Power Transformer Maintenance

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The objective of this course is to outline the suggested work procedures that are typically performed for transformer preventive maintenance. The suggested procedures presented in this course do not pertain to the major overhaul and transformer repair. Nevertheless, many procedures completed during routine maintenance and transformer major overhaul may be the same. The maintenance routines discussed in this section can be applied to a transformer that has not reached an advanced deterioration stage. Also, these suggestions are written for the average circumstances under which the transformer is required to work. It is further implied that all staff involved with the maintenance are adequately trained and have transformer maintenance experience. The suggested practices presented in this course are similar to those that manufacturers suggest for their equipment. If detailed instructions are needed, the student needs to consult manufacturer manuals. Transformer preventative maintenance involves routine inspection, adjustment, testing, minor fixes, and special handling instructions. Also, the trouble-free service of the equipment over its life depends on proper installation, operation, and maintenance.

Power Transformer Installation, Acceptance, and Maintenance Procedures

Transformer successful operation depends on correct installation, loading, and maintenance. Also it depends on proper design and manufacture. As is with all electrical devices, neglecting of certain requirements may lead to severe problems, if not to the equipment loss. The objective of transformer maintenance process can be summarized as follows:

Unscheduled Transformer Maintenance

This philosophy is based on reactionary operation mode. That is to say, maintain the equipment when it breaks down, otherwise do not take any actions.

Transformer Ordinary Maintenance

This philosophy considers making irregular visual inspection and doing repairs, adjustments, and necessary replacements.

Protective Maintenance

This approach consists of completing preventive, predictive and corrective maintenance. The preventive maintenance involves schedule maintenance and regular testing. Predictive maintenance involves extra monitoring and testing, whereas corrective maintenance considers repairing and restoring transformer integrity to its original condition when degraded conditions are found. The goal of the transformer protective maintenance is to control and prevent serious oil and winding insulation deterioration. Mineral oil and winding paper insulation are impacted by moisture, oxygen, heat, and other agents such as copper, iron, electric stress, etc. The end result is that oxidation happens in the oil which leads to transformer sludging. In sealed units ingress of moisture via atmosphere or seal leaks needs to be stopped. Moisture will decrease the dielectric strength of both the oil and the winding insulation systems. Also, transformer extra heating will cause the winding insulation (paper) to decompose which in-turn creates moisture. Increased moisture created in the paper not only decreases the paper insulating strength but also, as temperature increases, the moisture will migrate from the paper insulation to the oil and decrease its dielectric strength. The most important step is to construct transformers so that moisture and oxygen are kept out. The next step is to operate transformers so that they are not operated beyond their temperature ratings and limits. Also, the severity of deterioration needs to be controlled by periodically monitoring and testing transformer insulation, and take mitigation measures to restore transformer to its original condition. This approach can be summarized by the following:

1. Measure and control transformer heat

2. Inspect and maintain transformer auxiliary elements

3. Test and maintain transformer insulation

4. Maintain transformer bushing insulation

5. Maintain transformer protective coating

These points are discussed next under installation, maintenance and transformer testing. The transformers are divided into dry and liquid types for the purposes of this course.

Dry-Type Power Transformers

Installation

Factors that need to be clearly kept in mind when installing dry-type transformers are accessibility, ventilation, and atmospheric conditions. Ventilated dry-type power transformers are typically designed for application indoors in dry locations. They will work successfully where the humidity may be high, but under this condition it may be mandatory to take precautions to keep them dry if they are shut down for appreciable periods. Areas where there is dripping water need to be avoided. If this is not possible, adequate protection needs to be provided to stop water from entering the transformer enclosure. Precautions need to be taken to guard against accidental water entrance, such as might happen from an open window, by a break in a water or steam line, or from use of water near the transformers. Proper ventilation is mandatory for the adequate transformer cooling. Clean, dry air is recommended. Filtered air may decrease maintenance if the location presents a particular issue. When power transformers are installed in vaults or other restricted locations, adequate ventilation needs to be given to keep the air temperature within established limits when measured near the transformer inlets. Typically, this requires a minimum of 100 ft^3 of air per minute per kilowatt (kW) of transformer loss. The area of needed ventilating openings depends on the vault height. For self-cooled power transformers, the needed effective area needs to be at least 1 ft. for each inlet and outlet per 100 kVA of transformer rated capacity, after deduction of the area occupied by screens, gratings, or louvers.

