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HVDC Converter Transformers

Guidelines for Conducting Design Reviews for HVDC Converter Transformers

Joint Working Group
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Design Reviews for HVDC Converter Transformers

Members

Milan Saravolac (FR) (Convenor), Gilson Machado Bastos (BR), Narinder S. Dhaliwal (CA), Sergio E. Santo (BR), Thomas Freyhult (SE), Yanny H. Fu (NL), Jan Hajek (SE), A.C. Hall (UK), Peter Heinzig (DE), Ugo Piovan (IT), Vijay Prasher (IN), Shirasaka Yukiyasu (JP)

Corresponding Members

Michael Bridger (NZ), Peter W. Christensen (DK), Roger Cormack (ZA), John F.Graham (BR), Carlos Peixoto (BR), Liu Zehong (CN)

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Foreword

This document has been prepared by the CIGRE JWG A2/B4-28; “HVDC Converter Transformers” as a guide to customers of HVDC Converter Transformers for conducting design reviews with the equipment manufacturers.

The initiation of this JWG was proposed by the SC B4 in order to continue the activities of the JTF B4.04/A2-1; “Analysis of HVDC Thyristor Converter Transformers Performance”, which has concluded its activities and published reports in ELECTRA No.212 and CIGRE Brochure No.240. This TF concluded the evaluation of the available information on the performance of HVDC Converter Transformers with a recommendation to continue activities in this respect, while focusing more on improving the design review process and reviewing the standard test procedures with a view to ensure higher reliability in service, so that HVDC remain to be valid and reliable alternative to the modern HVAC systems.

Following the inauguration in 2004, the new JWG A2/B4-28 quickly converged to the agreement that the highest priority should be placed on the design review guide as it was believed that this document would provide a solid platform and effective tool for reviewing specific aspects of HVDC applications and interactions between Converter Transformers and associated systems, both AC and DC alike. It has been decided to base this document on the existing design review guide created by the CIGRE WG 12.22 (Greg Polovick (Convener) et al) which was published in the CIGRE Brochure No. 204 in 2002, while expanding on it further in order to address specific aspects associated with the HVDC Converter Transformer application, service requirements and electrical environment.

The main problem is that the failures of the HVDC Converter Transformers always lead to a major energy unavailability of the substation. To achieve the similar availability as for the AC systems more spare units would be required, what would eventually affect the competitiveness of the HVDC technology. It is essential to achieve and maintain a high reliability of the Converter Transformers. It is believed that one way of achieving this is through detailed and rigorous specifications and design reviews, based on a close collaboration between users and manufacturers which would address specific operating conditions and associated requirements on the transformer design, such as for example higher harmonic contents or transient waveforms.

On the other hand, equipment manufacturers would have to be able to prove the capability of understanding and controlling design margins and would be required to present the relevant design tools and verification/acceptance criteria. For the most of the modern manufacturers this should not present any difficulty.

A design review is a planned exercise to ensure that there is a common understanding of the applicable standards and specification requirements, and to provide an opportunity to scrutinize the design to ensure the requirements will be met, using the manufacturer’s proven materials and methodology.

This document is an outline, highlighting the various design features and technical requirements which should be reviewed to ensure compliance with the contract. It does not include design limits or parameters. It is the responsibility of the customer to ensure he or she has sufficient expertise to understand, and evaluate the design. This document does not supersede the responsibility for the adequacy of the design, or the design limits, which must remain with the manufacturer. Deficiencies which are identified shall be corrected. However any changes which are a “betterment” to the Design shall be subject to commercial resolution between the Purchaser and Manufacturer.

Because the review will include information which is proprietary in nature, it is considered essential that the discussions and information exchanged during the design review process be kept confidential.

1 Scope and Normative References

1.1 *Scope*

The scope concerns specific aspects of the electrical, mechanical, and thermal design of converter transformer(s) for HVDC applications with thyristor valves purchased by a customer.

1.2 *Normative References*

This design review guide applies to transformers manufactured in accordance with IEC standards, and the requirements included therein. For reference these standards are listed below.

