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PS 3 / BEST PRACTICES IN TRANSFORMERS AND REACTORS PROCUREMENT

PROCUREMENT OF TRANSFORMERS AND REACTORS - BEST PRACTICES ADOPTED TO ACHIEVE HIGHEST AVAILABILITY & RELIABILITY GOAL

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SUMMARY

Electricity Power is playing major role for economic growth and provide quality of life. Uninterrupted and quality Power become the primary requirement in present scenario. India is the third largest producer of electricity in the world. As a long-term perspective (for up to 2050-time horizon), there is a huge renewable potential of 300GW mainly through solar/wind utilizing waste land in India's desert regions.

Power Grid Corporation of India Limited (POWERGRID) is playing major role in development of transmission infrastructure essential for long-term sustainable growth of India's Power sector since 1992. Being operating largest synchronised Grid in the world, POWERGRID is presently having more than 3300 nos. of Transformers & Reactors of rating ranging from 66kV to 1200kV including Power Transformer, Shunt Reactor, Coupling Transformers for STATCOM/ SVC application, fault current limiting Series Reactors and HVDC Converter Transformers.

POWERGRID is maintaining system availability of more than 99.5%. The failure rate of Transformers & Reactors is well below the international failure rate. This is achieved due to reliable, trouble-free performance and minimal maintenance of Transformers and other associated equipment. In this paper, experience has been shared in various stages of Transformer procurement process followed by POWERGRID to achieve such milestones.

For procurement of such critical equipment, every process is very important like Qualifying requirement of Manufacturer, Technical specification, bidding process, bid evaluation,

Technical review (Design review), drawing approval, Quality Plan (MQP), Testing & commissioning.

Bidding process - For reliable and better Transformers it is desirable to allow participation of those manufacturers who are fulfilling the qualifying requirements, which includes the manufacturing capability and Operational experience. Financial position of manufacturers is also considered. In addition, manufacturers also have to comply the requirement of Technical Specification. Deviation to the technical specification and other commercial requirement evaluated thoroughly during the evaluation process. Various other methods including loss standardization have been implemented to smoothen the bidding process.

Detailed Engineering – This is the process which is being followed after the award of contract. In this stage design review, drawing approval and other critical points are being discussed and finalised. Transformer manufacturers to use items of sub-vendors/suppliers from POWERGRID approved source only. Type test of critical bought out items are also being reviewed during this stage. POWERGRID is having exhaustive inspection and quality checks from ordering of all raw materials, bought out items to testing & despatch of Transformer from manufacturer works. Erection and commissioning is also getting equally importance

Technical specification is most important part based on which Transformer is being designed, manufactured and tested. POWERGRID always strive for continuous improvement of specification based on manufacturing & operational feedback and align with the latest trend of proven technology. During detailed engineering, design review of Transformer & Reactor is being carried out complying the requirement of technical specification.

Further, in today's scenario, project completion schedule is reduced significantly. Procurement of Transformer within short span of time is one of the biggest challenges. To address the reduced delivery schedule, POWEGRID has standardized various parameters including General arrangement of Transformer, bushing dimensions, foundations, fixing of cooler bank position and other major accessories so that one can replace any make of Transformer & Reactor hassle free in least possible time. Standardization has significantly reduced the space requirement, replacement time and inventory cost. Further, standardization is also made in various other processes including Quality checks, raw material procurement, test procedures etc. This all has been achieved without compromising the quality of the Transformer. POWERGRID faced many challenges during this process, which are also addressed in this paper.

Capacity and capability assessment of Transformer manufactures and sub-suppliers are the part of procurement. To maintain the quality and to ensure trouble free performance, POWERGRID imposes penalty/ extended warranty based on violation of many performance parameters of Transformer during operation.

In this paper all the above stages have been presented elaborately and every stages POWERGRID experience for procurement of quality Transformers have been discussed.