Ventilated dry-type transformers need to be installed in areas free from unusual dust-producing mediums or chemical fumes. Transformers above 75 kVA need to be placed at least 12 in. from walls or other obstructions that might prevent free air circulation through and around each unit. The distance between adjacent power transformers must not be less than this figure. Smaller transformers can be directly installed on the wall but still need to be mounted at least 12 in. apart. Also, accessibility for maintenance needs be taken into account in locating a transformer. If the transformer is to be placed near combustible materials, the minimum clearances established by the National Electrical Code (NEC) need to be kept. The transformer enclosure is made to stop the entrance of most small animals and foreign objects. Nevertheless, in some areas it may be mandatory to give consideration to extra protection. Typically, a flat, level industrial floor is adequate and no special preparation is required because of the base construction used on these transformers, which completely eliminates the process of grouting sills into concrete floors. If noise is a factor in the location and operation of any power transformer, special consideration needs to be given to the equipment installation. The transformer impulse strength is less than that of liquid immersed units of the same voltage class. If there is any chance that transformers will be exposed to lightning or serious switching surges, proper protective equipment needs to be provided. Transformers of standard temperature rise are made to function at altitudes up to and including 3300 ft. Dry-type transformers depend on air for dissipation of their heat losses; consequently, the effect of decreased air density due to high altitude will increase the transformer temperature. Typical transformers can be used at altitudes higher than 3300 ft. if the load to be carried is decreased below nameplate rating as follows: If the power transformer is dry type, self-cooled, class AA, decrease the nameplate rating by 0.3% for each 330 ft. above the altitude of 3300 ft. If the transformer is dry type, forced air cooled, class AA/FA, decrease the nameplate rating by 0.5% for each 330 ft. above the altitude of 3300 ft. If the maximum 24 h average temperature of the cooling air is decreased below design levels, the altitude limitation of 3300 ft. can be safely surpassed without decreasing the transformer nameplate rating within the limitations of Table 1.

Table 1. Maximum 24h average cooling air temperature (°C)

Type of apparatus	Altitude			
	3300 ft.	6600 ft.	9900 ft.	13200 ft.
Dry type, class AA				
80°C rise	30	26	22	18
115°C rise	30	24	18	12
150°C rise	30	22	15	7
Dry-type, class AA/FA				
80°C rise	30	22	14	6
115°C rise	30	18	7	-5
150°C rise	30	15	0	-15

Transformer Inspection

New power transformers should be inspected for damage during transport once they are received. Inspection has to be made before removing from cars or trucks, and if any damage is evident or any indication of rough handling is noticeable, a claim needs to be filled with the carrier at once and the manufacturer has to be informed. Subsequently, covers should be removed and an internal inspection made for damage or displacement of parts, loose or broken elements, cracked porcelain, dirt or foreign material, and for the presence of free water or moisture. Corrective actions have to be if necessary. Shipping braces need to be removed if provided. After a transformer is moved, or if it is stored before installation, this examination needs to be repeated before placing the transformer in operation.

After arranging all the necessary primary and secondary connections, the transformer needs to be thoroughly examined. Before putting in operation, the operation of fans, motors, thermal protection relays, and other auxiliary elements has to be verified. All bolted connections that may have loosened in shipment must be tightened before putting in service. The case and core assembly of power transformers needs to be permanently and properly earthed.

Transformer Acceptance Tests

Once the transformer has been installed, the following tests should be completed for acceptance:

Insulation resistance (IR) test: The IR examination is of value for future comparative needs and also for determining the suitability of the power transformer of energizing or application of the high-potential (hi-pot) test. The IR test needs to be successfully passed for factory warranty to be valid. The IR test needs to be carried immediately prior to energizing the transformer or beginning the high potential test. Obtained figures, corrected to factory test temperature of 20°C, need to be equal to or higher than the figures presented in the Table 2, or a minimum of one half or more of factory test figures. In the case corrected test values at 20°C are less than the minimum of the above figures, than the transformer insulation condition is questionable.

Table 2. Dry-type transformer IR figures

Transformer Coil Rating Type (V)	Minimum DC Test Voltage	Minimum IR (MΩ) Dry Type Transformer
0-600	1000	500
601-5000	2500	5000
Higher than 5000	5000	25000

In the absence of previous reliable test figures, the following expression can be used for single-phase transformers, or single winding of a three-phase transformer for calculating the IR values.

$$IR = \frac{CE}{\sqrt{kVA}}$$

where

IR is the minimum 1min 500 V DC IR in MΩ from winding to earth, with other winding or windings guarded, or winding to winding with core guarded

C - 30 at 20°C measurements (C = 16 for tests of winding with other winding or windings earthed)

E - voltage rating of winding under test

kVA - rated capacity of winding under test

If the transformer under test is three-phase type, and all three individual windings are being tested as one, then:

E is the voltage rating of one of the single-phase windings (line-to-line for delta-connected units and line-to-neutral for star-connected units)

kVA - the rating of the three-phase winding under test

Polarization index (PI) test: This is an addition to IR test. In this test, the two IR measurements are completed, the first reading at 1min and the second reading at 10 min. Then the ratio of the 10min reading to 1min reading is calculated to give the PI dielectric absorption value.

A PI of winding-to-winding and winding-to-earth has to be found. A PI less than 2 is indicative of insulation deterioration and requires additional checks.

AC hi-pot (dielectric) test: The dielectric test puts a stress on the insulation since the dielectric test voltage is bigger than the normal voltage. The IR test has to be successfully passed immediately before completing the dielectric test to prevent the possibility of transformer damage due to moisture. The dielectric test supplements the IR tests by checking the transformer suitability for operation at rated voltage. Field test voltages should not surpass 75% of factory test values. The hi-pot test set needs to be variable to allow a gradual increase of test voltage from zero and a gradual decrease after the test is finished. These test figures are presented in Table 3.

