INSTALLATION, TESTING AND MAINTENANCE OF POWER DISTRIBUTION TRANSFORMER

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1. INTRODUCTION

Transformers are a live wire for all power transmission systems. Simply put, they are used for the purpose of voltage changing. Many types exist namely: power transformers (for transmission and distribution of electrical energy); autotransformers (for starting motors); instrument transformer (for circuit measurement) and test transformers (for producing high-test voltages). Transformers can be of the single phase or three-phase types. Irrespective of the type of power distribution transformer, the basic components are reasonably the same. These are a static type of machine designed for transformation of one alternating current system into another with a different voltage and current characteristic.

Any system put in place must be safe, **reliable (continuous)** and **effective**, thus transformers must be installed, tested and properly maintained in order to achieve the desired objective(s) in the power system. To install is to place or fix something in position for use and the act of doing this is referred to as **installation**. Thus, when a transformer is put in place ready for use anywhere within the power system, it is said to have been installed through an installation process.

Before installation and after, it is very necessary to ascertain the state of the transformer. This is only possible through **testing**, that is, subjecting the transformer to certain conditions that will show its quality.

In order that the installed transformer perform **reliably**, **safe** and **effectively**, it is very necessary to keep it in good condition. One way to do this is through **maintenance**. To maintain is to keep up; retain or continue and the art of keeping up or retaining in good condition is referred to as maintenance.

1.1 BASIC COMPONENTS OF POWER DISTRIBUTION TRANSFORMERS

The transformers consist basically of a **magnetic circuit (core or iron)** on which the **windings (or electric circuit)** are placed. It also comprises a number of **constituent parts** and elements designed mainly to facilitate the transformer use and maintenance.

These include:

(a) Various **insulators** (solid and liquid) for insulation/isolation of current carrying parts;

(b) **Bushings**; and

(c) **Leads** for connecting the windings to the transmission lines;

(d) **Switch gear (tap changer or tap switch)** for the transformer voltage adjustment;

(e) **Tanks** to contain the transformer oil and other accessories;

(f) **Cooling tubes. Radiators** and/or fans to enhance transformer cooling;

(g) **Protective gear** which operates when a fault arises in the transformer such as a Buchholz Relay.

Other components include: **Oil conservator** (to house excess oil resulting from expansion and also to supplement the oil level); the **Dehydrator** and the **thermisyphon filter** (to absorb the moisture carried by the air that enters the transformer thereby protecting the oil against moisture and catches particles in the incoming air thereby acting as a filter). Thermisyphon filters are installed on large transformers 2.5MVA and above allowing them to be operated for a very long time without having to remove the transformer from service for oil purification and regeneration thus maintaining the desired purity and dielectric strength; the **oil gauge** (which indicates the oil level when the transformer is being filled with oil after repair and also in service).

The basis of this brief on the basic components of transformers is to prepare a standard point for maintenance. All transformers need not have all the components described above. This is a function of the transformer rating (size) and duty. These components are sources of failure that will become evident during tests and therefore requiring maintenance (replacement or repairs).

1.2 TRANSFORMER SUBSTATIONS

Substations abound in the power system. The prime objective is to effectively and efficiently transmit and distribute electrical energy to the various and numerous customers connected to the system. The stations are usually located such that voltage drops as well as losses are minimized. The substations can be grouped as follows:

(a) The **Grid Substations** (also **injection substations**) at 132/33KV or 132/11KV.

(b) The **Primary Substations** at 33/11KV; and

(c) **Secondary Substations** at 11/0.415/0.24KV.

The capacities of the various substations are within the following ranges:

(i) 10 – 30MVA and 20 – 90MVA for the grid;

(ii) 5 – 20MVA and 5 – 30MVA for the primary and,

(iii) 100 – 2000KVA and 500 – 7500KVA for the secondary substation respectively for the various consumers listed.

Substations can be of the **indoor** or **outdoor** types. Irrespective of the types the following components are present: high voltage equipment, step-down transformers, consumers low voltage equipment, meters and protection equipment (circuit breakers, fuses). The location of the substation is such that it is near the load center in order to reduce the cable length and hence, power loss and voltage drop.

All stations should be of **fireproof construction, well ventilated and dry.** Cables are contained in earthenware pipes within the substation, or in concrete ducts in the floor cast in situ (for the indoor types).

In general, transformer installation can be grouped as follows:

(i) Pole mounted units;

(ii) Outdoor units and

(iii) Indoor units

Underground substations also exist.

1.3 TRANSFORMER TESTS

Tests are the principal means of detecting troubles and defects in electric equipment (transformers, motors, generators.) and of checking the quality of repair. Each test has certain **objective(s), techniques** and **requirements**. The tests can be broadly categorized as **pre-installation/repair** and **post-installation/repair** test respectively. The objective of the **pre-test** is to determine the state of the transformer and/or the scope and nature of the repair/maintenance work done or to be done, and also, to supply the performance data with which the post installation/repair/maintenance results are to be compared with. The essence of the **post-test** is to check the workmanship to make sure the transformer is free from defects that might upset its normal operation, to see that its performance complies with its data sheet values and applicable specifications and standards.