KEYWORDS
Technical specification, specific requirement, detailed engineering, Quality control, Manufacturing check points, Testing, performance warrantee, standardization

1. Introduction

Indian Electricity grid is one of the largest synchronised interconnected network in the world with 393 GW of installed power generation capacity as of 12 January 2022. POWERGRID, the largest Transmission utility in India, operates about 172,192 circuit kilometre Transmission Lines with 264 Sub-Stations and maintains more than 99.5 % Transmission system availability. The above network includes more than 3300 nos. of Transformers & of rating ranging from 66kV to 1200kV including Power Transformer, Shunt Reactor, Coupling Transformers for STATCOM/ SVC application, fault current limiting Series Reactors and HVDC Converter Transformers.

To operate such large Grid, reliability of equipment is inevitable to achieve highest availability. Transformer and Reactors, the major electrical equipment connected in the Grid, are always remain in the centre of attention as far as reliability and availability is concerned. To achieve highest availability, it is utmost important to address all issues during the entire Life cycle of Transformers & Reactors i.e. from procurement stage, design, manufacturing, testing, commissioning and maintenance at site. POWERGRID has taken various measures to improve all the above factors including the procurement process, a key area in Transformer Life cycle, resulted in achieving the highest availability of the system.

Though, the reliability and availability of the system has been enhanced by above measures, there are always some failures of Transformers & Reactors. These failures are thoroughly analysed and remedial measures are taken in Specifications, Design reviews, Manufacturing processes, raw material procurement and Maintenance practices to avoid such failures in future. Further, to minimize the repair/ restoration time, standardization of Transformer parameters has helped in replacement of failed units by spare Transformer (available anywhere in the country) in minimum time.

The Indian Transmission network is growing at exponential rate and there is an ambitious plan set by Government of India to achieve 500 GW of non-fossil power capacity by 2030 to utilize the huge potential of Green energy and as a part of mission to make fossil fuel consumption zero by 2070.

As, the new projects under Green energy are mainly linked Solar or wind generation, the gestation period of these projects is very less (10 to 18 months). Hence, drastic changes are required so that the procurement time of Transformers & Reactors matches with the Project completion schedule. POWERGRID has taken various measures i.e. development of more number of manufacturers in India under “Make in India” initiative of Govt. of India, empanelment of vendors for bidding, standardization of ratings of Transformers & Reactors, Standardization of Losses, Standardization of General Arrangement Drawing, Foundation, Bushings etc. With this, the procurement time has been significantly reduced and matching with the compressed timeline of the Project and significant improvements observed in the procurement process.

These improvement measures have been discussed in this paper in detailed.

2. Tendering Process of Transformers & Reactors

There is continuous demand for Transformers & Reactors with lower price and higher reliability. POWERGRID is regularly procuring Transformer of various ratings ranging from 66kV to 765kV (Power Transformer) and Shunt Reactor ranging from 132kV to 765kV. As Transformer & reactors are customised product, its fate is largely dependent on manufacture's practice. Hence, for good Transformer, selection of reputed manufacturers is one of the important requirements. POWERGRID is following stringent bidding process for procurement of Transformer & Reactor. There are many factors considered at the time of vendor selection during bidding process. The major parameters are like – Empanelment of vendors, Capacity & Capability, Financial conditions, past deliveries (timely or delay), past failures etc.

Deviation to the technical specification and other commercial requirement evaluated thoroughly during the evaluation process.

2.1. Bidders/manufacturers qualification requirement

2.1.1. Capacity & Capability

Bidders/manufactures should have capacity and capability to manufacture desired rating as per requirement and timely supply of Transformers & Reactors to meet the Project schedule requirement. Capacities and capabilities are decided based on assessment of manufacturer's works. It is generally carried out in line with CIGRE guideline "Guide for conducting factory capability assessment for power Transformers" working group A2.36.

2.1.2. Financial condition

To participate in bidding process, manufacturer should have sound financial backgrounds. Net Worth for last 3 financial years should be positive. Bidders / Manufacturers should fulfil the Minimum Average Annual Turnover (MAAT) and Liquid Assets (LA) requirement based on total project cost and delivery schedule of the equipment.

