Doc. No. : PRTD/AR/PF:03	Issue No. : 2	Issue Date: 30 Sep 2020	Report of Action Research

1.	Action Research Project No.	AR/0059
2.	Title of Action Research Project	Pre-standardization report on repair of distribution transformers
3.	Name & Designation of Officer	Shyam Kumar, Scientist 'C'
4.	Employee No.	65960
5.	Deptt./BO/RO & Place of Posting	ETD, BIS HQ
6.	Date of Approval of the Project	12 June 2020
7.	Objective of the Project	Distribution Transformer (DT), being one of the most expensive equipment of electricity distribution network, cannot be replaced every time it fails as this will put huge financial burden on the DISCOMs and ultimately on the consumers. The distribution transformer segment contributes to at least 3% of the distribution network losses. Efforts are being made to improve the efficiency of distribution transformers; however, there is no check on the efficiency and reliability of repaired transformers which are being put back into the network. As of now, there are no national or international standard guidelines available for carrying out repair of failed distribution transformers. The objective of this paper is to study the entire ecosystem of distribution transformer repairing which will include study of: — repairing guidelines being followed by transformer repairers in the country — after repair checks (safety and performance requirements) being done by various DISCOMs — global repair technologies which can help in efficient repair of failed distribution transformers — tests which are required to be performed on repaired distribution transformer to assess its reliability and performance
	Report of Action Research Activities	Please see report enclosed.
	Conclusion & Recommendations	Please see report enclosed.
	Any other information relevant to the Project	The project will help in the formulation of National Standard on 'Guidelines for repair of Distribution Transformers'.

(Shyam Kumar)
Scientist-C, ETD

Sc-F & H (ETD)
Sc-G & DDG (Stdn)
Sc-G & DDG (PRT)

Pre-Standardization report on Repair of Distribution Transformers

TABLE OF CONTENTS

1 INTRODUCTION

Power distribution is the final and most crucial link in the electricity supply chain and, unfortunately, the weakest one in the country. It assumes great significance as the segment has a direct impact on the sector's commercial viability, and ultimately on the consumers who pay for power services. The sector has been plagued by high distribution losses coupled with theft of electricity, low metering levels and poor financial health of utilities with low cost recovery. Due to the above, the distribution companies have not been able to undertake corresponding investments in infrastructure augmentation.

In India, power distribution companies (DISCOMs) are having high 24.96% Aggregate Technical & Commercial (AT&C) losses, with high 22% T&D losses. Of these, the Technical losses are estimated to be around 9% to 12%. These losses are fairly high as compared to other countries and this is continuously pressing the financial sustenance of DISCOMs. Distribution Transformers (DT) forms one of the important and high capex assets for DISCOMs. It is estimated that the average overall technical losses in DTs with these DISCOMs could be as high as 3%, compared to 0.5% ideal value. This makes DT one of the key intervention areas for the DISCOMs to bring down their overall network Technical losses.

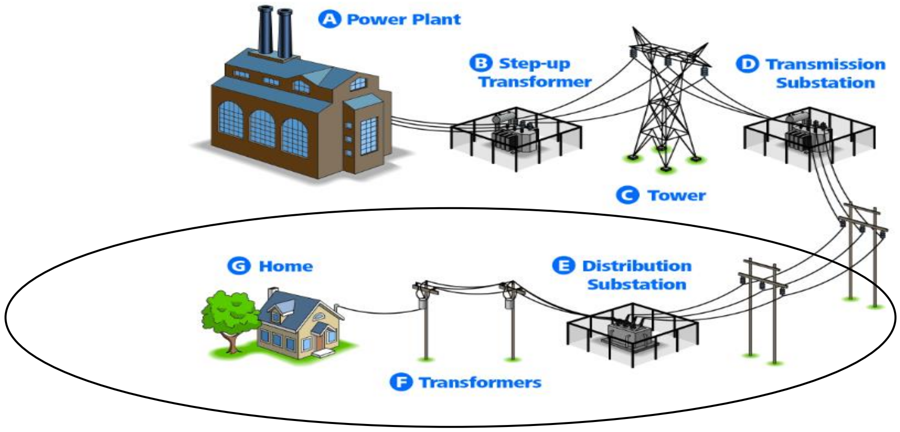
Distribution transformers placed in the network are subjected to a number of stresses such as over loading for longer periods, high temperature rise due to extreme environmental conditions, poor maintenance, lightning etc. which results in the failure of the transformer.

There are some 70 lakhs DTs in India of different capacities (as per CEA statistics), and some 6-8 lakhs DTs fail every year. This high failure rate is result of weak asset management practices including low quality of repairs, and maintenance of DTs. This has resulted into degrading DTs performance and higher than manufacturing spec technical losses. Unfortunately, most times DT failure rate is the only performance metric tracked by the DISCOMs, with oblivion to internal characteristics of the DTs, including the technical losses.

2 SCOPE

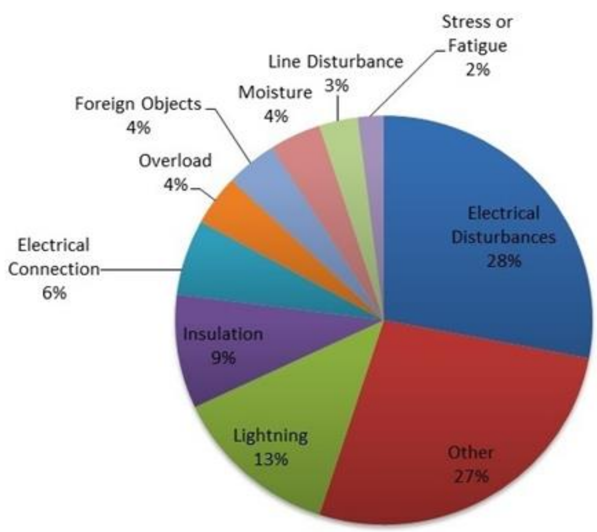
A Distribution Transformer (DT) is a transformer that provides the final voltage transformation by stepping voltages down within a distribution circuit or from a distribution circuit to an end user or application.

The distribution circuit voltages are 3.3 kV, 6.6 kV, 11 kV, 22 kV and 33 kV in the country. The power supply for the end users is 415 volt, 3 Phase (240 volt, 1 phase), 50 Hz. Transformers with primary voltages of 3.3, 6.6, 11, 22 or 33 kV and secondary voltage of 433 volt, 3 Phase (and 250 volt single phase) are called Distribution Transformers.



The estimated failure rate of distribution transformers in India is between 12% to 15%. Since the distribution transformer is one of the most costly equipment in the power distribution network, replacing failed distribution transformers with new transformers can put a huge burden on the economic standing of the DISCOMs. Hence, the option left is to repair the failed units and to put them back into the system.

DTs placed in the network are subjected to a number of stresses such as over loading beyond its nameplate ratings for longer periods, high temperature rise due to extreme environmental conditions, poor maintenance, etc. which results in the failure of the transformer.



One of the major challenges here is efficient and reliable repair of the failed distribution transformers; however, in absence of the standardized repair guidelines, there is no check on the efficiency and reliability of the repaired transformers. These inefficiently repaired transformers are adding to the distribution network losses as well as are also making the distribution system unreliable.

The objective of this Action Research Project is to study the entire framework of repair of failed distribution transformers and to prepare a pre-standardization report on the subject along with draft guidelines which may be utilized to set the Indian Standard on the subject.

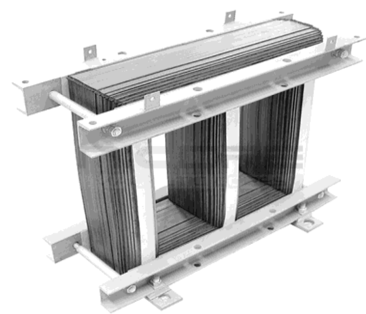
3 TRANSFORMER COMPONENTS AND FAILURE

The distribution transformer consists of Magnetic circuit (Core, yoke and clamp structures), Electrical circuit (windings and insulation), Terminals, bushings, tank, oil, radiator, conservator and breather as main parts.

The transformer can fail due to failure of any of the component as discussed below.

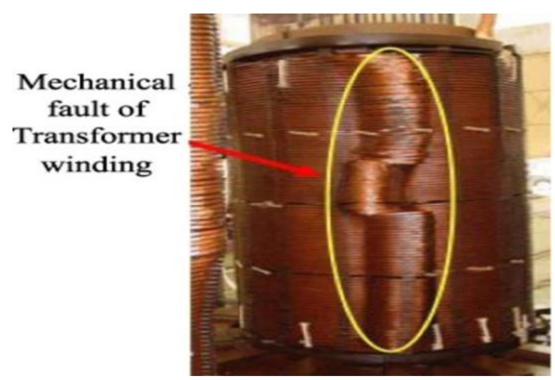
A. Core

The core of transformer carries magnetic flux and provides mechanical strength to the transformer. The core fails due to DC magnetization or displacement of the core steel during the construction of transformer.