Table 3. Dielectric test value for acceptance and periodic maintenance of dry-type power transformers

Transformer, winding rated, AC voltage (kV)	Factory test, AC voltage (kV)	Acceptance field test, AC voltage (75%) (kV)	Maintenance periodic test, AC voltage (65%) (kV)
1.2 and below	4	3.0	2.6
2.4	10	7.5	6.5
4.16	12	9.0	7.8
4.8	12	9.0	7.8
6.9	19	14.25	12.35
7.2	19	14.25	12.35
8.32	19	14.25	12.35
12.0	31	23.25	20.15
12.47	31	23.25	20.15
13.2	31	23.25	20.15
13.8	31	23.25	20.15

Transformer turns ratio (TTR) test: The TTR test is used to check transformer turns ratio. It measures the number of turns of the primary winding with respect to the number of turns in secondary winding. The accepted values of the TTR test should not be higher than 0.5% as compared with calculated figures.

Insulation power factor (PF) (dissipation factor) test: This test measures the watt loss in the tested insulation. Since it is an AC voltage test, it precisely indicates the wetness of the winding insulation and corona issues. This verification can be completed as PF tip-up test for dry type power transformers to further distinguish between a moisture or carbonization issues.

Maintenance

Similarly to other electric devices, these transformers need maintenance from time to time to assure successful service. Inspection has to be done at regular intervals and corrective actions need to be taken when necessary to assure the most satisfactory operation of this equipment. The frequency of inspection depends on operating conditions. For clean, dry areas, an inspection annually, or after a longer period, may be fine. Nevertheless, for other areas, such as may be encountered where the air is polluted with dust or chemical fumes, an inspection at 3 or 6 month intervals may be needed. Typically, after the first few inspection periods, final schedule can be made based on the existing conditions. Once the transformer is de-energized, covers over openings need to be removed. Inspections have to be made for dirt, especially accumulations in insulating surfaces or those which tend to prevent air flow, for loose connections, for the condition of tap changers or terminal boards, and for the general transformer condition. Observation has to be made for signs of overheating and of voltage creepage over insulating surfaces, as evidenced by carbonization tracking. Signs of rust, corrosion and deterioration of the paint need to be checked and mitigation measures taken if required. Fans, motors, and other auxiliary elements should be inspected and maintained.

Cleaning: If significant accumulations of dirt are found on the transformer windings or insulators when the transformer is checked, the dirt has to be removed to allow free air circulation and to guard against the possible insulation breakdowns. Special attention has to be given to cleaning top and bottom ends of winding assemblies and to cleaning out ventilating ducts.

The windings may be cleaned with a vacuum cleaner, blower, or with compressed air. The use of a vacuum cleaner is preferred as the first step in cleaning, followed by the use of compressed air or nitrogen. The compressed air or nitrogen should be clean and dry and should be used at a relatively low pressure. Lead supports, tap changers and terminal boards, bushings, and other major insulating surfaces have to be brushed or wiped with a dry cloth. The application of liquid cleaners is not recommended since some of them have deteriorating effect on most insulating materials.

Testing for routine maintenance: These tests are needed for routine maintenance of dry-type power transformers.

- IR test of winding-to-winding and winding-to-earth - This test is similar to the test listed under installation and acceptance.

- Dielectric absorption test needs to be done winding-to-winding and winding-to-earth for 10 min. The PI needs to be above 2.0 for acceptable limits.

- Turns ratio test (TTR) needs to be completed similarly to that under installation and acceptance.

- AC over-potential test should be done on all high- and low-voltage windings-to earth. This is an optional test for routine maintenance testing.

- Insulation PF test can be completed for each winding-to-earth and winding-to winding. The acceptable value is lower than 3%.

Drying-Out Techniques

For the purpose of drying out, power transformers can be considered as consisting of core and coil assembly. When it is mandatory to dry out a transformer before installation or after an extended shutdown under relatively high humidity, one of the following techniques may be used:

- External heat

- Internal heat

- External and internal heat

Before using any of these techniques, free moisture has to be blown or wiped off the windings to decrease the time of the drying period.

Drying by external heat - External heat may be brought to the transformer by one of the following techniques:

- By directing heated air into the bottom air inlets of the transformer enclosure

- By putting the core and coil assembly in a non-flammable box with openings at the top and bottom through which heated air can flow

- By putting the core and coil assembly in a properly ventilated oven

- By putting incandescent lamps in the transformer container

It is crucial that most of the heated air is blown through the winding ducts and not around the sides. Proper ventilation is vital in order that condensation does not take place in the transformer itself or inside the enclosure. A sufficient quantity of air has to be used to assure roughly equal inlet and outlet temperatures. When using either of the first two external heating methods heat may be obtained by the application of resistance grids or space heaters. These may either be placed inside the case or box or may be put outside and the heat blown into the bottom of the enclosure. The core or coil assembly has to be carefully protected against direct radiation from the heaters. It is suggested that the air temperature does not exceed 110°C.

