Azadi Ka Amrit Mahotsav

Government Of India

G20 भारत 2023 INDIA
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GUIDELINES AND BEST PRACTICES FOR

OPERATION & MAINTENANCE OF DISTRIBUTION TRANSFORMERS

March 2023

Government of India
Ministry of Power
Central Electricity Authority

घनश्याम प्रसाद
अध्यक्ष तथा पदेन सचिव भारत सरकार
GHANSHYAM PRASAD
Chairperson & Ex-officio Secretary
To the Government Of India

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सत्यमेव जयते

आज़ादी का अमृत महोत्सव

केन्द्रीय विद्युत प्राधिकरण
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FOREWORD

Government of India is committed to provide 24x7 reliable & quality power to all consumers and Distribution Transformer is one of the vital component in supply chain which is directly connecting the consumers. Some of the distribution utilities are still not able to supply 24x7 power supply to the consumers due to various reasons including faulty / non-availability of Distribution Transformers at supply end. The faulty Distribution Transformer not only causes the disruption of power supply to the consumers but also causes revenue losses to the distribution utilities. The distribution utilities which are already in the poor financial health, also suffer more losses due to faulty transformers.

As per the data available, there are about 1.3 Crore distribution transformers installed in the country having capacity over 6 Lakh MVA and the further addition in numbers and MVA capacity of distribution Transformers every year is a regular practice to meet load growth. However, it is noted that failure rate of distribution transformers is very high in some of the utilities (>10%) affecting quality & reliability of power supply to the consumers while some of the utilities have achieved DT failure rate less than 2% by adopting good practices in Planning, Design, Procurement, Erection, Commissioning and Operation and Maintenance of this key asset.

A need was felt to prepare a Guidelines on Best Practices in Operation and Maintenance of Distribution Transformers adopted by some of the utilities and in order to facilitate Discoms to adopt these best practices, the Guidelines are prepared by Central Electricity Authority after due consultation with stake holders.

I hope this Manual will be useful to all the Discoms and they would take full advantage of the best practices included in this Guidelines to reduce the DT failure rate and enhance the reliability of power supply. This manual with practical orientation would truly be rewarded if field personnel are appraised about the recommended good practices.

(Ghanshyam Prasad)

B.K. ARYA

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सदस्य
तथा पदेन अपर सचिव भारत सरकार
केन्द्रीय विद्युत प्राधिकरण
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PREFACE

Enactment of Electricity Act, 2003, had brought revolutionary changes in all the areas of the power sector. Distribution of Electricity is the most crucial area of the power sector which is directly connected to the consumers and as per Indian Electricity Act 2003, the responsibility of providing quality, reliable and affordable electricity to the consumers is primarily lies with respective Distribution Utilities. Central Government supplements the efforts of the States by providing funding to the Discoms through various schemes launched from time to time to achieve the target of providing 24x7 power supply to the consumers.

In this context, Distribution Transformer plays a very important and vital role for providing electricity to the consumers at desired voltage level. Hence, the thrust, to provide reliable & quality power to each consumer, is largely depend on the efficient working of Distribution Transformers. Although, the Distribution Transformers used in the country have been brought under mandatory BIS certification and BEE star labelling scheme resulting in standardization of the product, which has resulted in improvement of efficiency & quality of transformers and reduction of failure of transformers, but still , the failure rate of Distribution Transformers is very high in some of the States, which has to be brought down by proper health monitoring of the transformers and taking appropriate actions for O&M of the transformers.

In order to disseminate the best O&M practices for Distribution Transformers in the country, CEA has prepared these Guidelines which will serve as a guiding document for field staff of Discoms to take proper decisions in maintaining the health of the Distribution Transformers.

I hope that this Manual would serve as a guiding tool for all the Distribution Utilities for developing an efficient & economical distribution infrastructure in the country.

(B. K Arya)

CONTENTS

INTRODUCTION

The availability of 24x7 reliable power supply has a direct impact on the economic growth and socio-economic development of a nation. Although, electricity being a concurrent subject, Central Government and State Governments act together for providing reliable, quality and affordable power to its citizens, however, it is prime responsibility of respective Distribution Utilities in the States/ UTs to supply 24x7 quality and reliable power to all the consumers in their areas of operations.

The power sector in India has witnessed tremendous growth over the past few years in the areas of Generation, Transmission and Distribution. The installed generation capacity has significantly increased from 275 GW in Mar-2015 to 400 GW in Mar-2022. Enhancement of inter-regional transmission capacity to over 1.12 Lakh MW has resulted in achieving the One Nation One Grid objective. Government of India has been regularly supplementing resources of the States/ DISCOMs through Central Sector Schemes viz. DDUGJY, IPDS, Saubhagya & Revamped Distribution Sector Scheme (RDSS) for strengthening and augmentation of sub-transmission and distribution network. As a result of these initiatives, the country has achieved 100% village electrification and universal electricity access to all the households with significant improvement in availability of power supply in both rural and urban areas. The recently launched RDSS scheme carries the objective of improving the quality and reliability of power supply to consumers through a financially sustainable and operationally efficient distribution sector. Thus, ensuring uninterrupted power supply (24x7) across the country continues to remain a key focus area of GoI.

Although, various reforms/ schemes launched from time to time by Govt of India for distribution sector have significantly contributed for the development of power distribution infrastructure across the country, however, many distribution utilities are still not able to supply 24x7 power supply to the consumers due to various reasons including faulty /non availability of Distribution Transformers at supply end. Distribution Transformer is a device that provides the final voltage transformation by stepping down the available voltages to the voltage as used by the end user/consumer. Distribution Utilities are installing Distribution transformers as a new or capacity enhancement of existing transformer on a regular basis to meet the growing demand or replacement of faulty transformers. Hence, the proper & efficient working of Distribution transformers is the key factor for maintaining 24x7 reliable power supply to the consumers. The faults in Distribution Transformer can cause extensive damage which not only interrupts power supply to the consumers but also results in huge revenue losses to the discoms. The failure rates of some of the Discoms in the country during 2020-21 is as under-

SR no.	STATE	DISCOM	2020-21
1	Haryana	DHBVNL	7.76%
2		UHBVNL	8.96%
3	Chhattisgarh	CSPDCL	8.19%
4	Tripura	TSPDCL	10%
5	Bihar	NBPDCL	3.88%
6		SBPDCL	2.43%
7	Rajasthan	JVVNL	9.17%
8		AVVNL	10.07%
9		JdVVNL	10.64%
10	Kerala	KSEBL	1.90%
11	Tamil Nadu	TANGEDCO	3.01%
12	Mizoram	P&ED	7.27%
13	Uttar Pradesh	DVVNL	18.97%
14		MVVNL	13.21%
15		PVVNL	17.04%
16		PuVVNL	14.90%
17		KESCO	7.32%
18	Meghalaya	MePDCL	6.42%
19	J&K	JPDCL	26%
20		KPDCL	27.14%
21	Himachal Pradesh	HPSEBL	3.03%
22	Madhya Pradesh	MP-Central	10%
23		MP-West	6.48%
24	Assam	APDCL	2.66%

As Distribution Transformers (DTs) constitute one of the largest groups of equipment in the electrical network, hence, the losses in the Distribution Transformers also constitute one of the major factor of total technical losses in the network. As per data available in CEA, at present, there are about 1.3 Crore DTs are installed in the country having transformation capacity of over

6 Lakh MVA (March 2021). As Distribution Transformer is an integral part of the Electricity Distribution system, the demand of DTs will keep on increasing on the account of increase in generation capacity of both conventional and non-conventional sources besides the increase in loads of consumers / increase in per capita consumption of electricity and new avenues like electric vehicle charging stations etc. The demand will also increase due to replacement of old transformers with energy efficient transformers.

The distribution transformers, which are in service continuously recur the technical losses during transformation of electricity from one voltage to another, the electric utilities and industries are constantly striving for various methods and technologies to reduce these inherent transformer losses. Distribution Transformers carry a load, which varies from timeto time during the day & night but generally capacity of these transformers are decided to cater for themaximum load during the day. However, often the average load on DT is far less than the peak load which occurs only for few hours in a day. Keeping in view the average loading of Distribution Transformer, all day efficiency or efficiency at lighter loads have more significance for reducing network losses. BIS has issued the Indian Standards for Distribution Transformer (IS 1180) which stipulates the losses of Transformers at various levels. In case we assume an Avg high 10 % DT failure rate in the country, the number of DT failure would be around about 1.3 million/year. It is generally notices that most of the failed DTs are repaired and some are replaced which cost hugely to utilities on repair/ replacement of DTs. This is a huge financial burden on the utilities and it also reflects on the tariff of the consumer.

In order to ensure quality procurement along with higher energy efficiency requirements, some of the important points to be considered during procurement of Distribution transformers are highlighted below .

a) Distribution transformers are to be procured with Standard ratings as per IS. The maximum allowable losses at rated voltage and rated frequency permitted at 75°C for Distribution transformers can be chosen by the utility as per IS 1180 (as amended).
b) The above losses are maximum allowable and there would not be any positive tolerance.

c) As per the Electrical Transformers (Quality Control) Order, 2015 issued by Ministry of Heavy Industries and Public Enterprises, no person shall by himself or through any person on his behalf manufacture or store for sale, sell or distribute any electrical Transformers specified in the Schedule, which do not conform to the specified standards (i.e. IS 1180 Part-1, 2014) and do not bear Standard Mark of the Bureau of Indian Standards, on obtaining certification marks license.

   Accordingly, ISI marking on the Distribution transformer is mandatory and the product should be manufactured in compliance with IS 1180 Part-1: (2014).

d) Additionally, Star rating by BEE is also mandatory on Distribution transformers.

Regular inspections and periodic maintenance of Distribution transformers help to identify impending issues at the earlier stages and utilities may take necessary actions to prevent future problems. Distribution transformers must be regularly checked as an O&M practice especially for overloading, damaged connectors, worn-out power cords, burning smell, loose plugs or misaligned parts to minimize system failures and fire hazards. It is paramount that the maintenance crew pays attention to applicable Standards (Like ISO 9001-2015/ISO-12000) to maintain a safe working environment for both the equipmentand the maintenance staff.

The proper exercise of the maintenance schedule should also be adopted by Discoms as it will lead to extension of life of Distribution Transformers, reduction in failure rate, enhanced reliability of power supply system and consumer satisfaction thereby an appreciable increase in revenue of the utilities. The utilities will be inspired to adopt best practices in O & M of the DTs to achieve the life span of at least 25 years. It is noted that some of utilities who give proper importance to this maintenance & repair aspects including training of his O & M staff are able to achieve less than 2 % DT failure rate in the country.

The document covers the best practices for operation and maintenance of Distribution Transformers which may be useful for the distribution utilities. A brief description of working of Transformers, Design consideration, Best Practices and I.T. interventions have also been included in the document. This documentwill serve a good practicing and reference tool in the hands of field engineers for reducing the DT failure rates, reducing the downtime of the system, revenue saving and achieving 24x7 power for all.

The information included in this manual has been collected from various stake holders including manufacturers , discoms, industry etc. . These guidelines and best practices are for guidance purposes and may be used by Discom and manufactures/repairers of the distribution transformers.

CHAPTER-1
TRANSFORMER DESIGN & MATERIAL

Core Construction

Transformer core for the power frequency application is made of highly permeable material. High permeability helps in providing a low reluctance for the path of the flux and the flux lines mostly confine themselves to the iron. Relative permeability μ_r well over 1000 is achieved by the present day materials. Silicon steel in the form of thin lamination is used for the core material. Earlier, better magnetic propertieswere obtained by going in for hot rolled non-oriented to hot rolled grain oriented steel. However, now better Cold Rolled Grain Oriented (CRGO) lamination in the form of High permeability grade- has become available. Lamination thickness has progressively reduced from over 0.5mm to the present 0.23mm or upto0.18mm per lamination. These are coated with a thin layer of insulating varnish, oxide or phosphate. The magnetic material is required to have a high permeability μ and a high saturation flux density, a very low permanence and a small area under the B-H loop-to permit high flux density of operation with low magnetizing current and low hysteresis loss. The resistivity of the iron sheet itself is required to be high to reduce losses. The eddy current itself is highly reduced by making the laminations very thin. If the lamination is made too thin then the production cost of steel laminations increases. The steel should not have residual mechanical stresses which reduces its magnetic properties and hence mustbe annealed after slitting and cutting. The amorphous core transformers generally have less no-load losses in comparison to CRGO based Transformers due to different core material .

Broadly classifying, the core construction can be separated into two types:

(i) Core type and
(ii) Shell type

In a core type construction the winding surrounds the core. A few examples of single phase and three phase core type constructions are shown in Figure 1(a). In a shell type, on the other hand, the iron surrounds the winding as shown in figure 1(b) below:

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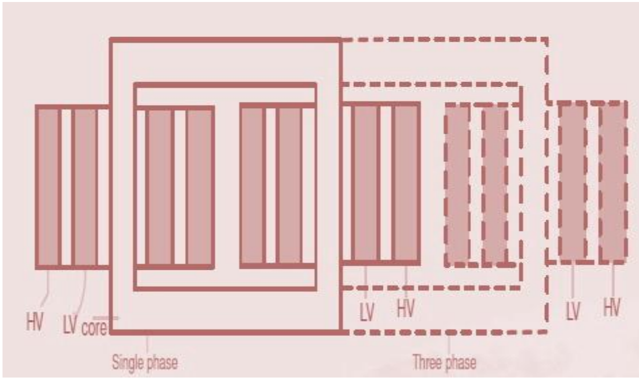
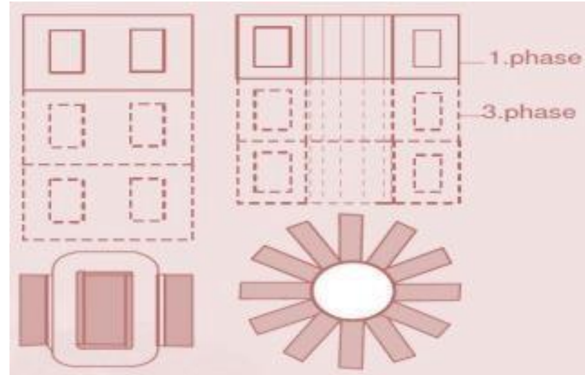
1. Indian Standard Code 1180- Part1 : Outdoor type oil immersed distribution transformers up to 2500 KVA, 33 KV-specifications.

2. At the design stage, design of low rating DTs used for HVDS and agricultural load (5/10/16/25 KVA) keeping in view the adverse site situations , R & D, modifications in design may be considered.





Core type **Shell type**

Figure 1: Core and Shell Type Construction of Transformer

In the case of very small transformers of rating 5/10/16/25 KVA the conductors are thin and round. Thesecan be easily wound on a former with rectangular or square cross section. With the rating of the transformer, the conductor size also increases.

Flat conductors are preferred to round ones for two reasons namely:

(a) Higher surface area for heat dissipation and

(b) Winding such conductor on rectangular former is easier.

However it introduces stress in the conductor, at the bends. From the point of view of the short circuit force withstand capability this is not desirable. In order to avoid these problems, the coils are made cylindrical and are wound on formers using heavy duty lathes. Thus the core construction is required to be such as to fill the circular space inside the coil with steel laminations. Stepped core construction thus becomes mandatory for the core of large transformers i.e. above 250 KVA.