B. Winding

Function of the windings is to carry current in the transformer and they are arranged as cylindrical shells around the core limb where each strand is wrapped with paper insulation. In addition to dielectric stress and thermal requirements the windings have to withstand mechanical forces that may cause winding displacement. Such forces can appear during short circuit and lightening. Windings mostly fail due to short circuit or transient over voltage.



The short circuit of windings may occur due to various reasons i.e. mechanical fault in the windings during the construction of transformer or fault in insulating material or hot spot creation or generation of copper sludge or low oil level in the transformer. Transient Overvoltage may result due to lightening or wrong connection of transformer or short circuit in the LT system.

C. Tank

Tank encloses the transformer core and windings as a physical protection as well as serves as container for oil used as coolant. It has to withstand environmental stresses such as corrosive atmosphere, high humidity and sun radiations. The tank is inspected for oil leakage, excessive corrosion, dents and other signs of rough handling. Internal arcing in an oil filled transformer can instantly vaporize surrounding oil which can lead to a high gas pressure inside the transformer and rupture the tank.

D. Solid Insulation

Solid insulation, made of cellulose base products such as press board and paper, is used between the windings for electrical isolation. Cellulose consists of long chain of glucose rings which degrades with time leading to shorter chains. Condition of paper is indicated by degree of polymerization (DP) as average number of these rings in the chain. New paper has DP between 1200-1400 where as DP < 200 means that the paper has a poor mechanical strength and may no longer withstand short circuit and other mechanical forces. This solid insulation is the weakest link in the transformer insulation system.

Solid insulation gets mechanical damage due to movement of the transformer or forces generated during short circuits. Faults in insulating material may occur due to generation of $CuSO_4$ or hot spots created due to low quantity of oil or overloading of transformer.

E. Transformer Oil

Unused Oil *Degraded Oil*

The transformer oil provides insulation between windings along with desired cooling in the transformer. Transformer oil is a highly refined product from mineral crude oil and consists of hydrocarbon composition such as paraffin, naphthalene and aromatic oils. The failure of cooling oil causes due to two reasons either malfunction of the oil circulation or poor heat transfer to secondary cooling circuit. This leads to increased viscosity of the oil in the transformer and too high temperature in the second cooling circuit. Moisture and oxygen coupled with heat are the major cause of oil contamination leading to generation of conducting particles. Thereby temperature inside the transformer will rise and failure of oil insulation results in a short circuit.

F. Bushings

Bushings are used to take out the winding terminals outside the tank with electrical insulation to connect the transformer with the power system. The bushings used are generally two types slid bushings and capacitance graded bushing. The solid bushing has a central conductor and porcelain or epoxy insulation around it. The main failure mode of bushing is short circuit. It may be due to material faults in the insulation or due to damage. The damage can occur due to sabotage, during shipping or due to flying parts from other failed equipment. Damages, cracks in the porcelain and bad gaskets provide ingress of water inside insulation of the bushing leading to its failure.

4 TRANSFORMER FAILURE MODES

A transformer can fail due to combination of electrical, mechanical or thermal factors and it is always difficult to find out a particular mode of failure. Most of the transformers fails due failure of insulation. So the transformer may fail electrically due to failure of insulation which may be result from electrical, mechanical or thermal stress.

A. Electrical Factors

There are various electrical factors for transformer failures which can be broadly classified in to following three categories: Transient or overvoltage conditions; Lightening and switching surges; Partial discharge.

B. Mechanical factors

Mechanical factors result in damage to the transformer windings rupturing its solid insulation. If the damage is acute the transformer may fail electrically. Winding of transformer may rupture due to electromechanical forces or damage during shipping. The other reason for failure may be as given below:

- Electromagnetic Forces;
- Shipping of the transformer;
- Buckling of the innermost winding;
- Conductor tipping;
- Conductor telescoping;
- Spiral Tightening;
- End ring crushing;
- Failure of coil clamping system;
- Displacement of transformers leads.

C. Thermal Factors

The cellulose insulation of transformer degrades with time due to heat generation during normal loading of transformer. It results in decrease in dielectric strength of the insulation and weakens the insulation to rupture under normal voltage conditions. The other reasons for failure may be as given below:

- Transformer overloading for prolonged period;
- Operation of transformer on nonlinear loads;
- Failure of cooling system;
- Blockage of oil ducts;
- Operation of transformer in an overexcited condition;
- Operation of transformer in high ambient temperature.

5 RESEARCH METHODOLOGY

The action research entailed the following:

A. To analyze the guidelines being followed by distribution transformer repairers in the country

B. To study the guidelines being followed by DISCOMs for getting failed DTs repaired

C. Literature Survey - To study the international best practices/ papers/ journals/ international standards being followed for repair of DTs

A. To analyze the guidelines being followed by distribution transformer repairers in country/industry experts

Due to challenge imposed by the COVID-19 restrictions, the repairer active associations from Madhya Pradesh and Maharashtra were consulted through virtual mode (telephonically, email etc.). The following has been informed by the repairers:

Discussion Outcomes:

- *Tolerance on no-load losses*: Due to aging effects, the transformer core gets saturated and adverse effect of this saturation increase core loss in the transformer. Hence, a tolerance of 50% increase in no load losses may be allowed.

- *Tolerance on load losses*: There is high technical loss deviation in old DTs, compared to the manufacturing specifications; however, the repairers are expected to meet the manufacturing specifications after replacement of the windings. For meeting the desired specifications, repairer has to use more winding material which is uneconomical. Hence, a tolerance of at least 10% on total losses may be provided.

- *Analysis of Cause of Failure:* Distribution transformer may fail due to various reasons. The root cause of failure may be lacunae in manufacturing practices or inappropriate operation & maintenance practices. Analysis of causes of failure would help in taking corrective measures and thereby reducing costs associated with repairs/ replacement. For the purpose of analysis, it is necessary to identify nature of failure and entity primarily responsible for defect. It is proposed that a check-list for analysis of failure of distribution transformers may be prepared and the same may be provided to the repairer for each failed DT.

- *Nameplate details*: It is observed that the distribution transformers of lower ranges are normally repaired by utility's Special Maintenance Workshops. Generally a register is maintained in the workshop, and also history card is maintained by the Utilities for individual Transformer originated from the Stores from which it is issued for installation and travel along with the transformer for repairs until it is condemned as unfit for service. However, it is not being followed with practice of communicating the details about repairs carried out. In certain cases the percentage impedance 4.5 % got reduced to 3 % after repairs. It is noted that the coil wire sizes are changed and resulting changes in percentage impedance and goes out to field unrecorded from such repair shops of Utilities.

It is, therefore, recommended that the detail about the percentage Impedance may be brought to the right column of the original name plate and two more empty columns may be provided for first repair and second repair to enable at least punching the Z% after repair on appropriate column.

Further, a model name plate to be fixed by repairer may also illustrated in the Standard as an annexure to keep the uniform display by all repairing units.

- Conversion of Aluminum would transformers to Copper wound transformers may not be recommended for theft prone areas

B. To study the guidelines being followed by DISCOMs for getting failed DTs repaired

The DISCOMs in the country were requested to provide the guidelines/practices being followed by them for repairing of the failed distribution transformers and tolerance for no-load/load losses. Comments received from following DISCOMs are summarized below:

i) *Inputs received from BSES Yamuna Power Limited*

- A tolerance of 50% for No-Load Loss after repair may be provided
- Acceptance limit for Load loss after repair may be considered as +10%
- guidelines for re- utilization of used mineral oil, if possible, may be added
- Clear guidelines for the retro-filling of Natural Ester oil in breathing type transformers may be added.
-

BYPL has also prepared documents on Repairing Process of DT's and Testing Process of DT's which incorporates process flow approach chart which may be included in the Indian Standard on the subject.

ii) *Inputs received from Bangalore Electricity Supply Company Limited (BESCOM)*

- A tolerance of 5% to 10% may be provided on total losses of the repaired transformers due to handling factors etc.

iii) *Inputs received from BSES Rajdhani Power Limited*

- No positive tolerance allowed in the load losses
- No-load losses also remain unchanged since the original core is reused

BRPL has also prepared documents on Repairing Process of DT's and Testing Process of DT's which incorporates process flow approach chart which may be included in the Indian Standard on the subject. BRPL has also formulated Technical specifications for repair of damaged/failed oil filed distribution transformers.

iv) *Inputs received from Kerala State Electricity Board (KSEB)*

- A tolerance of 50% for No-Load Loss after repair may be provided
- A +10% tolerance of the original loss limit as per IS may be given for Copper/load losses after repair, so as to ensure that the electrical characteristics of newly wound coils of the repaired transformers are same as that of the old one.

v) *Inputs received from Madhya Pradesh Poorv Kshetra Vidyut Vitaran Co. Ltd., Jabalpur*

- Loss tolerance may be given on account of ageing of transformers.
- Without knowing the original no-load loss, it is difficult to assess the condition of the core in the used transformers.
- Except worst condition transformers should not be scrapped.
- The tolerance on no load current which is not defined & decided in IS 1180 (Part l): 2014, it is not appropriate to prepare draft on the basis of the same IS because it will effect total losses at 50% & 100% loading.

vi) *Inputs received from Madhya Pradesh Paschim Kshetra Vidyut Vitaran Co. Ltd., Indore*

M.P.P.K.V.V.Co.Ltd., Indore, at present, meet out 25% requirement of distribution transformer by procuring new transformer as per latest IS and remaining 75% by repairing of failed transformers. In this way we are maintain our financial burden. By getting repairing of DTR it would be more economical than procurement of new DTRs. It is further stated that we are repairing about 35000 no.

