भारतीय मानक

Indian Standard

IS 18284 : 2023

वितरण ट्रांसफार्मर की मरम्मत के लिए — रीती संहिता

Repair of Distribution Transformers — Code of Practice

ICS 29.180

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Transformers Sectional Committee, ETD 16

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Transformers Sectional Committee, had been approved by the Electrotechnical Division Council.

Distribution transformers (DTs) are the backbone of electrical distribution network. Though they are some of the most reliable component of the electrical grid they are also prone to failure due to many factors both internal as well as external. Failure of distribution transformers results into interruption of power supply to consumers. This disruption affects the economy of nation in the form of loss of revenue, materials, repairing charges etc.

Presently, India incurs approximately INR 3 000 Crore per annum for repair of failed distribution transformers alone. Though better maintenance practices have helped in the reduction of failure rate, still most of the utilities, considering their economic conditions, are very much dependent on the repair of failed distribution transformers. This has made it of very much concern that root cause analysis of the failure should be done and properly recorded and the failed DTs are repaired in a standardized manner so as to minimize subsequent failures.

Also, under Sustainable Development Goal (SDG) 12 ‘Responsible Consumption and Production’, it is the responsibility of all to reduce waste generation through prevention, reduction, reuse and recycling. This standard supports SDG 12 by ensuring that failed distribution transformers are repaired in a standardized manner which would minimize subsequent failures and will ensure efficient and reliable functioning when these repaired transformers are put back into the distribution network.

This standard specifies the guidelines to be followed by the repairers for repair of liquid immersed (both mineral oil and ester liquid) as well as dry type distribution transformers covered under the scope of IS 1180 series.

The tolerance values specified on the losses have been kept on the higher side considering the practical difficulties of the Indian repair industry and feedback received from various stakeholders as well as current practices being followed by the utilities for repair of failed distribution transformers. The specified tolerance values may be reviewed in future when sufficient repair data will be available.

IS 1180 series is a necessary adjunct to this standard.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

The composition of the panel, ETD 16 : P01 and the Sectional Committee, ETD 16 responsible for the formulation of this standard in listed Annex H.

Indian Standard

REPAIR OF DISTRIBUTION TRANSFORMERS — CODE OF PRACTICE

1 SCOPE

1.1 This code gives the guidelines along with tests including failure analysis and record keeping for the repair of liquid-immersed, dry-type, outdoor/indoor type, stacked core/wound core with CRGO or amorphous core material, double wound distribution transformers with nominal system voltages up to and including 33 kV and of the following types and ratings:

a) Liquid-immersed: Oil/Natural Ester/Synthetic-Organic Ester:

   1) Three-phase ratings: up to and including 2 500 kVA (both sealed and non-sealed); and
   2) Single phase ratings: up to and including 100 kVA (sealed type).

b) Dry-Type:

   1) Three-phase ratings: up to and including 3 150 kVA; and
   2) Single phase ratings: up to and including 100 kVA.

1.2 This standard does not apply to transformers which are excluded from the scope of IS 1180 series (*see* NOTE 1, Clause **1** of IS 1180 series standards).

2 REFERENCES

The standards given below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of these standards:

IS No.	*Title*
IS 1180	Outdoor/Indoor type, oil-immersed distribution transformers up to and including 2 500 kVA, 33 kV:
(Part 1) : 2014	Mineral oil immersed
(Part 3) : 2021	Natural/Synthetic organic ester immersed
IS 12444 : 2020	Copper wire rods for electrical applications — Specification (*first revision*)
IS 1885 (Part 38) : 1993	Electro technical vocabulary: Part 38 Power transformers and reactors
IS 1866 : 2017	Mineral insulating oils in electrical equipment supervision and maintenance guidance (*first revision*)
IS 2026 (Part 1) : 2011	Power transformer: Part 1 General requirements
IS 5484 : 1997	EC grade aluminium rod produced by continuous casting and rolling — Specification (*second revision*)

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 1180 (Part 1), IS 1180 (Part 3), IS 1180 (Part 4), IS 1885 (Part 38) and IS 2026 (Part 1) shall apply.

4 CLASSIFICATION OF REPAIR ACTIVITIES

4.1 The extent of repair for any transformer depends upon the failure analysis comprising certain tests, such as visual inspection of active-part assembly (and if need be, disassembly of coils and inspection thereof), history of transformer including loading pattern, condition of tank and radiators/fins, number of times repair undergone in past, life of transformer, load tests, winding tests, core condition etc.

4.2 Repair activities may broadly be classified as:

a) Minor repair work which involves replacement/repair (whichever is applicable) of failed parts which are external to windings, for example, arcing/flashover from leads to earth or change of failed/damaged bushings, metal parts, OLTC/OCTC parts or other fittings/accessories, tank leakage, gasket replacement, PRV etc;
b) Major repair work which involves change of coils that have failed electrically or due to mechanical forces and change of a few

laminations or complete core, change of tank etc;

Enhancement of overloading capacity by increasing cooling by adding radiators is also considered as a major repair activity.

Sometimes repair of damaged/deformed tank and its paintwork would be necessary. This is also considered as a major repair activity.

c) Another type of important repair activity is overhauling/ rehabilitation of transformer which involves change of gaskets; change of insulating liquid if parameters do not meet the relevant standards; internal cleaning; tightening of core-coil assembly; repainting and re-servicing of fittings and accessories or replacement of accessories;
d) Augmentation of core or winding for enhancing the loading capacity, reliability and energy performance, increasing number of turns while rewinding etc. can also be considered as a repair activity; and
e) Retro-filling with ester liquid is another kind of minor repair activity which helps to increase the life of the transformer, its overloading capability and makes it eco-friendly and fire-safe.

This code defines general guidelines for all kinds of repair works indicated above.

5 GENERAL

5.1 Identification

Whenever a transformer is received for repair, the following four important aspects should be identified first:

a) Information regarding failure site of the transformer as stated by the customer (site report) including accident if any for example fire;
b) Information which is crucial and to be kept by the service centre for records;
c) Information that is to be attached to the transformer part being repaired; and
d) Information that can be assessed and retained by the customer post repair work.

5.1.1 *Recordkeeping*

Record keeping is an important step not only for the service centre but also for the customers who can quantify the pre- and post-condition of the transformer. Different utilities repair service centres may have different systems like log book or electronic data processing for record keeping.

Every time a transformer is received for repair, a unique record document or service order should be established. This document should briefly describe:

a) the root cause of failure as described by the customer;
b) items identified requiring repair by the repairer; and
c) a list of damaged or missing components.

In addition, photographs or digital images may be attached to this record document to confirm the state of the failed transformer upon receipt and to prepare further documentation for the repair process. If the transformer is liquid-filled type, the poly chlorinated bi-phenyl (PCB) concentration should also be clearly shown on the service order with supporting documentation from the customer or test laboratory.

For recordkeeping, technical information about the transformer should also be captured. This includes nameplate data, electrical test data (site and repair centre which is before and after repair), and details of the repairs required by the customer, the repairs performed, and a list of all parts that were replaced should also be maintained for physical verification. Records should be made available for review by the customer as and when required.

5.1.2 *Nameplate*

At the time of service, it should be ensured that the nameplate is intact and the information is clearly readable. In case the transformer is redesigned, the original nameplate should remain on the unit post-servicing, the new technical and design information should appear on the new nameplate mounted adjacent to the original.

5.1.3 *Service Centre Labels*

Before shipment, every repaired transformer should be permanently embossed or inscribed with the name or identifying logo of the repair centre or repair service provider including month & year of repair adjacent to the nameplate. The service order number for the most recent repair should also be clearly marked on the unit.

5.1.4 *Safety Considerations*

Adequate safety measures should be ensured while taking up repair of transformers considering the bulky size and electrical hazards due to voltage potentials involved. Requirements regarding safety of personnel, training and equipment are detailed in Annex D.

5.2 Assessment/Investigation for Failure of Transformer

Upon receiving a damaged transformer, the service centre should follow the process given below:

a) promptly inspect and test the transformer to identify the problem as per the service order and make first investigation report (FIR);
b) collect data for failure investigation before any other assessment;
c) carry out visual inspection to study the presence or absence of all major components and accessories with proper note-taking and physical recordkeeping;
d) take images/photographs of any electrical tracking, physical damage, oil levels and leakages, overheating, tempering, and encounters with animal or external factors such as natural calamities (disaster) etc;
e) collect as much information as possible about the operating conditions of the transformer at the time of failure;
f) collect and keep debris from any part, observed on visual inspection for further analysis;
g) during physical inspection, it is necessary to carefully note in as much detail as possible namely the position of all operating mechanisms, indicating devices, signs of physical damage (if visible), manufacturing defects, transportation defects, etc; and
h) test the transformer for its electrical integrity once the visual inspection and physical damage assessment are complete.

NOTES

1 Vital test parameters for conforming a transformer's electrical integrity are described in Annex A of this code.

2 Coil removal procedures are enlisted in **6** of this code.

5.3 Cleaning

Once the transformer is assessed/investigated as per the details given above, it should be cleaned to remove dust and debris. Prior to the disassembly, it is often advisable to clean transformer tanks and enclosures to avoid contamination of the core and coil assemblies when they are removed. The transformer under repair should be dismantled step-by-step, only till the extent required. Once disassembled, the components should be thoroughly cleaned. Any cleaning agent remaining on cleaned components should be allowed to evaporate while the residue should be removed carefully. Care should be taken while cleaning the more delicate components. Post-cleaning, the parts should be stored in a clean, dry location prior to assembly.

NOTE — Local environmental regulations must be followed and the effects of the cleaning agent upon the insulated components should be known before proceeding.

5.4 Terminals

5.4.1 *Leads*

A lead is often used to extend the start and/or finish of the coil to the terminals. A lead can be coloured or marked so as to correspond to the connection identification as shown on the nameplate or as specified in Indian Standards if any. A lead should have the correct temperature, voltage and current rating for the application and should be capable of withstanding elevated temperatures experienced during the repair process. Broken or damaged lead should be replaced.

5.4.2 *Connectors*

Connectors are electrical terminals of a transformer through which power transfer takes place. They are also called as Lugs. Once the transformer is received from the customer, the damaged or missing connectors should be identified and replaced. Connectors that require crimping of the connector barrel are recommended for use in a transformer. The connector should be sized to fit the lead and terminal based on the recommendations of the connector manufacturer. The connectors should be replaced with same material as of the metal part.

5.4.3 *Enclosures*

Transformer terminals are often enclosed within metal enclosures or cable box for enhancing safety measures. The integrity of these enclosures should be maintained. The enclosure should be large enough to accommodate leads and terminals so as not to cause overheating due to herding and to ensure that minimum electrical clearances and bending radius are maintained.

5.5 Accessories

All accessories, which may have been removed during disassembly (for example temperature gauges, pressure relief devices (PRDs), bushing, liquid level gauges, cooling fans, gas relays, current transformers, sudden pressure rise relays, etc, and any associated wiring) should be re-checked and validated to be complete and operating correctly before being returned to service. In case the original transformer is fitted with a silica gel breather, it should be replaced every time a transformer is received for repair. Arcing horn on HV bushing should be attached keeping minimum tip to tip spacing of 8.5 mm or as per the design. Replacement bushings should be similar to the original in design that is it should have proper current rating, Basic Impulse Level (BIL) and 50 Hz test levels equal to or higher than the windings to which they are connected. All the accessories must be safely kept and reinstalled before delivery.