Drying by internal heat - This technique is quite slow and should not be used in the case other methods are available. The transformer needs to be installed so that it allows free air circulation through the coils from the bottom to the top of the enclosure. One winding needs to be short circuited and sufficient voltage at normal frequency needs to be applied to the other winding to circulate roughly normal current.

It is suggested that the winding temperature does not exceed 100°C, as measured by resistance or by thermometers installed in the ducts between the windings. The thermometers need to be of the spirit type, since mercury thermometers give erroneous readings due to the heat generation in the mercury as a result of induced eddy currents. The terminal end windings (and not the taps) have to be used in order to circulate current through the entire winding. Adequate precautions have to be taken to save the operator from dangerous voltages.

Drying by external and internal heat - This technique combines two methods that are previously described. It is also the quickest technique. The transformer core and coil assembly need to be installed in a non-flammable box, or kept in its own case if appropriate. External heat is applied as described in the first technique, and current is circulated through the windings as described in the second technique. The needed current will be considerably less than when no external heating is applied but has to be sufficient to generate the desired winding temperature. It is suggested that the temperatures attained do not surpass those stated in previous two techniques. Drying time is dependent on the transformer condition, size, voltage, amount of absorbed moisture and the used drying method. The measurement of IR is useful in determining the drying status. Measurements have to be completed before starting the drying process and at 2 h intervals during drying. The starting value, if taken at ordinary temperatures, may be bigger even though the insulation may not be dry. Because IR changes inversely with temperature, the transformer temperature has to be kept roughly constant during the drying period to get comparative readings. As the transformer is heated, the moisture presence will be evident by the quick drop in resistance measurement. Following this period the IR will increase gradually until near the end of the drying period, when it will increase more quickly. Sometimes it will increase and fall through a short range before steadying, since moisture in the interior of the insulation is working out through the initially dried portions. IR measurements need to be completed for each winding-to-earth, with all windings earthed except the one being examined. Before completing IR measurements, the current has to be interrupted and the winding needs to be short circuited and earthed for at least 1 min to drain off any static charge. All readings need to be for the same time of application of test voltage, preferably 1 min. Constant attendance during the drying process is recommended.

Storage

Ventilated dry-type power transformers preferably need to be stored in a warm dry area with constant temperature. Ventilating openings need to be covered to keep out dust. In the case it is mandatory to leave a transformer outdoors it has be properly protected to stop moisture and foreign material from entering. Condensation and the moisture absorption can be prevented or decreased by the immediate installation of space heaters or other small electric heaters. In the case it is more convenient incandescent lamps may be substituted for the space heaters.

Liquid-Type Power Transformer

The following section presents general recommendations for installation and maintenance of liquid-filled power transformers. Many points listed for dry-type power transformers can be also applied to liquid-filled power transformers and will not be additionally discussed.

Installation

The transformer has to be installed in line with National Fire Protection Association (NFPA) Document 70, NEC Article 450. Because of the ban on askarel for use as a transformer insulating fluid, liquids such as silicone, RTemp, and others are being used. These liquids have a fire point of not less than 300°C and the NEC has classified these fluids as less flammable. The oil filled power transformers, if placed indoor need to be installed in a fire proof vault in line with NEC Article 450. Hence, they are typically installed outdoors with an oil pit (oil containment enclosure) filled with gravel or stones to contain the oil in case of spill. The gravel and stones are used to inhibit the oil from pooling in case of fire. It is crucial that local and NEC regulations are followed when installing transformers filled with these fluids. Important factor for transformer installation is ventilation. Proper ventilation needs to be provided in transformer rooms and vaults to carry transformer heat away. Self-cooled transformers need to have proper (2 to 3 ft.) space between each unit to allow free air movement. The ventilation needs to be dust-free, dry, and noncorrosive, and should not contain any detrimental pollutants. As with dry-type power transformers, precautions need to be taken to stop leakage of water into transformer rooms. The power transformer needs to be permanently earthed by means of 4/0 cable or larger to the substation earthing bus. The power transformer needs to be protected against lightning and other overvoltage conditions by suitable lightning arresters.

Inspection

New power transformers need to be examined when received for damage that may occur during transport. Examination needs to be done before unloading from the shipping carrier for indication of improper handling and injury to the transformer. After the power transformer is unloaded from the truck or railcar, an internal examination needs to be made for displacement of elements, broken or loose connections, dirt or foreign material, and the presence of water or moisture. In the case oil or transformer fluid was installed at the factory examine the power transformer for leaks. Also verify for positive gas pressure if the power transformer is equipped with an inert gas. Verification needs to include the examination of the transformer enclosure, bushings, anchor and tie rods, earthing straps, drains, covers, valves, and other elements that are provided with the transformer. If internal transformer tank inspection has to be done, ensure there is sufficient ventilation in the transformer tank before entering the tank. It is vital that there is at least 16% oxygen content before entering the transformer tank. The inspection port cover must not be opened under wet conditions. It is recommended practice not to expose the transformer liquid to the atmosphere if the relative humidity is above 65%.

