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IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers

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IEEE Power Engineering Society

Sponsored by the
Transformers Committee

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IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers

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Transformers Committee
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IEEE Power Engineering Society

Approved 5 December 2007

IEEE-SA Standards Board

Abstract: This guide provides guidance and recommended practices on the installation and maintenance of liquid-immersed power transformers rated 501 kVA and above with secondary voltages of 1000 V and above. This guide covers the entire range of power transformers, including extra high-voltage (EHV) transformers. This guide does not cover special transformers such as furnace transformers, rectifier transformers, etc. Distinctions are made as required for various MVA ratings, voltage ratings, and types of liquid insulation.

Keywords: installation, liquid-immersed transformer, maintenance, oil-filled transformer, oil processing, testing, transformer

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Introduction

This introduction is not part of IEEE Std C57.93-2007, IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers.

Power transformers usually represent one of the most important and most costly single items in substations. Furthermore, particularly for large transformers, their failure usually results in lengthy outages or downgrading of service. For these reasons, a high degree of care is required to properly install and maintain them.

Because of these considerations, IEEE and other standards-developing organizations have published, since at least the early 1920s, various recommendations for testing, installing, and maintaining transformers. This guide consolidates and replaces IEEE Std C57.12.11™-1980 and IEEE Std C57.12.12™-1980, which cover large transformers, and ASA C57.93-1958, which covers smaller units.

The intention of this guide is to assist users and manufacturers in the shipping, handling, inspection, installation, and maintenance of liquid-immersed power transformers and to assure that the units are placed in service in acceptable condition to provide years of reliable service. This guide also provides information on developing a maintenance and monitoring program.

NOTE—The manufacturer may specify more stringent requirements than this guide. For transformer warranty validation and other reasons, the manufacturer's guidelines should be followed.

This guide discusses the following two sizes of transformers:

- 501 kVA to 10 MVA, or with primary windings less than 69 kV
- 10 MVA and above, or with high-voltage windings of 69 kV and above

The working group of this guide recognizes that substantial variations exist among transformer manufacturers on certain aspects of transformer installation requirements and that these vary with size and voltage. This guide attempts to accommodate these variations and facilitate a full understanding between manufacturer and user. Generally, the user must conform to the manufacturer's minimum recommendations in order to obtain a proper warranty.

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IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers

1. Scope

The recommendations presented in this guide apply to the shipping, handling, inspection, installation, and maintenance of liquid-immersed power transformers rated 501 kVA and above with secondary voltages of 1000 V and above. This guide covers the entire range of power transformers, including extra high-voltage (EHV) transformers. This guide does not cover special transformers such as furnace transformers, rectifier transformers, etc. Distinctions are made as required for various MVA ratings, voltage ratings, and types of liquid insulation.

Clause 3 contains information for use with transformers rated below 10 MVA with high voltages less than 69 kV. Clause 4 applies to transformers rated 10 MVA and above with primary voltages of 69 kV and above, including EHV transformers.

NOTE 1—For transformers with primary voltages that are less than 69 kV and larger than 10 MVA, users should follow Clause 4.[1]

NOTE 2—The user should carefully read the instruction book supplied by the manufacturer. Any conflict with this guide that may occur should be resolved with the manufacturer for each specific installation.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D1816-2004, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.[2]

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[1] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.
[2] ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

ASTM D2668-2002, Standard Test Method for 2,6-Di-teriary-Butyl-Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption.

IEEE Std C57.12.00™-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers. [3, 4]

IEEE Std C57.104™-1991, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.

IEEE Std C57.106™-2002, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

IEEE Std 62™-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus.

IEEE Std 693™-2005, IEEE Recommended Practices for Seismic Design of Substations.

3. Liquid-immersed power transformers rated 501 kVA to 10 MVA, or with primary windings less than 69 kV

3.1 General

In general, these transformers can be either of the station or pad-mount configuration and may have load tap changing (LTC) equipment. They normally have sealed liquid or inert gas insulation preservation systems, and may have draw-lead-type high-voltage and bottom-connected low-voltage bushings. The radiators (if provided) may be welded directly to the tank.

For outdoor applications, the insulating liquid normally is conventional mineral oil or synthetic oil. For special applications, or for use indoors, they may contain less flammable or non-flammable or biodegradable liquids.

Forced cooling (if present) normally uses fans.

Transformers in this size range are usually shipped filled with all their insulating fluid and do not have shipping braces as such. Units rated 7.5–10 MVA are sometimes shipped without liquid or with some liquid removed and with the high-voltage bushings removed. Depending on shipping limitations, insulating fluid may be delivered separately for installation on site.

In this size and voltage range, impact recorders may not be utilized and most shipments are made by truck, directly to the site or a receiving facility. The presence of the manufacturer's or the carrier's representative (other than the driver) is seldom available upon receipt of the transformer at the destination.

3.2 Inspection and receipt

Many transformers in this size and voltage range are shipped completely assembled, tested, and filled with insulating liquid, ready for immediate service.

Most of these transformers are received oil filled with a positive pressure in the main tank and with radiators (if required) completely assembled. Upon receiving and before unloading, check for any visual

[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08854, USA.
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damage to tank, radiators, bushings or any external accessories. Upon receipt, each transformer should be checked for evidence of damage or leaks, and the internal gas pressure should be measured. A positive or negative pressure indicates that the tank has not developed any leak. Zero gauge pressure should be investigated. A small valve or a plug fitting could be opened slightly to check for the internal gas pressure. The de-energized tap switch should be operated and if necessary (provided that the bushings are installed or the winding leads are accessible), a ratio test may be carried out to ensure that it is functional.

If the transformer has been supplied with a series-parallel connection, the switch or other device that accomplishes the change in connection should be checked to assure that it is in the correct position for the intended application voltage. Unless otherwise specified by the customer, if the series-parallel connection is located in the HV winding, the connection should be set in the highest-voltage position. If series-parallel connection is located in the LV winding, the connection should be set in the lowest-voltage position.

NOTE—A series-parallel connection may be installed in either the HV or to the LV winding.

The transformer should be thoroughly inspected for nicks, dents, and scratches. Any damage to weather-resistant finishes should be repaired promptly.

Facilities for measuring core grounds, internal pressure, and access to the gas space for dew point determination on smaller transformers are seldom provided, unless specified. If a test means is provided, the core insulation should be tested.

In this smaller size range, some tank designs may not be able to withstand a vacuum for vacuum oil-filling, and must therefore be refilled with acceptable degasified oil without the benefit of a vacuum. For this reason, removal of the insulating liquid in the field for any reason should be avoided on these units. Transformers that can withstand vacuum have no special restrictions.

An increasingly popular test is a frequency response analysis test. The test may be requested as a factory test and, to be of maximum benefit, should be repeated as a receiving test. There is a complication in that the test results are somewhat different if done with oil or without oil. Test results may also be affected by ambient temperature, tap position etc. There needs to be coordination in the specification as to performing this test in the factory under conditions that can be repeated when the unit is received, and preferably before it is unloaded. After all, the premise of the test is to detect changes in the winding characteristics. Users should be aware that the test would add substantial cost to this size of transformers.

3.2.1 Station-type configuration

In addition to the above, all accessories, such as the liquid-level gauge, pressure-relief vent, thermometer(s), and winding temperature indicator (if provided), should be checked to ensure that they are operating properly. If high-voltage bushings have been supplied separately, they should be thoroughly checked for damage or leaks upon receipt.

3.2.2 Pad-mount configuration

Pad-mount transformers are almost always supplied completely assembled, tested, and filled with insulating liquid, ready for service. If specified, accessories are found in the high- or low-voltage terminal compartments. Make sure that all of the correct equipment has been provided and all items required for service are complete.

3.3 Internal inspection

If there is evidence of damage, notify the manufacturer. If tank openings are available so that an internal inspection is feasible, it is first necessary to break the seal by venting the internal pressure and purging the gas space with dry breathable air that has a maximum dew point of –45 °C (–49 °F).

3.3.1 General practices for internal inspection

When it is necessary to work inside power transformers, the workers should be aware of the rules and requirements of their company and all local, state and national codes with jurisdiction over the area in which the work is performed. The work should be done in accordance with all such applicable rules, codes and guidelines.

It is recognized that different organizations have interpreted such rules, codes, and guidelines for confined space entry in different ways and that the worker may also interpret such codes in slightly different ways. In the absence of such guidance, or as a minimum level of safe practices, the following items are recommended:

- Only workers who have been trained and are familiar with confined space entry procedures should work inside transformers.
- All bushing terminals and the transformer tank must be securely grounded, and all current transformer leads shorted.
- A least one person should remain outside the transformer while others are working inside. This person should keep in visual or audible contact with the workers inside. If a worker inside loses consciousness, the outside worker should call emergency rescue workers and never go into the transformer to attempt to remove the fallen worker.
- All risks of engulfment must be eliminated. Entering a transformer tank without first completely draining of oil is not recommended. If an inspection is carried out without all the oil removed, steps must be taken to eliminate the possibility of falling into the oil. If conservator tanks, radiators, coolers, pipes, or other sections of the transformer have been isolated by valves, but not drained, and the quantity of oil in these areas is sufficient to engulf the worker, the valves used to isolate these sections must be locked in the closed position.

WARNING

After the access-hole cover is removed, the transformer should not be entered until the shipping gas (including dry air) is completely purged with breathable dry air that has a maximum dew point of –45 °C. The oxygen content must be between 19.5% and 23% before entering the tank. Carbon monoxide levels should also be monitored and maintained at a level less than 25 ppm. The lower explosive limit (LEL) should be less than 20%. This replacement of gas with dry breathable air is necessary to provide sufficient oxygen to maintain good air quality and sustain life. If the unit was initially shipped in dry nitrogen, there is a possibility of trapped nitrogen pockets. In this case, a sufficient vacuum should be held for a predetermined period of time and the vacuum released with and refilled with dry breathable air. Shipping gas can be effectively removed from the tank by temporarily filling with dry oil, or by partially evacuating the tank to remove the shipping gas.

- If the transformer has been filled with nitrogen or another inert gas, the nitrogen or inert gas must be removed and replaced by dry breathable air. This can be accomplished by thorough purging or by first applying a vacuum to remove the nitrogen or inert gas, then refilling with dry breathable air.
- During the entire internal inspection process with personnel inside the tank, a minimum flow of 9.4×10^{-3} m^3/s (20 cfm) of breathable dry air with additional 2.4×10^{-3} m^3/s (5 cfm) for each additional person (or follow the local OSHA requirement, if available) is required to purge the tank. The oxygen content and combustible gas content must be checked periodically to ensure the levels are acceptable.
- Adequate lighting of non-explosive type must be provided.
- Movements inside a transformer should be slow and deliberate. There are often sharp protrusions that can cause cuts and contusions if the worker is not careful to avoid them. Workers should not attempt to squeeze into tight spaces where they might become stuck.

3.3.2 Atmospheric conditions

Moisture may condense on any surface cooler than the surrounding air. Excessive moisture in insulation or dielectric liquid lowers its dielectric strength and may cause a failure of the transformer. The transformer should not be opened under circumstances that permit the entrance of moisture, such as on days of high relative humidity (60% or higher), without precautions to limit the entrance of moisture. If the transformer is brought to a location warmer than the transformer itself, the transformer should be allowed to stand until all signs of external condensation have disappeared. There should be a continuing determination of tank oxygen content and a supply of dry purging air.

3.3.3 Inspection

To avoid the danger of any foreign objects falling into the transformer, all loose articles should be removed from the pockets of anyone working above the open transformer tank and all tools should be tied with clean cotton tape or seine cord securely fastened either to outside of the transformer tank or to a readily accessible point inside of the tank. Tools with parts that may become detached should be avoided. If any object is dropped into the transformer and cannot be retrieved, the manufacturer should be notified.

When the internal inspection is made, the manufacturer’s recommended procedures should be followed. Inspection will include, for example, removal of any shipping blocking; examination for indication of core shifting; test for unintentional core grounds; visual inspection of windings, leads, and connections including clamping, bracing, and blocking; inspection of tap switches, including contact wipe, alignment, and contact pressure; inspection of current transformers, including mounting supports, and condition and clearance of leads; examination of bushing draw leads; and checking for dirt, metal particles, moisture, etc. If any internal damage that may have been due to rough handling is found during this inspection, the carrier and the manufacturer should be notified. The manufacturer should also be notified if any foreign material is discovered. All tools should be accounted for after the internal inspection.