5.6 Tanks, Radiators and Enclosures

After thorough cleaning of the tanks and enclosures, rust or corrosion should be removed, and the affected areas should be re-painted after surface preparation. Additionally, any areas from where liquid was leaking should be repaired and painted. It is preferable to clean and paint the whole tank (inside and outside), radiator or enclosure as stipulated in **9**. Damaged or blocked radiator should be replaced.

It is recommended that on completion of repairs, the radiators (and tank) should be tested as per routine test procedure outlined in IS 1180 series.

5.7 Recommended List of Equipment

For carrying out quality repair of distribution transformer, the repairer should have certain basic repair and test equipment as listed in Annex F.

5.8 Major materials including gasket should conform to requirements specified in relevant part of IS 1180 series.

6 REPAIR OF CORE COIL ASSEMBLY

The most common rewind is that which is based on the original design. The winding process has essentially three components:

a) the investigation of the original failure;
b) gathering physical data for the existing core and coils; and
c) the actual winding of the new coils.

The capacity and energy performance of the transformer can be enhanced, depending on the condition and data of the existing core and tank, by core and/or winding augmentation. For details, (*see* Annex B).

6.1 Investigation

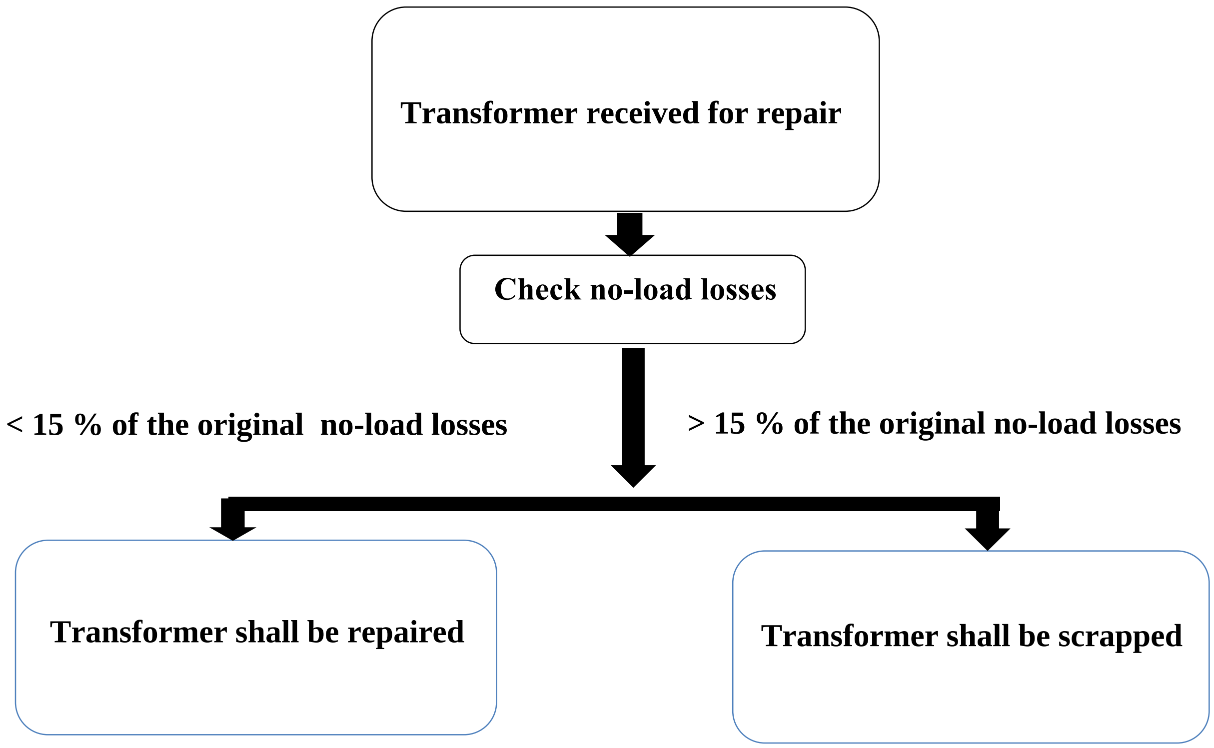
The rewinding process starts with the investigation of the failure that necessitated the rewind. Information gathered may prove helpful when rewinding the coils so that subsequent failures can be avoided or delayed. Some of the features that should be looked for are signs of overheating and its probable cause, reduced electrical clearances, material incompatibility, and the mechanical failure of components. If the fault cannot be located visually, electrical tests (*see* Annex A) as necessary can be carried out to determine the nature and location of the failure.

The customer should provide the detailed information recorded before installation, such as original no-load losses, load losses and percentage impedance etc of the transformer under repair.

6.1.1 Once the transformer reaches the repairer’s workshop, it is necessary to carry out no load test at rated voltage with healthy LV/dummy LV turns. Based on the results, repair of the transformer shall be carried out as follows:

a) If the measured no-load losses at the repairer’s workshop exceed 15 percent of the original no load losses (provided by the customer), then the transformer may not be suitable for repair and no repair works to be taken up and the core shall be scrapped; and
b) If the measured no-load losses at the repairer’s works are found below 15 percent of the original no load losses (provided by the customer), then the transformer shall be taken up for repair works.

The same is summarized below in the flow chart:



The total losses (pre-repair) shall then be calculated as below:

$$\textit{Total Losses}_{\text{pre-repair}} = \text{No-load losses measured at repairer's workshop} + \text{original load losses (provided by the customer)}$$

6.1.2 After repair, the total losses shall be measured and the same shall not exceed the total losses (pre-repair) by more than 10 percent that is.

$$\textit{Total Losses}_{\text{post-repair}} \leq 110 \text{ percent (that is } 1.10) \times \textit{Total Losses}_{\text{pre-repair}}$$

6.1.3 The tolerances on component losses (that is no-load losses and load losses) measured post-repair shall be as below:

Sl No.	*Component losses*	*Tolerances*
(1)	(2)	(3)
i)	No-load losses	+ 15 percent on the no-load losses measured at repairer's workshop
ii)	Load losses	+ 15 percent on the original load losses (provided by the customer)

NOTE — The tolerance values specified in above clauses are not applicable for repair of distribution transformers during the warranty period.

6.2 Data Collection

The repairer should capture maximum of the following information as far as possible from the earlier collected data (mainly during the core and coil assembly, from name-plate and by removing the individual winding coils) and should properly record the same:

a) Name plate data;
b) Physical overall dimensions of core-coil assembly including core clamp (for example length, width and height etc);
c) Basic coil design (cylindrical, spiral wound or disc);
d) Physical dimensions of the coils (for example I.D., O.D., radial thickness and height etc);
e) Electrical clearance dimensions, phase-to-phase and phase-to-ground;
f) Number of turns;
g) Turns per layer (LV and HV);
h) End clearance/End packing (LV and HV);
j) Direction the coils are wound;
k) Tap locations (physical and electrical);
m) Insulation material of winding conductor (wire and strip);
n) Size of conductor (LV and HV);
p) Number of conductors in parallel.
q) Conductor/foil material: Copper/Aluminium;
r) Resistance of each coil;
s) Special features such as extra supports, tying, main lead lengths etc;
t) Stacked core or wound core; in case of wound core whether CRGO or amorphous;

Measure core dimensions: In case of stacked core, measure width and thickness of each packet, core diameter, leg centre, window height, window width, total core frame length and total core frame height.

In case of wound core (CRGO/Amorphous), mention type of construction (Core type or shell type), measure sheet width, total stack thickness within LV Coil I.D., window height, window width (W1 and W2), total core frame length and total core frame height.

u) Grade of steel used to be found from supplier or by loss measurement;
v) Type of liquid used for liquid-immersed transformer: mineral oil or ester fluid;
w) Measure electrical and chemical properties of the liquid including DGA and Furanic Compounds, if applicable;
y) Loading cycle of transformer and maximum temperature rises; and
z) Physical weights of CCA before and after- if possible, core weights and coil weights separately.

6.3 Coil Winding

Coil winding should be carried out in a clean environment using a winding former build for the particular coil being wound. The winding former can either be a pressboard cylinder, wooden, metallic, expandable type or any other which gives perfect winding diameter. The winding is built up according to the data acquired from the original or modified design as indicated in **6.2**. Attention should be given to the size of cooling ducts, wire compaction and tension, tap locations, crossovers, connections, tightness of winding, uniformity in winding and spacers. Proper tension on the conductors ensures a tight, solid coil. The tension should be appropriate and should not lead to the stretching of the conductor. All crossovers and leads should have additional insulation applied to avoid mechanical breakdown of the conductor insulation during processing or service. Connections are made using a suitable joint (soldered, brazed or welded and cleaned to ensure no sharp edges) and separately insulated. Care must be taken to minimize the insulation build. Once the coil is complete, the physical dimensions and resistance should be checked. Coils for liquid immersed transformers should be dried for shrinkage and coils for dry-type transformers are dried and vacuum impregnated with suitable imp regnant material. Cast coils will undergo casting process (Encapsulation).

The no-load and load loss characteristics of the transformer can be improved by core and/or winding augmentation, (*see* Annex B).

6.4 Core Laminations

Cores are generally stacked cores or wound cores. The process of disassembly and assembly of the stacked and wound cores are described in **6.4.1** to **6.4.6**.

6.4.1 *Disassembly of Stacked Cores (CRGO)*

Core should be cleaned after removal of the windings and an accurate dimensional sketch of the core cross-section should be made prior to disassembly. In addition, the number of laminations stacked together should be counted and noted; this is usually two or three but can be more. In most cases, it is only the yoke that is un-stacked. Upon removal, all laminations should be stored properly and stacked together in the same order in which they are to be put back. Laminations from dry-type transformers may be bonded together with cured resin if the core and coil assembly were dipped as a unit. This makes un-stacking of the laminations difficult and requires extra care to avoid damaging them. Laminations should be well supported during storage and put in a safe and dry location.

If there are damaged or welded laminations in the core, they are to be kept aside and replaced by new ones as part of the repair procedure.

6.4.2 *Assembly of Stacked Cores and Coils*

Prior to assembly, the laminations and clamping arrangement should be cleaned. The laminations should be thoroughly inspected for signs of insulation breakdown and for burrs that should be removed. The packing rods between the core legs and the coils should be installed at this time which helps to centre the coils and secure them to the core. During assembly of the yoke, the laminations are replaced according to the sketch prepared prior to disassembly. It should be ensured that the laminations butt tightly against each other at all joints as excessive gaps can drastically reduce the flux density in the core. Once all the laminations are in place, the clamping assembly is put in place, insulated and the securing bolts torqued to recommended values. Next, the transformer coils should be ratio-tested to confirm the overall ratio and the electrical location of the taps. Magnetic Balance test (MBT) should also be conducted to eliminate possibility of any shorted turn.