The main raw material of transformers accounting for the major cost is core material i.e. CRGO/ Amorphous; is almost wholly imported. The dearth of the same and its rate fluctuations hamper timely supply of transformers. Although entry of low grade /defective CRGO steel is banned by the quality control order, however, its availability , in various forms like core assembly / secondary coils / offcuts etc., severely affects the quality of transformers. Govt of India is taking the steps like Phased Manufacturing Plan to start manufacturing CRGO/ Amorphous core in India under the ‘make in India program. Recently, Ministry of Steel, GoI vide Gazette Notification dated 29th July, 2021 has launched Production Linked Incentive Scheme (PLI) for Specialty Steel in India to be implemented over FY 2023-24 to FY 2029-30 with a budgetary outlay of ₹ 6,322 crore. Under the PLI Scheme Electrical Steel (CRGO/CRNO) has also been included to promote manufacturing of such Electrical Steel (CRGO/CRNO) within the country.

In the field, it is noted that a large number of various sizes of DTs are being used from 5 KVA - 2.5 MVA based on the load conditions in the field. This results in large inventories of Discom to keep account. It is a good practice that the sizes may be standardized at the Discoms level based on the actual load conditions as it will help in reduction in inventory, downtime in replacement of damaged DTs and reduction in the investment cost.

Losses in Transformers

The difference between the energy input and output is quantified as loss. Transformer generally is a high efficiency device as this is a static devices & transform the energy (Voltage/Current) from one level to another level through magnetization but do not have any moving part.

There are mainly three types of transformer losses: no-load losses, load losses and stray losses.

No-load losses

Losses incurred in the transformer, even when no energy is being transformed are referred to as No-load losses. These are also referred to as core losses. This loss is calculated based on the amount of power required to magnetize the core of the transformer. Since most DTs are energized 24/7, no-load losses are present at all times, whether a load is supplied by the transformer or not. When it is lightly loaded, no- load losses represent the greatest portion of the total losses.

No-load losses are caused by the magnetizing current needed to energize the core of the transformer, and do not vary according to the loading on the transformer. They are constant and occur 24 hours a day,365 days a year, regardless of the load, hence the term no-load losses. They can be categorized into five components: hysteresis losses in the core laminations, eddy current losses in the core laminations, I^2R losses due to no-load current, stray eddy current losses in core clamps, bolts and other core components,and dielectric losses. Hysteresis losses and eddy current losses contribute over 99% of the no-load losses,while stray eddy current, dielectric losses, and I^2R losses due to no-load current are small and consequently often neglected. Thinner lamination of the core steel reduces eddy current losses.

The biggest contributor to no-load losses is hysteresis losses. Hysteresis losses come from the molecules in the core laminations resisting being magnetized and demagnetized by the alternating magnetic field. This resistance by the molecules causes friction that result in heat. The Greek word, hysteresis, means "to lag" and refers to the fact that the magnetic flux lags behind the magnetic force. Choice and type of corematerial often decided at the designing stage reduces hysteresis.

Load losses

Load losses, on the other hand, are the losses incurred while carrying a load. These include winding losses,stray losses due to stray flux in the windings and core clamps, and circulating currents in parallel windings. Because load losses are a function of the square of the load current, they increase quickly as the transformer is loaded. Load losses represent the greatest portion of the total losses when a transformer is heavily loaded. The utility should maintain the transformer loss data as provided by OEM during supply & repairing stage (after repair). The same should be available on the name plate of the D.Ts.

Load losses vary according to the loading on the transformer. They include heat losses and eddy currentsin the primary and secondary conductors of the transformer. Heat losses, or I^2R losses, in the winding materials contribute the largest part of the load losses. They are created by resistance of the conductor to the flow of current or electrons. The electron motion causes the conductor molecules to move and produce friction and heat.

The energy generated by this motion can be calculated using the formula:

Watts = (volts)*(amperes) or VI.

According to Ohm's law, **V = IR**, or the voltage drop across a resistor equals the amount of resistance in the resistor, R, multiplied by the current, I, flowing in the resistor.

Hence, **Heat losses = (I) * (RI) or I^2R.**

Transformer designers cannot change I, or the current portion of the I^2R losses, which are determined bythe load requirements. They can only change the resistance or R part of the I^2R by using a material that has a low resistance per cross-sectional area without adding significantly to the cost of the transformer. Most transformer designers have found copper the best conductor considering the weight, size, cost andresistance of the conductor. Designers can also reduce the resistance of the conductor by increasing the cross-sectional area of the conductor. Here the use of Copper conductor having low resistance & low I^2R losses can be considered at design stage having better properties over the Aluminum conductor as given below:

	Aluminum 1350-O	Copper C11000-O
Property	Metric	Metric
Electric Conductivity	0.362 MS/cm	0.591 MS/cm
Electric Resistivity	2.83 X 10-6 ohm cm	1.71 X 10-6 ohm cm
Coefficient of Linear Expansion	23.8 X 10-6 m/m° C	17.3 X 10-6 m/m° C
Thermal Conductivity	234 W/m° K	391.1 W/m° K
Melting Point	660 ° C	1085 ° C
Tensile Strength, Ultimate	82.7 MPa	221 MPa
Shear Strength	55.2 MPa	152 MPa

Table 1: Properties of Aluminum & Copper

Stray Losses

The stray losses in a transformer comprise winding stray losses, viz. eddy loss and circulating current loss;the loss in the edge stack (smallest packet of the core limb); and the loss in structural parts, viz. frame, flitch plate and tank. Core loss at the impedance voltage being insignificantly low, is not considered in thepresent analysis. In case of large generator transformers, stray losses due to high current carrying leads also become significant. As the total stray losses with shielding measures in large rating transformers areof the order of 20-25% of the total load losses, it is imperative to estimate stray losses accurately as controlover these gives a competitive advantage. Measures like using judiciously designed magnetic shunts helpreduce the stray losses effectively.

Windings

Windings, made out of mainly Copper and or Aluminum wires, form another important part of the transformer. In a two winding transformer, two windings would be present. The one which is connected to the voltage source and creates the flux is called a primary winding. The second winding where the voltage is induced by induction is called a secondary winding. If the secondary voltage is less than that ofthe primary, the transformer is called a step down transformer. If the secondary voltage is more, it is a step up transformer. A step down transformer can be made to operate as a step up transformer by makingthe low voltage winding its primary. Hence it may be more appropriate to designate the windings as High Voltage (HV) and Low Voltage (LV). The winding with more number of turns will be a HV winding. The current on the HV side will be lower as V-I product is a constant and given as the VA rating of the transformer. Also the HV winding needs to be insulated more to withstand the higher voltage across it. HV also needs more clearance to the core, yoke or the body. These aspects influence the type of the winding used for the HV or LV windings.

Insulation System Characteristics (Cellulose & Oil)

The insulation used in the case of electrical conductors in a transformer is varnish or enamel in a dry typetransformer. In larger transformers to improve the heat transfer characteristics the conductors are insulated using un-impregnated paper or cloth and the whole core winding assembly is immersed in a tank containing transformer oil. The transformer oil thus has dual role. It is an insulator and also a coolant.The porous insulation around the conductor helps the oil reach the conductor surface and extract the heat. The conductor insulation may be called the minor insulation as the voltage required to be withstoodis not high. The major insulation is between the windings. Annular Bakelite cylinders serve this purpose. Oil ducts are also used as part of insulation between windings. The oil used in the transformer tank shouldbe free from moisture or other contamination to be of any use as an insulator.

Figure 2: Inter-Turn Faults due to poor insulating material

Some important specifications of Distribution Transformer

The Distribution Transformers are supplied to be suitable for satisfactory continuous operation under theclimatic conditions prevailing at site and to be specified by the purchaser, as per IS 1180 (Part-1) 2014 & IS 2026 .

A list of information to be provided at the time of procurement for some of the materials is given below:

1. About Location

(i) Location : __

(ii) Max ambient air temperature (deg.C) : __

(iii) Min. ambient air temperature (deg.C) : __

(iv) Max average daily ambient air temperature (deg.C) : __

(v) Max. Yearly weighted average ambient temperature (deg.C) : __

(vi) Max. Altitude above mean sea level (meters) : __

2. Terminal Connectors

The LV bushing and HV bushing stems shall be provided with suitable terminal connectors so as to connectthe jumper without disturbing the bushing stem. Bimetallic connectors shall be used in LV and HV side inorder to ensure sound and robust connection.

3. Terminal Markings

High voltage phase windings shall be marked both in the terminal boards inside the tank and on the outside with capital letter 1U, 1V, 1W and low voltage winding for the same phase marked by corresponding small letter 2U, 2V, 2W (terminal marking plate with taps to be provided as per IS 1180). The neutral point terminal shall be indicated by the letter 2N. Neutral terminal to be brought out and connected to local grounding terminal by an Earthing strip as per IS 1180.

4. Fittings

The following standard fittings as per IS 1180 or relevant standards shall be provided:

(a) Rating and terminal marking plates non-detachable

(b) Earthing terminals with lugs - 2 Nos.

(c) Lifting lugs for main tank & top cover

(d) Pulling lugs - 4 Nos

(e) HV bushings - 3 Nos.

(f) LV bushings - 3 Nos.

(g) Neutral bushings – 1 No.

(h) Terminal connectors on the HV/LV bushings

(i) Arcing horns or 9 kV 5kA lightning arrestors on HT side-3 no.

(j) Thermometer pocket with cap - 1 No.

(k) Air release device

(l) Stiffener angle 40 x 40 x 5 mm and vertical strip of 50 x 5 mm flat

(m) Radiators

(n) Prismatic oil level gauge

(o) Drain cum sampling valve

(p) Oil filling hole having M30 thread with plug and drain valve on the conservator

(q) Silica gel breather

(r) Pressure relief device or explosion vent.

(s) Base channel 75 x 40 mm

Note: For specifications the IS 1180 Clause: 9-16, 20 may be referred.

5. Fasteners

All bolts, studs, screw threads, pipe threads, bolt heads and nuts shall comply with the appropriate Indian Standards for metric threads, or the technical equivalent. Bolts or studs shall not be less than 6 mm in diameter except when used for small wiring terminals. All nuts and pins shall be adequately locked. Wherever possible bolts shall be fitted in such a manner that in the event of failure of locking resulting in the nuts working loose and falling off, the bolt will remain in position. All ferrous bolts, nuts and washers placed in outdoor positions shall be treated to prevent corrosion, by hotdip galvanizing, except high tensile steel bolts and spring washers which shall be electro- galvanized/plated. Appropriate precautions shall be taken to prevent electrolytic action between dissimilar metals. Each bolt or stud shall project at least one thread but not more than three threads through the nut, except when otherwise approved for terminal board studs or relay stems. If bolts nuts are placed so that they are inaccessible by means of ordinary spanners, special spanners shall be provided.Taper washers shall be provided wherever necessary.

6. Mounting Arrangement

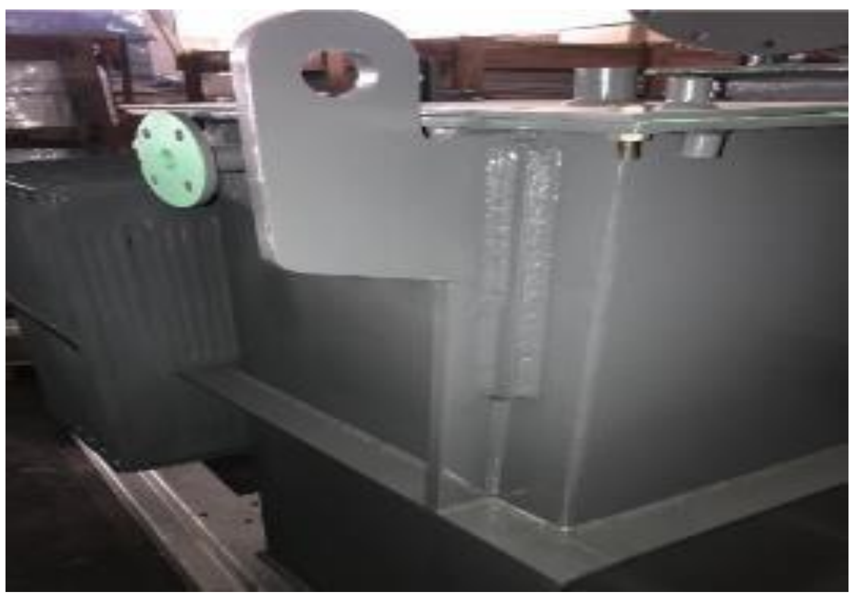
The mounting Arrangement of DT should be as per Indian standards and as per the past practices of Utilities. The Transformer may be mounted on Pole (Single/ double /4 pole) or Plinth as per the site conditions.

7. Standards of Lifting Lugs:-

The lifting lug design of transformer varies as per manufacturer. In distribution network due to load growth augmentation of the substations required to be done hence shifting of the transformers is done based on loading condition for asset optimization. If the lifting lugs are not designed with safety factors suitable for jerk loading then the lugs tends to break. The manual errors during welding and painting causes early rusting of welding. Rusting of welding near lifting lug drastically reduces the lifting strength. Hence it tends to breakaway while lifting of DT after few years in service. There is safety hazard for asset and working personnel.

a. Bent Lug b. Broken lug at the welding on tank

As per lifting devices standards the safety factor of 5 ensured in design of lifting lugs and with support stiffener at bottom taken to ensure longer life. The Hook design changed to lug design suitable for lifting with D-shackle arrangement.



‘The lifting lugs design of DTs should be such that it should be suitable for 120 degree lifting rope angle as per ASME B30.9 or relevant IS and at any point of time the maximum stress allowed on the Lug martial and welding shall be lesser than840kg/cm2 as per ANSI C.57.12.10 or relevant IS standards’.

CHAPTER-2

LIFE EXPECTANCY & FAILURE OF DTS (THEORETICAL V/S PRACTICAL LIFE)

Failure of Distribution Transformers

Distribution transformers are key elements of the power distribution network. As a critical and an expensive component of the distribution power systems, transformers play an important role in power delivery and the integrity of the power system network as a whole. The failure of Distribution Transformers leads to failure of Distribution system and subsequent outage which leads to financial loss in repair and replacement, loss of revenue and reduces quality and reliability of supplied power.

Some main reasons of DT failure are as under:-

Major Reasons

1. Insulation Failure
2. Damage to HT Coil
3. Damage to LT Coil
4. Damage to Core & Laminations
5. Failure to Tap Switch & Tap Arrangement

Minor Reasons

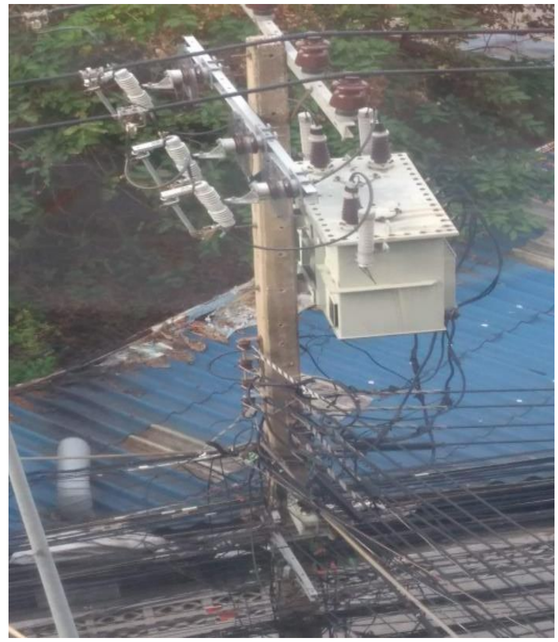
1. Oil Sample not Satisfactory
2. Lead connections cut of
3. Worn-out Bushing rods
4. Broken Bushings
5. Gasket Leakage
6. Welding Leakage
7. Leakage through Valves
8. Broken gauge glass
9. Broken vent diaphragm
10. Worn-out Breather

Transformers have operating limits beyond which transformer failure can occur like overloading and other operational problems. In such adverse conditions there can be heavy damage to the transformer and it may cause intolerable interruption of service to customers and may also cause loss to public property & life due to accidents. Since the lead time for repair and replacement of transformers is usually quite high, hence proper quality, timely maintenance, and adhering to timely checks and maintenance schedule should be followed to avoid the failure of DTs. In case of failure of Distribution Transformers, the faulty transformer is to be replaced by a health transformer by the utilities within the specified time limit as per Rules / Regulations notified by the Govt/ SERCs. Initially, the faulty transformers are replaced immediately by health transformer and afterward the faulty transformer is repaired in the workshop to be used again in the field.