3.4 Handling

Transformers should always be handled in accordance with the manufacturer’s special instructions and, normally, in an upright position. Smaller transformers may be bolted or otherwise attached to a pallet that can be easily handled with a forklift truck.

CAUTION

The center of gravity may shift on a partially assembled transformer, such as a transformer with radiators mounted on one side only.

Larger units will have lifting lugs designed to lift the transformer completely assembled and filled with insulating liquid. The transformer tank cover should always be securely fastened into place before lifting. Cable-lifting pull angles should not exceed 30 degrees from vertical. Otherwise, spreaders should be used to hold the lifting cables apart to avoid any bending of the structure or lifting hooks. Do not attempt to lift a transformer by placing a continuous loop of cable or chain around the transformer or lifting lugs. Jacking facilities will also be available on larger units; jacks should only be placed under the jack pads provided. When jacking a transformer, ensure that at least two jacks are used on adjacent corners and that the two adjacent corners are raised simultaneously and evenly to avoid warping the base. Refer to the manufacturer’s instructions for specific details pertaining to each unit. When using rollers, use as many as necessary to distribute the weight evenly on all rollers under the transformer.

To pull sideways, attach pulling eyes to the holes in the base at either end of the transformer. Care must be taken to avoid damage to the base and cabinet and to avoid tipping the transformer when pulling horizontally.

3.4.1 Pad-mount configuration

Most of the weight in a pad-mount transformer assembly is in the main tank, which holds the core and coil assembly and the insulating liquid. For this reason, the lifting and jacking facilities are mounted on the transformer tank itself. The terminal compartments are largely empty and weigh relatively little. Improper use of hoists or jacks could seriously damage the transformer or its attachments or cause personal injury.

On some transformers in this class, the terminal compartments will be permanently mounted to the transformer itself and the lifting and jacking facilities will be designed to accommodate the center of gravity of the complete assembly. Pad-mounted transformers may have a removable terminal compartment. The manufacturer's outline drawings should be consulted to determine if the lifting and jacking facilities are positioned for the assembled or disassembled or non-oil-filled configuration.

3.5 Assembly

Since transformers in this size range are normally shipped fully assembled and ready for service, there is little field assembly required. Units may be shipped filled with insulating liquid, but with the high-voltage bushings and fans removed for shipment. Above 7.5 MVA, some suppliers may ship the transformer filled with nitrogen or dry air and ship the insulating liquid separately in drums or by tank truck. If oil handling is required, see 4.8. Padmount transformers are normally shipped fully assembled with the insulating liquid in the transformer and under positive gas pressure, ready for service. Transformers should be mounted on a level pad that is strong enough to support the total weight involved. The transformer should be secured to the pad, especially in seismic "Moderate Zone" or greater. Refer to IEEE Std 693.[5]

Surge arresters supplied with the transformer, or separately purchased, should be installed. Manufacturer's instructions should be followed in the installation of protective fuses, switches, surge arresters, and other accessory equipment.

3.6 Storage

The transformer should be stored upright and completely assembled.

Sealed-tank units should be filled with the insulating liquid at its proper level and the gas space pressurized at approximately 14 kPa (2 lbf/in^2) at ambient temperatures between 10 °C and 30 °C (50 °F and 86 °F). Periodic inspection should ensure that positive gas pressure and proper liquid level are maintained at all times.

Conservator type units should be stored with proper liquid level in the conservators.

Transformers supplied without insulating liquid can be stored under nitrogen for a maximum period of six months, or as otherwise instructed by the manufacturer, provided a positive pressure is maintained. Inspection and drying should precede extended storage if required. Transformers stored outside a fenced area should be secured and barricaded. All bushing terminals should be solidly grounded to protect the transformer terminals and windings in the event of a lightning strike. Heaters in the control cabinets and motor drive housings of LTCs should be connected to a power supply and turned on to prevent condensation.

Insulating liquid supplied in drums or other containers should be placed in a dry location with moderate temperature variation. Drums stored outside must be protected from the possibility of water contamination. The drums should not be stored unprotected in an upright position, as water could collect on the top cover. The insulating liquid would then be susceptible to water contamination due to expansion and contraction of the liquid, which can create suction causing water seepage into the drum through the bungs. Drums may be

[5] Information on references can be found in Clause 2.

covered to reduce the risk of moisture ingress. All insulating liquids should be tested prior to use. Oil with poor test results shall be processed before use. Testing of oil in drums can be difficult; therefore, if possible, place the oil in bulk containers and allow it to settle before testing. If a test sample is required from the drums, the drums should be tilted for several minutes to allow any water to settle at the low point. A sample may than collected at the lowest point.

Should it be necessary to store the removable accessories, they should be stored in a clean dry place. The manufacturer should be contacted for explicit instructions on the storage of individual pieces for longer periods of time.

3.7 Tests

Limited pre-energization testing is normally required on small lower-voltage transformers that are essentially supplied fully tested, complete, and ready for being placed into service. As a minimum, the winding insulation resistance should be measured with a megohmmeter. For units equipped with de-energized tap changers and/or dual voltage switch, it is desirable to check the turns ratio at all de-energized taps and dual voltage switch (or series-parallel terminal board) positions and to check the dielectric strength and water content of the insulating liquid prior to placing the transformer into service. If access to a core ground lead is available, the core insulation should be tested.

Liquid samples from the transformer should be taken from a sampling valve at the bottom of the tank in accordance with the requirements of ASTM D923. Test samples should be taken only after the liquid has settled for some time, varying from eight hours for a drum to several days for bulk fluid containers. Water in cold insulating liquid is much slower in settling.

3.7.1 Pad-mount configuration

Pad-mount transformers are equipped with a variety of optional equipment. Many types of fuses and switches are available, and different gauges, drain valves, and pressure-relief devices may be obtained. Most such accessories are factory-installed, and no fieldwork is normally required to prepare them for operation. Follow manufacturer’s instructions for testing accessories or attachments. Make sure that all connectors (permanent or separable) are correctly rated and installed for the application.

Surge arresters shall be disconnected before tests are made on the transformer and should be reconnected immediately after tests are completed.

3.7.2 Hydrocarbon-based insulating oils (conventional and less flammable)

Refer to Table 7 of IEEE Std C57.106. The dielectric strength of the oil sample should not be less than 40 kV using the 2 mm gap, ASTM D1816 method.

3.7.3 Other insulating liquids

Refer to the supplier’s instructions for applicable tests, sampling procedures, and acceptance levels.

3.8 Energization

Prior to energization, there are a number of things that shall be checked to ensure that the correct internal connections have been made, that the transformer tank is properly grounded, and that other proper precautions have been taken.

3.8.1 Connections

WARNING
The transformer must be de-energized before any de-energized tap changer, series-parallel, dual-voltage, or delta-wye switches are operated. Attempting to change any de-energized tap changer, series-parallel, dual-voltage, or delta-wye switches on an energized transformer will result in damage to the equipment and possible serious personal injury.

Make sure that the de-energized tap changer is in the correct tap position for the required voltage.

Transformers equipped for dual-voltage or delta-wye (reconnectable winding) configurations usually have an externally operable switch mounted on the faceplate in the high-voltage terminal compartment. Units combining dual-voltage and delta-wye features may have two separate switches. Refer to the nameplate for information on adjusting these devices.

When dual-voltage or delta-wye switches are set to connect transformer windings in parallel, tap changers must be in the corresponding position shown on the transformer nameplate.

Before re-energizing the transformer after resetting dual-voltage or delta-wye switches, tap-changer settings should be checked against nameplate information for correct voltages and a transformer ratio test should be performed.

Transformers equipped with an internal terminal board should be shipped with the higher voltage connected in the HV winding, and the lower voltage connected in the LV winding, unless otherwise specified by the customer.

3.8.2 Connecting to bushings

Connections to bushings must be made without placing undue mechanical stress on the bushing terminals. Conductors should be securely fastened in place, adequately supported, and with allowance for expansion and contraction.

3.8.3 Energization under cold conditions

IEEE Std C57.12.00 considers energization at temperatures below –20 °C (–4 °F) as unusual service.

Three characteristics of the insulation/coolant system must be considered under cold start condition. These are dielectric strength versus temperature, specific gravity versus temperature, and the thermal characteristics of the liquid.

Dielectric liquids may exhibit a drop in dielectric strength at lower temperatures if moisture precipitates out, and even at high relative saturation levels of moisture in oil prior to precipitation. At colder temperatures, free ice or free water could exist in the system and could cause a dielectric failure. If an outside power source is available, consideration should be given to preheat the transformer in extreme cold weather prior to energization. Insulating the coolers/radiators to reduce heat loss should also be considered. In consideration of viscous insulating fluid in cold temperatures below –20 °C (–4 °F), it is prudent to energize any extremely cold transformer without load, and then to increase the load slowly. Temporarily, localized temperatures may exceed normal values. A properly designed transformer readily tolerates these transient conditions. At very low ambient temperatures, it will be some time before external radiators become effective, but at these low temperatures, the additional cooling should not be needed.

For start-up temperatures below –20°C (–4°F), it is recommended to energize the transformer, hold at no-load for at least 2 h and slowly increase the load in 25% increments, allowing a minimum of 30 min between each increment. In cases of directly connected generator step-up (GSU) transformers where energized operation at no-load may not be reasonable because of turbine or steam conditions or fuel cost considerations, other means of heating the oil may be a more reasonable approach.

3.9 Maintenance

Lack of attention to a transformer in service may lead to serious consequences. Careful periodic inspection is essential. The frequency of the inspection is determined by climatic conditions and severity of loading. Spare transformers should be given the same care as a transformer in operation. Check with the manufacturer for recommendations regarding special maintenance for the specific unit in question.

3.9.1 Routine DGA testing

Critical transformers should have oil samples taken from the main tank and other critical compartments for dissolved gas-in-oil (DGA) and moisture content testing frequently for the first few weeks of operation to make sure that no abnormal amount of gas or moisture is being developed. The DGA and moisture content testing should be carried out after the first day, three months, six months, and subsequently at one to three year intervals. If at any time the oil samples should test outside of acceptable values specified in IEEE Std C57.104 or IEEE Std C57.106, the reason for the unacceptable values should be investigated.

3.9.2 External inspection

External inspection should be carried out regularly and at least four times annually.

a) In locations where abnormal conditions prevail, such as excessive dust, corrosive gases, or salt deposits, the bushings should be regularly inspected and kept clean.

b) Radiators should be kept clean and free from any obstructions (bird's nests, wind-blown debris, etc.) that may interfere with the natural or forced-air flow across the cooling surfaces. Check all surfaces for evidence of corrosion.

c) Ventilators or screened openings on control compartments should be kept clean. Trapped insects or dirt accumulation will interfere with the free flow of air.

d) Accessory wiring (including rigid and flexible conduit, shielded cable and connectors) and alarm devices should be checked annually and replaced if defective.

e) The external ground connection should be checked annually for continuity by measuring the resistance between the tank and ground.

f) On all sealed tank units, the pressure-vacuum gauge should be checked daily for the first week, then quarterly for the first year, and then annually. It is evidence of either a defective gauge or a leak in the system if the gauge reads zero under different loading conditions.

g) For critical transformers, the liquid level should be checked daily for the first week, then quarterly for the first year, and then annually. Also check the liquid levels of liquid-filled bushings at this frequency.

h) Transformers equipped with auxiliary cooling equipment, such as fans and pumps, should have the following tests:

   — Operate fans (check if direction of rotation is correct, and check for broken fan blades).

   — Operate pumps (check liquid-flow indicator for proper flow and direction of flow; check for excessive noise).

i) If the transformer has a load tap changer (LTC), refer to 4.13.2.

4. Liquid-immersed power transformers rated 10 MVA and above or with high-voltage windings 69 kV and above

4.1 General

The recommendations presented in this clause apply to modern large liquid-immersed power transformers with high-voltage windings rated 69 kV and above. However, appropriate subclauses may be applied to lower-voltage transformers when similar conditions and similar transformer construction exist, and may also be used in servicing older transformers that have been opened for maintenance or repair work.