6.4.3 *Disassembly of Wound Cores (CRGO)*

Wound cores are often difficult to disassemble than stacked cores. Similar to the disassembly process of stacked cores, the number of laminations stacked together should be noted prior to disassembly. Overall dimensions also should be recorded accurately. The bands securing the laminations are cut and the laminations are then carefully removed. The urge to straighten the laminations upon removal should be avoided. Avoid too much bending since that will change the characteristics of the laminations and also make assembly very difficult. Avoid complete disassembly of the core. It will be easier to achieve proper assembly if fewer laminations are removed. When laminations are removed, they should be well supported and stored in a clean, safe location.

6.4.4 *Assembly of Wound Cores and Coils*

Prior to assembly, the laminations and clamping structure should be cleaned. The laminations should be inspected for insulation breakdown and for burrs that should be removed. During assembly, it is critical that the butt joints be secured and tight. This can be very difficult to achieve on some transformers. To help in this process, the core can be tightened and banded in stages, that is install a few laminations and apply temporary bands to tighten them. The temporary bands are then removed before additional laminations are installed. Once all laminations are assembled, the final clamping bands are applied, and the steel clamping structure is put in place, insulated and the bolts/tie rods torqued to the correct values. As mentioned in **6.4.2**, the coils should be tested at this point to ensure the proper ratio and the correct electrical location of the taps.

6.4.5 *Disassembly of Amorphous Wound Cores*

In amorphous-core transformers, cores are fixed, and the coils are inserted. Thus, for such transformers following steps should be followed prior to disassembly.

a) The core coil assembly should be upended (inverted) as the preferred position of core joints is at the bottom in the final transformer assembly. This places the core joints at the top:

NOTES

1 Care should be taken to place enough packing material between core and top channel to avoid core loop dislocation before inverting the coil assembly.

2 Amorphous cores have lap joints distributed inside the core window.

3 Amorphous cores are relatively easy to disassemble as core laminations are held in place and edges are coated with oil resistant epoxy/glue.

b) After removing the core clamps, yoke insulation, tie rods etc. the outer CRGO sheet should be unlocked and the core packets should be unlaced using a suitable round edged knife to avoid damage to lamination;

c) After opening all core joints, lamination packets are held vertically with help of CRGO sheet having width equal to amorphous lamination width and tied with the cotton tape;

d) Same procedure shall be repeated for other limbs. The damaged coil is then carefully removed with suitable lifting arrangement and placed on a clean surface:

NOTE — Amorphous material being brittle, chances of breakages cannot be eliminated but can be minimised by careful handling.

e) Core weight before and after shall be monitored for adequate performance; and

f) Disposal of broken pieces and scrap of amorphous metal shall be done as per local law of land.

6.4.6 *Assembly of Amorphous Wound Cores*

Prior to assembly, the following steps shall be followed:

a) Core surface should be cleaned. A magnet can be used to remove any damaged core flakes from bottom core. New insulation is provided if necessary and new coil is installed;
b) The CRGO support sheet is removed and the core lamination packets are laced. At this stage, proper overlapping of core joints as in original assembly should be ensured to achieve correct electrical parameters;
c) After lacing, the core packets are closed and locked with outer CRGO, same as before;
d) Core joints are covered using the insulation paper to contain amorphous flakes in place, if any;
e) Appropriate insulation is provided, and the steel core clamping structure is put in place;
f) The core coil assembly is inverted to have the core joints at the bottom. After inverting the core coil assembly, the packing is removed from the core and top core channel; and
g) Relevant tests like turns ratio and correct electrical location of the taps, insulation test to be performed.

6.5 Connections and Joints

There are essentially two connections that should be made when winding a transformer, those in the winding and connections external to the winding. All connections should be carefully prepared, cleaned to finish off any sharp edges or burr and to ensure mechanical and electrical integrity.

6.5.1 *Connections in the Winding*

There are several methods of making joints and splices, and the ones described in this code are mere examples. Connections in the winding can be used to connect various parts of the winding (as in a disc-style of winding), to slice in another spool of wire, or to provide tap connections for the winding. In all cases, the joint should be prepared and insulated to ensure electrical and mechanical integrity and to consume less space. Jointing being special process should be performed by qualified technicians. For a splice to meet these needs within the winding, a brazed or welded scarf joint or butt joint is often used. The two connecting pieces should be carefully prepared to ensure that all local insulation is removed and a good fit of one piece against the other is achieved. Once the brazing or welding is complete, all sharp protrusions and flux material should be removed. Strand insulation can be restored by applying a few layers of the appropriate insulation as described in **6.5.3**. If the coils contain wire that is smaller than 3.2 mm^2, splices within the winding should not be used. If the joint is a tap connection, a ‘T’ joint can be used. If the joint connects two parts of the winding such as in a disc-type of winding, a lap joint can be used if space permits; otherwise, a butt or scarf joint should be used. In all cases, all sharp protrusions should be removed after brazing or welding is complete. An additional piece of sheet insulation is often wrapped around the joint to protect adjacent turns. Where tap leads exit the winding, they are often securely tied into the winding to avoid breaking the conductor at this point.

6.5.2 *External Connections*

In most transformers, external connections are generally made to extend the tap leads or the main leads or to install a lug or similar connection device to the end of the leads. A piece of multi-strand wire or cable can be attached to the coil conductor where the wire exits the winding, or the connection can be made well outside the coil. If the connection is made external to the coil conductor, the wire used for this purpose can be attached to the winding wire by brazing, soldering or welding, or by using a crimp connector. The most secure connection can be ensured through brazing or welding but requires additional skill on the part of the worker. In addition, any fluxes or cleaning agents should be removed after the connection is made. Crimp connectors, bi-metallic ones, should be used when joining dissimilar metals or for attaching lugs or similar connection devices to the end of the leads.

NOTES

1 Cross section of the joint should be at least 1.5 times the cross section of wires being connected.

2 Dry joints should be avoided.

3 Cross section area of LT/HT leads should be decided based on the current carrying capacity.

6.5.3 *Insulating Connections*

For insulating the connections, the insulating materials should have proper voltage and temperature ratings, and clearly indicated for use in air or for use under the dielectric fluid. The insulation should extend beyond the connection in each direction to establish a creep age path to suit the voltage of the winding and to suit the environment (air or submerged in the liquid dielectric). The insulation should be secured in such a manner that it shall not dislocate or fall off during processing or in service. In addition, suitable sleeve is usually installed over any wire that extends beyond the coil.

6.6 Leads and Winding Connections as per Vector Group

The requirements for dry-type and liquid-filled transformers differ slightly. The leads for dry-type transformers often have to withstand high temperatures in contrast to which the leads for liquid-filled transformers should be able to withstand submersion in the dielectric. When multi-strand wire or cable is connected to the coil conductor, the cable or wire conductor is sized using a current density that is the same or preferably lower than that used for the coil conductor. As a guide, one can use a conductor of the same size or a larger size than that used by the original manufacturer. On small transformers, the coil conductor is often used as a lead. In this case, a sleeve is usually placed over the wire for added mechanical and electrical strength.

6.7 Final Assembly of the Transformer (After Repair)

The final assembly repair operations are different in liquid immersed transformers and dry type transformers.

Dry type transformer is normally assembled in ventilated or non-ventilated enclosure with relevant ingress protection. It should be offered for routine tests after complete fitting of accessories and gaskets.

The final assembly operations to repair a liquid-filled transformer needs more attention and care, for example:

a) Ensure dryness, cleanliness of tank and prepare tank with all new gaskets of suitable material, accessories, assemble metal parts and bushings as per design;
b) Before placing the assembly in oven IR testing should be carried out;
c) Before placing the core coil assembly in oven proper functioning of all heaters of the oven must be ensured;
d) Core coil assembly to be dried in oven to ensure required insulation resistance (IR) value so that water content in insulations is optimum possible level. Insulation resistance test is often used to qualify this criterion;
e) Tank the core coil assembly and complete all the connections and joints in minimum possible time to reduce exposure of dried windings to the atmosphere;
f) Tightening of gaskets/seals must be ensured after tanking;
g) During tanking of the core-coil assembly, the oil breakdown voltage (BDV) should be checked before filing into the transformer. In case used oil is being filled after filtration/centrifuging, its BDV should not be less than the BDV value specified in IS 1866;
h) Complete the impregnation process by dielectric fluid as per manufacturer’s guidelines;
j) For distribution transformers above 11 kV class, Oil filling should be done using vacuum pump by creating vacuum in the tank; and
k) Allow transformer to settle for at least 4 hours before testing.

Final assembly like tanking and impregnation sequence can be vice versa depending on the manufacturer’s facility and customers requirement.

7 REPAIRING OF LIQUID-FILLED TRANSFORMER

The operations to repair a liquid-filled transformer are similar to those described for dry-type transformers except final assembly and impregnation process. Much of the additional work required relates to the dielectric fluid and the tank. Retro-filling, as indicated in Annex C, helps to increase the life of the transformer, it is overloading capability, and makes it eco-friendly and safer from fire safety point of view.

7.1 Checking for Service Suitability

All name-plate data should be recorded on the service order form as described in **5.1.1**. If applicable, the PCB concentration should be verified.

7.1.1 *Tests*

Recommended that following tests should be performed as described in Annex A — the insulation resistance HV to LV, HV to G with LV grounded, LV to G with HV grounded; check ratio and winding resistance on all phases on all taps, if existing; if possible, energize the LV winding to attain full voltage, recording the magnetizing current and the energizing voltage.

7.1.2 *Equipment Checks*

All accessories should be checked for mechanical damage, noting the items inspected, those that are damaged, and the nature of the damage. The operation of any cooling fans and controls should be verified. The radiators, threaded fittings and gaskets should be checked for leaks. The bushings should be cleaned and checked for cracks. The proper operation of the tap changer, if any, should be checked. Alternatively, the security of the tap connections in the tank should also be checked.

7.1.3 *Summary of Results*

As described in **5.1.1**, all data and damaged items should be listed on the service order form. This information should then be passed to the customer with recommended repairs for the damaged items.

7.1.4 *Preparation for Shipment*

The transformer should be painted according to **9**. After the paint is applied and cured, the customer should be advised that work is complete, and the transformer is ready for shipment. Follow any specific instructions provided by the customer. Prepare the transformer for shipment according to **10**.

7.2 Overhauling

This operation usually requires noticeably more work for oil-filled transformers than for dry-type transformers. The purpose is to totally refurbish the transformer and accessories.

7.2.1 *Preliminary Inspection and Tests*

Perform a quick visual inspection to identify and record any mechanical damage to the tank or radiators and any fluid leaks or trace that may exist. The following tests should be performed — the insulation resistance HV to LV, HV to G with LV grounded, LV to G with HV grounded; ratio check all phases on all taps, if existing; and winding resistance check. Take insulating liquid samples for BDV analysis.