Details of Major Reasons for failure of DTs:

(A) Operation & Maintenance problem

- Winding failures resulting from short circuits, On-load tap changer failures mechanical problems, Turn to turn faults, inter layer faults, phase to phase faults short circuit, and overheating and open windingfaults.



- Core faults (core insulation failure, shorted laminations)
- Terminal failures (open leads, loose connections, short circuits)

- Abnormal operating conditions (overloading, overvoltage)
- External conditions (Moisture entry, lightning, loose conservator cap, pilferage of oil)

- Using single GO Switch for multiple DTs.

Figure 3: Single go switch for multiple DTs

- External faults

Figure 4: Cat/Monkey Electrocution

Figure 5: Top Covering by fence

(B) Manufacturing Side Defects

The manufacturing side defect includes Design/Manufacturing Errors/conditions such as loose or unsupported leads, loose blocking, poor brazing, poor joints in the intra winding leading to hotspot and insulation damage, inadequate core insulation, inferior short circuit strength, and foreign objects left in the tank. These causes of transformer failure can be further categorized into four types:

Other Reasons:-

1. **Failure caused by Raw Material**

Following are reasons of failure of raw material resulting transformer failure

- **Moisture in insulated paper** - The process to release moisture in paper is not good enough. This maycauses shorting of turns of winding in transformer.
- **Contamination in winding insulation** –Minimal or low contamination is found during raw material manufacturing process. It results the shorting of turn in winding.
- **Bubble in insulated paper** - The process to release bubble in paper is not good enough. After transformer is energized, the dielectric withstand at that point is not enough and it leads to short turnin winding.
- **Sharp edge of low voltage winding** - Short turn happens on low voltage foil type winding because sharp edge of winding deteriorates paper during winding process.
- **Change in supplier of raw material** - Because old supplier cannot supply raw material and quality of raw material from new supplier is not good enough.

2. **Failure caused by Assembly Process**

Following are the leaks in the assembly process resulting in transformer failure:

- **Assembly of gasket and quality of tank welding** - Moisture can go into the tank or transformer oil canleak. Dielectric strength will be reduced and breakdown will occur in the tank.
- **Assembly of winding to silicon steel core** - It causes deterioration of insulated paper between windingand steel core due to careless workmanship. Short circuit from winding to steel core will be found in transformer.

- **Assembly of tap changer** - Contact of tap changer is not tight; heat is generated at that point.
- **Assembly of low voltage busbar and bushing** - Bolt of busbar and bushing can be loose. It causesabnormal voltage and the customer equipment at load side will be damaged.
- **Winding connection** - It is from poorly soldered joints between winding and heat is generated at thosejoints.

3. Failure caused by Cleaning Process

Following are the leaks in the cleaning process resulting in transformer failure:

- **Small strip of winding/wiring in transformer -**During wiring process in transformer tank, cuttingcopper drops in the tank and cleaning is not well executed.
- **Small particle from welding busbar and winding -**Careless workmanship results in solder splashes onthe coil.
- **Small particle from busbar -**The selected busbar has sharp edges, small particle is found in theprocess to reduce sharp edges and cleaning is not well executed.

4. Unspecified Causes

Unspecified causes mean they can be either from assembly process or design process.

- **Small clearance or long bolt** - Short circuit between bolt and low voltage busbar is found in transformer tank because design clearance is not sufficient or bolt is too long.
- **Small design clearance of winding** - Short circuit between tank and winding is found in transformer tank because design clearance between wiring and tank is not sufficient or worker is insufficiently skilled.
- **Thickness of transformer tank or lifting measure** – Due to rapid increases in transformer steel prices,manufacturers attempt cost reduction by lowering thickness of transformer to the max possible. If the lifting angle is lower than the design when lifting transformer, tank can be deformed at the welding point between lifting lug and tank.

(C) Utility Side Defect

Utility Side Defects include leaks in the Operation and Maintenance process and External factors causingDT failure. In following section, leaks in the Operation and Maintenance process and External factor resulting in these failures are elaborated:

- **Overloading**- Transformer that experiences sustained loading that exceeds the name plate capacity often faces failure due to overloading.

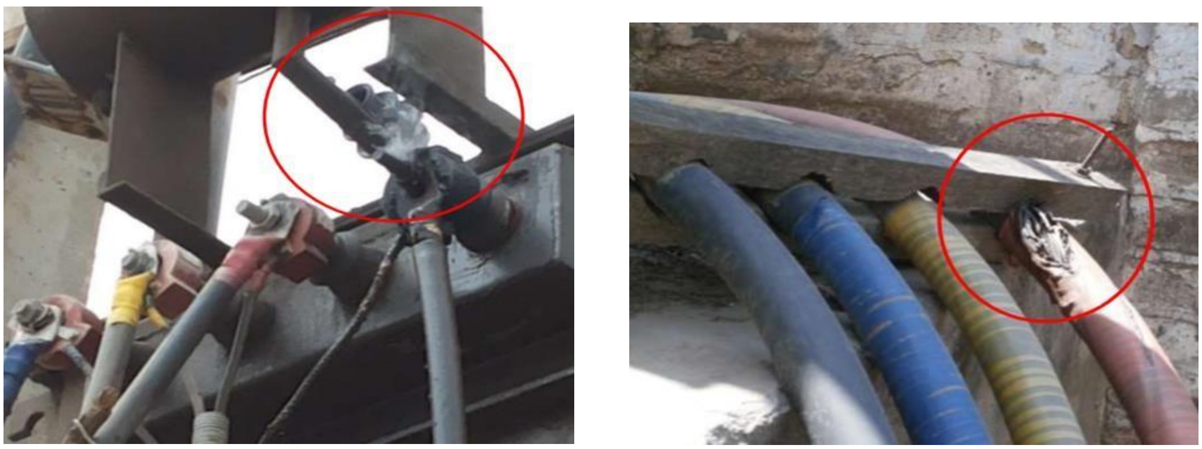


Figure 6: Burning of Lead due to overloading

- **Line Surge** - Failure caused by switching surges, voltage spikes, line faults/flashovers, and other T&D abnormalities suggest that more attention should be given to surge protection, or the adequacy of coil clamping and short circuit strength.
- **Loose Connections** - Loose connections, improper mating of dissimilar metals, improper torqueing ofbolted connections etc. can also lead to failure of a transformer.

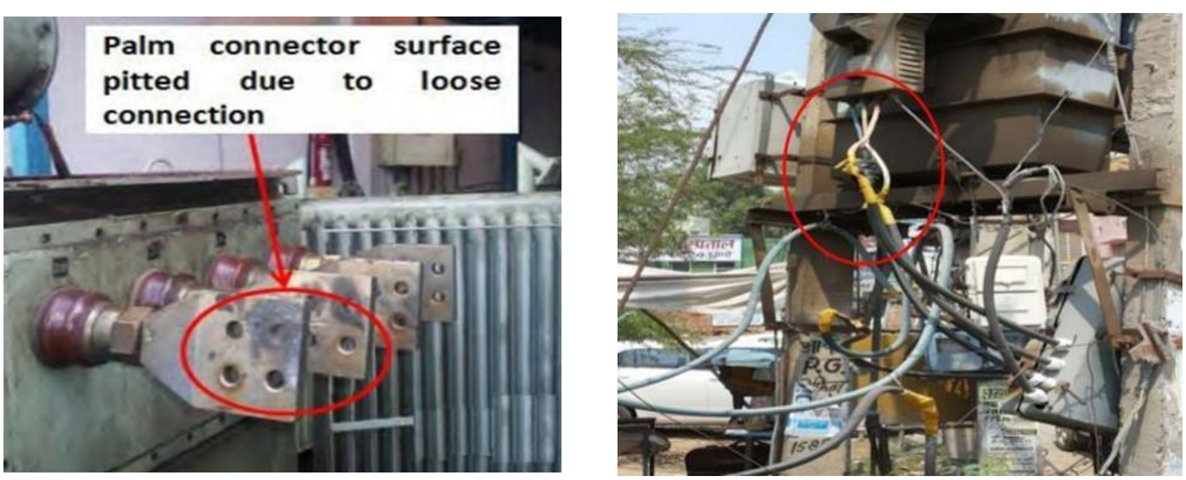


Figure 7: Loose Connection

Figure 8: Loose jointed LT Leads

- **Oil Contamination**- resulting in slugging, carbon tracking and humidity in the oil can often result in transformer failure.
- **Water Ingression-** Water ingression through improper sealing / damaged tank body causes loss of dielectric strength resulting to insulation failure. Mostly, the lower most HV coil gets affected due to water settling at the bottom of the tank.
- **Improper/inadequate Maintenance**- Inadequate or improper maintenance and operation is a majorcause of transformer failures. It includes disconnected or improperly set controls, loss of coolant, accumulation of dirt and oil, and corrosion.
- **External Factors**- Several external factors like floods, fire explosions, lightening and moisture could also cause the failure of the distribution transformer.
- **Poor Earthing-** Improper earthing is one of the main reason casing unbalanced voltages, floating neutral and causing DT failure. Some poor examples of earthing are given below:

Figure 9: Improper Earthing Connection

Most of the DTs have very high earthing resistance value. Some sample photograph is follow as:

Figure 10: Improper rating of earth wire

- **Improper Oil Level**

  Improper oil level in the DTs due to poor maintenance, leakage and theft of oil as it causes temperature rise, hotspot leading to DT failure especially in rural areas.

Figure 11: Low Oil Level

Figure 12: Heavy Oil Leakage

- **Improper Size of fuses**

  No use of MCB on LT side of DTs and using improper size of the fuses (for ease by maintenance staff)is another major reason for failure of DTs and affecting the safety of DTs and public life.

Figure 13: Installation of inappropriate rating & size of fuses

- **Lightning Arrestors (LA) not properly installed**

  Las not properly installed or not installed are the reason of DT failures due to lightning.

Figure 14: No LA Protection: Direct tapping from 11 KV Feeder

- **Improper/ No usage of Breathers**

  Poor maintenance of breathers/ Silica Gel or no usage of breather lead to lowering the moisturecontent of transformer oil and thereby causing the failure of DTs.

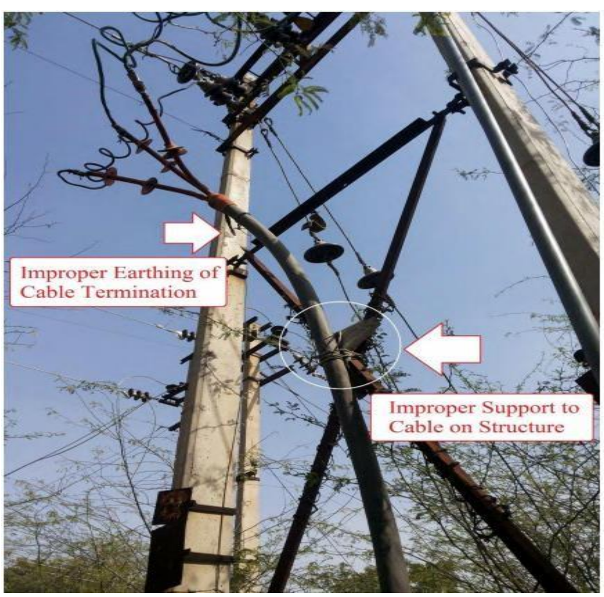
Figure 15: Breather not available **Figure 16: White Silica Gel in Breather**

External faults:

These are usually utility side defects. Like poor cable jointing.

Improper Support to Cables on pole

Suitable & proper Support must be provided to Cable when it needs to be connected with over Headlines/Distribution Transformers. As due to improper support, cable end terminations have to bear excessive pressure & weight of Cable and may lead to failure of Cable end termination.



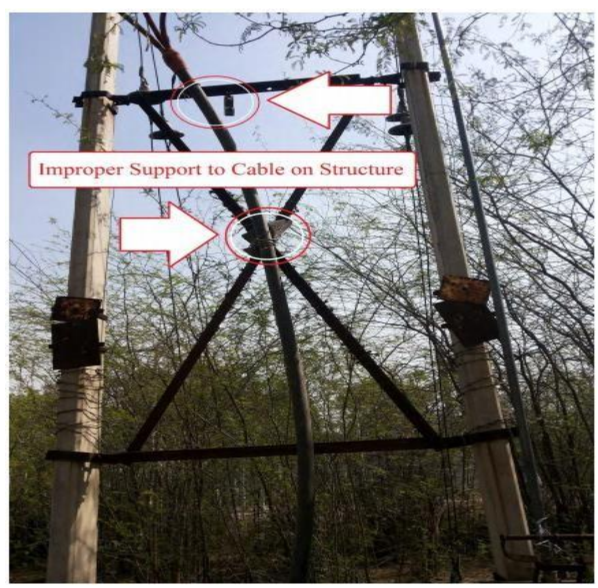


Figure 17: Improper Support to Cables on Pole

As can be seen from the above list both manufacturing and operation & maintenance related factors causefailure of DTs. It is essential to improve the processes at manufacturing end, and adopting best practice at the utilityends. It is noted that around 80% of the failed DTs are repaired and the remaining are generally replaced by a new distribution transformer unit as these may be beyond repairing , resulting a huge losses to Discom every year.

An abstract of failure due to operational and manufacturing defects is described in the table below:

Type of Failure	Operational Defects	Manufacturing Defect
Winding failures		
a) Turn-turn faults, phase-phase faults, phase-ground	1. Overheating of thetransformer. 2. Overload.	Use of improper insulation material for the winding/use of low quality material, bad insulation covering.
b)Open winding	Short circuit at transformer	Improper brazing / connection
c)Opening at core joints	Short Circuit Improper transportation	1. Design short comings 2. Poor clamping of laminations at yokearea
Core faults: These are mostly manufacturing defects		
a)Core insulation failure	Continuous overloading and overheating of the transformer	Improper varnishing of the stamping,improper formation of core.
b)Shorted laminations	Short terminal circuit at thetransformer	Use of improper insulation, improper formation of core, burr to the lamination blades, improper core bolt insulation.
Terminal failures		
a)Open leads	---	Bad insulation covering, improper brazingof joints.
b)Loose connections	---	Improper joining terminals
c)Short circuits	---	Loose connection, improper use of theinsulating material, bad insulation covering.
Off-load tap changer failures		
a)Mechanical	Improper handling changerswitch of tap	---
b)Electrical	Failure of insulating oil	---
c)Short circuit	Sparking at the contacts	---
d)Overheating	1. Frequent operation 2. Cold-welding effect caused	---

	by rare / occasional operation	
Abnormal operating conditions: These are purely utility side defects.		
Type of Failure	**Operational Defects**	**Manufacturing Defect**
a)Over fluxing	Overvoltage in system	---
b)Overvoltage	Due to operation problem like no load in the night hours or oversizing of capacitor bank.	---
c)Overheating	Failure of the cooling, improper maintenance/ checking of oil level in conservator/ transformer and not topping up oil to required level, unbalanced load conditions.	Insufficient cooling ducts in the winding.
d)Overloading	Continuous over loading of transformer beyond rated capacity. Improper contact of fuses/over capacity fuses.	---

Besides above, the mismanagement in procurement process, lack of skilled technician/ workers non adherence to BIS (ISI marking) mandates and guidelines, absence of root cause analysis for untimely failure, absence of asset management philosophy and aging of assets are also contributing to the failure of DTs.