2.1.3. Technical requirement

Manufacturer should have adequate experience of design, manufacturing, testing and successful operation of similar rating of Transformer or Reactor (as applicable) for minimum period as mentioned in the bid document.

Further, foreign manufacturers are being encouraged for establishing manufacturing facilities in India for Transformer and Reactor under "Make in India" initiative of Govt. of India.

2.1.4. Loss standardization

Previously bidders were required to quote the losses of Transformer in the bid document. The evaluation of the bid involved differential loss capitalization as per prevailing rates mentioned in the bid document. However, there are many complexities observed during bid evaluation process and project execution stage i.e. change in position of the Bidders (from L1 to L2/ L3..), wrong or incorrect loss figures quoted by Bidders sometimes leads to bid rejection, frequent change in Losses in various packages by Bidders in their bids to remain competitive.

This frequent change of losses in various packages of Transformers/ Reactors resulted into change in design of Transformer which subsequently increases the design / drawing preparation and approval time.

To ascertain procurement of efficient equipment with reduced uncertainty during bidding process & overall execution time, POWERGRID has standardised the Losses of all rating of Transformers& Reactors after deliberations with all the major suppliers.

Though the Losses have been standardized, Manufacturers are always encouraged to adopt new proven and tested technologies/ Material/ Processes for efficient and quality Transformers.

3. Technical specification

Technical specification is one of the key documents and play major role on reliability and availability of the Transformer. It is being followed by manufacturer from beginning of the process i.e. design to raw material procurement, manufacturing, final testing, transportation, erection and commissioning. POWERGRID has revised their Technical specification time to time to align with the latest International standards and also adopted various best practices.

Following major changes have been made in recent past in the specification of Transformers and Reactors:

3.1. Design Review

Design review is considered as one of the best tool to review the internal and overall design of the Transformer. Design reviews are also an opportunity for an exchange of information between the purchaser and the manufacturer, for the purchaser to obtain a better understanding of the technical capabilities of the manufacturer and for the manufacturer to better understand the need of the purchaser. In the same line POWERGRID engineers are also acquainted with new technology different practices and gain knowledge on Transformer technology.

Design review of Transformer is carried out based on short circuit tested Transformer of similar rating. During this design review process, any failures at test bed or at site are also discussed and manufacturers are advised to take suitable measures after proper technical route cause analysis. Adoption of new tested and proven technologies proposed by manufacturers are also discussed and accepted based on requirement.

As per POWERGRID practice, Design review is generally carried out during detailed engineering stage keeping in view that project completion schedule is reducing day by day. During this review manufacturer submit all technical parameters and technical document/calculation as per the requirement of technical specification. Manufacturer are advised to adopt their standard and proven practices for Transformer & reactor supplied earlier and are under operation.

3.2. Requirement of Dynamic Short Circuit Test

POWERGRID faced many Short circuit failures of large Transformers at early days. Earlier, Large Transformer were connected to grid without carrying out short circuit test due to limitation of test facilities. After detailed analysis and based on experience POWERGRID introduced short circuit test on large Power Transformer. After that failures attributed to short circuit test has been drastically reduced.

Dynamic short circuit test is one of the important test for Transformer. It not only validates the mechanical integrity of the design but also manufacturing processes and construction of the Transformer.

To have better Transformer, POWERGRID has specified requirement of short circuit test on similar rating Transformer. The offered Transformer should comply the requirement of similarity clause specified in IS 2026 (PART 5) / IEC 60076-5 with respect to short circuit tested Transformer. Further, design review of offered Transformer shall be carried out based on the design of short circuit tested Transformer.

As short circuit test facility has been developed in India for Transformers upto 765kV, manufacturers are carrying out Short circuit test on 500MVA, (765/√3)/(400//√3)/33kV 1-Phase Autotransformer and 500MVA, 400/220/33kV 3-Phase Autotransformer also, being a regular supply in the Grid.