Increasing applications of larger capacity high-voltage transformers with reduced basic impulse level (BIL) has brought forth the need for increasing care during installation and service. Installation and handling requirements become more stringent for these units, and so this clause may apply to these transformers. High-voltage transformers, with even higher dielectric and thermal stresses, demand a higher degree of care during installation and operation. To maintain the dielectric strength of the insulation system, it is essential to avoid moisture and entrapped gas bubbles. Since the dielectric liquid is an essential portion of the insulation system, liquid quality and care in handling are extremely important. Large power transformers are usually shipped without liquid to reduce weight. To prevent the entrance of moisture during transit, the tank is filled with dry air or dry nitrogen under pressure. To ensure a continuous supply of dry gas, a transformer is often shipped with a gas bottle and a pressure regulator connected to its tank.

NOTE—In some cases, these transformers are partially or completely liquid-filled when received, in which case the instructions relative to initial filling may be disregarded. It may not be necessary to drain this liquid from the transformer except as required for inspection and repair. However, if any part of the main insulation system of the active part is exposed to air or nitrogen, it may be desirable to drain the oil and refill the unit under vacuum, particularly for higher-voltage units such as 130 kV and above.

At the installation site, all reasonable precautions should be exercised to avoid exposure of the insulation systems to moisture. Generally, the user must conform to the transformer manufacturer's minimum recommendations in order to maintain a warranty. Prior to starting installation of the transformer, a detailed procedure for handling, inspecting, assembling, vacuum treating, oil filling, and testing of the transformer should be developed, and agreement between all parties concerned should be obtained. The manufacturer often also supplies limiting values for each transformer including winding moisture content, dissolved gas content, particle count, and dielectric strength of liquid. This guide only covers the general order of magnitude of limits and the means required to reach these values.

Normally, the manufacturer will recommend the level of insulation dryness to be attained. Surface moisture content can be estimated from the moisture equilibrium chart, with the transformer in a correct state of equilibrium (see Figure B.2).

4.2 Shipping

4.2.1 General

This subclause is intended to apply not only for original shipment of transformers from the factory to the user, but also as a guide for later shipment by the user, whether to another station, another utility, or to the factory for repair. Large power transformers are normally shipped on railroad cars. When the distance involved and weight and dimensions of the transformer permit, shipment may be done by truck.

When shipping weight and transportation regulations permit, the transformer may be shipped by truck filled with insulating liquid. For larger units shipped by rail, the insulating liquid is shipped separately and the transformer is filled with dry air. Dry nitrogen may also be used but must be removed and purged with proper procedures to allow for internal entry. Internal gas pressure should be high enough to assure that it will remain positive during any expected low temperatures in transit, especially during mountain crossings. Long distance and/or duration shipments of transformers may require external gas bottles and regulator controls to ensure positive pressure is maintained throughout the shipment.

WARNING

Transformers shipped filled with dry nitrogen should be labeled with external caution notice or notices affixed to the tank indicating how such a unit should be handled, and that vacuuming may be needed to remove all of the nitrogen, prior to any planned entry

4.2.2 Shipping terminology

See C.3.

4.2.2.1 Transformers shipped free on board factory

Power transformers purchased "free on board" (FOB) factory become the purchaser's property as soon as they leave the factory and are accepted by the carrier. The purchaser is responsible for any transit damage and also for obtaining proof that damage occurred in transit. The purchaser must initiate filing of the necessary claim forms and obtain proof that any damage occurred as a result of shipment. The manufacturer may assist the purchaser in this effort.

4.2.2.2 Transformers shipped FOB destination

Power transformers purchased FOB destination are owned by the manufacturer during shipment and become the purchaser's property when they are accepted at the destination. The manufacturer is responsible for transit damage and, should this occur, is also responsible for obtaining proof that damage occurred in transit. The purchaser may assist the manufacturer in this effort. The manufacturer must initiate filing of the necessary claim forms and obtain proof that any damage occurred as a result of shipment.

4.2.3 Railroad shipments

4.2.3.1 Routing

The rail route that the shipment will follow must be thoroughly cleared with the accepting carrier for both weight and dimensional clearances. Railroad carriers will not guarantee any routing clearance for an extended period of time. Extraordinarily large transformers that require shipment may need to have dimensional clearances confirmed with the use of a specific rail car to permit its transportation. Shipment on other rail cars has to be confirmed on an individual shipment basis.

4.2.3.2 Acceptance by carrier

Detailed instructions for affixing a transformer to an open-top rail car can be obtained from the railroad. The originating railroad will inspect the loaded car to determine that it complies with appropriate rules and regulations on loading of rail cars including blocking and tie-down. Measurements of oversized loads will be made by the originating railroad at this time and will be reported to all carriers involved in the route. Oversize loads are also measured at each carrier interchange.

4.2.3.3 Rail cars

Various types of rail cars are available for special shipments. Depressed center rail cars provide a means of shipping tall transformers to meet shipping height restrictions. A transformer may be shipped with a temporary, low-height shipping cover with the permanent cover shipped separately. In some cases, a very tall transformer may be laid on one side for shipping. Only transformers specifically designed with extra bracing to support the core and coils can be laid on one side for shipment. A special car can be used to gain additional height clearance, if the transformer is designed for such a car. Specialty cars are in short supply and so should not be requested unless actually needed.

In general, the load capacity of the car should be selected according to the weight of the load. A high-capacity car, for example, should not be used to carry a light load because of excessive vibration and shock to the load. When the transformer shipping weight is close to the car's weight capacity, the transformer will receive a much softer ride. Conversely, the car must be capable of transporting the weight of the transformer.

To reduce the chances of shipping damage due to rough handling, several measures may be taken. Rail cars with shock absorbers or cushion couplers can be requested. Empty idler cars (such as box cars) that lead and follow the loaded car to further cushion axial impacts can also be ordered. Instructions that prohibit rail car humping and unpowered switching are also useful.

Signage stating which end of the rail car is to be delivered to the front end of the rail siding may be beneficial in some specific unloading situations.

When the rail car is delivered to the shipper, an inspection of the car should be made to be sure the car is in good condition. All wood-floor cars should have all floorboards in place and in good condition. Steel floors should be reasonably flat and free of protrusions.

After the transformer is loaded, the rail car springs should be checked to ensure that they are not excessively compressed. Also, the distance between the top of rail and the bottom of drop-center cars should be checked after loading to determine if required railroad clearances are being met.

4.2.3.4 Rail car loading standard

The Association of American Railroads (AAR) has published a standard for loading rail cars [B20].[6]

4.2.3.5 Block and tie-down

When using steel deck cars, 1 in × 6 in or larger wood planks or sheathing should be placed under the transformer weight-bearing surfaces to provide cushioning. Load the transformer so that its centers of gravity align with the centerlines of the car to prevent tilting and to equally distribute the load on the axles. Wood cushioning also will help prevent the transformer from sliding along the deck of the railcar.

The AAR standard is quite specific as to the design, the quantity, and the positioning of blocks and tie-downs. Other parties such as insurers may require additional blocks and tie-downs beyond those listed in the AAR standard. Blocking members typically consist of steel plates or structural shapes that butt against the transformer base and are welded to the car deck. Tie-downs typically are steel rods or steel cable connected to fittings on the transformer and anchored to the car. The shipper is responsible for providing and installing these items.

Bottom blocking, consisting of steel channels or bars, should be positioned against the transformer base or bottom plate and then welded to the car.

In addition to blocking the bottom of the transformer on the car, the transformer may also be bolted to the car floor. This is done with long bolts through a hole in each jacking pad and the car floor.

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[6] The numbers in brackets correspond to those in the bibliography in Annex A.

All top and bottom tie-down rods and bolts should be double nutted and prick-punched. This permits retightening in transit. Nuts should not be welded. Spring-loaded tie rods are not recommended.

All top tie-down rods should be brought as close to vertical into the rail car pocket as possible. Criss-cross rods are to be used only when some obstruction prevents using vertical rods.

4.2.3.6 Impact recorders

An impact recorder, which records the g-force magnitudes of impacts versus time, should be affixed firmly to a structural component of the transformer main tank to minimize any high-frequency resonance that may occur as a result of unsupported structures. In addition, consideration should be given to also mounting a recorder on the rail car. Mechanical chart type and electronic data logging recorders are commonly available to record longitudinal, vertical, and latitudinal impacts as well as the time and date when an impact occurred. Electronic impact recorders should have a method to protect it from tampering (stopping the device, deleting data, etc.) until at the final destination or when the manufacturer or purchaser deems it necessary to retrieve the information. Impact recorders should be left in place on transformer until transformer is rigged into its final position. The instrument will provide a permanent record of any impacts, which the load undergoes in transit. The recorder must run long enough to allow for delays in shipment. For electronic impact recorders, the recorder should be set up to not overwrite or remove any existing data in the event of a shipping delay. For larger transformers or those of critical importance, consider the requirement of duplicate recorders. Recorders attached directly to the car may be sufficient for some transformers. The transformer manufacturer should be consulted.

4.2.3.7 Personal escort, special freight team service

For critical shipments, particularly where transit time is important, an escort familiar with railroad operations (commonly referred to as a *Rider*) may accompany the shipment. Escorts, however, have very little control in managing events during transit. The escort can attest to how the load was handled and report daily on progress and delays.

Special freight team service can be arranged, and is sometimes required, for special routes where the transformer-loaded car travels in a separate train and is not normal freight service.

4.2.4 Truck shipments

Truck shipment requirements from the factory, directly to the substation site, and from the rail siding to the substation are set by consultation with the trucking firm. The carrier will secure the proper travel permits and determine the government-approved route.

Tie down and blocking is normally the responsibility of the carrier. Chains and chain blocks are typically used to secure the transformer to the truck bed. As with rail shipment, there are government standards for securing these loads. There are opportunities for damage to the transformer during truck shipment due to unexpected changes in routes, undocumented changes to mapped routes including recent road paving work, etc. Impact recorders may be used at the discretion of the manufacturer or requested by the user to monitor truck shipments. Oil spills are an environmental issue so all valves and fittings should be plugged and dry.

4.2.5 Water shipment

Water shipments can be in the hold of a ship or on the top of barges. Ensure that the shipment can sustain a list/tilt of 30 degrees. Usually the accessories, such as bushings, radiators, pumps/ fans, etc., are shipped separately (but normally on the same vessel) in containers.

Water shipments can expose the transformer exterior to excessive moisture and, therefore, liberal use of desiccant in control boxes, current transformer compartments, etc., is strongly recommended.

In addition, it is prudent practice to cover and seal off exposed instruments, dial gauges, etc., to prevent the ingress of moisture, seawater, or both.

4.3 Inspection and receipt

The proper handling and storage of all accessory components is necessary. Carefully follow the manufacturer's recommendations as to type of storage, positioning, and support of all accessories.

4.3.1 External, prior to unloading

When a transformer is received, a thorough external inspection should be made before the unit is removed from the car. Inspect carefully for any apparent damage or shifting of the transformer during transit. If there is evidence of damage or rough handling in transit, an inspector representing the carrier and the manufacturer should be notified. In all cases, the manufacturer's instructions should be followed. For shipments equipped with impact recorders, representatives from the purchaser and carrier should be present to inspect the transformer and examine the impact recorder chart and/or electronically stored impact data at the site location. For smaller transformers in this size range, this may not be considered necessary.

NOTE—Rough handling, for which shippers and riggers are responsible, generally begin as indicated in the following table. These are not design values, but rather values for which discussion between the manufacturer and user should be considered.

Type of impact	Levels for discussion
Longitudinal	3g
Vertical	2g
Transverse	2g

Check the impact recorder charts and/or electronically stored impact data for accelerations in excess of the manufacturer's specified limits. Whenever practical, the hauling agent should be present when the seal is broken or the electronic recorder is interrogated. Check guy rod tension, tie rods, blocking, and welds to the rail car.