7.2.2 *Removal of Core and Coils*

The oil should be drained out from the tank and stored in tanks specially designed for the purpose (separate tank for mineral oil, Natural ester, Synthetic organic ester and silicon fluid). This will help in preventing oil contamination by other substances. When draining the oil from a damaged transformer, the contaminants in or floating on the oil can foul the transformer windings. Thus, a filter should be used in the suction line to prevent contamination or damage to the pump. Precautionary measures should be taken to prevent leakages. Once the oil is drained and all components (such as the conservator, the bushings, tap switch operators, and thermometer pockets) are removed, the cover is then removed by removing the clamp that holds it in place, unbolting it or cutting the weld. For the latter case, the tank should be purged with and pressurized with nitrogen prior to cutting the weld. Bushings should be removed or protected from metal splatter. After the cover is removed, any remaining accessories that require access from inside the tank can be removed. The core and coil assembly can then be carefully lifted from the tank. Allow the core and coil assembly to drain over the tank for a short time and then place it on the floor over a drip tray. Cover the assembly with a polyethylene sheet. In case of natural ester immersed transformers, core coil shall be cleaned with normal mineral oil and stretch wrapped with polyurethane film to avoid thin film polymerisation if any.

7.2.3 *Major Inspection and Tests*

Underswell-lit condition of the unit, perform a detailed inspection of the core and coil assembly, the inside of the tank, and all the accessories that were removed. Items that require special attention are: the tap changer and its connections; the core clamping assembly; insulation between the core and the clamping structure; blocking; coil insulation; coil leads; any accessible conductor joints; bushings; inside of the tank; conservator; radiators; and all accessories. Tests performed at this time are insulation resistance between the core and the clamping structure, functional tests on all accessories and a degree of polymerization on the paper. The results listing the deficiencies, recommendations and repair costs should be provided to the customer. The customer may choose to repair only the most critical deficiencies or enhanced repairing/retro-filling for better asset life. These should be repaired along with “standard” repairs listed by the service centre as part of the overhaul.

7.2.4 *Cleaning and Repairs*

All components are cleaned using appropriate methods for each item. The core and coil assembly is flushed using mineral oil at very low pressure. The tank, cover, conservator, control boxes and bushing terminal boxes should be thoroughly cleaned using shot blasting in case major damage in paintwork is observed during visual inspection; otherwise, conventional methods for cleaning may also be used. On larger transformers, cleaning the inside of the tank can expose personnel to additional unwanted hazards, such as toxic, flammable or suffocating vapours from solvents in a confined work space, therefore, relevant PPE to be used. These issues should be resolved to avoid undue risk to service personnel and to satisfy the local regulating authorities. After surface preparation and prior to cleaning is the appropriate time to add or replace any radiators or cooling tubes. The gaskets and seals should be replaced with materials resistant to deterioration by insulating fluid. The oil should be processed and cleaned to remove particulates, gases and acids. For re-utilization of mineral oil, (*see* Annex G).

For retro-filling of transformer with ester liquid, guidelines as per Annex C should be followed.

Once all the repairs have been completed, the unit can be reassembled.

7.2.5 *Reassembly*

Reassembling the transformer starts with drying the core and coil assembly. This is best accomplished by placing the core and coils into an oven where the temperature does not exceed 95 °C.

NOTE — Ester filled transformer core coil assembly required to be dipped in hot mineral oil (60 °C) or cleaned with minimal oil pressure before putting in oven.

Ensure that an absorbent material is present around the base of the core and coil assembly to soak up oil that will drain from the insulation. Scrap oil and other materials (cotton waste etc) used for oil soaking to be disposed as per local regulations. Prior to removing the core and coil assembly from the oven, ensure that the work area is clean, and that cleanliness will be maintained throughout the assembly process. When the core and coil assembly is removed from the oven or drying tank, the clamping bolts should be checked for tightness. The assembly is then lifted, quickly lowered into the tank, and all hold down supports installed and tightened. The core coil assembly along with tank should be placed in oven as per standard operating process based on the available facility. The tank is then quickly filled with dielectric fluid (preferably under vacuum) to the top of the transformer core to ensure all insulating material is submerged under dielectric fluid. The dielectric fluid should be above room temperature. Install all sidewall components, replacing any damaged control wiring. Install the cover and all cover-mounted components. The transformer is then filled with the remaining fluid until the correct fluid level is shown on the fluid level gauge. The security of all joints is confirmed by pressurizing the transformer tank with approximately 03 PSI of dry air and inspecting all joints for leak proof connections. If time permits, the transformer should remain pressurized for12 hours and then the pressure should be checked. Mask all the bushings, gauges and valves, and paint the unit as described in **9**.

For natural esters, ensure adequate sealing of transformer as recommended by the supplier.

7.2.6 *Final Tests*

The following tests should be conducted on the transformer-insulation resistance core-to-ground; insulation resistances between each winding and between each winding and ground; turns ratio test; phase relation check or polarity check; winding resistance; open circuit core loss; copper loss; separate source voltage withstand test for HV and LV windings; and an induced overvoltage withstand test. Optional test that may be carried out is magnetic balance test. All tests are described in Annex A. Once all tests are complete, oil samples should be taken for conducting BDV test. The results should confirm that no internal problems occurred during testing and recorded for comparison with the future test results.

7.2.7 *Packaging and Shipment*

The transformer should be prepared for shipment as described in **10**.

7.3 Rewind

On receipt of the unit, record the necessary information and establish documentation as outlined in **5.1.1**.

7.3.1 *Inspection and Test*

If a fault initiated the need for a rewind, investigation should be carried out as described in **6.1**. The core and coil assembly should then be removed as described in **7.2.2**. Once the core and coil assembly is removed, the extent of the damage should be determined, and a cost estimate and scope of work should be prepared for the customer.

7.3.2 *Dismantle (for Three-Phase Unit if Necessary)*

Remove the entire superstructure and lead support systems. Remove the upper clamping structure, upper blocking and insulation between the core and the clamping structure. Store all components neatly for reassembly. Un-stack the top yoke as described in **6.4.1**.

At this point, some of the data listed in **6.2** should be recorded. To free the coil from the core, all blocking between the core and the ground insulation should be removed. The coils can be carefully lifted from the core limbs using suitably fashioned lifting hooks. It is important to support the coils well at this stage to prevent unnecessary damage. Once removed from the core, the coil can be placed in a winding machine, unwound and the remaining data obtained. Depending on coil construction, one may be able to separate the HV and LV winding and replace the affected coils.

7.3.3 *Winding New Coils*

Winding the new coils should be carried out as described in **6.3**.

7.3.4 *Reassembly*

The coils are set on the core limbs using the same equipment used to remove them. The core is then assembled according to **6.4**. The block or insulation layers between the core and coils are installed to centre the coil and to secure the core and coil assembly. On wound-core units this material also prevents the core from damaging the winding. The core clamping structure and the superstructure assembly are installed, and it is ensured that the clamping structure is properly insulated from the core. At this time, the blocking between the top of the coils and the clamping structure should also be installed. The position of the clamping structure should be adjusted to ensure that the blocks are tight. Once the bolts securing the clamping structure are properly tightened, the lead support structure should be installed, and the line leads and the tap leads are secured.

7.3.5 *Final Tests*

Once the transformer is fully assembled, the unit should be tested to ensure that the repair was successful and to provide a record of the transformer condition after the repair. Recommended tests post repair are—ratio check, phase relation and polarity check, winding resistance, insulation resistance, separate source voltage withstand test, induced over voltage withstand test, core loss test and copper loss test. Optional test that may be carried out is magnetic balance test. All the tests are described in Annex A.

7.3.6 *Shipment*

The transformer is prepared for shipment according to **10**.

8 REPAIRING OF DRY-TYPE TRANSFORMER

There are three basic levels of repair: verifying service suitability, overhaul and rewind or another major component replacement. An outline for these three basic levels of service is as follows:

8.1 Checking for Service Suitability

All name-plate data should be recorded on the service order form as described in **5.1.1**.

8.1.1 *Tests*

The following tests should be performed — the insulation resistance HV to LV, HV to G with LV grounded LV to G with HV grounded; ratio check and winding resistance on all phases on all taps; energize the LV to attain full voltage, recording the magnetizing current and the energizing voltage.

8.1.2 *Equipment Checks*

All accessories and enclosures (if available) should be checked for mechanical damage, noting the items inspected, listing those that are damaged, and the nature of the damage. The operation of any cooling fans and controls should be verified. Standoff insulators in the enclosure or on top of the transformer should be checked for cracks or chips. All insulators should be cleaned and the security of all leads and tap connections should be established. Insulated supports used for the HV winding leads or tap connections should also be checked for mechanical security and damaged components. Lastly, the bolted joints on all bus connections should be checked for tightness.

8.1.3 *Summary of Results*

As described in **5.1.1**, all data and a list of damaged items should be mentioned on the service order form. This information should then be passed to the customer with recommended repairs for the damaged items including that of enhanced repair. In this case, the customer may choose not to have the additional repairs carried out. However, the list of items requiring repair may be used at a future date to establish the amount of work required.

8.1.4 *Preparation for Shipment*

The transformer should be painted as described in **9**. After the paint is applied and cured, the customer should be advised that the work is complete, and the transformer is ready for shipment. Specific shipping instructions if provided by the customer regarding carrier, routing, packaging, or shipping address should be met. The transformer should be prepared for shipment according to **10**.

8.2 Overhauling

Overhauling requires more work than that described in preceding sections. The purpose of overhauling is to totally refurbish the transformer and accessories. In this case, with the customer’s concurrence one should proceed to carry out the repairs. In addition, after cleaning the core and coil assembly, a coating of insulating resin may be applied.

To achieve a better result, the enclosure may be thoroughly cleaned using shot blasting process in case major damage in paintwork is observed during visual inspection. Otherwise, conventional methods for cleaning may also be used.

8.3 Rewind

Upon receiving the unit, proper records should be setup and necessary information should be recorded as outlined in **5.1.1**.

8.3.1 *Inspection and Test*

If the rewind was initiated by a fault, an investigation should be carried out as described in **6.1**. All data should be recorded, and once the fault has been located and the extent of damage determined, scope of work should be prepared for the customer.

8.3.2 *Dismantle Core and Coil Assembly (for Three Phase Transformers)*

If necessary, the core and coil assembly should be removed from the enclosure including the entire superstructure and lead support systems. After this, the upper clamping structure, upper blocking and insulation between core and the clamping structure should be removed. All components should be stored neatly for assembly. Un-stack the top yoke as described in **6.4.1**. The laminations should be well supported.

At this stage, the data for items listed in **6.2** should be recorded. The coils can be removed now from the core by first removing all blocking between the core and the coil ground insulation. The coils can be lifted from the core limbs using suitably fashioned lifting hooks. The coils should be supported well at this stage to prevent unnecessary damage arising out of impact. Once removed from the core, the coils can be placed in a winding machine, unwound and the remaining data can be obtained through measurement. Depending on coil construction, one may be able to separate the HV and LV windings and replace the affected coils.

8.3.3 *Winding of New Coils*

Winding the new coils should be carried out as described in **6.3**. In case of epoxy cast coils, if found faulty, they should be replaced by new ones.

8.3.4 *Reassembly*

The coils are set on the core limbs using the same equipment used to remove them. The core is then assembled according to **6.4.2**. After completion of core coil assembly, apply corrosion resistant coat on edges of core laminations to avoid rusting of the same.