- Without knowing the original no-load loss, it is difficult to assess the condition of the core in the used transformers
- A tolerance of 50% for No-Load Loss after repair may be provided
- It is very difficult to maintain name plate details and technical details (digital image etc.) of repaired transformers as we are repairing more than 35000 units every year.

vii) *Inputs received from Tata power – Delhi Distribution Limited*

- Tolerance on no-load losses should be less than 10% of the original losses
- To include repairing criteria/matrix for any transformer according to age, economic limit and technical feasibility before repair
- To include flux density, current density etc.
- Conversion of AL wound to Cu Wound transformer is not recommended for theft prone and remote areas
- In general ratings above 400 kVA transformers should be wound copper winding only.

Tata power – Delhi Distribution Limited has formulated specification for repairing of failed distribution transformers.

C. Literature Survey - To study the international best practices/papers/journals being followed for repair of DTs

i) EASA AR200 Guide for the repair of Power and Distribution Transformers

Electrical Apparatus Service Association (EASA), Inc. has published a Guide for the repair of Power and Distribution Transformers. This document provided guidelines for each step of the repair of power and distribution transformers. This document describes record keeping, tests and analysis and general guidelines for the repair of power and distribution transformers.
This document covers repair guidelines for both liquid immersed distribution transformers and dry type distribution transformers.
There are 05 sections and 03 Appendix in this document namely:

Section 1	This section specifies general requirements which include identification of the failed transformer, condition assessment and failure investigation, cleaning of the transformers, packaging and transportation
Section 2	This section includes many tests that can be performed on a transformer to assess the condition of the transformer and to verify repair results and adequacy of design.
Section 3	This section specifies rewinding process which has three components: the investigation of the failure, gathering data for the new coils and the actual winding of the new coils.
Section 4	This section specifies requirements for verifying suitability, overhaul, and rewind or other major component replacement for dry type transformers.
Section 5	This section specifies requirements for verifying suitability, overhaul, and rewind or other major component replacement for liquid filled transformers.

Appendix A	This appendix specifies the safety considerations for electrical testing including requirements for personnel safety and safety of the test area, units under test and test panels.
Appendix B	This appendix provides reference information such as temperature correction factors for insulation resistance tests, temperature correction factors for insulation power factor tests for liquid filled transformers, various winding connections for a phase sequence test, and recommended test levels for new windings for both dry and oil filled equipment.
Appendix C	This appendix gives information regarding replacing aluminum conductor with Copper conductor giving characteristics of both the materials.

It may be noted that the EASA specification doesn't specify requirements for repairing of amorphous core based distribution transformers which are covered under IS 1180 series.

ii) Paper on Impact of Inspection Strategy on Repairing Cost of Distribution Transformer

This paper primarily focuses on how exterior and inside inspection procedure matters of overall repairing cost of DISCOM. Generally External inspection done as failed transformer comes at divisional store. Then it will send to repairing company then Internal Inspection carried out by the Inspection team. The External and Internal inspection is very important as per as cost and reliability of distribution transformer is a concern. The proper inspection procedure will definitely reduce the cost of per transformer and over all repairing expenses of DISCOM:

External Inspection: External inspection mainly concern with the Oil, bushing, any kind of leakage on the body of the transformer, Breather. Examiner engineer should observe and check transformer very carefully and make an external report based on all the Outer peripherals of the transformer.

Internal Inspection: It is compulsory to lock transformer with a seal by the concern authority before sending transformer at repairing company. This may protect the transformer to attain any unauthentic operation. Check oil of all transformers by the repairing engineer in the presence of inspection team. This is also verified with the External inspection report. External inspection carried out again for verifying. Then dismantle all transformers to be inspecting of internal inspection. All HV Damage coils must be impaired by the repairing engineer in the presence of the inspection team. This may avoid reprocess of the damaged HV coil. The weight of the coil should be measured very carefully as it increases the cost of repairing.

iii) Paper on Technical Loss Reduction through Active Repair of Distribution Transformers: Results from the field

Active repair of DTs is a method that primarily focuses on technical loss reduction in DTs through winding compensation, including any change in winding material. The core is left unchanged as different makes of DTs will require different laminates design and cuts and that would not be an easy and replicable repair methodology. Active repair can be carried on both the breakdown as well as functional legacy DTs. Case studies as published in this paper shows for a sum total savings of 1838 kWh/year compared to baseline losses and payback of 6.26 years for 100 kVA transformer and a sum total savings of 5476 kWh/year compared to baseline losses, and payback of 3.97 years for 200 kVA transformers.

iv) Losses and payback period analysis for 100 kVA transformer done by Madhya Pradesh Madhya Kshetra Vidyut Vitaran Co. Ltd. (MPMKVVCL), Bhopal

MPMKVVCL, Bhopal has done a losses and payback period analysis for Energy Level-2 and Energy Level-3 100 kVA, aluminum wound CRGO core distribution transformer in comparison with repaired Star 1 non-BIS distribution transformer along with different categories such as transformers installed for residential, market/commercial, office use and industrial purposes. Details of study are given below:

LOSSES AND PAYBACK PERIOD ANALYSIS FOR ENERGY LEVEL-2 AND ENERGY LEVEL-3 100 KVA (Aluminium wound CRGO) DTR IN COMPARISON WITH REPAIRED (STAR-1 NON BIS DTR) DTR ALONG WITH DIFFERENT CATEGORIES

PAYBACK PERIOD

CATEGORY OF DTR	GROUP	AVG LOADING	DAYS	REPAIRED DTR WITH TOLERENCE		ENERGY LEVEL -2 DTR		ENERGY LEVEL -3 DTR		DIFFERENCE OF LOSSES IN AMOUNT OF LEVEL-2 DTR W.R.T. NON BIS REPAIRED DTR (IN RUPPEES)	DIFFERENCE OF LOSSES IN AMOUNT OF LEVEL-3 DTR W.R.T. NON BIS REPAIRED DTR (IN RUPPEES)	PAYBACK	
				TOTAL LOSSES IN UNIT	TOTAL LOSSES IN COST IN RUPPEES	TOTAL LOSSES IN UNIT	TOTAL LOSSES IN COST IN RUPPEES	TOTAL LOSSES IN UNIT	TOTAL LOSSES OF AMOUNT IN RUPPEES			FOR LEVEL-2 DTR	FOR LEVEL-3 DTR
RESIDENTIAL	1	14	151	535	2139	335	1340	332	1327	799	812		
	2	23	122	1119	4475	702	2807	696	2783	1668	1692		
	3	19	92	794	3175	500	1999	496	1985	1176	1190		
TOTAL		19	365	2448	9789	1537	6146	1524	6095	3643	3694	36	39
MARKET/ COMMERCIAL	1	11	89	685	2738	434	1736	433	1732	1002	1006		
	2	13	93	734	2936	465	1858	463	1852	1078	1084		
	3	15	123	985	3941	623	2492	621	2483	1449	1458		
	4	20	60	504	2016	318	1271	316	1264	745	752		
TOTAL		15	365	2908	11631	1840	7357	1833	7331	4274	4300	31	34
OFFICE USE CATEGORY	1	2	120	879	3517	303	1213	303	1212	2304	2305		
	2	3	153	1029	4115	715	2859	715	2859	1256	1256		
	3	5	92	680	2722	432	1730	432	1729	992	993		
TOTAL		3.33	365	2588	10354	1450	5802	1450	5800	4552	4554	29	32
INDUSTRIAL	1	8	365	2799	11198	1775	7101	1772	7087	4097	4111		
TOTAL		8	365	2799	11198	1775	7101	1772	7087	4097	4111	32	35

DGM (R&D CELL)
O/o. MANAGING DIRECTOR,
M.P.M.K.V.V.C.L., BHOPAL, M.P.