CHAPTER-3
ADOPTION OF BEST PRACTICES

Considering the huge financial loss to manufacturers and utilities in repairing and replacing the damaged DTs, it is necessary to identify and follow best practices across all aspects of Distribution Transformers from load forecasting & planning, stringent procurement , specifications for raw material for transformer manufacturing at manufacturer's end, to the operation and maintenance and repairing of transformers at the utility end. Some of the challenges faced by the industry are lack of mandatory guidelines for installation operation and maintenance of transformers like bad earthing practices, usage of inferior material in transformer manufacturing, overloading of transformers, tampering/bypassing protection equipment, theft of material/oil which leads to fire and failure of transformers etc.

Distribution Transformers play a very important and vital role in delivering electricity to the last mile. It can be rightly said that the Distribution industry is bringing light to the people. The thrust by the GoI to provide quality power to every household through various schemes like DDUGJY/ IPDS/ RAPDRP/ Saubhagya and recently launched Revamped Distribution Sector Scheme (RDSS) , have given a huge fillip to the demand of DTs across India. The demand of Distribution transformers is catered majorly by the domestic Industry; import of transformers is very marginal/project specific. The Industry is dominated mostly by -MSME units spread all over India and mainly supplying to their respective state utilities. There are large scale units also which apart from having Pan India presence are also engaged in transformer exports.

A. Standardization of operational practices of utilities

There is a lot of variation in operational practices of private and government owned utilities; this drastically affects the performance of the system and DT failure rate. It is observed that the failure rate ofDTs in private utilities is very less as compared to the government owned utilities. Further it is observed that this failure rate is less than 1 % in developed countries compared to around 10 % in India in some utilities. High failure rates of system equipment leads to financial burden on the utilities in terms of repair and replacement cost and indirect revenue loss due to the non-availability of the system. A developing countrylike India needs to have lower failure rates for the growth in the power sector. Private utilities have adopted good operational practices compared to government utilities to keep check on failure of DTs. However, further modifications are required in operational practices, design aspect, hybrid design for DTs in private as well as government utilities. In this regard, following points may be considered:-

i. DT metering with smart metering facility helps to identify & minimize overvoltage, overloading & unbalancing.
ii. Use of tap-changers in DTs may be minimized to eliminate probability of failure due to tap-changers.
iii. Use of special anti-corrosion coating/paint at the outer tank body reduces the chances of rust & corrosion.
iv. Use of HRC fuse / horn gap type fuse arrangement will help to improve fusing efficiency.
v. Lug / clamp connection in between riser & bushing minimises the probability of internal open circuit.

B. Analysis of cause of failure & maintaining history card for Distribution Transformer

Distribution transformer may fail due to various reasons. The root cause of failure may be lacunae in manufacturing practices or inappropriate operation and maintenance practices. Analysis of causes of failure would help in taking corrective measures and 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.

The LT side of the DT has the voltage level at which power is distributed to end consumers. In India, typicalvoltage level of DT is 11kV/433V. However, some utilities also use 22kV/433V & 33kV/433V voltage level also. The Standard KVA ratings of DTs which should be as per IS 1180 (as amendment). DTs are typically three phase; however, some distribution systems also use single phase DTs.

The Discom should consider sound asset management practice for getting best out of their high capex DTinventory, narrowing down to three to four standard ratings may prove beneficial for reduced inventory, procurement, carrying and landing cost. These should be based on sound load forecasting projections to avoid replacing DT frequently to cope up with load growth in the area.

The life of a transformer is dependent upon the life of its insulation. The term “transformer life” gives animpression as if it was quite definite, but in fact a transformer hardly ever “dies”. It is usually “killed” by some unusual stresses breaking down a weakened part leading to the end of the transformer. As stated transformer insulation deteriorates as a function of time and temperature. Transformer temperature, in turn, is related to loading. The winding I^2R losses, the core losses, and the stray losses in the tank and metal support structures are the principle sources of heat that cause the oil and winding temperature rise. Various investigators have not agreed on life-duration at any given temperature. However, they do agree, that between 80°C to 140°C, the rate of loss of life due to ageing of transformer insulation is “doubled” for every 6°C rise in temperature. Losses in the transformer cause thermal stress in the activepart. This leads to ageing and decomposition of both oil and cellulose which liberate gases within the transformer. The amount and type of gases formed and dissolved into the oil can be determined with thehelp of Dissolved Gas Analysis (DGA). Similar to a blood test or scanner examination of human body, Dissolved Gas Analysis can give an early diagnosis and increase the chances of finding the appropriate cure.

- The operating conditions, particularly in rural India, like weather conditions, overloading, through or passing faults, inadequate protection, public interference, poor maintenance of LT and 11 kV lines often results in distribution transformer failure.
- Distribution transformers installed in rural areas form the bulk of these transformers. They are very much exposed to vulnerable weather conditions particularly lightning. These transformers feed lengthy Low Tension (LT) lines which are more prone to faults because of these atmospheric conditions.
- Majority of the transformers have poor efficiency because of improper or unbalanced loading conditions.It is common practice to connect additional electrical load on these transformers on the basis of maximumdemand recorded at some point of time or on the basis of assessed maximum demand without considering the seasonal variations and the actual diversity factor.
- Un-authorized electrical connections also result in overloading. Wide variation in load and ambient temperature make undesired ingress of moisture, particularly in rural areas, which weakens the dielectricstrength of transformer oil, forms sludge and deposits on the winding which on passage of time may obstruct the ducts in the winding provided for oil circulation.
- The routine maintenance of LT and 11 kV lines and protective equipment’s associated with these

transformers are also poor.

- Prolonged operation of distribution transformer under abnormal operating condition such as faults, overloading or unbalance load deteriorate the insulating materials; ultimately leading to failure.

C. Examination of failed Distribution Transformers

External Check up	Internal Physical Verification	Healthiness Test
1. Oil level and Quantity available. 2. Places of oil leakage 3. Condition of Breather & silicagel. 4. Condition of Bushing & Bushing rods. 5. Condition of Vent Diaphragm. 6. Condition of Valves. 7. IR Value & continuity. 8. BDV Test on oil.	1. Conditions of HT coils in all the three phases. 2. Checkup of lead connection from coil (Delta & Star points) 3. Condition of core. 4. Condition of Tap switch and connections. 5. Condition of Core earthing. 6. Presence of sludge & moisture in oil & physical condition of oil.	1. By injecting 15V on LV side & measuring stack voltage of HT coil. 2. Short circuit test by injecting 400V on HV side & short circuiting the LV side.

D. Some General Observations/Case Studies on Averting DTs Failure

Details of Defects Noticed at Field	Observation at Lab	Probable Cause for the Defects	Rectification done and suggestions to avoid recurrence in future
Case 1: All 3 HT Fuses blows out slowly after 1 Hour (Examined at Field)	Case 1: HT Leads insulation near top of bushing found charred	Case 1: Conservator oil level below bushing rod. Absence of oil around caused heating of leads.	Case 1: Insulation Sleeves changed. Higher oil level was asked to be maintained.
Case 2: Oil spurt out (Similar happening on previous transformers also)	Case 2: B Phase end windings (Top and Bottom found shattered)	Case 2: Lightning surges entered and caused shattering. (Area prone to lightning)	Case2: Coil rewound and sent. The previous failure was also in same “B” Phase. Asked to examine HT LAS of “B” Phase. All three LAS Changed and no such failure thereafter.

Case 3: Undue heating in LT Rod. "R" Ph. Rod worn out and insulation tape charred.	Case3: "R" Phase rod inside connection loosened.	Case3: Connection loosened due to improper handling of bushing during jumper connections.	Case 3: Connections tightened and sent for use. Advised to use checknuts and proper handling.
Case 4: L.T. Voltage Measured-OK. But found drop in voltage when load is connected.	Case 4: Neutral Bushing Connection loosened inside.	Case 4: Improper handling of neutral bushing during meggering.	Case 4: Neutral connection set right and sent for use. Advised to handle bushing connections properly.
Case 5: LT Voltage-OK. But load in "R" Phase could not be loaded.	Case 5: LT & HT connection found alright. No visual defect SC test revealed no current in R Phase, full current in neutral.	Case 5: Examined the soldered connections in "R" Phase and found "R" Phase bottom delta connection improper. (not completely cut)	Case 5: Defective Connections resoldered and found OK. Improper soldering gave way during use.
Case 6: HT Fuse in all 3 Phases blown out.	Case 6: Inter turn short in R Phase-3rd Stack Y Phase-4th Stack B Phase-2nd & 3rd Stack	Case 6: Suspected heavy absorption of moisture. Oil sample not satisfactory. Crackle test proved positive.	Case 6: All good stacks removed. Core with LT coil placed in Hot Air Chamber and dried. Failed coils replaced. Put into use after circulation and test.
Case 7: HT Fuse frequently blows out in "B" Phase.	Case 7: Insulation of lead inside "B" Phase bushing found charred. All coils in Good condition.	Case 7: Insulation of lead inside "B" Phase Bushing found charred. All coils in Good condition.	Case7: Advised the field to release Air monthly. Charred insulation replaced and sent for use.
Case 8: Informed that (a) No oil could be taken from sampling valve-oil not flowing out. (b) Oil level in conservator is full(attended at field).	Case 8: Examined at spot and observed that the "Field Report is correct."	Case 8: Examined at spot and observed that the "Field Report is Correct."	Case 8: Air trapped under the bottom portion and pushed the oil up. Advised to release air frequently through air plug and also through top lid
Case 9: HT in "R" Phase blown out. (Similar failure in 5 months)	Case 9: "R" Phase HT Coils failed with symmetry giving way. LT "R" Phase also failed.	Case 9: Due to Heavy Short Circuit forces because of intermittent feeding of fault current.	Case 9: LT "R" Phase conductor frequently touched nearby neutral. Fuse not blown. Earth value high-30 Ohms. Asked to rectify earthing system and adopt proper LT fuse.

Case 10: HT fuse blowing out on load.(attended at site)	Case 10: Oil level found upto core level only. Gauge glass showing OK level. HT Lead insulation charred due to heat. Coil alright.	Case 10: Gauge Glass indication misleading. Actually oil level is low.	Case 10: Gauge Glass cleaned. Block in air hole removed. Insulation of leads strengthened. Transformer put back in service OK.
Case 11: HT Fuse blown out LT IR Value Zero.	Case 11: All LT leads removed. Now LT Megger value is 30 M Ohms.	Case 11: "Zero"I.R. value is on LT leads & not in transformer.	Case 11: The LT lines and cables was asked to be inspected and defects rectified.
Case 12: HT Fuse is blown out.	Case 12: Core & channel short circuited with "C" phase coil top stack and leads. Earthing of core not found.	Case 12: Core not kept earthed (not provided after repairs). Stray Voltage caused short circuit.	Case 12: Advised the field to revamp earthing system. Transformer condemned since liminations got charred.
Case 13: Transformer changed for two times due to unequal voltage.	Case 13: No fault in the two transformers brought to Lab.	Case 13: Advised to inspect the line for any jumper cut.	Case 13: Reported that one phase line cut on load side with incoming three phase intact in pin insulator (Location in the midst of a lake full of water).
Case 14: Removed as unequal voltage. IR value and continuity OK.	Case 14: Delta connection cut in bottom of "B" Phase	Case 14: May be due to ageing and wear & tear	Case 14: Continuity test is OK since it is connected in Delta. Soldered and sent for use.
Case 15: HT Fuse blown out. IR value and continuity OK.	Case 15: "B" Phase coil inter-turn short in 2nd stack. No shattering of coils/contacting with Earth.	Case 15: Insulation failure due to ageing. Since no earth contact of winding, IR values are OK.	Case 15: Failed stack replaced and sent for use. Flexibility of connection increased and soldered with rod.
Case 16: Unequal voltage. Continuity not found with the "B" Phase HT.	Case 16: HT lead in "B" bushing rod, come out.	Case 16: The lead was tight. Hence came out from Rod.	Case 16: Flexibility of connection increased and soldered with Rod.

Case 17: Oil Sample not satisfactory for 3 consecutive tests.	Case 17: Found heavy sludges & moisture absorption IR value low. Found vent pipe diaphragm broken. Gauge glass broken. Breather all right.	Case 17: Sludging due to ageing, water entry through vent pipe & gauge glass.	Case 17: Oil completely discharged. Core and coil cleaned. Dried in chamber. Put hot oil circulation with new oil and tested OK.
Case 18: Frequent failure of certain make transformer.	Case 18: Causal examination revealed low quantity of oil than that at name plate-260Ltrs. Available 30 Ltrs.	Case 18: Non availability of sufficient oil-very small spacing between tank & core and top cover, leads to failure.	Case 18: Taken up with company by Purchase with. (Ineffective cooling system)

CASE STUDIES OF TRANSFORMER FAILURE WITH ANALYSIS

All three transformers under consideration were supplied by different manufacturers and have the same specifications as follows - 200 kVA, 11/0.433 kV, Dy 11, 50 Hz, 3-phase, high voltage winding current – 10.5 A, low voltage winding current–266.67 A, aluminum wound.

Case	Location	Operated Period	Fault Details	Diagnosis Result
A	rural area	failed after 23 months i.e. within warranty period of 3 years	It was found by inspection that one phase of HV windings was damaged severely. 	Diagnosis results Failure of one phase of HV windings is caused by overloading. Overloading/unbalanced loading due to power theft by hooking or poor maintenance is one of the major causes of transformer failure. It may be assumed that stealing of power by some of the consumers would have been done by hooking the approachable bottom most conductor i.e. B phase of the system. This resulted into severe over loading. 

B	urban area	failed after only 11 months i.e. within warranty period of 3 years	It was found that all three HV windings were charred as shown in figure below:  Fig. 1 All the three LV windings were also found burnt  Fig. 2 shows one phase of burnt LV windings.	It is a case of severe overheating due to overloading. This transformer was supplying residential and some commercial buildings. The large number of personal computers and adjustable speed drives/air conditioners in commercial buildings generate very high levels of harmonics and can result in effective overloading of the distribution transformer supplying the buildings. Cold load pickup (CLP) current may also be considered as one of the reasons of its failure. In India load shedding of 1 to 6 hours is a routine of daily life. CLP current is many times greater than pre outage current which causes heavy overloading of the distribution transformer. The color of oil clearly shows the effect of overheating on the liquid insulation. In A, charred paper insulation present in the oil can be seen at the bottom of the jar. As the conductor is made of Aluminum, it comes out in the melted form and solidifies, which can be clearly seen on the top of the winding. 

C	rural area	failed after 4 years and 4 months i.e. beyond warranty period	It was found by inspection that one phase of both HV and LV windings were severely burnt/damaged as shown in fig below: 	It is again the case of excessive overloading on B phase. The overloading has increased the temperature of B phase of LV winding to such an extent that Aluminum conductor of winding became brittle and came out in the powdered form as shown in figure below. The reason of powdered form is an impurity of Iron in Aluminum i.e. pure Aluminum is not used for conductor. The excessive overloading on B phase would have been caused by unbalanced load poor maintenance, low oil level and no oil level. People hook on lowest conductor which is most approachable i.e. B phase. With this unauthorized connection they run their agricultural pump sets diagnosis as ethylene is the principal gas with some amount of ethane and methane, the cause of which is overheating of the oil. Presence of carbon dioxide and carbon mono oxide indicate the paper degradation. Due to this, there is overheating of the oil take place and causes release of ethylene which is the principal gas with some amount of ethane & methane & ultimately breakdownof the DTs. 

