

TECHNICAL SPECIFICATIONS FOR THE PROCUREMENT OF A 250 MVAR, 400 KV VARIABLE SHUNT REACTOR

Study No.: 2734

Ljubljana, May 2026

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High Voltage and Power Plants

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ABSTRACT

This document defines the technical specifications for the procurement, supply, installation, testing and commissioning of a 250 Mvar, 400 kV variable shunt reactor to be installed at the 400/110 kV Krško Substation. The document is intended to form part of the technical tender documentation.

The requirements are based on the applicable IEC, EN and SIST standards, relevant technical publications, and previous experience gained from the preparation of specifications for recently procured and installed 150 Mvar variable shunt reactors and 300 MVA, 400 kV power transformers in the Slovenian transmission network.

Keywords: variable shunt reactor, 400 kV network, technical specifications, procurement, shunt compensation.

LIST OF ABBREVIATIONS

COLM	Central On-line Monitoring
DGA	Dissolved Gas Analysis
EMC	Electromagnetic Compatibility
FAT	Factory Acceptance Tests
SAT	Site Acceptance Tests
FRA	Frequency Response Analysis
FRNC	Flame-Retardant, Non Corrosive / Flame-Retardant, Non-Combustible
OLM	On-line Monitoring
OLTC	On-load Tap Changer
REF	Restricted Earth Fault Protection
S/S	Substation
TOC	Total Ownership Cost
TS	Technical Specification
VSR	Variable Shunt Reactor
Purchaser	ELES, d. o. o.
Contractor	Elektroinštitut Milan Vidmar
Tenderer	the economic operator submitting the tender
Supplier / Manufacturer	the entity responsible for manufacturing and supplying the VSR

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1 GENERAL INTRODUCTORY INFORMATION

1.1 *Scope of Tender documents*

This Tender Document defines the requirements for the supply, installation and commissioning of one Variable Shunt Reactor (VSR) at the 400/110 kV Krško Substation. The scope shall include new high-voltage connections for the VSR, a complete new control, protection and measuring system, and a new auxiliary power supply system. The on-line monitoring system at Krško Substation shall be newly installed, and the on-line monitoring functionality of the VSR shall be fully integrated into this system.

1.2 *On-site Conditions*

The Tenderer shall take into account the following on-site conditions:

- The site altitude is below 1,000 m above sea level.
- The equipment shall be designed for the following ambient temperature ranges:
 - indoor equipment: from -5 °C to +40 °C, with an average relative humidity of up to 95 % over 24 hours;
 - outdoor equipment: from -25 °C to +40 °C.
- The equipment shall be designed to withstand seismic conditions. The design ground acceleration shall be $a_g = 0.275 g$, for medium ground conditions, $T_b = 0.15 s$, and importance class IV in accordance with SIST EN 1998-1.
- The pollution level shall correspond to pollution degree b, in accordance with IEC/TS 60815-1.
- Ice conditions shall correspond to Class 10, in accordance with the applicable IEC standards.
- The equipment shall be designed for wind loading corresponding to a wind speed of 42 m/s or a wind pressure of 1.1 kN/m².
- The equipment shall comply with the maximum permissible audible noise level of 75 dB sound pressure level for the Variable Shunt Reactor at rated voltage.
- The equipment shall comply with the electromagnetic compatibility requirements applicable to similar high-voltage power substations.

2 GENERAL REQUIREMENTS

2.1 *Measuring units*

All units concerning measurements shall be indicated in SI-System (Système International d'Unités).

2.2 *Standards and codes*

Unless specified elsewhere in the below Special Technical Specifications, the design, used materials, manufacture and testing procedures of all products specified in this Tender document shall comply with the approved standard(s).

Approved standards are:

- EN (European standards),
- ISO (International Standardization Organization),
- IEC (International Electrotechnical Commission).

Approved standard publications issued by the following organizations of standardization are considered being approved standards for the execution of works:

- SIST - Industrial standards valid in Republic Slovenia,
- EN, CEN, CENELEC - European standards,
- ISO - International Standardization Organization,
- IEC - International Electrotechnical Commission,
- DIN – Deutsche Industrie Norm (German industrial standards)
- ASTM - American Society for Testing and Materials.

If no SIST, EN, IEC, DIN, ASTM or ISO standards exist for any special case, then the Tenderer can submit a national standard to the Customer. Any other standard as proposed by the Tenderer will be accepted on the approval of the Customer and applications in the Contract, and provided the Standards are written or translated into Contract Language and the equivalent standards as listed under the following Article are indicated.

2.3 *Materials and workmanship*

Material's physical properties shall comply with the below tender requirements and be selected to fit best the basic target of the customer to achieve good reliability, low maintenance cost and a long lifespan of the product. Materials shall be conforming to the latest technical achievements and in accordance with latest issue of the respective Standards. Material specifications, including grade or class, shall be shown on the appropriate detailed drawings to be later submitted for review in course of setting of

Contract. It is in the bidder interest to clearly demonstrate its remarkable achievements presenting comprehensive this concerning references.

If during manufacturing of the equipment, deviations from the documentation and/or instructions occur, the Tenderer must immediately announce the Customer about them.

2.4 Cleanliness of the production facility

The manufacturer shall ensure clean production conditions suitable for the manufacture of the equipment covered by this technical specification. For this purpose, the manufacturer shall have a documented quality system in place for the assurance of cleanliness in the production facility.

Regular measurements of airborne dust particles shall be performed in accordance with ISO 14644-1, or an equivalent recognised standard. The measured cleanliness level of the relevant production areas shall be at least ISO class 8.

The bidder/manufacturer shall submit documentary evidence confirming fulfilment of this requirement, including, but not limited to, an expert opinion, inspection report, particle measurement results, or equivalent documentation issued by a competent body.

2.5 Controlled atmosphere requirements

The manufacturer shall ensure controlled atmospheric conditions during the handling and assembly of the active part of the VSR after completion of the drying process.

From the moment the active part is removed from the drying process until completion of the assembly, the active part shall be kept under controlled atmospheric conditions. During this period, the relative humidity shall not exceed 15 %, and the ambient temperature shall not exceed 25°C.

These conditions shall be maintained until the active part is closed and the oil-filling process is initiated. The manufacturer shall provide appropriate records demonstrating that the required humidity and temperature limits were maintained during this critical production phase.

2.6 Standard voltages

The following standard voltages listed in Table 1 are applied on site:

Table 1: Standard voltages

Transmission System		
Network rated voltage	400 kV	110 kV
Highest system voltage = Highest voltage for equipment	420 kV	123 kV
Grounding	Effective	Effective
Low voltage System		
Three phase AC voltage	400/230 V, $\pm 5\%$, five wire, grounded (TN-C-S)	
Single phase AC voltage	230 V, $\pm 5\%$, three-wire, grounded (TN-C-S)	
DC control and protection voltage	220 V, -15 %, +10 %, not grounded	
Inverter AC Supply	230 V, $\pm 1\%$, three-wire, grounded (TN-S)	

The voltages are maximum nominal operating voltages according to IEC 60038. AC system frequency is 50 Hz.

2.7 Components identification, Inscriptions and Displays

In readably visible locations the identifications plates made of non-corroding or otherwise disintegrating material should be applied. Identification plate shall contain at least the producer's name, serial number, date of production and main technical data. All safety related (warning) plates, necessary for safe operation, and safety at work, shall have the standardized attributes in force on site and put in visible place. All identification plates shall be in Slovene language.

Each cable or wiring connec

ion shall be on both sides suitably marked according to the designation from the cable list and the pertaining drawings.

2.8 Colour Code

In general, the colour coding of wiring in control panels, electrical connections, etc., shall be in accordance with the respective recommendations stated in IEC Standards (Table 2). Live parts of electrical connections shall respect the colour coding according to IEC 60445.

Table 2: Colour code

CONDUCTORS		Alpha-numeric Designation	Symbol	Colour
AC System	Phase 1	L1		Brown
	Phase 2	L2		Black
	Phase 3	L3		Grey
	Neutral	N		Light blue
DC System	Positive	L+	+	Red
	Negative	L-	-	Blue
	Neutral	M		Light blue
Common Grounding and Neutral in TN-C Systems		PEN		Green/yellow
Protection Grounding		PE		Green/yellow
Grounding		E		Black/light blue

Colour code on control panels and displays shall be marked to distinguish between the following voltage levels:

- 400 kV red
- 110 kV black
- 400/230 V violet
- 220 V DC orange.

2.9 VSR Design

The design of the unit shall enable installation on a flat surface and shall ensure compliance with all technical tender requirements, easy maintenance, and reliable and safe operation. During the design stage, the Tenderer shall take into account the latest good engineering practice, as well as the latest applicable international and national recommendations, standards, and regulations. All site-specific requirements, including compatibility with the existing equipment and installations, shall also be considered.

Wherever possible, individual components and parts shall be standardised. This shall reduce the required number of spare parts and thereby simplify maintenance, exchange, and/or replacement. For this purpose, the Customer may require the use of certain types of small mechanical and electrical materials for the supplied equipment.

The equipment, including all auxiliary parts necessary for normal operation, shall be free from defects. During the design, manufacturing, and erection stages, the Tenderer shall

comply with all protection measures required by applicable codes and standards, with particular attention to grounding/earthing.

All LV electrical parts, which can be energised must be mechanically protected against accidental touching or additionally insulated. Mechanical protection could be disassembled with a special tool only.

2.10 Manufacturing requirements

The VSR equipment (motor drive and marshaling cabinet etc.) shall be manufactured according to the latest good engineering practice having a mechanical protection level IP 55 at least according to SIST EN 60529.

Equipment must be provided with the required grounding connections.

LV connecting terminals, relays and instruments shall be placed in the protected part, being easily accessible during operation, and at the same time protected against accidental touch. Connection identification designations shall be clear and mounted on visible places.

Easy access shall be ensured to the terminals or connections and for the equipment and elements maintenance. Elements for manual operation control and monitoring shall be installed 80 to 180 cm above the final floor.

All equipment shall be suitable for the cable connections from the lower side; connection terminals shall be placed to allow for an easy access and assembling.

Control, signalling and power supply cables shall have cable shield grounded through EMC cable glands. EMC cable glands shall be supplied together with the VSR.

Each cubicle or box shall have on the side, where the cables are grounded, an adequately shaped (one or more) plates, allowing reliable connection of cable shields to the ground (according to EMC guidelines and at least fulfilling the SIST EN 61936-1, IEC TR

61000-5-2 and IEC TR 61000-5-6 requirements).

All equipment shall be designed to prevent short circuiting caused by animals. On the lower side of the cubicles and boxes, metal plate with cable glands shall be installed.

All devices, connections and incoming cables shall be designed in a way to be prevented from the fire arise, fire expanding or any damage caused by the fire.

All cubicles and other equipment shall be equipped with connection terminals of adequate quality and numbered with durable numbers and designations, produced by a renown producer with positive references in this field. Terminals shall be harmonized with the site and its choice can be requested by the Customer. Requested terminal producers are Weidmueller, Phoenix or similar of equal quality. All wiring connections shall be equipped with element/terminal designation.

All switching and protection equipment (circuit breakers, switches, MCBs, fuses, ...) must be of the adequate quality, produced by a company with positive references on the market and can be matter of the onsite harmonizing on Customer request. Components produced by Moeller, Siemens, Schneider or ABB are preferred. Elements shall be installed into the cubicle in a logical order.

In any case, cubicle disconnection from the power supply using in-cubicle mounted hand-controlled switching elements shall be po

sible. For easier equipment operation monitoring, doors shall be equipped with adequate signalization.

Devices shall be of modular type, composed from units, suitable for easy transportation and erection. Composing parts shall be fast exchangeable with no special tool required.

All conductors' connections shall be adequately handled (silvered or tinned) according to valid standards.

Supplied and erected equipment shall withstand all electrical, mechanical and thermal loading, which can arise during normal operation of the unit and in eventual short-circuit or ground-fault conditions.

Distances between conductors and grounded parts shall be according to valid technical codes and standards.

All cubicles and boxes shall be made from stainless steel.

Control and connection boxes shall be equipped with an anti-condensation heater. Operation of heaters shall be automatic with adjustable thermostatic relay. Cubicles shall be equipped with the light, switched on and off with a door mounted micro-switch.

Each component shall be equipped with producer and type designation and with nameplates for use designation in Slovene language.

Equipment parts, which are constantly or temporary on high voltage potential, must be protected against accidental touch and visible designated according to safety codes.

2.11 Cabinets and Marshalling Racks

Cabinets and marshalling racks shall be made from folded stainless-steel sheet having minimum thickness of 1.5 mm to ensure rigid mechanical support to the control and monitoring equipment. They must be supplied completed with all frames, doors (hinges and locks).

The cubicles, panels and marshalling racks shall be workshop completed and tested with all elements, labels, internal wiring, with all cable terminal connections and designations.

All cubicles must be suitable for continuous operation under the climatic conditions prevailing at Site. An adequate corrosion protection is also requested.

A proper natural ventilation of cubicles with dust-protected vent openings shall ensure keeping the temperature inside the cubicle below 55 °C in any conditions, supposing the maximum ambient temperature of 40 °C and equipment in normal operation.

It shall be designed according to IEC 60529, protection class IP 55.

All equipment inside cubicles must be installed in such a way to enable cable entry as needed due to implemented cable trays. Cable connections to cubicles must be provided with suitable seals as to prevent the ingress of dust, water, vermin, or the propagation of an eventual fire.

Each panels/cubicle must be provided with grounding devices for grounding of incoming cables as requested by EMC regulations. A Cu grounding bar having a minimum cross-section of 30 x 5 mm shall run the full length of the cubicles, panels or boards. Each grounding bar shall be directly connected to the reactor tank by using NYYJ Cu 70 mm² conductor. All metallic cable shields of external cables (entering this cubicle) shall be directly connected using screws to the grounding bar. All metallic cable shields of internal cables (entering this cubicle) shall be connected to the grounding system using EMC cable glands.

All metallic parts of cubicle/panel/rack must be directly connected in order to form a unique galvanic unit due to operational safety and EMC. Doors and other not fixed parts must be grounded together with the cubicle/panel/rack housing applying Cu braided flexible connection having minimum cross-section of 16 mm².

All elements intended for operational interactions (instruments, control and selector switches, indicating lamps, pushbuttons, displays and others) shall be flush-mounted at conveniently accessible heights on the front of the cubicle or cubicle door. These elements must be installed higher than 80, but not more than 180 cm above the ground in a logical and clear manner. The layouts of all the front views are subject of the Customer approval.

An adequate vibration and shock-absorbers must be installed wherever required for the correct operation of installed elements.

After accomplishment of the final commissioning, all panels/cubicles must have at least 20 % spare space for installing of additional elements.

Clearances between live parts and to earth shall be in accordance with the latest relevant technical and safety regulations. Equipment live parts must be protected against accidental human touch and adequately labelled.

Anti-condensation heaters, with AC single phase power supply, shall maintain the inside temperature of cubicles or compartments by about 5 °C above the ambient temperature to prevent internal condensation. Heaters in switchgear cubicles, control cubicles, panels, desks, etc., shall

be temperature controlled automatically by adjustable thermostats.

2.12 LV cables of the VSR

All cables of voltages 230/400 V AC and 220 V DC shall be made for temperature range from -25 °C to 120 °C and shall be suitable for outdoor installation. Copper cord shall be flexible, finely wired (IEC 60228, cl. 5); insulation shall be flame retardant and non combustible (FRNC), marked/numbered, with screen of tinned copper shield (at least 80 % of the area around the circumference), sheath shall be FRNC. All material shall be halogen free and UV resistant.

2.13 Instrumentation and control equipment

Measuring ranges of delivered sensors and other elements of all measuring devices, particularly of the OLM, must be adapted to the ranges where the measuring values are to be normally expected.

An adequate length of cables supplied as integral part of the measuring/control devices must be provided to strictly avoid any additional couplings between the sensor and the destined terminal box. Prefabricated field proven connectors must be provided for such integrated sensor-cable components.

The following general requirements shall be respected:

- Equipment shall be suitable (e.g. IP protections level) for the ambient in which the instrument will be located.
- All analogue transmitters shall have a current output of 4-20 mA. DC isolated output is strictly requested. Two wire connections are preferred. If this is not applicable, a power supply is requested.
- Current capacity and electric resistance of contacts must enable reliable direct connection to the control system (220 V DC).
- All supplied equipment must enable satisfactory terminating and grounding of cables.
- All transmitters shall have internals and fittings of a corrosion resistant material suitable to the medium being measured.
- All components shall be suitable for continuous operation under site conditions.
- All instrumentation and control circuits shall be designed for 220 V DC.
- Measuring points selected for protection purposes shall be separated and shall not be combined with the control system.
- All protection devices must enable two separated, normally open, free contacts (trip contacts) for protection system.

2.14 Low voltage switchgear and protective elements

All auxiliary system elements shall be dimensioned in a way to assure continuous operation of the entire cooling system at nominal VSR loading (MCBs, cables, wiring and other).

MCBs shall be of single or three phase type, adequately current dimensioned, with sealed doors/opening mechanism. If required they must be equipped with auxiliary contacts.

Contactors must be air type with enclosure class AC 3 acc. to IEC standards. Switched on, they shall withstand fault currents until breaking executed by the selective over-current protection element. Thermal overcurrent trigger shall be of the adjustable type, suitable to the drive requirements and temperature compensated to the temperature 70 °C.

Fuses shall be selective type; they shall suitably break short circuit currents in the circuit. No special tools for fuse replacement should be required for up to 63 A rated current.

Switches shall enable hand control from the front side. They shall be equipped with a control handle and self-cleaning contacts in hard enclosure, with mechanism for fast on and off operation, capable of switching of the rated current. They may be equipped with HRC fuses in parallel if necessary.

2.15 Wiring and connection elements

All wiring inside panels, racks, boards, etc. shall be made of stranded copper wires with a minimum cross-section of 1.5 mm². The insulation material shall be of fire-resistant and UV - resistant polyvinyl chloride (PVC), or of other approved type. The wiring shall be capable to withstand without deterioration under conditions prevailing at the individual place of installation. All control and power cables must be shielded.

Every wiring connection must be completed with wiring terminations, dimensioned according to the wiring cross-section. All connections to the outer devices must be arranged on one or more terminal strips.

Terminal strips shall be numbered beginning from left to right and from top to bottom.

Terminals shall be of the adequate quality and shall be harmonized to the substation where they have been mounted on the terminal strip. Terminals shall be self-supported, non-inflammable consisting of two separate pressure clamping plates suitable for connection of incoming or outgoing stranded or solid conductors respectively. All internal wiring shall enter the terminal block at one side only. All terminal blocks shall contain 20 % spare terminals of category C. Insulation barriers shall be provided between

each pair of power circuits and between the terminal categories, their shape shall be such as to give adequate protection to the terminals whilst allowing easy access to the same.

All connections shall be efficiently protected against oxidation and electrolysis damage. All connections shall be designated with non-ageing identification ferrules. The ferrules shall be clamped in such a way that they cannot become loose after removing the wire from the terminal.

2.16 Auxiliary equipment

Where appropriate, each constitutive part of the VSR unit shall be equipped with all necessary auxiliary switches, contactors and mechanisms of indication/signalling, protection, metering, control, interlocking and other function/services. All auxiliary switches shall be wired up to a terminal board, assembled in an accessible position clear of the operating mechanism and are to be protected in a suitable way to obtain a strong long lasting contact system.

All equipment, whether fitted with a heating device

or not, shall be provided with suitable drainage and be free from pockets in which moisture can collect.

The protection relays shall be adequately selected for the system elements protection. The protection relays shall be equipped with all necessary auxiliaries such as tripping unit, time relay, external resetting device (hand reset flag with seal-in operation). The relays shall provide easy access for testing and setting purposes. Tripping of a protection system shall be indicated as an alarm.

3 ACCEPTANCE TESTS

Acceptance tests comprise equipment testing intended to formally verify design, construction and functional ability of a device and system. Complying with specifications is assessed by verification of analytical data, element testing and operation demonstrations. Final acceptance shall include also verification of the supply completeness and approval of the relevant documentation.

Beside type tests and special measurements and tests, required in Special technical specifications, the most important tests are:

- interphase control and measurements in the manufacturing process,
- factory acceptance tests and
- site acceptance tests.

3.1 Interphase control and measurements in the manufacturing process

Inter-phase measurements on the active part of the VSR will be performed to verify the electrical condition and insulation integrity between phases. Samples of the paper insulation will be taken and included in the drying process of the windings and the active part for subsequent DP analysis, to assess the condition and ageing level of the cellulose insulation. A visual inspection of the VSR active part will also be carried out to identify any visible mechanical damage, contamination, deformation, displacement of components, loosened connections, or other abnormalities before further assembly or continuation of the refurbishment process. The inspection hold points will be defined during the design review.

3.2 Factory acceptance test

Factory acceptance test (FAT) shall be executed in the manufacturer's works applying suitable testing equipment and supervised/certified by the factory QA/QC services. Tenderer shall prepare written procedures for factory testing, according to valid technical codes and latest standards. Factory testing procedures proposal shall be submitted to the Customer for approval. Factory tests shall be executed by the Tenderer according to by Customer approved procedures under witnessing by the customer or/and customer's authorized personnel. The order of the tests must be carried out in accordance with the applicable standards. Regardless of FAT results, the Tenderer remains responsible for correct equipment operation after transportation and erection/assembling at site. Responsibility is not depending on the Customers FAT approval. Factory tests shall be carried out according to approved procedures, all pertaining activities shall be done by the Tenderer. Independently from the Customer test approval, also after erection, the Tenderer remains still responsible for the correct operation of the equipment. It is the Tenderer's duty to plan and organize the test procedures execution. Factory acceptance test shall verify all in related documents specified attributes/functionality of the equipment in the factory environment. Tenderer shall prepare in advance the testing timetable with

a list of testing procedures to be done and inform Customer before testing according to the time schedule, approved by Customer. Tenderer duty is to submit measurement procedures, certificates and other evidence about impeccability and suitability of the testing and measuring equipment. All deviations from the expected and required results, characteristics and magnitudes/values shall be documented in the Manufacturer's diary. Necessary repair and/or any corrective actions shall be enlisted, described, examined and commented by Customer and Tenderer representatives. In case of any deviations, the project manager can demand in name of the Customer a stop-works and repeating testing and/or examination of unsuitable equipment or auxiliary modules. The VSR shall be energised at rated frequency under test conditions corresponding, as far as practicable, to the rated operating conditions. For a three-phase unit, three-phase excitation shall be applied where required by IEC 60076-6 and by the approved test programme. The Factory Acceptance Test shall include three-phase testing at rated voltage and rated reactive power, where technically feasible and in accordance with IEC 60076-6 and the approved test programme.

3.3 Site acceptance test

Site tests on equipment shall be performed by the Tenderer after erection on the site and before technical commissioning. Before start, the Tenderer shall submit to Customer all proposed procedures to approve.

Site acceptance tests shall be executed by the Tenderer according to by Customer approved procedures under witnessing by the customer or/and customer's authorized personnel. The order of the tests must be carried out in accordance with the applicable standards.