For gas-filled shipments, the gas pressure should remain positive even in the coldest weather. Upon arrival at the site, check the gas pressure in the tank and in the supply cylinder, if one is provided. If the gas pressure is zero, there is a possibility that outside air and moisture may have entered the tank and the manufacturer should be notified. Check the oxygen content and dew point of the gas in the tank. It may be safely assumed that the transformer has not been contaminated in transit with outside air or moisture if the dew point of the gas indicates a relative humidity of less than 1% and the oxygen content is below 1% (if shipped in nitrogen). Moisture content, in terms of temperature, pressure, and dew point, should be essentially the same as when the unit was shipped. If the oxygen content and dew points are outside these values, drying may be necessary and the manufacturer should be notified. The core grounds should be tested. The specification may require the manufacturer to test the dew point of the shipping gas as the transformer leaves the factory. If this is so, the dew point (moisture content) of the shipping gas may be described on the shipping documents or a tag at the gas sample valve.

An increasingly popular test is a frequency response analysis test. The test may be requested as a factory test and to be of maximum benefit, should be repeated as a receiving test. There is a complication in that the test results are somewhat different if done in oil or without oil. Test results may also be affected by ambient temperature, tap position etc. There needs to be coordination in the specification as to performing this test in the factory under conditions that can be repeated when the unit is received, and preferably before it is unloaded. For example, tests could be done without oil and winding leads may be brought out through small test bushings. After all, the premise of the test is to detect changes in the winding characteristics.

4.3.2 Internal, prior to unloading

Some users and manufacturers recommend that an internal inspection be made of the transformer on the rail car in all cases. Others recommend an internal inspection on the rail car only if an external inspection indicates possible shipping damage, or if there is no provision to check the core ground externally. If an internal inspection is made on the rail car, it should be made after notifying the carrier and the manufacturer and with their respective representatives present. If there is provision for checking the core ground this should be done. On some transformers it may be necessary to break the seal to gain access to the core-grounding strap. It will be necessary to release the pressure to zero before opening the access covers. Check the core ground, reseal the opening, and then introduce breathable dry air until the desired positive pressure is reached.

Breathable dry air should be continuously supplied into the transformer while the access cover is being removed, and whenever anyone is inside. Extreme care must be taken that the oxygen content is between 19.5% and 23%. The CO level should be less than 25 mg/kg (25 ppm) and the lower explosive limit (LEL) should be lower than 20% or as otherwise indicated by the OSHA requirements. Dew point should be kept as close as possible to the value as measured at the factory. The transformer should not be left open any longer than necessary—preferably less than 2 h. See 4.4.2.

If the delivering carrier will not permit internal inspection of the transformer on the car, and there is evidence or indication of shipping damage, it should be noted on the acceptance slip that there are “possible internal or hidden damages.” When the transformer has been removed to the installation site or to some other convenient locations to permit internal inspection, proceed as outlined in 4.4. Request that a representative of the carrier be present during the inspection.

4.4 Internal inspection

4.4.1 Atmospheric conditions

Moisture may condense on any surface cooler than the surrounding air. Excessive moisture in insulation or dielectric liquid lowers its dielectric strength and may cause a failure of the transformer. The transformer should not be opened under circumstances that permit the entrance of moisture, such as on days of high relative humidity (60% or higher), without precautions to limit the entrance of moisture. If the transformer is brought to a location warmer than the transformer itself, the transformer should be allowed to stand until all signs of external condensation have disappeared. There should be a continuing determination of tank oxygen content and a supply of dry purging air.

4.4.2 Inspection

Access for internal inspection and assembly is normally obtained through a manway.

WARNING

After the access/manway cover is removed, the transformer should not be entered until the shipping gas (including dry air) is completely purged with breathable dry air that has a maximum dew point of –45°C. The oxygen content must be between 19.5% and 23% before entering the tank. Carbon monoxide levels should also be monitored and maintained at a level less than 25 ppm. The LEL should be less than 20%. This replacement of gas with dry air is necessary to provide sufficient oxygen to sustain life. If the unit was initially shipped in dry nitrogen, there is a possibility of trapped nitrogen pockets. In this case, a sufficient vacuum should be held for a predetermined period of time and the vacuum released with and refilled with dry breathable air. Shipping gas can be effectively removed from the tank by temporarily filling with dry oil, or by partially evacuating the tank to remove the shipping gas.

During the entire internal inspection process with personnel inside the tank, a minimum flow of 9.4×10^{-3} m^3/s (20 cfm) of breathable dry air with additional 2.4×10^{-3} m^3/s (5 cfm) for each additional person (or follow the local OSHA requirement, if available) is required to purge the tank. The oxygen content and combustible gas content must be checked periodically to ensure the levels are acceptable.

In addition to monitoring the oxygen and combustible gas content, most utilities also require issuing of a Confined Space Entry Permit to ensure adequate ventilation, continuous gas monitoring; the presence of a safety watcher during the entire inspection event, as well as a plan in place for extrication of an incapacitated worker from inside the transformer tank.

For lighting inside the transformer, an explosion-proof type operated by a low-voltage (<50 volts) isolated power supply should be used.

To avoid the danger of any foreign objects falling into the transformer, all loose articles should be removed from the pockets of anyone working above the open transformer tank and all tools should be tied with clean cotton tape or seine cord securely fastened either to the outside of the transformer tank or to a readily accessible point inside the tank. Tools with parts that may become detached should be avoided. If any object is dropped into the transformer and cannot be retrieved, the manufacturer must be notified.

When the internal inspection is made, the manufacturer’s recommendations should be followed. Inspection will include, for example, removal of any shipping blocking; examination for indication of core shifting; test for unintentional core grounds; visual inspection of windings, leads, and connections including clamping, bracing, and blocking; inspection of tap switches, including contact wipe, alignments, and contact pressure; inspection of current transformers, including supports, and condition and clearance of leads; examination of bushing draw leads; and checking for dirt, metal particles, moisture, etc. If any internal damage that may have been due to rough handling is found during this inspection, the carrier and the manufacturer should be notified. The manufacturer should also be notified if any foreign material is discovered. All tools should be accounted for after the internal inspection.

4.5 Handling

4.5.1 Complete transformer

The transformer should always be handled in the normal upright position unless information from the manufacturer indicates it can be handled otherwise. Where a transformer cannot be handled by a crane or moved on wheels, it may be skidded or moved on rollers or slip plates, depending upon compatibility of transformer base design and the type of surface over which it is to be moved. Transformers built in accordance with current standards have bases designed for rolling in two directions.

4.5.2 Lifting with slings

Lifting lugs and eyes are normally provided for lifting the complete transformer, and the necessary additional means are provided for lifting the various parts for assembly. The lifting lugs and eyes are designed for vertical lift only. When lifting the complete transformer or a heavy piece, the cable should be so attached to provide a vertical force to each lug. As an added precaution to prevent buckling the tank walls, the cover should always be securely fastened in place. Use lifting cables of appropriate length so that the transformer will be lifted evenly. Lifting lugs on most transformers are designed to lift the transformer completely assembled and filled with dielectric liquid. The approximate total weight of the transformer is given on the nameplate and on the outline drawing. Refer to the manufacturer’s information for proper handling and lifting instructions.

NOTE 1—It may not be possible to lift an entirely assembled transformer due to interference with bushings, etc.

NOTE 2—It is usually not possible to lift the transformer with slings if the cover has been removed for any reason.

4.5.3 Raising with jacks

Jack bosses or pads are provided on all transformers in this class so that the transformers can be raised by means of jacks. On some transformers, jacks may be placed under the transformer bottom plate at points designated by the manufacturer. The drawings or manufacturer's instruction book should be consulted.

4.6 Anchorage

A properly designed anchorage system is one of the important requirements to withstand the seismic activities at the location of installation. The recommended anchorage system is made by welding the transformer base to structural steel members embedded in, or firmly anchored to, a concrete foundation. A bolted anchorage system may also be used. Follow the manufacturer's instruction on the bolt sizes, strength, location, and procedures.

4.7 Assembly

4.7.1 General

The transformer tank and bushings (if installed) should be solidly grounded before the start of installation. Ensure that all safety and environmental codes are understood and followed by all the people involved. Always refer to the manufacturer's instruction manual prior to and during assembly for the manufacturer's specific assembly requirements.

Moisture ingress should be minimized by opening only the necessary tank access ports at any time. Ensure all the tools required for the assembly operation are readily available to avoid unnecessary exposure of the core, coils, and insulation to moisture. To prevent unnecessary prolonged exposure, avoid opening two or more access ports that result in air drafts inside the tank of the transformer. If rain or other forms of precipitation is expected, seal or protect all openings from moisture ingress. During the entire time when a transformer is open, it is advisable to continuously purge transformer with dry air.

After the internal inspection has been completed, bushings, radiators and cooling equipment should be installed. The radiators, coolers, and bushings will be handled in different ways as prescribed by the manufacturer of the equipment, but in general should be lifted in a vertical position during handling and installation. After bushing installation, the bushings should be grounded. This equipment must be free of condensation or other forms of precipitation prior to installation. Many different types, thickness, and shapes of gaskets may be used in assembling the various components. The manufacturer usually provides specific instructions for these. If a temporary shipping cover or bushing pockets are used, remove and replace them with the permanent device and pressure test the transformer. There may be temporary internal shipping braces that need to be removed also.

The manufacturer may require liquid filling prior to removing the shipping cover. Evacuate the transformer and fill with breathable dry air making certain that the oxygen content of the entire gas space is between 19.5% and 23%. During the internal work such as internal inspection or installation of bushings etc, maintain a continuous supply of breathable dry air for the safety of personnel and to minimize the entrance of moisture. Continue to monitor the internal air quality while people are working inside the tank. If internal work will take more than one day, the transformer should be sealed under positive pressure overnight. Ensure that a pressure regulator is installed in the dry air tanks to prevent over pressuring the transformer tank during this process. The transformer should then be purged with breathable dry air before work is resumed. Manufacturers may require that the dew point be monitored during the assembly process.

4.7.2 Bushings

Bushings should be absolutely clean and dry when installed. Gaskets and gasket recesses should be carefully cleaned. Gaskets should be carefully placed and uniformly clamped so that tight seals are formed.

Current-carrying connections should be thoroughly cleaned and solidly bolted. Cone-disk washers, if used to maintain bolt pressure, should be compressed to the manufacturer's recommendations. The bushing central cavity should be swabbed to remove particulate contaminants. Instructions for handling the high-voltage bushings should be included with the bushing crate.

When the transformer bushings are to be externally connected to a rigid bus or tubing bus, provision must be made for thermal expansion of the conductors to prevent excessive mechanical stress on the bushing. Mechanical loading on ends of bushings should not exceed design limits.

The bushing should undergo power factor and capacitance testing prior to its installation onto the transformer. When a voltage or test tap is provided, regardless of bushing size or rating, the capacitance of C1 and C2 or C1 respectively, should be measured. It is important to determine if the bushing should be operated with the test tap grounded or ungrounded when the transformer is placed in service. Furthermore, the installation of bushing monitoring systems should be reviewed with the transformer and/or bushing manufacturer to ensure no unintentional stresses on the bushing.

4.7.3 Heat exchangers and piping

If the coolers or radiators are opened when they are at a lower temperature than the ambient air, condensation may take place that will be difficult to completely remove. Radiators or coolers, piping, valves, pumps, and fittings, especially those that are unsealed in shipment or are never assembled to the transformer in the factory, should be thoroughly cleaned and flushed (if contaminated) with clean, warm 25–35 °C (77–95 °F) dielectric liquid before being fitted to the transformer. Make sure that all gaskets are properly seated on the gasket seats at the time of installation. Where necessary to mount a gasket in a vertical plane, the use of gasket cement to hold the gasket in place during installation may be required. The use of white petroleum jelly on the gasket surface may ease installation and prevent damage of a cemented gasket during installation.

Radiators or heat exchangers are usually capable of withstanding full vacuum. If not, these should not be installed until after the tank has been filled with dielectric liquid under vacuum. If liquid-to-water heat exchangers are provided, it is recommended that the water passage be drained and vented to atmosphere prior to drawing a vacuum on the transformer tank. Pressure test the liquid passages of the heat exchangers with filtered dielectric liquid.