Power Transformer Acceptance Tests

Before a power transformer is energized, it needs to pass following acceptance tests:

IR test - The IR test is useful for checking if the transformer is in good condition and also to make a benchmark for future comparative tests. The measured IR values are a function of temperature, whether the coils are immersed in the transformer liquid or not, or whether the windings are cold or hot. The measured values need to be corrected to 20°C by multiplying them by proper correction factors. The technique of measuring IR by a megohm-meter indicates the IR directly in millions of ohms (or megohms). This technique has a minimum voltage range that is presented in Table 4. It is suggested for the different voltage rated transformers.

Table 4. Liquid-filled transformer IR figures

Transformer Coil Rating Type (V)	Minimum DC Test Voltage	Minimum IR (MΩ) – Liquid-filled transformer
0-600	1000	100
601-5000	2500	1000
Higher than 5000	5000	5000

In the absence of consensus regulations on what constitutes a proper IR value, the Nation Electrical Testing Association (NETA) recommends the values of Table 4 to be used for acceptance and maintenance transformer testing. The measured IR values have to be compared to factory test values if available for purposes of evaluating the results. It is recommended to watch for the trend to determine if the measured values keep stable or are heading downward. Even though the measured values may be above the minimum figure, a downward trend over a period of time may suggest changes which require further investigation. In the absence of reliable previous test information, the following expression may be used for single-phase transformers, or single transformer winding of three-phase power transformer

$$IR = \frac{CE}{\sqrt{kVA}}$$

where

IR is the minimum 1min 500 V DC IR in megohms from winding-to-earth, with other winding or windings guarded, or winding-to-winding with core guarded

C = 30 at 20°C measurements (C = 0.8 for tests of winding with other winding or windings earthed)

E is the voltage rating of tested winding

kVA is the rated capacity of tested winding

In the case transformer under test is of the three-phase type, and all three individual windings are being examined as one, then:

E is the voltage rating of one of the single-phase windings (phase-to-phase for delta-connected units and phase-to-neutral for star-connected units).

kVA is the rating of the tested three phase winding

Insulating liquid dielectric test - The insulating liquid needs to be sampled in line with ASTM D-923 standard and checked for determination of its dielectric strength, acidity, moisture, interfacial tension, color, and PF. These verifications are done to ensure that the insulating liquid has not changed from its established levels or that the dielectric strength has not been decreased through accumulation of contaminants and pollutants. The samples for oil are taken from the bottom of the transformer tank, while the samples for askarel and silicone are taken from the top of the tank.

TTR - The TTR test is done to ensure that the transformer turns ratio is correct and that none of the transformer windings are shorted out. Essentially, it compares the number of turns in winding 1 with the number of turns in winding 2. The test needs to be completed for each tap position for transformers equipped with tap changers.

The TTR test can also check transformer polarity. The TTR test value for acceptance must not be higher than 0.5% when compared to calculated values.

Hi-pot test - The hi-pot test (also known as the over-potential test) needs to be completed on all high- and low-voltage windings of the transformer to earth. Either AC or DC voltage can be applied. Nevertheless, the accepted practice is to use either an AC or DC hi-pot test to transformers up to 34 kV. For transformers above 34 kV, only the AC hi-pot test is used. For transformer acceptance, the AC hi-pot test can be used at rated transformer voltage for 3 min. This is a go or no-go test. In the case hi-pot voltage is held without any failure or transformer malfunction, the transformer is considered to have successfully passed the test.

PF (dissipation factor) test - This test needs to be completed on important and/or large power transformers. This test stresses the insulation in proportion to the stresses generated in normal operation because it is an AC voltage test.

Frequency response analysis (FRA) - FRA is completed on large power transformers to verify mechanical properties of the windings and core. The objective of the test is to discover changes in the transformer physical characteristics caused by through faults, shipment, repair, or other forces. A voltage signal is applied to the transformer terminals over a wide frequency range and the reflected response is checked.

Transformer Maintenance

The main objective of power transformer maintenance is to protect against breakdowns by discovering potential risks and eliminating them. Hence, periodic transformer maintenance will ensure many years of trouble-free service. The power transformer is a very simple, rugged device and is typically ignored and forgotten until transformer failure happens. Nevertheless, power transformers are crucial element in the electrical system and they need proper care and attention. Power transformer maintenance schedules need to be determined according to the critical or noncritical nature of the transformer and the connected load. Apparently, large power transformers are more important than small lighting and distribution transformers. Therefore, they require more attention and care. Adequate transformer maintenance needs to include routine inspection and repair, transformer liquid maintenance and examination, transformer winding insulation maintenance and testing, and any other special maintenance that is suggested by the transformer manufacturer. A power transformer maintenance and testing plan with suggested frequency is presented in Table 5.