IEC 60044	Current Transformers
IEC 60050	International Electrotechnical Vocabulary
IEC 60050 (421)	International Electrotechnical Vocabulary – Chapter 421: Power Transformers and Reactors
IEC 60060-1	General Definitions and Test Requirements
IEC 60071-1	Insulation Coordination - Part 1: Definitions, Principles and Rules
IEC 60071-2	Insulation Coordination - Part 2: Application Guide IEC 60076 Power Transformers
IEC 60076-1	Part 1: General
IEC 60076-2	Part 2: Temperature Rise
IEC 60076-3	Part 3: Insulation Levels and Dielectric Tests
IEC 60076-5	Part 5: Ability to withstand Short-Circuit
IEC 60076-7	Part 7: Loading guide for oil-immersed Power Transformers
IEC 60076-8	Application Guide for Power Transformers
IEC 60076-10	Determination of Transformer and Reactor Sound Levels
IEC 60137	Bushings for Alternating Voltage Above 1000 V
IEC 60214-1	Tap-Changers - Part 1: Performance requirements and Test Methods
IEC 60214-2	Tap-Changers - Part 2: Application guide
IEC 60270	Partial Discharge Measurement
IEC 60289	Reactors
IEC 60296	Specification for Unused Mineral Oil for Transformers and Switchgear
IEC 61378-2	Converter transformers – part 2 Transformers for HVDC applications
IEC 61378-3	Converter transformers - Part 3: Application guide
IEC 62199	Bushing for DC application

The standard used should be that version in effect at the time of purchase.

Other standards may be specified throughout the world. Those standards specified by the customer should prevail.

1.3 *Quality Assurance*

For the purpose of this design review guide it is considered that the manufacturer is certified to be in compliance with ISO 9001, or has a Quality Assurance system in place which is acceptable to the Purchaser. The manufacturer will present their Quality Plan during the design review.

2 Definitions

For the purpose of this design review guide, the definitions of IEC 60050 are used.

(a) **Prototype Feature** – A first, full-scale application of a new design or fabrication feature.
(b) **NDT** – Non-destructive tests (or testing). Usually used in the context of examining welds by radiographic or ultrasonic methods or other non-destructive methods.
(c) **Betterment** – An improvement (in the design) that adds value to the transformer or increases safety margins.

3 Objectives

The basic objectives of the design review are:

- To ensure that there is a clear and mutual understanding of the technical requirements.
- To verify the system and project requirements as per specification and to indicate areas where special attention may be required.
- To verify that the design complies with the technical requirements.
- To identify any prototype features and evaluate their reliability and risks.

4 Schedules

Prior to award of a contract, the manufacturer and customer should agree on the design review schedule.

4.1 Pre-award Review

Prior to award of a contract, a review may be held in order to evaluate the following:

- Technical specification and standard requirements,
- Any special system or project requirements,
- Contract requirements,
- Purchaser's intended inspection program,
- Supplier capability:
  - HVDC design,
  - Manufacturing, tools and equipment,
  - HVDC testing,
  - Quality control,
  - Material sourcing and subcontracting,
  - Safety,
  - Environmental issues.

- o References,

4.2 Design Review

A design review, initiated and chaired by the Purchaser should be held for the purpose of conducting an in-depth review of the ordered HVDC Converter Transformer and to allow the Purchaser to have a clear understanding of the overall design. This review is preferably held after the completion of the electrical, thermal and mechanical design calculations of the core and coils assembly, the preliminary outline drawing, the rating plate drawing and before ordering key materials like copper, core steel, etc.. These reviews are normally held at the manufacturer’s plant which allows for direct access to the manufacturer’s design and factory information and personnel.

Information sharing is essential for an effective design review. At the same time the Manufacturer has a legitimate right to protect its know how. For a mutually satisfactory outcome, both goals need to be achieved by means of the following:

- Non disclosure agreements ,
- Agreement about extent and protection of information provided for evaluation purposes on “need to know” bases.

Information essential for an effective design review should be shared but copies of any know how related information are not normally handed over.