3.3. Core & Winding

Cold Rolled Grain Oriented (CRGO) Silicon Steel & Copper are the major raw materials for Transformers. Superior grade (High permeability grade) CRGO specified in the Technical specification. All important and critical points for CRGO like – Static discharges, hotspot temperature, single point earthing has been taken care in the specification.

Further, to strengthen the insulation of core to tank, core to yoke clamp (frame) and yoke clamp (frame) to tank to avoid multiple earthing and unwanted discharges, minimum 500MΩ Insulation resistance is specified shall for all cases mentioned above in addition to withstand a voltage of 2.5 kV (DC) for 1 minute. The above improvement helps a lot in minimizing DGA issues due to multiple earthing.

Cleanliness and dust free environment is very essential for manufacturing of winding, processing of winding assembly for large rating Transformer. The manufacturer shall ensure that windings of all Transformers are made in clean, dust proof (Cleanroom class ISO 9 or better as per ISO 14644-1), humidity-controlled environment with positive atmospheric pressure.

The conductors shall be of electrolytic grade copper free from scales and burrs. Oxygen content shall be as per IS 12444. Epoxy bonded Continuously Transposed Conductor (CTC) shall be used in main winding for rated current of 400 A or more.

Thermal stress on winding has been reduced by reducing the temperature rise limit of winding, oil and hotspot (Oil rise 45 Deg C, winding rise 50 for Transformer and Oil rise 40 Deg C, winding rise 45 Deg C for Reactor, Hotspot rise 61 Deg.C, Tank hotspot limited 110 Deg C).

3.4. Insulating Oil

Based on experience and after lot of deliberations with experts around the globe, POWERGRID has mentioned all the parameters of insulating oil. Insulating oil is naphthenic base. It is generally followed IEC 60296 for all major parameters.

As per practice, new oil after successful testing is directly delivered to the designated site in returnable oil drums / flexi bag / stainless steel tanker to avoid multiple handling. Manufacturer use their oil meeting the specification requirement for impregnation and testing. The above practice reduces the commissioning time of the Transformer.

Further, as an initiative for clean and green environment, POWERGRID is also doing one pilot project for use of Natural Ester in 420kV 50 MVAR 3-Phase Shunt Reactor and Synthetic Ester in 315MVA, 400/220/33kV Auto Transformer. One sufficient experience is gained, same may be used in more number of Transformers & Reactors in future.

3.5. Bushings

Earlier, POWERGRID was specifying OIP Bushings for Transformers & Reactors. These OIP Bushings were one of the main factors for failures of Transformers & Reactors. Sometimes, the failure was so devastating that complete equipment got damaged and consequential damages were happened during the failure. Issues of human safety were also associated with these failures.

To avoid failures associated with OIP Bushings, it was decided to specify RIP/ RIS Bushings in Transformers & Reactors. These RIP/ RIS Bushing are presently being specified for Transformer & Reactors upto 400kV class. Further, one pilot project is also undertaken for procurement and Type test of 800kV and 420kV High current RIP Bushing for 765kV Transformer & Reactors. Based on successful operational feedback and establishment of sufficient manufacturing capacity by various Bushing manufacturers, RIP/ RIS Bushings may be considered for 765kV Transformers & Reactors also.

Further, External creepage has been increased from minimum 25 mm/kV to 31mm/kV to avoid external flashovers which are generally observed in polluted and coastal areas.

3.6. Gasket

In long run operation, gasket plays important role. All gasketed joints in contact with oil shall be designed, manufactured and assembled to ensure long-term leak and maintenance free operation. Proper selection of gasket material helps to avoid leakage of oil from tank. All gasketed joints shall be of the O-ring and groove type. If gasket is compressible, metallic stops/other suitable means shall be provided to prevent over-compression.

All tank gaskets have been specified as NBR (Acrylonitrile butadiene Rubber) and properties of all the above gaskets / O-Rings have to comply with the requirements of IS-11149 (Grade IV). Material selected shall suit temperature conditions expected to be encountered. Neoprene / cork sheets gaskets are not acceptable.