Table 5. Transformer Inspection and Maintenance Plan

General inspection	**Frequency**
Ground connections	Every 6 months
Tap changer	Every 6 months
Lighting arresters	Every 6 months
Pressure relief devices	Every 3 months
Breather	Monthly
Auxiliary equipment	Annually
External inspection	Every 6 months
Internal inspection	5 to 10 years
Protective devices	Yearly
Protective alarms	Monthly
Load current	Hourly or use recording meters
Voltage	Hourly or use recording meters
Liquid level	Hourly or use recording meters
Temperature	Hourly or use recording meters
Insulating liquid	**Frequency**
Interfacial tension	Annually
PF test	Annually
Moisture content	Annually
Gas analysis test	Annually
Dielectric strength	Annually
Colour	Annually
Neutralization number	Annually
Solid insulation (winding)	**Frequency**
Hi-pot (AC or DC)	Five years or more
Induced voltage	Five years or more
Polarization recovery voltage	Annually
DC winding resistance	Annually
IR	Annually
PF	Annually
FRA	Annually
PI	Annually

Routine repair and inspection - Routine transformer repair and inspection involve visual verification of the transformer operating conditions and necessary repair. The observation frequency depends upon the transformer critical importance, the environmental conditions, and/or the operating situation. Different organizations such as the NFPA, NETA, and transformer manufacturers have published instructions for inspection intervals and what to inspect. Following are common instructions for completing a routine inspection.

Load current - The transformer loading affects transformer heating. The transformer temperature affects its life expectancy, and it is vital on large units to monitor load on an hourly basis. For proper transformer loading, refer to ANSI standard C57.92 for liquid-immersed power transformers and ANSI C57.96 for dry-type power transformers. For small transformers, a reading can be done on a daily or weekly basis.

Voltage - The transformer voltage needs to be monitored similarly to load current. To maintain rated secondary voltage, proper primary voltage would need to be applied. Voltage readings can be taken in conjunction with load current or recording voltmeters can be used. On lower importance transformers, voltage readings can be taken on a weekly basis.

Liquid level - Liquid level is vital since it not only supplies the cooling medium but also insulates the windings. Loss of liquid may happen due to the fluid evaporation or due to leakage. Liquid-level readings can be done when load readings are being taken. Liquid lost by the power transformer needs be immediately replaced.

Temperature - The transformer load-carrying ability depends on its thermal capacity. The total transformer temperature is the sum of the ambient temperature, winding insulation temperature, and hot-spot temperature. Typically, the average ambient is 30°C; the temperature increase above ambient for class A insulation is 55°C with an allowable hot-spot rise of an additional 15°C, which then gives an overall temperature of 100°C. Any time the transformer is operated above its thermal rating, loss in overall transformer life can be expected. An 8°C rule or class A insulation and 12°C rule for class B insulation are used in the industry for assessing the transformer life. Therefore, in the case transformer with class A insulation are operated above their thermal ratings by 8°C, the transformer life can be expected to be cut in half. Also, operating transformers with class B insulation 12°C above their thermal ratings will cut the transformer life in half. To observe the temperature for big critical power transformers, it is suggested that the following readings be taken on a daily basis.

- Liquid temperature
- Ambient air temperature
- Water temperature (for water-cooled power transformers)
- Oil temperature (for forced oil-cooled power transformers)

Protective devices - Basic power transformer protection is included in NEC. This protection is upgraded with extra protective relays and elements.

It is critical that protective devices are examined and maintained on a regular basis to make sure that these elements operate in case of transformer malfunction or damage. The following protective elements along with other protective elements not listed here need to be inspected and maintained on a yearly basis:

- Wiring and current-transformer connected to protective relays
- Overcurrent phase and earth relays
- Under- and overvoltage protection relays
- Alarm and auxiliary protection relays
- Differential protection relays
- Sudden pressure protection relays

Protective alarms – Power transformers are equipped with different types of alarms, such as over-temperature, liquid temperature, and pressure-relief elements. Typically, these are open-type contacts that can be connected to either alarm or trip the circuit breaker. The alarm contact and connected wiring need to be inspected on a monthly basis.

Earth connections - The power transformer tank is solidly earthed to eliminate electric shock per the NEC standards. The earthing straps for transformer tanks need to be checked for loose, broken, or corroded connections. The substation earth resistance will depend upon the type and substation rating. The earth resistance may vary from less than 1Ω for large sized substations to 25 Ω for very small-sized substations. These inspections should be done on annual basis.

Lightning arrester - When power transformers are supplied from transmission lines, lightning arresters are used to protect the transformer from lightning and other surges. Lightning arresters need to be checked for looseness, broken parts, dirt, and other pollutants. All dirt and deposit have to be cleaned, loose connections tightened, and broken elements replaced during this verification. The inspection of lightning arrestor and its earthing system has to be done annually.

Pressure-relief device – Majority of sealed transformers are provided with pressure-relief elements to relieve excessive pressure in the tank due to the internal arcing. This element is set to open at a pressure of 10–15 psi. Routine verification of pressure-relief elements needs to include checking for leaks around joints, diaphragm cracking, etc. This check needs to be done quarterly.