All equipment producer instructions and guidance, generally valid codes, standards and Customer requirements shall be considered.

The Customer and Tenderer shall be agreed in written about consequences, if the equipment will not fulfil required acceptance conditions in the agreed time.

4 TECHNICAL ENVIRONMENTAL AND SAFETY REGULATIONS

Tenderer's obligation and responsibility is to consider Slovene branch official acts, based on the Slovene SIST standards, European EN and international IEC standards, to fulfil all requirements of the EU guidelines. In case, that above mentioned standards for certain equipment does not exist, Tenderer can propose the application of other acceptable national standards, subject to prior approval by the customer.

Tenderer must consider at least the following (Slovenian Laws are listed in Slovenian original Titles):

- Gradbeni zakon (GZ-1) (Uradni list RS, št. 199/21, 105/22 – ZZNŠPP, 133/23, 85/24 – ZAID-A, 47/25 – odl. US in 75/25), with corresponding changes and amendments,
- Zakon o meroslovju ZMer-1-UPB1 (Ur. list RS 26/05),
- Zakon o standardizaciji (ZSta-1) (Ur. list RS 59/99),
- Zakon o varnosti in zdravju pri delu (ZVZD-1) (Ur. list RS 43/11),
- Zakon o varstvu pred požarom ZVPoz (Ur. list RS 3/07 – uradno prečiščeno besedilo, 9/11, 83/12, 61/17 – GZ, 189/20 – ZFRO in 43/22) with corresponding legislation,
- Zakon o varstvu okolja ZVO-1 (Ur. list RS, št. 39/06, 49/06 – ZMetD, 66/06 – odl. US, 33/07 – ZPNačrt, 57/08 – ZFO-1A, 70/08, 108/09, 108/09 – ZPNačrt-A, 48/12, 57/12, 92/13, 56/15, 102/15, 30/16, 61/17 – GZ, 21/18 – ZNOrg, 84/18 – ZIURKOE, 158/20 in 44/22 – ZVO-2).

Tenderer shall consider required guidelines for EMC (by IEC and EN standards).

Tenderer shall indicate all recommendations, codes and standards, which will be used for the equipment production and testing.

5 MATERIALS AND WORKMANSHIP

Materials used in the manufacture of the specified equipment shall be of the kind, composition and physical properties best adapted to their various purposes in accordance with the best up-to-date engineering practice.

The materials used for the manufacture of the equipment shall be new, first quality, suitable for use, with no defects or imperfections and appropriate according to above mentioned standards.

All surfaces shall be precisely and smoothly treated. Painted surfaces shall be rounded on the corners with minimum radius of 2 mm. Drills and openings shall be designed not to weaken the basic construction or material.

Welding shall be performed only by qualified personnel with approved certificates. Welding shall conform to the welding standards valid in Republic of Slovenia.

In general, allowed designed material and steel structures loading shall not exceed required values from standards DIN 18800.

Material and work procedures for the supplied equipment shall be carefully selected respecting the purpose of the equipment but taking into consideration all site and operation conditions too. Incoming material and manufacturing stage inspection procedures, inspection of the finalized product shall be verified by the documented (written) QA/QC producer procedure.

6 PACKAGING

The Contractor shall prepare/preserve/secure, pack and load all materials and equipment in such a manner that they are protected from damage during the shipment and will be responsible for all damage resulting from improper packing. Each part of the package shall be plainly marked with basic information (content, weight, correct handling) on two opposite sides. All parts exceeding 50 kg gross weight shall be prepared for shipment so, that handling by machines is possible. All electrical parts and delicate mechanical parts subject to damage from moisture shall be packed in hermetically sealed containers. Oil shipping requirements are described in Chapter 15.9.

7 TRANSPORTATION, LOADING AND UNLOADING

Equipment construction shall be suitable for the railway or road transportation (the decision shall be taken by Tenderer). For each type of the equipment, the greatest weight and dimension of the package shall be listed.

All heavier equipment items shall be equipped with lifting hooks or jacks for transportation and erection purposes.

Tenderer shall organize transportation, loading and unloading entirely at its own responsibility. He must examine all possibilities for transportation of heavy and big equipment to the site and in site to the final position. The Tenderer shall inform Customer in detail about the most important transportation data, at least three months after Contract signing. The Tenderer shall offer separate prices for transportation services and for transport insurance.

During transport to the final site, the VSR shall be equipped with two (2) mechanical stress measuring device (Shock recorder (x, y and z direction)) which shall be placed diagonally each other on the tank. After transportation the device shall be opened and records analyzed by a commission, in presence of the Tenderer and Customer. The Tenderer shall submit to the Customer a written report about the transport stresses.

VSR transport is possible via the Ljubljana–Krško or Zagreb – Krško motorway, exit Krško, and from the exit onwards via the regional and local roads to the Krško Substation. Another option is transport by railway to near Krško Substation and, after transshipment, via the access road to the installation site. In the case of transport by ship, transport from the Port of Koper to Krško is possible.

Transport of the equipment on site must be organised by Tenderer.

The Tenderer shall bear full responsibility for all transport, transshipment, unloading, on-site movement and positioning of the equipment up to its final installation location.

8 DOCUMENTATION

The Tenderer shall submit to the Customer a list of all planned documents, detailed descriptions, calculations, curves, graphs, studies and similar documented information, necessary and/or important for the quality assessment and evaluation of each equipment and device to be produced or supplied. The list of documents must also indicate the dates of submission of documents to the Customer and the original formats of documents already approved. From the submitted list, the Customer will determine the documents that he will check and approve.

Before equipment and device production, documentation shall be submitted to the Customer for approval according to the time schedule for submitting of documentation. Documentation review shall be executed in the commonly agreed term, (3) weeks are foreseen. In case of remarks, dealing with tender requirements, the Tenderer shall make corrections to his documentation in appropriate time and return the revised documentation to the Customer. Any disagreement or misunderstanding shall be solved in a meeting of both parties.

The Tenderer shall provide a BIM model for the equipment (LOD 400).

In case, that during the project certain document part or document as a whole is not clear or is insufficient, the Customer can request completion or additional documentation.

The review shall not relieve the Contractor of the responsibility for guaranteed conformity to the operation requirements.

All documentation shall fulfil in form, content and language Slovene legislation requirements and the international standards.

9 WARRANTY PERIOD

The general Defects Liability Period (warranty period) for the tendered equipment is defined in contract. The guarantee period for anti-corrosion protection is also defined in contract.

At reclamation in case of failure or other irregularity of the equipment during warranty period, the Tenderer shall send his representative to the site in time not later than 2 (two) days after receiving the written announcement. If he does not reply according to the requirement, Customer has right to require a new equipment on Tenderer costs.

Failures or deficiencies of the supplied equipment after the reclamation shall be stated by common commission, consisted of Tenderer and Customer representatives.

All commission stated faults or deficiencies must be repaired by the Tenderer in time not later than 2 (two) weeks after commission meeting or according to the commission conclusion.

If during the erection or in the warranty period failures are indicated, which affect the required reliability, the Tenderer shall repair or replace all unsuitable equipment at his own costs.

All repairs performed during the warranty period must comply with the same technical requirements (as defined in the technical tender documentation) and contractual provisions (including warranty coverage and contractual penalties) as those applicable to the manufacture of a new VSR.

For replaced equipment or device, warranty conditions are also defined in contract, except for software failures, which shall be repaired at Tenderer cost also after that period. Dismantling, erection, testing, transport, insurance and all other costs connected with the new part shall be covered by the Tenderer. The Tenderer shall dismount and takeover failed parts on his own expense. Customer does not have any right to require repayment of the indirectly caused damages.

If the Tenderer and Customer representative can not agree, decision from the accredited institution / accredited laboratory for questionable device testing is obligated for both.

10 ERECTION SUPERVISION AND OPERATION START

Erection conditions shall be assured by the Tenderer.

The Tenderer shall assure:

- erection with expert supervision personnel for erection, preoperational testing and start-up,
- special tools and erection devices,
- VSR erection and
- all the start-up and other functional tests.

Tenderer shall recommend the erection executing company. The proposal must be approved by the Customer.

11 SPARE PARTS

The Tenderer shall provide service activities and functionality identical spare parts of the VSR during the overall lifetime of the equipment (min. period of 40 years).

The supply of spare parts includes:

- 1 piece of HV phase bushing,
- 1 piece of HV N bushing.

Bushings should be stored in containers for permanent storage (more than 10 years).

12 TRAINING

The Tenderer shall offer a suitable program of expert training of the Customer's personnel.

Training shall be organized as:

- training at erection site after erection and before operation start-up under the Tenderer expert leadership and
- Training for shall be intended to the operation and maintenance personnel (10 people at site for 1 day for VSR and 10 people at site for 1 day for monitoring system), from this remaining time is left for additional information, explanations, etc. in the warranty period.

Training shall be based on the equipment applications for S/S Krško.

Training plan shall be defined in amount, personnel, site and expense in the offer. Training costs shall be covered by the Tenderer and shall be added to the Tender price.

13 MAIN TECHNICAL CHARACTERISTICS

13.1 General and ratings

The data listed in Table 3 include technical specification for variable shunt reactor to serve as basis in the process of bidding. The backbone to formulate its content were in references cited standards and other publications.

Table 3: General data

Type of VSR	3-Phase, 5-legged, gapped core
Application:	Outdoor from - 25 °C to + 40 °C
Standard:	IEC 60076-6
Rated system voltage/nominal system voltage [kV]:	400
Highest voltage for equipment U_m [kV]:	420
Insulation level (line):	AC 630, LI 1425/CW 1550, SI 1050,
Insulation level (neutral) [kV]:	LI 650, AC 275
Number of phases:	3
Rated reactive power at U_r (U_m) and 50 Hz [Mvar]:	250
Regulation range at U_r (U_m) and 50 Hz [Mvar]:	125-250
Rated frequency f_r [Hz]:	50
Rated voltage U_r [kV]:	420
Rated current I_r (at 250 MVAR and 420 kV) [A]	Approximately 345
Inrush current [A]:	Acc. to EN 60076-6
Winding connection:	YN, with neutral terminal brought out
Linearity from rated voltage [%]: The VSR shall maintain a substantially linear voltage-current characteristic up to 115 % of rated voltage (U_r) at the maximum reactive-power tap position.	1.15 U_r
Sound level at U_m acc. to IEC 60076-10 [dB] (method sound pressure):	75
Type of cooling:	ONAN
Temperature rise limits:	

Average winding [K]:	60
Top oil [K]:	55
Winding hot spot [K]:	73
VSR oil:	Type A (fully inhibited high-grade oil), TVAL, acc. to IEC 60296:2020
Rated reactance at rated voltage and frequency X_r [Ω]:	705.6 +/- 5 % (acc. IEC)
Zero-sequence rated reactance:	(shall be equal to the positive sequence reactance with an applied zero-sequence voltage in any position of tap-changer)
Losses at max. /mid./min. positions (at U_m) [kW]:	$\leq 320/260/200$

Guaranteed losses, sound level, temperature rise and functional performance: to be demonstrated at 420 kV, 50 Hz, at maximum reactive power tap/setting, unless otherwise specified.

13.2 Operating conditions

Operating conditions in S/S Krško depend on the operating requirements of the national transmission network power demand. The Slovenian national transmission system is at the highest voltage level interconnected with ENTSO-E 400 kV network.

Normal operating conditions are met when the S/S is operating at:

- rated voltage ± 0 %,
- rated frequency ± 2 %,

Abnormal operating conditions assume:

- rated voltage ± 5 %,
- rated frequency ± 5 %,

The highest values of three phase short circuit current on the busbars in S/S Krško:

- 400 kV busbars $I''_{k3} = 41.9$ kA
- 110 kV busbars $I''_{k3} = 44.2$ kA
- Short circuit duration $t_k = 1$ s.

The design shall meet also all other site requirements listed in General Technical Specifications.

400 kV transmission network has effectively grounded neutral point (grounding factor 1.1),
110 kV network has effectively grounded neutral point (grounding factor 1.1).

13.3 Continuous output rating

Continuous output rating of the VSR as specified in tables of technical data shall be guaranteed within the limits of winding temperature rises and hot spots specified in the table of rated data.

If the VSR fails to meet the requirements, then the Tenderer shall be bound to modify the VSR or the equipment causing the deficiency within six months to bring the output to the Customer's requirements.

13.4 Losses

Losses of the VSR, shall be as shown in Table 3 (see Chapter 13.1), guaranteed with tolerance + 0. If the above stated losses should be found higher during FAT, the Customer will assert his right for reducing purchase price according to below calculated price.

For a stepwise adjustable shunt reactor, the losses in the two extreme positions and the middle position shall be taken as basis.

If the losses measured any position during FAT should deviate by more than +10 %, (SIST EN 60076–6), from the losses guaranteed in the tender, the buyer reserves the right to reject the shunt reactor.

If the losses should exceed the guaranteed value, a deduction in the purchase price corresponding to the excess must be made.

The manufacturer must declare the guaranteed losses (Q_{\max} , Q_{mid} , Q_{\min}) as defined in the Table 3 (see Chapter 13.1).

14 SCOPE AND LIMITS OF SUPPLY

14.1 Scope of supply

Specifications and requirements stated in the Tender Documents are not to be considered as a limitation. The Tenderer is to supply all other parts of equipment and render all those services free of charge that from whatsoever reasons or faults have not been specifically stated in the Tender, if they are of essential importance for continuous, reliable and safe operation of the Works.

The scope of the supply and the Works to be carried out include but is not limited to:

- variable shunt reactor 250 MVAR acc. to technical data from clause 13.1, acc. to General technical specifications and Special technical specifications, all together with required documentation,
- packaging and transportation, placing VSR to the foundations including transportation insurance,
- VSR erection (bushing insulators, cooling system, conservator, oil filling...),
- erection supervision, site tests and site acceptance tests, commissioning, all acc. to General technical specifications and Special technical specifications,
- training of Customer's personnel,
- used packaging material removal from the site and clearing away parts of the equipment
- 12 pieces of 3D-printed VSR models at a 1:40 scale,
- spare parts delivery.

No civil works are included in the scope of supply. Tenderer shall assure and carry out collecting and sending on time to the Customer of all necessary documentation for timely continuation of all works on the project.

Time limits equipment supply shall be defined in Contract to be signed by both the Tenderer and the Customer.

14.2 Erection tools

All tools, necessary for the VSR erection works in accordance with detailed description and instructions, shall be assured by the Tenderer or by its electrical erection subsupplier.

14.3 Limits of supply

The following interfacing points concerning the VSR equipment unloaded and placed to its foundation, and to other equipment shall be considered as the limit of supply:

- To the civil structure: foundations of the VSR

- To other primary electrical equipment:
 - HV terminals (3),
 - HV neutral terminal (1).
- To the secondary electrical devices:
 - 400/230 V AC terminals to the substation auxiliary power supply system,
 - terminal strips and optical connectors for connections to the control and monitoring equipment system,
 - terminal for VSR grounding.

14.4 Scope of erection and supervision

All erection works on the VSR and on the cooling equipment shall be performed and achieved by Tenderer in accordance with limits of supply.

Tenderer shall unload VSR and provide on site transport supervision, up to the final place.

Tenderer shall present erection and supervision works program and estimation of pertaining costs, which shall be included in the offered price.

All works must be performed in compliance with the applicable environmental and occupational health and safety standards. In particular, the Tenderer must observe the requirements and guidelines of ISO 14001 and OHSAS 45001, under which the Customer is certified.

15 CONSTRUCTION, MATERIALS, WORKMANSHIP

15.1 Standards

As stated in General Technical Specifications, the latest edition of IEC and other standards shall be binding the Tenderer for the manufacture, erection and testing of the VSR.

The list of applicable standards and clauses shall be proposed by the Tenderer and agreed with the Customer before signing the Contract.

Here below, some of important IEC Standards were selected and listed for reference:

- IEC 60076 Power transformers
- IEC 60076-1 General
- IEC 60076-2 Temperature rise for liquid-immersed transformers
- IEC 60076-3 Insulation level & dielectric tests external clearances in air
- IEC 60076-4 Guide to the lightning impulse and switching impulse testing
Power transformers and reactors
- IEC 60076-5 Ability to withstand short circuit
- IEC 60076-6 Reactors
- IEC 60076-7 Loading guide for oil-immersed power transformers
- IEC 60076-10 Determination of sound levels
- IEC 60296 Fluids for electrotechnical applications – Mineral insulating oils for electrical equipment
- IEC 60214 (-1, -2) Tap-changers
- IEC 60450 Measurement of the average viscometric degree of
polymerization of new and aged cellulosic electrically
insulating materials
- IEC 60567 Oil-filled electrical equipment - Sampling of free gases and
analysis of free and dissolved gases in mineral oils and other
insulating liquids - Guidance
- IEC 60599 Mineral oil-impregnated electrical equipment in service –
Guidance on the interpretation of dissolved and free gases
analysis
- IEC 60616 Terminal and tapping markings for power transformers

- IEC 60617 Graphical symbols for diagrams

Part 6: Production and conversion of electrical
- IEC 61125 Insulating liquids – Test methods for oxidation stability – Test method for evaluating the oxidation stability of insulating liquids in the delivered state
- IEC 61181 Mineral oil-filled electrical equipment - Application of dissolved gas analysis (DGA) to factory tests on electrical equipment
- IEC 61198 Mineral insulating oils – Methods for the determination of 2 furfural and related compounds
- SIST EN 61869-1 Instrument transformers -- Part 1: General requirements
- SIST EN 61869-2 Instrument transformers - Part 2: Additional requirements for current transformers
- IEC 60422 Mineral insulating oils in electrical equipment – Supervision and maintenance guidance
- SIST EN ISO 2409 Paints and varnishes — Cross-cut test
- SIST EN ISO 4624 Paints and varnishes — Pull-off test for adhesion
- SIST EN ISO 8501-1 Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
- SIST EN ISO 12944-2 Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 2: Classification of environments
- SIST EN ISO 12944-5 Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 5: Protective paint systems
- DIN 3230-3 Technical delivery conditions for valves — Compilation of test methods
- DIN 4100 Welded Structural Steelwork with Predominantly Static Loading; Design and Structural Details
- DIN 18800 Steel structures — for example, DIN 18800-1: Steel structures — Part 1: Design and construction

15.2 General requirements

The VSR shall meet the latest stage of achievements in the design and construction of reactors and power transformers. Equipment and materials shall be designed to conform to the imposed climatic and operating conditions. The mechanical and electrical design of the VSR shall be based on the following conditions and requirements:

- a) The main dimensions must consider all requirements and limitations from the site and from the attached drawings.
- b) The maximum permissible temperature rise of the VSR oil (top oil) shall not exceed 55 K and the average temperature rise of the winding is to be limited to 60 K (hot spot 73 K). The VSR, completely assembled with bushings and connections, shall be designed and constructed to withstand without damage the effects of inrush currents and transient phenomena which may arise during system faults in service, such as line-to-line, double line-to-earth and three-phase faults associated with the relevant system and
- c) SR grounding conditions.
- d) The VSR shall be designed with particular attention to the suppression of harmonic voltages to eliminate wave form distortion and from any eventual high frequency disturbances reaching such a magnitude to cause interference with communication circuits.
- e) The VSR shall be constructed as gapped iron core-type transformer, for outdoor installation.

15.3 Magnetic circuit

a) The Core

The magnetic circuit shall be designed and manufactured to avoid harmful static discharges, circulating currents, unintended short-circuit paths within the core or towards the earthed clamping structure, and flux components perpendicular to the plane of laminations which may cause excessive local heating.

The core shall be manufactured from high-grade, non-ageing, low-loss, cold-rolled grain-oriented electrical steel, suitable for the specified reactor duty. The material properties, including sheet t

ickness, specific losses, insulation coating and magnetic characteristics, shall be documented by material certificates. The quality of the steel and its insulation coating shall be uniform and suitable for continuous operation in hot insulating oil.

The laminations shall be cut, processed and assembled in such a manner as to minimise burrs, edge damage, local overheating, additional losses, vibration and noise. Both sides of each lamination shall be insulated by a coating resistant to pressure, temperature, ageing and hot insulating oil.

A gapped-core concept shall be applied, unless an alternative technically equivalent solution is proposed by the manufacturer and approved by the purchaser. The core gaps shall be designed to ensure mechanical stability, dimensional stability, low vibration, low noise emission and stable reactance over the specified operating range. Gap spacers and supporting elements shall be made of mechanically rigid, thermally stable, oil-compatible and ageing-resistant insulating material. The manufacturer shall provide evidence of the suitability of the selected material and construction.

The core and its clamping structure shall be designed to withstand, without damage, displacement or permanent deformation, all mechanical stresses arising from rated operation, specified overloads, short-circuit currents, transportation, lifting, handling, seismic requirements where applicable, and installation. The clamping arrangement shall prevent loosening or shifting of the core laminations during the service life of the reactor.

The column clamping structure shall be designed to avoid excessive stray losses and local overheating. Non-magnetic structural parts, magnetic shunts, shielding or other proven design measures shall be applied where necessary. The manufacturer shall demonstrate by calculation and/or design documentation that no structural part is subject to unacceptable local heating.

Suitable cooling ducts shall be provided where necessary to ensure free oil circulation and efficient cooling of the core and yoke. Under all specified service conditions, including rated operation and speci

ified steady overload conditions, the core hot-spot temperature shall not exceed the specified guaranteed value. Any core-supporting or clamping element in contact with cellulose insulation shall remain within the temperature limits applicable to the insulation system.

Unless otherwise specified or approved by the purchaser, the core shall be of five-limb construction, consisting of three main limbs and two side limbs, or of another construction demonstrated by the manufacturer to provide equivalent or superior magnetic, thermal, mechanical and acoustic performance.

The magnetic circuit shall be insulated from all structural parts. The core, core frame, core bolts, clamping structure and any magnetic shunts shall be arranged to allow insulation resistance testing and verification of the earthing system. The insulation between the magnetic circuit and the frame/tank shall withstand a test voltage of not less than 2 kV RMS for one minute, or another value specified in the applicable standards and approved design documentation.

The core shall be earthed at one clearly defined point only, unless otherwise technically justified by the manufacturer and approved by the purchaser. The earthing connection shall be made through insulated conductors brought to accessible terminals mounted on the outside of the tank. The arrangement shall permit disconnection for testing of the core insulation resistance without opening the tank or disturbing the active part.

The core clamping structure, core frame and any separate magnetic shunts or jointing structures shall be insulated and earthed in accordance with the approved earthing scheme. The manufacturer shall provide a detailed drawing of the core earthing arrangement, including the location, cross-section and accessibility of all earthing conductors and test terminals. The main earthing conductor shall have a cross-sectional area of not less than 80 mm², unless otherwise justified by design calculation and approved by the purchaser. Connections inserted between laminations may have a reduced cross-sectional area, but shall not be less than 20 mm².

At rated voltage, rated frequency and all specified normal operating conditions, the maximum flux density in any part of the core shall not exceed the guaranteed design value. Unless otherwise approved by the purchaser, the flux density shall not exceed 1.75 T in normal continuous operation and 1.90 T under specified steady overload conditions. The manufacturer shall submit flux-density calculations for rated operation, maximum continuous voltage, specified overload conditions and all relevant regulating positions.