3.7. Particles in the oil

To avoid contamination and particles in the Transformer oil, particle analysis is specified before carrying out FAT at manufacturer's works and after completion of the oil filtration at site. The procedure and interpretation shall be in accordance with the recommendation of CIGRE report WG-12.17- "Effect of particles on Transformer dielectric strength".

3.8. Extended warrantee:

For better performance in long run and to strengthen the design and quality, few important criteria/ parameters have been specified and in case of violation of the above parameters during operation within standard warrantee period, provision is there for imposition of additional or extended warrantee. Adoption of stringent parameters lead to more attention by manufacturers during all the stages of manufacturing to achieve best quality product.

The important criteria are as follows:

a) Repair, inside the Transformer and OLTC (including oil migration) either at site or at factory is carried out after commissioning.

b) The concentration of any fault gas is more than values of condition-1 indicated in clause no 6.5 of IEEE-C57.104-2008

c) The winding tan delta goes beyond 0.005 or increase more than 0.001 within a year w.r.t. pre-commissioning values. No temperature correction factor shall be applicable for tan delta.

d) The moisture content goes above 12 ppm at any temperature during operation including full load.

4. Standardization

POWERGRID has standardised various drawings, processes due to following advantages:

- The procurement process become simple and delivery time would be reduced resulting in early completion of project
- Due to standard design, frequent design reviews can be avoided
- Standard ratings and standard civil foundation block would facilitate interchangeability of different make of Transformer / reactor
- Standard fittings and accessories
- Lesser requirement of inventories

4.1. General arrangement and foundation drawing

Due to massive expansion in Indian Grid in last few years and compressed timeline of the projects, there were frequent requirement of shifting of Transformers destined for a particular location to some other location to meet the commissioning targets. During initial stages, problems in mismatch of Bushing termination to connect with the HV/IV/ Tertiary/ Neutral according to the Substation layout, difference in foundations etc. were observed due to change of make of Transformers/ Reactors.

To eliminate the above issues, POWERGRID has standardised the General arrangement drawing for all make of Transformers which are frequently procured i.e. 500MVA, (765/√3)/ (400//√3)/33kV 1-Phase Autotransformer and 500MVA, 400/220/33kV 3-Phase Autotransformer. Initially lot of challenges were faced to align all manufactures to make standard General Arrangement because of their existing design practice, internal active part arrangement etc. However, after lot of technical deliberations with the manufacturers, finally standardization was successful. A typical GA drawing of 765kV and 400kV 500MVA Transformer is attached at Fig. 1 below for reference. Standardize relative location of Bushing terminations, Cooler bank location, Roller assembly etc. keeping in view of interchangeability. With this arrangement erection time has been significantly reduced.