1.1.3 APPLICATION TEST STANDARDS AND SPECIFICATIONS

Transformers are tested in accordance with a program, which includes the detection of likely defects and a check on the performance characteristics for compliance with relevant standards or specifications.

These standard tests can either be:

(i) **Routine tests:** All transformers are subjected to these.

(ii) **Type tests:** These are carried out on the first unit only of a new design.

Also, we can talk of **preliminary** and **final** test respectively. The former are tests carried out before transformer is assembled in its tank in order to ensure that any faults detected are rectified and include the following: Core Insulation, Ratio, Polarity and Resistance test respectively. The final tests are carried out complete with all external components and fittings which are likely to affect the performance of the transformer and generally include the following:

(i) Ratio and Polarity tests;

(ii) Surge-voltage withstand test;

(iii) Separate-source-voltage withstand test;

(iv) Induced-over-voltage withstand test and internal discharge test;

(v) Resistance of windings (DC resistance test);

(vi) No-load loss and no-load current test (open circuit test);

(vii) Noise test (humming);

(viii) Zero sequence impedance test;

(ix) Temperature rise test and

(x) Insulation resistance test.

All the tests are routine tests except (ii) and (x) which are type tests and (ii) and (ix) which are special tests.

The acceptance test sequence is as follows:

(a) Electric strength of transformer oil

(b) Winding insulation resistance

(c) Electric strength of insulation with applied voltage

(d) Electric strength of insulation with induced voltage

(e) Open-circuit conditions.

There are yet other tests, referred to as **proof tests.** These are test applied to individual parts and units of a transformer in the process of manufacture and assembly. The purpose of these tests is to prevent faulty parts and units from being installed in the transformer and check those parts and units, which cannot be tested in the finished transformers. These are primarily the windings, core and switches.

The following tests constitute those in the post repair category:

(1) Oil test.

(2) Transformation ratio/angular (vector) displacement group.

(3) DC resistance of windings.

(4) Open – circuit and short – circuit current and losses.

(5) Insulation resistance of the windings.

(6) Applied high tension, power frequency test of the major insulation for dielectric strength.

(7) Induced voltage test of the turn insulation for dielectric strength.

It is not possible that at any point in time, all of these tests must be performed. However, various authorities/power supply authorities and manufacturers make specific demand and requirement for transformers before being certified fit to be hooked up to the entire system. By **NEPA standards,** it is necessary and required that the following tests be carried out on transformers:

(a) Insulation resistance test,

(b) Ratio test

(c) Excitation test

(d) Oil test

1.3.1 TRANSFORMER TEST PROCEDURES
(Types of Post-Repair Tests/Significance)

(i)Oil Test.

This uses a high voltage oil tester to determine the dielectric strength of the oil. The oil sample collected is about 0.5 liter, put in the test vessel and allowed to settle for about 20 minutes to free it from air bubbles. An increased voltage is applied until break down occurs. Six such readings are noted at 10 minutes interval. The average break down voltage is obtained using the last 5 readings. A reading of between 25-30 kV is acceptable.

Other possible oil tests include: abridged chemical analysis in order to determine its acid number, the flash point of its vapour, the reaction of a water extraction, the suspended carbon content and the mechanical impurity content.

(ii) The D.C. Winding Resistance Test.

This brings out any likely defects paused unnoticed during repair such as poor soldered or brazed joint at the tap changer, broken parallel conductors etc. such defects raise the D.C. resistance owing to an increase in the contact resistance at the joints and within the defective sections. Resistance variation should not exceed 2%. An avometer/ a multi-meter can be used to do this test.

(iii) The Insulation Resistance Test

An insulation megger (digital or analogue) is used with a 1000V range to test the insulation resistance from the H.V. winding to the tank with the L.V. winding grounded from the L.V. winding to the tank with the H.V. winding grounded, and between the L.V. and H.V. winding connected together and to the tank. At 20°C, at least 300MΩ is satisfactory for transformers up to 6MVA and 600Ω are satisfactory for units from 10MVA and above. In general, 1000MΩ at a test voltage of 100V are satisfactory (say, M.G) and NEPA accepts any value between 200MΩ and infinity.

(iv) **The Open Circuit Test (Core loss/Magnetizing current test)**

This detect core defects evident by increase in magnetizing current and associated losses thus reducing the overall efficiency or overheating of the transformer.

Note: V. is increased in step until the rated normal value is obtained. However, if a reduced voltage is used, transformation must be performed to the rated value in order to get the appropriate P_o, I_o. This test might also serve to determine the transformer ratio.

(v) **Short Circuit Test (Load loss or impedance Test).**

The impedance voltage is the voltage that will cause the rated full-load current to flow in the windings. Normally the LV windings are short-circuited for this test and the transformer energized from the H.V. side. This test detects defects in the windings viz. Incorrect transposition of conductors, partly or fully broken conductors, improperly made soldered/brazed joints, using smaller cross-section area conductor. These defects manifest by raising the ohmic resistance of the winding and entail an additional loss under no load.