The core support frame and associated structures shall be designed to avoid pockets which could prevent complete draining of oil through the drain valve. The design shall also avoid air traps and shall ensure complete oil impregnation and venting during filling, vacuum treatment and commissioning.

The manufacturer shall submit, as part of the technical documentation, at least the following: core construction drawings, material data sheets, flux-density calculations, thermal calculations, earthing scheme, transport bracing concept, lifting and handling instructions, and evidence that the design complies with the specified sound level and temperature-rise requirements.

b) Sound and vibrations requirements

The gapped core limbs shall be designed with sufficient mechanical rigidity and dimensional stability to withstand the axial and radial forces occurring during operation, specified overloads, switching operations, transport and short-circuit conditions. The design shall prevent permanent deformation, loosening or displacement of core gap spacers, core packets and clamping structures.

The core clamping system, gap spacers and supporting structures shall be designed to minimise vibration and airborne sound e

ission. The guaranteed sound level shall apply to the complete reactor assembly at rated voltage, rated frequency and the regulating position resulting in the highest sound emission.

For a VSR rated 250 MVAR, the A-weighted sound pressure level shall not exceed 75 dB(A), measured in accordance with IEC 60076-10. The measuring distance, measuring surface, background-noise correction, cooling-equipment operating condition and test arrangement shall be stated in the factory test report. The manufacturer shall also state

the corresponding A-weighted sound power level, LWA, determined in accordance with IEC 60076-10.

The vibration level shall be measured at agreed measuring points on the tank wall, tank cover and other relevant structural parts. The peak-to-peak displacement of vibration shall not exceed 100 μm at rated voltage, rated frequency and the regulating position resulting in the highest vibration level. The measuring points, measuring directions, instrumentation, frequency range and operating condition shall be defined before the factory acceptance test and reported in the test report.

c) Resonance

Since the VSR will be connected via a 400 kV cable line, the design of the VSR must consider the cable's capacitive admittance and the associated generation of reactive power. The sizing of the reactor must be based on the overall reactive power balance of the connection line and the VSR, considering different operating regimes, including low-load operation, disconnected or limited VSR output, and possible conditions of elevated voltages in the 400 kV network.

The core and all relevant associated mechanical structures shall be designed so that their natural frequencies are sufficiently separated from all dominant excitation frequencies, to avoid any risk of mechanical resonance phenomena under all specified operating conditions.

The natural frequencies of the active part and associated mechanical structures shall be sufficiently separated from the dominant excitation frequencies caused by magnetic forces, magnetostriction, winding forces, cooling equipment

and other periodic vibration sources. For a 50 Hz system, particular attention shall be paid to excitation components at 50 Hz, 100 Hz and relevant higher harmonic frequencies.

The design shall avoid resonance at rated voltage, rated frequency, specified overload conditions and all regulating positions. The manufacturer shall submit a mechanical resonance assessment identifying the relevant natural frequencies, expected excitation frequencies and applied separation margins.

The manufacturer shall demonstrate that the design prevents excessive vibration, increased sound emission, loosening of mechanical parts, structural fatigue and deterioration of the insulation system throughout the service life of the reactor. Where required, the assessment shall be verified by vibration measurements during factory testing.

d) Linearity

The magnetic circuit shall be designed so that the reactor maintains a substantially linear magnetic characteristic over the complete specified operating range.

The maximum flux density shall be selected to avoid magnetic saturation and to ensure linearity of the voltage-current characteristic up to an applied voltage of 1.15 times the rated voltage, corresponding to 483 kV RMS for a rated voltage of 420 kV RMS, at the highest rated reactive power and the most onerous regulating position.

Within this range, the reactor current shall remain proportional to the applied voltage within the guaranteed tolerance limits. The manufacturer shall submit magnetisation

characteristic calculations, including the maximum flux density and the estimated saturation knee point, for rated voltage, maximum continuous voltage, specified overvoltage conditions and all relevant regulating positions.

The linearity shall be verified during factory testing in accordance with the applicable standards and the approved test programme. The measured voltage-current characteristic shall be included in the factory test report.

15.4 Windings

The windings shall be designed, manufactured and tested in accordance with the latest applicable IEC, EN and national standards, in particular IEC 60076-6 and the relevant parts of IEC 60076, and with proven good engineering practice for high-voltage oil-immersed shunt reactors.

The VSR shall be an oil-immersed, three-phase, five-limb unit. The air-gapped magnetic circuit shall be designed so that the phase windings are magnetically and electrically independent to the extent required for the specified VSR performance, regulating range and insulation coordination.

The winding design shall consider all electrical, dielectric, thermal and mechanical stresses occurring during manufacturing, transport, installation, testing, energisation, normal operation, specified overloads, switching operations, transient overvoltages and short-circuit conditions. The windings, leads, internal connections, supports and clamping structures shall withstand all specified test voltages, operating voltages, overvoltages and mechanical forces without damage, displacement, deformation or deterioration.

Attention shall be paid to lightning impulse withstand requirements, including chopped-wave lightning impulse testing, where specified. The winding insulation design shall ensure proper control of impulse-voltage distribution, with the initial impulse-voltage distribution being as close as practicable to the final linear voltage distribution. The surge response of the reactor windings shall be considered, including the effects of lightning impulse, chopped lightning impulse, switching overvoltage and internal voltage distribution along the windings.

The winding conductors shall be made of high-conductivity electrolytic copper, free from burrs, sharp edges, scales and surface defects, and shall comply with applicable IEC/EN or equivalent recognised standards. Conductors shall be adequately transposed, where required, to minimise circulating currents, eddy-current losses and local overheating, and to equalise current and temperature distribution within the windings.

The conductor insulation shall be made of thermally upgraded cellulose paper of proven quality, suitable for use in hot insulating liquid and compatible with the complete insulation system. Thermally upgraded insulating paper of proven quality, e.g. Weidmann, shall be applied for the winding insulation system, unless an alternative insulation system of equal or superior performance is proposed by the manufacturer and approved by the purchaser. The applied paper, pressboard, spacers, barriers and other cellulose-based materials shall be compatible with the selected insulating liquid and with the specified drying, impregnation and operating conditions. Additional requirements concerning insulating oil and solid insulation materials are specified in Chapter 15.9.

All insulating materials used for the windings, leads, spacers, barriers and winding supports shall be chemically stable, non-catalytic and inert in hot insulating oil under the specified service conditions. They shall not soften, ooze, shrink, collapse, crack or otherwise deteriorate in a manner that could reduce dielectric strength, mechanical integrity, mechanical stability or oil circulation capability.

The 400 kV windings shall be manufactured, assembled and insulated in a clean, dust-controlled, conditioned and monitored environment suitable for high-voltage winding production. Appropriate measures shall be taken to prevent contamination by dust, moisture, metallic particles or other foreign matter during winding manufacture, insulation assembly, drying, active-part assembly and tanking.

The coils shall be formed, shaped, dried, pressed, braced and clamped to withstand thermal expansion and contraction, electromagnetic forces, transport stresses, vibration, energisation forces and short-circuit forces without permanent deformation or loosening. All conductor joints within the windings shall be made by brazing or by another proven method approved by the purchaser. The manufacturer shall provide evidence that the selected jointing method is suitable for the specified thermal, mechanical and electrical duty.

The coil assembly, insulating spacers, ribs, blocks, barriers and oil ducts shall ensure effective oil circulation, adequate cooling and minimisation of winding hot spots under rated operation, specified overloads and the most onerous regulating position. The winding support arrangement shall provide uniform support to the windings and shall restrain movement caused by transient disturbances, electromagnetic forces, vibration, thermal cycling and transport stresses. All spacers, barriers and supporting elements shall be properly positioned, evenly spaced and mechanically locked where required.

The windings shall be securely clamped and braced. All leads to the terminal board, bushings and internal connections shall be adequately supported to prevent displacement, deformation, fatigue or damage due to transport, vibration, electromagnetic forces, operating currents, inrush currents, switching transients, short-circuit conditions or any

other service conditions. During transportation, all winding terminals and internal connections requiring special protection shall be properly fixed, supported and protected against mechanical damage. Where terminals are led outside the tank for transport purposes, they shall be protected by suitable metallic enclosures.

All windings shall be processed after construction by a proven treatment involving drying, pre-shrinkage and oil impregnation. The treatment process shall ensure the required mechanical stability, dimensional stability, moisture content, dielectric strength and long-term ageing performance of the winding insulation system.

At least twelve fibre-optic temperature sensors shall be installed in selected winding locations, distributed among the three phases and embedded where the highest winding temperatures are expected. The exact sensor locations shall be determined based on thermal design calculations and agreed with the purchaser before manufacture. In addition, at least two fibre-optic sensors shall be installed in a selected oil cooling channel of the core or active part.

The fibre-optic temperature measurement system shall be suitable for continuous operation in hot transformer oil and under the specified electromagnetic, thermal, mechanical and dielectric conditions. Sensors and measuring equipment shall be of proven type, such as FISO, LumaSense/Luxtron, Neoptix or technically equivalent, subject to purchaser approval. Sensor locations, routing, fixing method, feedthroughs, connection details and channel identification shall be documented in the relevant drawings.

The variable shunt reactor shall be designed and manufactured to withstand the test voltage levels specified in IEC/EN 60076 and in this specification. The required insulation levels are given in Table 4. The connection between windings shall be a star connection, and the neutral terminal shall be brought out and shall comply with the insulation requirements for $U_m = 145$ kV as specified in IEC/EN 60076-3.

Table 4: Test voltages/Insulation Levels

Terminal	U_m (kV _{rms})	Test voltages/Insulation Levels			
		Power Frequency (kV _{rms})	Lightning Impulse Full wave (kV _{crest})	Lightning Impulse Chopped wave (kV _{crest})	Switching Impulse 250/2500ms (kV _{crest})
Line	420	630	1425	1550	1050
Neutral	145	275	650	--	--

Graded insulation may be used for the reactor windings. The insulation levels of the line end, neutral end and regulation windings shall be clearly indicated in the technical data schedule and shall comply with the insulation levels specified in this specification.

A cylindrical electrostatic earthed shield may be provided around the core limbs inside the windings where required by the insulation design. If applied, the shield shall be designed, insulated, earthed and supported to avoid local overheating, partial discharges, circulating currents, mechanical loosening or deterioration of the insulation system.

The windings shall be designed and manufactured to withstand the thermal and dynamic stresses occurring under all specified operating conditions, including energisation of the reactor at 420 kV RMS at any OLTC position. Attention shall be paid to energisation at the tap-changer position corresponding to the highest rated reactive power. This withstand capability shall be demonstrated by design calculations and, where available, by a type-test report or service experience from a similar variable shunt reactor.

The core and winding clamping design shall consider the resonant vibration frequencies of the complete reactor structure. The clamping shall remain effective throughout the service life of the reactor. The natural frequencies of the windings, core, clamping system, tank and all relevant supporting structures shall be sufficiently separated from all dominant excitation frequencies to avoid mechanical resonance phenomena under all specified operating conditions.

The use of metal-oxide arresters across the regulation winding to limit overvoltages shall not be permitted. The winding insulation, voltage distribution and regulation winding arrangement shall therefore be designed to withstand the specified operating voltages, test voltages and transient overvoltages without reliance on such arresters.

The inrush current shall be kept as low as practicable to avoid unacceptable disturbances in the power system during energisation of the variable shunt reactor and to avoid neutral-current peak values and durations that could initiate unwanted operation of earth-fault protection. When the reactor is energised at an applied voltage of 420 kV RMS and the tap-changer is set to the position corresponding to the highest rated reactive power, the ratio between the peak value of the inrush current and the rated RMS current shall not exceed 6.0 p.u.

The manufacturer shall submit an inrush-current assessment based on calculation and/or simulation. The assessment shall cover the most onerous energisation conditions, including at least the tap-changer position corresponding to the highest rated reactive power, worst-case point-on-wave energisation, relevant residual flux conditions, network source impedance assumptions and the expected neutral-current peak value and duration. The assessment shall demonstrate that the specified inrush-current limit and protection-coordination requirements are fulfilled.

The variable shunt reactor shall have a linear voltage-current characteristic up to an applied voltage of 115 % of the rated voltage, corresponding to 483 kV RMS for a rated voltage of 420 kV RMS, at rated frequency and with the tap-changer set to the position corresponding

to the highest rated reactive power. The tenderer shall state the slope angle α_2 of the voltage-current characteristic in the saturated region, in accordance with IEC 60076-6.

A detailed description of the winding design shall be submitted with the tender. As a mandatory requirement for acceptability of the bid, the following information shall be provided:

- type of regulation, which shall be coarse-fine;
- confirmation that a tap-changer manufactured by Maschinenfabrik Reinhausen, Germany, shall be applied;
- type and technical data of the on-load tap-changer;
- position of entry of the 420 kV terminals, i.e. middle-height entry or top entry of the main winding;
- cross-sectional drawing of the main and regulation windings;
- type of main winding, e.g. interleaved, intershielded or other proven design;
- evaluation of the radial temperature gradient by calculation or modelling, including justification of the applied method;
- hot-spot temperature assessment, including the assumed hot-spot factor in accordance with IEC 60076-2 and justification of its adequacy;
- insulation levels of the line, neutral and regulation windings;
- winding insulation concept and impulse-voltage distribution assessment;
- winding mechanicals withstand assessment, including energisation and short-circuit forces;
- inrush-current calculation and/or simulation report;
- winding drying, pre-shrinkage and impregnation procedure;
- details of conductor material, conductor insulation, transposition and cooling ducts;
- arrangement of winding leads, terminal connections and supports;
- fibre-optic temperature sensor layout and installation details.

In order to facilitate the design and manufacture of the regulation windings and, at the same time, to minimise the required number of OLTC positions in accordance with the commercially available maximum rated step voltage, rated through-current and rated switching capacity, it is acceptable that the reactive power steps are not equal over the complete regulating range. However, the reactive power difference between adjacent tap positions shall not exceed 5 MVar.

The number of OLTC positions shall be selected by the manufacturer based on conservative design criteria and shall not exceed 33 positions, unless otherwise approved by the purchaser.

The degree of polymerisation of the cellulose insulation after treatment shall be certified. Where epoxy-bonded or resin-bonded insulation materials are used, the degree of bonding or curing shall also be certified.

The reactor shall be designed and manufactured to prevent copper sulphide deposition and other ageing phenomena associated with the interaction of copper, insulating oil and solid insulation. Attention shall be paid to winding conductors, varnished wires, bare conductors, conductor joints and high-temperature regions. The manufacturer shall state the preventive design and material measures applied to avoid copper sulphide formation during service.

15.5 VSR Insulation oil and paper

Only new oil of Type A, TVAI quality shall be used. The oil shall be fully inhibited, high-grade insulating oil complying with the requirements of IEC 60296:2020, Table 3 – General Specifications. The oil properties must comply with all the requirements cited in the Schedule of technical data and acc. to standard IEC 60296:2020 and should be tested according to IEC, DIN, ISO, ASTM standard methods and comply with the requirements given in the Table of technical data.

In case that an antioxidant is added to oil, it shall not contain sulphur components. Oil shall not contain corrosive sulphur or potentially corrosive sulphur and shall be tested acc. to DIN 51353 and IEC 62535 standards to be considered non-corrosive.

The initial filling of the VSR shall be carried out using the same type of insulating liquid as used during the Factory Acceptance Tests (FAT), either TVAI fully inhibited high grade naphthenic oil or fully inhibited high grade insulating oil produced from GTL (Gas-to-Liquid) base oils.

The oil used during the Factory Acceptance Tests (FAT) must be of the same origin as used for on-site filling. If a different type of oil is used then the miscibility and compatibility of the oils shall be verified by an accredited laboratory in accordance with IEC 60296:2020, Clause 5.3 – Miscibility and compatibility.

Before the initial oil filling of the shunt reactor on site, an examination shall be carried out to verify that the VSR insulating liquid complies with the requirements specified in the technical specification of this document. In addition, the oxidation stability of the batch of insulating liquid intended for filling the VSR shall be verified in accordance with IEC 61125.

Concerning the quality of the applied paper insulation, the purchaser will impose on the bidder to respect the following.

Before the manufacturing process is initiated, the degree of polymerization (DP) of the paper insulation to be used shall be verified in accordance with IEC 60450.

The Contractor will be requested to submit to the purchaser before the factory release the paper insulation test report and of the applied oil as well. It should be emphasized that the purchaser will release the oil shipment to the site exclusively after obtaining the

certification of PCB absence (below 2 ppm) in the oil sample taken from the delivery tank. This certification shall be sent to purchaser in acreditable report.

The shunt reactor shall be supplied and shipped without initial oil filling. The tank should be filled with dry air or nitrogen and kept under over-pressure above ambient air pressure. Oil shall be delivered in tank, under the nutrition pressure, in sufficient quantity to refill the reactor oil volume and to compensate for losses during subsequent processing at site. Oil type Shell Diala S4 ZX-I or Nynas Nytro 4000X must be used.

Thermally upgraded insulating paper from the Weidmann production shall be used. The reduction of Nitrogen content of thermally upgraded paper, after exposed to the sealed tube test in accordance with ASTM D-982, should not be higher than 50 %.

All samples of paper insulation to be used for winding manufacturing (one representative sample for each winding) shall be properly sampled and traceably labeled prior to manufacturing (paper type, winding type, identification marking indicating that the paper is intended for pre-manufacturing testing). Testing of the average degree of paper polymerization shall be done before manufacturing release.

- DP - average degree of polymerization must not be lower than 1100.

Further on, the testing of paper polymerization degree shall be done after drying in each of manufacturing phases. Paper samples taken and tested after drying process (windings and active part of VSR) shall fulfil the following requirements:

- average degree of polymerization of all paper samples must not be lower than 1100,
- average degree of polymerization of any from all tested samples must be higher than 1050,
- Humidity (moisture) must not exceed 0.5 %.

These pilot samples shall follow the same path of drying process as the reactor itself and will be subjected to inspection and testing after each phase during drying process.

Sample taking and testing shall be performed by an authorized and accredited independent body selected and assigned by the Customer.

The Supplier shall submit to the Customer all paper and oil test results performed on its behalf.

15.6 On-Load Tap Changer

The variable shunt reactor shall be equipped with an on-load tap-changer for regulation of the absorbed reactive power.

The type of regulation shall be coarse/fine with a limited regulating range. The on-load tap-changer shall be a motor-operated vacuum type tap-changer manufactured by Maschinenfabrik Reinhausen GmbH, Germany. The OLTC shall be of the MR VACUTAP type and shall be equipped with the MR ETOS system for control, automation, monitoring and diagnostic functions.

The OLTC, motor-drive mechanism, control equipment and monitoring system shall comply with IEC 60214-1 and with all applicable requirements of the IEC 60076 series, this specification and the manufacturer's approved design documentation.

The OLTC shall be selected and dimensioned for the specific duty of the variable shunt reactor, including the specified regulating range, rated current, step voltage, switching duty, insulation levels, number of tap positions, short-circuit withstand requirements and transient overvoltages. The OLTC shall be suitable for all specified operating conditions of the reactor, including energisation, normal operation, switching operations, specified overload conditions and all tap positions.

The OLTC shall have sufficient rated through-current, rated step voltage, rated switching capacity and insulation level to ground for the proposed VSR regulation arrangement. The OLTC insulation level to ground shall be selected by the manufacturer according to the proposed regulation design, but in any case, it shall not be lower than the insulation level corresponding to highest voltage for equipment $U_m = 145$ kV, with test voltages in accordance with the applicable IEC standards and this specification.

The maximum operating current at which the OLTC can successfully perform tap-changing operations shall be at least 20 % higher than the highest current occurring in the relevant VSR winding under the specified operating conditions.

The OLTC shall be designed to withstand the same short-circuit current and dielectric test requirements as applicable to the associated VSR windings and connections, in any tap position. The manufacturer shall demonstrate this by design documentation and test evidence in accordance with IEC 60214-1 and the approved test programme.

The OLTC shall be of a design that allows the installation of instrument current transformers inside the tank for differential protection purposes, where required by the protection design.

The power switching part of the OLTC shall be based on vacuum interrupter technology. The diverter switch or selector switch compartment arrangement shall be in accordance with the approved MR VACUTAP design. Where a separate oil compartment is provided for the OLTC switching part, it shall be connected to a separate conservator section through a dedicated oil surge relay and shall be arranged so that the OLTC oil is separated from the main reactor tank oil. The arrangement shall prevent adverse influence of OLTC operation on the oil of the main VSR tank and on the active part of the reactor.

The tap selector may be housed in the main tank, depending on the approved MR design. In any case, the tap selector, diverter switch, transition resistors or other OLTC components shall be arranged according to the manufacturer's approved construction and shall not compromise dielectric withstand, oil circulation, accessibility, monitoring or maintenance.

The operation of the OLTC shall be of stored-energy and quick-release type, where applicable for the selected MR VACUTAP design. Energy storage and operation shall be possible by motor drive and by emergency manual operation. The use of blade springs shall not be accepted, unless they are part of the standard approved MR VACUTAP design and

explicitly confirmed by MR for the specified duty. Local and remote electrical operation shall be provided.

The OLTC motor drive shall be suitable for a 400/230 V AC, 50 Hz auxiliary supply and shall be complete with motor protection, circuit breaker, limit switches, auxiliary contacts, anti-pumping protection, step-by-step control, electrical and mechanical interlocks, end-position protection, local/remote control facilities, operation counter, position indication, alarm and trip contacts, monitoring equipment and all required accessories.

The driving mechanism, local controls, protection devices and ETOS-related equipment shall be installed in a weather-proof and vermin-proof cabinet with a degree of protection not lower than IP55. The cabinet shall be ventilated or heated as required to prevent condensation and to ensure reliable operation under the specified ambient conditions. The cabinet shall be equipped with hinged doors, padlock facility and a transparent window or display arrangement enabling local verification of the tap position.

When the cabinet doors are opened, live parts shall not be directly accessible to accidental touch. All terminals, wiring, control equipment and auxiliary devices shall be arranged to ensure safe operation, inspection and maintenance.

The OLTC motor-drive and control cabinet shall include at least the following equipment, as applicable to the selected MR VACUTAP and ETOS configuration:

- totally enclosed three-phase driving motor, 400 V AC, 50 Hz;
- motor protection circuit breaker with magnetic and thermal overcurrent protection and auxiliary contacts wired to terminal blocks;
- operating contactors or equivalent drive-control equipment;
- step-by-step control and anti-pumping interlocks;
- electrical and mechanical end stops;
- local mechanical tap-position indicator;
- local electrical tap-position indication through ETOS;
- local control switches or pushbuttons for raise/lower operation;
- selector switch for local/remote control, where applicable;
- interlocks between raise and lower commands;
- provision for remote control and remote tap-position indication;
- removable emergency manual operating handle, mechanically and electrically interlocked with motor operation;
- suitable reduction gear for manual operation;
- six-digit operation counter or equivalent digital operation-counting function;
- space heater controlled by thermostat or hygrostat;
- internal lighting;

- service socket rated not less than 10 A;
- terminal blocks for all external wiring;
- alarm and status contacts for integration into the station control and protection system;
- communication interfaces required for ETOS and the substation control system.