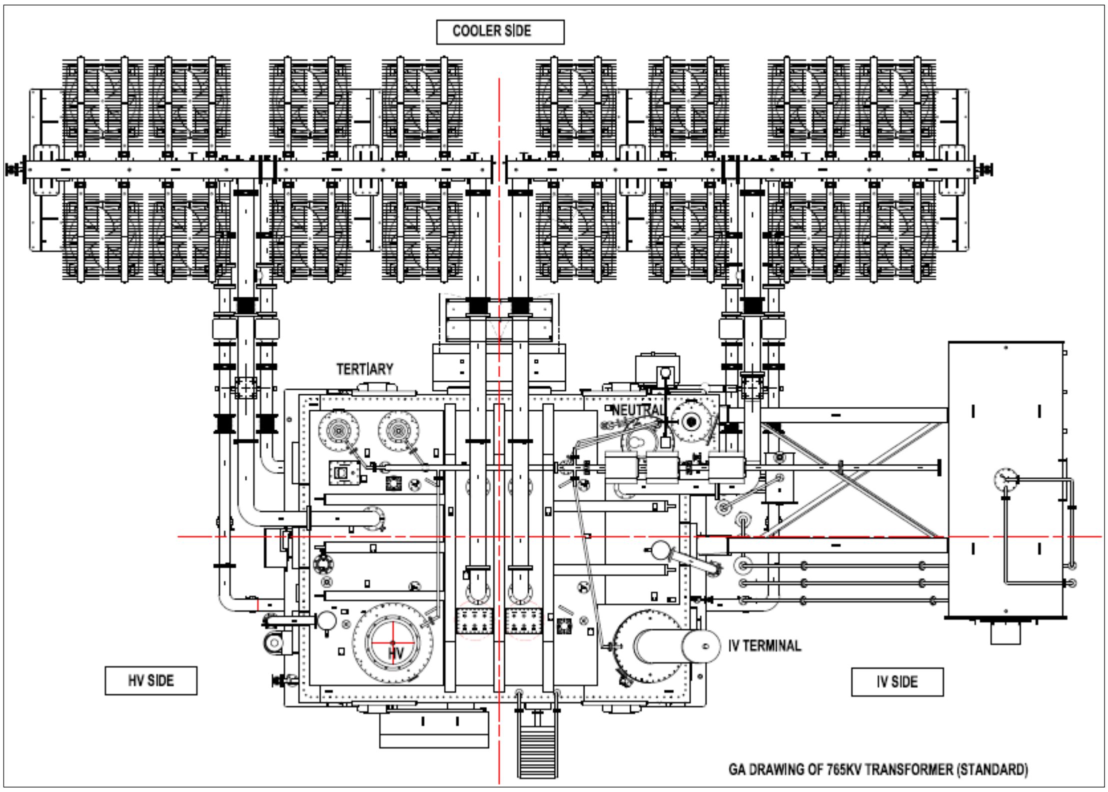

Fig.1 (Typical standard GA drawing of 765kV Transformer)

Foundation of above Transformers are also standardised. Location of coolers, main tank (major foundation blocks) and firewalls has been fixed. Manufacturers are required to fix their locking arrangement in the foundation block. For fixing of cooler banks and other structure, anchor-fastener with chemical grouting arrangement (instead of providing pockets for bolting) is followed for fast fixing all fittings, cooler banks etc. With this arrangement foundation work can be undertaken in advance for any make of transformer to meet the commissioning target matched with project completion time. Further, in case of failure of Transformer, its replacement becomes very easy and less time consuming due to availability of Interchangeable Transformers. This has resulted in significant improvement of system reliability and availability. Further, the inventory requirement is also reduced significantly. A typical standard foundation of 765kV Transformer is given in Fig. 2 below for reference.