4.3 Additional Design Review

Additional design review meetings may be required to follow up on any changes resulting from the first design review or to review those features for which the design had not been completed at the time of the first design review meeting. These may include review of:

- The seismic withstand,
- The tank design,
- Protection and control wiring systems,
- Accessories, including their arrangement on the tank,
- Transportation,
- Others.

5 Subjects for Design Review

The design review should examine the functionality of the transformer to perform within the specified operating requirements and includes the following considerations:

- Specification requirements,
- System data,
- Environmental data,

- Transformer design,
- Fabrications,
- Inspection and test plan,
- Transportation and installation (when applicable).

6 System Data

The specified system conditions under which the transformer will be required to operate should be reviewed. These should include:

(a) AC system voltage variations. The usage of the tapchanger should be examined, indicating the number of anticipated operations per year. The tap range and subdivision needs to be considered. A number of specifications seem to require a very large range but in small voltage steps which can require a tapchanger with more position than in readily available models . The appropriate nominal position and increment needs to be set realistically. The reactive power flow conditions need to be considered because of the effect on the tapchanger switching and voltage regulation.

(b) AC system frequency variation and voltage transients.

(c) DC and harmonic system components.

(d) AC system short circuit capacity including system operating data. Waveforms of s/c current to be established for AC and DC side.

(e) System switching and transformer protection. The type of transformer protective switching should be described. It is possible that the transformer manufacturer may also want to insist on some particular protection against unbalance or circulating current. The type and application of over-voltage protection should be reviewed. There is a need for a full study of overvoltage protection and calculation of energy absorption because the setting of the insulation coordination and hence the voltage levels are fundamental to the test specification and design of the transformer. The characteristics and location of arrestors on the DC and AC side of the converter transformer and DC bridge are key parts of the system design. The surge arrestors can help limit overvoltage caused by transients. Equally it is important to consider which if any of the surge arrestors are to be used during the testing of the transformer, or if their voltage limiting effect is to be taken into account for the test conditions. Description of the AC system around the DC terminal and associated protection should be provided including contingency scenarios and actions.

(f) System earthing conditions and grounding DC currents (due to single pole operation). The position and quality of the DC grounding is important for long-line operation and significant bias currents, independent of any geomagnetic currents that can be induced. Typical specifications require accommodation of up to 10 Amperes DC bias current in the neutral of the converter transformer. The quality and stability of the earthing point connection is a matter of concern. Problems have been reported due to loss of earthing capability due to changes in ground water conditions, galvanic corrosion and high resistance joints leading to poor earthing and ingress of transient voltages through a neutral connection or the equipment grounding terminals. Circulating currents within the earthing and grounding system may be present if care is not taken to consider earthing arrangements because of the very large area covered by the grounding mat for a substation. A review of the earthing of the transformer and possible parallel paths is necessary. Wherever possible the system designers should be involved in this review.

(g) The system connections to the transformer should be discussed noting that the surge impedance is less for cable and bus connections. This may affect the terminal impedance used during impulse tests.

(h) High frequency transients. Some system operations such as switching of large capacitor banks, GIS or cables are known to produce fast transients (FTs), or very fast transients (VFTs). These and other possible sources of FTs and VFTs may result in excessive voltages within the transformer. These may generate internal resonances. A high frequency (HF) model of the transformer should be available containing information on the frequency dependent damping characteristics and results of interaction studies for any scenario provided by the system designer. There is a concern that apart from those generated locally by switching, transients may also be injected into the substation by transmission over the DC lines from outside the station due to coupling from other lines and operations at the far end of the line. The protection and filtering of the incoming lines against high frequency transients should be considered carefully.

(i) Voltage transients. They are caused by valve operation and especially by high firing angle operation and commutation failures. The actual predicted waveshapes from the planned valve operation under all extremes of operation should be available. These calculations need to be supported by actual measurements or simulations on the same valve or similar in these operating conditions. Experience has shown that the normal predictions do not properly represent some of the very high frequency transients actually present at site under certain load conditions, particularly when the system is lightly loaded and providing reactive power compensation. The internal design of the transformer however needs to consider how these transients would be accommodated in the transformer or prevented from entering the transformer.