The OLTC oil expansion tank, where applicable for the selected MR design, shall be connected to the OLTC switching compartment by a dedicated pipe. The connecting pipe shall be provided with a separate OLTC protection relay. The closing valve shall be installed on the conservator side of the oil-flow relay. The OLTC conservator compartment shall be equipped with its own magnetic oil-level indicator, low-oil-level alarm contact, filling valve, drain valve, air breather installed at accessible eye level and overpressure protection device.

The OLTC shall be capable of performing at least 300,000 switching operations before first maintenance requiring intervention such as greasing or mechanical servicing of the drive mechanism. Replacement of vacuum interrupter cells shall not be required before at least 600,000 switching operations. The manufacturer shall confirm the applicable maintenance intervals for the selected MR VACUTAP type and VSR duty.

Provision shall be made for emergency manual operation. Motor operation and manual operation shall be mechanically and electrically interlocked so that simultaneous operation is impossible. Manual operation shall be possible only under safe and clearly defined conditions.

The OLTC shall be equipped with the MR ETOS system. ETOS shall provide OLTC control, monitoring, diagnostic and communication functions, including at least tap-position monitoring, operation counting, motor-drive status, OLTC alarms, OLTC protection relay status, local and remote-control functions, event recording and transmission of relevant OLTC data to the reactor online monitoring system and substation control system.

The ETOS system shall be suitable for integration into the station control and monitoring system. The required communication protocols, signal lists, binary inputs and outputs, analogue values, alarms, events, timestamps, cybersecurity requirements and time-synchronisation method shall be agreed with the purchaser during detailed design.

The OLTC shall provide all necessary signals for protection, control, monitoring and diagnostics, including at least:

- tap position;
- tap-change in progress;
- raise/lower command status;
- local/remote status;
- motor supply status;

- motor protection trip;
- OLTC protection relay alarm/trip;
- oil-level alarm, where applicable;
- operation counter;
- ETOS system alarm;
- ETOS communication status;
- maintenance or service indication;
- any additional alarms required by the MR VACUTAP and ETOS configuration.

The manufacturer shall submit complete OLTC documentation with the tender and during detailed design, including at least:

- confirmation that the OLTC is manufactured by Maschinenfabrik Reinhausen GmbH, Germany;
- exact MR VACUTAP type designation;
- exact ETOS configuration and functional description;
- OLTC rated through-current;
- rated step voltage;
- rated switching capacity;
- insulation level to ground;
- number of operating positions;
- tap-change sequence and coarse/fine regulation scheme;
- short-circuit withstand data;
- expected maintenance intervals;
- number of operations before first maintenance;
- number of operations before vacuum interrupter replacement;
- motor-drive technical data;
- control cabinet layout;
- ETOS signal list and communication interface;
- oil system arrangement, where applicable;
- protection relay details;
- dimensional drawings and installation requirements;
- routine and type-test certificates according to IEC 60214-1;
- operating, maintenance and commissioning instructions.

The OLTC shall be fully compatible with the VSR design, insulation coordination, protection concept, control concept and online monitoring system. All interfaces between the OLTC, reactor active part, motor drive, ETOS system, protection system and station control system shall be clearly defined by the manufacturer and approved by the purchaser before manufacturing.

On-load tap changers (OLTC) selection general requirements are given in following Table 5.

Table 5: OLTC-general requirements

On-load tap changers (OLTC) general requirements	
Reactor MVar-rating	250 MVA
Connection of tap winding	(for wye connection)
Rated voltage of the VSR U_r	420 kV _{rms}
Rated tap power	≤ 5 MVar
Rated step capacity: $P_{st} = U_l \cdot I_n$ and the appropriate tap changer shall be determined:	
Number of service tap positions	< 33
Insulation level to ground (Highest voltage for equipment)	≥ 145 kV
Lightning impulse withstand voltage of the internal insulation	≥ 650 kV
Power frequency withstand voltage of the internal insulation	≥ 275 kV _{rms}
OLTC type	Vacuum type
Number of poles	
Nominal voltage level of OLTC	≥ 145 kV
Tap selector size/insulation level	≥ 145 kV
According to standard	IEC 60214

In addition to the above requirements, the manufacturer shall check and state the OLTC operating performance resulting from the selected coarse/fine regulation arrangement and its integration into the reactor design.

The manufacturer shall provide the time required for changing between the following VSR reactive-power tap positions:

- from maximum reactive-power position to minimum reactive-power position;
- from maximum reactive-power position to middle reactive-power position;
- from minimum reactive-power position to middle reactive-power position.

The stated times shall include the complete operating sequence required for the selected MR VACUTAP coarse/fine arrangement, including all necessary intermediate tap-changing operations. The manufacturer shall clearly indicate whether the stated times refer to motor-driven operation, manual emergency operation, or both.

The manufacturer shall provide the following data for the motor-drive unit:

- manufacturer;
- exact type designation;
- motor supply voltage;
- motor rated power;
- rated current;
- control voltage;
- number of operations per tap change, where applicable;
- tap-changing time per step;
- total travel time over the complete regulating range;
- auxiliary supply requirements;
- protection and interlocking arrangement.

Where required by the purchaser, the following equipment shall be supplied loose for installation in the control switchboard:

- digital tap-position indicator;
- local/remote changeover switch;
- lower/raise control switch;
- automatic voltage regulator for individual control of the variable shunt reactor.

The automatic voltage regulator shall be suitable for individual control of the unit and shall operate based on a voltage input provided by the purchaser. The voltage-transformer ratio, burden, accuracy class and signal characteristics shall be confirmed during detailed design and stated in the order.

All loose-supplied equipment shall be fully compatible with the MR VACUTAP on-load tap-changer, the MR ETOS system, the motor-drive unit, the reactor control concept and the station control system. The manufacturer shall provide all wiring diagrams, terminal diagrams, signal lists, mounting details and interface requirements necessary for installation, commissioning and operation.

The on-load tap changer control box must be equipped with a LOCAL/REMOTE selector switch, enabling:

- local control via two buttons (RAISE/LOWER) for up and down switching,
- RAISE/LOWER remote commands via the control system, where two potential-free inputs for Raise/Lower commands must be available at a voltage level of 220 V DC.

The position indicator should be implemented via a BCD encoder; the indication shall be routed to the corresponding relay housing on the control and protection cabinets. Position indicator scale shall be designed in a way that in the »1« position, all windings of the HV winding are included.

The selection of a particular OLTC will render optimum technical and economical efficiency if requirements due to operation and testing of all conditions of the associated reactor windings are met. In general, usual safety margins may be neglected in case when OLTC was designed, tested, selected and operated in accordance with the following IEC standards:

- IEC 60214–1, Tap-Changers, Part 1: Performance requirements and test methods,
- IEC 60214–2, Tap-Changers, Part 2: Application Guide.

15.7 Cooling system

The cooling system of the VSR shall be ONAN.

The cooling system shall be designed for continuous operation at rated reactive power without exceeding the specified temperature-rise limits, based on an ambient air temperature of 40 °C in shade, unless otherwise specified.

Radiators shall preferably be mounted directly on the reactor tank. Alternatively, subject to purchaser approval, they may be mounted on a separate steel framework and connected to the tank by approved flexible oil-tight connectors.

The number and cooling capacity of the radiators shall be selected so that the reactor can operate continuously at the specified full power rating with one radiator out of service, without exceeding the specified temperature-rise limits.

The radiators shall be detachable and connected to the tank or radiator headers by flanged connections with oil-resistant O-ring gaskets or other approved sealing arrangements. Each radiator group shall be provided with isolating butterfly valves at the inlet and outlet, enabling isolation and removal without draining or lowering the oil level in the main tank.

Each radiator shall be provided with vent and drain plugs and suitable lifting lugs. Radiators and radiator headers shall withstand full vacuum, oil pressure, thermal expansion, transport loads and operational vibration.

The radiators shall be of robust pressed-steel construction and shall be securely fastened to the tank or to an approved independent framework. The design shall ensure vibration-free operation and oil-tightness under all specified service conditions, including wind, ambient temperature variations and reactor vibration.

Oil-tight blind flanges with suitable gaskets shall be provided for shipment of the tank without radiators and for use when a radiator or radiator group is removed. A drain plug and a vent plug shall be provided in each radiator header.

Radiators shall be suitably protected against corrosion. If galvanised radiators are applied, they shall not be painted unless otherwise approved by the purchaser.

The manufacturer shall submit cooling-system drawings, cooling-capacity calculations, verification of operation with one radiator out of service, valve arrangement, vacuum withstand confirmation and filling, venting and draining procedures.

Cooling equipment specification is given in Table 6.

Table 6: Cooling equipment

Cooling equipment		Oil immersed with natural cooling (ONAN)
1	The radiator bank of the Shunt Reactor	Shall be tank mounted, alternatively separately mounted.
2	Material for Radiators	Radiators shall be made from pressed steel, galvanized and not painted.
3	Cooling banks, oil pipelines shall withstand the same overpressure and vacuum as required for the VSR tanks.	
4	Each radiator bank shall be provided with the following accessories. All necessary flanged pipes between cooler banks and VSR tank, coupling, expansion, and sealing devices, support structures, etc.	
a		Top and bottom shut off valve.
b		Drain valve and sampling valve.
c		Air release plug.
d		Four grounding terminals of two (2) 75 x 12 mm galvanized steel flats.
e		Lifting lugs
5	Radiator bank shall be provided as follows	Each radiator bank shall be detachable and shall be provided with flanged inlet and outlet branches.
6	Expansion joint	If required, shall be provided on top and bottom cooler pipe connection.
7	Temperature sensors	Measuring pockets must be installed for inlet and outlet temperature measurement of the cooling system
8	Radiators placing shall consider available space in the substation.	

15.8 Bushings

Bushings for voltage levels $U_m = 420$ kV and $U_m = 145$ kV shall be of the resin-impregnated condenser type, RIP, oil-free, with silicone composite insulators. The bushings shall be manufactured in the European Union or in Switzerland, unless otherwise explicitly approved by the purchaser. The same requirements shall also apply to the neutral bushing, where applicable.

The bushings shall comply with IEC 60137 and with all applicable requirements of this specification. The insulation withstand levels of the bushings shall be at least equal to the specific basic insulation level, switching impulse withstand level where applicable, lightning impulse withstand level and power-frequency withstand voltage of the corresponding windings. The bushing insulation levels and creepage distances are given in Table 7.

For each combination of highest voltage for equipment and insulation level, only one bushing type shall be used. The use of different bushing types for the same voltage and insulation level combination shall not be permitted, to ensure interchange ability, uniform maintenance practice and standardisation of spare parts.

The rated current of each bushing shall be selected considering the rated current of the variable shunt reactor, rated reactance, rated frequency, operating conditions, overload requirements and thermal limits. The rated current of the bushing shall not be lower than the maximum current occurring in the corresponding reactor terminal under the specified operating conditions.

Where the rated current of the bushing is selected from the standardised rated-current values specified in IEC/EN 60137, the selected value shall be the nearest standard value equal to or higher than the required reactor current.

The shed material shall be a polymeric material based on silicone. The final polymer compound, after the addition of functional fillers, shall contain at least one-third pure silicone rubber. It shall not contain ethylene-vinyl acetate, ethylene-propylene rubber, ethylene-propylene-diene monomer or other UV-sensitive material. Only high-temperature vulcanised silicone rubber or liquid silicone rubber shall be used. Room-temperature vulcanised silicone rubber shall not be used for high-voltage applications.

The silicone housing shall have a tracking resistance of at least 4.5 kV, class 1A, in accordance with IEC 60587. The hydrophobicity recovery shall be WC 1–3 within 48 hours after complete loss of hydrophobicity, assessed in accordance with IEC TS 62073 or an equivalent approved method.

All hollow silicone composite insulators shall comply with IEC 61462 and the relevant parts of IEC 62217. The design of the composite insulators shall be verified by design tests and type tests in accordance with IEC 61462 and IEC 62217. Each composite insulator shall be subjected to the applicable routine tests in accordance with IEC 61462.

The bushings shall be completely oil-tight and shall be provided with capacitance and dielectric dissipation factor, $\tan \delta$, measuring terminals or capacitive taps, as applicable. Phase bushings shall be equipped with capacitive taps for measurement and diagnostic purposes. The measuring terminals and capacitive taps shall allow capacitance and $\tan \delta$ measurements without disconnection of the primary connections. They shall be accessible, protected against moisture ingress and suitable for safe testing during commissioning and maintenance.

The bushings shall be designed and installed so that replacement is possible with minimum lowering of the reactor oil level. The manufacturer shall describe the required procedure for bushing replacement, including oil-level requirements, lifting arrangement, sealing arrangement and precautions for maintaining cleanliness and dielectric integrity.

Each bushing shall be provided with a rating plate in accordance with IEC 60137. The rating plate shall include at least the manufacturer's identification, type designation, catalogue number, year of manufacture, serial number, rated voltage, highest voltage for equipment, rated current, insulation levels, capacitance, dielectric dissipation factor reference value, mechanical characteristics and mounting angle where applicable. If the mounting angle exceeds 30°, it shall be clearly indicated on the rating plate.

Neutral bushing terminals shall have the same shape and diameter, unless otherwise specified in the approved design documentation. Terminal dimensions, connection details and permissible mechanical terminal loads shall be stated in the technical documentation. The high-voltage terminals shall be suitable for direct connection to aluminium-alloy clamping material. The terminal design shall prevent galvanic corrosion, excessive contact resistance, local overheating and mechanical overstressing. Contact surfaces, fastening details, permissible terminal loads and required tightening torques shall be stated in the technical documentation.

The 400 kV terminals shall be of bolted type with a 60 mm diameter, unless otherwise specified in the approved design documentation. The terminal shape, dimensions, drilling pattern and connection arrangement shall be submitted for purchaser approval.

The location of the bushings on the VSR tank, as well as the phase sequence and terminal arrangement, shall comply with the layout shown in the attached drawings. Any deviation from the specified bushing location, terminal sequence or connection arrangement shall be subject to prior written approval by the purchaser.

The high-voltage bushings of all three phases and the neutral bushing shall be selected, and the VSR tank or cover shall be designed, so as to allow the installation of instrument current transformers on all three phases and at the neutral point for protection and monitoring purposes, where required by the protection concept. The instrument current transformers shall comply with IEC 61869-2 and with the accuracy, burden, rated current, short-time current and insulation requirements specified in this specification.

The bushing arrangement shall be designed to withstand all mechanical, thermal, electrical and environmental stresses occurring during transport, installation, testing, operation, switching transients, short-circuit conditions, wind loading, seismic loading where applicable and maintenance. Adequate clearances, creepage distances, corona shielding and electric-field grading shall be provided.

The manufacturer shall submit complete bushing documentation, including at least:

- bushing manufacturer and type designation;

- confirmation of resin-impregnated condenser, oil-free design;
- confirmation that the bushings are manufactured in the European Union or in Switzerland, unless otherwise approved by the purchaser;
- rated voltage, rated current and highest voltage for equipment;
- insulation levels and test voltages;
- creepage distance and pollution class;
- silicone material data and hydrophobicity performance;
- IEC 60137 type-test and routine-test certificates;
- IEC 61462 and IEC 62217 compliance evidence for composite insulators;
- capacitance and $\tan \delta$ reference values;
- terminal dimensions and mechanical terminal-load limits;
- bushing arrangement drawings;
- replacement procedure;
- current-transformer accommodation details HV and HV neutral bushings;
- maintenance and testing instructions.

Bushing insulation levels and creepage distances are given in Table 7.

Table 7: Bushing's insulation levels

Terminal	No.	U_m (kV _{rms})	Insulation Levels			Min. creepage distance (mm)
			Power Frequency, under rain (kV _{rms})	Lightning Impulse (kV _{crest})	Switching Impulse 250/2500 ms (kV _{crest})	
Line	3	420	≥ 650	1550	1050	≥ 11500
Neutral	1	145	275	650	--	≥ 3625

The minimal air clearances to be respected in the assembling layout of bushing must exceed the values given in the Table 8.

Table 8: Minimal air clearances

Highest voltage for equipment, U_m	Minimum free air clearances	
	Phase - Earth	Phase – Phase
145	900	N/A
420	3100	3500

Cylindrical terminals are accepted in those cases where the terminal is a natural termination of the internal conductor arrangement.

Terminals of copper or a copper alloy shall be tin coated to layer thickness of at least 50 μm . Copper alloy sensitive to stress corrosion must not be used.

15.9 Current transformers

The current transformers shall fulfil the requirements of IEC 61869-1 and IEC 61869-2.

The current transformers shall be designed for the rated primary current according to Table 9. The rated primary current shall be selected considering the rated reactive power, rated voltage, rated reactance, rated frequency, regulating range, specified overload conditions and the maximum current occurring in the corresponding reactor terminal.

For a VSR rated 250 MVAR at 420 kV, the calculated rated phase current is approximately 344 A. Therefore, the rated primary current of the current transformers shall be 500 A, unless the manufacturer's design calculations show that a higher current rating is required. In such a case, the next higher standard rated current in accordance with IEC/EN 61869 shall be selected and submitted for purchaser approval.

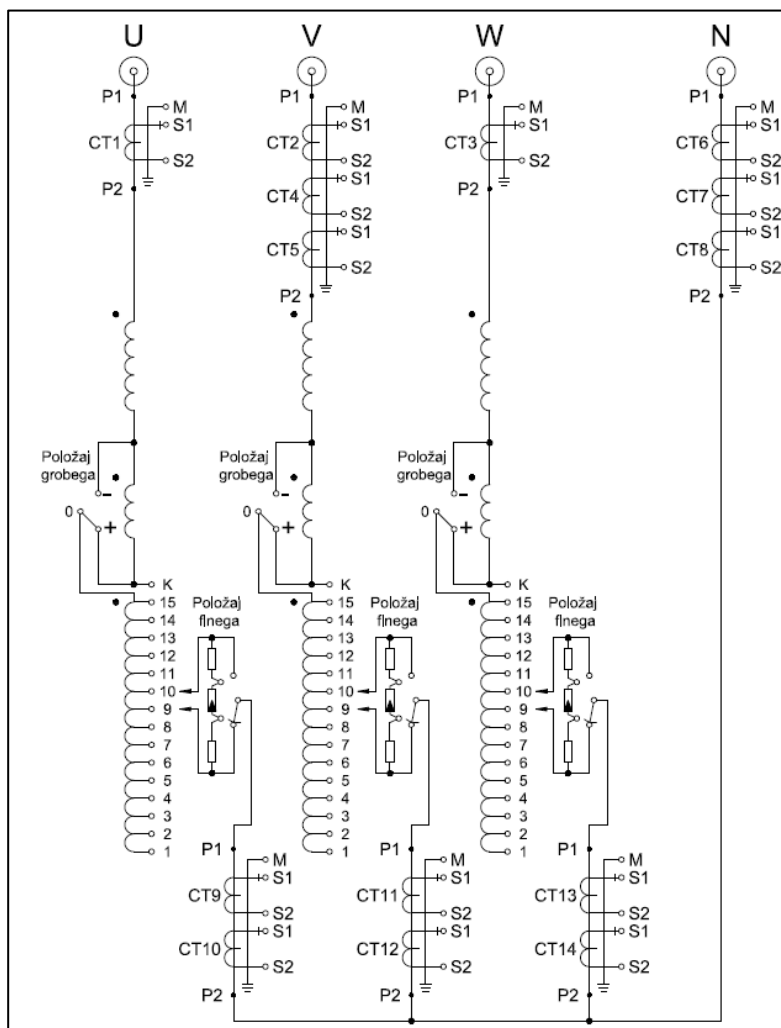


Figure 1: Current transformers in VSR

CT characteristics			
CT Nr.:	Rated primary/secondary currents	Class	Burden power
CT 1-3	500/1 A	Class 3	15 VA
CT 4	400/1 A	Class 3	15 VA
CT 5	500/1 A	Class 3	10 VA
CT 6-8	500/1 A	5P30	30 VA
CT 9-10	500/1 A	5P30	30 VA
CT 11-12	500/1 A	5P30	30 VA
CT 13-14	500/1 A	5P30	30 VA

Table 9: Current transformers

(nominal primary currents will be defined by the manufacturer)

Rated secondary current shall be 1 A.

One metering core for temperature imaging shall be incorporated in one phase bushing and shall not be class P. Means shall be provided for external calibration by current injection into the current transformer secondary circuit. The cores shall be provided with a common 35 mm² test conductor, by means of which current transformer testing can be carried out without magnetizing and loading of the reactor.

Accuracy class of the relaying cores in the neutral bushing shall fulfil the requirements given in the below Table 9.

Accuracy class of the metering cores shall fulfil the requirements given in the below Table 9.

The manufacturer shall verify that the selected current transformers are suitable for the specified protection, monitoring and temperature-imaging functions, including burden, accuracy, short-time current withstand, dynamic current withstand, thermal current withstand and the required performance under all specified operating and fault conditions.

Transformation ratio of (internal assembled near the OLTC) neutral point current transformers in all phases shall be Table 9. For protection purpose two core in each phase should be applied Table 9. All others current transformers are specified in Tender for primary equipment of S/S Krško. It is obligatory to define type and number of cores for on-line monitoring system, which will be mounted on bushing at HV side.

Neutral point current transformers should be protected from stray fluxes with the flux equalizing winding.

15.10 Measuring, monitoring and protection equipment

The VSR shall be fitted with a local control and marshalling cabinet mounted on the reactor tank in a position easily accessible from ground level or from an approved service platform.

The cabinet shall be of weather-proof and corrosion-resistant design, suitable for outdoor installation under the specified service conditions. The degree of protection shall be not lower than IP55, unless otherwise specified. The cabinet shall be adequately ventilated and equipped with an anti-condensation heater controlled by a thermostat or hygrostat.

Internal illumination shall be provided by LED lighting fixtures of standard commercial type. The lighting shall be operated by door contacts and by a manual control switch.

The cabinet shall contain the required control, monitoring, protection, signalling and marshalling equipment associated with the reactor auxiliaries, including termination of all secondary circuits. The internal arrangement of the cabinet shall keep protection, control, measurement, auxiliary AC, auxiliary DC and communication circuits clearly separated from each other, permitting easy and safe inspection, testing, maintenance and replacement of each item without disturbing the others.

Electrical connections between sensors, current transformers, protection devices, monitoring equipment and all other accessories and the local control cabinet shall be installed in corrosion-resistant metallic conduits, cable ducts or raceways of adequate size. They shall be securely fastened to the reactor tank or supporting structure and arranged so as to prevent mechanical damage, vibration, water accumulation and excessive thermal stress.

The main technical data, location and dimensions of all measuring, monitoring and protection devices shall be described in the tender and shown on the relevant reactor drawings. The arrangement shall be subject to purchaser approval.

The VSR shall be monitored through the distributed microprocessor-based substation supervisory and control system. All required signals shall be made available for protection, control, monitoring, alarm, event recording and remote supervision.

Where signals are required by more than one system, enough mutually independent, potential-free and electrically decoupled contacts shall be provided. Protection and trip circuits shall be clearly separated from alarm, indication, monitoring and control circuits.