Some Interventions for DTs failures

- To account for short time overloading, use of dual rated transformer may be considered, as this concept is in practice in some developed countries.
- To avoid the overloading of DT due to power theft, ABC cable /UG cable may be used. The ABC cable network will cut short the problem of illegal electricity connection and reduce distribution losses. It would also prevent power theft that is done by taking direct and non-metered connections from HT and LT lines, thus will avoid the overloading and failure of DTs.
- This significant failure rate of distribution transformer in the country can be curbed to some extent by employing Complete Self-Protection (CSP) scheme which enables the transformer to protect itself from faults. In this scheme, transformers are equipped with primary fuses, secondary side circuit breakers and lightning arresters. The primary side fuse is mounted inside the primary bushing and is in series with the primary winding to isolate the transformer in case of faults inside the transformer or on its LT side. Secondary circuit breakers and lightning arresters are there to protect the transformer from overloads, LT side faults and lightning strokes respectively.
- Use of Smart substation in addition to internal protection devices for monitoring internal condition of transformers (specially remote) will be help to use in remote/ rural areas.

ASSET MANAGEMENT PRACTICES

It was mentioned that though rate of failure of DTs has decreased in the last few years, it is still very high. This high rate of failure may be due to either poor quality of product or poor operational practices adopted by distribution utilities. While poor quality of DT could be result of poor quality processes followed during the manufacturing process, poor operational practices could be due to varied reasons.

One of the most important reasons for poor operational practices is poor culture of asset maintenance, as some entities don't undertake any preventive maintenance. As a result, maintenance occurs only after failure of equipment. It has been noticed that culture of maintenance of the assets is better among private than in public sector utilities.

Second reason for poor maintenance is non-availability of money for maintenance. Several utilities in the country are facing acute cash flow problems. This results in avoidance of preventive maintenance costs. However, due to various reasons, purchase of DTs is undertaken.

Finally, the failure rate is generally higher during the warranty period of the transformer as compared to transformers already in operation. While utilities accuse manufacturers of poor quality of material, manufacturers state that utility staff ignores maintenance of the transformer under warranty period. Further, without ascertaining reason for failure and thereby responsibility of failure, manufacturer is forced to undertake repairs of the transformer. As a result, manufacturer is forced to suffer losses.

In order to address these issues, it is suggested that the manufacturer may be asked to provide maintenance services for the warranty period in some sample areas so that they may set an example for proper maintenance of DTs and simultaneously the maintenance staff of utilities may be trained and accustomed for following maintenance practices. The costs associated with sample annual maintenance contract may be included in the initial cost of the transformer and the other modalities of these responsibilities may be worked out mutually. Besides these best practice in procurement and not merely adopting L1 area criterion, good asset management, drawing specifications of material strictly as per relevant BIS standards, drawing selection criterion for experience and quality vendors may be followed. However some space for MSME vendors may be kept.

In the following table current operational practices are tabulated, further proposed practices and key benefits of adopting proposed practices are added in the subsequent columns followed by the initiative taking by authority for the proposed practices.

	Current Practices	**Best Practices**	**Key Benefits & Initiatives**
Tender /Bidding	Tender is open to all interested vendors.	The vendor registration should be based on the past history of the supply of material, number of order completion with the utility and so the process of self-certified vendors based on performance assessment.	Better Vendors Participation
	EMD and Bank guarantee is taken for each tender.	The utility should take certain amount as security deposit on permanent basis.	The process of depositing EMD and BG is avoided.
		Trial order is given to new vendors; third party inspection of factory may be arranged by the utility.	Better Quality
		Regular supplier/s may also be inspected during the manufacturing process by a third party.	Better Quality
		Vendor registration for the raw material can also be carried out to ensure good quality of the raw material is used by the manufacturer.	As raw material suppliers are pre-defined in the tender quality of the raw material is maintained.

	Clause of challenge testing is used by some utilities.	The clause of challenge testing should be incorporated in tender document of all utilities.	Through challenge testing other manufacturers can keep watch on the quality of DT supplied by their competitors to utilities.
	In some private sector utilities tender evaluation is based on the TCO analysis.	Capitalization must be incorporated in every tender and thus the supplier must be judged on the concept of TCO.	This will ensure strict compliance to the guaranteed losses by the strict inspection regime.
	E-bidding process is followed by some utilities only.	It should be made mandatory to follow E- procurement process by all the utilities.	Transparency
	There is neither an in-built qualification criterion in the tender norany process to qualify manufacturers to participate in the tender	Detailed pre-qualification Criteria should be defined in the tender, and followed by all utilities by all the utilities	Quality Vendor Selection
Regulation/ guideline	Many utilities have not started using higher star rated DTs.	As the efficiency of high star rated DT is more than lowstar rated DT, Utility may use the Total owning cost (TOC) method for the analysis of the cost of the DT and take the decision on which DT to be used. GoI & BEE has already issued clear directives for use of star rated DTs.	TOC analysis may be useful analysis when selection is between the high star and low star rated DT, if the TOC cost of the high star rated DT is more, utility may should go for the use high star rated DT, even though the initial capital cost is higher for high star rated DTs
Customer Interface Process			
Proposal management	Tendered quantity is offered only to the L1 bidder	Quantity may be divided in the group of L1, L2.	As the quantity is divided into the L1, L2 …. if any vendor fails to supply the DT at offered price or may be due to some other reason, continuity of the supply of the DT is will not disturbed
Contract award	Contract is awarded on the basis of L1 criteria.	Tender evaluation using Weighted Average Criteria.	Low quality material supplier vendor may get eliminated
		Tender evaluation should be done based on both technical and commercial terms. History of the manufacturer should be considered. History of supply may include order completion period, delay in the schedule etc.	Equal emphasis is given to quality and cost.
Quality Process	Utility demand for the test certificate of the raw material and the Type test certificate for the DT.	If the clause of the use of the raw material from the registered supplier is mentioned in the tender then the quality of the raw material may be maintained.	

	Inspection for the raw material check and during the mfg. process of DT is arranged. However, many times the inspection is only on paper.	Fixing the responsibility of the Officer coming for the inspection may be more effective. The KPI for the inspected officer may be maintained for future record.	Officer will ensure the inspection and will become more aware of his responsibilities.
Warranty Process	Warranty terms and condition are not defined.	Fault covered under the warranty condition should be defined.	Negligence in operations, loading, maintenance of DT avoided. DT failure rate under warranty conditions may reduce.
		Warranty is given for the manufacturing defect only.	National loss due to negligence may be avoided.
		DT failure analysis may be arranged out by the joint inspection with the DTM.	Guilty person will be punished.
	Current Practices	**Best Practices**	**Key Benefits & Initiatives**
		Fixing the responsibility of the utility person after failure analysis and bringing the failure in the KPI index of the maintenance in charge.	Utility practices of O&M will improve.
Collection Process	Manufacturer supply DTs to the location specified by the utility in the order.	Central Store should be formed by utility. DTs will be transferred to the required place from central store by utility.	The revenue loss due to off supply of the Utilities and customers will reduce. If DT were collected at the central store, utility would have the facility to test DTs.
Operations Process			
Testing Process	Routine test is carried by many utility on sample taken from DT lot delivered by manufacturer to storage	Each and every DT from factory should be visually inspected at the store for any physical damage.	If Utility goes for 100% DT testing, then inspection during the manufacturing process may be avoided. **Initiative can be taken by the utility.**
		Utility may go for the CUT- OPEN testing of DT at their store rather than visiting the manufacturer factory	Malpractices during the inspection of the manufacturing process may be avoided
		Utility should go for losses testing at store for the same percentage of the random sample selected from the lot size.	
		Each and every DT should be going through the following test at Utility store. • Insulation resistance test. • Losses test.	As each and every DT is tested, DT failure rate may reduce and loss due to transportation, installation of DT may be saved.

	Many utilities have started using poly numbered seal; one nameplate duly engraved with the details of mfg. months, Sr. no. etc. which is welded on one side of tank and sr. no. to be engraved/ punched on top core mounting channel. This is incorporated for receiving tested transformers.	Should be standard practice and followed by all utilities.	For maintaining the history of DTs.
	Current Practices	**Best Practices**	**Key Benefits & Initiatives**
Installation Process	Installation of DT iscarried by the contractor employed by the utility.	Utility authority should keep keen watch on the work carried by the contractor. Fixing up the responsibility for the installation of DT may be carried out.	DT failure rate may reduce.
	The relevant IS standard is not followed by the contractor, workers due to lack of knowledge.	Utility offices should take care that the IS standards followed and proper protection devices should beinstalled.	DT failure rate may reduce.
	Adequate protection for the DT is not provided nor maintained.	DT manufacturer may give checklist for the Do's and Don'ts.	DT failure rate will reduce.
Maintenance Process	Maintenance carried by contractor/utility staff.	Proper training of maintenance should be given to the utility staff. Log book should be maintained by the utility. Maintenance activity should be assessed by utility's higher authority.	DT failure rate will reduce. Initiative can be taken by the utility.
	Establishing a good DTs repair workshop	Establishing a well-equipped DTS workshop having facilities for coil rewinding, oil BDV test, Dissolved gas analysis test, tan-delta test, corrosive sulphur test, flash & fire point test etc. A proper record of all test carried out should be maintained.	Maintaining Test certificate of DTs post repair will help in root cause analysis, performance evaluation, providing solution matrix for corresponding root cause. This will ultimately result in reduction of DT failure rate and improvement in system efficiency.

CHAPTER-4
PREVENTIVE & PREDICTIVE MAINTENANCE SCHEDULES FOR OIL FILLED/ DRY TYPE DISTRIBUTION TRANSFORMERS

Transformer is the heart of any power system. Hence preventive maintenance is always cost effective and saves time. Any failure of the transformer affects the functioning of the power system and reliability of supply. Following are some operational and maintenance practices that must be included in the maintenance schedule for better performance of the DT.

Care to be Exercised to Avoid Failure		
In Manufacturing Stage	**During Transport**	**In Working Conditions**
1. Proper insulation arrangement. 2. Mechanical rigidity to withstand heavy forces. 3. Adequate cooling arrangement. 4. Adequate quantity of oil for insulation & cooling. 5. Maintaining atmospheric pressure inside with pure air. 6. Rigid fixing of core coil unit inside main tank. 7. Pucca earthing of core & other metallic parts.	1. Safe handling during transport and erection. 2. Adoption of standards for erection of transformer structure. 3. Utilizing standard methods of lifting of Transformers i.e. cranes, chain pulley instead of handling by pulling through bushings.	1. Maintenance of oil level. 2. Maintenance of Breather with silicagel & oil seal. 3. Periodical testing of IR Values. 4. Periodical tests in transformer. 5. Earth resistance values and Earth maintenance. 6. Keeping standard voltage & current at load terminals. 7. Maintaining LAS to prevent damage due to surges. 8. Maintaining LT System 9. Keeping the loading within the limits. 10. Standard Construction of LT lines.

It may be noted that the list given is not exhaustive. Further, some/all of practices mentioned below may already be part of the maintenance manual of distribution utilities. Comprehensive list of activities may be drawn by utilities in consultation with transformer manufacturers and as per IS 10028 Part 2 & 3-1981, IS 1180 Part 1-2014 & IS 2026 Part-1, their subsequent parts and amendments. Such lists should be made available at every distribution substation. Following list has been drawn on the basis of components/parameters of the distribution transformers.

- Oil:
  - Oil level checking. Leakages to be attended.
  - Oil BDV and acidity checking at regular intervals. If acidity is between 0.5 to 1mg KOH, oil shouldbe kept under observation.
  - BDV, Color and smell of oil are indicative.
  - Sludge, dust, dirt, moisture can be removed by filtration.
- Insulation Resistance:
  - Insulation resistance of the transformer should be checked once in 6 months.
  - Megger values along with oil values indicate the condition of transformer.
- Bushings:
  - Bushings should be cleaned and inspected for any cracks.
  - Dust and dirt deposition, Salt or chemical deposition, cement or acid fumes depositions should becarefully noted and rectified.
- Periodic checking of any loose connections of the terminations of HV and LV side.
- Breather examination. Dehydration of Silica gel if necessary.
- Explosion-vent diaphragm examination.
- Conservator to be cleaned from inside after every three years.
- Regular inspection of oil and winding temperature meter readings.
- Cleanliness in the Substation yard with all nets, vines, shrubs removed.
- Each and every transformer operating in the system must be reconditioned after a specified running cycle, maybe after 15 to 20 years while considering the reconditioning of such transformers, the active repair approach may be considered, to achieve technical loss reduction, enhance KVA capacity and reliability Under the active repair core is kept unchanged and all corrections are affected through winding redesign and/or change of material i.e. from Aluminum to Copper. However the core is also restacked tightly to reduce the air gap between the laminations.

a) Check list for Distribution Transformers

1. For oil filled Distribution Transformers

Sl. No	Type of Check	Item	Frequency	Points to be checked	Action to be taken in case of any anomaly
1	Physical condition	Breather	As and when required/ Half Yearly	a) Silica Gel should be blue. b) No crack in body of breather & oil cup c) Oil level in oil cup should be up to the mark	a) If not, replace with blue silica gel. b) If any defect in body/cup replace it. c) If not oil filling to be done in cup up to the mark
2	Physical Condition	Oil leakages	As and when required/ Half yearly	a) Check for any oil leakage from transformer tank, radiators, HV-LV bushings& any gasket joint etc.	a) Oil leakage to be attended at site, if not possible at site then transformer to be sent to work shop.
3	Physical Condition	Oil level	As and when required/ Half yearly	a) Oil level to be checked in gauge.	a) If oil level not up to the mark then oil top up to be done immediately with fresh oil.
4	Physical Condition	Palm connector & AL bus -bar	Yearly	a) Check for any arcing /pitting mark on Palm connector & AL bus-bar. b) Check for any discoloration due to local heating.	a) If any defect Palm connector & AL bus bar to be replaced separately.
5	Physical Condition	HV-LV bushings	Yearly	a) Check for any crack/ flash mark on HV-LV bushingsif any. b) Check for dust on HV-LV bushing.	a) Defective Bushing tobe replaced. b) Bushing to be cleaned with dry cloths.
6	Physical Condition	Tank body & radiators	Yearly	a) Check for dust & rust on transformer body & radiators.	a) Tank body & radiators to be cleaned. b) Painting is to be done if required.
7	Physical Condition	Tank body earthing	Yearly	a) Tank body should be earthed at two places with separate earthing point.	a) If not, tank body earthing to be done at two places.
8	Physical Condition	Neutral earthing	Yearly	a) Neutral should be earthed at two placedwith separate earthing point.	a) If not, neutral earthing to be done at two places.
9	Physical Condition	Arcing horns	Yearly	a) Check for pair of arcingon each phase of HV bushing. b) Check for alignment of arcing horn.	a) If not, then arcing horns to be fitted. b) Arcing horn alignment to be done.
10	Electrical	Earth resistance	Yearly	a) Earth resistance shouldbe = <1 Ohm	a) If not then check for earthing pit or go for new earthing

11	Electrical	IR Value	Yearly	a) IR value shall be equal forall three phases for HT-E,LT-E, HT-LT. b) Normally IR value shall be minimum 100 MΩ for HV& 50 MΩ for LV windings at the temp of 50°C. c) Compare previous & present IR value.	a) If not then recheck the IR values. b) If values are lower than the values specified then plan for overhauling/ replacement. c) If IR value decreased more than 20% then need to investigate.
12	Electrical	Oil BDV	Yearly	a) BDV of transformer oil have to be greater than 30 kV (avg) at 2.5 mmgap.	a) If oil BDV is less than 30 KV then plan for overhauling/ replacement.
13	Mechanical	HV-LV termination	Yearly	a) Check for intactness of HV–LV termination, cleaning for LV leads & HV cable. b) Check for any tension on HV-LV terminals due to cable/ conductor.	a) If not tightening HV-LV nut-bolt and accessories to bedone. b) Tension on HV-LV terminals due to cable/ conductor to be rectified.
14	Mechanical	Vibration in transformer	As and when required/ yearly	a) Check for any abnormal sound from transformer. There should be a healthy humming sound.	a) If abnormal sound observed then keep watch/plan for overhauling/replaceme nt.
15	Electrical	Thermo scanning	As and when required/ Half yearly	a) Check for thermo scanning half yearly/ before and after of planned maintenance during pre and post maintenance visit.	a) Take corrective action if hot spot and other abnormality detected.
16	Electrical	Oil	Every five year of service	a) In addition to Oil BDV given additional test to be conducted on oil every five years of service; Wate r content<35 PPM, Tan delta<0. 5, Resistivity>1.0x10^11o h m-cm, Acidity<0.30 mg KOH/g, Sludge-0% by wt, and Flash point>125	a) If results are not with in limit then transformer to be sentfor overhauling at work shop.