(j) Current harmonics with defined values for each harmonic order (not just total harmonic distortion (THD) or Eddy Loss Enhancement Factor). In case the transformer has more than 2 windings wound on the same core limb, depending on type of magnetic coupling among different windings, for each harmonic, the phase relationship among the phase currents injected in the valve windings should be provided.

The accuracy of impedance matching should be reviewed with a view of canceling the higher harmonics in the windings.

Note: for more information refer to IEC 61378-3, Clause 9.1.4 Transformers with three or more windings wound on the same core limb.

(k) Effects of DC line faults need to be discussed.

7 Environmental Information

The environmental conditions under which the transformer will be required to operate should be reviewed. Any conditions which result in a variation in the design or materials from the manufacturer's standards should be highlighted and examined. Special considerations may be required for very cold operation (pump start up overloads and effect on dielectric system) and also very warm operation. The temperature variation affects the DC conductivity and hence the voltage distribution. The temperature range is important to establish the validity of the design in all operational conditions. The level of solar radiation input is also a possible concern, particularly in the hot climates, where the additional energy input can give excessive top oil temperatures and insulation deterioration if not properly taken care off. Items without a proper oil circulation such as external portions of bushings and cable boxes may be more susceptible to this effect and have reportedly given problems even in the colder climate conditions.
The following should be considered:

(a) Ambient temperature range, rate of change and effect on the overload capability,
(b) Solar radiation,
(c) Site altitude,
(d) Humidity,

(e) Pollution,
(f) Seismic zone and response spectra,
(g) Geomagnetic currents,
(h) Ultraviolet (UV) radiation,
(i) Isoceraunic level.

8 Transformer Specific Requirements

Although there are many specifications involved prescribing the requirements for transformers, including national and international standards, the intent of this section is to review the specific technical performance requirements of the contract as set out in the technical specifications and schedules.

(a) MVA ratings

In addition to the fundamental nameplate ratings, any requirements for planned or emergency overloads should be specified and reviewed. Attention should be paid to cleat bars, bushings and tapchanger overload capacity and any magnetic leakage requirements. The voltage level is normally different at each end of a line but consideration should be given to whether the normal direction of power flow may actually be reversed.

(b) AC & DC Terminal voltages

Followings aspects should be considered:

- No load
- Range of operating voltage to provide power transmission
- Winding connections and vector relationships
- Tapchanger requirements - the regulation range, di/dt and phase shift of voltage actually being switched should be considered.

(c) Insulation levels - line to line and line to ground

(d) Winding impedances

The winding impedances should be reviewed including tolerances between phases and variation across the tapping range. This is important for the proper operation of the HVDC scheme, but difficult to achieve. .

(e) Cooling provisions

Any special requirement regarding redundancy or overload capacity should be reviewed together with any impact on the control scheme.

(f) Temperature limits

Temperature limits should be reviewed taking into account different loading requirements, existing standards and thermal class of the transformer insulation system.

(g) Losses - No load and load losses

The service losses cannot be realistically measured during the factory acceptance tests and must be calculated. The review needs to look into the validity of the calculations. This needs to take account of the field distribution particularly of the harmonics and their phase relationship within the windings. There may be very high localized eddy or circulating currents within parts of the valve windings, contributing to a significant loss. Justifying the calculations may require comparison to a model and the tolerance or contingency factor for the calculations needs to be specified. The manufacturer is expected to be able to demonstrate capability of calculating distribution of losses in the active part.

(h) Impact of the high firing angle

Operation at a high firing angle (including 90 degrees) and the duration of such operation on the Converter Transformer should be addressed.

9 Transformer Design

The manufacturer should demonstrate how its design will function reliably within the operating requirements including transient conditions while meeting the performance guarantees. Sufficient information should be presented for each basic element to review the design for functionality. Necessary information for maintenance to achieve adequate life expectancy should be covered by the Transformer manual.

If there are any prototype features in the design or fabrication, they should be highlighted and assessed for risk, reliability and reproducibility in all manufacturing facilities involved. Changes made to the design from that offered and/or discussed in detail during the pre-award review should be presented and described by the manufacturer. Unique or specialty transformers may require special or additional considerations.