As a minimum, measuring and protection devices shall provide the following number of potential-free contacts:

- at least one contact for each alarm or signalling function;
- at least two independent contacts for each trip function.

In addition to potential-free contacts, standardised analogue outputs 4–20 mA shall be provided for remote monitoring where specified. Digital communication signals shall also be provided where applicable, for the MR ETOS system, online monitoring equipment and station control system integration.

The following measuring, monitoring and protection equipment shall be supplied as a minimum:

- a) One double-float Buchholz relay for the main reactor tank, equipped with test cock, gas sampling facility, shut-off valves and sufficient independent contacts for alarm (2x) and trip functions (2x).
- b) One dial-type oil temperature indicator with maximum demand indicator and with enough independent and adjustable contacts for cooling control system (2x), alarm (1x) and tripping purposes (2x). The range of temperature indication shall be 0 °C to 160 °C. The device must be equipped with analog isolated current output 4-20 mA.
- c) One resistance-type temperature sensor, Pt100, three-wire connection, for remote measurement of top-oil temperature (4-20 mA). The manufacturer shall provide the measuring value/temperature characteristic.
- d) One winding temperature indicator system for local and remote monitoring of winding temperature, with enough adjustable contacts for cooling control system (2x), alarm (1x) and tripping purposes (2x). The range of temperature indication shall be 0 °C to 160 °C. The device must be equipped with analog isolated current output 4-20 mA.
- e) Fibre-optic winding temperature monitoring equipment connected to the fibre-optic sensors installed in the windings and oil cooling channel in core, as specified in the winding section. The system shall provide local and remote indication, alarm and trip functions, event recording and communication with the reactor monitoring system.
- f) Current transformers for winding temperature indicator and OLTC (in phase B), monitoring (all phases) or other specified functions. These current transformers shall not be of protection class P. Means shall be provided for external calibration by current injection into the current-transformer secondary circuit.
- g) There will be an agreed number of current transformers at the neutral point.
- h) One magnetic-type oil level indicator for the main reactor oil conservator, with at least two independent adjustable contacts for low and high oil level alarm.
- i) One magnetic-type oil level indicator for the OLTC oil conservator compartment, with at least two independent adjustable contacts for low and high oil level alarm.
- j) One protection relay for the OLTC oil compartment, such as an oil-flow relay, oil surge relay or equivalent protection device according to the approved MR VACUTAP arrangement (e.g., MR RS2001) with potential independent protection contacts (2x).
- k) Two spring-operated pressure relief device or pressure relief valve on the main tank and one spring operated pressure relief device on OLTC provided with a trip contacts (2x) as specified.
- l) Monitoring, control and diagnostic equipment associated with the MR ETOS system for the MR VACUTAP on-load tap-changer, including OLTC position, operation counter, motor-drive status, alarms, trips, maintenance indication, event recording and communication interface to the station control system.

The Buchholz relay for the main tank shall be provided with two electrically separate contacts as a minimum:

- one contact activated by slow gas formation, to be used for alarm;
- one contact activated by heavy gas formation, sudden oil flow or low oil level, to be used for tripping.

The Buchholz relay shall be provided with shut-off valves. Where technically feasible and approved by the manufacturer, a bypass arrangement may be provided to allow relay replacement without draining the main tank. Any testing, isolation or replacement of the relay while the reactor is in service shall be subject to the manufacturer's approved operating and safety procedure.

Each oil compartment shall be protected separately. The main reactor tank and the OLTC oil compartment shall have separate protection, monitoring and alarm/trip functions.

Gas sampling and functional testing of the Buchholz relay shall be possible without draining the reactor oil. The relay shall be located in a position that allows safe access for inspection, testing, gas sampling and maintenance from ground level, ladder or approved service platform.

All protection and monitoring devices shall be arranged so that alarm and trip functions are clearly identified. Trip contacts shall be wired to dedicated terminal blocks and shall be galvanically separated from alarm and indication circuits.

All measuring and monitoring equipment shall be suitable for the specified environmental conditions, auxiliary supply system, electromagnetic environment and substation control philosophy. The equipment shall comply with the applicable IEC standards and the general technical specifications.

The manufacturer shall submit complete documentation for the measuring, monitoring and protection equipment, including at least:

- list of all measuring, monitoring and protection devices;
- manufacturer and type designation of each device;
- technical data sheets;
- setting ranges and proposed settings;
- contact functions and contact ratings;
- analogue output ranges, including 4–20 mA signals;
- digital communication interfaces and protocols;
- terminal diagrams;
- wiring diagrams;
- cabinet layout;
- alarm and trip matrix;

- interface list for the substation control system;
- test and commissioning procedures;
- maintenance instructions.

15.11 On-line monitoring system

The offered variable shunt reactor shall be equipped with a complete on-line monitoring system, hereinafter referred to as OLM.

The OLM shall provide continuous monitoring, diagnostics, data acquisition, data storage, alarm handling, event recording and communication with the substation control system and the central on-line monitoring system. The OLM shall be fully integrated with the VSR measuring, monitoring and protection equipment the MR ETOS and other systems.

The OLM supply and installation shall include, as a minimum:

- supply, installation and commissioning of all measuring and sensor equipment installed on or inside the VSR;
- supply, installation and commissioning of the local OLM control module or control box on the VSR;
- supply, installation and commissioning of the OLM server in the substation control house;
- communication connections between sensors, measuring equipment, the local OLM control module, the local control cabinet, the OLM server in the substation control house and connection to the existing Customer diagnostic centre;
- supply and laying of optical communication cables between the local OLM control module and the OLM server in the substation control house;
- support of analogue and digital communication with sensors and intelligent electronic devices;
- connection, calibration and parameterisation of fibre-optic temperature sensors installed in the VSR windings and oil cooling channel;
- connection, calibration and parameterisation of the MR ETOS system to the OLM;
- supply and installation of all applicable software on the OLM server located in the substation control house;
- supply and installation of application software for measurement, calculation, evaluation, display and storage of monitored quantities;
- parameterisation of all sensors, measured values, calculated values, alarms, events and communication interfaces;
- integration into the central on-line monitoring system (DAC SCADA);
- start-up, testing and commissioning of the complete OLM;
- technical documentation, including detailed design documentation, erection documentation, commissioning documentation and as-built documentation.

The central on-line monitoring system, hereinafter referred to as DAC SCADA, is intended for direct monitoring and diagnostics of power transformers and variable shunt reactors. It enables robust and fast multi-user access, permanent data storage, data processing, data analysis and display using web-based technologies and tools.

Local OLM data shall be transmitted to the DAC SCADA by means of a service application capturing raw-format data, including process values, events and alarms.

The tenderer shall ensure complete interoperability of the supplied OLM with the above-described DAC SCADA. The OLM shall support communication with DAC SCADA by means of Modbus TCP, IEC 61850, or web services. The final communication protocols, signal lists, data structure, timestamps, alarm classes and interface requirements shall be agreed with the purchaser during detailed design.

The tenderer shall include the VSR in the common DAC SCADA. Operating data, diagnostic values, calculated values and alarm/event states shall be simultaneously visible. The tenderer shall enable storage of all parameter values, calculated values and alarm/event states of the VSR OLM in the ELES central database.

The OLM shall be designed so that no data from sensors or local monitoring equipment is lost in the event of a short DAC SCADA downtime or temporary communication interruption. Local buffering of data, events and alarms shall be provided. After communication is restored, buffered data shall be automatically transferred.

15.12 Measuring equipment and sensors

The OLM shall include all required measuring equipment and sensors. Where technically possible, sensors and intelligent devices shall support analogue or digital communication, such as Modbus TCP, DNP3 or IEC 61850.

The following VSR quantities shall be captured and monitored as a minimum:

- top-oil temperature;
- bottom-oil temperature;
- ambient temperature;
- temperatures of incoming and outgoing radiator oil pipelines;
- dissolved gas and moisture in oil, including at least hydrogen, carbon monoxide and moisture measurement, e.g. Morgan Schaffer Calisto 2 or technically equivalent equipment approved by the purchaser;
- operating current taken from the internal instrument current transformer;
- gas accumulation in the Buchholz relay;
- power factor or dielectric dissipation factor where applicable;
- operating voltages from external VTs;

- transient overvoltages, capacitance and dielectric dissipation factor / power factor of HV bushings, e.g. OMICRON MONTRANO, MR MSENSE BM or technically equivalent equipment approved by the purchaser (test tap shall be approved by bushing producer);
- tap-changer monitoring data from MR ETOS, including tap position, number of switching operations, switching sequence, switching time, motor-drive status, diagnostic information and maintenance indicators;
- OLTC oil temperature, where applicable;
- vibration sensors (measuring range 5 Hz to 10 kHz (e.g. WISE- or technically equivalent equipment approved by the purchaser)) – (3) three pieces.
- status of all relevant protection, alarm and trip devices;
- status of auxiliary systems, communication links and monitoring devices.

The OLM software shall provide calculation, evaluation, display, storage and reporting of measured and calculated parameters. As a minimum, the software shall provide the following functions:

- calculation of winding hot-spot temperature in accordance with IEC 60076-7;
- calculation or estimation of relative moisture content of paper insulation;
- evaluation of insulation ageing in accordance with IEC 60076-7;
- calculation of ageing rate of insulation in accordance with IEC 60076-7;
- calculation of cumulative ageing rate;
- calculation or estimation of actual losses;
- calculation or indication of bubbling temperature;
- indication and recording of overvoltage events in all three phases;
- indication and recording of overcurrent events in all three phases, with a sampling time of 20 ms or less;
- evaluation of OLTC contact usage based on actual current and tap position;
- monitoring of VSR bushing capacitance change;
- monitoring of bushing dielectric dissipation factor / power factor;
- trend analysis of measured and calculated values;
- alarm and event evaluation;
- diagnostic reporting.

The OLM software shall also provide the following capabilities:

- review of archived data and reports;
- review of main operating and diagnostic parameters;
- statistical data analysis;
- archiving of measured data, calculated values and analysis results;
- monitoring of sensor-to-server communication connections;
- supervision of sensor operation and sensor status;

- examination of connected equipment status;
- data archiving in a standardised database, preferably MS SQL or another database approved by the purchaser;
- automatic backup and duplication of stored data for security reasons;
- display and download of any selected combination of monitored data;
- simultaneous display of operating data and alarm states of each transformer or VSR included in the on-line monitoring system, including units from other substations where applicable;
- graphical display of each transformer or VSR, including a picture or schematic representation of the corresponding device;
- retrieval of limit values for measured process values by the customer's DAC SCADA, including low-active, low-inactive, high-active and high-inactive limits, where required;
- alarm visualisation;
- annunciation of alarm states to responsible personnel via intranet, internet, e-mail, SMS, mobile application or other approved method;
- user parameterisation of alarm levels, limit values, historical database processing and other user-defined settings.

All offered software shall be inspected and approved by the purchaser before commissioning. The software shall be user-friendly and shall allow access from personal computers via an appropriate server through the customer's intranet and, where approved, through secure internet access. Connected users shall be able to use the permitted display, diagnostic and reporting functions according to their access rights.

The software shall allow user parameterisation of alarm thresholds, warning thresholds, calculation parameters, historical data handling and other configurable functions. Access to parameterisation functions shall be protected by user authentication and access-level management.

Data shall be stored locally with high time resolution. After a defined period, average values of each measured quantity shall be automatically stored in the long-term database. All asynchronous phenomena, including alarms, trips, trip-change operations, status changes and communication failures, shall be stored separately with exact date, time, measured value and event description.

All events and alarms shall be time stamped. The time-synchronisation method shall be agreed with the purchaser and shall be compatible with the substation control and monitoring system.

Software updates shall be supplied to the purchaser free of charge for at least three years after the first installation and commissioning. Updates shall include correction of software errors, compatibility improvements and security updates. Updates shall not reduce any functionality accepted during commissioning.

Main OLM elements installed on the reactor shall be designed and manufactured by a recognised equipment manufacturer with proven experience in power engineering and transformer/reactor monitoring systems.

The OLM shall be designed so that servicing and elimination of potential failures can be performed using standard components, without the need for returning equipment to the manufacturer, except where specialised factory repair is unavoidable.

The OLM supplier shall provide sufficient training to the purchaser's personnel to enable operation, first-level diagnostics, data retrieval, parameterisation, backup handling and basic service intervention on the server unit and local monitoring equipment. The system shall be designed so that qualified personnel of the purchaser or the purchaser's authorised contractor can restore normal operation by using the supplied operation and maintenance instructions.

The software upgrades, user interface, alarm texts, monitor screens and display masks shall be provided in the Slovene language. Technical documentation shall be provided in English and, where required by the purchaser, also in Slovene.

The manufacturer shall submit complete OLM documentation, including at least:

- OLM architecture diagram;
- list of all sensors and monitoring devices;
- manufacturer and type designation of each sensor and device;
- measuring ranges and accuracy data;
- communication protocol descriptions;
- signal list for OLM, ETOS, substation control system and DAC SCADA;
- database structure and data-storage concept;
- alarm and event list;
- calculation methods and applied standards;
- software description;
- cyber-security and user-access concept;
- time-synchronisation concept;
- cabinet and server arrangement drawings;
- cable and fibre-optic connection diagrams;
- terminal diagrams;
- parameterisation list;
- testing and commissioning procedures;
- backup and restore procedure;
- operation and maintenance manuals;
- training programme for purchaser personnel;
- as-built documentation.

The complete OLM, including all sensors, communication links, server equipment, software, ETOS interface, bushing sensor interface and DAC SCADA integration, shall be tested during commissioning. The test shall verify correct measurement, calculation, alarm generation, event recording, data storage, communication, visualisation and data transfer to the central monitoring system.

15.13 Erection works

Erection works shall contain:

- connection points for VSR sensors erection (in the factory and on site),
- measuring sensors erection,
- control box erection (control module),
- system server erection
- communication connections between sensors and control box realization,
- optical cable: control box – system server in the relay house and connection (distance of appx. 200 m),
- software installation for substation server and user computers, which shall be connected to the server via intranet/internet in both substations,
- parameterization (alarm levels) for supervised VSR,
- integration into the central monitoring system DAC SCADA.

15.14 Winding and core temperature optical sensors

Direct measurement of winding hot-spot temperature shall be provided by fibre-optic temperature sensors installed in the windings of the VSR.

At least twelve fibre-optic temperature sensors shall be installed. The sensors shall be distributed among the three phases and located at positions where the highest winding temperatures are expected. At least two additional sensors, or one of the specified measuring sensors if approved by the purchaser, shall be installed in a selected oil cooling channel of the VSR core or active part.

The preliminary number, location and function of each sensor shall be proposed by the manufacturer based on thermal design calculations. The final locations of the fibre-optic measuring sensors shall be reviewed and agreed with the purchaser during the design review, before manufacture.

The fibre-optic temperature measuring system shall include sensors, tank-wall feedthroughs or connection interfaces, a local winding temperature indicator on or near the VSR tank and remote monitoring via the on-line monitoring system.

The sensors and measuring equipment shall be suitable for continuous operation in hot transformer oil and under the specified electromagnetic, thermal, mechanical and dielectric conditions. They shall be compatible with the winding insulation system, drying

process, oil impregnation process, thermal expansion, vibration and expected service life of the reactor.

Fibre-optic sensors and measuring equipment manufactured by FISO, LumaSense/Luxtron, Neoptix, or technically equivalent equipment approved by the purchaser, are acceptable.

The manufacturer shall submit sensor layout drawings, installation procedure, channel identification list, calibration certificates, factory test results, commissioning test results and operation and maintenance instructions.

15.15 VSR tank and equipment

The VSR tank and its cover shall be fabricated from tested high-tensile, low-carbon steel plate of adequate thickness. The VSR tank shall be of welded box-type construction, with a bolted flat cover and vertical box-beam stiffeners.

The tank, cover, stiffeners, lifting points, jacking points, pulling eyes, under-base supports and all structural parts shall be designed so that packing, lifting, rolling, skidding, transport, handling, erection and service operation do not cause overstressing, permanent deformation or damage to any part of the reactor, whether the tank is empty, partially filled, fully oil-filled or containing the complete core-and-coil assembly.

The tank shall be completely oil-tight and watertight under all specified operating, transport and test conditions. The tank cover shall be bolted and sealed independently of the tank type or design. All seams shall be welded in the factory and, wherever practicable, double-welded. All welding work shall be performed by qualified welders. All oil-tight welds shall be tested to verify that no oil leakage will occur.

The main VSR tank, OLTC/diverter-switch oil compartment, radiators, conservator, valves, gaskets, flanges, oil pipes and associated oil-containing equipment shall be designed to withstand, without permanent deformation or leakage, full vacuum and an internal overpressure of 100 kPa, unless otherwise specified for components. The reactor shall remain oil-tight under these conditions and at the top-oil temperatures that may occur during operation.

During the vacuum test, the permissible loss of vacuum shall not exceed 6 mm Hg in six hours. The overpressure test shall have a duration of 24 hours. The completely assembled VSR shall also be capable of withstanding, without damage under service conditions, pressure forces exceeding acc. to IEC 60076-1-11.8 above the maximum pressure-relief device setting.

The tank shall be of bolted-cover type. At least two manholes, fitted with bolted covers, shall be provided on the tank. They shall be suitably positioned and of sufficient size to allow access to the lower ends of bushings, winding leads, internal current transformers,

OLTC-related internal parts and other equipment requiring inspection or maintenance. Inspection covers shall be provided with lifting handles.

Gaskets shall be made of oil-resistant synthetic rubber or another approved material suitable for continuous operation in hot transformer oil. Gaskets shall be located on flanges with steel stops or equivalent means to avoid over-compression. O-ring gasket technology shall be applied wherever feasible. The tank-cover gasket shall be seated in machined grooves or in grooves formed by continuously welded steel bars around the flanges. Details of gasket materials, gasket arrangement and sealing design shall be submitted for purchaser approval, together with suitable references demonstrating long-term leakage-free operation.

The tank and covers shall be designed to avoid external pockets where water may accumulate and internal pockets where oil may remain after draining, where air may be trapped during filling, or where gas may accumulate and impair operation of the gas-actuated relay. Venting pipes shall connect all points where air or gas may collect to the gas relay or to an approved venting arrangement.

The tank design shall prevent water from remaining on the outer surfaces. All openings on the tank cover shall be raised at least 25 mm above the outer surface of the cover. All covers shall be equipped with suitable lifting handles.

Suitable pockets shall be provided on the tank cover for oil-temperature and winding-temperature indicators, including resistance or capillary temperature sensors. Thermometer bulbs or resistance sensors shall be removable without lowering the oil level in the tank. The pockets shall be located where the highest oil temperature is expected. Unused pockets shall be fitted with tight plugs preventing water ingress.

All studs, bolts and nuts shall be made of corrosion-resistant material, hot-dip galvanised steel or stainless steel, as appropriate for the location and service conditions. All bolted joints exposed to atmosphere shall be protected against corrosion and loosening.

Special measures shall be taken to minimise the effects of stray flux caused by high-current conductors and leakage flux. Non-magnetic steel, magnetic shielding, flux shunts or other suitable design measures shall be applied where necessary to avoid local overheating, excessive losses, vibration or structural damage.

The tank and accessories shall be designed and manufactured to avoid detrimental effects from vibration. The maximum vibration amplitude measured on the tank shall not exceed the values stated in the List of Guaranteed Characteristics at maximum operating voltage. The stresses in the tank, measured by strain gauges or calculated by suitable mechanical analysis, shall not exceed the specified permissible values at maximum operating voltage.

The active part shall not be bolted directly to the tank in a manner that would result in unacceptable vibration transfer. Suitable vibration-reducing design measures shall be

applied where necessary, for example resilient or damping elements between the active part and tank structure, subject to manufacturer's design and purchaser approval.

The tank cover and tank walls shall be provided with an adequate number and size of openings for erection, assembly, inspection and maintenance of bushings, OLTC components, internal current transformers, winding leads, core earthing connections and other internal equipment.

Oil and gas sampling, inspection, maintenance and reading of measuring instruments shall, wherever practicable, be possible from operating height and at a safe distance from live parts. Activities intended to be performed while the reactor is in service shall be possible without danger to operating personnel and shall comply with the manufacturer's approved safety procedures.

All pipe flanges must be made of stainless material to prevent rusting on the points where anticorrosion protection may be damaged.

Metallic continuity shall be ensured between all parts forming the tank, cover, pipework, fittings, radiators, support structures and accessories so that they are maintained at the same potential. Suitable electrical bonding connections shall be provided where necessary.

Suitable electrical connections shall ensure that all tank parts, fitting frames, pipework and accessory structures are solidly earthed. Four tank grounding pads shall be provided, located near the corners of the tank base. The grounding pads shall be copper-faced steel pads or stainless-steel pads without copper facing, welded to the tank base. Each pad shall include a clamp-type terminal and bolts suitable for connection of the station grounding conductor.

Steel plates for jacking lugs shall be located near the corners of the tank base. Lifting lugs shall be provided for lifting the completely assembled reactor filled with oil and for lifting the active part only, where applicable.

Pulling eyes shall be mounted near the tank base for dragging or skidding the reactor. The tank bottom shall be provided with skids or an under-base suitable for movement on a flat surface. In addition, standing feet shall be provided for permanent installation of the VSR.

The tank design and dimensions of the main parts shall be also suitable for railway transportation supported on side brackets. For this purpose, two sets of brackets to be bolted to the tank shall be provided. Provisions shall also be made for bracing during transportation on a low-bed trailer. Detailed transport requirements shall be provided by the purchaser and shall be considered by the manufacturer during detailed design.

Each tank shall be provided with:

- lifting lugs suitable for lifting the reactor;

- four jacking lugs close to the tank base;
- pulling eyes close to each corner of the tank, with an opening not less than 50 mm in diameter;
- pulling eyes designed so that each one can withstand the full pulling force during sliding or skidding of the complete reactor;
- provisions for brackets for transportation on side-beam railway cars;
- provisions for bracing during transportation on a low-bed trailer.

The following accessories shall be provided on the tank as a minimum:

- drain valve;
- oil filter valves;
- three oil sampling valves;
 - one oil sampling point at cover level;
 - one oil sampling point at approximately half tank height;
 - one oil sampling point at tank bottom level;
- arrangement enabling all oil samples to be taken safely from tank-bottom operating level during normal reactor operation;
- valve for connection of a vacuum pump, with characteristics and position to be agreed after order placement;
- valves for connection of an on-line dissolved gas analyser;
- five thermometer pockets on the tank cover, with locations subject to purchaser approval, of which one shall be suitable for thermal replica/winding-temperature imaging;
- two isolating butterfly valves on the connections of each radiator;
- flanges for connection of radiators to the tank or to the headers of a separate cooling system;
- four tank grounding pads as specified above.