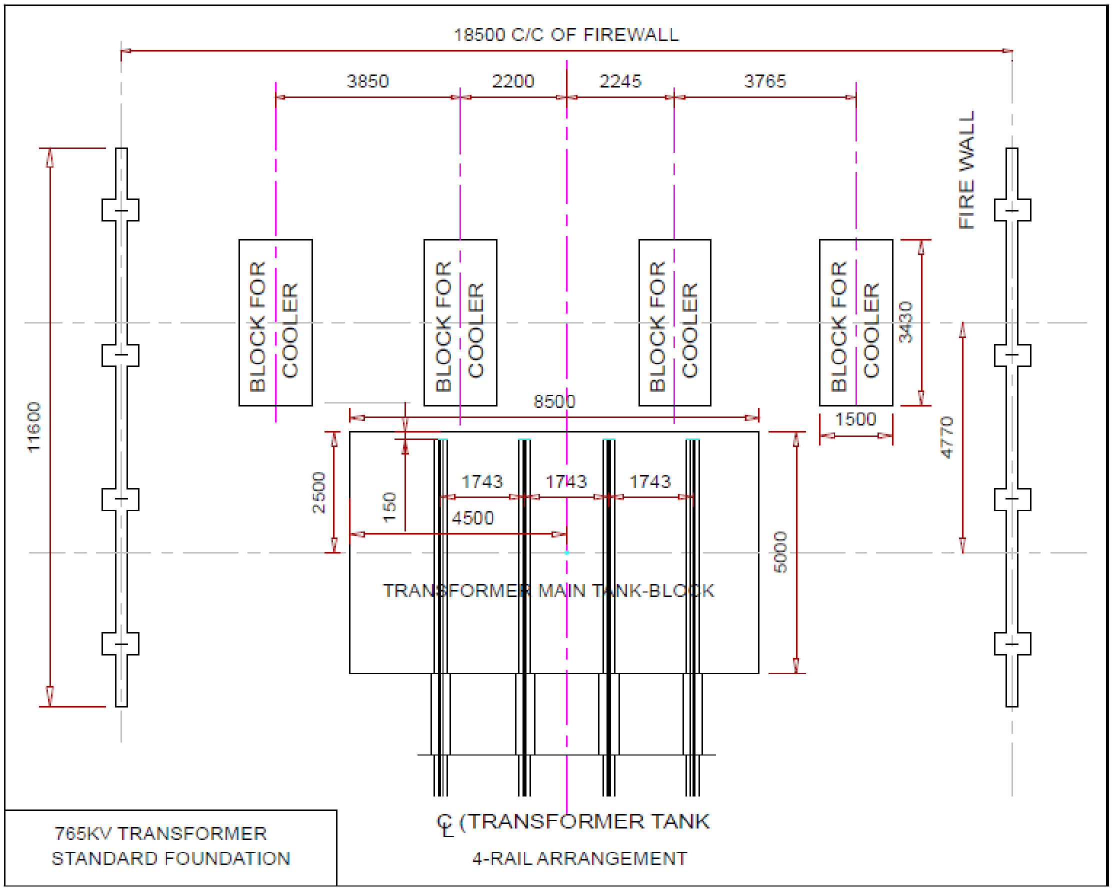

Fig. 2 (Typical standard foundation drawing of 765kV Transformer)

4.2. Bushing Oil end dimensions and connection

Initially various manufacturers were supplying Bushings as per their standard practice which caused lot of problems as Bushing of one manufacturer cannot be possible to replace by other manufacturer due to difference in oil end connection (draw lead/ draw rod/ bottom connected), oil end dimensions, flange etc. This has resulted in keeping huge inventory of spares, which sometimes could not be possible and resulting in long restoration time in case of failure of Bushings.

To address this problem, POWERGRID has standardised Bushings ratings, dimensions and connection arrangement for all make of Bushings. As the manufacturers have to change their Bushing design/ dimensions, there was lot of resistance initially. However, after lot of technical discussions, Bushing manufacturers agreed for standardization. Now Bushings of all manufacturers are interchangeable.

Typical parameters of Bushings fixed for various rating bushings is given in Fig. 3 below.