The measured input power represents the total load loss at the rated load at about 75°C. it is thus necessary to measure the winding resistance during this test in order to compare/prorate the readings obtained. This test can also confirm the real rating of a transformer.

(vi) **Ratio/Phase Interconnection Test**

To determine the transformer ratio, to check phase interconnection and the connection of taps to the tap changer.

Apply at least 2% of the rated voltage simultaneously on all the phases of the transformer. Use the tap changer in a step-wise manner to adjust the voltage. If the variation in voltage between the phases does not exceed by 2%, then all is well.

The phase interconnection asserts that the windings have been properly interconnected and that the angular or phase displacement is correct.

(viii) **Induced High-Voltage Test.**

This determines the strength of the insulation between the turns and other parts operating at different potentials.

The test involve operating the transformer at between 15 – 30% higher then the nominal voltage on open circuit for a very short time (say 1 minute). If no current inrushes/discharges/other symptoms of defects are observed, then the transformer is okay.

1.4 INSTALLATION OF POWER-DISTRIBUTION TRANSFORMERS

Different types of substation exist in the entire power system namely injection substation (at the grid level 132/33KV or 132/11KV to feed various zones and districts). Primary substations (33/11KV to feed major industrial, commercial and medium sized consumers); secondary substations (11/0.415/0.240KV to feed small industrial, small commercial and domestic consumers). They vary in sizes and complexity and also in size, complexity and installation techniques.

Depending on the size of the installation, one or more supply feeder cables will be brought into one or more substations, then by injection to various primary substations to various secondary substation and then to consumers. The substation is built to house the step-up transformers and/or step down transformers, the consumers low voltage equipment, meters, protection equipment (circuit breakers and fuses) and feeder pillar.

The substation should be of fireproof construction, well ventilated and dry. Adequate space should be allowed for moving equipment about and provision should be made to limit the spread of fire in the event of escape of burning oil. Also, the substation must be prevented from intruders and should be kept very clean and tidy.

Substation/transformers are installed outdoors, indoors and some transformers are mounted on H-type poles. However, one must properly site the substation in order to minimize cable runs, power losses and voltage drops. The entire process requires that the following actions be taken in general:

i. **Survey**
ii. **Construction**
iii. **Testing, and**
iv. **Commissioning**

Basically a substation needs a building, or fence and plinth(s) plus high voltage control equipment (in most cases), a transformer or transformers, and a low voltage distribution board of either the indoor or street feeder pillar type (comprising incoming withdrawable links, phase and neutral busbars and high breaking capacity fuses (for up to eight outgoing distributor cable ways). Resetable maximum-demand indicators are often fitted to enable a check to be kept of the transformer load. Thus, the major work aspects are electrical and civil engineering based.

The only productive component in a substation is the transformer. All other items, including building and civil works are to the detriment of economy and the associated low voltage (L.V) network.

It is worthy to note at this point that injection substations make provision for offices and/or residential quarters for staff and space for some key operation personnel.

1.4.1 SURVEY

The aim is to locate an appropriated or best site for the substation and assess the civil works to be carried out as well as all the materials/other accessories required.

The primary and grid substation sties require a large space which can be very costly and individual design problems adopted to save space and contain transformer noise. For space economy without compromising standard, substations occupy the following approximate land areas:

i. **Primary substation : 836m²**

ii. **Secondary substation: 15m²**

iii. **Grid substation: 1672 to 2508cm² or 2 to 3 time that of primary substation.**

For a grid/injection substation, a compact installation is possible at the extra cost of more civil works, plus elaborate fire and safety precautions.

Some common instruments for use includes pencil, paper, cutlass, pegs, tape for measurement, razor set. All these will assist from the mapping of the area to the construction stage.

1.4.2 CONSTRUCTION & INSTALLATION

This includes both civil and electrical works ranging from the foundation level for the substation building (indoor) and the plinths (for outdoor substation), the fencing (outdoor) and other electrical gadgets.

The located site is pegged and the civil/building works commence getting an appropriate base ready for the transformer and other accessories to be put in place. For a typical secondary substation with between 100-500KVA transformer, the size of the plinth is about 1.52m x 1.22m x 1.22 (5'x4'x4') and the fence size is about 4.57m x 3.05m (15'x10'x10') covering a gross area of about 150 square feet (13.94m²). **The figures (A18/A19, 6,7,8) show the various outlay.** It should be noted that no construction could commence without the appropriate drawings/plan/sketch/schematic for all the electrical and civil works.

The other figures (A18 & A10) show typical out door and indoor substations at the primary and secondary levels respectively. (See Appendixes).

For indoor substations, provisions are made to limit the spread of fire in the event of the escape of burning oil. This is achieved by placing oil-filled equipment above a pit filled with graded chipping. This tends to absorb leaking oil. The floor is sloped away from the switch gear (the gradient being not less than 1 meter in 100m) towards the sump so that in the event of water getting into the substation, it will run away from the switch gear. The windows should be located high up the walls and the glass should be unbreakable. Doors should be of solid construction and kept locked, the keys being retained by a responsible person and the supply authority. Emergency doors must be fitted with crash barriers.