2. Checklist for mobile trollies

Sl. No.	Type of Check	Item	Frequency	Points to be checked	Action to be taken in case of any anomaly
1	Physical Condition	Trolley	As and when required/ Half yearly	a) Check for physical condition of trolley.	a) If damaged then plan for rectification.
2	Physical Condition	Tyre	As and when required/Half yearly	b) Check for condition of tyres. c) Check for air pressure in tyre.	a) If damaged then plan for rectification. b) If not ok then plan for filling of air.
3	Physical Condition	Earthing	As and when required/ Half yearly	a) Check for earthing between transformers to earthing point provided on trolley.	a) If not ok then rectification to be done.

3. Checklist for Testing

Sl. No.	Type of Test	Test	Significance	Frequency	Minimum/ Maximum required values
1	Electrical	BDV	Poor oil BDV shows ingress of moisture, dust and carbon particles.	Yearly	>30 KV (as per IS 1866)
2	Chemical	Water Content	Water (Moisture) will dissolve in insulating oil and will contribute a hazard not only to the dielectric performance of the oil itself but also to the solid insulation immersed in oil.	5 yearly/as and when required	<35 PPM
3	Chemical	Tan Delta	It is a good value to indicate the quality of insulation. High value of DDF indicates the presence of contaminants, deterioration products such as water, oxidation products, metal soaps, soluble varnishes and resins.	5 yearly/as and when required	<0.5
4	Chemical	Flash Point	It is the minimum temperature at which heated oil gives off sufficient vapour to form a flammable mixture with air.	5 yearly/as and when required	>125
5	Chemical	Resistivity	It is the resistance between the opposite phases of a centimeter cube of the liquid. IR of the windings in a transformer depends on the resistivity of the oil also. Low resistivity indicates the presence of moisture and or conductive contaminants in oil.	5 yearly/as and when required	>1x10^11 ohm-cm

6	Chemical	Sludge Content	Sludge is oil deterioration products or contaminates, or both which are insoluble in oil.	5 yearly/as and when required	0% by weight
7	Chemical	Acidity	Measure of free organic and inorganic acids present together in the oil.	5 yearly/as and when required	<0.30 mg of KOH/g (as per IS 1866)

4. For Dry Type Transformers

S No	Type of Check	Item	Frequency	Points to be checked	Action to be taken in case of any anomaly
1	Physical Condition	HV-LV bushings	Yearly	b) Check for any crack/ flash mark on HV-LV bushings if any c) Check for dust on HV-LV bushing.	a) Defective Bushing to be replaced. b) Bushing to be cleaned with dry cloths.
2	Physical Condition	Enclosure, Doors, marshaling Box	Yearly	a) Check for dust & rust on enclosure & HV-LV Cable box.	a) Enclosure & HV-LV cable box to be cleaned.
3	Physical Condition	Enclosure doors & marshaling box Door	Yearly	d) Check for doors are properly closed or not. e) There should not be any open space at cable (HV & LV) inlet & earthing strip.	a) Ensure all doors shall be properly closed. b) Any open space/gap to be filled with insulating material.
4	Physical Condition	Marshaling Box	Yearly	a) Check for working/setting for thermostat.	a) Proper setting to be done if required.
				b) Check for working and physical condition of energy meter. c) Check for working for lamp.	b) Energy meter should be in working condition. c) Lamp should be switched off when door is closed.
5	Physical Condition	Active part	Yearly	Check for dustdeposition over core coil assembly of transformer.	Dust cleaning to be done with the help of air blower if required.
6	Physical Condition	Enclosure Earthing	Yearly	a) Enclosure should be earthed at two placed with separate earthing point.	a) If not, tank body earthing to be done at two places.
7	Physical Condition	Neutral earthing	Yearly	a) Neutral should be earthed at two placed with separate earthing point.	a) If not, neutral earthing to be done at two places.
8	Electrical	Earth resistance	Yearly	a) Earth resistance should be = <1 Ohm	a) If not, then check for earthing pit or go for new earthing.

9	Electrical	IR Value	Yearly	a) IR value shall be equalfor all three phases for HT-E, LT-E and HT-LT. b) Normally IR value shall be minimum 100 MΩ for HV & 50 MΩ for LV windings at temp of 50°C.	a) If not then recheck the IR values. b) If value is lower than the values specified then plan for overhauling/replacement.
10	Mechanical	HV-LV termination	Yearly	a) Check for intactness of HV-LV termination b) Check for any tension on HV-LV terminals due to cable.	a) If not tightening, HV-LV nut-bold and accessories to be done. b) Tension on HV-LV terminals due to cable to be rectified.
11	Mechanical	Vibration in transformer	As and when required/ yearly	a) Check for any abnormal sound from transformer. There should be a healthy humming sound.	a) If abnormal sound observed then keep Watch/plan for overhauling/replacement.
12	Electrical	Thermo scanning	As and when required/ Half yearly	a) Check for thermo scanning half yearly/before and after of planned maintenance during pre and post maintenance visit.	a) Take corrective action if hot spot and other abnormality detected.
13	Electrical	Exhaust fan	As and when required/ Half yearly	a) Check for working of exhaust fan.	a) Ensure for working of exhaust fan.

5. Maintenance Schedule for DTs of capacity less than 1000 KVA (As per IS 10028 Part-III 1981):

Inspection Frequency	Items to be inspected	Inspection Note	Action required if Inspection shows unsatisfactory conditions
Online status monitoring through Communicating/Smart Meters (AMI/AMR)	1. Load (Amp.) 2. Temperature 3. Voltage	• Checks against rated values • Oil/ambient temperature. • Check against rated figures.	• Check for reasons
Monthly status monitoring	Dehydrating breather (if available)	• Check air passage and color of silica gel	• If Silica gel is pink, change by spare charge. The pink gel may be re-activated for reuse.

	1. Oil 2. Connection Bushing 3. Unbalancing	• Check oil level. • Check tightness. • Check load on all the three phases and neutral current	• If low, top up with dry oil and examine cause of leak. • If loose, tighten. • If unbalancing is found, action should be taken for balancing of load in all phases.
Quarterly	Bushing	• Examine for physical cracks and dirt deposits. • Check load on all the three phases and neutral current • Check for thermo graphic scanning of Critical DTs	• Clear or replace. • If unbalancing is found, action should be taken for balancing of load in all phases.
Half Yearly	1. Non-conservator transformer 2. Cable box, gasketed joints. 3. Gauges, Painting.	• Check for moisture under cover. • Inspect. • Inspect.	• Improve ventilation, check oil. • Attend to remove defects. • Attend to remove defects.
Yearly	1. Oil in transformer 2. Earth resistance 3. Relays, alarm and their circuits etc.	• Check for dielectric strength, water content, acidity and sludge. • Examine relays and alarm contacts, their operations and fuses etc. • Checks relay accuracy.	• Take suitable action to restore quantity and quality of oil. • Take suitable action if earth resistance is high. • Clear the components and replace contacts and fuses, if necessary, Change the setting, if necessary.
2 Yearly	Non-Conservator transformer	• Internal inspection above core.	• Filter the oil regardless of condition.
5 Yearly		• Overall inspection	

6. Maintenance Schedule for Transformer of Capacity 1000 KVA and above:

Inspection Frequency	Items to be inspected	Inspection Note	Action required if Inspection shows unsatisfactory conditions
Online through Communicating Meters (AMI/AMR)	1. Ambient Temperature 2. Winding and oil temperature 3. Load (ampere) andvoltage.	• Check if temperature rise is reasonable. • Check against rated figures.	• Nil • Shut down the transformerand investigate if either is persistently higher than normal. • Nil

monthly	1. Oil level in bushing 2. Relief diaphragm 3. Silica gel breather	• Check against transformer oil level. • Check the air passage for free; • Check color of the active agent.	• If low, top up with dry oil, examine the transformer forleaks. • Replace if found cracked orbroken. • If Silica gel is pink, change by spare charge. The pink gel maybe re-activated for reuse.
Quarterly	1. Bushing 2. Oil in transformer 3. OLTC 4. Indoor transformer	• Examine for physical cracks and dirt deposits. • Check for dielectric strength and water content. • Check oil in OLTC and driving mechanism. • Check ventilation. • Check for thermo graphic scanning of Critical DTs	• Clear or replace. • Take suitable action to restore quantity of oil. • Replace burst or worn parts orother defective parts. • Nil
Half Yearly	1. Oil Cooler	• Test for pressure.	• Nil
Yearly	1. Oil in transformer 3. Oil filled bushing Cable boxes 4. Gasket joint 5. Surge deviator 6. Relays, alarm andtheir circuits etc. 7. Earth resistance	• Check for dielectric strength, water content, acidity and sludge. • Test oil. • Inspect. • Examine for cracks and dirt deposits. • Examine relays and alarm contacts, their operations, fuses etc.	• Take suitable action to restorequality of oil. • Filter or replace. • Nil • Tighten the bolts evenly toavoid uneven pressure. • Clean or replace. • Clear the components and replace contacts and fuses, ifnecessary. • Take suitable action if earthresistance is high.
	8. Cable boxes 9. Gasket joint 10. Surge deviator 11. Relays, alarm andtheir circuits etc. 12. Earth resistance	• Inspect. • Examine for cracks and dirt deposits. • Examine relays and alarm contacts, their operations, fuses etc.	• Nil • Tighten the bolts evenly toavoid uneven pressure. • Clean or replace. • Clear the components and replace contacts and fuses, ifnecessary. • Take suitable action if earth resistance is high.
5 Yearly	1000 KVA to 2500 KVA	• Overall inspection including lifting of core coil unit.	• Wash by housing down withclean oil.
7 to 10 Yearly	Above 2500 KVA	• Overall inspection	

7. Troubleshooting Chart for all Transformers

Trouble	Cause	Remedy
Rise in temperature		
High temperature	Overvoltage	Check the circuit voltage or transformer connections to avoid over excitation.
	Overcurrent	If possible, reduce load. Heating can often be reduced by improving power factor of load. Check parallel Circuits for circulating currents which may he caused by Improper ratios or impedances.
	High Ambient temperatures	Either improve ventilation or relocate transformer in lower ambient temperature.
	Insufficient cooling	If unit is artificially cooled, make sure cooling is adequate
	Lower Liquid Level	Fill to proper level.
	Sludge oil	Use filter press to wash off core and coils. Filter oil to remove sludge.
	Short circuited core	Test for exciting current and no-load loss. If high, inspect core and repair.
Electrical Troubles		
Winding Failure	Lighting. Short-circuit	Usually, when a transformer winding falls, the transformer is automatically disconnected from the power source by theopening of the supply breaker or fuse. Smoke or cooling liquid may be expelled from the case, accompanied by noise.When there is any such evidence of a winding failure, the transformer should not be re-energized at full rated voltage, because this might result in additional internal damage. Alsoit would introduce a fire hazard in transformers. After disconnection from both source and load, the following observations and test are recommended. a) External mechanical or electrical damage to bushings,leads, potheads, disconnecting switches, or other accessories b) Level of insulating liquid In all compartments, c) Temperature of insulating Liquid wherever it can be measured. d) Evidence of leakage of insulating liquid or scaling compound.
	Overload	
	Oil of low dielectric strength	
	Foreign material	
Core Failure	Core-insulation break down (Core, bolts, clamps, or between laminations)	
High exciting current	Short-circuited core	Test core loss. If high, it is probably due to a short-circuitedcore. Test core insulation. Repair if damaged. If laminations are welded together, refer to manufacturer.
	Open core joints	Core-loss test will show no appreciable increase. Pound joints together and retightens clamping structure.
Incorrect Voltage	Improper ratio	Change terminal-board connection or ratio-adjuster position to give correct voltage.
	Supply voltage abnormal	Change tap connections or readjust supply voltage.
	High-resistance joint / connection inside DT main tank	Joints through proper lugs to avoid leakage/high resistance or may use tight screw joint.
Audible internal arcing and radio interference	Isolated metallic part	The source should be immediately determined. Makecertain that all normally grounded parts are grounded, such as the clamps and core.
	Loose Connections	Same as above. Tighten all connections.

	Low liquid level, exposing live parts	Maintain proper liquid level.
Bushing flashover	lightning	Provide adequate lightning protection
	Dirty Bushings	Clean bushing porcelains, frequency depending on dirt accumulation.
	No / insufficient amount of dielectric / insulating material near collar region	Provide proper/ sufficient amount of dielectric / insulating material.
Mechanical Troubles		
Leakage through screw joints	Foreign material in threads. Oval nipples, Poor threads, Improper filler, Improper assembly.	Make tight screw joints or gasket joints.
Leakage at gasket	Poor scarfed joints, insufficient or uneven Compression, Improper preparation of gaskets and gasket surface.	Tighten the gasket joints by applying a uniform pressure with uniform tightening by torque spanner having pressuregauge.
Leakage in welds	Shipping strains, imperfect weld	Repair leaks in welds.
Pressure-relief diaphragm cracked	Improper assembly. Mechanical damage	Replace diaphragm. Inspect imide of pipe for evidence of rust or moisture. Be sure to dry alit transformer if there is achance that drops of water may have settled directly on windings or other vulnerable locations, as oil test may not always reveal presence of free water.
Pressure-Teller diaphragm ruptured	Internal fault	Check to see that valve between conservator and lank isopen and that ventilator on conservator is not blocked.
	In conservator transformer- obstructed oil flow or breathing	
	In gas-seal transformer- obstructed pressure relief valve	Make certain that relief valve functions and their valves In discharge line are open.
	In sealed transformer- liquid level too high	Liquid level should be adjusted to that corresponding Withliquid temperature to allow ample space for expansion of liquid.
Moisture condensation in open-type transformers and air filled compartments	Improper or insufficient ventilation	Make sure that all ventilator openings are free.
Moisture condensation in sealed transformers	Cracked diaphragm	See remedies above for cracked and ruptured diaphragms.
	Moisture In oil	Filter all.
Audio noise	Leaky gaskets and joints. Accessories and external transformer parts are set Into resonant vibration giving off loud noise	Make certain all joints are tight. Tighten loose parts. In somecases parts may be stressed into resonant slate. Releasing pressure and shimming will remedy this condition.
Rusting and deterioration of paint Finish	Abraded surfaces and weathering	Bare metal or mechanical parts should be coveted With grease.

Fractured metal or porcelain parts of bushings	Unusual strains placed on terminal connections	Cables and bus-bars attached to transformer terminals should be adequately supported. In the case of heavy leads, flexible connections should be provided to remove strain on the terminal and bushing porcelain.
Oil Troubles (see also IS: 1866-1978 & IS 335)		
Low dielectric strength	Condensation in open type transformers from improper ventilation	Make certain that ventilating openings are unobstructed
	Broken relief diaphragm	Replace diaphragm.
	Leaky cooling coil	Test cooling coil and repair
Badly discolored oil	Contaminated by varnishes carbonized oil due to switching winding or core failure	Retain oil if dielectric strength is satisfactory.
Oxidation (sludge or acidity)	Exposure to air	'Wash down' core and coils and tank. Filter and reclaim or replace oil.
	High operating temperature	Same as above. Either reduce load or improve cooling.