9.1 Core

The manufacturer should describe their design for the core, explaining how it will perform within the operating parameters. Specific items which should be reviewed include the following:

(a) A general description of the core

- Cross sectional areas,
- Operating flux density, rated and maximum allowed,
- Number of wound and unwound legs,
- Type or grade of material,
- Core and clamping grounding circuit (and provision for testing in the field),
- Weight,
- Method used for joints, extent of overlap and tolerances,
- Core clamping method and structure,
- Bonding and securing,
- Electrical insulation – between magnetic circuit and clamping/support structure, elimination of closed metallic loops,
- Leakage flux control (outer core packets slotting, use of flux collectors or rejectors etc.).

(b) Losses and noise

a. Fundamental frequency,
b. Voltage harmonics,
c. DC bias.

(c) Excitation current

(d) Inrush current

(e) Thermal aspects - limits

a. Control,
b. Core asymmetry of the yoke,
c. Cooling ducts and spacers.

(f) Over-excitation limits

(g) Transportation arrangement and transportation supports.

9.2 Windings

(a) General arrangement

The manufacturer should describe each of the windings in sufficient detail to provide a clear understanding of the physical arrangements. The description should include the following:

- Number of turns,
- Winding type and dimensions, including axial and radial spacer details,
- Type of conductor or cable, including number of strands and conductor insulation,
- Conductor arrangement including description and location of transpositions
- Current densities,
- Additional loss factor due to harmonics and effect of the leakage field,
- Tapping lead arrangement and control of eddy losses,
- Any special arrangement required for testing (this may include special test taps, etc.).

(b) Insulation design

The insulation system is exposed to combined AC and DC voltage stresses during service which can not be realized simultaneously in the test field and which are therefore simulated by separate AC, DC and Polarity Reversal tests. The specified test shall ensure that a successfully tested transformer has sufficient insulation strength to withstand the service stresses over its lifetime.

The manufacturer should present an insulation layout drawing. Each major region of the insulation structure (i.e. main gap between windings, shielding and/or ground insulation at winding ends, inner winding to core, outer winding to tank, axially along windings) should be identified with the test or operating condition which is most critical to its dimensioning and design. A brief summary of the stresses in the critical regions for each test or operating condition should be reviewed.

In this regard, the electric field simulations are recommended. These should cover all test voltages the insulation system is exposed to (AC, DC and PR) in order to ensure that voltage stresses are acceptable taking into account the overall duration of the tests and associated electrical field transients (over the entire range of temperature variation). The manufacturer should present the basis for these calculations:

- Permittivity of materials used,
- Conductivity of materials used,
- Consideration of temperature and field strength dependencies of the material properties,
- Boundary conditions used for electric field simulation.

The manufacturer should demonstrate how the insulation is designed to withstand the imposed stresses, i.e. indicate insulation structure, corresponding stress and resultant dielectric strength:

- Turn to turn,
- Section to section,
- Winding to winding,
- Winding to ground,
- Phase to phase,
- Location of electrostatic plates and shields,
  other winding stresses at:
    - Winding nodes *
    - Leads,
    - Due to transferred voltages from other windings.

* Nodes are coil interconnections and changes in winding construction that cause a change in the series capacitance of the winding.

The manufacturer should present information on the range of oil conductivities for which the results of the evaluation of insulation are valid.

(c) Thermal design

c.1. Losses

The manufacturer should provide the calculated total service losses as per IEC 61378-2 part 7.4 and 10.3.2. and IEC 61378-3 part 9.1.3. and indicate these losses for different ratings.

c.2. Cooling

The manufacturer should describe how the windings will be adequately cooled. This designation should include details on:

- Cooling type,
- Redundancy, overload requirements or other conditions specified,
- Cooling controls strategy,
- Oil ducts and dimensions,
- Oil direction guides: number and location,
- Oil flow system,
- Distribution of oil velocities including any limits related to static electrification.

c.3. Temperature

The manufacturer should present a description of the thermal model of the windings and a summary of the calculated temperatures for the various specified ratings/loading, including any overload and cooling conditions. This should include:

- Winding temperature rises and temperature distribution,
- Oil temperature rises and temperature distribution,
- Indication of the hot spot location and temperature,
- Anticipated temperatures and capabilities of bushings, cable connections, tapchangers, leads and busbars,
- Provision for oil expansion for the main tank and a separate expansion for the tapchanger.