Breather - Many power transformers are equipped with breathers of either the open type or dehydrating type. The function of the dehydrating agent is to stop moisture from entering the transformer enclosure. Most dehydrating breathers contain silica gel, which will change colour from blue when dry to pale pink when wet. Verification can be made through a glass window provided for the purpose. The breathers need to be inspected on a monthly basis. Dehydrating agent needs to be replaced or reconditioned if found restrictive or wet.

Auxiliary equipment - Auxiliary equipment needed for cooling, such as fans, oil pumps, control elements, and wiring, need to be checked annually. The equipment needs to be cleaned and damaged parts replaced.

External inspection - The power transformer needs to be given an external check twice per year. The check needs to include tank examination, radiators, auxiliary devices, gasket leakage, and metal elements for corrosion. Also, the electrical connection needs to be inspected for tightness and overheating. Transformer bushings need to be verified for mechanical damage, cleanness, and leakage. Bushings need to be regularly wiped clean to minimize flashovers.

Internal inspection - This verification involves the tank and core internal check. On liquid-filled power transformers, the covers can be removed to check for evidence of moisture or rust around the bushing supports and transformer top cover. To check the tank and core, the liquid can be drained out. Core examination needs to be done to check for sludge deposits, loose connections, and any damage to the transformer elements. Presence of carbon may indicate internal issues. The winding inspection needs to be checked for damage to terminal panels, barriers, loose connections, and overall winding connections. Apparently, such things as untanking the power transformer for internal inspection would have to be judiciously made and would depend on transformer age, its overloading and trouble history. Inspection frequency needs to be 5 to 10 years or more.

Power transformer fluid - All power transformer fluids are subject to deterioration, and the main pollutants are air, moisture, and heat. These pollutants react with transformer fluid and generate acids and sludge. In turn, acid attacks the winding insulation, and sludge deposits tend to decrease cooling. Transformer fluid moisture tends to decrease the fluid dielectric strength, which combined with sludge, will decrease the flashover value of insulators and terminal boards inside the transformer tank. As previously discussed, frequent transformer inspection is required to maintain the fluid in a contaminant-free state.

Drying-Out Techniques

Similar to dry-type power transformers, the liquid insulating power transformer can be considered as consisting of core and coil assembly, except that the assembly is immersed in an insulating fluid. Actions are taken to prevent and discover the infiltration and increase of moisture content. Before the transformer liquid becomes saturated with water, the winding paper insulation has already absorbed a concentration of moisture because of its high affinity for water. The water in the paper insulation speeds up the degradation of the insulation and decreases its electrical integrity.

Simple technique for discovering the water content in the transformer oil can be made by an approximate technique known as the cloud test. It consists of cooling a test tube sample of oil in an ice bath. If a cloud appears in the test tube above 0°C, the transformer has excessive moisture. Confirmation of the water content in the power transformer can be done by a laboratory test. The moisture distribution in the power transformer is always in a state of unequilibrium. Through the cooler range of temperatures, the transformer winding solid insulation will tend to absorb more moisture than the transformer liquid. Nevertheless, as the transformer is loaded, the increase in winding temperature will release this moisture. This change due to varying loads and temperature is constant, regardless of whether there is an excess of water or only a very small quantity of moisture in the power transformer. Also, power transformer liquids such as oil tend to hold more water with an increase in temperature. Therefore, there will be more moisture in the transformer oil when it is loaded than when it is unloaded. Other effects, such as paper insulation decomposition, will tend to create more moisture in the transformer liquid. When it becomes mandatory to dry out liquid power transformers, the following techniques can be used: (1) Heat alone or (2) Heat followed by vacuum.

Heat alone - This technique involves application of heat to the transformer alone. One technique of heat application is oven drying, which can be done at any of the service shops of major manufacturers. When the power transformer is oven dried, it is crucial to observe winding resistance to understand when the transformer, reaches oven temperature (100°C–120°C). PF and IR measurements need to be done at about 6 h intervals to see when drying is completed, that is, when at least four readings are of the same value.

Heat followed by vacuum - The heating of the power transformer with liquid can be done by applying short circuit to the power transformer or by circulating hot oil by means of an external system. Similarly to the previous technique, PF and IR measurement need to be done at about 6 h intervals. Drying is detected by at least four readings that are the same. The field drying techniques may involve heating the transformer liquid, removing the liquid, and promptly applying high vacuum. Another technique may involve removing the liquid and heating the power transformer by hot air circulation. Once the winding reaches 90°C–100°C a high vacuum is applied. Once the temperature drops below 50°C, drying is stopped. The typical length of time to apply heat and vacuum may be a week or more, depending on the transformer size. Once the transformer is dried and the vacuum pulled, clean transformer liquid can be introduced into the power transformer. Following precautions that need to be observed during this process are:

- Before the vacuum is pulled, ensure that the tank is braced for full vacuum
- The drying air temperature should not surpass 100°C

If new undried coils are used for replacement purposes, the coil clamps need to be checked after drying is done since shrinkage may occur during drying. When drying is done on an energized power transformer, precautions need to be taken to stop bubble formation during the degassing phase. Otherwise, immediate damage may happen. The power transformer liquid level needs to be carefully watched because unintentional lowering of transformer liquid level may cause transformer damage.