Manager (R&D)
MPMKVVCL, BHOPAL

iv) Several national reports published by **Central Electricity Authority (CEA) on Code based failure analysis system of distribution system**, **Forum of Regulators on best practices and strategies for distribution loss reduction**, **Powergrid report on transmission and distribution in India** were studied with respect to distribution network and its associated challenges like transformer failure, loss reduction, fault identification etc.

6. RECOMMENDATIONS

When a distribution transformer fails, generally the focus of the DISCOM is to get it functional and put it back into the network, without much focus on the quality of repair. The poorly designed rate contracts and unavailability of failure analysis report/manufacturing specifications of the failed DT can push repairer to resort to using low quality materials and non-scientific repairs. Also, the DT repairer community is not very knowledgeable and do not follow the best practices. The equipment used for losses measurement or estimation are also not well kept and updated for accuracy. And in absence of any standardized guidelines, the failed units are repaired based on the practical knowledge of the workers who are sometimes not even qualified to be appointed for the task.

Based on the above information, it is recommended to have an Indian Standard on the subject ‘Guidelines for Repair of Distribution Transformers’ which will address the above highlighted issues and challenges faced by the DISCOMs and the repairers in the country. It is proposed that standard must cover the following important requirements and criteria for ensuring good quality of the repaired transformers:

- Clause on recordkeeping should be included in the standard as this will ensure that data is available with the utilities
- Clause on investigation/ analysis of failure of transformer should be added
- Repairing process for each type of transformer viz. dry type or liquid filled type, CRGO core or amorphous core should be specified step by step for easy understanding of the repairers
- Requirement for instrument calibration should be made compulsory
- Tests to be done after and before repair should be specified clearly and acceptance parameters should be defined
- A clause on evaluation of loss reduction in repaired transformers may also be added based on the survey details available at sl. 5(iii) and 5(iv) above.

Considering the above recommendations and incorporation of the requirements mentioned in the report, a working draft has been prepared which is enclosed at Annex I.

7 REFERENCES

1. *Central Electricity Authority (CEA)* “Guidelines for distribution utilities for development of distribution infrastructure published”
2. *Power Grid Corporation of India Limited* “A report on Transmission and Distribution in India"
3. *Punjab State Electricity Board* “Manual on damaged transformers”
4. *EASA AR200* “Guide for the repair of Power and Distribution Transformers”
5. *Shri Nirav J Patel, Shri Nikunj J Dhimar, Shri Pratik D Solanki and Shri Jay A Patel* “Impact of Inspection Strategy on Repairing Cost of Distribution Transformer” in Asian Journal of Electrical Sciences
6. *Shri Manas Kundu, Shri Samir Jadhav and Shri Kunjan Bagdia, pManifold Business Solutions* “Technical Loss Reduction Through Active Repair of Distribution Transformers: Results from the field”
7. *Shri Jaspreet Singhand, Shri Sanjeev Singh* “Transformer Failure Analysis: Reasons and Methods” in ACMEE - 2016 by International Journal of Engineering Research & Technology (IJERT)
8. *Forum of Regulators* “Best practices and strategies for distribution loss reduction - Final report”
9. *Madhya Pradesh Madhya Kshetra Vidyut Vitaran Co. Ltd. (MPMKVVCL),* Bhopal **“**Losses and payback period analysis for 100 kVA transformer”

ANNEX I

Draft Indian Standard

GUIDELINES FOR REPAIR OF DISTRIBUTION TRANSFORMERS

1 SCOPE

1.1 This Indian Standard covers general guidelines for the repair of distribution transformers along with requirements for tests, analysis and record keeping.

The guidelines given in this code applies to all distribution transformers received for repair, such as stacked-core/wound-core with conventional core steel or amorphous core; three phase liquid-immersed (mineral oil/ester fluid) distribution transformers up to & including 2500 kVA, 33 kV, three phase dry-type distribution transformers up to &including 3150 kVA, 33 kV and single-phase liquid immersed and dry type distribution transformers up to & including 100 kVA, 33 kV as per IS 1180 series.

This standard does not apply to transformers excluded from the scope of IS 1180 series.

1.2 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 & radiators/fins, number of times repairundergone in past; life of transformer; load tests, winding tests,core conditionetc.

1.3 Repair activities may broadly be classified as:

1.3.1 Minor repair work involvesfailure of parts such as external to windings, 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.

1.3.2 Major repair work involves change of coilsthat have failed electrically or due to mechanical forces andchange of a few laminations or complete core, change of tank.Rating can be enhanced by increasing cooling by adding radiator.Sometimes damage/deformation of tank and its paintwork shall also be involved which is a major repair activity.

1.3.3 Another type of important repair activity is overhauling/rehabilitation of transformer which involveschange of gaskets; change of oil if parameters do not meet relevant standards; internal cleaning; tightening of core-coil assembly; and repainting and re-servicing of fittings and accessories or replacement of accessories.

1.3.4 Reduction of transformer losses to make it energy efficient by change of design like increase of number of turns etc, while rewinding. Transformer winding may be redesigned & replaced with higher conductivity material-based windings to equalise as far as possible with the efficiency level of new transformers and increasing overload capability.

1.3.5 Retro-filling with ester fluids is another kind of minor repair activity which helps to increase life of the transformer, its overloading capability, and makes it eco-friendly and fire-safe which can be done at site too.

Thiscodeof practice defines general guidelines for all kinds of repair work indicated above.

2 REFERENCES

2.1 The following Indian standards are necessary adjunct to this standard.

IS Number	***Title***
2026 Part 1 : 2011	Power Transformer Part 1 General Requirements
1180 (Part 1) : 2014	Outdoor/indoor type, oil-immersed distribution transformers up to and including 2,500 kVA, 33 kV Part 1: Mineral oil immersed
1180 (Part 2) : 2021	Outdoor/indoor type, oil-immersed distribution transformers up to and including 2,500 kVA, 33 kV Part 2: Natural/Synthetic Esterimmersed
1180 (Part 4) (*under preparation*)	Outdoor/indoor type distribution transformers up to and including 3,150 kVA, 33 kV Part 3:Dry type
1885 (Part 38)	Electrotechnical Vocabulary: Power Transformers and Reactors

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 2026 (Part1), IS 1180 (Part 1), IS 1180 (Part 2), IS 1180 (Part 3) and IS 1885 (Part 38) shall apply.

4 GENERAL

4.1 Identification

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

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

4.1.1 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 utility or it's repair vendor may have different systems like log book or electronic data processing.

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 by the engineer 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 & 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.

4.1.2 Name-plate

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

4.1.3Service Centre Labels

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

4.2 Assessment/Investigation for failure of Transformer

Upon receiving a damaged transformer, the service centre should follow the processgivenbelow:

a) promptly inspect and test the transformer to identify the problem as per the service order& 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)
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 inspectionfor further analysis
g) During *physical inspection*, cautiously note in as much detail as possible - the position of all operating mechanisms, indicating devices, signs of physical damage (if visible), manufacturing defects, transportation defects, etc.
h) Once the visual inspection and physical damage assessment are complete, test the transformer for its electrical integrity

NOTES

1 Vital test parameters for conforming a transformer's electrical integrity are described in Section 8 of this code.
2 Coil removal procedures are enlisted in Section 6 of this code.

4.3 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 advisableto clean transformer tanks and enclosures to avoid contamination of the core and coil assemblies oncethey 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. Local environmental regulations must be followed and the effects of the cleaning agent upon the insulated components should be known before proceeding.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.

4.4 Terminals

4.4.1 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 name-plate or as per relevant Indian Standards/International Standards. A lead should have the correct temperature, voltage and current rating for the application and should be capable of withstanding elevated temperature experienced during the repair process. Broken or damaged lead shall be replaced.

4.4.2 Connectors

Connectors are electrical terminalsof 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 mustbe 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 recommendations of the connector manufacturer, while repair connectors shall be replaced with same material of metal part.

4.4.3 Enclosures

Transformer terminals are often enclosedwithin metal enclosuresor cable box for enhancing safety measures. The integrity of such 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.

4.5Accessories

All accessories,which may have been removed during disassembly (e.g. temperature gauges, pressure relief devices,bushing, liquid level gauges, cooling fans, gas relays, current transformers, sudden pressure rise relays, etc., and any associated wiring), should be re-checked and validatedto be complete and operating correctly before being returned to service. Replacement bushings should be similar to the original in design; have proper current rating; have Basic Impulse Level(BIL), and 50 Hz test levels higher than the windings to which they are connected.All the components must be safely kept and reinstalled before delivery.

4.6 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 paint the whole tank inside & outside, radiator damaged or blocked for circulation can be replaced, radiator or enclosureas stipulated in section 9. It is recommended that oncompletion of repairs,the radiators (and tank) be pressure tested, if possible, as outlined in Section21.5 of IS 1180.

4.7 Recommended list of equipment

For facilitating basic qualitative repair of DT, the repairer shall have certain basic reapr and test equipments as listed in Annex ....