This should include consideration of temperatures over the tapping range where applicable, as well as the effect of the harmonic currents. In addition, the manufacturer should show that the effect of the additional DC solid insulation has been taken into account during the thermal design.

Where direct winding temperature measuring probes are required, the locations of the probes should be reviewed. The manufacturer should demonstrate that the insertion of the fiber optic probes will be effected without prejudice for the dielectric withstand capability It should be noted there is very limited experience in fitting valve windings with fiber optic probes.

(d) Mechanical strength

The manufacturer should provide a description of the capability of the windings to withstand the mechanical forces due to the specified external short circuits as per IEC 60076-5. In addition and if required, capability to withstand electromagnetic forces due to inrush currents should be demonstrated as well.

(e) Cancellation of higher harmonic fluxes in multi winding transformers.
Should be reviewed as per IEC 61378-3 part 9.1.3.

9.3 Core and Winding Assembly

The manufacturer should describe the general assembly and mechanical features for the following:

(a) Coil clamping including the clamping pressure used for both sizing and service and providing short circuit withstand capability,

(b) Provision for withstanding shipping accelerations and the design values; additional supports added for shipping only,

(c) Tie rods:
- o Design,
- o Material and strength,
- o Placement,
- o Temperature due to stray flux.

9.4 Leads and Cleats

Special attention should be paid to the dielectric and thermal design of leads connected to the valve windings and/or bushing.

The manufacturer should describe the arrangements used for the winding leads and interconnections. This should include details for the following:

(a) Methods used for joining interconnections.

It is assumed that the following points are reviewed during the manufacturer qualification/evaluation process:

- Brazed connections – Certification of the Brazer for the type of connections,
- Crimped connections – Method to ensure proper insertion and proper crimped connection,
- Bolted connections – Adequate bolt size to ensure proper clamping pressure,
- Spring connections – Design adequate for life of transformer considering loss of spring tension due to age and overheating,
- Draw lead or draw rod connections considering current densities.

- Contact resistance measurement,
- Type of internal bolting hardware (plated not typically allowed, stainless steel prone to thread shearing) should be reviewed for mechanical and electrical performance.

(b) Insulation design.

The following should be reviewed:

- Shields - methodology for ensuring good potential connection of shields/ potential and accessibility to test shield integrity,

- Dielectric stresses under specified conditions and withstand capability.

(c) Hotspots and provisions for cooling critical areas. The manufacturer should indicate what and where the critical areas are.

(d) Providing mechanical support.

9.5 Drying and Processing

The manufacturer should describe its methods for moisture removal from the insulation ensuring the design dimensions of the coils are achieved. The acceptance criteria should be included.

In addition, the manufacturer should present activities intended for minimizing particles in the active part and ensuring low particle level in the insulating oil in service.

9.6 Leakage Flux Control

The manufacturer should describe how they achieve the control of the leakage flux outside core and coils assembly, including:

- Type of shielding (collectors, rejectors),

- Flux / loss densities at full load and maximum overloads.

- Methods used for fastening and grounding them.

9.7 Sound Level

The manufacturer and customer should have a mutual and clear understanding for the requirements for the sound level. That is, what is the guarantee, what is it based on and how it will be measured.

The manufacturer should present a description of the design provisions which are used to meet the specified sound level.

The noise level under no load conditions including any specific requirement above 1.0 p.u. voltage and full load should be reviewed

It is generally considered that the core and windings are the primary source of transformer noise. These should include effects of the DC bias in the core and harmonic currents in the windings, however other sources may also contribute to the operating sound levels:

- Leakage flux collectors and rejectors,
- Cooling fans,
- Oil pumps.

.

While these sources may not contribute to the sound level measured per the “standard”, the customer may have an interest in knowing the effects for operational considerations.