The tank, cover, accessories, valves, pipework and fittings shall be arranged so that filling, draining, vacuum treatment, oil circulation, oil filtering, sampling, venting and maintenance can be performed safely and efficiently. The arrangement shall avoid air traps and ensure complete oil filling and effective gas venting. The ladder shall be equipped with a protection system to secure personnel against falling. The VSR cover shall be provided with certified fall-arrest anchorage points for securing personnel safety harnesses during inspection and maintenance activities on the VSR. The manufacturer shall submit complete tank and equipment documentation, including at least:

- tank general arrangement drawings;
- tank structural drawings;
- cover and manhole arrangement;
- gasket and sealing details;
- welding and weld-testing procedures;
- vacuum and overpressure test procedure;
- lifting, jacking, pulling and skidding arrangement;
- railway and road transport arrangement;
- grounding and bonding arrangement;
- valve and sampling arrangement;
- oil filling, draining and venting procedure;
- thermometer pocket arrangement;
- vibration mitigation concept;
- strain/stress verification where applicable;
- fall-protection system documentation;
- maintenance and inspection procedures.

15.16 Conservator

The conservator shall be located above the highest point of the oil system on the VSR tank cover. Pipe connections between the tank and the conservator shall be arranged so as to avoid accumulation of air or gas under the tank cover and to ensure proper gas flow to the gas-actuated relay.

The location of the conservator shall allow the passage and required clearances of the high-voltage conductors above the VSR. The final location and arrangement of the conservator shall be defined by the manufacturer and submitted for purchaser approval. The arrangement of the HV connections is shown on the corresponding drawings.

The conservator shall be designed to accommodate oil expansion and contraction over the complete specified operating temperature range. Between the lowest and highest oil levels, the conservator shall have a usable capacity of not less than 7 % of the total cold oil volume of the reactor, including the tank, radiators and associated oil-filled equipment. The conservator shall be suitable for an oil temperature range from $-25\text{ }^{\circ}\text{C}$ to $+120\text{ }^{\circ}\text{C}$.

The conservator shall be provided with a synthetic diaphragm or air-cell bag, airtight and oil-resistant, to prevent direct contact between oil and ambient air. The inside of the air cell shall be in contact with ambient air through a dehydrating silica-gel breather with oil seal. The outside of the air cell shall be in direct contact with the oil. The conservator and air-cell system shall be suitable for vacuum filling of the reactor oil system.

The conservator vessel shall be provided with separate compartments for the main VSR oil system and for the on-load tap-changer oil system, where applicable. Each compartment shall have its own oil-level indicator, filling and draining facilities, breather arrangement and alarm contacts, as required by the approved oil-system design.

The conservator shall be equipped with:

- filling cap or filling valve;
- drain valve or drain plug;
- inspection openings of sufficient size for inspection, cleaning and maintenance;
- bolted inspection covers fitted with handles;
- lifting lugs;
- dehydrating silica-gel breather with oil seal;
- magnetic oil-level indicator;
- low oil-level and high oil-level alarm contacts;
- pipe connection to the gas-actuated Buchholz relay;
- pipe connection to the main tank;
- isolating valves as required for maintenance and relay removal.

The connection pipe between the conservator and the main tank shall be arranged as a straight sloped pipe wherever practicable, with an internal diameter of not less than 50 mm. The pipe shall have a continuous slope of approximately 3° to 7° to the horizontal and shall be arranged to ensure reliable gas flow to the Buchholz relay. The pipe connection to the conservator shall protrude at least 25 mm inside the conservator, unless an alternative proven arrangement is approved by the purchaser.

The Buchholz relay shall be installed in the pipe between the main tank and the conservator. Suitable isolating valves shall be provided on both sides of the relay. A bypass pipe and associated valves shall be provided, where approved by the manufacturer and purchaser, to permit removal or replacement of the Buchholz relay while maintaining the connection between the conservator and the main tank. Any such operation shall be subject to the manufacturer's approved safety and operating procedure.

The conservator shall be full-vacuum proof and shall withstand the specified vacuum-filling and oil-treatment procedures without permanent deformation, leakage or damage to the air-cell system. The manufacturer shall provide confirmation that the conservator, air cell, fittings and pipework are suitable for the specified vacuum conditions.

A magnetic-type oil-level indicator shall be provided for each conservator compartment. The indicator shall have a dial diameter of not less than 125 mm and shall indicate at least the minimum, maximum and 20 °C oil levels. The oil-level indicator shall be located at a convenient height and position allowing safe reading from ground level or from an approved access platform. The indicator shall be equipped with independent alarm auxiliary contacts for low and high oil-level indications.

The conservator shall have bolted, not welded or riveted, connections to its supports and pipework where removal may be required. The arrangement shall allow convenient removal of the conservator when necessary, without interference with HV conductors, bushings, pipework, access platforms or other equipment.

The conservator position shall provide adequate clearance from all electrical open-air connections and other live parts. It shall not obstruct access to bushings, Buchholz relay, OLTC equipment, radiators, valves, inspection openings or measuring devices.

The VSR shall be provided with a suitable platform for inspection, gas sampling, testing and maintenance of the Buchholz relay. The platform and access ladder shall be designed in accordance with applicable safety requirements and shall include protection against falling. Safe access shall be provided to oil filling devices, drain valves, inspection openings, lifting points, breathers and oil-level indicators.

The conservator, supports, pipework, valves, breathers, oil-level indicators and accessories shall be designed and installed to withstand all mechanical, thermal, vacuum, pressure, vibration, wind and environmental stresses occurring during transport, installation, oil filling, vacuum treatment, operation and maintenance.

The manufacturer shall submit complete conservator documentation, including at least:

- conservator arrangement drawing;
- compartment arrangement for main VSR oil and OLTC oil;
- usable oil expansion volume calculation;
- air-cell/diaphragm design data;
- vacuums withstand confirmation;
- breather arrangement;
- oil-level indicator details;
- alarm contact details;
- Buchholz relay pipe arrangement;
- isolating and bypass valve arrangement;
- filling, draining and venting procedure;
- access platform and ladder arrangement;
- maintenance and inspection instructions.

15.17 Dehydrating breather

Each conservator compartment requiring connection to ambient air shall be equipped with a dehydrating breather and an oil trap or oil seal.

The dehydrating breather shall be a maintenance-free, self-regenerating n the quality class of Maschinenfabrik Reinhausen products. It shall be equipped with silica gel and an

automatic regeneration heater activated when the silica gel reaches the specified moisture level. Under normal service conditions, replacement of silica gel shall not be required.

The breather shall be suitable for the site environmental conditions specified in the General Technical Specifications. The auxiliary supply voltage shall be 230 V AC, and signal contacts shall be suitable for 220 V DC control circuits.

The breather shall provide alarm and status signals for power supply failure, heater or regeneration failure, high moisture condition and device fault. The heater supply shall be supervised by suitable current monitoring so that failure of the regeneration function is detected and signalled.

Where two breathers are installed for the same oil system, a three-way valve or equivalent arrangement shall ensure continuous operation of at least one breather during inspection, maintenance or replacement of the other.

The breather shall be arranged so that the passage of air is through the dehydrating medium and so that unnecessary continuous exposure of the silica gel to ambient atmosphere is prevented. Local indication of moisture condition shall be provided by colour change or equivalent indication.

All breathers shall be installed at an accessible height, approximately 1.5 m above ground level or above the relevant service platform, allowing safe inspection and maintenance.

A diaphragm or air-cell system shall be provided in the conservator to separate the oil from ambient air, as specified in the conservator section. No chemical-type on-line oil filter shall be used as oil preservation equipment.

The manufacturer shall submit the breather type designation, operating principle, auxiliary supply data, alarm and signal list, valve arrangement, mounting details and maintenance instructions.

15.18 Piping, valves, joints and gaskets

All necessary drain valves, filling valves, shut-off valves, isolating valves, check valves, air-release plugs, sampling valves, blanking plates, end fittings, pipe connections and associated accessories shall be supplied in sufficient quantity to suit the size, arrangement and maintenance requirements of the VSR.

The arrangement shall allow safe oil filling, draining, filtering, vacuum treatment, oil sampling, venting, inspection, maintenance and removal of components attached to the tank, conservator, radiators and OLTC oil system.

All valves shall comply with DIN 3230-3, leakage rate 1, or with an equivalent approved standard. The final number, type, size and location of all valves shall be subject to purchaser approval.

All valves, fittings, pipes, joints, flanges and seals shall be designed and manufactured from materials suitable for continuous operation in hot transformer oil and for outdoor service under the specified environmental conditions. They shall not deteriorate due to oil,

temperature, ageing, humidity, ultraviolet radiation, corrosion, vibration or other service influences.

Every element shall be designed so that it can be easily inspected, maintained, isolated or replaced. All piping and valve arrangements shall be clearly accessible and shall not obstruct access to bushings, radiators, conservator, Buchholz relay, OLTC equipment, measuring devices, sampling points or other accessories.

All valves up to and including DN 50 shall be made of brass, gunmetal or another approved corrosion-resistant material. Larger valves may have cast-iron bodies with gunmetal or equivalent corrosion-resistant fittings, subject to purchaser approval.

Each valve shall be provided with a clear and durable position indicator showing whether the valve is open or closed. Where necessary, valves shall be capable of being locked or sealed in the required operating position.

All oil-tight joints shall be made with machined flanges and approved gasket types. The gasket material and sealing arrangement shall be submitted for purchaser approval. Means shall be provided to prevent over-compression of gaskets. All joint faces shall be arranged to prevent ingress of water and leakage of oil, with the minimum practicable gasket surface exposed to oil and air.

All gaskets between metallic parts shall be designed so that, after tightening, metal-to-metal contact or another approved compression-limiting arrangement is achieved. O-ring gasket technology shall be applied wherever feasible.

All valves, pipe ends, flanges and joints that are not in use shall be closed with suitable oil-tight end fittings, screw caps, blanking plates or blind flanges.

All piping shall be arranged with suitable slopes and venting points to avoid air pockets during oil filling and to enable complete draining where required. Pipes shall be adequately supported and protected against vibration, mechanical damage, thermal expansion and transport stresses.

All valves, pipes, fittings, joints and gaskets shall be correctly identified, labelled and documented in the VSR drawings and in the final valve schedule. The valve schedule shall include valve number, function, type, size, material, location, normal operating position and associated interlocks or alarms where applicable.

The VSR shall be equipped with the following valves and connections as a minimum.

The VSR tank shall be equipped with:

- a) one DN 50 drain valve arranged so that the tank can be completely drained of oil;
- b) two DN 50 oil-filtering and oil-treatment valves, located near the bottom of the tank and diagonally opposite near the cover level, suitable for connection of oil-treatment equipment in accordance with purchaser requirements and, where applicable, IEC 60567;
- c) one valve or connection for vacuum pump connection, with characteristics and position to be agreed during detailed design;

d) three oil-sampling valves, arranged for sampling from the following levels:

- top oil level;
- approximately middle tank height;
- bottom tank level.

The oil-sampling valves shall be routed, where necessary, to an accessible operating height so that oil samples can be taken safely during normal reactor operation and at a safe distance from live parts. Sampling arrangements shall comply with IEC 60567 where applicable.

Unless otherwise agreed with the manufacturer and approved by the purchaser, the sampling and oil-treatment connections shall be located at suitable positions near the tank bottom and at two diagonally opposite corners, where practicable.

The conservator system shall be equipped with:

- a) one valve arrangement for the oil pipe bypassing the Buchholz relay, where a bypass is provided;
- b) two isolating valves for isolation and removal of the Buchholz relay;
- c) one oil filling plug or filling valve;
- d) one drain valve arranged so that the conservator compartment can be completely drained of oil;
- e) additional valves and fittings required for separate conservator compartments, including the main VSR oil compartment and the OLTC oil compartment, where applicable.

Radiators shall be equipped with valves at each connection point between the tank and the radiators or between the radiator headers and the separate cooling system, in accordance with the VSR cooling-system requirements.

Each radiator or radiator group shall be provided with isolating valves at the inlet and outlet, enabling isolation and removal without draining or lowering the oil level in the main tank. Each radiator and radiator header shall also be provided with vent and drain plugs.

The OLTC oil system shall be provided with all valves, drain connections, filling connections, sampling connections, isolating valves, protection-relay connections and conservator connections required by the approved MR VACUTAP design.

The OLTC oil compartment and associated conservator section shall be arranged so that filling, draining, sampling, venting, protection-relay testing and maintenance can be performed safely and without contamination of the main VSR oil system.

The manufacturer shall submit complete documentation for piping, valves, joints and gaskets, including at least:

- piping and instrumentation arrangement;
- valve schedule;
- material specifications for valves, pipes, fittings and gaskets;
- gasket and flange details;
- valve normal operating positions;
- filling, draining and venting procedure;
- oil sampling arrangement;
- oil filtering and vacuum-treatment connection details;
- radiator isolation arrangement;
- Buchholz relay isolation and bypass arrangement;
- OLTC oil-system valve arrangement;
- maintenance and replacement instructions.

15.19 VSR pressure relief valves / devices

The VSR main tank shall be equipped with approved pressure relief devices of spring-controlled type, suitable for rapid release of internal overpressure that may occur in the oil-filled tank and associated oil-filled connection parts.

The number, size, operating pressure and location of the pressure relief devices shall be determined by the manufacturer based on the tank design, oil volume, internal pressure withstand capability and applicable standards, and shall be submitted to the purchaser for a approval.

Each pressure relief device shall be of adequate size and shall operate at a static pressure lower than the hydraulic test pressure of the tank. The pressure relief device shall be designed and selected so as to prevent permanent deformation or damage to the tank under internal fault or abnormal pressure conditions.

Each pressure relief device shall be provided with at least one normally open signalling contact for remote alarm indication. Remote monitoring of the pressure relief devices shall be possible. Activation of any pressure relief device shall generate an alarm in the local control cabinet and in the remote monitoring/control system.

Each pressure relief device shall be provided with a mechanical operation indicator, clearly visible from operating height and from a safe distance from live parts. It shall be possible for operating personnel to determine locally, without danger, whether a pressure relief device has operated.

The pressure relief devices shall preferably be mounted on the tank cover. Each device shall be provided with a skirt or equivalent arrangement extending at least 25 mm into the tank in order to prevent gas accumulation below the device and to avoid obstruction of gas flow. The discharge from each pressure relief device shall be directed away from the VSR top cover, bushings, operating positions, access paths, measuring devices and other equipment. Suitable oil discharge pipes, ducts or extensions shall be provided to lead discharged oil safely down to the oil collector or oil containment system.

Measures shall be taken to protect personnel, surrounding equipment and structures against oil splashes and hot oil discharge in the event of operation of the pressure relief device.

The pressure relief devices shall be designed and tested in accordance with IEC/EN 50216 - 5. Type-test and routine-test certificates shall be submitted to the purchaser.

The OLTC oil compartment/tap-changer tank shall be equipped with a pressure relief device providing equivalent safety functionality to that of the main oil tank, unless the approved MR VACUTAP design provides another manufacturer-approved pressure protection arrangement. The OLTC pressure relief device shall also be equipped with local indication and remote alarm signalling.

The manufacturer shall submit complete documentation for the pressure relief devices, including at least:

- manufacturer and type designation;
- number and location of devices;
- rated discharge capacity;
- operating pressure;
- reset characteristics, where applicable;
- contact arrangement and contact rating;
- local mechanical indication arrangement;
- remote alarm signal arrangement;
- oil discharge direction and discharge piping arrangement;
- compliance and test certificates according to IEC/EN 50216-5;
- installation and maintenance instructions.

15.20 Identification plates

The VSR shall be provided with identification, rating, instruction and warning plates made of approved corrosion-resistant material suitable for continuous outdoor service under the specified environmental conditions.

All plates shall be permanently fixed, durable, weather-resistant, UV-resistant and clearly legible throughout the service life of the reactor. The inscriptions shall be in English, unless otherwise specified by the purchaser. Where required, inscriptions shall also be provided in Slovene.

The following plates shall be supplied as a minimum:

- a rating plate in accordance with IEC 60076, including voltage, current, reactive power and connection data for each tap position;
- a diagram plate showing the plan view of the VSR and the correct physical relationship, designation and phase sequence of all terminals;
- a valve and air-release plate showing the location, designation and function of all oil valves, sampling valves, drain valves, filling valves, filtering valves, air-release cocks, air-release plugs and other relevant oil-system components;
- a warning instruction on the valve plate requiring the operator to refer to the maintenance instructions before applying vacuum treatment;
- information on insulating liquid, including mineral insulating oil type in accordance with IEC 60296, where applicable;
- numbered identification plates for all oil valves, cocks, oil pumps where applicable, fans where applicable, water valves where applicable, breathers, oil-level indicators, sampling points and other accessories requiring identification;
- valve-mounted plates or labels whose inscriptions shall correspond exactly to the designations shown on the valve plate and in the valve schedule;
- a plate or durable diagram showing all electrical circuits, terminal blocks and external connection designations. This plate shall be located on the inner side of the hinged door of the marshalling kiosk or local control cabinet;
- a lifting, jacking and pulling plate showing the points for jacking, lifting and pulling, the permissible load-carrying capacities and the necessary dimensions and permitted angles of lifting ropes or slings;
- connection designation plates for all terminals and external connection points.

All plates related to terminal designations, operating positions, valve identification, oil sampling and safety instructions shall be clearly visible and readable from normal operating level or from the designated service platform. The manufacturer shall submit the proposed wording, material, dimensions, fixing method and location of all identification plates for purchaser approval before manufacture.

15.21 Grounding terminals

The VSR tank shall be provided with four grounding terminals, located diagonally near the bottom corners of the tank.

The grounding terminals shall be of stainless-steel flag type or copper-faced steel pads of adequate size. They shall be designed to carry the specified lower-voltage system short-circuit current for at least 3 s without thermal or mechanical damage.

The grounding terminals shall be welded directly to the VSR tank and shall provide a reliable, low-resistance and corrosion-resistant connection to the station grounding system.

Each grounding terminal shall be provided with suitable holes, bolts, nuts and washers for connection of the station grounding conductor. The terminal dimensions, drilling pattern and permissible conductor size shall be submitted for purchaser approval.

All grounding connections, bonding conductors and grounding identification markings shall be coloured yellow green in accordance with applicable standards.

All metallic parts of the tank, cover, pipework, radiators, conservator, cabinets, cable ducts, support structures and accessories shall be electrically bonded to the main tank grounding system. The bonding arrangement shall ensure equipotential connection of all accessible metallic parts.

The manufacturer shall submit the grounding arrangement drawing, including the location, dimensions and material of grounding terminals, conductor connection details and short-circuit withstand verification.

15.22 Anticorrosion protection

Departures from or additions to this Technical Specification shall be clearly specified in the tender documentation and shall be subject to approval by the Purchaser.

The VSR tank and all associated metallic equipment shall be adequately protected against corrosion for continuous outdoor service under the specified environmental conditions. The anticorrosion protection system for the VSR tank and associated equipment shall be based on an epoxy-polyurethane coating system, colour RAL 7038, in accordance with SIST EN ISO 12944 and the requirements given in Table 11: Anticorrosion protection of VSR tank. Application and execution of coating works shall follow the recommendations of SIST EN ISO 12944-7.

The anticorrosion protection of the VSR tank and associated equipment shall be performed after successful completion of the leak test.

The construction of the tank and associated equipment shall allow access to all parts requiring surface preparation, painting, inspection, repair and maintenance.

Transformer radiators shall be protected by hot-dip galvanizing in accordance with Table 10: Anticorrosion protection of VSR radiators and the recommendations of SIST EN ISO 14713-2 and SIST EN ISO 1461. Radiators shall not be painted unless otherwise approved by the Purchaser.

The proposed anticorrosion protection system, including coating materials, surface preparation method, surface roughness, dry-film thickness, curing conditions, repair procedure and inspection plan, shall be submitted to the Purchaser for approval before application.

Inspection personnel shall be certified according to NACE Level II or III, FROSIO Level II or III, or shall have other equivalent competence supported by many years of documented and qualified professional experience.

The inspection plan shall cover at least the inspections specified in Table 13: Inspections.

Table 10: Anticorrosion protection of VSR radiators

Item	Requirement
Expected service life of corrosion protection according to SIST EN ISO 14713-1	VH — Very High
Corrosivity according to SIST EN ISO 14713-1	C4 — High
Design recommendations	Recommendations according to SIST EN ISO 14713-2 shall be followed.
Surface treatment	Hot-dip galvanizing according to SIST EN ISO 1461
Zinc layer thickness	Minimum average coating thickness: 85 µm
Acceptance criteria	Average coating thickness: minimum 85 µm ; local coating thickness: minimum 70 µm , according to Table 2 of SIST EN ISO 1461.

Table 11: Anticorrosion protection of VSR tank

Item	Requirement
Expected service life of corrosion protection according to SIST EN ISO 12944-1	H — High
Corrosivity according to SIST EN ISO 12944-2	C4 — High
Special exposure	External surfaces: sunlight / UV exposure. Internal surfaces: transformer oil.
Design requirements	Design features shall comply with Annex C of SIST EN ISO 12944-3 .
Design recommendations	Best practice examples according to Annexes A, B and D of SIST EN ISO 12944-3 shall be followed.
Pretreatment requirements prior to surface preparation	Minimum preparation grade P2 according to SIST EN ISO 8501-3 . The preparation grade shall be checked before transport to the surface protection facility.
Surface preparation according to SIST EN ISO 8501-1	Rust grade before preparation: A or B . Surface preparation: abrasive blast-cleaning to preparation grade Sa 2½ .
Surface roughness according to SIST EN ISO 8503-2	Medium G , grit blast profile.

Table 12: Protective coating specification

Coating layer	Internal surfaces	External surfaces — system C4.10 according to Table C.4, Annex C, SIST EN ISO 12944-5
Primer	Epoxy polyamide primer	Zinc-rich epoxy primer
Dry-film thickness of primer	80 µm	60 µm
Intermediate coating	None	Epoxy polyamide coating with micaceous iron oxide
Dry-film thickness of intermediate coating	—	80 µm
Topcoat	None	Acryl-isocyanate / polyurethane topcoat, RAL 7038
Dry-film thickness of topcoat	—	60 µm
Total dry-film thickness	80 µm, maximum 120 µm	200 µm

The zinc-rich epoxy primer shall contain zinc dust pigment equal to or greater than 80 % by mass in the dry film. The zinc dust pigment shall comply with ISO 3549.

The acceptance criteria for total dry-film thickness shall be according to ISO 19840, using the 80/20 rule.

Internal surfaces in contact with transformer oil shall be coated with an oil-resistant epoxy coating compatible with hot mineral insulating oil according to IEC 60296. The internal coating shall not adversely affect the insulating oil, the solid insulation system or the long-term dielectric properties of the VSR.

Table 13: Inspections

Type of inspection	Method / standard	Requirement	Minimum scope	Comment
Cleanliness of compressed air	ASTM D4285	According to ASTM D4285	Random testing	Test shall be performed with a white cotton cloth.
Oil and grease in abrasives	ASTM D7393	According to ASTM D7393	Every quarter	Applies to circulating abrasives.
Climatic conditions	SIST EN ISO 8502-4	Air temperature: minimum 10 °C . Surface temperature: minimum 10 °C and at least 3 °C above dew point . Relative humidity: maximum 85 % .	Before and after each coating step, at least twice per shift	The coating manufacturer may specify additional or more stringent requirements.