5 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: the investigation of the original failure, gathering physical data for the new coils, and the actual winding of the new coils. However, for improved performancelike reliability or capacity enhancement including energy performance a modifiedwinding design towards augmentation, as indicated in annexure A, may be implemented depending on the condition & data of the existing core & tank. It is recommended to replace all windings &insulation of conductor with higher insulation class material to get enhanced thermal capability.

5.1 Investigation

The rewinding process starts with the investigation of the failure that necessitated the rewind. Information gathered may provehelpful when rewinding the coils so that subsequent failures can be avoided or delayed. Some of the features that should be looked for aresigns 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 such as those described in Section8 can be used to determine the nature and location of the failure. It is recommended to carry out no load test at rated voltage with healthy LV/dummy LV turns to ensure that the no load losses do not exceed 1.5 times the original no load losses measured as per IS 2026 (Part 1). In case, if no load losses exceeds 1.5 times the original no load losses, the transformer should be redesigned or transformer core to be scrapped.

5.2 Data Collection

From the earlier collected data, i.e. during the core and coil assembly, from name-plate and by removing the individual winding coils following information can be obtained and should be properly recorded:

a) Name-plate data
b) Basic coil design(cylindrical, spiral wound or disc)
c) Physical dimensions of the coils
d) Electrical clearance dimensions, phase-to-phase and phase-to-ground
e) Number of turns
f) Direction the coils are wound
g) Tap locations (physical and electrical)
h) Insulation material
i) Size of conductor (LV & HV)
j) Number of conductors in parallel
k) Conductor/foil material: Copper /Aluminium
l) Resistance of each coil
m) Special features such as extra supports, tying, main lead lengths, etc.
n) Stacked core or wound core; in case of wound core whether CRGO or amorphous
o) Measure core dimensions: In case of stacked core, measure width and thickness of each packet
p) Grade of steel used to be found from supplier or by loss measurement
q) Type of liquid used for liquid-immersed transformer: mineral oil or ester fluid or silicone oil
r) Measure electrical and chemical properties of the liquid including DGA and Furanic Compounds, if applicable
s) Loading cycle of transformer and maximum temperature rises
t) Physical weights of CCA before & after- if possible, core weights & coil weight separately.

5.3 Coil Winding

Coil winding should be carried outin a clean environment using a winding formerbuild for the particular coil being wound. The winding former can eitherbe 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 Section 5. Attentionshould begiven to the size of cooling ducts, wire compaction and tension, tap locations, crossovers, connections, tightness of winding, uniformity in winding & 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) cleaned to ensure no sharp edges which isseparately insulated. Care mustbe taken to minimize the insulation build. Once the coil is complete, the physical dimensions and resistance should be checked. Coils for liquid immersed will be dried for shrinkage &Coils for dry-type transformers are dried and vacuum impregnated with suitable impregnant material. Cast coils will undergo casting process (Encapsulation).

5.4 Core Laminations

Cores are generally stacked cores or wound cores.The process of disassembly and assembly of the stacked and wound cores are describedinSections5.4.1 to 5.4.6.

5.4.1 Disassembly of Stacked Cores (CRGO)

Core to be cleaned after removal of windings and an accurate dimensionalsketch of the core cross-section should be made prior to disassembly because the cores are often other than rectangular or square cross-sections. In addition, the number of stacked togetherlaminations 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.

5.4.2 Assemblyof Stacked Cores&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 tocentre the coils and secure them to the core. During assembly of the yoke, Core to clamp insulation can be replaced, 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) shouldalso be conducted to eliminate possibility of any shorted turn.

5.4.3Disassembly of Wound Cores (CRGO)

Woundcores 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 easierto achieve proper assemblyif fewer laminations are removed. When laminations are removed, they should be well supported and stored in a clean, safe location.

5.4.4 Assembly of Wound Cores & 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, i.e. 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 Section5.4.2, the coils should be tested at this point to ensure the proper ratio and the correct electrical location of the taps.

5.4.5Disassembly of Amorphous Wound Cores

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

1. Since, the preferred position of core joints is at the bottom in the final transformer assembly, so, the core coil assembly should be upended (inverted). This places the core joints at the top. 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.
4. 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.

5. 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.
6. Same procedure shall be repeated for other limbs.Thedamaged coil is then carefully removed with suitable lifting arrangement and placed on aclean surface.
7. Amorphous materialbeing brittle, chances of breakagescannot be eliminated but can be minimised to maximum extent by careful handling.
8. Core weight before & after shall be monitored for adequate performance.
9. Disposal of broken pieces & scrap of amorphous metal shall be done as per local law of land.

5.4.6Assembly of Amorphous Wound Cores

Prior to assembly following steps shall be followed:

1. 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.
2. 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.
3. After lacing, the core packetsare closedand locked with outer CRGO, same as before.
4. Core joints are covered using the insulation paper to contain amorphousflakesin place, if any.
5. Appropriate insulation is provided,and the steel core clamping structure is put in place.
6. 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.
7. Relevant tests like magnetic balance test, turns ratio and correct electrical location of the taps, insulation test to be performed.

5.5Connections& Joints

There are essentially two connections that should be made while winding and connectionsexternal to the winding. All connections should be carefully prepared, cleaned to ensure no sharp edges or burr & also ensure mechanical and electrical integrity.

5.5.1Connections in the Winding

There are severalmethods of making joints and splices, and the onesdescribed 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 consumeless space. Jointing being special process to 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 Section5.5.3. If the coils contain wire that is smaller than (3.2 Sq.mm), splices within the winding should be avoided. 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.

5.5.2External 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 mustbe 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.

5.5.3Insulating 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 creepage 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 will not fall off during processing or in service. In addition, suitable sleeve is usually installed over any wire that extends beyond the coil.

5.6Leads& 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 due to submergence 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.

5.7 **Final assembly of transformer (After repair)**

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

Dry type transformers normally assemble in ventilated or non-ventilated enclosure as with relevant ingress protection & offered for routine test after complete accessories & gaskets fitting.

The final assembly operations to repair a liquid-filled transformer needs more attention & care has to be taken like,

a) Ensure dryness, cleanliness of tank& prepare tank with all new gaskets of suitable material, accessories, assemble metal parts & bushings as per design.
b) Core coil assembly to be dried in oven to ensure required PI value so that water contain in insulations is optimum possible level. Insulation resistance test & polarisation index ratios are often used to qualify these criteria.
c) Tank the core coil assembly & complete all connections & joints at minimum possible time to reduce exposure of dried windings to atmosphere.
d) Complete the impregnation process by dieletric fluid as per fluid manufacturers guideline.
e) Allow transformer to settle for minimum 4 hours & offer for testing.

Final assembly like tanking &impregnation sequence can be vice versa depending on manufacturers facility & customers requirement-

6 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 & impregnation process. Much of the additional work required relates to the dielectric fluid and the tank.Retro-filling, as indicated in Annexure B, is a minor repair activity which helps to increase life of the transformer, its overloading capability, and makes it eco-friendly and safer from fire safety point of view.

6.1*Checking for Service Suitability*

All name-plate data should be recorded on the service order form as described in Section4.1.1. If applicable, the PCB concentration should be verified.

6.1.1Tests

Recommended that following tests should be performed—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.

6.1.2Equipment Checks

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

6.1.3Summary of Results

As described in Section 4.1.1, 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.

6.1.4Preparation for Shipment

The transformer should be painted according toSection9. 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 toSection10.

6.2 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.

6.2.1 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 oil samples for PCB analysis, quality analysis, gas-in-oil analysis, and furan analysis (see Section 8.5.6).

6.2.2 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&silicon fluid). This will help in preventing oil contamination by other substances. The PCB concentration should be checked beforecommencing any draining procedures. When draining the oil from a damaged transformer, thecontaminants 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 filled transformers, core coil shall be cleaned with normal mineral oil & stretch wrap with polyurethane film to avoid thin film polymerisation if any.

6.2.3Major Inspection and Tests

Underwell-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 test on the paper. The results listing the deficiencies, recommendations and repair costs should be provided to the customer. The customer may choose to repair & retro-fill only the most critical deficiencies or enhanced repairing for better asset life. These should be repaired along with "standard" repairs listed by the service centre as part of the overhaul.

6.2.4 Cleaning and Repairs

All components are cleaned using appropriate methods for each item. The core and coil assembly are flushed using mineral oil at very low pressure. The tank, cover, conservator, control boxes and bushing terminal boxes should be sandblasted and thoroughly cleaned. Forlarger 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. 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 replacedwith materials resistant to deterioration by transformer oil/fluid. The coil should be processed & cleaned to remove particulates, gases and acids. Alternatively, it can be replaced with new fluid like ester. Once all the repairs have been completed, the unit can be reassembled.