*The list of some materials for the construction of a typical distribution substation (300KVA) is given in sections 1.4.5.

1.4.3 Testing: The purpose for tests has already been dealt with. A list of the most relevant ones (post installation test) are here enumerated.

i. Insulation resistance of the lines (HT) and their associated auxiliaries such as insulators and lightning arrestors.

ii. Insulation resistance tests for the H.T and L.T cables and their associated auxiliaries such as feeder pillar, H.T fuse holders,

iii. Insulation resistance test of the transformer windings HT/LT, HT/E and LT/E (200-MΩ okay).

iv. Ratio tests of the transformer,

v. Excitation test through the secondary windings with the primary open.

vi. Dielectric strength test for the oil.

vii. Testing the earth resistance of the substation including the transformer neutral, channel iron, cables, feeder pillar, transformer body, and lightning arrestors. (1-10 Ohms okay). These tests must be separately done and all metal works should be bonded if possible.

1.4.4 COMMISIONING

This is done after all the necessary and required tests have been satisfactorily carried out by switching on the transformer on no load. The output voltage is monitored and the necessary tap changing effected. The transformer is allowed for at least twenty-four hours in this state before it is loaded, synchronized with the entire power system a process known as **'SOAKING'**.

1.4.5 **Materials Required For the Erection of A 300KVA Distribution Substation.**

These include:

1. 2 Nos. 10.36m or 34' wooden or concrete H – type pole;
2. 1 complete set (3 Nos.) of J & P 'D' fuse;
3. 1 set of 11KV lightning arrestor;
4. 100m. 70mm^2 bare hard drawn copper;
5. 20 Nos. 6' galvanized earth rod;
6. 1 No. 300KVA. 11/0.415KVA transformers;
7. 1 No. 4 way feeder pillar;
8. 15 Nos. bimetal line tap;

9. 2 lengths channel iron 5" x 3" x 21'

10. 15m. 70mm² 3-core. PVC. 11kV underground(u/g) cable;

11. 1no. 11kVRaychem kit. 3 core. outdoor termination (50-95)mm²;

12. 1no. 11kV Raychem kit. 3 core, indoor termination (50-95)mm²;

13. 1no. 11kV Raychem kit mounting bracket complete with insulators;

14. 24. Nos. 70mm² cable socket;

15. 8 Nos.. 300mm² cable socket;

16. 1 No. Everite pipe;

17. 24m, 300mm² single core PVC underground(u/g) cable;

18. 3 tins of fluxite soldering paste;

19. 4 sticks of plumbers metal 40/60 alloy;

20. 95 sticks of tin man's soldier 60/40 alloy;

21. 4 liters of kerosene oil;

22. 4 liters of electro clean solvent;

23. 1 roll of kaleris tape;

24. 5 rolls of Lassoric tape;

25. 45m. 70mm² 4 - core PVC underground(u/g) cable (for 3 outgoing units at least with each outgoer cable being approximately 15m);

26. Sufficient cement/gravel/chain link;

<u>Note:</u> If the overhead (o/h) mains has not been strung to the substation location. the following materials will be included to the list:

27. Bolt & nuts. (9Nos. of 5/8x2"; 12Nos. of 5/8x7"; 12Nos. of 5/8x9"; 12Nos. of 5/8x11".

28. 6 Nos. of 11kV pin insulator;

29. 6 Nos. of 11 kV spindle;

30. 6 Nos. of pilot spindle;

31. 6 Nos. of11kV (Disc) strain insulator

32. 6 Nos. of Adaptor socket clevis (pilkington type);

33. 6 Nos. of Adaptor clevis ball;

34. 6 Nos. of Galvanized steel iron, six-bolt clamp;

35. 2 Nos. of 11kV stay insulator;

36. 2 Nos. of 11kV stay rod 7/8x8";

37. 30m 7/8 S.W.G. stay wire.

1.5 MAINTENANCE OF POWER-DISTRIBUTION TRANSFORMERS

Maintenance, in general is a process that involves repair, replacement, and renewal in order to ensure that systems/artifacts are in good working condition at all times.

The objective of maintenance is to attain a condition where the system or artifact always functions as if they were new. No known methods exist for preventing normal wear and tear of components, modules and systems/subsystems.

The maintenance process involves the minimization, containment and correction of the wear and tear.

Different types of maintenance can be embarked upon to cater for both natural and artificial conditions and include the following:

i. Preventive

ii. Schedule and

iii. Breakdown, maintenance respectively.

Similarly repairs can be categorized as minor and major repairs respectively.

Maintenance is related to the cost and complexity of the equipment viz the maintenance of pole mounted transformers and those in generation and transmission. Since each maintenance operation has its own risk to introducing a cause of failure, care must be taken not to over-maintain the equipment. The periods adopted for maintenance usually takes into consideration the following: environmental factors, loading and mode of use. In most cases, the procedure is to inspect the possible cause of failure and only if necessary, to carry out further work. There must also be a system of reporting defects found in order to maintain the confidence in the scheme.