If the transformer has a wound core, the core should be placed in and around the coils as described in **6.4**. The block or insulation layers between the core and coils are installed to centre the coil in securing the core and coil assembly. Concentricity of core, LV winding and HV winding shall be maintained. On wound core units, applying anti-corrosive coat also prevents the core from damaging the winding. The core clamping structure and the items for superstructure are installed and it is ensured that the clamping structure is properly insulated from the core. At this time, the block between the top of the coils and the clamping structure is installed. The position of the clamping structure should be adjusted to ensure the blocks are tight. Once the bolts for the clamping structure are properly tightened, the lead support structure is installed in case of Vacuum Pressure Impregnated (VPI) transformers and mechanically sturdy connection in case of cast resin dry type transformers and the line leads and the tap leads are secured.

8.3.5 *Final Tests*

Once the transformer is fully assembled, the unit should be tested to ensure that the repair was successful and to provide a record of the transformer condition after the repair. Recommended tests post repair are—ratio check, phase relation and polarity check, winding resistance, insulation resistance, separate source voltage withstand test, induced over voltage withstand test, core loss test and copper loss test. Optional tests that may be carried out are magnetic balance test, PI, power factor, recovery voltage and dc step voltage. All these tests have been described in Annex A.

8.3.6 *Shipment*

The transformer is prepared for shipment according to **10**.

9 PAINTING

At some point during the repair process, often just prior to shipping, the transformer should be painted. The customer should specify the colour. Before using any paint product, the engineer should know its characteristics, and be aware of safety and health hazards the product presents. The repairer should also be aware of any environmental regulations covering the usage of product. It is important that painting be carried out under controlled conditions according to the paint manufacturer’s instructions. The work should be carried out in a heated, well-ventilated area isolated from other personnel. For spray applications, a paint booth or spray recovery system is recommended. The person applying the paint should be supplied with all necessary safety equipment including the face mask, face shield, oxygen supply system, protective gloves and coveralls. The surfaces to be painted should be clean and free from oil and grease. It is important to protect items such as bushings or gauges during the painting process. The coverings on the bushings and any other items should be removed when the paint has cured.

10 PACKING AND TRANSPORTATION

After all repairs are completed, the transformer should be labelled as described in **4.4** and packaged to prevent damage during transportation to the customer. The type of packaging and method of transport should be provided to the transport company and the customer. It should be confirmed that no PCB contamination is present in the liquid-filled transformers. The distribution transformer should be transported generally in liquid-filled condition. In either case, the transport agency should be equipped with an emergency response kit. Additional protection should be provided for fragile items such as bushings, gauges, etc. Extra care should be taken to secure and support enclosures for dry-type transformers to avoid damage by crushing during shipment. For larger units, the enclosure may be disassembled, or special supports can be fabricated to prevent damage. For smaller units, this can be achieved by bolting the enclosure (and core and coil assembly) to a pallet. In all cases, it should be ensured that the transformer has been securely tied to the transport vehicle and is properly protected against the weather. Unless otherwise instructed by the customer, the tap switch or tap connections should always be set at the rated voltage position.

ANNEXA

(*Clause* 5.2, 6.1, 7.1.1, 7.2.6, 7.3.5 *and* 8.3.5)

METHOD OF TESTS

A-1 GENERAL

The test methods specified in this annexure shall be used to assess the condition of the transformers and to verify the repair results or adequacy of design.

A-2 INSTRUMENT CALIBRATION

The test equipment should meet the accuracy requirements for recording the test results.

The test equipment should be calibrated as per the relevant standards and should bear a mark or label verifying calibration. Calibration certificates should be stored and provided to customer if required.

A-3 INSULATION CONDITION TESTS

Assessment of insulation condition is fundamental to the transformer operation. One or more of the following tests should be performed to gain information about the insulation system. Note that trended test results are usually more informative than that of a single test result. For this reason, all test results should be recorded and retained for further reference.

A-3.1 Insulation Resistance and Di-Electric Strength Test

This test is usually performed to obtain three different winding insulation resistance values—high voltage to low voltage and ground; low voltage to high voltage and ground; and high voltage to low voltage. It can also be used to obtain insulation resistance values between the core and ground when there is core-to-ground connector that can be removed so as to electrically isolate the core from ground. For best results, the transformer should be clean and dry before performing this test.

If the transformer has more than two windings, the insulation resistance of winding should be measured in turn with the other windings grounded. The insulation resistance should be measured with a dc insulation resistance tester, that is, a mega-ohmmeter. The test equipment should be suitably sized for the transformer or winding to be tested and the test performed at a voltage level consistent with the voltage rating of the winding under test. Suggested test voltages are given in the Table 1.

Table 1 Insulation Resistance Test Voltages

(*Clause* A-3.1)

Sl No.	Winding Voltage Class (kV)	Insulation Test Voltage(dc)
(1)	(2)	(3)
i)	Upto 1.1	1 000
ii)	3.3 – 11	2 500
iii)	22 – 33	5 000

The temperature of the winding should be measured at the same time as the insulation resistance value is obtained, which will allow the resistance reading to be corrected to a common temperature such as 27 °C. Temperature correction factors are given in Annex E. Test voltage is applied for 1minute. All accessories attached to the winding should be disconnected and grounded to the core. Recommended minimum insulation resistance values may be obtained from the manufacturer's operation manual. In absence of this information typical minimum values as given in Table 2 shall apply. In case if the resistance values obtained are below these values, one should investigate to determine the cause of the low values. The significance of one insulation resistance reading is not well defined for liquid-filled or dry-type transformer; consequently, these values are best used to determine equipment suitability for over-voltage tests or for trending over time.

Table 2 Recommended Minimum Insulation Resistance for Dry-Type Transformers

(*Clause* A-3.1)

Sl No.	Winding Voltage Class (kV)	Insulation Resistance (MΩ)
(1)	(2)	(3)
i)	Upto 1.1	600
ii)	3.3	1 000
iii)	6.6	1 500
iv)	11.0	2 000
v)	22 – 33.0	3 000

The recommended minimum one-minute insulation resistance for oil-filled transformers is given by the relationship:

$$R_{min} = C \text{ x } E/(kVA)^{1/2}$$

where

- R = the minimum insulation resistance in mega ohms (MΩ);
- C = 1.5 for transformers at 20 °C and 30 for un-tanked core and coils;
- E = voltage rating in volts (phase-to-phase) for delta-connected transformer and phase-to-neutral for wye-connected transformers; and
- kVA = rated capacity of the winding under test (if three-phase winding is being tested where all the windings are being tested as one, the rated capacity of the three-phase winding is used).

The resistance should be corrected to a reference temperature as follows:

$$R_{ref} = k_t \times R_t$$

where

- k_t = correction factor for the temperature at which measurement was taken (*see* Table 5 in Annex E for correction factor for various temperatures); and
- R_t = measured value of resistance.

Moisture generally affects the insulation resistance of dry-type transformers. To confirm the presence of moisture, the insulation resistance can be measured at two different voltages. For example, if the insulated resistance at 500 V dc and 1 000 Vdc differ by more than 25 percent, this can indicate the presence of moisture in the winding.

A-3.2 Polarization Index Test

This is an extension of the one-minute insulation resistance test described in **A-3.1**, and has the advantage that moisture has little effect on these measurements. The same dc voltage used for the one-minute test is applied for a period of 10 minutes. Resistance measurements are recorded after one minute and 10 minutes. The polarization index is the ratio of the 10 minute resistance to the one-minute resistance. Equipment with values below 1.3 should be investigated for possible insulation contamination. This is most reliable for dry-type insulation systems; consequently, the result should be interpreted with caution for liquid-filled equipment.

NOTE — This test is optional.

A-4 OTHER TESTS

There are other tests that can be performed on a transformer to assess its condition. These tests do not test the insulation system directly but provide meaningful information about the other components.

A-4.1 Winding Resistance Test [IS 2026 (Part 1)]

To obtain accurate results, this test is usually performed using a winding resistance bridge. On a new or rewound transformer, this information can be used to determine the copper or load losses that will occur in the transformer and separate them from eddy current losses in the winding. This test can also be used to detect faulty joints or tap switch contacts within the winding. Note that when measuring the resistance of the LV winding on large transformers, it can take several minutes for the measurement equipment to reach a stable value. At the same time, oil temperature and also the winding temperature should be measured. The resistance value can be corrected to a common temperature using the relationship:

$$R_{ref} = R_t \text{x } (T_{ref} + 235)/(T_t + 235) \quad \text{(for Copper)}$$

and

$$R_{ref} = R_t \text{x } (T_{ref} + 225)/(T_t + 225) \quad \text{(for Aluminium)}$$

where

- ref = reference temperature; and
- t = test temperature at which the values were obtained.

A-4.2 Measurement of Voltage ratio or Transformer Turns Ratio (TTR) Test

Low-voltage ac is applied to the low-voltage winding of the transformer, and the voltage induced in the high-voltage winding is measured through test set reference transformers and a null meter. Using the TTR test set one can determine the polarity of the transformer, phase relations, and turn ratio. Measurements should be taken on all taps. Unsatisfactory results can be indication of loose connections, tap changer misalignment, short circuits, incorrect turns after rewind, or open circuits in the winding. The maximum variation of the measured value is 0.5 percent.

Table 3 Common TTR Responses and Associated Transformer Condition
(*Clause* A-4.2)

Sl No.	TTR Reading	Condition
(1)	(2)	(3)
i)	Low current and no output volts	Open turn in the excited winding
ii)	Normal current, output voltage low or unstable	Open turn in output winding
iii)	High current and difficulty balancing the bridge	High resistance in test leads or tap charger

A-4.3 Polarity Test

This test can usually be performed with the TTR metre described in **A-4.2.** Alternatively, a low amplitude AC voltage source and voltmeter can be used. One terminal of the HV winding and the LV winding are connected together, and the low amplitude ac source is connected to the HV winding. The voltage across the remaining terminals HV to LV is measured. The result, if greater than the voltage applied to the HV winding, indicates that the polarity is additive. Alternatively, if the voltage is lower than that applied to the HV winding, the polarity is subtractive. This test can also be performed on three-phase transformers if both the ends of the HV and LV windings for each phase are accessible. Test one phase at a time with all other terminals open circuited. For additive polarity, the HV and LV winding are wound in the opposite direction. When they are wound in the same direction, a transformer is described as having subtractive polarity. This characteristic becomes very important when more than one transformer is connected in parallel to supply a load. If the polarities are not the same, large voltage and current imbalances will occur that can damage the transformers or the connected load.

A-4.4 Phase Sequence Test

This test is used to determine the phase relationships between the HV and LV windings. It is particularly useful after a transformer has been rewound and connected following disassembly in the factory or in a service centre. It is recommended that this test be performed any time the leads from the core and coil assembly are disconnected from the terminals. In this way, one can be sure they are connected properly after the work is complete. The test is similar to the polarity test expect that the line and neutral coil leads are connected as they would be in service. Connect corresponding terminals together, one from HV and one from LV (usually U1 and U1). Connections for various winding configuration are shown in Figure 1 in Annex E.

A low amplitude (120 V or less) three-phase ac voltage is then applied to the HV winding. The voltage between the remaining terminals are then measured and recorded. The magnitudes are then compared to the expected magnitudes based on overlaying the phase relation diagrams from the name-plate and calculating the phase relation sum of the voltages being measured.