8. Checking Format for maintenance schedule of DTs

S.N.	Description	Frequency	Remark
1.	Load on all three phases of transformer and for unbalancing of load	Daily	For transformer of 1000KVA & more
2.	Oil temperature – Ambient temperature	Daily	For transformer of 1000 KVA & more
3.	Voltage on each phase	Daily	For transformer of 1000 KVA & more
4.	Dehydrating breather silica zed color	Daily	For transformer of 1000 KVA & more
5.	Oil level in transformer and oil leakage from tank or bushing	Monthly	For all capacity
6.	Sound and vibration of transformer	Monthly	For all capacity
7.	Bushing for cracks and dirt deposit	Quarterly	For all capacity
8.	Earthing of transformer body, neutral point	Quarterly	For all capacity
9.	Rusting or deterioration in paint finish	Quarterly	For all capacity
10.	Any special remark		
Date		Signature Name	

9. Causes & Effects

Abnormality	Causes/ Effect	Preventive-Corrective action plan
Electrical Stress	1. Flash over due to Phase to phase & Phase to earth clearance at cable termination	Ensure sufficient clearance
	2. Termination failure due to Core crossing above cut back area at cable termination	Ensure core crossing below cut back area at cable termination
	3. Termination failure due to Contaminated surface of terminations	Ensure cleanliness of terminations
	4. Cable failure due to Cable testing at high voltage (DC)	Ensure Testing at Recommended Voltage
Mechanical Stress	1. Stress develop due to Improper Bending Radius	Ensure Proper Bending radius
	2. Stress develop due to Mechanical vibrations	Ensure proper depth
	3. Stress develop due to Improper cable supports	Ensure proper span length
Thermal Stress	1. Insulation degradation due to overloading	Ensure Recommended Loading
	2. Insulation degradation due to Hot spot at joints & Terminations	Ensure proper Tightening/ crimping of Lugs & Ferrules
	3. Insulation degradation due to Improper Earthing connections	Ensure Cable earthing connected with Sub-station earthing
External damage	Insulation Damaged by external agency	Ensure Patrolling of cable routes
Water ingress	Leakage current through the cable insulation/ cable failure, Corrosion in cable conductor & Armour due ingress of water	Ensure Lug seal to be intact at outdoor termination.

10. Storage & Handling of insulating oils-

Following care should be exercised in storage and handling of oil barrels-

1. Rough handling of drums should be avoided.
2. Drums should not be kept in open but should be stored under cover.
3. Drums should not be kept in vertical position with its plug on the top.
4. It should be placed in horizontal position in such a way that there is a head of oil on the stopper or plug to prevent the entry or water or moisture.
5. Oil from drums should always be treated before use.
6. Vessel or drum for handling of oil should always be clean, free from dust, dirt contaminants or moisture. Flexible pipe and hand pumps used for taking out and filling oil should also be clean, their end be covered properly so as to avoid being contaminated.

Appearance (Few Thumb Rules to be applied to know the health of T/f oil)-

1. Colour:- The colour of oil darkens with the age. Very dark colour may suggest excessive oxidation.
2. Clarity:- Cloudiness if it appears while cooling of oil sample, is indication of presence of moisture which can be confirmed by crackle test. If cloudiness is present when oil sample is warm and oil does not become clear even after heating, it is an indication of contamination. A greenish tinge will indicate presence of copper slats which usually occurs during advance stage of deterioration of oil.
3. Smell- (1) Gassy smell suggests the cracking of oil.
   (2) A Strong acid smell suggests the presence of excessive amount of volatile acids due to deterioration of oil.
   (3) A pungent acetylene like smell which is common in oil samples drawn from switchgear, if present in oil sample drawn from a transformer indicates gas formation due to arcing or hot spots etc.

Final conclusions have to be drawn only after the others tests are made and not merely on the basis of above observations.

CHAPTER-5
TESTS, RECOMMENDED TOOLS AND TEST DATA

The DTs are required to be tested at manufacturer end, thereafter routine test in the field and aftercarrying out the maintenance/ repair work as per IS 1180 Part-1, IS 2026 Part-1 to 5.

Routine Tests

- Ratio, polarity and phase sequence.
- No load current and losses at rated frequency, rated voltage and at 90% & 110% voltage.
- Load loss at rated current and normal frequency
- Impedance voltage test
- Resistance of windings
- Insulation resistance
- Induced over voltage withstand test.
- Separate source voltage withstand test.
- Neutral current measurement
- BDV and moisture content of oil in transformer (For mineral oil : IS 335 (2018), Ester oil : IEC 60247 & IEC61099)

Special Tests

- Lightening impulse chopped on the tail.
- Short circuit test.
- Transformer tank together with its radiator and other fittings shall be subjected to pressure corresponding to twice the normal pressure or 0.35 kg/cm^2 whichever is lower, measured at the base of the tank and maintained for an hour. The permanent deflection of the flat plates after the excess pressure has been released, shall not exceed the figures for vacuum test.
- The pressure relief device shall be subject to increasing fluid/air pressure. It shall operate before reaching the test pressure as specified in the above clause. The operating pressure shall be recorded. The device shall seal-off after the excess pressure has been released.
- Oil samples (one sample per lot) to comply with IS 1866.
- Single phase LV excitation current at all three phases (for reference)

Type Tests to be conducted on one Unit

- In addition to the tests mentioned above the following tests shall be conducted.
- Temperature rise test.
- Lightening impulse withstand voltage test :

- Oil samples (before and after short-circuit and temperatures rise test) for each tested transformer

Typical Tests carried out before commissioning / energizing of DTs

1) General inspection	a) Control and relay panels, etc. b) Junction boxes and marshalling kiosks.
2) Secondary injection	On all transformer protection relays
3) Primary injection (also to be repeated at the end of all othercommissioning tests)	a) Tests on operation and stability of earth fault relays on high voltageside. b) Tests on line directional elements of high-voltage line relays. c) Tests on high speed neutral ammeter. d) Tests on overcurrent relays on low- voltage side. e) Tests on operation and stability of earth fault relays on low-voltage side. f) Tests on operation of standby earth fault relay on low-voltage, side. g) Tests on overcurrent relay on high- voltage side (when currenttransformers are not in transformer bushings). h) Voltage compensation.
4) Ratio tests	a) With 415 V applied on high-voltage side, measure the voltage betweenall phases on the low-voltage side for every tap position. b) To check phasing, measure volts : A to a, b and c B to a, b and cC to a, b and c Where A, B and C are the terminals of three phases on high-voltage side and a, b and c are the corresponding terminals on low-voltage side. c) Magnetic balance test.
5) Tripping tests	a) High voltage. b) Low voltage. c) Inter-tripping tests. d) Winding temperature trips.
6) Calibrate earthing resistance	---
7) Buchholtz relays	a) Tests for angle, air injection, etc. b) Check that there is no air in protector before commissioning. c) When energizing transformer, close in on ‘Trip’, etc. d) Check for stability when oil pumps are started: 1) at ambient temperature, 2) At a winding temperature of 80°C or above.
8) Alarm circuits	a) Buchholtz relay

	b) Oil and winding temperature thermo- meter. c) Cooling gear failure.
9) Fans and pumps	a) Check that the oil valves are open in cooling circuit. b) Check the rotation of pumps, automatic starting overload devices, etc. c) Check stability of Buchboltz relay [see7 (d) above].
10) Tap changing tests to check mechanism, indication, buzzer, lamp, etc.	---
11) Phasing tests	a) At 4 15 V [see 4 (b) above]. b) Between transformers in a bank. c) To prove internal and external connection for parallel operation. d) On auxiliary supplies and voltage transformers.
12) Insulation tests	a) On high and low voltage windings. b) On current and voltage transformers, circuits, etc.
13) Site test for oil	a) Check oil level. b) Dielectric test. c) Volume resistivity. d) Acidity e) tan delta f) Water content.
14) Voltage compensation test (if compensating current transformers are fitted)	a) Primary injection [see 3 (h) above]. b) Load tests [see 20 (g) below]. c) If necessary, switch in with relays connected to correctly compensated voltages from the other transformer.
15) See that neutral earthing switches are closed before making alive.	---
16) Check transformers on equal taps before switching in.	a) For transformers in a bank. b) For transformers in parallel.
17) Set down relays before closing in-advise control	---
18) If necessary, arrange temporary protection for soaking and switching in, for example unrestricted earthfault, if soaking from low voltage side with 113 V and 213 V open	---
19) Set up relays after soaking and before going on load-advise control.	---

20) Load tests	a) Voltmeter, ammeters, etc., on both high and low voltage sides. b) Overcurrent. c) No spill in high voltage star point. d) No creeping of contacts on both high and low voltage earth faultrelays e) Voltages on relays. f) Directional elements - low voltage, directional overcurrent and theearth- fault relays (if fitted). g) Voltage compensation.
21) Tap changing test on load over full range of taps	---
22) Advise control of any new equipment commissioned	---
23) If possible for transformers rated above 1000 kVA, when beingenergized for the first time, the voltage should be built up gradually	---
24) Low voltage excitation current	---
25) Single-phase, magnetic balance Test	---

LIST OF TOOLS FOR MAINTENANCE & TESTING EQUIPMENT

A tentative list of tools required for the activities related to transformer repairing at site is given below:

Sl. No.	Tools
1	Special tools for dismounting of the OL TC.
2	D shackles -1 ton
3	D shackles -5 ton
4	D shackles – Max. load /3, multiple quantities
5	Slings - 1 ton (wirerope/nylon)
6	Slings – 5 tons (wire rope/nylon)
7	Slings – Max load/3, (wire rope) 4 nos.
8	Pump – 1/2 hp
9	Pump – 3 hp + starter
10	Hose 25 m long minimum (multiple quantities)
11	Extension board – 3 ph& 1 ph
12	Spanners DE type (size : 8-9 to 32-36
13	Spanners ring type (size : 8-9 to 32-36)
14	Ring & DE spanner 55 size
15	Box spanner (size : 8-9 to 32-36)
16	Torque spanner with pressure gauge meter.
17	Sledge hammer – 5 kg
18	Hammer - 1 kg
19	Mallet

20	Screwdrivers -various sizes
21	Hacksaw frame standard size
22	Hacksaw blades HSS type
23	Tommy bars -20 mm dia 3 ft' lon
24	Chisels: 1 in wide, 2' wide
25	No. punch (8x8) various sizes
26	Flat files (small & regular
27	Half round files (small & regular)
28	Round files (small & regular
29	Welding machine
30	Drilling machine
31	Grinding machine
32	Gas cutting set with cylinders
33	Pipe 3" dia 5 ft. long
34	Knives for paper cutting etc.
S.No.	**Special Tools**
1	Winding lifting arrangement
2	Lead cutting tools
3	Brazing machine
4	Brazing rods
5	Brazing torch nozzles and oxy-acetylene cylinders
6	Hydraulic Crimping Tools (cutting tools & crimping dies)
7	Stools for yoke unlacing of adequate height and wt. capacity
8	Nylon slings for tying the winding to lifting frame
9	Wooden / MS pallets for lamination storage
10	Fans

11	Torches
12	Vacuum cleaners
13	Lamination stack tying arrangement
14	Asbestos sheets for heat insulation during brazing.
15	Dry air generator and compressor setup.
16	Scaffolding arrangement for access to the active part during
S.No.	**Test instruments**
1	2 kV test set
2	Megger 1 kV
3	Megger 5 kV motorized
4	Ratio meter
5	Winding resistance kit
6	Millimeters
7	Dew point meter
8	Tan delta kit
9	Clamp meters
10	Variac 1 phase and 3 phase
11	Continuity tester

LIST OF CONSUMABLES REQUIRED FOR REPAIR/ REFURBISHMENT JOBS AT SITES

S. No.	Materials
1	Crepe Paper Rolls -25 mm wide
2	Crepe Paper Rolls -15 mm wide
3	20 mil Paper Rolls PCB Sheets -1.5 mm thk. (impregnated)
4	PCB Sheets -3.0 mm thk. (impregnated)
5	Cotton Tape Rolls-l/2"
6	Cotton Tape Rolls-l"
7	Newar Tape Rolls-
8	Permali studs & nuts -10 mm
9	Permali studs & nuts -12 mm
10	Permali studs & nuts -16 mm
11	Permali studs & nuts -20 mm
12	PCB/PW off cuts (impregnated)
13	PVA glue
14	Fibre glass tube-core bolts
15	Fibre glass washer-core bolts
16	Oil drums with 209 litres each as per IS : 335
17	Common Blocks (various sizes)
18	Terelene Tapes
19	Cotton waste
20	Cotton cloth (markin type)
21	Sand paper

22	Blanking plates-various sizes
23	Plastic sheets/polythene
24	Carbon Tetra Chloride (cleaning agent)
25	Wooden coil bobbins
26	Guidelines for Repair of Power Transformers at Site
27	Empty oil drums
28	Wooden boxes with locks
29	Plastic bags (small)
30	Plastic bags (medium)
31	Undelible markers
32	Tags (fibre)
33	String roll
34	Plastic buckets and mugs
35	Tarpaulins (large)
36	Themocoal foam -8 mm thk. Profile

GUIDELINES FOR INTERPRETING THE FIELD TEST DATA

Field Issues	Summary of Field Issues	Recommendations
DT Protection Issues	Usage of appropriate rating of Fuse play vital role in DT protection system. It is observed that proper ratings of fuse either on LT or HT side of DT are not being used. Fuses are used for protection of DT whereas a general practice is to use multiple strands of conductor wires so that fuse does not blow. As a matter of fact operational efforts are being saved through usage of overrated fusesbut by sacrificing the valuable asset. Further LAs are used for protection of DTs from Surge voltage and impulse voltage; there is no practice of usage of LA. LAs whereverinstalled are found in non-operational or disconnected condition	Standard practices may be followed and awareness against such practices should be made.
No Earthing or Improper/ Poor Earthing System	Generally in most of the cases earthing is in High risk i.e. either no Earthing, Poor earthing or High value of Earth resistance. However, in some other cases it is in alarmingsituation. Any DT installation require 5 no's of individual earthing, two for neutral, two for Body and one for structure. Also Earth resistance value should be below 1 Ohm. If earthing system is not proper then fault clearance time will increase and DT has to bear the high fault current for more duration which might lead to the failure of DT.	Correct analysis of every DT failure is must for effective reduction in DT failure rate. Earthing inspection & routine check-up should be done.
Issues relatedto Oil	Low level of oil in DT can be due to oil leakage/seepage or oil theft. The major problem arises due to low level oil is no circulation of oil through radiator hole which leads ineffective cooling of DTs. As a result of ineffective cooling insulation of DT gets deteriorated. Similarly low BDV value of oil in almost all the cases shows that Breathers are neglected on DT. Following are the major issues observed with respect to the usage of breathers i. In most of the cases breather is not installed ii. In few cases breather are installed but same are not maintained properly. Cases are observed where breather is broken/damaged, Oil cap not available/broken andsilica gel inside Breather is in damaged condition. Furtherdamaged diaphragm of PRV is not replaced at site, so the oil is in direct contact with atmospheric air. As a result ofabove factors oil is getting contaminated with both	Keeping in view the shortage of staff and huge no of DTs in utilities, the utilities may do the complete process out sourcing. The BDV value of oil falls during service when the oil is contaminated due to dust, water, other extraneous matters or dissolved gases etc. During service the breakdown voltage should not fall below 30 KV for one minute for 2.5mm gap of electrodes. If the values goes down, oil should be filtered to remove the contaminants.

	moisture and dust. This subsequently deteriorates the oil quality and affects insulation of DT which further leads to failure of DT.	
Unbalance dLoading	Study shows most of DTs are in unbalance loading condition. In most of the cases DT neutral found carrying current equivalent to phase current. As a result Neutral wire found overheated which ultimately affects the health of DT. This results in fast deterioration of insulation of same phase which ultimately leads to failureof DT.	Quality installation of newly installed DTs should be ensured and load balancing /checking activity should be done regularly. Many times Poor oil quality, poor earthing, and loose joints have been found in newly installed DTs. It is recommended to form a quality inspection team which should conduct a quality check of installed DT and old DTs in operation.