Type of inspection	Method / standard	Requirement	Minimum scope	Comment
Rust grade	SIST EN ISO 8501-1	Rust grade A or B	100 % of the whole surface	Before start of surface preparation.
Preparation grade	SIST EN ISO 8501-3	Minimum P2	100 % of the whole surface	Before start of surface preparation.
Blast-cleaned surface	SIST EN ISO 8501-1, SIST EN ISO 8503-2, SIST EN ISO 8502-3	Preparation grade Sa 2½ . Surface roughness: Medium G . Dust quantity: maximum rating 2 . Dust particle size: maximum rating 1 .	100 % of the whole surface	Before application of the first coating layer / primer. The Client shall have the opportunity to perform inspection.
Visual inspection of painted surface	Visual inspection	Each coat shall be continuous and covering, without unacceptable runs, drops, pores, holidays, cracks, inclusions or other surface defects.	100 % of the whole surface	Applies to both flat surfaces and edges.
Dry-film thickness	ISO 19840	According to the approved coating specification	According to ISO 19840	Acceptance according to ISO 19840, 80/20 rule.
Adhesion	SIST EN ISO 16276-1	Minimum 5 MPa	According to SIST EN ISO 16276-1	Not applicable to hot-dip galvanizing.

The dry-film thickness shall be measured and documented after application. The Manufacturer shall submit coating inspection records, including at least:

- surface-preparation records;
- climatic conditions during coating application;
- coating material batch numbers;
- dry-film thickness measurements;
- adhesion test results;
- repair records;
- final inspection reports.

All coating damage occurring during manufacture, transport, erection or commissioning shall be repaired in accordance with the approved repair procedure and the coating manufacturer's instructions. Repaired areas shall provide the same level of corrosion protection as the original coating system.

Galvanized components shall be protected in accordance with the applicable standards and shall be compatible with adjoining painted surfaces, fasteners and support structures. Contact between dissimilar metals shall be designed to avoid galvanic corrosion.

15.23 Support Reactions

The tenderer shall provide documentation clearly defining the magnitude and direction of loads and support reactions at all equipment supports.

The documentation shall include support reactions for at least the following load cases:

- permanent load, including the self-weight of the complete equipment;
- transport and handling loads, where applicable;
- operational loads, where applicable;
- earthquake load.

The effect of earthquake loading shall be analysed separately for all three orthogonal directions: X, Y and Z. The coordinate system used for the analysis shall be clearly defined in the documentation and shown on the relevant drawings.

The results shall be presented in tabular form for each individual support. For each support, the tenderer shall state at least:

- support identification;
- support location;
- load case;
- vertical reaction;
- horizontal reactions in X and Y directions;
- resulting force;
- direction of the reaction;
- uplift force, where applicable;
- sliding force, where applicable;
- overturning moment, where applicable;
- required anchoring force, where applicable.

For line supports, the support reactions shall be given separately at the beginning and at the end of each support, as proposed in the schedules of technical data.

The support-reaction documentation shall be sufficiently detailed to enable design and verification of the foundations, anchor bolts, support structures and any seismic restraints required for the VSR installation.

The manufacturer shall submit the calculation method, assumptions, applied load combinations, seismic input data, safety factors and final support-reaction tables for purchaser approval.

15.24 VSR Foundation

The VSR shall be installed on a reinforced concrete foundation. The VSR shall be supported by five steel line supports. The arrangement, dimensions and positions of the line supports shall be coordinated with the VSR tank design, transport arrangement, jacking points, pulling points and the support reactions specified by the manufacturer.

To prevent overturning, sliding or excessive displacement of the VSR during a seismic event, the reactor shall be anchored to the foundation. Anchoring shall be provided at four points on each long side of the VSR, i.e. at a total of eight anchoring points, unless otherwise justified by the manufacturer and approved by the purchaser.

The locations of the anchors and line supports are shown in Figure 1. Any deviation from the indicated arrangement shall be subject to purchaser approval.

The manufacturer shall provide all necessary data for the design and verification of the foundation and anchoring system, including:

- total equipment weight;
- centre of gravity;
- support reactions under permanent load;
- support reactions under seismic load in X, Y and Z directions;
- uplift forces;
- horizontal forces;
- sliding forces;
- overturning moments;
- required anchoring forces;
- recommended anchor dimensions and arrangement;
- permissible tolerances for foundation levelness and alignment.

The foundation, steel line supports and anchoring system shall be designed to withstand all loads occurring during installation, operation, maintenance, short-circuit conditions where applicable, wind loading and seismic loading.

The final foundation and anchoring arrangement shall be coordinated with the manufacturer's support-reaction documentation and shall be submitted for purchaser approval before construction.

Figure 2: VSR Foundation

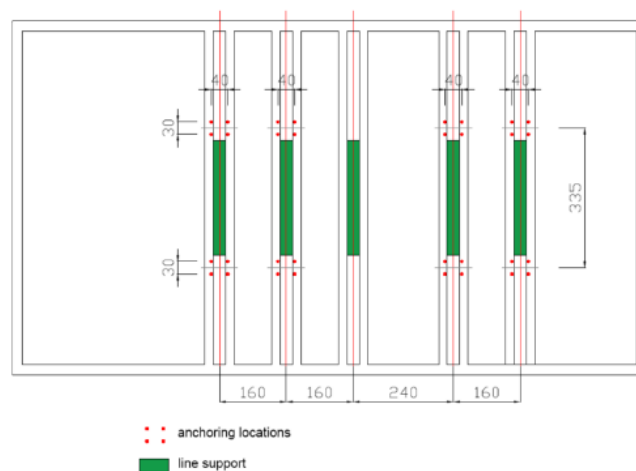


Figure 1: Locations of the anchors and line supports

16 ERECTION REQUIREMENTS

16.1 Erection works at site

The complete erection, assembly, installation and preparation for commissioning of the VSR and all associated equipment at site shall be within the scope and responsibility of the Tenderer.

The erection company, if different from the Tenderer, shall be nominated by the Tenderer and shall be subject to approval by the Purchaser. Such approval shall not release the Tenderer from full responsibility for the quality, completeness, safety and timely execution of all erection works.

The VSR shall be assembled as far as practicable at the manufacturer's works. All remaining erection, assembly, installation, connection, adjustment and preparation works required at site shall be carried out by the Tenderer.

The Tenderer shall provide all labour, supervision, tools, special tools, lifting equipment, jacks, transport devices, temporary supports, consumables and auxiliary equipment required for safe and complete erection of the VSR, cooling system, conservator, bushings, OLTC equipment, monitoring equipment, control cabinets, pipework, valves, accessories and all other components included in the supply.

The Tenderer shall organise and perform all site transportation, unloading, lifting, positioning and handling of equipment and components that have to be assembled to the VSR. The Tenderer shall ensure that the erection organisation, personnel, equipment and working methods are suitable for the specified works and that the Purchaser has no additional expenses or obligations, except for agreed supervision, coordination and witnessing activities.

All erection works shall be performed in accordance with the approved erection procedure, manufacturer's instructions, project documentation, General Technical Specification, applicable laws and regulations, site safety rules and good engineering practice.

The Tenderer shall prepare and implement all necessary health and safety measures, environmental protection measures, method statements, risk assessments, lifting plans, transport plans, fire protection measures, security arrangements and emergency procedures required for the erection works.

For site transportation and erection activities, the Tenderer shall comply with the safety plan and site rules provided by the Purchaser, as well as with all applicable health, safety and environmental requirements. The Tenderer shall consider that other equipment and systems at site may remain in normal operation and may be energised during the erection works. All works shall therefore be planned and executed so as not to endanger personnel, existing equipment or the continuity of operation of other systems.

The Tenderer shall be responsible for protecting the VSR and all delivered equipment against mechanical damage, moisture ingress, contamination, corrosion and any other deterioration during storage, handling, erection and installation at site.

16.2 Erection supervision

The Tenderer shall provide qualified and experienced specialists for supervision and execution of erection, assembly, installation and preparation for commissioning of the VSR and associated equipment.

The Tenderer shall supervise all erection and assembly activities to ensure that the equipment is installed in accordance with the manufacturer's requirements and that all contractual guarantees remain valid.

The Tenderer shall prepare and submit an erection supervision programme, including:

- description of supervision activities;
- required number and qualification of specialists;
- estimated duration of supervision and erection activities;
- working schedule;
- required site conditions;
- required interfaces with the Purchaser and other contractors;
- list of special tools and lifting equipment;
- health and safety requirements;
- associated costs, where applicable.

The Tenderer shall ensure that any subcontractor engaged for erection or assembly works is competent, properly equipped, adequately supervised and fully informed of the applicable technical, safety and environmental requirements. The use of subcontractors shall not limit or reduce the Tenderer's responsibility.

16.3 Other requirements

The Tenderer shall prepare and submit a detailed written erection manual covering all site activities required for the VSR and associated equipment. The erection manual shall include, as a minimum:

- unloading and site transport procedure;
- lifting and handling instructions;
- storage requirements;
- assembly sequence;
- installation of radiators, conservator, bushings, OLTC equipment, control cabinets, monitoring equipment, pipework, valves and accessories;
- oil filling, oil treatment, vacuum treatment and venting procedure;
- mechanical alignment and tightening instructions;
- electrical connection and earthing instructions;
- protection of equipment during erection;
- cleanliness requirements;
- required tools and special tools;
- inspection and check points;

- safety precautions;
- environmental protection measures;
- final inspection procedure before testing and commissioning.

All erection requirements shall comply with the General Technical Specifications. Any additional erection devices, jacks, lifts, temporary structures, special tools or auxiliary equipment required for proper and safe erection shall be included in the Tenderer's scope of supply.

After successful completion of erection, the Tenderer shall immediately proceed with the specified testing and commissioning procedures in accordance with this specification and the approved test programme. After completion of erection and before commencement of commissioning tests, the Tenderer shall issue an official erection completion report confirming that all erection works have been completed and that the equipment is ready for testing.

The Tenderer shall provide all necessary technical data related to the VSR to other contractors involved in the project, where such data are required for connection of the VSR to other systems. All exchanged technical data affecting interfaces, installation, operation, protection, control, monitoring or safety shall be submitted to the Purchaser for approval. Informative data may be exchanged directly with other contractors, with the Purchaser being kept informed.

During erection, the Tenderer shall cooperate with the Purchaser, the site coordinator and all other contractors involved in the project. The Tenderer shall coordinate its works with the overall site schedule and shall not interfere with erection, testing or operation of other equipment.

The Tenderer shall be responsible for local transportation, lifting, positioning, assembly and auxiliary power supply required for its own erection works, unless otherwise explicitly stated in the contract. Any requirements for temporary power supply, compressed air, water, lighting, storage area, crane access or other site facilities shall be clearly stated by the Tenderer in advance.

After completion of erection, the Tenderer shall remove from site all packaging materials, temporary supports, waste materials, tools, unused consumables and other objects used during transport, storage and erection of the VSR and associated equipment. The working area shall be left clean, safe and ready for testing and commissioning.

In case of disagreement between contractors during erection, the Purchaser shall give the final decision regarding coordination and interface issues. Such decision shall be binding for all project participants. This shall not release the Tenderer from its contractual responsibility for the correct and complete erection of the VSR and associated equipment.

17 INSPECTION AND TESTS

Tests shall be performed to verify that all materials, components, assemblies and the complete VSR comply with this specification, the guaranteed technical data, approved drawings, applicable standards and the intended operating conditions.

All tests shall be carried out in accordance with the applicable IEC standards, particularly the relevant parts of IEC 60076, including IEC 60076-6 for reactors, IEC 60076-3 for insulation levels and dielectric tests, and other applicable standards referenced in this specification.

Unless otherwise agreed between the Tenderer and the Purchaser, the tests shall be performed in the sequence required by the applicable standards and by the approved inspection and test plan.

The Tenderer shall submit all certificates, test reports, measuring records, calibration certificates and other evidence required to demonstrate conformity of the equipment.

The Tenderer shall also perform any additional tests not explicitly listed in this specification but required by applicable standards, the approved design, safe operation, completeness of supply or by the Purchaser.

All testing devices, measuring instruments, test equipment, calibration equipment, temporary connections and auxiliary equipment required for testing shall be provided by the Tenderer. All measuring instruments shall have valid calibration certificates traceable to recognised standards.

The Tenderer shall notify the Purchaser in writing of the date, time, place and scope of each witnessed test at least four weeks before the planned test date. The final test date shall be confirmed and approved at least 14 days before the test. The Purchaser or the Purchaser's representative shall have the right to witness any test, inspection or verification activity.

Certified test reports shall be submitted to the Purchaser immediately after completion of each test or within the agreed period. Final acceptance shall be subject to review and approval of the test reports by the Purchaser.

The Purchaser reserves the right to request an independent expert opinion or independent verification of test results, measuring methods, type-test evidence, routine-test results or special-test results.

All deviations from specified, guaranteed or standard values shall be documented in the manufacturing and test records. Necessary corrective actions shall be listed, described and submitted to the Purchaser for review. In the event of deviations, non-conformities or doubtful results, the Purchaser may require interruption of testing, additional diagnostics, corrective works and repeated testing of the affected equipment or assemblies.

If any repair, replacement or modification of equipment is required after factory tests or site tests, the Tenderer shall perform the necessary works without delay and shall submit all repeated test results to the Purchaser for approval.

Tests shall be used to verify whether the material and devices comply with the specification. All tests must be executed in the way to consider operation conditions. All test results shall be submitted to the Customer for supervision and approval. Customer is reserving a right to get another independent opinion (checking correctness of the measuring results, tests, type tests...).

All tests shall be executed according to IEC standard requirements (including with the correct sequence of tests), if not differently agreed between Tenderer and Customer. Tenderer must submit certificates and other evidence about impeccability of the equipment.

Tenderer shall execute also all other tests, which are not mentioned in these specifications, but they are necessary for completeness and equipment security, if required by the Customer.

All necessary testing devices and instruments shall be provided by the Tenderer.

Tenderer shall announce the Customer about date, time and scope of testing at least four (4) weeks before tests, test date shall be approved at least 14 days before execution. Tenderer must allow Customer or his representative to be present at any test procedure. Certified test report must be submitted to the Customer immediately after each test.

All deviations from the required values shall be documented in the manufacturing records. Necessary corrective actions shall be enlisted and described and examined by Customer and Tenderer representatives. At any deviations, the project manager can demand in name of the Customer an interruption and repeated testing/diagnostics of equipment or additional modules found unsuitable. Tests shall be applied to verify whether the material and devices comply with the specification. All test results shall be recorded and submitted to the Customer for supervision and approval. Customer is reserving the right to get another independent opinion (regarding evaluation correctness of testing and measuring results, in particular the type tests results).

If after factory or on site testing, for any reason repair of the equipment or replacement of any parts are necessary, the Tenderer shall finish all works as soon as possible. The Tenderer shall submit to the Customer all results of repeated tests.

17.1 Factory tests

Factory tests shall be carried out at the manufacturer's works in accordance with the approved QA/QC plan, inspection and test plan, applicable IEC standards and this specification.

Based on the QA/QC plan, the Purchaser shall define inspection points, witness points and hold points at which the Purchaser or the Purchaser's representative intends to be present.

During manufacture of the various VSR parts, the Purchaser may require any part, assembly or component to be inspected or tested in the presence of the Purchaser or the Purchaser's representative. The Tenderer shall therefore systematically inform the Purchaser in writing when equipment or components are ready for inspection or testing.

Where material samples, oil samples, insulation samples or other test samples are required, the Tenderer shall prepare and provide them in accordance with the approved test programme. Tests requiring independent verification shall be performed by an independent accredited laboratory or institution approved by the Purchaser.

The complete VSR shall be subject to factory acceptance tests, FAT, at the Tenderer's works in the presence of the Purchaser or the Purchaser's representative. The purpose of the FAT

is to verify conformity with guaranteed data, approved design documentation, this specification and applicable standards.

Detailed test procedures and acceptance criteria shall be submitted to the Purchaser for approval before testing.

Factory tests shall comprise:

- routine tests;
- type tests, where required;
- special tests, where required;
- functional tests;
- inspections and verifications;
- tests on accessories, monitoring systems and auxiliary equipment.

a) Routine tests

The following routine tests and inspections shall be carried out as a minimum:

- visual inspection;
- dimensional check of the VSR main dimensions;
- check of general construction and appearance;
- check of nameplates, identification plates and terminal markings;
- verification of drawings, terminal arrangement and phase sequence;
- measurement of winding resistance in all relevant tap positions;
- measurement of reactance in accordance with IEC 60076-6;
- measurement of losses in accordance with IEC 60076-6;
- measurement of loss and current at specified voltage levels, including where applicable 0.90 p.u., 1.00 p.u. and 1.10 p.u.;
- verification of reactance and loss at the tap positions required by the approved test programme;
- dielectric tests in accordance with IEC 60076-3 and IEC 60076-6;
- separate-source AC withstand voltage test;
- induced AC withstand voltage test;
- induced overvoltage test with partial discharge measurement, where applicable;
- lightning impulse test, where applicable according to the specified insulation level and approved test programme;
- switching impulse test, where applicable for the specified voltage level and insulation coordination;
- partial discharge measurement;
- measurement of insulation resistance;
- measurement of capacitance and dielectric dissipation factor, $\tan \delta$, of winding insulation;

- measurement of capacitance and $\tan \delta$ of bushings;
- verification of core and frame insulation;
- functional tests of the on-load tap-changer, OLTC;
- functional tests of OLTC motor drive and MR ETOS interface;
- functional tests of marshalling cabinet, control circuits, alarms, trips and auxiliary circuits;
- functional tests of cooling system valves and monitoring contacts;
- pressure relief device functional verification;
- verification of Buchholz relay, oil-level indicators and temperature indicators;
- verification of fibre-optic temperature sensors and measuring channels;
- Frequency Response Analysis, FRA, as a reference fingerprint test;
- oil testing before and after dielectric tests;
 - dissolved gas analysis, DGA, before and after dielectric tests and after temperature-rise test;
 - 2-FAL analysis, HPLC, before and after dielectric tests and after temperature-rise test;
- verification of tightness of oil-filled compartments, as applicable;
- verification of grounding and bonding connections;
- final inspection before dispatch.

Additional routine-test requirements: The load losses, loss current and reactor current shall be measured as specified in IEC 60076-6. Measurements shall also be made under the maximum flux condition of the magnetic circuit, where required by the approved test programme. Unless otherwise agreed, measurements shall be made at 0.90 p.u., 1.00 p.u. and 1.10 p.u. voltage.

For the induced overvoltage test with partial discharge measurement, the partial discharge level measured at the end of the test period shall not exceed 100 pC and shall not show a rising tendency during the last 15 minutes exceeding 5 %, unless otherwise required by the applicable standard or agreed acceptance criteria.

DGA and 2-FAL results before and after dielectric tests and after temperature-rise test shall be evaluated in accordance with applicable IEC and CIGRE guidance. Oil sampling and analysis shall be carried out in accordance with the applicable standards, including IEC 60567 and IEC 60475 where relevant.

Capacitance and $\tan \delta$ measurements shall be corrected to 20 °C. The temperature correction factors used shall be submitted by the Tenderer and included in the test report. Unless otherwise specified or justified by the manufacturer and approved by the Purchaser, the following maximum $\tan \delta$ values shall apply:

- winding insulation: 1.0 %;
- bushings: 0.5 %;
- insulating oil: 0.2 %.

The partial discharge level of the reactor at the time of dispatch shall not exceed 100 pC, unless stricter acceptance criteria are specified in the approved test programme.

b) Type tests

The following type tests shall be carried out where required by this specification, by the applicable standards or where valid type-test evidence from an equivalent VSR design is not accepted by the Purchaser:

- temperature-rise test in accordance with IEC 60076-6;
- thermographic inspection during or after the temperature-rise test;
- measurement of vibration for liquid-immersed reactors in accordance with IEC 60076-6;
- measurement of sound level in accordance with IEC 60076-6 and IEC 60076-10;
- chopped lightning impulse test in accordance with IEC 60076-3 and IEC 60076-6, where specified;
- measurement of power consumption of auxiliary equipment, including OLTC motor drive, heaters, monitoring equipment and any other relevant auxiliaries;
- verification of cooling performance, including the specified operation with one radiator out of service, where applicable;
- verification of fibre-optic temperature measurement during thermal testing.

Temperature-rise test requirements: Gas chromatographic analysis of oil shall be performed before and after the temperature-rise test. Oil sampling shall be performed in accordance with applicable IEC standards. DGA results shall be evaluated in accordance with IEC 60599 and relevant IEC/CIGRE guidance.

The temperature-rise test shall include sufficient time to reach thermal stability. Where core hot-spot or active-part thermal behaviour is to be verified, the test shall include a period of stable saturated temperature, with duration to be agreed in the approved test programme.

Temperature-rise measurements shall be performed using conventional oil temperature indicators/winding temperature indicators and the installed fibre-optic temperature sensors. The fibre-optic temperature measuring system shall be operational during the temperature-rise test and shall be demonstrated during the test.

During the test, the hottest fibre-optic probes for each phase shall be identified. Temperature data from all fibre-optic probes shall be recorded and included in the test report. Values obtained from fibre-optic sensors and conventional OTI/WTI instruments shall be compared. Both systems shall demonstrate compliance with the specified temperature limits and guarantees.

c) Special tests

The following special tests shall be performed when required by the Purchaser, this specification, the applicable standards or the approved test programme:

- measurement of zero-sequence reactance on three-phase reactors in accordance with IEC 60076-6;
- measurement of mutual reactance on three-phase reactors in accordance with IEC 60076-6;
- measurement of harmonics of current in accordance with IEC 60076-6;
- measurement of losses closes to reference temperature;
- determination of linearity of reactance;
- measurement of magnetic characteristic;
- determination of voltage-current characteristic in the saturated region;
- determination of slope angle α_2 according to IEC 60076-6;
- verification of linear voltage-current characteristic up to 115 % of rated voltage at the highest rated reactive power tap position;
- measurement of tap-changer motor-drive power consumption;
- current transformer tests;
- oil examination in accordance with IEC 60296 and IEC 60422;
- degree of polymerisation of paper insulation;
- complete VSR vacuum test;
- complete VSR overpressure test;
- tightness test of oil-filled compartments;
- FRA test, if not already performed as a routine reference test;
- tests on fibre-optic temperature sensors;
- verification of degree of protection of the marshalling cabinet, minimum IP55;
- knee-point voltage measurement, where applicable;
- vibration and stress measurement;
- strain-gauge measurements on tank, where required;
- verification of support reactions, where required;
- verification of resonance behaviour, where required;
- verification of online monitoring system functionality;
- verification of interface with MR ETOS;
- verification of interface with the central online monitoring system;
- verification of inrush current by calculation, simulation and/or test where practicable;
- verification of tank, conservator, radiator and OLTC oil compartment tightness;
- verification of pressure relief devices in accordance with IEC/EN 50216-5.

The complete VSR vacuum test and overpressure test shall be performed in accordance with the approved procedure. The test pressures, duration, acceptance criteria and measuring method shall be submitted to the Purchaser for approval before testing.