A-4.5 No-Load Loss Test

This test is mostly performed on a new transformer to verify the core losses or iron losses. However, this test can also be performed on a transformer under repair to determine whether there are shorts between laminations and to provide a reference for future tests. This test can be performed using one wattmeter on a single-phase transformer and one-, two- or three-watt meters on a three-phase transformer. The low-voltage winding is energized to rated voltage with the HV winding open circuit. The watts measured are the no-load losses, and the current is the excitation current. It is important that the supply waveform be sinusoidal and at the correct frequency. The losses are measured with a wattmeter suitable for use at low power factor. Unfortunately, without knowing the original losses it may be difficult to assess the condition of the core in a used transformer. The losses obtained in this manner include dielectric losses as well as stray losses and copper I^2R losses, both due to the exciting current.

A-4.6 Load Loss and Impedance Test

This test is carried out to determine the losses within a transformer due to the resistance of the HV and LV windings. Once again, the energizing source should have balanced voltages, and the waveform should be sinusoidal. If these two criteria are met, the measurement can then easily be made with one, two- or three-watt meters. The usual method is to short circuit the LV winding and energizes the HV winding on the 100 percent tap until rated current is achieved. The watts measured are the load losses and the voltage required to circulate the rated current is the impedance voltage. The winding temperature should also be recorded at this time. The reference temperature used for determining copper losses is 75 °C. The recorded readings will contain core losses as well as the load or copper losses; the core losses can usually be neglected unless the impendence of the transformer is unusually high.

A-5 Applied Voltage Tests

To confirm that a particular transformer or accessory can withstand the electrical stresses in service, it is subjected to a high-voltage test. This test uses ac source and the electrical stress is usually applied between the windings and ground. The HV and LV windings are usually tested separately with the windings not being tested connected to the ground. To avoid damaging the insulation, avoid application of the high-potential test voltage. High-voltage tests should not be used on equipment with graded insulation systems. That is because the insulation level at the neutral end of the winding is less than at the line end.

A-5.1 Separate Source Voltage Withstand Test

A 50 Hz single-phase ac supply is connected to the HV and LV windings separately. The winding under test has all terminals shorted together. The other winding terminals are also shorted and connected to the ground. The 50 Hz source should be suitably sized to provide the necessary charging current for the transformer being tested, and the waveform should be purely sinusoidal. The test voltage is raised to the test value at a slow, controlled rate. It should, however, not be so slow as to unnecessarily extend the test period. Usually, the above criterion can be met if the voltage is raised to 75 percent of the test value in 5 seconds to 10 seconds and the rate of rise from there on is 2 percent to 3 percent of the test value per second. The test value is maintained for one minute, and the voltage smoothly but rapidly decreased after that time. The equipment is deemed to have passed the test if the test voltage is maintained for the one-minute period without any disruptive discharge.

A-5.2 High Frequency Induced Over-Voltage Test

This test is used to verify the integrity of the turn-to-turn insulation in single-phase and three-phase transformers, as well as phase-to-phase insulation in three-phase transformers. It may also be used in place of the 50 Hz high potential test for graded insulation systems. The test is carried out at high frequency to reduce the exciting current required to energize the transformer. Common preferences are 100 Hz up to 200 Hz. To keep the severity of the test essentially constant for various frequencies, the duration of the test is limited to 7 200 cycles. The test supply is applied to each phase of the LV winding of the transformer under test. The HV winding is left open. The voltage is raised smoothly and quickly to the test value (less than 15 s), held for the 7 200 cycles, then reduced smoothly and quickly (less than 5 s) to zero. The transformer is deemed to have passed the test if no disruptive discharge occurs during the test.

A-5.3 Test Levels of Windings

Test level for transformer windings vary depending on the type of transformer and the voltage class. The ratings and drawings (R and D) plate test values should be used. If R and D plate or the manufacturer’s information is not available, refer to IS 1180 (Part 1) and IS 2026 (Part 3). If the equipment has been overhauled or is being checked for suitability of service, values not less than 80 percent should be used. If all the HV and LV windings are replaced, then tests shall be done at 100 percent values. Values are shown for both liquid-filled and dry-type transformers.

NOTE — Caution: The values indicated in IS 2026 are for equipment with fully insulated neutrals. Equipment with reduced insulation at the neutral should be subjected to induced overvoltage withstand test only. Altitude correction factors should be used for equipment tested above 1 000 m.

A-5.4 *Test Levels of Accessories*

New or fully reconditioned accessories containing voltage sensitive circuits should be tested at 1 500 V Ac 50 Hz for one minute. Current sensing circuits should be tested at 2.5 kV Ac 50 Hz for one minute.

ANNEX B

(*Clause* 6, 6.3 *and* 7)

GUIDELINES FOR ENHANCING RELIABILITY AND ENERGY PERFORMANCE IN REPAIRED DISTRIBUTION TRANSFORMER

GENERAL

This Annex describes redesigning of winding that can be made during repair and/or rewinding within the bounds of the original transformer tank and core design.

NOTE — All coil dimensions should remain same so as to fit in the original core window and tank.

B-1 ACTIVE REPAIR OFDISTRIBUTION TRANSFORMER

The loading capacity, energy efficiency and overall reliability of the repaired distribution transformers can be enhanced by way of augmentation or replacement of the active materials – core and winding, depending on the condition and design of the existing core and tank. This type of repair is commonly known as 'active repair of distribution transformers.

B-1.2 Types of Active Repairs

The following two types of active repairs can be useful for upgrading transformers apart from normal maintenance activities:

a) Core Augmentation

Core augmentation can help in reducing the no-load losses. However, generally, the core is left unchanged. A repairer may consider replacement of core or a part of it or damaged laminations by maintaining the matching geometry, if necessary.

NOTE — The laminations shall comply with the existing regulations if any.

b) Winding Augmentation

Winding augmentation is an approach to increase a transformer's useful life by improving its no load and load loss characteristics. Augmenting refers to replacing high resistivity winding material with low resistivity material, using material with lower thermal coefficient of linear expansion etc. in one or both the windings. Distribution transformers can be modified to take increased load potential by maximizing the efficiency at which excess heat is dissipated from the main core and windings. For material characteristics, (*see* **B-1.4**).

Alternatively, for enhancing the capacity of the transformer, additional cooling methods such as adding cooling fans, cleaning the radiator fins, etc. can be considered depending on the condition and design of the existing core and tank.

B-1.3 Target for Loss Reduction during Repair of Distribution Transformer

During active repair one should target to attain as close as possible to energy efficiency level 1 of total losses (No Load + Full Load) at least at 100 percent loading as per IS 1180 series.

B-1.4 MATERIAL CHARACTERISTICS

Before changing a conductor, it is important to consider the following:

a) How will the differences in thermal characteristics of the materials affect short-term overload capability;
b) How will the difference in material properties affect the original blocking and bracing system;
c) How will the difference in conductivity affect the conductor size;
d) How will the difference in conductor size affect the coil resistance and reactance; and
e) How can the different conductor size affect the size of the coil (axial length) and hence its ability to withstand short circuits.

The material for magnet wire should conform to IS 5484 in case of aluminium and IS 12444 in case of annealed copper.

B-1.4.1 *Electrical Properties*

Differences in electrical conductivity/resistivity allow a copper conductor with cross sectional area 61 percent as large to replace an Aluminium conductor.

Since a smaller conductor size will require less space for the same number of turns, it is necessary to consider how this change will affect coil diameter, mean length per turn (MLT) and coil height. These factors can impact the resistance and leakage reactance of the coil.

B-1.4.2 *Physical Properties*

Copper has a lower thermal coefficient of linear expansion than aluminium; so, for larger coils provision for expansion need not be required for copper. Therefore, any such provisions incorporated into the original design may not change.

Copper is also 3.3 times as dense as aluminium, so an equivalent copper conductor that has only about 61 percent of the cross-sectional area would weigh about twice as much as the original aluminium conductor. Therefore, additional or stronger support or blocking may be required for the copper coils.

B-1.4.3 *Thermal Properties*

Due to differences in the thermal properties of the materials, a copper coil can absorb more energy for a given temperature rise than an aluminium coil. Therefore, a copper coil can withstand higher short-circuit currents than an equivalent aluminium coil, or the same short-circuit current for a longer time.

B-1.4.4 *Mechanical Properties*

Copper coils can withstand mechanical operating stresses better because the mechanical properties of copper are greater than those of aluminium. This assumes that the width-to-depth ratio of the conductor is similar, and the coils are blocked and supported in a manner similar to the original. When copper replaces aluminium, the winding on the new coils may be shorter than the original. If the heights of the old and new coils differ significantly, the style blocking may have to be changed to withstand the expected increase short-circuit forces. As part of any change in conductor material, make sure the replacement coil is of the same height as the original.

ANNEX C

(*Clause* 7 *and* 7.2.4)

GUIDELINES FOR RETRO- FILLING WITH ESTER FLUID DURING REPAIR

Transformer's performance depends heavily on its insulation system; therefore, the insulation is perhaps the most critical transformer part. The prime function of transformer insulating liquid is to insulate and cool the system. In the present times, its role has been expanded far beyond these two important functions.

Ester dielectric fluid provides fire safety as well as prevents thermal ageing. It helps to improve the loading capacity without changing design of the transformer. Safety and fluid containment are some of the major concerns in addition to enhanced life. Aging substation infrastructure, environmental protection, and resource sustainability are other growing issues. Ester based alternate fluids are now available in market namely. Natural Esters and Synthetic organic ester which overcome the limitations of conventional mineral oil in terms of biodegradability, low fire point and consequent safety issues with transformer explosions and fires that can cause catastrophic damages.

NOTE — All core coil dimensions should remain as such so as to fit in the original tank.

C-1 GENERAL

Replacing the mineral oil in a distribution transformer (retro-filling) with ester fluid can be an effective way to upgrade fire safety, slow the thermal aging of cellulose insulation, enhance peak loading capability and lower the environmental risk in otherwise healthy transformers.

Extensive laboratory testing and field retro-fill experience has confirmed excellent miscibility and overall retro-fill compatibility for Ester fluid with many dielectric fluids including conventional mineral oil, high temperature hydrocarbon fluids), PCBs, and most PCB substitutes except silicone. Ester fluid is not miscible with silicone and should not be applied in transformers previously containing silicone.

Ester fluids have service proven stability in sealed transformers. Transformers with free breathing conservators should be retrofitted with suitable liquid preservation system such as airbags in the conservator to prevent direct contact of natural ester with the atmosphere. This will help ensure long term stability of the natural ester fluid. Synthetic organic ester can work in free breathing transformers as well as non-breathing transformer and fluid may not call for any sealing device.

Draining and flushing cannot remove all the dielectric fluid from a transformer, particularly from insulating paper. The mineral oil in the paper insulation will eventually leach out into the Ester fluid until equilibrium is achieved. Mineral oil is fully miscible and compatible with Ester fluid; however, if the concentration of residual mineral oil exceeds 7.5 percent by volume in natural ester, then natural ester fluid's fire point will fall below 300 °C and 4 percent by volume in synthetic ester then synthetic ester fluid's fire point will fall below 300 °C. Following this guide should limit the residual oil to 7 percent in natural ester retro-fill and 4 percent in synthetic ester fluid.