1.5.1 TRANSFORMERS FAULTS

In order to maintain, repair or replace any equipment and associated component of equipment, it is paramount to know the basic component of the equipment and also, the possible faults that can occur on equipment. The basic components of the transformer include the core, the windings, the tank, the tap changer, the dielectric, (oil, bushing, paper, wood) and other accessories such as indicators (oil level, temperature), breathers, conservators, protection equipment (relays) and fans. Failure can occur due to a malfunction from any of the listed items. Generally, the causes of faults may be due to insulation deterioration, faulty manufacture or maintenance or excess applied voltage. The following is a general classification of transformer faults:

(1) Phase-to-phase faults on the HT connections or windings;

(2) Earth faults on HT windings or connections;

(3) Phase-to-phase faults on LT windings or connections;

(4) Earth-faults on LT windings or connections;

(5) Phase-to-phase faults on tap-change gear;

(6) Earth faults on tap-change gear;

(7) Interturn faults in main tank;

(8) Interturn faults in tap-change compartment;

(9) Core faults;

(10) Low oil;

(11) Over load and

(12) Tap-change mechanism.

1.5.1.1 TIPS ON TRANSFORMER MAINTENANCE – GENERAL,

The following is a guide to enhance transformer maintenance practice all bothering on safety, reliability, cost effectiveness and environmental friendliness.

(1) Transformer should be inspected thoroughly as soon as they are received from the manufacturer or supplier;

(2) Distribution transformers should never be energized unless the oil is at the proper level;

(3) Transformers should be handled with care, avoiding severe jarring that might damage the internal structure;

(4) Transformers should always be inspected by the crew before installation, that is the bushings, access plates and other fittings should be inspected and thoroughly tightened before the transformer is placed in operation;

(5) When replenishing oil care must be taken so that:

- (i) moisture does not enter the transformer
- (ii) nothing falls into the tank

(6) Transformers should never be moved or lifted by the bushings or other attachments but with the lifting lugs provided for this purpose;

(7) When a transformer is mounted on a pole, care should be taken to see that the transformer is in a vertical position and securely fastened so that a severe impact against the pole will not jar it loose;

(8) When performing maintenance inspections, all bushings, connections, protective devices, gaskets; the paint finish on the tank, and all other exterior fixtures should be inspected for evidence of rust, corrosion or over-heating. The oil level should be checked, and the condition of the oil tested;

(9) If an inspection cover is removed from a transformer for inspection, it should be replaced. If the gasket is not in perfect condition, it should be replaced;

(10) When working with any transformer, the connections on both the high and low sides should be opened, to avoid danger from feedback voltage.

1.5.1.2 THE PURPOSE OF TRANSFORMER MAINTENANCE

A few basic procedures avert costly transformer failures and interruption of service after they have been properly installed due to periodical inspection and maintenance. If these procedures are neglected over the years a transformer might fail without any warning causing expensive repairs or replacement and loss of production. This is the essence of transformer maintenance.

1.5.1.3 MECHANICS (WAYS) OF PROPER TRANSFORMER MAINTENANCE

This basically consist of

(1) keeping all parts clean and protected from rust, dirt, and corrosion

(2) testing the winding insulation and the insulating cooling liquid

(3) inspecting and testing the protective and indicating devices

(4) inspecting the transformer internally

(5) inspecting the auxiliary equipment such as fans, coolers, lightning arrestors and grounds.

1.5.1.4 RULES GOVERNING TRANSFORMER OPERATION

Although a transformer and its associated equipment do not have as many moving parts as most electrical equipment, the same basic rules still apply. These basic fundamental rules are:

(1) Current carrying components must operate in a moisture-free insulating liquid or area,

(2) The installation must be kept clean from dirt, rust or corrosion,

(3) All moving parts must be kept well lubricated

(4) All enclosures containing insulating and cooling liquids as well as weatherproof enclosures that protect the equipment from the weather **must be kept tight.**

1.5.1.5 INSPECTION AND MAINTENANCE OF TRANSFORMERS

The frequency of inspection and maintenance of transformers and their associated equipment varies but basically depends upon their **size, type** and **use.** Large power transformers normally require more frequent inspection and maintenance than small lighting and distribution transformers. This is due mainly to the fact that they are costly to replace, they serve electrical equipment critical for plant production, they have more associated equipment such as cooling fans, forced oil pumps or protective alarms that must be properly maintained to insure a trouble-free installation. Operation personnel should make a schedule for inspection and maintenance keep a **logbook** and closely follow the schedule. The record kept should list information relative to the installation showing the transformer specifications/characteristics part history, repairs and tests made and spare parts.

The following includes most of the equipment that requires periodic inspection and maintenance and if a schedule is made and followed closely by the plant personnel and operators **continuous service and trouble-free installation** is assured: load and voltage; liquid level; temperature (for oil, air and water); pressure vacuum gauge (for sealed tank transformers and gas-oil-sealed preservation systems; fans; pumps and their controls; dehydrating breathers; pressure-relief devices; insulating liquid, core and coils. The adjoining tables explain and illustrate inspection and maintenance actions to be taken.