An estimate of the increase in the anticipated sound level between factory measurements and field measurements where harmonics and DC magnetization may contribute should be discussed.

9.8 Seismic

Many countries have regions which experience various degrees of seismic activity. Transformers which are purchased for those regions need to withstand the rigors imposed during a seismic event as per specification. Generally the seismic activity stresses on the core and coil assembly are much less than the stresses which occur during shipping or system faults. However other structures should be reviewed.

(a) Structural analysis

The manufacturer should present a summary of the structural analysis of the transformer due to seismic loading. It should include the method of analysis and the design criteria for the following:

- Flexible expansion/contraction requirements of piping, etc.,
- Adequacy of provision for anchoring to the foundation,
- Weld design and loading,
- Stresses and strengths of the:
    - Radiator assembly,
    - Conservator,
    - Bushings,
    - Other ancillary components as appropriate.

10 Fabrication

10.1 General Construction

The following items may be considered at design review stage:

- Details of gaskets and stops for all flanged joints on the main tank, life expectancy of gasket materials,
- Ancillaries,
- External insulation distances between phases and phase to earth,
- Number of Pressure Relief Devices and effectiveness, route discharge away from control cabinets and areas where personnel may be standing normally,
- Location and description of manholes provided for inspection and access,
- Ability to gain access to bushing taps and CT secondary terminals location of and access to tank grounding points,
- Design of cover such as slope, gas traps, arrangement of ancillary equipment etc.,
- Safety precautions,

- Provisions for mounting of a fire protection system.

Once the tank design is completed and available for review, the manufacturer should provide the following Cover, Base and Tank Construction data in accordance with the specifications and may discuss any of the following points:

- Arrangement of stiffeners/bracing for distortion due to pressure variations,
- Fit of interfaces between cover, tank body, flanges. Ensure that all flange surfaces cannot trap water against the gaskets,
- Location and details on lifting and jacking devices, review potential obstructions,
- Tank draining location,
- Base Structure: design and mechanical strength considerations and fitness for the intended foundation,
- Provision and location of required valves. Any required access for oil sampling during transformer operation should be identified, location of all ancillaries,
- Location and description of manholes provided for inspection and access.
- Ability to gain access to bushing taps and CT secondary terminals location of and access to tank grounding points,
- Ladder placement,
- Centre of gravity of transformer for alignment on foundation and lifting.

10.2 External Cooling Equipment

The following points should be considered during the design review:

- Fit of interfaces; flanges,
- Pressure leakage pre-test details,
- Internal cleaning details, shut-off valves, review design and material,
- Pumps,
- Fans,
- Maintenance access,
- Ambient protection,
- Climatic conditions.

10.3 Conservators/Preservation Systems

The following points should be considered during the design review:

- Fit of interfaces, flanges,
- Volume considerations function of temperature variations (including extreme climatic conditions), details of air cell,
- Pressure/vacuum capabilities,

- Moisture controlling devices.

10.4 Fabrication Drawings

The following points should be considered during the design review:

- Conform to requirements with regard to welding and NDT (Non Destructive Testing),
- Details to show all weld and NDT processes complete with symbols,
- Location and identification of welds to receive NDT,
- Welding procedures and certification.

10.5 Gas Collection System Design

Review of the cover design to ensure that all gas is directed to a collection point (or points).

- Ensure non-gas pipe connections project below the cover and out of the way for personnel work on the cover.
- Ensure all pockets are piped or blocked.
- Cover supports or bracing has separate holes or slots to avoid trapping gas.
- Slopes are adequate.

10.6 Surface Preparation and Painting

The manufacturer should detail the following data and processes for Tanks, Radiators, Conservator, etc.:

- Blast material,
- Checking of blast profile,
- Paint system,
- Calibration of dry film thickness gauges,
- Adhesion testing.

11 Testing

The Inspection and Test Plan shall be made available and reviewed. The purpose is to make sure that the testing requirements of the contract and standards are properly implemented. Special attention should be given where the requirements and information required varies from the existing standards or normal practice of the manufacturer.

The discussion should be based on relevant standards referred to in this document and technical specifications.