It is recommended to carry out retro-fill of transformers in controlled atmosphere like repair workshop or transformer factory.

Due assessment is needed for the condition of the existing insulation of Transformer before such retro-filling activity is undertaken so that the benefit is realized.

C-2 TRANSFORMER CONDITION ASSESSMENT

A visual inspection to confirm integrity of all seals/bolted connections and proper operation of gauges should be performed. This may indicate whether additional maintenance operations should be performed while the unit is out of service as given in **6**.

The following steps should be followed prior to retro filling of the transformers:

a) Obtain original Operation and Maintenance guide for transformer;
b) Obtain transformer gasket set;
c) Keep replacement parts;
d) Note site limitations for service equipment;
e) Schedule old oil disposal as per local regulations;
f) Schedule fluid and container for flush fluid;
g) Note location of drain, fill and vacuum connections;
h) Limit air and moisture exposure whenever possible;
j) Ensure fluid filling set up or filter machine; and
k) Ensure sealing device fitment in case of natural ester.

C-3 RETROFILL KEYPOINT

Table 4 Retro fill Key points
(*Clause* C-3)

Sl No.	Step	Key Points	Comment
(1)	(2)	(3)	(4)
i)	Adhere to all required safety precautions, codes, and regulations	Follow manufacturer's recommendations for servicing each transformer; additionally, adhere to all required safety precautions, codes, and regulations	—
ii)	Visual inspection	Confirm integrity of seals, bushings, and bolted connections	—
iii)	Drain oil	Allow time for oil to drip to bottom of tank	A longer drip time is advantageous to reduce residual mineral oil
iv)	Rinse with ester (~ 5 percent - 10 percent of the fluid volume)	This step rinses most of the remaining free oil to the bottom of the tank	Minimizes residual oil and other contaminants
v)	Remove dregs from tank bottom	Minimizes the residual oil and other contaminants	—
vi)	Replace Gaskets with new set	Helps ensure proper sealing	Original gaskets that weep or leak should be replaced. Elastomers including NBR types with higher nitrile content, silicone or fluoropolymer are recommended. Gaskets with higher temperature demands warrant the use of silicone or fluoropolymer (Viton) compositions.
vii)	Fill transformer directly from tote or drum	Heating and filtering are not recommended	Ester fluid as-received in sealed totes and drums is satisfactory for use in distribution transformers
viii)	Top off with dry air or nitrogen and bring headspace pressure to 2 psing - 3 psig (13 kPsa - 20 kPa)	Verify gaskets and seals are working properly	Limits exposure to oxygen and atmospheric contaminants to minimum possible
ix)	Install retro fill label	Fill out retro fill label using indelible pen	Document ester fluid batch number from tote or drum for future reference
x)	Wait to energize unit	2 hours minimum, 4 hours is preferred	Allows gas bubbles to dissipate
xi)	Next day, check pressure to ensure proper seal	Limits exposure to oxygen and atmospheric contaminants	—

C-3.1 Preparing Oil Filtration Machine for Filling of Ester Fluid at Site (If Separate Machine for Ester is Not Available)

Following instructions are to be used in conjunction with OEM guidelines if filter machine requested to be used:

a) Take out all left out mineral oil (Old/New/Processed) from degassing chamber, heat exchanger, Condenser, Cartridge filter chamber, Magnetic Strainer, activated alumina chamber, paper filter chamber, pipe line etc;
b) Replace Cartridge filter if used for old mineral oil;
c) Replace paper filter or bypass it, remove clay filter or bypass it;
d) Take ester fluid in clean drum, take fluid in machine (heat exchanger, degassing chamber.) Heat the fluid at 105 °C;
e) After reaching fluid temperature 105 °C, put machine in circulation mode with flexible pipe also in circulation;
f) Check suitability of flexible pipes for 105 °C, if not reduce temperature accordingly which may lead to increase time for circulation. (Normally pipes are suitable for 105 °C);
g) Take out the ester fluid in separate drum including fluid from Degassing chamber and Heat Exchanger;
h) Ester fluid used for cleaning of machine and pipe can be disposed or mixed with Mineral oil (MO) and use in another MO filled transformer after treatment. Check the transformer for fluid level and ensure tank is almost filled with ester fluid. If not check fluid level and empty space should be filled with slightly overpressure Nitrogen; and
j) Ensure transformer is assembled with sealing device and radiator and all accessories as per contract.

C-3.2 Retro-Filling at Site by Filter Machine

a) Ensure transformer old oil is removed, all leakages attended, faulty parts, accessories are replaced, required gaskets are replaced and flushing is done and conservator is sealed;
b) Apply rough vacuum in conservator air release plug;
c) Connect fluid filling pipe at bottom/top of tank;
d) Start filling the fluid till conservator is filled;
e) Open air release plug of radiator and apply rough vacuum if possible;
f) Open bottom valve of radiator this will allow fluid to flow from tank;
g) Fluid filling in Radiators and compensating the level in tank shall be done simultaneously; and
h) Re-fit air release plug once all radiators is fully filled with Fluid.

C-3.2.1 *Filling of Ester Fluid in ON Load Tap Changer-OLTC*

a) Check the OLTC tank for fluid level and ensure tank is almost filled with ester fluid;
b) Ensure OLTC Tank is assembled with conservator [With Non-Return Valve (NRV) in case of natural esters, [*see* IS 1180 (Part 3)] for details]and all accessories as per contract;
c) Apply rough vacuum in conservator air release plug;
d) Connect fluid filling pipe at bottom/top of tank;
e) Start filling the fluid till conservator is filled to normal level;
f) Ensure minimum possible exposure of fluid to air;
g) Check fluid parameters as per contract before starting filtration (BDV in Normal case), Complete filtration cycles as required (3 to 4;
h) Measure parameters after filtration and check as per contract (BDV ≤ 70KV is normally sufficient);
j) Allow fluid to cool down to normal temperature;
k) Release air/gasses and ensure fluid level in transformer and OLTC as per contract; and
m) Transformer can be charged as per standard recommended practice (follow steps like no load for few hours and increasing load in steps).

C-4 MEASUREMENT AND MONITORING

Transformer retro-filled with ester can be monitored and maintained the same way like mineral oil filled transformers. Parameters like Fire point, Viscosity, Breakdown Voltage, can be monitored and acceptance criteria shall be set as per agreement between buyer and seller.

ANNEX D

(*Clause* 5.1.4)

ELECTRICAL TESTING SAFETY CONSIDERATIONS

D-1 PERSONNEL SAFETY

D-1.1 Training

Employees should be trained for a safe operation of all the equipment they are expected to use in their daily activities. This includes all test equipment, tools, and lifting or handling equipment. Training should be provided using relevant equipment, operation manuals, hands-on training and/or video-training tapes. When properly trained in the use of the service-centre equipment, employees should be expected to carry out their activities in a safe manner.

D-1.2 Clothing

Local regulatory requirements for workplace safety should be followed. As a minimum, clothing should be suitable for the work to be performed. Flame-retardant material is recommended. Wearing exposed jewellery should be avoided. Safety glasses and safety shoes should be worn at all times.

D-1.3 Supervision

Unexperienced employees should work under the guidance of an experienced and qualified person within the test area. At least two persons should be present in the test area at all times.

D-1.4 First Aid

Personnel should be trained in the procedure for obtaining/providing emergency medical aid.

D-2 TEST AREA

D-2.1 Enclosure

The test area should be enclosed by a fence or painted (preferably yellow). Red or yellow warning lights may also be placed at the corners of the test area.

D-2.2 Gates

When a metallic fence is used for the enclosure, it should be grounded. If the fence is made from many standalone sections, or includes gates, then separate sections should be interlocked with the power source. The power source will be shut off when one of the sections is parted or the gate opened.

D-2.3 Signs

Electrical hazard signs should be posted around the perimeter of the test area. Unauthorized personnel should not enter the test area.

D-2.4 Lighting

The test area should be well illuminated.

D-2.5 Safety Equipment

Fire equipment and first aid equipment should be readily available, and personnel should be trained in their use. When oil-filled equipment is being tested, an emergency oil spill response kit should be available if there is risk that a large oil leak will occur.

D-2.6 Test Unit Clearance

The test area should be large enough to allow personnel to move around the equipment with ease to facilitate setup and inspection. Proper electrical clearances between energized test equipment and adjacent apparatus must be maintained. Proper electrical clearances between energized test equipment and personnel performing the test must be maintained.

D-2.7 Exclusivity

Only the unit under test and the pertinent test equipment should be in the test area at the time of test.

D-2.8 Grounding

Items on the test unit that are normally at ground potential should be grounded. In addition, portable ground and appropriate “hot stick” should be available to ground the energized components when the tests are complete.

D-3 UNIT UNDER TEST

D-3.1 Suitability for Test

Test personnel should verify that the unit is physically and electrically suitable to undergo the proposed test procedures.

D-4 TEST PANELS

D-4.1 Construction

All test panels should be constructed to protect the operator from the energized equipment they contain (dead front design). There should be no exposed, bare, energized items that the operator can accidentally touch. The test panel should also contain appropriate fault current interrupting equipment (fuses or circuit breakers) to limit the fault current to the test panel capacity or less. A separate interrupting device is preferred for high-voltage ac or dc tests that can restrict the fault current to very low values, thus avoiding excess damage.

D-4.2 Test Voltage

The voltage level on all voltage sources should be clearly marked. For voltage levels above 600 V, a special interlock procedure should be incorporated to prevent inadvertent application of the wrong test voltage. Voltage sources should be free of harmonics, and the phase voltages and currents should be balanced.

D-4.3 Indication of Energization

It is recommended that a light, clearly visible in the vicinity of the test area, be illuminated when the test panels are energized and voltage may appear on the unit under test.

D-4.4 Disconnect

A means of providing a visible disconnect between the panel and the power source should be clearly seen from the test area. The purpose of this device is to provide isolation of the test panel from the power source. This is often a manually operated switch or thermal-magnetic breaker.

D-4.5 Safety Switch

A highly visible switching device should be mounted on the panel that will disconnect it from the power source. This is frequently an electrically operated device such as a contactor or breaker. It is usually operated by a clearly identifiable and easily accessible push button. A hand-held push button or foot operated switch should also be available to one or more of the test participants to provide an additional means of interrupting the test.

D-4.6 Test Leads

Test leads and clips used for testing should be used for that purpose only. They should have the proper current and voltage rating for the test to be performed and should be maintained in good physical condition.