4.7.4 Other accessories

The liquid-level gauge, temperature gauges, and other accessories should be installed in accordance with manufacturer's instructions. Gas detector relay piping that is removed for shipment will usually have break points identified to facilitate reassembly. Check the tap winding ratio and operation of the tap changer to be sure that it operates properly in both directions and that full contact area on all taps and adequate contact pressure is maintained on all contacts. A winding ratio test on the de-energized tap changer, prior to filling the transformer is recommended. Check the operation of the liquid-level gauge before sealing the tank. The conservator tank and associated piping should be inspected and cleaned as necessary to remove any debris. All current transformers should be checked for ratio and polarity before filling the transformer. If equipped, all fiber optic winding and oil temperature probes should be tested for proper operation prior to oil filling the transformer. Install a refrigerated condenser on the tank cover if necessary for drying the transformer. The core should be meggered to ensure there are no unintentional grounds.

4.7.5 Controls systems

Control systems for modern transformers have many sensitive electronic components. To avoid damage during installation and commissioning, refer to the instruction manuals provided by the manufacturer.

4.8 Vacuum treatment

Many smaller transformers in this size range do not require preliminary oil filling or heating the core and coils prior to vacuum filling. Check with the manufacturer's specific requirements. If field drying of the insulation due to moisture ingress is not required, as determined by moisture content in terms of temperature, pressure, and dew point, proceed with vacuum treatment and final filling as follows.

CAUTIONS

a) Ensure the transformer tank and all fittings are suitable for vacuum, including:

   1) Conservator tank (tank and bladder, if equipped, have to be *pressure-equalized*)

   2) Radiators, pumps, and their valves

   If any of these fittings are not designed to withstand vacuum, they need to be removed or valved off.

b) Ensure the LTC is suitable for vacuum or has its pressure *equalized*.

c) Ensure instrumentation is suitable for vacuum (older combustible gas sensor units must not only be isolated but usually removed from the transformer during application of a vacuum).

d) Ensure no additional structure load is to be put on top of the transformer under vacuum. Work on top of the transformer while under vacuum should be avoided due to personnel safety concerns in the event that vacuum is suddenly lost and the tank surface moves abruptly. A transformer under vacuum should not be moved.

4.8.1 Preparation

Leave the pressure-relief device blanked off until after the final vacuum filling, unless the manufacturer's instructions indicate the device can withstand full vacuum. If separate liquid-expansion tanks or inert-gas equipment or other devices that will not withstand full vacuum are provided, these should be isolated from the main tank before applying vacuum. In some transformers, the barriers between the main tank and other compartments, such as the wall mounted and insert types on-load tap changers, will not withstand full vacuum on one side with atmospheric pressure on the other side. Where such conditions prevail, equalized vacuum or at least a partial vacuum must also be established on the other side so that the pressure differential will not damage the barriers.

Additionally, caution should be taken to assure that there are no rigid external connections made up to the bushings, tankor outrigger mounted arresters, or insulators during vacuum operation. Tank deflections to these items with rigid connections to the porcelains could result in porcelain breakage or stress tank walls. After all parts have been assembled, the tank should be sealed and pressure tested to ensure that all joints are tight. Pressure-test the entire assembly at a minimum gauge pressure of 14 kPa (2 lbf/in^2) and a maximum gauge pressure of 35 kPa (5 lbf/in^2). Some manufacturers also recommend using a vacuum test to determine that the pressure rise with the tank sealed does not exceed manufacturer's recommendations.

With either pressure or vacuum tests, it is important to be sure of the pressure-differential conditions permissible on the LTC diverter switch barrier board, which may not be capable of withstanding any pressure differential. Check all gasketed joints with a suitable leak detector. The tank should hold the gas pressure for at least 4 h without leakage. All leaks detected in the above manner must be eliminated before starting the vacuum filling.

NOTE 1—Any air leakage into the transformer tank, while a vacuum is being drawn on the transformer, may seriously contaminate the transformer insulation. Air, when drawn into a vacuum, expands and drops in temperature, consequently releasing moisture. If the core and coils are cold, the moisture released from the air will condense on these parts and will be absorbed into the paper insulation. To avoid this hazard, all leaks should be eliminated before starting the vacuum processing, and the core and coils may be heated. This may be done by applying heat externally, by short-circuiting, or prior to vacuum treatment, by partially filling with dielectric liquid circulated through a heat exchanger. If external heat is applied, it must be at a moderate temperature to avoid overheating the insulation. The method of applying current to heat up the windings is considered to be risky and not recommended. Recommendations of the manufacturer regarding the maximum allowable temperature should not be exceeded.

NOTE 2—As an aid to field personnel using vacuum equipment calibrated in various units, Table B.1 is included for ready conversion.

NOTE 3—If a liquid other than conventional transformer oil is used, the user should check with the manufacturer regarding specific procedures to follow concerning testing, filling, handling, and use of the liquid. A small amount of silicone-based oil will cause extreme frothing of conventional hydrocarbon-based mineral oil when it is vacuum processed.

If preliminary liquid filling was used, ensuring that all leaks have been eliminated, drain the liquid and proceed with the vacuum treatment. The liquid may be drained as quickly as desired, but a rapid rate may create a partial vacuum within the tank. The drain valve should be closed immediately after the tank is empty to prevent entrance of air through the drain connection. Because unforeseen delays may occur before the vacuum treatment is applied, it is recommended that the dielectric liquid be replaced with dry gas during the draining process. Make certain that sufficient gas cylinders are available to fill the tank. After the liquid drain valve is closed, continue to admit dry gas until a positive gauge pressure exists in the tank.

4.8.2 Vacuum treatment

The principal function of vacuum treatment is to remove trapped air and moisture from the insulation and enable the insulation to attain its full dielectric strength. Small gas bubbles have much lower dielectric strength than the dielectric liquid and may, if located at a point of high stress, lead to failure. By removing most of the gas from the transformer and from the liquid by vacuum filling, the hazard of the small bubbles of free undissolved gas that remain in the windings and insulation is greatly reduced. Vacuum alone may not be adequate for excessive moisture removal and heating of the core and coils may also be required at lower ambient temperatures.

The degree of vacuum required depends on the voltage rating of the windings and insulation and should be determined in consultation between the manufacturer and purchaser before assembly is begun. In general, a vacuum treatment at pressures of the order of 2 mmHg (.078 inHg) [absolute] may be sufficient for transformers rated below 138 kV. For higher voltage transformers, vacuum treatment at pressures less than 1 mmHg (.039 inHg) [absolute] pressure may be required. An additional benefit gained from the treatment at high vacuum is that the moisture introduced into the transformer insulation during assembly can be removed before the transformer is energized.

A vacuum pump capable of evacuating the tank to the required degree of vacuum in approximately 2–3 h is recommended. Connect the vacuum pump to the vacuum connection on top of the transformer with pipe or reinforced hose of sufficient size to minimize line losses. If no connection was provided for this purpose, an adapter plate for the pressure-relief outlet, with suitable pipe connection, can be fabricated. In order to obtain an accurate vacuum value, it is essential that connection of the gauge or manometer be as close to the tank as possible and preferably at a different location on the tank as the vacuum hose. Check all pipe joints for leaks by pulling a high vacuum or by pressure testing before connecting to the transformer. Close all liquid and gas valves. Start the vacuum pump and continue pumping until the tank pressure is constant. Close the vacuum pump valve and check for leaks in the tank or piping. If all joints are tight, there should be no appreciable increase in residual pressure (the rate of rise depends on the volume of oil in the transformer, but is typically less than 1.0 mmHg in a period of 30 min).

4.8.3 Vacuum leakage tests

NOTE—This test is based on 1982 CEA Commissioning Guide for Substation Apparatus [B8].

An excessive leak rate can be very dangerous to transformer insulation when a large capacity vacuum pump is used. Atmospheric air will enter the transformer and may deposit moisture in the transformer. Three tests shall be done using the Method A as outlined below. The first test is to be done after the transformer has been evacuated to the order of 550 microns. The second test is performed one hour after the first and the third test is performed one hour after the second test.

4.8.3.1 Vacuum connection system leakage

Close the valve closest to the transformer and evacuate the vacuum pump system (including booster pump, oil, and ice traps) and determine the vacuum pump blank-off absolute pressure at this valve. The blank-off absolute pressure should be less than 10 Pa.

4.8.3.2 Assembled unit vacuum leakage tests

New transformers can generally attain a maximum mass gas leak rate of 20 m^3 Pa per minute. This leak rate can be converted to a more usable pressure rise per hour value by using Equation (1) through Equation (4).

a) For metric units in Pa/h:
Maximum pressure rise for volume of oil (V):

$$\text{Pa/hour} = \frac{1200}{\text{V (in cubic meters)}} \tag{1}$$

Or, for volume of oil in liters:

$$\text{Pa/hour} = 1200 \times \frac{1000}{\text{V (in liters)}} \tag{2}$$

b) For metric units in micron Hg/h:

Maximum allowable pressure rise for transformer with volume of oil (V):

$$\text{micron Hg/h} = \frac{9\,000\,000}{\text{V (oil in liters)}} \tag{3}$$

Example: The maximum allowable pressure rise for a transformer with a main tank containing 35 000 liters of oil would be calculated as follows in Equation (4).

$$\frac{9\,000\,000}{35\,000} = 260 \text{ micron Hg/h} \tag{4}$$

Evacuate the unit to the order of 100 Pa at the maximum rate of the pumps unless otherwise restricted by the transformer manufacturer. Close the main vacuum valve between the transformer tank and vacuum pumping system.

Method A

Record tank absolute pressure every two minutes for five readings. The vacuum pump blank-off pressure should be reconfirmed during this recording period and the backing pump gas ballast valve opened to dehydrate the lubricating oil. Plot the pressure readings and approximate the later section of the curve with a straight line. Calculate the pressure rise per hour.

Method B

Take two readings of the pressure; 60 min and 90 min after the vacuum valve to the pump is closed, the first 60 min is allowed for de-absorption of gasses from the insulation.

$$* \text{ Leakage} = \frac{V(P_{90} - P_{60})(\text{mmHgLiters})}{30 \text{ min (min.)}}$$

Where V is the volume of oil of the transformer tank in liters.

— Leakage of less than 150 mm Hg liters per minute is equivalent to 20 m^3Pa/min. If the leakage rate exceeds 20 m^3Pa/min, corrective action to re-tighten all mounting bolts and fittings and/or application of silicone sealant or similar material to suspected fittings is required. If satisfactory, open the main vacuum valve and repeat the evacuation until the vacuum condition is stable or below 50 Pa. Repeat the pressure rise recording, extending the recording an additional four readings at five-minute intervals.

4.8.3.3 Vacuum hold time and hot oil circulation

After an acceptable leak rate is obtained, the vacuum will be held for a period of time as per the manufacturer's recommendation. The following vacuum hold time as a function of the kV class of transformer is given for reference (see Table 1).

Table 1— Vacuum hold times

kV class	Vacuum hold time in hours
69 kV	12 or more
138 kV	24 or more
230 kV	48 or more
345 kV	48 or more
500 kV	60 or more
765 kV	60 or more

— During the vacuum hold period, hot oil may be pumped into the tank to raise the temperature of the winding insulation to expedite the moisture removal. In such case, hot oil processed from an oil heater to a temperature of 60 °C to 90 °C may be pumped into and circulated until a desired temperature of the winding insulation is obtained. The oil is then drained off as quickly as possible to allow the moisture to be removed by the vacuum pump. This heating process may be repeated as required.

4.8.4 Processing dielectric liquid

If dielectric liquid is delivered in tankers or drums, check the quality of the fluid while it is still in the containers. For acceptable properties of the insulating liquid as received, after processing and prior to energization, consult manufacturer and utilities instructions and IEEE Std C57.106.

If liquid-storage facilities are available, a sufficient quantity of new dielectric liquid to fill the transformer should be dried and stored in the clean liquid-storage tank with a desiccant dryer before starting to fill the transformer. If liquid-storage facilities are not available, continue circulating dielectric liquid through the processing equipment until the prescribed dielectric strength is consistently obtained. A sample of the liquid should be taken prior to filling and retained for future checks, such as power factor, etc.