Table 1: SUMMARY OF TRANSFORMER TROUBLES/CAUSES

S/N	PART	TROUBLE	CAUSE(S)
1.	Windings	• Turn-to-turn short circuit	Natural aging or wear of insulation; repeated overloads; dynamic forces due to complete short circuit.
		• Fault to frame (break down); inter-phase short circuit	Aging of insulation, high moisture content of oil, low oil level. Internal/External over-voltages deformed windings due to heavy short circuit current.
		• Open - Circuit	Burned-off leads on windings due to poor quality of soldered joints or electro-dynamic forces in the wake of a complete short-circuit.
2	Tap.Changer	No Contact	Maladjustment of tap changer.

		Fused Contact Surface	Thermal effect of short-circuit currents on contacts.
3	Terminal Bushings	Electric Breakdown (flash-over) to shell	Cracks in porcelain shells Low oil level in transformer Dirt on internal surfaces of porcelain shell.
		Electric Breakdown of insulation on inter-phase leads	Damaged insulation on leads to terminal Bushings Damaged insulation on leads to tap changer.
4	Core	Burned Iron	Improper insulation between laminations or clamping bolts. Loose or improperly clamped laminations Short circuits because of damaged insulation between yokes and core Short circuits in grounding of the core on the lead side of the HV and LV windings.
5	Tank & Fittings	Oil leak through welded and flanged joints Oil leak from plug cock	Impairment of welded or flanged joints as a result of mechanical or temperature factors. Poor fit between the plug and the cock body. Damaged gasket under its flange.

Note:

- A transformer with a damaged winding or other part MUST be immediately removed from service and turned in for repair.
- Only persons well versed in the symptoms, causes of troubles, detection of trouble and remedies must be allowed to be in charge of fault tracing (examination for likely defects).

1.5.1.6 ADAPTIVE MAINTENANCE OF POWER-DISTRIBUTION TRANSFORMERS

This is based on 'copy creativity' and 're-inventing the wheel' theories. It is enhanced by proper knowledge of the entire power system/transformer sub-components. The object is to source materials locally and improve the reliability of the transformer. It also reduces the bulk weight of the transformer. The theory of adaptive maintenance is also possible only when the roles played by the sub-components and their characteristic factors complementing such roles are obvious to the maintenance staff. Research has looked into the possibility of using wooden bushings and vegetable oils as alternatives to porcelain bushings and transformers. This is due to the cost savings of the former and their ready availability as well as the fact that their source of origin is a renewable one. Shock absorption capability of wooden bushings vis-à-vis their porcelain counterpart is another major in consideration favour of wooden bushing. Bushings are meant to serve as external connector from the terminal leads with the transformer to the exterior. They should isolate these live conductors from the body. Similarly, transformer oil acts as a coolant and insulant carrying away heat from the core and windings/associating insulators and also strengthening inter coil insulation. These two: wooden bushing and coconut oil have been used on a 10KVA, 50Hz, 11/041 5 kV distribution transformer prototype and the results, were very encouraging in comparison with a standard identical control prototype. In mind was that indoor substation and transformers with concealed bushing cabinet exist, thus weather hazards are reasonably taken care of in the use of wooden busing replicas. For vegetable oils, their chemical stability is yet to be fully ascertained. However, both models have not been used under sustained simulated/practical load conditions over a reasonable length of time. The figures show the wooden busing prototypes and the Table show comparative test results for busing (wooden/porcelain) and oil (transformer oil and vegetable oil).

1.5.1.7 DETAILED SCOPE OF TRANSFORMER MAINTENANCE – CASE STUDY

(a) Requirement for Reconditioned Transformer Insulation

It must be able to withstand without damage and impairment to dielectric properties the complete program of post-repair tests and also all electric, thermal, and chemical factors likely to occur in service. The quality of insulation is the principal indicator of a transformer's reliability in service.

The insulation (Rigid & Soft) is affected by any of the following:

- Excess amount of **moisture, traces of solvent, air or gas pockets**(which reduces drastically the **dielectric strength** of the oil and the **service life** of the transformer).
- Presence of **mechanical impurities** (such as fibers) reduces breakdown voltage of the transformer oil.
- **Complete short circuits** in the windings subject SRB paper cylinders to mechanical action due to *electrodynamic forces produced by the short-circuited windings.*

(b) FAULT LOCATION/EFFECTS

i. H.V. winding–this is the most vulnerable and frequently damaged part.
ii. L.V. winding –this is very rarely damaged.

(c) REASONS FOR FAILURE

i. Reduction in dielectric strength of the insulation within some particular area of a winding.
ii. Electric break-down of the insulation between turns
iii. Turn-to-turn short circuit

These lead to complete failure of the transformer. Also, voltage transferred from the HV side to the LV side because of impairment in the insulation between them may result in failure.

Other sources of fault include:

iv. Terminal Bushing
v. Tap Changer
vi. The Cover
vii. The tank .

Table 3 shows the degree to which various components contribute to fault(s) in a transformer.