SITE TESTING REPORT

Test Report

1.Insulation Resistance Values (Megger Test):

R-e	Y-e	B-e	r-e	y-e	b-e	P-S

2.Winding Continuity Test:

RY	YB	BR	Ry	Yb	Br

3.Pressure Test:

4.BDV test:

5.Insulation Resistance Values (Megger Test):

R-e	Y-e	B-e	r-e	y-e	b-e	P-S

6.Winding Continuity Test:

RY	YB	BR	Ry	Yb	Br

7.Ration Test:

Primary Voltage					Secondary Voltage			
RY	YB	BR	Ry	yb	Br	Rn	Yn	bn

8.L V Magnetic Balance Test:

	ry	yb	br	rn	yn	Bn	Lr	ly	lb
a.Fuse inserted in R ph									
b.Fuse inserted in R ph									
c.Fuse inserted in R ph									

9.Remarks and Comments:

CHAPTER-6
IT/OT/AL CLOUD BASED ASSET MANAGEMENT TOOLS & APPLICATIONS

Smart Substation

The Smart Substation is an advanced version of the self-protected transformer. The internal protection devices in addition to the indicators and monitoring devices are installed at the sub-station for monitoring the internal condition/unmanned operation of the DTs/ substation. Smart Substations are need of the hour to increase reliability of supply and reduce losses in the system. Following are some of the important features of smart sub-station:-

1. Various sensors /devices are installed to monitor Voltage, Current, Load condition, power factor, Oil temperature of the transformer, temperature of the internal part, oil level indicator, and operational condition of the protection devices etc.
2. Remote monitoring and operation is through the GPRS/GPS/IOT / RF based system.
3. Automatic Protection devices to protect the transformer from abnormal conditions like overload, over voltage, short circuit, internal short circuit, etc.
4. Energy metering system for Energy audit and automatic theft detection system.

Smart Transformers (VFI- vacuum fault interrupter)

These types of transformers have superior control and monitoring capability of modern microprocessor based relays for increased reliability and system longevity. The VFI control communicates directly to control rooms or within a system network over standard protocols such as Mod bus RTU/TCP, DNP RTU/TCP/UDD and continuous diagnostic information from the transformer allows the transformer to be controlled or monitored remotely for diagnostic and control decisions.

The main advantages of Smart Transformers/Substations are as indicated below:

(i) Better MIS and Business intelligence

(ii) Demand side management,

(iii) Reduction in DT failure rates, downtime by monitoring and automated evaluation & improvement in reliability indices like SAIDI/ SAIFI/ CAIDI/ CAIFI etc.

(iv) Reduction in total harmonic distortions, improvement in voltage regulation, reduction inphase imbalance.

(v) Achieving the safety of system, full safety in work permits, Maintenance, breakdown histories and planning of the system.

(vi) Status monitoring via Communication from smart metering with the support of communication technologies to support various application s like SCADA, DMS etc.

Smart Meters for Performance Monitoring / Remote Monitoring of Distribution Transformers

Transformers are the vital element of the electric power distribution infrastructure. It should be monitored regularly to prevent any potential faults. Failure of the DTs easily costs several Crore rupees for repair or replacement, and results in revenue losses and loss of service to customers until the systemis restored.

Distribution transformers in our country face the problem of high failures, mainly due to Transformer burning / damage and Oil loss etc. Since these transformers are installed in Utilities in very large numbers and at scattered locations in urban as well as rural areas, their health monitoring through manual means is not at all feasible.Metering of Distribution transformers and reading the meter data remotely will definitely assist Utilities in their health monitoring to a large extent apart from DT-wise energy auditing and accounting to extract loss pockets.

Given that several thousand transformers are operational under any distribution utility, it is not possible to physically monitor these transformers. It is necessary to develop systems for remote monitoring. For this purpose, GPRS/GPS/IOT /RF based smart metering system may be installed on the transformer. The meter should measure, monitor and record different system parameters including those mentioned in the earlier section. The meter can continuously monitor the performance of the transformer and signal the control center through communication channels in case of abnormal behavior.

In urban area, large No. of Distribution transformers are equipped with communicable meters with AMR facility under RAPDRP and IPDS and are read remotely at Data center for seamless energy accounting and auditing. However, a few issues have been observed in meter data availability for these DTs, mainly due to day to day operation and maintenance of AMR system of DT meters, mis-alignment or failure of modem, communication failures, non-restoration of DT metering system by the Utility staff / outsourced agency engaged in replacement of faulty Distribution transformers and the meter along-with communication equipment is not re-connected.

As of now, all the Distribution Transformers in rural area do not have Metering facility (or AMR/AMI) hence for such areas Smart Meters DTMU along with metering facility may be provided. Under the Revamped Distribution Sector Scheme (RDSS) launched by the GoI in July 2021, it is envisaged to install 25 Crore Smart Meter in the country along with smart system meters on all Feeders and Distribution transformers for accurate Energy Audit and accounting .

Further, as the meter keeps record of different system parameters, transformer failure analysis can be done; the cause of the transformer failure can be easily identified and analyzed before taking decision onrepairs/replacement.

Suggestions :

- To take the full advantages of already installed AMR/AMI meters , the day to day operation and maintenance of AMR/AMI system of DT meters installed in urban areas may be outsourced, since Utility staff is mainly engaged in restoration of power supply and their maintenance. The scope of work of the outsourced agency should also cover co-ordination with Utility staff / outsourced agency engaged in replacement of faulty Distribution transformers etc., so that they ensure that the meter along-with communication equipment is re-connected for continuous data flow and updation of GIS repository (as per requirement) in such cases.
- This will enable seamless energy accounting and auditing with minimal manual intervention. Exception reports of DT metering data will also identify problems of overloading, light loading and unbalanced loading of Distribution transformers for taking further corrective actions and reduction in DT failure rates.

IT based Preventive and Predictive Maintenance of DTs

Utilities, where IT enabling works were undertaken under GoI schemes (RAPDRP/IPDS), they have implemented two IT based Application modules (i.e. Asset and Maintenance management system), which can be utilized by distribution utility in facilitation of preventive and predictive management on their electrical assets.

The Maintenance Management System helps utility in better planning and co-ordination of various maintenance activities; reduce breakdowns through preventive and predictive maintenance, to maintain maintenance history, to review and control maintenance costs and providing a feedback to management for timely decision making. Following functionalities may be used-

- Forecasting of planned maintenance jobs
- Automatic creation of Work Order (Time or usage based)
- Automatic generation of schedule, priority etc.
- Identification of opportunity maintenance jobs
- Creation of short/medium term planning
- Creation of Inspection work
- Forecasting and Resource planning and review
- Analysis and report on MTBF and MTTR

The Asset Management system will facilitate in resource planning efficiently to enable utility to take quick and correct decision making in day to day operation. Following functionalities may be used-

- Compilation of assets and reduction of inventory and down time of equipment
- Predict the completion of useful life of an asset for its timely replacement.
- Coupled with Trouble call management system, it will keep track on maintenance work on each asset along with cost incurred.
- Conduct Statistical analysis on conditions and criticality of assets, Asset age and asset performance, Risk Management (insurance claim etc.).

Distribution Transformer Monitoring Unit (DTMU)

Mainly voltage and current flowing through Distribution transformers can be monitored through DT meters, other critical parameters of distribution transformers like oil temperature, oil humidity, oil level etc. can be selected for online monitoring to avoid transformer failures and help take preventive actions to avert asset loss.

The Distribution Transformer Monitoring Unit (DTMU) is an intelligent device which monitors the identified parameters of the Distribution Transformers and communicate the same to the control center via some communication technology. The parameters like oil temperature, oil humidity, oil level etc. can be selected for online monitoring to avoid transformer failures and help take preventive actions to avert asset loss.

It will also help to take proactive actions to prevent such failures and issues. However, the add on module or unit should be easily mounted on a Distribution Transformer and

it must aim at ensuring optimal/ least cost IT based solutions for new transformers and retrofitting in existing transformers. The followings points should be taken care for designing the features of DTMU:-

- The DTMU for the different categories of distribution transformers must be a simple, cost effective but robust device and should be able to monitor all parameters.
- The DTMU should be configurable for generating alarms based on pre-defined threshold values. The system shall either have an in built GPS/GPRS/IOT/RF modem or be made compatible with existing meters to transmit these data to a Centralized Condition Monitoring Software. DTMU shall also have the capability to report any sudden loss of the sensors indicating a possible theft.
- DTMU may also have a built in module that can track the transformer, in case of theft. The unit should be designed to withstand ambient temperatures ranging from -10 degrees C up to 50 degrees Celsius.
- All the sensors (temperature measurement, level measurement etc.) should be robust pre-fabricated harnesses for easy installation and maintenance.

USE CASE- DT Health Monitoring Integrated with DIDOs of Smart Meters

In order to solve the oil leakages and oil theft problems with Distribution Transformers (DTs), , the existing features in a DT smart meter may be enhanced with DIs (Digital Inputs) and DO (Digital Output) of some critical parameters of DTs , extended upto its standardized terminal block (fig. 1). Thus, it leverages and enhances the capabilities of smart meters for substation equipment monitoring. With this, the complete monitoring of substation is done through the use of Digital inputs and digital output in meters and programming the cards as desired applications over and above error free metering and meter data analysis.

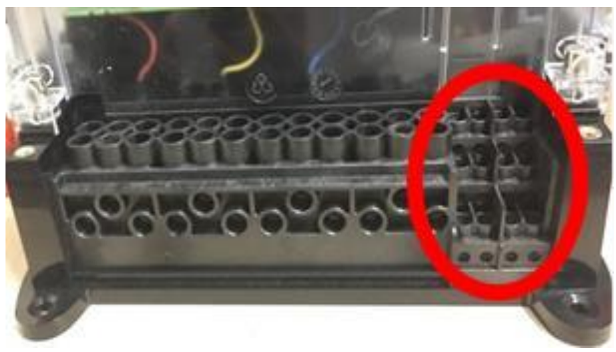


Fig. 1: DIDO at terminal block of Smart meters

The DIDO in smart meters, may be used for the oil level and temperature monitoring of the distribution transformers. Special sensors may be used for monitoring of oil level low and temperature rise of the oil which can be DIDO port of smart meters and may be communicated to the control center along with the Metering data to monitor almost all the parameters of DTs

Some suggested Sensors for DIDO

Float sensor: A metallic dome shaped float sensor with threaded-wall lid may be used for mounting in the conservator tank of the DT, replacing it's conventional lid (shown in fig. 2). This dome shaped structure floats to a calibrated level when it is immersed in the oil and rests on a lower level. It may be connected to a cable which signals digital 0 and 1, as per the two floating statuses of the metallic dome.

Fig. 2: Float sensor for oil-level monitoring.

OTI (Oil Temperature Indicator): It may be used for real-time monitoring of the temperature of oil inside the DT. It may have a user configurable marking to set the permissible limits for the oil temperature rise. This may also be displayed through a display panel provide along its periphery (shown in fig. 3). It may digitally signal through the cable attached to it, in case the oil- temperature exceeds the configured limits.

Fig. 3: Oil Temperature Indicator (OTI)

Operation of DIDO Sensors

As shown in the above figure , the float sensor and OTI mounted in the transformer, are connected to the Digital Inputs of the smart meter installed with the DT, and its digital output is connected to the upstream circuit breaker of the transformer.

When someone tries to steal oil from the transformer or there is any oil-leakage, the oil-level in the transformer will start getting lower and hence the metal drum of the float sensor will dip and hit its lower limit. This will in turn digitally signal through the attached cable, to the digital input of smart meter. The smart meter is programmed to immediately signal this to the HES (Head-End System), through the communication network (GPRS/IOT/RF etc). The HES shall immediately send an alert SMS to the concerned zonal staff about the oil- theft in DT, with the details of its location (pre-fed at HES via Geographical Information System (GIS), as per the installed serial number of the smart meter).

In case the OTI also signals high temperature as well, during this time, the smart meter is programmed to trip the upstream circuit-breaker connected through its digital output. Thus, the transformer shall be saved from burning/ failure in both the cases.

IoT based solution for transformer overload handling and life extension

The Transformer failures generally occurs due to insulation failures. Overheating caused by Overloading deteriorates the insulation life and causes early aging in transformers. Smart IOT based solution may be used for controlling the temperature rise of transformer.The cooling fan can be installed for additional cooling of transformers which can be controlled via smart devices which can trigger based on the oil temperature rise. This low cost solution can helpin mitigating the temporary seasonal overloading of transformers. This can be installed on pole mounted transformers and plinth mounted transformers also with structure. A specialized algorithm feed in the controller keep check on temperature rise of DT and switches on first cooling fan at 65 degrees and second cooling fan at 70 degrees (configurable preset values). Thiscontroller also gives command to upstream breaker for tripping for sustained overloading resulting in temperature rise to 90 degrees. Also data is stored in local memory and on web serverfor every ON and OFF operation along with temperature and date and time stamp for future analysis. Also alerts are generated when fan is nonfunctional and at high temperature rise threshold of 90 degrees. With alert message or email, the maintenance crew can be mobilized to check the loading and making alternate arrangement like mobile transformer installation or loadshifting to other DT etc. Hence DT can be saved.

Pole mounted DT with auto cooling system

Plinth mounted DT with auto cooling system

Chapter-7

NATIONAL & INTERNATIONAL QUALITY STANDARDS, ENERGY STANDARDS, MANUFACTURINGPROCESS STANDARDS, GUIDELINES & MANUALS

Indian Standard	Title	International & Internationally recognized standard
IS - 2026/1977	Specification for Power Transformer	IEC 60076
IS - 1180	Outdoor Distribution Transformer up to and including 2500 kVA	---
IS 12444	Specification for Copper Wire Rod	ASTM B-49
IS - 3347/1967	Specification for Porcelain Transformer Bushing	DIN 42531,23,3
IS - 335/1983	Specification for Transformer Oil	---
IS 5/1961	Specification for Colours for Ready Mixed Paints	BS 148, D-1473
IS - 2099/1973	Specification for High Voltage Porcelain Bushings	D-1533- 1934
IS - 7421/1974	Specification for Low Voltage Bushings	IEC Pub 296-19
IS - 3347	Specification for Outdoor Bushings	DIN 42531 to 3
IS - 5484	Specification for Al Wire Rods	ASTM B - 233 IEC
IS - 9335	Specification for Insulating Kraft Paper	60554
IS - 1576	Specification for Insulating Press Board	IEC 60641
IS- 6600-1972	Guidelines for Loading of Oil Immersed Transformers	IEC 60076

Details of IS 2026 (All IS Should be used as amended upto date)

(Part 1) 2011	General
(Part 2) 2010	Temperature-rise (first revision)
(Part 3) 2009	Insulation levels, dielectric tests & external clearances in air
(Part 4) 1977	Terminal markings, tapings and connections
(Part 5) 2011	Ability to withstand short circuit (first revision)

Reference

- Various Manuals of Utilities.
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