ANNEX E

(*Clause* A-3.1 *and* A-4.4)

REFERENCE INFORMATIONON CORRECTION FACTORS AND WINDING CONNECTIONS

E-1 TEMPERATURE CORRECTION FACTORS ON MEASURED VALUES FOR INSULATION RESISTANCE TESTS AND INSULATION POWER FACTOR TESTS FOR LIQUID-FILLED TRANSFORMERS ARE GIVEN IN TABLE 5

Table 5 Temperature Correction Factors for Insulation Resistance Tests

(*Clause* A-3.1 *and* E-1)

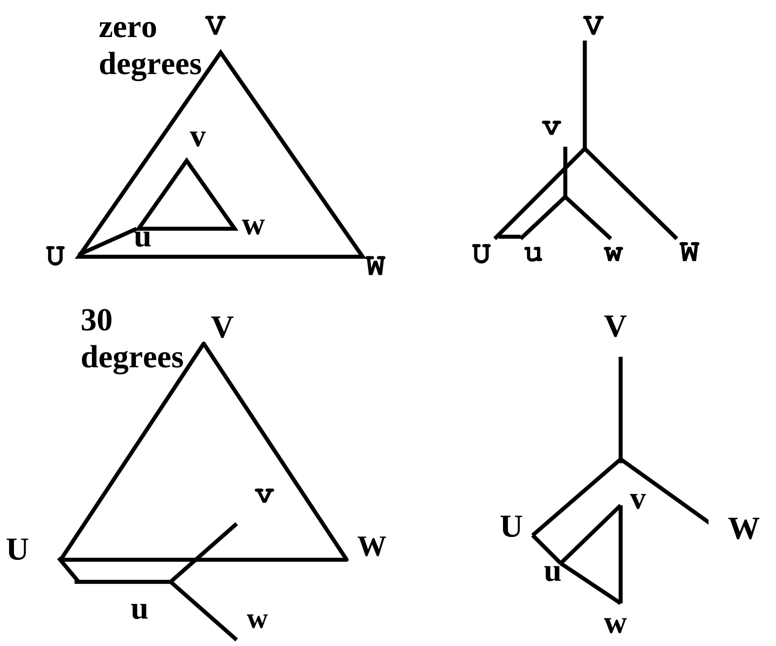
Sl No.	**Temperature (°C)**	**Transformers**	
		Liquid filled	Dry-type
(1)	(2)	(3)	(4)
i)	0	0.25	0.40
ii)	5	0.36	0.45
iii)	10	0.50	0.50
iv)	15	0.74	0.75
v)	20	1.00	1.00
vi)	25	1.40	1.30
vii)	30	1.98	1.60
viii)	35	2.80	2.05
ix)	40	3.95	2.50
x)	45	5.60	3.25
xi)	50	7.85	4.00
xii)	55	11.20	5.20
xiii)	60	15.85	5.40
xiv)	65	22.40	8.70
xv)	70	31.75	10.00
xvi)	75	44.70	13.00

Table 6 Temperature Correction Factors for Insulation Power Factor Tests for Liquid-filled Transformers

(*Clause* A-3.1 *and* E-1)

Sl No.	Test Temperature (ºC)	Correction Factor K
(1)	(2)	(3)
i)	10	0.80
ii)	15	0.90
iii)	20	1.00
iv)	25	1.12
v)	30	1.25
vi)	35	1.40
vii)	40	1.55
viii)	45	1.75
ix)	50	1.95
x)	55	2.18
xi)	60	2.42
xii)	65	2.70
xiii)	70	3.00

E-2 VARIOUS WINDING CONNECTIONS FOR A PHASE SEQUENCE TEST ARE SHOWN BELOW IN FIG. 1



Connect U to u:
Measure V - v, W - v, U - V, V - w, W - w
V – w = W – v
V – v < U – V
V – v < V – w
V – v = W – w

Connect U to u:
Measure W-v, W-w, U-W, V-v, V-w
W – v = W – w
W – v < U – W
V – v < V – w
V – v < U – w

FIG 1 VARIOUS WINDING CONNECTIONS FOR A PHASE SEQUENCE TEST

ANNEX F

(*Clause* 5.7)

LIST OF MAJOR EQUIPMENT REQUIRED FOR REPAIR AND TESTING OF DISTRIBUTION TRANSFORMERS

F-1 EQUIPMENT REQUIRED FOR REPAIRING

a) LV Coil Winding Machine (For Layer Type Coil);
b) HV Coil Winding Machine (For Cross-over Coil);
c) LV/HV Coil Winding Machine (For Disc Type Coil);
d) Insulation Cutting/Shearing Machine;
e) Manual Press Machine - For dovetailed Spacer/block Cutting;
f) Air Drying Oven (for Assembly/coils) - with Trolley;
g) Weighing Machine – Digital;
h) EOT Crane;
j) Oil Filter Machine;
k) Oil Storage Tank.

NOTE — Applicable regulatory requirements for oil storage tank, if any, should be followed.

m) Drill Machine;
n) Welding Machine;
p) Gas Welding/Brazing Set;
q) Compressor;
r) Spray Painting Gun; and
s) Other Zigs, Tools and Accessories.

F-2 TEST EQUIPMENT AND FACILITY REQUIRED FOR DT REPAIRS

a) Turn ratio meter;
b) Winding resistance meter;
c) Megger;
d) Portable HV tester;
e) HV testing transformer;
f) Single phase variac;
g) Three phase variac;
h) M-G Set (DVDF test set);
j) Intermediate testing transformer;
k) Current transformers;
m) Potential transformers;
n) Power analyser;
p) Test bench;
q) Oil test kit (BDV); and
r) Digital clamp meter.

ANNEX G

(*Clause* 7.2.4)

GUIDELINES FOR RE-UTILIZATION OF MINERAL OIL

Reconditioning of normal used oil is carried out by vacuum dehydration wherein the oil is circulated from transformer tank to vacuum dehydration plant and back to transformer repeatedly till water ppm and BDV values are within specified limits. Reconditioning can also be carried out on-site.

Reclaiming can be done off-line or online. In online mode, the used oil from transformer is pumped into a column of sorbents consisting of Fuller's Earth or Bauxite or combination of proprietary sorbent and the outlet of the sorbent column can be fed into vacuum dehydration plant. The oil from vacuum plant goes back to transformer. This circulation is continued till TAN Value, IFT, DDF, BDV, water ppm are reached within the specified range.

NOTE — The minimum breakdown voltage (BDV) should be as per the requirement specified in IS 1866 and maximum value of acidity should be 0.03 mg KOH/g.

In off-line mode, the oil from transformer is collected in a storage tank from the transformer and the above operation is carried out in off-site facility.

Online mode is preferred if the oil quantity is small.

NOTES

1 Reconditioning eliminates only water and particle contamination while reclaiming removes polar impurities such as acids from the oil. Reconditioning is preferred when only water and BDV are off-limits in a transformer in service as per standards. Reclaiming is generally done if TAN, DDF, IFT also go outside limits of specs. Re-refining is done if the oil is unfit for reclaiming also.

2 IS 1866 provides guideline for maintenance and supervision of mineral insulating oil which includes reconditioning or reclaim.

ANNEX H

(*Foreword*)

COMMITTEE COMPOSITION

Transformers Sectional Committee ETD 16

Organization	*Representative(s)*
Central Power Research Institute, Bengaluru	SHRI S. SUDHAKAR REDDY **(*Chairperson*)**
ABB India Limited, Bengaluru	SHRI ABHAY KUMAR AGRAWAL SHRI TARUN KUMAR GARG (*Alternate* I) SHRIANKUR TIWARI(*Alternate* II)
Avi-Oil India Private Limited, Noida	SHRI VIVEK GUPTA
BSES Rajdhani Power Limited, New Delhi	MS SUPRIYA RAINA SHRI GOPAL NARIYA (*Alternate*)
Bharat Heavy Electrical Limited, New Delhi	SHRI S. K. GUPTA SHRI MILIND KULKARNI(*Alternate*)
Bureau of Energy Efficiency, New Delhi	MS P. SAMAL SHRI KAMRAN SHAIKH (*Alternate* I) MS NEHA KUMARI (*Alternate* II)
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CTR Manufacturing Industries Limited, Ghaziabad	SHRI S. A. VYAS SHRI B. D. RAUT (*Alternate* I) SHRI O. C. KOLOMBKAR (*Alternate* II)
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Central Electricity Authority, New Delhi	SHRI Y. K. SWARNKAR SHRIMATI VANDANA SINGHAL (*Alternate* I) SHRI BHANWAR SINGH MEENA (*Alternate* II)
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Central Public Works Department, New Delhi	SHRI CHAITANYA KUMAR VERMA SHRI D. K. TULANI (*Alternate*)
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Development Commissioner Micro-Small and Medium Enterprises	SHRI MANOJ KHUNEKAR SHRI DATTA A. POTDUKHE (*Alternate*)
E.I. DuPont India Private Limited, Gurugram	SHRI SAILESH POROHIT SHRI RAVINDRA PANDEY(*Alternate*)
Easun-MR Tap Changers Private Limited, Chennai	SHRI SHRIKANT POTNIS SHRI R. PRAKASH (*Alternate*)
Electrical Research and Development Association, Vadodara	SHRI KAPIL SHARMA DR ANIL S. KHOPKAR (*Alternate*)

Organization	*Representative(s)*
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Haryana Vidyut Prasaran Nigam Limited, Panchkula	Er Vikas Malik Er Abhishek Gupta (*Alternate*)
Hitachi Metals (India) Private Limited, Gurugram	Shri K. Thukaram Shri M. Srinivas Chetanya (*Alternate*)
Indian Electrical and Electronics Manufacturers Association, New Delhi	Shri Rishabh Raj Joshi
Indian Transformers Manufacturers Association, Vaishali	Shri J. M. Malik Shri B. Lal (*Alternate* I) Shri A. K. Kaul (*Alternate* II)
International Copper Association India, Mumbai	Shri Manas Kundu Shri Mayur Karmakar (*Alternate*)
M & I Materials India Private Limited, New Delhi	Shri Amit Kumar Ms Monika Sharma (*Alternate*)
Maharashtra State Electricity Distribution Company Limited, Mumbai	Shri Manish Wath Shri Gajanan Jaiswal (*Alternate*)
Ministry of Heavy Industries and Public Enterprises, New Delhi	Shrigaurav Kishor Joshi
NTPC Limited, New Delhi	Shri Venkatesh Vuppuluri Shri Hirdesh Gupta (*Alternate*)
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Power Grid Corporation of India, Gurugram	Shri B. N. De Bhowmick (*Alternate* II)
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Transformers and Rectifiers (India) Limited, Ahmedabad	Shri A. S. Jhala Shri Sunil Thakkar (*Alternate*)
Vijai Electricals Limited, Haridwar	Shri A. V. Eswaran Shri P. S. Rao (*Alternate*)

Organization	*Representative(s)*
In Personal Capacity	SHRI V. K. LAKHIANI SHRI P K MUKHERJEE (*Alternate* I) SHRI RAMCHANDRAN PILLAI (*Alternate* II) SHRI MOORKATH VIJAYAKUMARAN (*Alternate* III) SHRI NAGARJUNA BABU NANNAPANENI (*Alternate* IV)
BIS Directorate General	MS PRITI BHATNAGAR, SCIENTIST 'F'/SENIOR DIRECTOR AND HEAD (ELECTRO TECHNICAL) [REPRESENTING DIRECTOR GENERAL (*Ex-officio*)]

Member Secretary
SHRI NEERAJ KUSHWAHA
SCIENTIST 'B'/ASSISTANT DIRECTOR,
ELECTRO TECHNICAL, BIS

Panel for repair of distribution transformers, ETD 16 : P01

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Calcutta Electric Supply Corporation Limited, Kolkata	SHRI SUKALYAN GHOSAL
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