Table 3: PERCENTAGE FAULT POSSIBILITIES RESULTING IN TOTAL DAMAGE OF TRANSFORMERS.

S/N	Description	Percentage (%)
1.	Windings & current carrying parts	53
2.	Terminal Bushings	18
3.	Tap Changes	12
4.	Other parts	17

(d) PRIME CAUSES OF FAILURE

- Improper Maintenance
- Low quality repair

(e) FAULT DETECTION

1. External Parts: (conservator, tank, fittings, porcelain shell of terminal Bushings) spark gap fuse

   - By careful visual inspection.

2. Internal Parts: (windings, core, tap changer oil etc.)

   - By various tests.

- Open circuit Test

  Symptom: Increased no load current due to any of the following:

  - Turn-to-turn short-circuit in a winding.
  - Short circuit through clamping bolts/parts.
  - Wrong connection of parallel windings.

(f) NEED FOR FAULT TRACING/DETECTION

This result in the following:

- Establish the possible cause of the fault.
- The nature and extent of damage
- Determination of the materials, tools and fixtures required.
- Determination of how much time maybe needed for the repair.

(g) NEED FOR VISUAL INSPECTION (External Examination)

- To detect visible defects such as :

  - cracks in cemented joints
  - cracks in chipped spots on porcelain shell of the terminal bushings.
  - Oil leaks through broken or welded & defective flanged joints
  - Mechanical damage to circulating tubes, conservator and other fittings.

(h) Repairs Effected On A faulty Winding

- Reinsulation: (using cotton, silk, glass, tape of cable or telephone paper e). The process involves – removal of the old insulation, annealing, straightening and application of new insulation.

- Possible Damage to Windings/repairs effected

  - winding insulation : Reinsulated or change
  - fused/damage wires: change

- Partly burnt winding: change, partial rewinding and reinsulation for small areas **only** otherwise replace completely since material matching is difficult and the former method reduce the **service life** to ½ - ↓.

Note: It is usually necessary to dry a repaired winding.

(i) Repair Effected on the Core

- partial reconditioning: Minor damages on the punching or other parts such as local short circuits, fused areas between/on some laminations, damage insulation, loose yoke clamps, dents and nicks. Then procedure involves drilling out the fused area, unclamping separation of laminations, straighten edges and introduction of inter-lamination telephone paper insulation/re-clamping, occasionally baking.
- complete disassembly and reblading: Severe damage such as "Iron burn" destroying a good proportion of laminations and insulation components. The method involves preparing the work area, core disassembly, cleaning and insulation of the transformer, reblading and clamping.

(j) Repairs Effected on Tap Changers

In 10 cases out of a hundred, transformers fail because of a malfunction in the tap changer (notably damaged contacts).

- Common tap changer troubles/remedies – General

  - Poor fit of movable contacts to the fixed contacts.
  - Loose connection of taps to the terminals on the tap changer.
  - Loose connection of taps to the windings.

Note: ALL the above causes a local heat build-up, which puts the transformer out of service with time.

- Repair of off-load tap changer (Ratio adjuster)

  - Clean and carefully examine all parts especially the mating surfaces on both contacts.
  - Tighten up all fasteners.
  - Replace damage springs, worn parts and spacers.
  - Properly align all contacts/ensure proper mating.
  - Free all jammed contacts.
  - Test to ensure proper functioning on all taps.

- Faults/Remedy

- Burned/Fused contacts: - Replace with new factory-made or fabricated ones using the same materials.
- Coated Contact: - resulting from exposure to oil resulting in a thin yellow film which increases the contact resistance - Clean off the film using a dirt-free cloth or rag moistened with acetone, or purified petrol.

Note: This film is responsible for damaged contacts and heat build up,

- Repair of On load tap changer – General

This is more complicated and includes

- Cleaning
- Washing and rubbing of all internal/external parts
- Operations necessitated by the design of the individual parts and the large number of contacts.

- **Inspection – Things to inspect.**

  - tap selector
  - contactors
  - Electric part of operating mechanism (master switch contact, relays and limit switches).
  - Test.

➢ **Faults/Remedy**

(a) **Soot covering/slight fusing:**- clean contacts and restore to shape by filling.
(b) **Heavy damage:**- replace contact
(c) **Excessive play** in the operating mechanism (selector/main contact, in the contactor).

- Cause(s): Burning resulting from maladjustment and contactor and selector.

- Remedy:

  - Tighten joints
  - Replace parts with oversized holes
  - Replace parts showing heavy wear
  - Readjust the contactor & selector

* Test the unit always at the end of each action.

(k) **Repair Effected On Terminal Bushing**

Area of failure: Between the porcelain shells and metal flange.

Note: Terminal bushing must be oil tight.

Reasons:

- Differing thermal expansion which gives rise to heavy mechanical forces in the wake of sudden temperature changes.
- Electrodynamics forces produced by short circuits flowing through the central conductor or terminal.

- Faults/Remedy

❖ Chipped spots/cracks

  - Wash and give two coats of varnish in minor cases otherwise replace the shell.