6.2.5Reassembly

Reassembling the transformer starts with drying the core and coil assembly. Ester filled transformer core coil assembly needed to be dipped in hot mineral oil (60^0C) or cleaned with minimal oil pressure before putting in oven.This is best accomplished by placing the coreandcoils into an oven where the temperature does not exceed 95°C. Dissipation factor measurements to determine when the insulation is dry can be taken during the drying cycle. 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 & oil socked scrapped to be disposed as per local land of law.

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. Some of OEM may put core coil assembly along with tank in to oven as per their procedure & facility which is acceptable. The tank is then quickly filled with oil (preferably under vacuum)to the top of the transformer core to ensure all insulating material is submerged under dielectric fluid. The oil 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 oil level gauge. The security of all joints is confirmed by pressurizing the transformer tank with approximately 3 psi of dry air and inspecting all joints for leakproof connections. If time permits, the transformer should remain pressurized 12 hours and the pressure should be checked in the morning. Mask all bushings, gauges and valves, and paint the unit as described in Section9.

For natural ester ensure adequate sealing of transformer as recommended by fluid supplier.

6.2.6Final Tests

The following tests are recommended on the transformer—insulation resistance core-to-ground; insulation resistances between each winding and between each winding and ground; magnetic balance test; turns ratio test; phase relation check or polarity check; winding resistance; open circuit core loss; copper loss; AC high-potential test for HV and LV windings; and an induced potential test. All tests are described in Section8. Once all tests are complete, oil samples should be taken for gas-in-oil analysis and quality assessment. The results confirm that no internal problems occur during testing and form a record for comparison with future test results.

6.2.7Packaging and Shipment

The transformer can be prepared for shipment as described in Section10.

6.3Rewind

On receipt of the unit, record the necessary information and establish documentation as outlined in Section 4.1.1.

6.3.1Inspection and Test

If a fault initiated the need for a rewind, investigation should be carried out as described in Section 5.1. The core and coil assembly should then be removed as described in Section 6.2.2. Once the coreand 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.

6.3.2Dismantle(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 Section5.4.1.

At this point, some of the data listed in Section5.2 should be recorded. To free the coil from the core, all blocking between the core and the ground insulation should be removed. Using suitably fashioned lifting hooks, the coils can be carefully lifted from the core limbs. 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.

6.3.3 Winding New Coils

Winding the new coils should be carried out as described in Section5.3.

6.3.4 Reassembly

The coils are set on the core limbs using the same equipment used to remove them. The core is then assembled according to Section5.4. If the transformer has a wound core, the core should be placed in and around the coils as described in Section5.4. 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 form 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.

6.3.5 Final Tests

Once the transformer is fully assembled, the unit is tested to ensure that the repair was successful and to provide a record of the transformer condition after the repair. Recommended tests are—magnetic balance test; ratio check , phase relation and polarity check, winding resistance, insulation resistance, winding tangent delta test; AC high voltagetest, induced overvoltagetest, core loss test and copper loss test. All the tests have been previouslydescribed in Section6.2.6

6.3.6 Shipment

The transformer is prepared for shipment according to Section10.

7 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:

7.1 Checking for Service Suitability

All name-plate data should be recorded on the service order form as described in Section 4.1.1.

7.1.1 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.

7.1.2 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.

7.1.3 Summary of Results

As described in Section 4.1.1, 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.

7.1.4 Preparation for Shipment

The transformer should be painted as described in Section 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 Section 10.

7.2 Overhauling

Overhauling requires more work than that described in preceding sections. The purpose of overhauling is to 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. The enclosure maybe sand blasted before painting to achieve a better result.

7.3 Rewind

Upon receiving the unit, proper records should be setup and necessary information should be recorded as outlined in Section4.1.1.

7.3.1 **Inspection and Test**

If the rewind was initiated by a fault, an investigation should be carried out as described in Section 5.1.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.

7.3.2 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. Storing of top yoke should take place as described in Section 5.4.1. The laminations should be well supported.

At this stage, the data for items listed in Section 5.2 should be recorded. The coils can be removed nowfrom the core by first removing all blocking between the core and the coil ground insulation. Using suitably fashioned lifting hooks, the coils can be lifted from the core limbs. 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 lathe, unwound and the remaining data can be obtained through measurement. Depending on coilconstruction, one may be able to separate the HV and LV windings and replace the affected coils.

7.3.3 Winding of New Coils

Winding the new coils should be carried out as described in Section 5.3. In case of epoxy cast coils, if found faulty, they should be replaced by new ones .

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 Section 5.4.2. 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 Section 5.4. 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 & HV winding shall be maintained. On wound core units, 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 VPI & Mechanically sturdy connection in case of cast resin dry type 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 (TTR), phase relation and polarity check, winding resistance, insulation resistance& PI, ac or dc high potential test, induced potential test, core loss test and copper loss test. Optional tests that may be carried out are power factor, recovery voltage and dc step voltage. All these tests have been described in greater detail in Section 8.3.

7.3.6 Shipment

The transformer is prepared for shipment according to Section 10.

8 TESTING

There are varioustests that can be performed on a transformer. Some of these tests are used to assessthe condition of the transformer while others are used to verify repair results or adequacy of design.

8.1 Safety Considerations

Handling and testing of any electrical apparatus or component can be hazardous, and transformers are no different. Considering the bulky size and huge voltage potentials under consideration, proper safety measures must be ensured. Items regarding safety of personnel, training, and equipment requirements are presented in AnnexureC of this standardcode.

8.2 Instrument Calibration

Accuracy becomes very important if tests are carried out to confirm performance characteristics. Each instrument requires thattest results be calibrated at least annually against standards traceable to the Bureau of Indian Standards (BIS) or other relevant national NABL accredited laboratories. In addition, the test equipment should meet the accuracy requirements as perrelevant Indian standards, if any

Each instrument, used for test and validation, should bear a mark or label verifying calibration. If high importance is attached to the test results, the instrument should be calibrated immediately before and after the completion of the test procedure. In some cases, a calibration curve might be useful.

8.3 Insulation Condition Tests

Assessmentof the condition of Insulation is fundamental to transformer operation. One or more of the following tests should be performed to gain information about the insulation system. Note that trending 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.

8.3.1Insulation 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 fromground. 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, i.e., a meg-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

Winding Voltage Class (kV)	**Insulation Test Voltage(dc)**
1.1	1,000
3.3–11.0	2,500
22–33.0	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 AnnexureD. Test voltage are 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 the absence of this information typical values as given in Table 2 shall apply. 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

Winding Voltage Class (kV)	**Insulation Resistance (MΩ)**
1.1	600

3.3 6.6	1,000 1,500
11.0	2,000
22–33.0	3,000

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

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

where,

R = the minimum insulation resistance in MΩ
C = 1.5 for transformers at 20°Cand 30°C 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
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)

Moisture generally affects the insulation resistance for 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.

8.3.2Polarization Index Test

This is an extension of the one-minute insulation resistance test described in 8.3.1, 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 10minutes. Resistance measurements are recorded after one minute and ten 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.

8.4 Other Tests

There are other tests that can be performed on a transformer to assess its condition. These testsdonot test the insulation system directly but provide meaningful information about the other components.

8.4.1Winding 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 as also the winding temperature should be measured. The resistance value can be corrected to a common temperature using the relationship:

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

And,

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

where,
ref = reference temperature
t = test temperature at which the values were obtained.

8.4.2 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 0.5percent

Table 3: Common TTR Responses and Associated Transformer Condition

TTR Reading	Condition
Low current and no output volts	Open turn in the excited winding
Normal current, output voltage low or unstable	Open turn in output winding
High current and difficulty balancing the bridge	High resistance in test leads or tap charger

8.4.3 Polarity Test

This test can usually be performed with the TTR metre described in Section8.4.2. 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.

8.4.4 Phase Sequence Test

This test is used to determine the phase relationships between the high-voltage and low-voltage 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 AnnexureD.

A low amplitude (120 Vor 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.

8.4.5 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 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.

8.4.6 Single Phase Low Voltage Excitation Test

This test can be used at regular intervals over the life of a transformer. By comparing the test data from one test to another, one can monitor the condition of the transformer. The test can also be used as a diagnostic tool when troubleshooting transformer failures.

A single-phase 50 Hz test voltage of 10% of the rated voltage is applied to the HV winding. For star-connected transformer, the test voltage is applied in turn between the high voltage terminal and the neutral. For delta-connected transformers, the voltage is applied between the high voltage terminals in turn and the third terminal is grounded. It is important to ensure the polarity of the test leads is the same for all tests. The current, voltage and watts are recorded.

When testing single phase transformer, the voltage is applied to high voltage terminals twice. The second time the test leads are reversed so that the originally on U1 is placed on u1,etc., the two currents should agree within 10percent.

For three-phase transformers, the current through the coil on the centre leg of the core will be somewhat less than the currents in the other two phases. The currents on the outside two pages should be within 15% of each other, and values for the centre leg should not be more than either outside leg. In all cases, results from one test to another should agree within 5percent.

