IP20 class of ingress protection. 2 Nos. Earthing Terminals shall be provided on the cabinet. Return terminal shall be isolated from the earthing terminal Lifting hooks shall be provided for easy lifting and movement |
| 22 | Testing | As per section 5 |

4 Delivery

4.1 Requirements for Labelling, Cleaning, Packaging, Handling & Shipment

Refer to ATC document for more details.

5 Testing

All testing operations shall be listed in the MIP. The Supplier shall provide detailed test procedures regarding all testing operations, for approval by ITER-India. This shall include list of test equipment to be used, detailed procedure with scheme, passing criteria etc.

For each milestone the Supplier shall provide necessary support to test the component/system and to demonstrate that the required performance meets the criteria.

5.1 Factory Acceptance Tests (FAT)

Routine verifications shall be performed on the thyristor converter to detect faults in materials and workmanship and to confirm the proper functioning of the manufactured assembly. The list of main tests to be performed on thyristor converter are highlighted in Table 3 .

The performance of the tests shall be witnessed by ITER-INDIA representative. The final FAT report shall be submitted to ITER-India for approval.

Table 3: List of main Tests at Factory

| Sr. No | Test Name | Details |
|--------|---|--|
| 1 | Visual inspection | Visual inspection of the assembly to ensure there is no physical damage, clearances are compliant, proper wiring, labelling etc. |
| 2 | High voltage insulation test | a.c. or d.c. voltage test shall be performed on the final assembly to ensure that the manufacturing process has not affected the insulation coordination of the product. Test voltage shall be as per IEC 60146. The test is successfully passed if no electrical breakdown occurs during the test. |
| 3 | Insulation Resistance Test | One minute after the a.c. or d.c. voltage test, the insulation resistance is to be measured by applying a direct voltage of a least 500 V. |
| 4 | Auxiliaries, control and Protection Check | The function of all the auxiliary, control and protection devices shall be checked. |
| 5 | Rated voltage test at light load | This test is carried out to verify the rated voltage operation and that all parts of the electrical, control and cooling of the equipment operate properly together with the main circuit. |
| 6 | Rated Current Test at reduced voltage | The d.c. terminals shall be short-circuited directly or with a reactor. The a.c. terminals of the converter connected with an alternating voltage of sufficient value to cause at least the rated continuous direct current to flow During the test, the control equipment, if any and auxiliaries have to be supplied separately with rated voltage. |
| 7 | Temperature Rise Test (at rated current) at least for 1hour | Whenever possible, the temperature rise test should be conducted at rated load conditions. In other cases, the test shall be conducted at rated current and reduced voltage. The |

| | | |
|---|-----------------|--|
| | | temperature rise on the heatsink shall be recorded. The rise of virtual junction temperature shall be calculated based on the temperature measurements in order to show that the assembly is capable of carrying the specified load duty without exceeding maximum virtual junction temperature for the devices. This shall consider the actual current sharing between parallel valve devices. Also, the current sharing between parallel devices shall be measured during this test. |
| 8 | Functional Test | The equipment shall also be subjected to functional tests to verify all the technical specifications highlighted in Table 2 if not already confirmed in above tests. For instance; accuracy, current adjustment, Closed-loop Current Control, Open-loop Voltage Control, local/remote control mode, alarms, faults etc. |

5.2 Delivery and Site Acceptance Test

After approval of FAT report and shipment release, the Supplier shall deliver the thyristor converter at ITER-India, Institute for Plasma Research, Bhat, Gandhinagar. The inspection report shall be issued and shall be signed by both the ITER-INDIA and the supplier upon receipt of the shipment.

The Site Acceptance Tests shall be planned based on the Factory tests. In general, the ITER-India envisions a simplified set of tests on-site mainly aimed at demonstrating the performance of the thyristor converter as was achieved at the Factory. However, ITER-India reserve right for requesting to perform all the Factory Tests for the Site Acceptance Tests. Additionally, power test at rated current shall be carried out at site on load provided by ITER-India, IPR as specified in Table 2.

All the services, tools and connections needed for site Installation and acceptance Tests will be carried out by ITER-India on recommendation and under supervision of supplier, however Supplier shall remain responsible for demonstration of site acceptance tests and onsite training for operation of the thyristor converter.

Ownership of the components shall be transferred from the Supplier to the ITER-India upon acceptance of inspection report after delivery of thyristor converter. However, the transfer of ownership to the ITER-India shall not relieve the Supplier of its obligations under this Contract for on-site demonstration of thyristor converter and for any non-conformities of the components for the duration of the warranty period.

The Supplier shall provide a standard commercial warranty covering repair or replacement of the components as per conditions of this contract.

6 Contract Management and Quality Assurance

Prior to commencement of any work under this Contract, the supplier shall appoint single technical point of contact for this contract to streamline the communications.

“Manufacturing and Inspection Plan” (MIP) shall be produced by the Supplier and approved by ITER-India, who will mark up any intended intervention point. MIP is used to monitor Quality Control and acceptance tests during the execution of the Contract. The overseeing of the quality control operation by ITER-India shall not release the Supplier from his responsibility in meeting any aspect of this Technical Specification.

The ITER-India shall ensure a close oversight of the contract in accordance with approved Manufacturing and Inspection Plans (MIP). This monitoring shall include Control Points at critical steps in the Suppliers’ plans. The control points shall be integrated into the agreed schedule.

A Notification Point (NP) is a milestone where the Supplier is required to notify the ITER-INDIA, that it has completed a specific task or a specific deliverable and is proceeding to the next task or to the next action on the specific deliverable. A NP is meant to enable the ITER-INDIA personnel to follow the progress of the Contract and possibly to witness a critical manufacturing step at the Supplier’s premises. The Notification shall be sent by the Supplier to the ITER-INDIA at least 2 working days prior to the scheduled manufacturing step. The ITER-INDIA shall decide whether or not they want to attend. A NP shall not affect the production flow of the Supplier that shall continue the work even without a reply from ITER-India.

A Hold Point (HP) is a milestone where the Supplier is required to notify ITER-India, that it has completed a specific task or a specific deliverable and must stop the associated processes until a HP Clearance is issued. The HP Clearance shall be issued on the basis of clearly identified Quality Control and data and Acceptance test results to be provided to the ITER-INDIA at the time of the request. The ITER-INDIA shall review the Suppliers data and to notify the Supplier of its decision. In case of clearance the Supplier shall resume its activity. In case of rejection, the Supplier shall develop a recovery plan that shall be submitted and reviewed by the ITER-INDIA.

A Witness Point (W) is a milestone which identifies an operation to be witnessed.

Review (R) identifies a document or report to be reviewed.

The preliminary list of Control Points is defined bellow:

Progress meetings shall be conducted in-person or via video conference, depending on progress of the works.

The Supplier shall ensure that access rights are granted to ITER-INDIA personnel at all locations where work is being performed.

ITER-INDIA will review the following minimum control points: It should be noted that control points in additional to those mentioned below may be included on the MIP by ITER-India.

- MIP approval
- Acceptance of Detailed Design Documents Drawings prior start of Manufacturing
- Factory Acceptance Testing
- FAT report Approval and shipment release (before shipment)
- Inspection report (after reception in ITER-India)
- Site Acceptance Test (SAT)

Any deviation or non-conformity to the requirements of this Technical Specification shall be formally registered in a document.