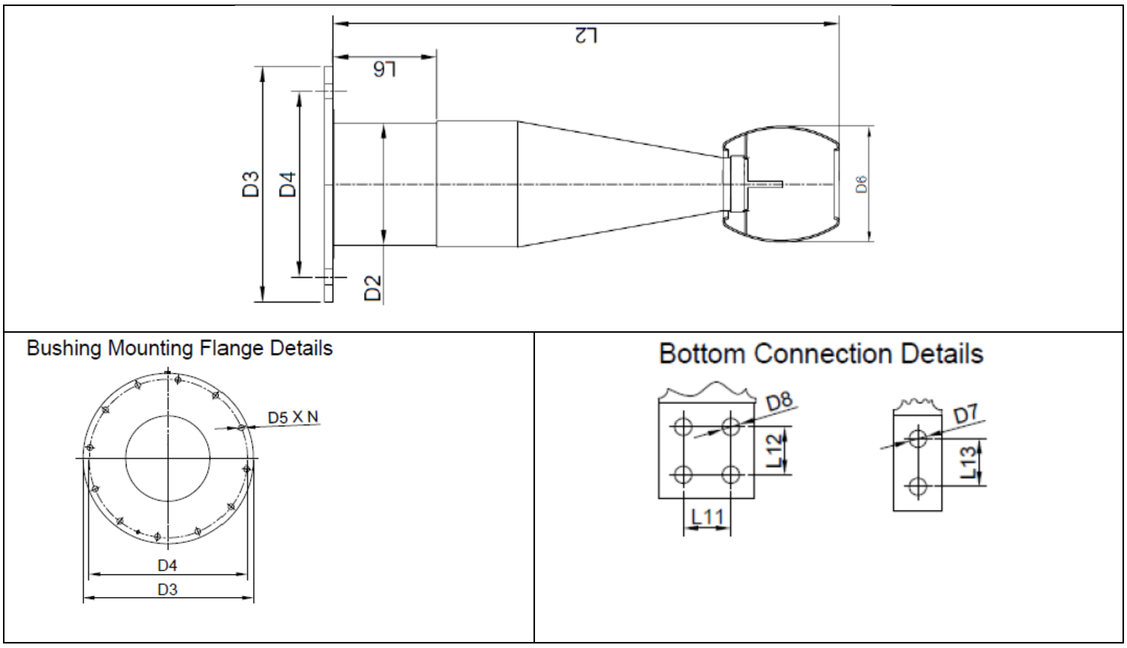

Fig.3 (Typical Oil end parameters standardized for Bushing)

5. Quality control, Manufacturing check points

To comply the requirement of technical specification POWERGRID approves Manufacturing Quality Plan submitted by various manufacturers as per standard format which covers necessary check points from procurement of raw material to manufacturing, various processes including testing of the equipment.

POWERGRID has a practice of periodical process audit of every manufacturer (basically who are supplying raw material and bought out items to Transformer manufacturers). Based on successful compliance in line with technical specification manufacturers are approved for supply of raw material and bought out items. Accordingly, Compendium of Vendor (COV) has been prepared. Transformer/Reactor manufacturers have to procure above items from POWERGRID approved vendors listed in COV.

In addition to above POWERGRID Quality team approves the procurement of CRGO, Copper, Insulation items, Insulating Oil, Fabrication of Tank based on approved design document and technical specification and MQP. Further, Customer hold point (CHP) /Inspection clearance report is used at various stages of process like-Core Building, Core-Coil Assembly, Vapour Phase Drying, Tanking, Oil filing and Testing after successful compliance in line with approved MQP and technical specification. After clearance of current process, manufacturers are allowed to proceed for next stage of manufacturing.

6. Stringent Factory Acceptance Tests

Testing is one of the ways to validate the design, manufacturing, material selection and requirement of technical specification. POWERGRID has specified Routine & Type tests in line with IEC 60076 and some special tests (as routine or type) based on experience to ensure quality product and suitable for long run operation. In Transformer special tests like - Overload testing in short-circuit method, Over-excitation test, (for 765kV Transformer), Measurement of transferred surge on Tertiary, Short duration heat run test (for routine tested units) and for Reactors special tests like - 2-Hour excitation test except type tested unit, Vibration & stress measurement at $Um/\sqrt{3}$ level and $1.05Um/\sqrt{3}$ level and Short time over voltage Test (765kV Reactor) are mentioned in technical specification.

Standard Test procedure

There are certain areas in IEC 60076 where certain agreement is required between manufacturer and purchaser. Further, there are some tests, where ambiguity is there regarding test procedure/ acceptance of test results. To have more clarity and uniformity in the testing, POWERGRID prepared exhaustive Standard test procedure after detailed deliberations with all manufactures. It helps to shorten the total testing time and become a good reference document for test inspector assigned for witnessing testing.

7. CONCLUSION

Earlier, there were failures of Transformers & Reactors in POWERGRID mainly due to Short circuit fault in underlying system, Dielectric failures, Bushing failures, Core earthing related issues, moisture related issues.

POWERGRID adopted various improvement measures as highlighted above from time to time to improve the performance of Transformer & Reactor to achieve highest Availability & Reliability goal. With this, the failures of Transformers & Reactors have reduced significantly and failure rate has come down below International failure rate. The Transmission Network availability is achieved more than 99.5% due to better performance of Transformer & Reactor connected in the Grid.

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