8.4.7 Load Loss 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-wattmeters. The usual method is to short circuit the LV winding and energizes the HV winding on the 100 percenttap 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 are copper losses; the core losses can usually be neglected unless the impendence of the transformer is unusually high. In the latter case, the core losses can be measured at the exciting voltage used to obtain the copper losses and subtracted from the value initially recorded. It is also important to ensure in this test thatthe method used to short circuit the LV winding does not appreciably change the resistance of the LV circuit; otherwise, the measured losses will be affected. The conductors used to make the short circuit connection should have a current-carrying capacity equal to or greater than that the corresponding transformer leads.

Tolerance in load losses : To be discussed

8.4.8Single-Phase Impendence Test

This test is used to perform impedance tests on single-phase or three-phase transformer windings using reduced current. The test results will not match factory test results but are particularly useful on three-phase transformer where one expects all three phases to be the same within 2percent. The key item when performingthis test on three-phase transformers is to establish single-phase flux paths in the core when testing each phase. The secondary windings are shorted for the test, then a single-phase voltage is applied to each phase, one at a time, and the current measured. The impedance can be calculated from the following formula:

$$\%Z = (1/50) \times (E_{12}/I_{12}+E_{23}/I_{23}+E_{31}/I_{31}) \times (kVA_{3phase}/kV^2_{LL})$$

Note: *The E subscripts of the above formula identify the lead numbers of the phases under test.*

TheIsubscripts identify the leads associated with the voltage being applied, e.g., if voltage is applied to leads 1 and2, the current will be that of lead 1 or lead 2.

The LL subscript denotes line-to-line.

8.5Applied Voltage Tests

To confirm that a particular transformer or accessory can withstand the electrical stresses in service, it is subjected to a high-voltagetest. 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-voltagetests 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.

*8.5.1*Separate Source*Voltage withstandTest*

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 75percent of the test value in 5 to 10 seconds and the rate of rise from there on is 2to 3 percent of the test value per second. The test value is maintained for one minute, and the voltage smoothly but rapidly decreases 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.

8.5.2High Frequency Induced Over-VoltageTest

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 to200 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 appliedto 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.

8.5.3 Test Levelsof Windings

Test level for transformer windings vary depending on the type of transformer and the voltage class. The ratings and drawings (R&D) plate test values should be used. If R&D plate or the manufacturer's information is not available, please refer IS 1180 (Part 1) and IS2026 (Part 3). If the equipment has been overhauled or is being checked for suitability of service, values not less than 80percent (*what should be the value 65 or 80 % ??)*should be used. If all the HV & LV windings are replaced, then testsshall be done at 100 percent values. Values are shown for both liquid-filled and dry-type transformers.

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 potential tests only. Altitude correction factors should be used for equipment tested.

8.5.4Test Levels of Accessories

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

8.5.5Gas-in-Oil Analysis

One of the more informative tests that can be performed on liquid filled transformer is gas-in-oil analysis. During transformer operation, the deterioration of the insulation materials generates gases that getdissolved in the oil. By determining the amount of gas produced and the rate of generation of gas, one can detect faults before they become catastrophic. This test should be performed regularly on all liquid-filled transformers. Those who take samples should be well trained in this operation, as the accuracy of the results is highly dependent on the sample being collected. Results from this test can inform the operator about localized or general overheating, arcing or corona activity, and deterioration of the paper. For acceptance criteria refer to IS 10593. This test can be used on other dielectric fluids, however, some less flammable dielectric fluids, such as the natural or synthetic esters, are either non-gassing or exhibit gas generation characteristics quite different from mineral oils. If this is the case, thenreferIS 16785. For assistance, one should contact the transformer manufacturer or the fluid manufacturer.

8.5.6 Other Oil Tests

Additional information about the condition of the transformer can be obtained from Furan analysis and liquid quality tests. The former determines the quantity of Furan (a by-product of paper breakdown) in the fluid. The latter test is used to assess the condition of the oil. For this, parameterssuch as moisture content, acidity, colour, interfacial tension power factor and dielectric strength are measured. By drying and reconditioning the oil using filters and 'Fullers earth', the oil can be restored to virtually new condition. For acceptance criteria, refer to IS 1866, Mineral Insulating Oils in Electrical Equipment Supervision and Maintenance Guidance. The physical condition of the paper can be determined by testing the tensile strength of a small sample, or by determining the degree of polymerization. For natural ester refer to IS 16659 &for synthetic organic ester refer to16081& 16099.

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 engineershould 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, oxygensupply system, protective gloves and coveralls. The surfaces to be painted should be clean and free from oil and grease. Once the paint is applied, the coverings on the bushings and any other items should be removed.

10 Packing and Transportation

After all repairs are completed, the transformer should be labelled as described in Section4.4 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 thatno PCB contamination is presentin liquid-filled transformers.The transformer shall be transported generally in liquid-filledcondition. 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. Forlarger 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 instructed otherwise by the customer, the tap switch or tap connections should always be set at the rated voltage position.

ANNEXUREA

ENHANCING RELIABILITY AND ENERGY PERFORMANCE IN RAPAIRED DISTRIBUTION TRANSFORMER

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

NOTE — All coil dimensions should remain same soas to fit in the original core window & tank.

A.1 ACTIVE REPAIR OFDISTRIBUTION TRANSFORMER

High cost of Legacy DT replacement with the new ones is a major challenge for most utilities. Also, the lead-time is usually very long. Moreover, replacing a DT involves downtime loss for utilities and hence revenue is affected. Therefore, the concept of active repairs with additional benefits as compared to simple rewinding based on business as usual repair method is an effective way.

A.1.1 Distribution Transformer Loss Reduction during Repairs

Across all major distribution utilities including private players, DTs are repaired only when they fail or get damaged. This offers an opportunity to reduce the losses on DTs. This can be done by augmentation or replacement of the active materials, core and winding, depending upon the condition and design of DT.

A.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 – by reduction of no load losses& current by increased no. of turns
b) Winding Augmentation/Replacemente.g. by replacing high resistivity material with low resistivity material, using material with lower thermal coefficient of linear expansion etc.in one or both the windings.

A.1.3 Core or Winding Augmentation

Core or winding augmentation is an approach to increase a transformer’s useful life by improving its no load and load loss characteristics.Augmenting refers to upgrading a transformer by adding more cooling methods to fulfil its growing heat dissipation (out of energy) requirements. DTs can be modified to take increased load potential by maximizing the efficiency at which excess heat is dissipated from the main core and windings.

Upgrading a transformer instead of purchasing a new unit is more cost-effective, minimizes disruptions to site operations and increases expected useful working life as well.

A.1.4. 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 % loading as per IS 1180 (Part1): 2014.

A.1.5 MATERIAL CHARACTERISTICS

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

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?
e. How can the different conductor size affect the size of the coil (axial length) and hence its ability to withstand short circuits?

Aluminium used for magnet wire application is as per IS 5484. And in case of copper used for magnet wire the standard is IS 12444. In both cases, the material is fully annealed.

A1.5.1 Electrical Properties

Differences in electrical conductivity/resistivity allow a copper conductor with section 61% as large to replace an Aluminium conductor.

Since a smaller conductor size will obviously 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.

A.1.5.2 Physical Properties

Copper has a lower thermal coefficient of linear expansion than aluminium; sofor larger coils provision for expansion need not be as great for copper. Alternatively, any such provisions incorporated into the original design for aluminium will be more than adequate for copper.

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.

A.1.5.3 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.

A.1.5.4 Mechanical properties

Copper coils can withstand mechanical operating stresses better because the mechanical properties of copper are greater thanthose of aluminium. This assumes that the width-to-depth ratio of the conductor is similar, andthe coils are blocked and supported in a manner similar to the original. This last point is important. 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.

ANNEXURE B

RETRO- FILLING WITH ESTER FLUIDS DURING REPAIR TO INCREASE LIFE AND FIRE SAFETY

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

Ester dielectric fluid is high thermal class insulation, provides fire safety as well as prevent thermal ageing. It helps to improve the load capacity without changing design of 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 viz. Natural Esters & Synthetic organic ester which take over 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:Allcore coil dimensions should remain so as to fit in the original Tank.

B.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 sealing device to prevent the dielectric fluids from coming in contact with replenishing air. 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 &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% by volume in natural ester, then natural ester fluid's fire point will fall below 300°C &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% in natural ester retro-fill &4 percent in synthetic ester fluid.

It is always better to do retro-fill of transformers in control atmosphere like repair workshop or Transformer factory but all the transformer dismantling & shifting to workshop may not be possible & this guide will help to retro-fill transformers at site too.

B2. 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.