17.2 On site tests

a) Acceptance tests

The VSR shall be subject to site acceptance tests, SAT, after transportation, erection, oil filling, oil treatment and final assembly on the foundation.

The purpose of the site tests is to verify that the VSR and all associated equipment have been transported, erected, connected, filled, treated, tested and commissioned correctly and are suitable for safe operation.

All site tests shall be performed in the presence of the Purchaser or the Purchaser's representative. The tests shall verify conformity with this specification, the approved design documentation, guaranteed characteristics, manufacturer's instructions and applicable standards.

The detailed measuring methods, test conditions, test sequence, energisation requirements and acceptance criteria shall be agreed between the Tenderer and the Purchaser in the approved site test programme. Any special requirements concerning grid operation, energisation, or outage planning shall be agreed in advance.

All required standard and special test equipment, insulation testers, measuring bridges, high-voltage measuring sources, current sources, auxiliary supplies, calibration equipment and all other equipment necessary for site testing shall be provided by the Tenderer.

At least the following measurements, inspections and tests shall be carried out at site:

- visual inspection after transport and erection;
- inspection of transport impact recorders, where applicable;
- check of tank, radiators, conservator, bushings, OLTC equipment, pipework, valves, gaskets and accessories;
- check of oil leakage and tightness of all oil-filled compartments;
- tank and equipment pressure/tightness verification, where required;
- verification of correct installation on foundation and supports;
- verification of anchoring, grounding and bonding connections;
- final anticorrosion protection check and repair verification;
- measurement of insulation resistance;
- measurement of winding resistance;

- magnetizing current at 400 V
- capacitance and $\tan \delta$ measurement of winding insulation to earth;
- capacitance and $\tan \delta$ measurement of bushings;
- measurement of bushing capacitance and reference values for online monitoring;
- FRA test and comparison with factory reference fingerprint;
- measurement of FDS (frequency analysis of dielectrics)
- moisture content of oil;
- physical-chemical oil testing acc. to IEC 60422 of the new VSR oil;
- DGA after oil filling and before energisation;
- evaluation of winding insulation moisture condition, where applicable;
- recalibration and current injection test of temperature indicators and thermal-image circuits;
- verification of fibre-optic temperature sensor channels;
- verification of local and remote temperature indication;
- 2 kV withstand test on control, monitoring and auxiliary wiring, where applicable and safe for connected electronic devices;
- continuity and polarity checks of current transformers;
- current injection tests of CT circuits;
- functional test of the on-load tap-changer;
- verification of MR ETOS signals, alarms, diagnostics and communication;
- functional test of control and monitoring equipment;
- functional test of the online monitoring system;
- verification of communication with the substation control system;
- verification of communication with the central online monitoring system;
- functional test of alarm and trip circuits;
- functional test of Buchholz relay contacts;
- functional test of pressure relief device contacts;
- functional test of oil-level indicators;
- functional test of dehydrating breathers;
- cooling system functional test, including valve positions and temperature measurements;
- check of radiator isolation valves, venting and draining arrangements;

- check of all sampling valves and oil treatment connections;
- verification of marshalling cabinet heating, lighting, ventilation and IP protection condition;
- verification of all potential-free contacts and 4–20 mA signals;
- verification of all nameplates, warning plates and identification plates;
- final inspection before energisation.

b) Site oil test

Before first oil filling of the shunt reactor on site an examination shall be carried out to check the VSR oil quality acc. to IEC 60296 and IEC 61125.

Oil sampling at site shall be performed after oil filling and oil treatment, after completion of erection and before energisation. Further samples shall be taken after energisation and after an agreed initial operating period, if required by the Purchaser.

Oil tests shall include, as a minimum:

- physical-chemical oil analysis in accordance with IEC 60422:
 - breakdown voltage;
 - water content;
 - acidity;
 - interfacial tension;
 - dielectric dissipation factor;
 - resistivity;
 - antioxidant content.
- DGA;
- 2-FAL content
- any additional tests required by the Purchaser or the oil supplier.

Sampling, handling and analysis of oil and gas samples shall be carried out in accordance with applicable IEC standards and the approved test programme.

c) Test reports and acceptance

All site test results shall be recorded in certified test reports. The reports shall include measuring methods, instruments used, calibration data, ambient conditions, oil temperature, test conditions, measured values, acceptance criteria and conclusions.

The Tenderer shall submit complete site test reports to the Purchaser for approval. The VSR shall not be released for energisation until all mandatory site tests have been successfully completed and the Purchaser has accepted the relevant test results.

Any non-conformity detected during site tests shall be corrected by the Tenderer. After correction, the relevant test shall be repeated, and the repeated test results shall be submitted to the Purchaser for approval.

18 QUALITY CONTROL DOCUMENTATION

Documents officially certified must be sent to the Customer, not later than FAT date.

18.1 QA certificates

- Insulated copper conductors,
- Steel sheet core,
- Hard insulation materials,
- Insulation oil,
- Construction steel,
- Wiring cables,
- Paint and its oil resistance.

18.2 Test reports

- Bushings,
- Current transformers,
- Radiators,
- Auxiliary cubicles,
- OLTC
- OLM
- Interphase inspection report.

18.3 Functional test and QA certificates

- Buchholz relay,
- Protection relay for the OLTC oil compartment
- Over-pressure valve,
- Bushing sensors
- Top oil temperature indicator,
- Pt 100 temperature measuring sensors,
- On-line monitoring system,
- Gas sensors,
- Humidity sensors,
- Optical temperature sensors,
- Winding temperature indicator,

- Magnetic oil level indicators,
- Capillary contact thermometer,
- On load tap changer,
- On load tap changer motor drive,
- MR ETOS control system,
- Voltage regulation,
- Conservator synthetic diaphragm or air-cell bag and dehydrating breathers,
- Vibration sensors.

18.4 VSR tank test documents

18.5 Overpressure and vacuum test report

18.6 Anticorrosive protection inspection report

18.7 Interphase inspection report

- Magnetic cores,
- Windings,
- Active part,
- Active part drying.

19 SUPPLIER DOCUMENTATION

Before the start of VSR manufacture, the Tenderer shall submit a complete document list for the project. The list shall include all drawings, calculations, data sheets, manuals, procedures, test plans, test reports, certificates and other documents to be prepared for the project in accordance with the Purchaser's requirements and established practice.

The document list shall include, as a minimum:

- document title;
- document number;
- document revision;
- document type;
- planned submission date;
- required approval date;
- document status;
- language;
- editable/original format;
- PDF format;
- classification of the document;
- indication whether the document is submitted for approval, review, information or final documentation.

The Purchaser shall review and approve the document list as part of the design review process. The Tenderer and the Purchaser shall agree the submission dates for all documents that are relevant to the project schedule during contract clarification or contract signing.

No manufacture of the relevant VSR parts shall start before the corresponding design documents, drawings and calculations have been submitted to and approved by the Purchaser, where approval is required.

The Tenderer shall submit all documents in electronic format. Final documentation shall be submitted in both PDF format and editable/original format, unless otherwise agreed. Drawings shall be submitted in PDF and CAD format. Data sheets, schedules and lists shall be submitted in PDF and editable spreadsheet or word-processing format, as applicable.

Documents required for operation, maintenance, transport, erection, safety and identification shall be provided in Slovene language, unless otherwise approved by the Purchaser. Technical design documentation may be submitted in English, unless otherwise specified.

The following documents shall be submitted as a minimum.

19.1 General project documentation

- documentation classification plan;
- complete project document list with planned dates of issue;
- document submission schedule;
- document approval schedule;
- design review document package;
- list of applicable standards;
- list of deviations from this specification, if any;
- list of guaranteed technical characteristics;
- VSR technical data sheet;
- equipment list with manufacturers and type designations;
- list of all seals on VSR (with indication of type, dimensions and material);
- list of cables installed on VSR (own use, control, signaling cables, etc.);
- list of spare parts and special tools;
- list of consumables;
- list of interfaces with other project systems;
- general arrangement drawing of the VSR;
- temporary/preliminary dimension drawing;
- final dimension drawing;
- transport drawing,
- VSR equipment and device list, in Slovene language;
- identification and rating plate drawings, in Slovene language;
- diagram plate and terminal designation plate drawings;
- valve plate and valve identification drawings;
- lifting, jacking and pulling plate drawings,
- open BIM 3D format (.IFC format) - (LOD 400) model. In addition to 3D drawings of VSR elements, the BIM model must also contain all technical data from the VSR design (voltages, weight, etc.).

19.2 Active part and electrical design documentation

- core design description;
- winding design description;
- cross-sectional drawing of main and regulation windings;
- core and winding assembly drawing;
- core grounding principle and drawing;
- winding insulation concept;
- dielectric stress calculations;
- impulse-voltage distribution assessment;
- chopped lightning impulse withstand assessment, where applicable;
- voltage-current characteristic and linearity assessment;
- magnetic characteristic calculation;
- flux-density calculations;
- short-circuit force withstand calculation;
- inrush-current calculation and/or simulation report;
- thermal calculation;
- winding hot-spot temperature assessment;
- radial temperature-gradient assessment;
- resonance assessment;
- vibration assessment;
- sound-level calculation or prediction;
- calculation of losses;
- calculation of reactance and regulation range;
- support-reaction calculation;
- seismic resistance calculation.

19.3 OLTC documentation

- OLTC technical data sheet;
- confirmation of Maschinenfabrik Reinhausen manufacture;
- exact MR VACUTAP type designation;
- exact MR ETOS configuration;
- OLTC switching diagram;
- regulation scheme and coarse/fine switching sequence;
- regulation switch operation diagrams;
- tap-position table;
- time span for changing between specified reactor power tap positions;

- OLTC rated through-current;
- rated step voltage;
- rated switching capacity;
- insulation level to ground;
- number of operating positions;
- motor-drive unit data sheet;
- motor-drive manufacturer, type and motor voltage;
- motor-drive electrical power consumption data;
- OLTC protection relay details;
- ETOS signal list;
- ETOS communication interface description;
- ETOS integration documentation;
- OLTC maintenance intervals and service instructions;
- OLTC routine and type-test certificates according to IEC 60214-1.

19.4 Bushings and current transformers

- bushing technical data sheets;
- bushing manufacturer and type designation;
- confirmation of resin-impregnated condenser, oil-free design;
- confirmation of manufacture in the European Union or Switzerland, unless otherwise approved;
- bushing dimension drawings;
- bushing insulation levels;
- bushing creepage distances;
- bushing capacitance and $\tan \delta$ reference values;
- bushing terminal drawings and mechanical terminal-load limits;
- bushing replacement procedure;
- compliance evidence according to IEC 60137;
- composite insulator compliance evidence according to IEC 61462 and IEC 62217;
- current transformer technical data sheets;
- CT arrangement drawings for phase-B and neutral bushings;
- CT accuracy, burden and short-time current data;
- CT test reports and certificates according to IEC 61869.

19.5 Tank, cooling system and oil system documentation

- VSR tank design drawings;
- tank cover and manhole arrangement drawings;
- tank structural drawings;
- tank accessories arrangement;
- gasket and sealing details;
- welding and weld-testing procedures;
- tank vacuum and overpressure test procedure;
- conservator arrangement drawing;
- conservator air-cell/diaphragm documentation;
- Buchholz relay arrangement;
- pressure relief device arrangement;
- pressure relief device certificates according to IEC/EN 50216-5;
- cooling system drawings;
- radiator arrangement drawings;
- radiator data sheets;
- N-1 cooling-capacity verification;
- piping and instrumentation arrangement;
- valve schedule;
- oil filling, draining, filtering, sampling and venting procedure;
- oil sampling arrangement;
- self-regenerating dehydrating breather documentation;
- anticorrosion protection system;
- coating system data sheets;
- coating inspection and repair procedure.

19.6 Measuring, monitoring, protection and auxiliary systems

- cooling control cabinet dimension drawing;
- protection and signalling cabinet dimension drawing;
- OLTC cabinet dimension drawing;
- on-line monitoring cabinet/device box dimension drawing;

- marshalling cabinet layout;
- wiring diagrams;
- terminal diagrams;
- cable laying drawing for control, signalling, measurement and auxiliary supply cables;
- list of alarms and trips;
- alarm and trip matrix;
- list of potential-free contacts;
- list of analogue signals, including 4–20 mA signals;
- list of digital communication signals;
- control and protection equipment data sheets;
- measuring system drawings;
- primary protection documentation;
- Buchholz relay technical documentation;
- oil temperature and winding temperature indicator documentation;
- fibre-optic temperature measurement system technical documentation;
- optical sensor layout;
- position of winding temperature sensors, to be confirmed during design review;
- calibration certificates for sensors and measuring equipment;
- on-line monitoring system documentation;
- OLM architecture diagram;
- OLM sensor list;
- OLM signal list;
- OLM/DAC SCADA integration documentation;
- MR ETOS to OLM interface documentation;
- communication protocol description;
- database and data-storage concept;
- cyber-security and user-access concept;
- software description;
- monitoring display/mask documentation;
- documentation for integration into the central monitoring system.

19.7 Foundation, transport and erection documentation

- proposal of VSR foundation according to the corresponding drawing;
- support-reaction documentation;
- foundation and anchoring data;
- seismic anchoring requirements;

- transport drawing;
- transport plate;
- transport elaborate, in Slovene language;
- transport, lifting and handling instructions;
- railway and road transport arrangement;
- storage instructions;
- on-site erection works description;
- erection manual;
- lifting plan;
- site transport and handling plan;
- oil filling and vacuum treatment procedure at site;
- fall-protection system documentation;
- health, safety and environmental plan for erection activities;
- interface requirements for other contractors.

19.8 Quality, inspection and test documentation

- QA/QC plan;
- inspection and test plan;
- list of witness points and hold points;
- factory testing detailed description and plan;
- on-site testing detailed description and plan for S/S Krško;
- list of test equipment;
- calibration certificates for test equipment;
- material certificates;
- welding certificates and weld inspection reports;
- drying process report/protocol;
- oil test reports;
- factory test reports;
- type-test reports;
- special-test reports;
- SAT reports;
- non-conformity reports, where applicable;
- corrective action reports, where applicable;
- final inspection reports;
- final acceptance documentation.

19.9 Operation and maintenance documentation

- training program;
- operation manual for the VSR, in Slovene language;
- maintenance manual for the VSR, in Slovene language;
- operation and maintenance manuals for all main accessories, in Slovene language where required;
- OLTC operation and maintenance manual;
- MR ETOS operation and maintenance manual;
- OLM operation and maintenance manual;
- dehydrating breather operation and maintenance manual;
- bushing maintenance and testing instructions;
- cooling system maintenance instructions;
- oil sampling and oil testing instructions;
- spare parts catalogue;
- special tools list;
- recommended maintenance schedule;
- troubleshooting instructions;
- emergency procedures;
- commissioning instructions;
- as-built documentation.

19.10 Dynamic thermal model of the VSR

The bidder shall provide information on the feasibility of developing a dynamic thermal model of the VSR, enabling monitoring of the thermal state of the equipment during operation and assessment of the permissible loading or short-term overloading capability based on actual operating and ambient conditions.

Where applicable, the model should consider at least the following:

- actual VSR loading;
- ambient temperature;
- thermal inertia of the active part and cooling system;
- oil and winding temperatures, or equivalent hot-spot temperature;
- cooling mode;
- previous operating regime;

- permissible temperature limits and ageing of the insulation system.

The bidder shall specify whether such a model can be developed on the basis of the VSR design, type-test and/or factory data, and shall identify the input measurements and signals required for its use during operation. The bidder shall also state whether the model can be integrated into the purchaser's existing monitoring, diagnostic, SCADA and/or EMS systems.

19.11 Carbon footprint of VSR manufacturing

The bidder and/or manufacturer shall provide information on the estimated carbon footprint generated during the manufacturing of the VSR. The scope of the calculation shall be an LCA, Life Cycle Assessment, in accordance with ISO 14040/ISO 14044. The LCA results shall be prepared in a format suitable for possible subsequent EPD (Environmental Product Declaration) calculations.

Final as-built documentation shall be submitted after completion of erection, testing and commissioning. It shall include all approved final drawings, calculations, data sheets, manuals, certificates, FAT reports, SAT reports, commissioning reports and any modifications introduced during manufacture, transport, erection or commissioning.

20 TENDERER DOCUMENTATION

The Tenderer shall submit at least the following data required by the Tender:

- Documents required in General tender specification,
- Calculation of losses,
- Calculation of noise level,
- Calculation of thermal design at 420 kV and 440 kV (continuous operation; only for information),
- Equipment and works specification with filled Tables of technical data,
- List of routine and type tests for similar VSR,
- VSR description and auxiliary equipment operation description with catalogues and pamphlets,
- Preliminary drawings for VSR,
- Information about materials, used for cores, windings and winding insulation,
- Drawings, catalogues and pamphlets for standard elements, mounted on the VSR,
- Magnetic core and winding production description,
- description and evidence of the procedure for performing the final assembly of the VSR in the factory
- Proposed timetable plan for VSR production and supply (MS Project - last version) in digital version and paper printed,
- Proposed time schedule for documents submitting with dates of approval,
- Training program.

For the design review, see Clause 19.

Documentation for the designing of civil works (VSR foundation) shall be submitted to the Customer/Purchaser at least three (3) months after signing the contract.

21 SCHEDULES OF TECHNICAL DATA

VARIABLE SHUNT REACTOR 250 MVAR (3-phase, gapped core, 5 legged)				
Item	Description		Requested values	Tender data (guaranteed)
1	Producer			
2	Type designation			
	GUARANTEED VALUES			
	NOMINAL VALUES			
3	Rated reactive power	Mvar	250	
4	Number of phases		3	
5	Rated voltage (U_r)	kV	420	
6	Rated power at rated voltage	Mvar	250	
7	Minimum power at rated voltage	Mvar	≤ 125	
8	Maximum power at max. operating voltage	Mvar		
9	Minimum power at max. Operating voltage	Mvar		
10	Rated current	A		
11	Inrush current	A	acc. To EN 60076-6	
12	Range of constant impedance (Linearity)	%	115	
13	Short-time withstand current (2 s)	kA	50	
14	Winding connection		YN	
15	On load tap changer	%	50-100 % Qr	
16	Rated reactance at rated voltage and frequency	Ω	705.6 +/- 5 % (acc. IEC)	
17	Zero-sequence rated reactance	Ω		
18	Grounding of the neutral point	Li 650/275		
19	TOTAL LOSSES			
19.1	at maximum pos. and at U_r	kW	≤ 320	
19.2	at middle pos. and at U_r	kW	≤ 260	
19.3	at minimum pos. and at U_r	kW	≤ 200	
20	TEMPERATURE RISE			
20.1	Max. temperature rise at rated power from Chapter 13.1 Table 3 and highest environment temperature:			
20.2	- upper oil (measurement with thermometer on the top of the tank)	K	55	
20.3	- windings (calculated value, based on measured resistance)	K	60	
20.4	Temperature rise at the winding hot spot	K	73	
21	INSULATION LEVELS			
21.1	Insulation level of:			
	- Line	kV	420	
	- Neutral	kV	145	

21.2	Separate-source power-frequency over voltage 50 Hz, 60 s:			
	- Line	kV rms	630	
	- Neutral	kV rms	275	
21.3	Induced over voltage withstand test for:			
	- Line	kV rms		
21.4	Impulse over voltage withstand test for:			
	- lightning impulse (line)	kV	1425	
	- chopped wave (line)	kV	1550	
	- switching impulse (line)	kV	1050	
	- lightning impulse (neutral)	kV	650	
22	VSR OIL AND PAPER			
22.1	Factory tests:			
	- manufacturer			
	- supplier's designation			
	additional requirements for VSR oil before and after dielectric tests, temperature rise test, and other tests:		maximum permissible concentration increases:	
	- H ₂	μl/l (ppm)	< 10	
	- CH ₄	μl/l (ppm)	< 5	
	- C ₂ H ₆	μl/l (ppm)	< 5	
	- C ₂ H ₄	μl/l (ppm)	< 2	
	- C ₂ H ₂	μl/l (ppm)	< 0,1	
	- 2FAL	mg/kg (ppm)	< 0,01	
22.2	Insulating paper after VSR drying process			
	- VSR paper manufacturer		Wiedmann	
	- average degree of polymerization value of all DPv samples		≥ 1100	
	- average degree of polymerization value of an individual DPv sample		≥ 1050	
	- moisture content of the paper insulation	%	max. 0.5	
22.3	VSR oil after filling in VSR before energization	oil quality level in accordance with the requirements of IEC 60422:2024, Table 3, with the exception of the additional requirements specified by the Purchaser:		
	- water content	mg/kg (ppm)	max. 5	
	- acidity	mg KOH/g	max. 0,01	
	- interfacial tension	mN/m	min. 40	
	- oxidation stability		acc. to IEC 61125	
	-inhibitor content		>90% of original value	
22.4	VSR oil (before filling):			
	- quantity of oil perVSR	t		

	- manufacturer		SHELL or NYNAS	
	- supplier's designation		Diala S4 ZX-I or Nytro 4000X	
	- type of oil		Type A (fully inhibited high grade oil)	
23	BUSHINGS			
23.1	HV line bushings			
	Producer		Hitachi Energy/Moser Glaser	
	Type			
	- material		composite	
	- insulation level	kV	420	
	- rated voltage	kV		
	- rated current	A		
	- short time current (1s)	kA	50	
	- power frequency over voltage withstand test - on dry	kV rms		
	- power frequency over voltage withstand test - on wet	kV rms	650	
	- impulse over voltage test - lightning impulse	kV	1550	
	- cantilever force maximum	N		
	- creepage distance	mm	≥ 11500	
23.2	HV neutral bushing :			
	Producer		Hitachi Energy/Moser Glaser	
	Type			
	- material		composite	
	- insulation level	kV	145	
	- rated voltage	kV		
	- rated current	A		
	- short time current (1s)	kA	50	
	- power frequency over voltage withstand test - on dry	kV rms		
	- power frequency over voltage withstand test - on wet	kV rms	275	
	- impulse over voltage test - lightning impulse	kV	650	
	- cantilever force maximum	N		
	- creepage distance	mm	≥ 3625	
24	COOLING SYSTEM ONAN			
24.1	Number of radiators			
25	MECHANICAL CONSTRUCTION			
25.1	Maximums withstand pressure in VSR tank (over operation pressure) and pertinent oil pipelines and accessories for 24 hours without leakage-acc. to IEC 60076-1-11.8	kPa		
25.2	Full vacuum in VSR tank and in pertinent oil pipelines and accessories without permanent distortion - acc. to	kPa		

	IEC 60076-1-11.11			
26	Sound pressure level measured acc. to IEC 60076-10 - ONAN	dB (A)	≤ 75 at U_r	
27	Gross weight and maximum dimensions of the heaviest single part to be transported and lifted during site erection works:			
	- weight	t		
	- length	m		
	- width	m		
	- height	m		
28	Gross weight and maximum dimensions of completely assembled VSR, including oil:			
	- weight	t		
	- length	m		
	- width	m		
	- height	m		
29	Total power consumption of all VSR auxiliaries at continuous full load operation	kW		
30	Vibration level	max. 100 μm peak to peak, average value 40 μm peak to peak.		