The manufacturer should present evidence of calculations/analysis carried out in order to ensure that the specified requirements will be met and that transformer will be fit for service. However, the test requirements may not fully represent all service conditions due to practical limitations of the test procedures and facilities. Wherever feasible, additional calculations/evaluations should be present in order to demonstrate compliance with the requirements of the specification.

It should be born in mind that the oil quality (in particular the oil resistivity and particle count) and temperature may affect the dielectric performance so the test plan should include points of review of the characteristics of oil used for test.

12 Ancillary Equipment

The manufacturer should provide details and data for the following major accessories, or ancillary equipment.

12.1 Bushings

The following points should be considered during the design review:

- Manufacturer,
- Tests performed by the manufacturer,
- Type and general construction of the bushing,
- Use of lower terminal shields or insulation assembly,
- Sensitivity of matching the shields and bushings,
- Availability of spares,
- Dielectric design of the oil-end insulation structure,
- Shed materials (porcelain / silicon) and shed profile,
- Creep and flashover distance.

It shall be noted that the dielectric stress distribution in and around the oil side of valve bushings depends on the structure of both the valve bushings and the associated barrier insulation system. Therefore each of these needs to be designed taking into account the other. It follows that it is not possible to assume that a replacement valve bushing with a dielectric design different from the original one will work properly with the original barrier insulation system and vice versa.

12.2 Current Transformers

- Manufacturer
- Ratio and accuracy
- Overload characteristics.
- Any special requirement.

12.3 Tapchangers

- Manufacturer
- Test report
- Type, ratings and tapping range

- Overload capabilities
- Dielectric capabilities and protection
- Transient withstand capability
- di/dt
- Tie in resistor requirements
- Power factor
- Maintenance requirements.
- Any special requirements

12.4 Internal Surge Arresters

The manufacturer should provide descriptions for any internally connected arresters or non-linear resistors or other means of voltage control. The location and mounting arrangement should be reviewed.

12.5 Control Cabinet and External Cabling

The following items should be reviewed to ensure the needs specified by the Purchaser are met:

- Cabinet adequate size and power rating to accommodate the Purchaser's cables and connections,
- Cooling controls and alarm and trip functions,
- Terminal block type,
- Wiring standards,
- Adequate heating and ventilation.

Cables from transformer accessories should be suitable for the environment and protected mechanically.

12.6 On-line Monitoring Equipment

The intended use of specified equipment and sensors for on-line monitoring should be reviewed. Fitness for the site conditions in view of ambient, electromagnetic compatibility (EMC) and any mechanical stresses should be considered.

13 Transportation and Installation

The intended shipping process should be reviewed. This includes consideration of:

- Routing,
- Dimensional clearance limitations,
- Shipping weight limitations,
- Use of impact recorders, more than one is recommended, the use of electronic records and their interpretation should be addressed,
- Site handling,
- Erection subcontractors and warranty considerations,
- Oil supply,
- Clear demarcation of where the manufacturers' responsibility ends and the purchasers begin should be agreed upon.

14 Local Legislation and Regulations; Purchasers Policies

One area of review is frequently overlooked. This is the requirement, where specified, to comply with local regulations and the Purchasers Policies. Some examples of local regulations include the following.

(a) Worker safety

Local regulations frequently require specific provisions for:

- Ladders,
- Protection from rotating shafts,
- Clearance to electrical parts,
- Fall arrest systems,
- Hazardous materials,
- Confined space,
- Transportation of dangerous goods,
- Workplace Health Information Material Sheets (WHMIS).

(b) Noise bylaws

(c) Environmental protection

(d) Compliance with the environment (ISO 14001)

- Spills, cleanup and reporting.

15 Oil Quality

Due to the service requirements of HVDC Converter Transformers, special attention should be paid to the selection of the cooling and insulating oil. In particular, the following properties should be clearly stated and reviewed:

- Type / Grade,
- Resistivity,
- Corrosivity,
- Particle count,
- Breakdown strength.

Specific requirements (which may include test procedures, standards and acceptance criteria) should be discussed (this should also be covered by the transformer specification).