Transformer Storage

Power transformers need to be stored in a safe, dry, ventilated area with uniform temperature. In areas where no controls for uniform temperature exist, condensation and absorption of water can be reduced by installation of space heaters. Transformers using askarel as an insulating liquid will require special storage areas.

Power Transformer Diagnostic Guide

For troubleshooting needs, a diagnostic guide and causes of transformer failures are given in Table 6. This data is by no means complete, and the student is advised to check and test for the problem and its cause.

Table 6. Causes of transformer damage

Winding damage	**Terminal board damage**
Turn to turn failures	Loose connections
Surges	Leads (open)
Moisture	Links
External faults	Moisture
Overheating	Insufficient insulation
Open winding	Tracking
Deterioration	Short circuits
Improper blocking of turns	
Grounds	
Phase to phase faults	
Mechanical failures	
Tap changer damage	**Core damage**
Mechanical	Core insulation failures
Electrical	Ground strap broken
Contacts	Shorted laminations
Leads	Loose clamps, bolts, and wedges
Tracking	
Overheating	
Short circuits	
Oil leaks	
External faults	
Bushing damage	**Miscellaneous damage**
Aging	CTs failures
Contamination	Metal particles in oil
Cracking	Damage in shipment
Flashover due to animals	External faults
Flashover due to surges	Bushing flange grounding
Moisture	Poor tank weld
Low oil or fluid	Auxiliary system failures
	Overvoltage
	Overloads
	Other unknown problems

Generally, the following conditions will cause indicated troubles:

Overtemperature - Overtemperature can be created by an overcurrent, overvoltage, insufficient cooling, low liquid level, sludge in the transformer liquid, high ambient, or short-circuited core. In dry-type power transformers, this condition can be caused by clogged ducts.

Winding insulation failure - This is an electrical fault in the transformer winding insulation where it can involve phase-to-earth, line-to-line, three-line and/or earth, or turn-to-turn-type short circuit. The causes for this type of damage may be due to a short-circuit fault, lightning, overload or overcurrent condition, or transformer liquid containing moisture and pollutants.

Incorrect secondary voltage - This situation can happen due to improper turns ratio, abnormal primary voltage, and/or transformer shorted turns.

Bushing failure - Bushing damage can be created by flashover due to dirt accumulation and/or lightning strikes.

Internal arcing - Internal arcing can be created by low liquid level exposing live parts of the power transformer, loose connections, or failure of the transformer dielectric. Typically, internal arcing can become audible and cause radio interference.

Core failure - This situation happens due to the damage of core laminations, core, bolts, clamps, etc.

High exciting current - Typically, high exciting currents are due to short-circuited core and/or open core joints.

Low dielectric strength - This situation can be created by condensation and moisture penetration due to inadequate ventilation, broken relief diaphragm, leaks around transformer accessories, or cooling coil leakage.

Oil oxidation – Typically, oxidation ends in the formation of acids and sludge in the transformer liquid. It happens mainly due to exposure to air and high operating temperatures.

Pressure-relief diaphragm broken - This situation happens due to an internal fault that can cause excessive internal pressures or the transformer liquid level being too high or excessive internal pressure due to transformer loading.

Discoloration of transformer liquid - Discoloration is created by liquid carbonization due to switching, core damage, or pollutants.

Leakage of transformer liquid - Leakage can happen through screw joints, around gaskets, welds, casting, pressure-relief elements, etc. The main causes are inadequate assembly of mechanical elements, inadequate filters, poor joints, improper surface finishing, defects in the used material, or insufficient tightness of mechanical elements.

Moisture condensation - The main causes for moisture condensation are inadequate ventilation in open-type power transformers and a cracked diaphragm or leaking gaskets in sealed-type power transformer.

Gas-sealed power transformer troubles - In gas-sealed power transformers, additional issues can be the loss of gas, oxygen content above 5%, or gas regulator problems. These issues are created by gas leaks above the oil, leaky valve seats, insufficient gas space, and/or insufficient flushing of gas space with nitrogen.

Transformer switching equipment troubles - Many power transformers are provided with tap chargers and other switching elements. The issues related with these transformers may be excessive contact wearing, mechanism overtravel, moisture condensation in mechanism liquid, etc. Excessive contact wear happens due to loss of contact pressure from weakened springs or a contact-making voltmeter set at too narrow bandwidth or insufficient time delay. Mechanism overtravel typically happens due to defective or inadequate adjustment of controller contacts. Moisture condensation happens due to improper ventilation, and carbonization happens due to excessive operation and lack of filtering. Control fuse blowing and mechanism motor stalling happen due to short circuits in the control circuit, mechanical binding, or low-voltage conditions in the control elements.