CAUTION

Dielectric liquid passing through filter papers or ungrounded or unbonded hoses may acquire an electrostatic charge that will be transferred to the transformer windings as the transformer is filled. Under some conditions, the electrostatic voltage on the winding may be hazardous to personnel or equipment. To avoid this possibility, all externally accessible transformer bushing terminals, as well as the tank and liquid filtering equipment including oil hoses, should be properly grounded during filling.

4.8.5 Vacuum filling

After attaining the required vacuum, and holding the vacuum for the required period of time as in 4.8.3.3, or depending on manufacturer's instructions, filling may begin. Fill with processed, warm dielectric fluid, as specified by the manufacturer. An oil temperature between 60 °C (140 °F) and 80 °C (176 °F) is recommended, as higher temperature oil will speed up the impregnation of solid insulation. The dielectric liquid should be introduced from a point opposite the vacuum pump above the core and coils in a manner such that it will not stream on the paper insulation. (Fluid inlet and vacuum connections should be separated as far as possible to keep liquid spray from entering the vacuum pump.) The liquid line should be connected to the upper filter-press connection or other suitable connection on top of the tank. The processed liquid is admitted through this connection, the rate of flow being regulated by a valve at the tank to maintain a positive liquid pressure external to the tank at all times, and to maintain the vacuum at or near its original value. The filling rate should not exceed 1.25 cm/min (0.5 in/min).

Filling, at least to a point above the core and coils, should be in one continuous operation. If the vacuum is broken for any substantial period, it may require draining and refilling to prevent formation of gas bubbles. Maintain a positive inlet liquid hose gauge pressure during the entire filling process. Gas bubbles or water in the liquid will expand in proportion to the vacuum obtained and be drawn out by the vacuum pump.

CAUTION

Do not allow dielectric liquid to enter the vacuum pump. For transformers with nitrogen pressure systems, fill the tank to the indicated level; for conservator-type transformers, fill as high as possible [perhaps 100 mm (4 in) from the top] before removing the vacuum. Break the vacuum with dry bottled gas to a positive pressure. For nitrogen pressure systems, this should be a gauge pressure of 14–35 kPa (2–5 lbf/in^2).

Remove vacuum equipment. For nitrogen-pressure-type transformers, activate the automatic gas equipment and maintain positive pressure continuously. For conservator-type transformers, install the conservator and any remaining fittings and accessories. Complete the filling of the transformer and fill the conservator in accordance with the manufacturer's instructions.

CAUTION

Caution must be taken with the pressure-relief device blanked off. Overfilling without pressure relief can cause tank damage.

To bleed off any trapped air open all designated vent points until a solid stream of oil emerges after operating the pumps, in case of forced-oil-cooled transformers. The assembled transformer should not be energized until a period of hold time (as per Table 2) has elapsed in order to allow the insulating oil to absorb residual gas and thoroughly impregnate the insulation.

Table 2— Hold times before energization

Voltage class	Hold time before energization (hours)
69 kV	12
138 kV	24
230 kV	24
345 kV	48
500 kV	48
765 kV	72

4.9 Field drying of insulation

In the event that the internal inspection reveals signs of moisture in the transformer or if the gas seal on the tank was damaged in transit, field drying may be necessary. If possible, determine the extent of the moisture and the manner in which it entered the tank. The transformer manufacturer should be requested to make recommendations concerning further checks and steps for drying out the transformer. The goal of field drying is to attain a comparable value of residual moisture content to that found in the factory. If drying is determined to be necessary, one or more of the following methods may be used:

— **Method 1**: Circulating hot oil. This method is very slow and not as effective as the vacuum methods.

— **Method 2**: High vacuum. This method is used with and without heat. Heat increases the efficiency and decreases the drying time required. It is the method generally used for large MVA units, for high voltage, and for reduced insulation classes.

— **Method 3**: Hot air. The method is not as effective as the vacuum methods.

Other methods or combinations of these methods may be used where facilities are available. The equipment detailed in C.1 will provide the necessary capability for the vast majority of cases. A thorough knowledge of vacuum technology and of vapor pressure will greatly assist field personnel in their job performance.

4.9.1 Method 1—Circulating hot oil

This method is not commonly used. It requires the use of a suitable oil filter, vacuum-drier type or blotter press, plus an oil heater. The heater must be capable of raising and maintaining an oil temperature of approximately 85 °C (185 °F) as the oil is circulated in the transformer tank until the insulation is dry. The transformer should be filled with oil to cover the core and windings and the oil circulated through the heater. Wherever possible, to reduce heat losses due to radiation, the oil should be prevented from circulating through the coolers by closing the bottom valves of the coolers. The outside of the transformer tank and the piping should be insulated to reduce the dry-out time and the amount of heating required to keep the oil temperature constant.

With this method, the moisture is removed through the oil filter. If a blotter-press filter is used, the rate of water extraction will depend upon the degree of saturation of the filter papers. Filter papers must be extremely dry and papers must be changed frequently if this method is to be effective. If a vacuum-drier type of oil filter is used, the rate of water extraction will depend upon the vacuum maintained in the filter and upon the rate of transfer of water from the paper insulation to the oil. This rate of transfer of moisture increases with temperature; hence, it is desirable to operate at the highest temperature that will not cause deterioration of the oil. The rate of drying can be increased by application of vacuum to the surface of the oil. It is preferable to maintain a vacuum on the order of 1 mmHg (133 Pa) above the oil during the above heating cycle, although a low positive gauge pressure 7–14 kPa (1–2 1bf/in^2) of dry gas can be used at this stage if desired. Following this treatment, quickly drain the main tank oil to storage, either under a vacuum or with a blanket of dry gas, and commence vacuum treatment. If less flammable dielectric liquids are used, they may be warmed to a higher temperature to facilitate impregnation of the cellulose insulation. Contact the liquid's manufacturer for exact recommendations.

Another version of the method is to circulate hot oil to heat the unit. When the core and coils reach the desired temperature, the oil is drained and a vacuum pulled. The unit is then purged with nitrogen or dry air, and a dew point is taken. The process may be repeated until an acceptable dew point is obtained.

4.9.2 Method 2—High vacuum (with or without hot oil circulation)

This method requires the use of a suitable vacuum pump, capable of pumping down to an absolute pressure of 0.05 mmHg (6.7 Pa) or lower, and an optional refrigerated vapor trap to collect the water. While no additional heat is required if an adequate vacuum pump is used and the insulation temperature is above freezing, heating the insulation with hot oil circulation will increase the efficiency and reduce the time required significantly.

Drain the liquid from the transformer, filling the tank with dry nitrogen as the liquid is drained. Heat exchangers may be left on the unit if the top valve is closed and the bottom valve left open to assure that no moisture condenses in the heat exchanger. Seal all tank openings, preferably with blanking plates. Connect the vapor trap and vacuum pump to a suitable pipe connection on the tank. To minimize line losses and speed up the drying, the vapor trap should be located as close to the transformer tank as possible. (A small quantity of water expands into a large volume of vapor at very low pressures; hence the capacity of the vacuum pump is greatly increased by using the vapor trap to remove water ahead of the pump.) Seal the tank and pressure test for leaks. After ensuring that all leaks have been eliminated, start the vacuum pump. Water extraction from the insulation will begin when the residual vapor pressure in the tank is reduced below the vapor pressure of water in the insulation. If any leaks are present, this pressure may not be attained; hence, it is imperative that all leaks be eliminated. After the residual pressure in the transformer has been reduced to the point that water is being extracted, the residual water content of the insulation may be estimated from Figure B.2 for the prevailing winding temperature and pressure. Drying may be continued as long as moisture is being extracted or may be terminated when the residual moisture content of the insulation has been reduced to the desired level.

Another empirical method is to seal the tank and frequently measure pressure rise with a total gas vacuum gauge over a 30 min period. The vapor pressure is then determined from the change of pressure rise rate after extrapolating real gas leakage effects back to time zero. Still another method is to monitor absolute pressure with both McLeod-type (real gas) and thermocouple or Pirani-type (total gas) vacuum gauges until the absolute or differential pressures, or both, are at predetermined levels. The manufacturer may also specify some period of vacuum treatment; in any case, a minimum of 12 h for 69 kV and 24 h for higher kV class equipment is recommended. The knowledge of vapor pressure and of the insulation temperature can be used with the moisture equilibrium chart shown in Annex B, Figure B.2 to determine insulation dryness and to provide an intelligent determination of the vacuum treatment endpoint.

CAUTIONS

a) Ensure the transformer tank and all fittings are suitable for vacuum, including:

   1) Conservator tank (tank, bladder, breather, level gauge, etc.)

   2) Radiators, pumps, and their valves

   If any of these fittings are not designed to withstand vacuum, they need to be removed or valved off.

b) Ensure the LTC is suitable for vacuum or has its pressure "equalized."

c) Ensure instrumentation is suitable for vacuum (older combustible gas sensors must not only be isolated but usually removed from the transformer during application of a vacuum).

4.9.3 Method 3—Hot air

This method may be particularly useful to dry out older transformers with tanks that are not designed to withstand full vacuum.

With the transformer assembled in its tank, the tank should be insulated in order to reduce the amount of heating required, and also to keep the interior of the tank at a uniform temperature to prevent condensation in the tank.

Clean dry air should be forced by a fan over the heating elements, then through an opening at the base of the tank to pass over and through the coils before exhausting through an opening in the cover. Baffles should be placed between the hot-air inlet and the windings to prevent the flow of hot air from being concentrated on one small portion of the windings.

Thermometers should be positioned in the inlet and outlet air streams and the quantity of air circulated should be such that only a small difference between inlet and outlet temperatures is obtained. The temperature of the inlet air should be about 100 °C (212 °F).

CAUTION

When drying liquid-soaked insulation with hot air, care should be taken to avoid open flames near the transformer particularly near the air exhaust where liquid vapors will be concentrated. The flash point of conventional transformer oil is approximately 145 °C (293 °F). Fire extinguishers, preferably the carbon dioxide type, should be located near the transformer before beginning the drying.

The air flow rate required to obtain minimum drying time varies with the size of the tanks. The following table is an approximate guide. Smaller air flow rate may be used but the required drying time will be longer

Area of tank base	(m^2)	2.8	5.6	9.3	11.6	14.0
	(ft^2)	30	60	100	125	150
Air fow rate	(m^3/min)	28	57	85	113	142
	(ft^3/min)	1000	2000	3000	4000	5000

4.9.4 Completion of drying

As soon as the transformer can be considered dry, it is essential that the tank be immediately filled with dielectric liquid to cover the core and winding. Filling under vacuum is much preferred.

During the entire drying-out process, regular readings of winding temperatures and of insulation resistance between windings and between each winding and ground should be recorded.

Note that some methods of measuring insulation resistance and power factor can result in excess voltage stress on windings not in oil. As the drying proceeds, it will be noted that the insulation resistance will fall, due to the increase in temperature and release of moisture. The resistance will then begin to rise, and the rate of increase slows down as the drying nears completion. When the insulation resistance flattens out to a constant value, the transformer is not completely dry but it has reached the maximum degree of dryness obtainable with the drying system being used.

Power factor tests may be used instead or in addition to insulation resistance tests for determining the progress of the drying. Power factor will increase as the temperature increases, then decrease as moisture is extracted and flatten out as the drying nears completion.

CAUTION

At some stages in the drying-out procedure, an explosive mixture of liquid vapors and air may exist.

4.10 Reprocessing

Reprocessing is performed on a transformer to increase the dielectric strength of the transformer internal insulation system. It is the most common field method for drying and/or re-impregnating the cellulose insulation. Reprocessing is not normally required for the majority of new medium or large power transformer installations. A reprocessing process on new or aged transformers should not exceed the mechanical or thermal design limitations of the transformer or the transformers' ancillary equipment. A reprocessing process may be performed for the following reasons.

— The transformer manufacturer may require reprocessing for the installation of a new transformer. When reprocessing is required, the manufacturer should provide the process criterion along with limiting mechanical and thermal criterion as part of the instruction literature.

— The transformer manufacturer may require reprocessing on a new transformer for the following additional reasons.

  a) The transformer core/coil assembly has been out of oil for a period of time that will require re-impregnating the cellulose insulation. The period of time and reprocessing criterion should be determined by the original manufacturer and the user, based on all available information on the existing insulation condition.

  b) It has been determined that the cellulose insulating materials absorbed an unacceptable amount of moisture during shipment or storage.