- Destroyed cemented joint

    (i) **Up to 30% destruction around circumference:** repair by cleaning away the destroyed current and pouring the joint with a freshly prepared cementing compound.
    (ii) **More than 30% destruction around the circumference with the shell loose in the flange:** – Re-cement the bushing completely.

Note: A good terminal bushing fit for service is leak proof at the surface or the joint between the flange and the porcelain shell. Pressure test to certify.

(l) Faults/Repair Effected On Leads

Causes of damage to S.R.B. Insulation paper on the leads or sleeves.

- Charring within isolated areas or all over the insulation of the lead;

- Procedure to repair a damaged insulation

    - Disconnect the lead from the tap changer, the winding or the terminal bushing.
    - Remove damaged insulation
    - Clean conductor and rid it from insulation traces
    - Slip in new insulation
    - Reconnect lead to tap changer, winding or terminal bushing.

- Damaged lead conductor (Fused at the surface or the soldered joint between the lead and the flexible connector maybe broken).

Remedy – Make a new conductor to replace the damaged one
- Remake the soldered joint between the lead and the flexible connector

Note: The new lead must be made of the same material as the one being replaced.

(m) Repairs Effected On the Tank, Cover, Conservator, Filters and Fittings

Things to check – General

- Oil leaks firm fittings/joints
- Fasteners for stripped or otherwise damaged thread.
- Presence/condition of gaskets.
- Security of the mounting of the relief – stack flange on the cover
- See if the burst diaphragm in the relief staled is intact.
- Impact welded joints.

Note: Remove/correct all observed defects.

a) Poor Welded Joint

- Chip defective area with a chisel.
- Clean up chipped area to rid it of dirt/oil.
- Remake the weld.

b) Oil leakage from joints between the circulating tubes/tank

- Caulk the joints.

c) Oil leak from plug cock

- Grind the plug to seat with an abrasive powder.

d) Fasteners (bolts, screwed nuts) with stripped thread

- Replace.

e) Damaged Gaskets (cuts)

- Replace with oil proof rubber of the same thickness.

f) Rusted Surfaces

- Scratch-brush and paint.

g) Filters & Dehydrators.

- Fill with fresh or regenerated silica.
- Free them from sludge/dirt (Thermisyphon filter, dehydrator, oil cocks).

h) **Blocked oil cock, dehydrator, thermisyphon filter**

- Free them from sludge/dirt.

Note: This paper has not dealt with repair of Buchholz relay, thermometer, spark-gap fuse and other instruments and protective devices which are normally repaired in specialized laboratories.

(n) Management of Transformer Oil

Fault: Low breakdown voltage.

Cause: Presence of moisture and impurities.

Remedy: Purify and dry, otherwise change completely.

(o) The Relevance of Testing Transformer/Types of Tests.

Tests are the principal means of detecting troubles, defects and checking the quality of repair. All tests have objectives, techniques and basic requirements. A pre-repair test for instance determines the scope and nature of the repair work to be done and supplies the performance data with which the post repair results could be compared with.

1.5.1.8 Importance of testing Reconditioned Transformers.

- To check workmanship.
- To make sure it is free from defects that might upset its normal operation.
- To see that its performance complies with its data-sheet values, applicable specifications and standards.

- **Other Specific Post-repair Test**

  These include:

  - Testing the tank for tightness
  - Testing on-load tap changers and mechanisms including relays.

1.5.1.9 Specific Types of Repair/Procedure

(a) Replacement of terminal bushings. Depends on whether bushings are positioned sideways or at the tank cover.

(b) Reconditioning of tap changer contacts. *Partially drain oil up to top yoke level and affect the repair.

(c) Core-coil assembly. *Drain the entire oil and lift unit out of the tank.

1.6 SOME Equipment Required

1. Adjustable or double-ended wrenches (for ants & bolt heads)
2. Rubber slab/wooden board
3. Work bench
4. Crane/lifts (to take out core/coil assembly),
5. U-shaped core search coil. C-shaped core search coil. U-shaped core feed coil. indicator (instruments for the detection of turn-to-turn short etc.
6. lathe machine (to apply insulation to windings)
7. Winding machine (to make windings)
8. Tensioner (for use in fabricating transformer windings
9. Rollers/positions to handle the core
10. Varnishing machine
11. Baking furnace
12. Insulation merger
13. Special fixtures and slings.
14. Pressure pump to test bushings.
15. Soldering/brazing tools
16. Cutting tools.

1.7 CONCLUSION/RECOMMENDATION

Maintenance culture is very necessary for any equipment designed, produced, installed and commissioned to render specific services. This must become part of our technological awareness if we want to operate safe, reliable and efficient systems. Aspect such as rewinding, heat treatment, cannibalized varnish impregnation was not dealt with in detail but constitute vital aspects of maintenance of transformers.

It is recommended that power supply authorities look in the direction of adaptive technologies as a way to enhance reliability, continuity, efficiency and cost effectiveness in their short and long term plans and management for the systems. They should also encourage training/retraining of staff (technical) with new theories and development in their areas of specialization (maintenance of installed plants and equipment.

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