Pre-Retrofill Steps:

1. Obtain original Operation and Maintenance guide for transformer
2. Obtain transformer gasket set
3. Keep replacement parts
4. Note site limitations for service equipment
5. Schedule old oil disposal as per local land of law
6. Schedule fluid & container for flush fluid
7. Note location of drain, fill, & vacuum connections
8. Limit air and moisture exposure whenever possible
9.Ensure fluid filling set up or filter machine
10. Ensure sealing device fitment in case of natural ester

B.3 RETROFILL KEYPOINT

Step	Key Points	Comment
. 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	—
. Visual inspection	Confirm integrity of seals, bushings, and bolted connections	—
. Drain oil	Allow time for oil to drip to bottom of tank	A longer drip time is advantageous to reduce residual mineral oil
. Rinse with ester (~ 5-10% 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
. Remove dregs from	Minimizes the residual oil and other	—

tank bottom	contaminants	
. 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.
. 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
Top off with dry air or nitrogen and bring headspace pressure to 2-3 psig (13-20 kPa)	Verify gaskets and seals are working properly	Limits exposure to oxygen and atmospheric contaminants to minimum possible
Install retrofill label	Fill out Retrofill label using indelible pen	Document ester fluid batch number from tote or drum for future reference
Wait to energize unit	2 hours minimum, 4 hours is preferred	Allows gas bubbles to dissipate
Next day, check pressure to ensure proper seal	Limits exposure to oxygen and atmospheric contaminants	—

B3.1Preparing 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.

1. 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.
2. Replace Cartridge filter if are used for old mineral oil.
3. Replace paper filter or bypass it, remove clay filter or bypass it.
4. Take 100 liter ester fluid in clean drum, take fluid in machine (heat exchanger, degassing chamber.) Heat the fluid at 105°C.
5. After reaching fluid temperature 105°C, put machine in circulation mode with flexible pipe also in circulation.
6. 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)
7. Take out the ester fluid in separate drum including fluid from Degassing chamber & Heat Exchanger.

8. Ester fluid used for cleaning of machine &pipe can be disposed or mixed with Mineral oil (MO) & 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 & empty space should be filled with slightly overpressure Nitrogen.
9. Ensure transformer is assembled with sealing device and radiator and all accessories as per contract.

B3.2 Retro-filling at site by Filter machine

1. Ensure transformer old oil is removed, all leakages attended, faulty parts, accessories are replaced, required gaskets are replaced & flushing is done & conservator is sealed.
2. Apply rough vacuum in conservator air release plug.
3. Connect fluid filling pipe at bottom of tank.
4. Start filling the fluid till conservator is filled.
5. Open air release plug of radiator & apply rough vacuum if possible.
6. Open bottom valve of radiator this will allow fluid to flow from tank.
7. Fluid filling in Radiators& compensating the level in tank shall be done simultaneously.
8. Re-fit air release plug once all radiators is fully filled with Fluid.

B3.2.1 Filling of Ester fluid in ON load tap changer-OLTC

1. Check the OLTC tank for fluid level and ensure tank is all most filled with natural esterfluid.
2. Ensure OLTC Tank is assembled with conservator (With Non-Return Valve-NRV) and all accessories as per contract.
3. Apply rough vacuum in conservator air release plug.
4. Connect fluid filling pipe at bottom of tank.
5. Start filling the fluid till conservator is filled to normal level.
6. Ensure minimum possible exposure of fluid to air.
7. Check fluid parameters as per contract before starting filtration (BDV in Normal case), Complete filtration cycles as required (3 to 4).
8. Measure parameters after filtration & check as per contract (BDV $\leq$ 70KV is normally sufficient).
9. Allow fluid to cool down to normal temperature.
10. Release air/gasses & ensure fluid level in transformer & OLTC as per contract.
11. Transformer can be charged as per std. practice (IEC guideline like no load for few hours & increasing load in steps).
12. B4 Measurement & monitoring

Transformer retro-filled with ester can be monitored & maintained same like mineral oil filled transformers. Parameters like Fire point, Viscosity, Breakdown Voltage, Water contain & before after thermography can be monitored & acceptance criteria shall be set as agreement between byer & seller.

ANNEXUREC

ELECTRICAL TESTING SAFETY CONSIDERATIONS

C.1 PERSONNEL SAFETY

C.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.

C.1.2 Clothing

Local regulatory agencies responsible for workplace safety will have requirements that must be met. One should determine what these rules are and ensure that they are followed. As a minimum, clothing should be suitable for the work to be performed. Flameretarding material is recommended. Wearing exposed jewellery should be avoided. Safety glasses and safety shoes should be worn at all times.

C.1.3 Supervision

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

C.1.4 First Aid

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

C.2 TEST AREA

C.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.

C.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.

C.2.3 Signs

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

C.2.4 Lighting

The test area should be well illuminated.

C.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.

C.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.

C.2.7 Exclusivity

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

C.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.

C.3 UNIT UNDER TEST

C.3.1 Suitability for Test

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

C.4 TEST PANELS

C.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 canaccidentally 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.

C.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.

C.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.

C.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.

C.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.

C.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.

ANNEXURED
REFERENCE INFORMATION

D.1 Temperature Correction Factor for Insulation Resistance Tests and Insulation Power Factor Tests for Liquid-filled Transformers are given below in Tables4 and Table 5 respectively.

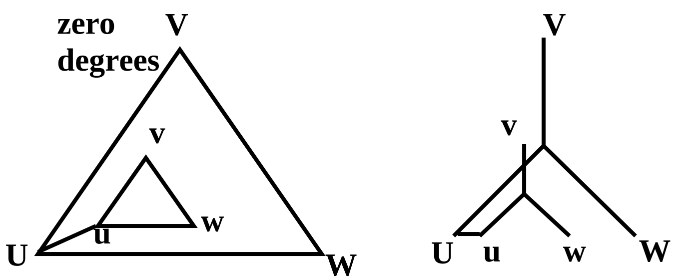
Table 4: Temperature Correction Factors for Insulation Resistance Tests

Temperature (ºC)	Transformers	
	Liquid filled	Dry-type
0	0.25	0.40
5	0.36	0.45
10	0.50	0.50
15.6	0.74	0.75
20	1.00	1.00
25	1.400	1.30
30	1.98	1.60
35	2.80	2.05
40	3.95	2.50
45	5.60	3.25
50	7.85	4.00
55	11.20	5.20
60	15.85	5.40
65	22.40	8.70
70	31.75	10.00
75	44.70	13.00

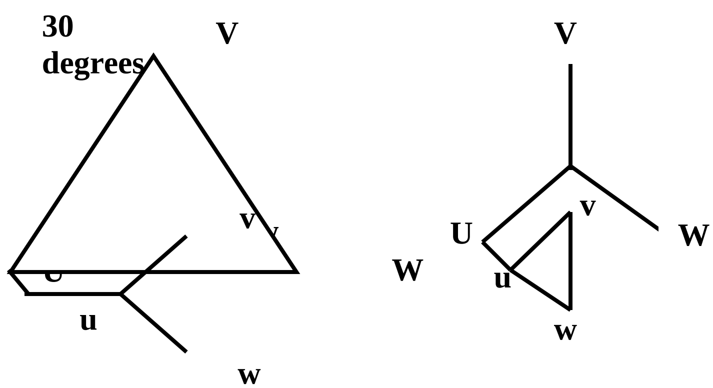
Table 5: Temperature Correction Factors for Insulation Power Factor Tests for Liquid-Filled Transformers

Test Temperature (ºC)	Correction Factor (K)
10	0.80
15	0.90
20	1.00
25	1.12
30	1.25
35	1.40
40	1.55
45	1.75
50	1.95
55	2.18

60	2.42
65	2.70
70	3.00



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

Figure 1: Various Winding Connections for a Phase Sequence Test

ANNEX E

BASIC REPAIR AND TESTEQUIPMENT REQUIRED FOR DT REPAIRS

Equipments required for repairing

- LV Coil Winding Machine (For Layer Type Coil)
- HV Coil Winding Machine (For Cross-over Coil)
- LV/HV Coil Winding Machine (For Disc Type Coil)
- Insulation Cutting/Shearing M/c
- Manual Press Machine - For dovetailed Spacer/block Cutting
- Air Drying Oven (for Assembly/coils) - with Trolly
- Weighing M/c - Digital
- Pallet Trolley
- EOT Crane
- Oil Filter M/c
- Oil Storage Tank
- Drill M/c
- Welding M/c
- Gas Welding/Brazing Set
- Compressor
- Spray Painting Gun
- Other Zigs, Tools & Accessories

Test Equipment & Facility Required for DT Repairs

- Turn Ratio meter
- Winding Resistance meter
- Megger
- Portable HV tester
- HV testing Transformer
- Single Phase Variac
- Three Phase Variac
- M-G Set (DVDF Test Set)
- Intermediate Testing Trf.
- Current Transformers
- Potential Transformers
- Power Analyser
- Test Bench
- Oil Test Kit (BDV)
- Digital Clamp Meter