— The end user may determine the need to reprocess a transformer for one of the following reasons.

  a) Re-impregnate the cellulose insulating materials after being out of oil for a prolonged period of time.

  b) Remove excessive moisture from the transformer insulating system (cellulose and/or oil).

4.10.1 Considerations for reprocessing

The most important factors to increase the dielectric strength of the insulation system using reprocessing are temperature, vacuum, and set time (often referred to as *absorption*). These are the factors required to remove moisture from the transformer oil, remove moisture from the cellulose insulation, and/or to re-impregnate the cellulose insulation. The intent is to heat, filter, and de-gasify the oil while circulating the oil through the transformer tank under vacuum. After heating the cellulose, the oil is drained from the tank and vacuum is applied to the exposed, heated, cellulose insulation. Final oil filling may occur after using one or more of the following methods to determine dryness.

a) A designated period of vacuum time.

b) Monitoring of oil quality, vacuum and moisture extraction.

c) Measuring the amount of extracted water.

d) Monitoring the internal tank relative humidity/dew point.

An insulation power factor measurement is recommended after the transformer set time in oil. The insulation power factor measurement should be the final verification on the integrity of the insulation system.

4.10.2 Methodology for reprocessing and absorption

Following are generic field instructions for reprocessing and transformer set time before energization. In addition to the CAUTION notes provided with the items below, the manufacturers' instruction literature should be consulted for other electrical, mechanical, or thermal design limitations that may prohibit the use of this or other reprocessing field processes. Mechanical and thermal recommendations for the reprocessing process are as follows:

- General equipment recommendations. Specifications may vary based on size of the transformer and ambient temperatures. Refer to Annex C for further information.
- Oil entrance into the transformer tank should be through the top main cover or at the top main tank walls as close to the cover as possible.

CAUTION

If ambient temperatures are 5 °C (41 °F) or less, the oil should be heated gradually and directed so that it does not splash on porcelain bushings. Failure to comply may break the bushing porcelains due to thermal shock.

CAUTION

Most field processing units are capable of heating transformer oil above 85 °C (185 °F) using resistive heating elements or other means through heat-exchangers. Field heating of transformer oil above 85 °C (185 °F) may scorch the oil causing combustible gases to dissolve in the oil. These gases may misrepresent the baseline of future dissolved gas analysis (DGA).

- Vacuum connections should be at the top of the transformer tank as far away as possible from the oil entrance.

CAUTION

Review the transformer instruction literature to be sure that the main transformer tank, auxiliary tanks, terminal boards between compartments and all ancillary items are rated for designated full vacuum [101.35 kPa (14.7 PSI)] at elevated temperatures. Epoxy or non-metallic terminal boards may not be rated for full vacuum at elevated temperatures. Ancillary devices such as fault pressure relays or monitoring devices may require removal or valving off, if not rated for full vacuum.

CAUTION

Conservator tanks with rubber bladders may be designed for full vacuum. Prior to applying vacuum to a conservator tank designed for full vacuum, ensure conservator tank and the rubber bladders are in equalization. Vacuum applied to the conservator tank without equalization to the rubber bladder may damage or weaken the rubber bladder.

CAUTION

If external bushing connections are made, be certain there is sufficient slack in the external line connections to allow for bushing movement caused by flexing of the transformer cover and/or walls. Failure to relieve this stress at the bushing connection may result in damage to the bushing seals and loss of oil.

Oil discharge from the main transformer tank should be from the bottom of the tank. A positive displacement oil pump should be used at the tank discharge valve within 152.4 cm (5 ft) of the tank wall.

Vacuum should be maintained at the best possible level with the lowest possible oil level in the transformer tank to maintain oil discharge without pump cavitations. A minimum oil head of approximately 91.4 cm (36 in) is required to maintain oil flow [2.5 L/s (39.6 gal/min)] under full vacuum with a positive displacement pump. Table 3 provides recommended vacuum levels for reprocessing and final oil fill. The vacuum level will initially be affected by the oil quality and moisture level in the oil. Ideally, the oil level in the main tank should be below all major insulation. After oil filling, allow a minimum set time as in Table 4 prior to energization of the unit. Additional recommendations for the oil circulation and vacuum dry-out process include the following:

a) Prior to vacuum and oil circulation, close all the bottom valves to cooling equipment. Close all valves to ancillary items that will not withstand full vacuum.

b) Oil circulation through the tank should continue until the moisture and gas content of the oil are acceptable and the cellulose insulation is heated sufficiently to facilitate moisture extraction under vacuum.

c) When ambient temperatures are below 0 °C (32 °F), an oil level greater than 91.4 cm (36 in) may be necessary to act as a heat sink to obtain the desired temperatures. Thermal blankets on the exposed tank walls may also be necessary.

d) Circulate 85 °C (185 °F) oil through the tank until the oil discharge temperature stabilizes at 50 °C (122 °F) or higher.

e) When oil discharge temperature stabilizes at 50 °C (122 °F) or greater, drain the oil to a level below the coil assemblies or drain completely. Apply vacuum as indicated in Table 3 based on one of the following options.

    1) A designated period of vacuum time.
    2) Monitoring of oil quality, vacuum and moisture extraction.
    3) Measuring the amount of extracted water.
    4) Monitoring the internal tank relative humidity/dew point.

Table 3—Recommendations for vacuum drying (insulation exposed) and final oil fill Vacuum, Absolute Pressure, microns (mm Hg)

Voltage class (kV)	Vacuum (mm Hg) final oil filling
69	1000 microns, (1 mmHg)
138	1000 microns, (1 mmHg)
230	1000 microns, (1 mmHg)
345	750 microns, (0.75 mmHg)
500	500 microns, (0.5 mmHg)
765	500 microns, (0.5 mmHg)

Table 4—Recommended minimum set time (absorption), after final oil filling of reprocessed units

Voltage class (kV)	Minimum set time, absorption (hours)
69	48
138	48
230	48
345	60
500	72
765	96

Note that the time required is longer than the Hold Time required for new units. Extended set times may be required if the core/coil assembly was out of oil for a prolonged period.

Final verification of the dielectric strength of the insulation system should be an insulation power factor test. An acceptable insulation power factor value for a new transformer is < 0.5 % or as specified by the manufacturer. Reference IEEE Std 62-1995, 6.1.6.2 and 6.1.6.8.

4.11 Tests after the transformer has been assembled and filled with dielectric liquid

Tests should be made, which can be done during the set time recommended in Table 4, and the test reports preserved to ensure that the transformer is ready for service and to provide a basis for comparison with factory values and future maintenance tests. The following tests are suggested. All or any portion of these tests may be made, depending on the equipment available and the importance of the particular transformer.

a) Insulation resistance test on each winding to ground and between windings.

b) Insulation power factor or dissipation factor test on each winding to ground and between windings. Capacitance should also be measured on each connection. In addition, core insulation should also be tested.

c) Power factor or dissipation factor test on all bushings equipped with a power factor tap or capacitance tap. Both C1 and C2 insulation should be measured.

d) Winding ratio test on each tap. If LTC transformer, check winding ratio on all LTC positions.

e) Check winding resistance of all windings with a Kelvin bridge or another suitable test device and compare with factory test results.

f) Check operation of liquid-level and hot-spot temperature indicating and control devices.

g) Check dissolved gas, dielectric strength, power factor, interfacial tension, neutralization number, and water content of the dielectric liquid.

h) Check oxygen content and total combustible gas content of nitrogen gas cushion in sealed tank transformers. A total combustible gas test, where applicable, and a dissolved gas-in-oil test of the dielectric fluid should also be made soon after the transformer is in service at operating temperature to provide a suitable post-energization reference "bench mark."

i) Check operation of auxiliary equipment, such as LTCs, liquid-circulating pumps, fans, or liquid or water flow meters in accordance with manufacturer's instructions.

j) Check polarity and excitation current at reduced test voltages.

k) Check resistance, ratio, and polarity of instrument transformers when provided. These tests should be made at the terminal blocks in the control cabinet.

l) Frequency response measurement compared to factory results, if applicable.

NOTE—If final bushings are not used in the factory, test results may differ.

All these tests should be within acceptable limits prior to energization.

4.12 Energization

At this stage, all necessary verifications and tests should have been done and the results checked to be well in conformance with established tolerances or limits and the recommended set times (see Table 4) have been observed.

Energize the transformer, and hold at rated voltage and no load for a period according to Table 5 (Note 1). While this period of energization at no load may not be necessary, it is helpful to understand and evaluate the transformer in this condition prior to applying load. During this energizing period, before loading the transformer, it is recommended to do the following surveillance actions:

— Check for excessive audible noise and vibration

— Monitor temperature of oil, recording to be taken at time intervals (every hour) until stabilization

— Monitor temperature of winding hot spots, recording to be taken at time intervals (every hour) until stabilization

— Monitor ambient temperature

— Operate and check performance of LTC through all positions, within rated voltages (if applicable)

— Operate and check performance of cooling pumps and fans (if applicable)

— Inspect for oil leaks and check all oil level indicators and gas detector relay (if applicable)

— Take oil samples at the beginning and also at the end of the energizing period for to retest for moisture content and DGA. Oil sampling in LTC diverter switch compartment (if applicable) could be interesting for investigation and monitoring purposes. (Note 2)

Table 5—Recommended minimum energization time at no load

Voltage class	Energizing period (hours)	Suggested minimum energizing period (hours)
230 kV – 800 kV	**24**	**12**
120 – 170 kV	**12**	**8**
< 120 kV	**8**	**8**

NOTE 1—In case there is difference between values recommended in Table 5 and the manufacturer recommended time make sure to meet at least the manufacturer's time.

NOTE 2—The DGA results with the transformer energized and in no-load condition obtained at the end of the energizing period will be kept for reference and diagnostic purpose if needed. In case there is doubt with certain amount of gas concentration in the results, it will be necessary to proceed also with the analysis of oil samples taken in the beginning of the energizing period for comparison and evaluation.

The transformer is now ready for service. However, observe the transformer carefully (particularly in critical low ambient temperature areas in which case gradual loading would be recommended) for the first few hours after load is applied. The following are some recommended surveillance actions:

— Monitor the load and temperatures of oil and winding hot spots; recording to be taken at time intervals (every hour) until stabilization

— Check for excessive audible noise and vibration

— Check the gas detector relay (if applicable)

— Check for correct operation of the LTC (if applicable)

Make a daily inspection during the first few days to look for any oil leaks, sudden increases of temperatures or any abnormal operation of the gas detector relay (if applicable), and any abnormal operation of accessories (bushings, LTC, DETC, etc.).

4.13 Maintenance

Because of their electrical location in a power system, transformers are often subjected to heavy electrical and mechanical stresses. To avoid failures and problems, it is essential to conduct a program of careful supervision and maintenance. The life of a transformer is highly dependent upon the heat prevailing in the windings and core of the unit; therefore, it is important that the temperature be periodically monitored. Also, as is the case with all liquid-filled electrical apparatus, the integrity of the dielectric liquid is extremely important and should be maintained at a high quality. If the liquid is removed such that the winding is exposed, all of the liquid should be removed and the transformer vacuum-filled, as described in 4.8.

It is important that the LTCs be maintained in accordance with the manufacturer's recommendations. Some LTC manufacturers specify the first inspection based on time period or number of operations and then based on the arcing contact wear to estimate the time interval between subsequent inspections. It is generally accepted that all new LTCs are inspected internally at the end of the first year of service, regardless of the number of operations. The purpose of this internal inspection is two-fold. First, it is to ensure that the internal mechanism is functioning properly; second, to measure switching contact wear so that the time interval between subsequent inspections may be estimated.

4.13.1 Maintenance intervals for transformers

For the first few days, daily inspections are recommended for recently energized transformers. Before the warranty period ends, all new transformers should be maintained as described under the three-year maintenance interval in 4.13.1.5.

4.13.1.1 Recently energized transformers

Oil samples should be taken for DGA at 24 h and 72 h after carrying normal load to check for abnormal gas generation.

The following are oil samples to be taken routinely or the first year:

a) Bi-weekly DGA analysis for the first month.

b) Semi-annual DGA analysis for first year.

4.13.1.2 Maintenance—station inspection interval (at least monthly)

a) Check all liquid level gauges including main tank, oil expansion tank and bushings.

b) Record winding hot spot and top liquid temperatures (both instantaneous and maximum values); reset all maximum indicator hands on temperature gauges.

c) For gas-blanketed transformers, the transformer gas pressure should be recorded. The cylinder pressure of transformers equipped with nitrogen systems should also be checked.

d) For transformers with an oil expansion tank, inspect dehydrating breather.

e) Check the pressure relief device for operation or a target indication.

f) Check the bushings for chipped or broken sheds.

g) Check the arresters for broken or damaged sheds.

h) Check the general condition of the unit, including ground connections, paint condition, possible liquid leaks, etc.

i) If applicable, test transformer alarm annunciator and any other monitoring or alarm device.

j) Check transformer loading, voltage and neutral current values.

Transformers equipped with auxiliary cooling equipment such as fans and pumps should have the following tests:

— Operate fans
— Operate pumps and check liquid-flow indicator

NOTE—If not in operation, cooling equipment should be operated in groups to reduce the probability of static electrification with all pumps running.

k) Unusual or abnormal conditions may require further investigation or tests.

4.13.1.3 Maintenance—at least annually

a) Inspect coolers for leaks.
b) Check cooler fans and fins for damage and proper operation.
c) Clean coolers.
d) Infrared thermography may be appropriate; record ambient temperature, winding and top oil temperatures, and loading. Hot spots may be located in the following components:
    1) Transformer main tank
    2) Transformer bushings
    3) Tap changer compartments housing contacts and motor drive housings—also record tap position and number of tap changes
    4) Control cabinet
    5) Coolers/radiators
    6) Fans and pumps
    7) Overhead connections and ancillary equipment
    8) Isophase bus to transformer interface (for generator step-up units)

4.13.1.4 Maintenance—one to three years, based on voltage and BIL

a) Test the transformer insulating liquid for dielectric strength and note color of oil. Fluid analysis such as moisture content, interfacial tension, inhibitor content, or acid value, may be appropriate.
b) Conduct a total combustible gas (TCG) analysis test of the gas space on all gas-blanketed transformers. A desire or need for closer monitoring will require frequent testing.
c) Conduct a dissolved gas analysis. Guidelines are published in IEEE Std C57.104-1991. The analysis of dissolved gas data in less-flammable dielectric liquids may be different than in conventional transformer oil. The user is referred to the liquid manufacturer's specific guidelines. Extreme care must be exercised in drawing this sample. Do not draw a sample unless the transformer is under positive internal pressure. To ensure a reliable and accurate analysis, the proper container and sampling instructions are essential.
d) Furan—Testing of the Furan content of oil to track the paper degradation

Once a guideline value has been exceeded, further investigation and analysis should be made. More frequent testing may be needed.

4.13.1.5 Maintenance—three to seven years, or as required by condition-based maintenance, based on voltage and BIL

Performance of the following maintenance requires that the transformer be removed from service. Perform the maintenance as listed in 4.13.1.4, plus the following:

a) Inspect the bushings for any chipped spots; clean the surface to remove any foreign material.

b) Check all external connections, including the ground connections, to assure a solid mechanical and electrical connection.

c) Conduct power-factor or dissipation factor tests of the transformer and bushing insulation systems and compare these test results with previous tests to determine a trend in insulation deterioration. Increasing values may require further analysis.

d) Verify the integrity of thermal and alarm sensors and circuitry.

e) A transformer-turns-ratio test should be conducted.

f) Winding resistance measurements should be made and compared with factory measurements.

g) Verify the condition of all oil pumps by checking running current.

h) Inspect cooling system and electrical supply to pumps and fans.

i) Core ground should be tested if accessible, and leakage reactance, as well as core excitation tests should be performed.

4.13.2 Maintenance intervals for transformer load-tap-changing (LTC) equipment

Some LTC manufacturers specify the first inspection based on time period or number of operations and then based on the arcing contact wear to estimate the time interval between subsequent inspections. Other manufacturers specify the same interval for first and subsequent inspections. This limit may vary between three and five years.

Maintenance frequency may in general depend on the voltage stress on the LTCs, i.e., it depends on the location in the winding where LTCs are installed.

4.13.2.1 Maintenance—station inspection interval

a) Record operations counter reading.

b) Record tap position indicator, both instantaneous and drag hand values, and reset.

c) Check the liquid levels of each oil-filled compartment, such as the tap changer compartment, the change-over selector compartment, and the diverter switch compartment.

d) Check breather vent for any discharge of liquid. Check desiccant if present.

e) Check compartment exteriors for liquid leaks.

f) Inspect motor mechanism and control circuitry for abnormal conditions.

g) Verify control switch positions and compartment heater operation.

4.13.2.2 Maintenance—as established by manufacturer or trending

Replacement of LTC oil filters is dependent upon such factors as the condition of the oil and frequency of LTC operation.

a) Record operating pressure.

b) Record counter operation.

c) Note condition/color of oil and oil filter.

d) Record operating pressure on returning to service.

4.13.2.3 Maintenance—one to three years; based on voltage and BIL

a) Test the insulating liquid for dielectric strength and acidity; note color of oil. Additional fluid analysis, such as moisture content and interfacial tension may be appropriate.

b) Conduct a dissolved gas analysis. Extreme care must be exercised in drawing this sample. To ensure reliable and accurate analysis, the proper container and sampling instructions are essential.

c) Conduct an operational test of any relay and control equipment (voltage management).

4.13.2.4 Maintenance—three to seven years, based on voltage and BIL

Although this subclause addresses a three-year to seven-year interval, the actual required interval will depend on the following factors:

a) Measured arcing contact wear after the first maintenance service interval and projected contact life.

b) Maximum period between internal inspections specified by the LTC manufacturer.

c) Owner's policy regarding inspection intervals. This may be a different time period than allowed by the manufacturer but should always consider the manufacturer's recommendation.

It should be noted that some LTCs are completely self-contained, i.e., the tap selector, the change-over selector, and the diverter switches are mounted in separate oil-filled compartments, allowing internal inspections without removing the transformer's insulating fluid.

There is a second type of LTC, in which the tap selector and the change-over selector is located within the transformer tank; normally suspended from an insulating compartment that contains the diverter switches. With this type of LTC, the diverter switches may be examined without disturbing the transformer oil. However, an inspection of the tap selector and change-over selector normally requires the removal of the insulating fluid and entrance to the transformer.

The following procedure applies to self-contained LTCs:

a) De-energize the transformer and apply grounds to the bushings.

b) Drain the LTC compartment(s).

c) Remove cover plates and flush carbon deposits from operating mechanism and compartment walls.

d) Make a thorough inspection of all internal components, particularly noting contact wear. An effort should be made to determine the remaining contact life. Both stationary and movable contacts should be observed. Note evidence of inadequate or uneven contact pressure, contact alignment, and carbon formation on any portion of all contact structures.

For LTCs mounted on the cover of the transformer where the tap selector and change-over selector are located in the main transformer oil, the manufacturer's instructions should be followed.

CAUTION

If the inspection of the tap selector and change-over selector contacts show any sign of arcing, as differentiated from overheating, the cause of the arcing must be determined and corrected. Arcing on the non-arcing contacts may lead to a catastrophic failure of the LTC. The LTC manufacturer should be informed and corrective action taken.

Where applicable, the following applies:

a) *Change-over selector*. Normally these contacts are subjected only to mechanical wear and should not indicate any erosion. They do not operate as often as the tap selector contacts and do not break load current. But because these contacts do carry the full load current of the LTC at all times, it is essential to check them for any carbon buildup or pitting, which many indicate poor contact pressure and overheating.

b) *Vacuum interrupters.* During each tap change a small quantity of contact metal is vaporized, resulting in eventual erosion of the contact tips. Since the contacts are not visible, an external wear indicator is normally provided to help determine the remaining contact life. Consult the manufacturer's instructions for proper gauging technique. An ac hi-pot test should be applied to the bottle to validate its vacuum.

CAUTION

There is potential to generate x-rays and a damaged bottle may explode during testing, follow manufacturer's recommendations for testing.

c) Check all gear train assemblies for chipped or broken teeth. A nominal amount of backlash should be expected in the mating of these gears.

d) Check all connections for tightness and overheating.

e) Operate the mechanisms through their entire range to be certain that there is no mechanical interference and that contact alignment is proper on all steps.

f) Operate the regulating equipment to the full "raised" and the full "lowered" positions to check the upper and lower switches.

g) Observe whether the drive mechanism is stopping properly on position.

h) Check counter for proper operation.

i) Inspect all oil seals and mechanism drive train for liquid leaks and lubrication.

j) Conduct an inspection and test of the LTC control, including voltage level, time delay, bandwidth, etc.

k) Perform a transformer-turns-ratio test on three tap positions: full-raised, neutral, and one step below neutral.

4.13.3 Final "maintenance"—disposal

When a transformer is decommissioned for disposal, obtain a sample of insulation from various portions of the winding and leads to provide samples for Degree of Polymerization testing. These results will contribute to the body of knowledge on "sister" or like populations of transformers in order to make reasonable decisions about their condition.

4.14 Storage guidelines

The following are general guidelines for the short or the long-term storage of a power transformer and its components and accessories. The transformer manufacturer may have specific requirements that must be followed to maintain warranty during the storage period. Consult with the manufacturer and refer to the transformer instruction book accompanying the transformer.

4.14.1 Storage of main transformer

4.14.1.1 Storage general guideline

The transformer should be stored on a solid foundation suitable for the term of the storage. If timbers or cribbing are used, the timbers should be closely and evenly spaced. Transformers should not be stored on rollers, blocks, or jacks.

The preferred method of storage is to store transformer under oil with all the accessories fully installed. Heaters in the control cabinet should be connected to a power supply and energized to prevent condensation.

The transformer tank, installed bushings and accessories should be grounded and the unit protected from lightning.

Oil containment should be provided to contain oil in case of any leaks or spills.

Detailed records, including pressure readings, should be kept of all inspections of the stored equipment. The frequency and recording of inspections may be a condition for maintenance of warranty by the manufacturer.

In areas of high seismic activity, transformer should be filled with oil. Oil filling is particularly appropriate as oil can assist in dampening internal motion during a seismic event.

4.14.1.2 Methods and duration of storage

Methods of protecting the active components of the transformer during storage are the same as those used during shipment, which is actually a storage period in itself. They include filling the tank with dry air, dry nitrogen, or dry oil.

Three time periods are typical in terms of storage requirements. Time period starts when unit is without oil as it leaves the factory. They are less than three months, up to six months, and longer than six months. Generally, but not universally, storage in dry air or dry nitrogen is acceptable for a period less than three months, storage in dry nitrogen or oil is required for up to six months, and oil filling is generally recommended for longer than six months. In such cases, insulation dry out and oil processing should be carried out in such manner as if the transformer were to be put in service. Some manufacturers begin the first three-month period from the time of shipment, while others begin the period upon receipt of the transformer. Regardless of the storage period, the best method of storage is to fully assemble the transformer on its permanent foundation and vacuum fill it with oil. It should be recognized that while a transformer sits without being oil filled, the impregnated insulation is draining oil. This is the limitation in prolonged storage in dry gas.

Dry air storage has the advantage of reduced exposure of transformer insulation during internal inspection and assembly since purging of the gas is not required before a person can enter the unit.

Nitrogen being an inert gas is more compatible with transformer cellulose-based insulation; however, it may take considerable time to pull a vacuum to remove the nitrogen gas and to purge the gas with dry breathable air before a person can safely enter the unit. Storage beyond three months in nitrogen will require the use of degassing equipment when finally vacuum filling the unit with oil.

Before a transformer is stored in dry gas, the dew point should be checked against the manufacturer's requirements.

When the transformer is finally vacuum-filled with oil, the vacuum period prior to oil filling should be extended. A period of extended vacuum of 24 h is recommended and must be at least one hour for each month of storage.

When a transformer stored in dry gas is installed, a minimum of 72 h should be allowed between oil filling and energizing to allow for oil impregnation of the insulation that drained during storage.

4.14.1.2.1 Storage—less than 90 days

Dry Air or Dry Nitrogen—The transformer must be kept under positive pressure between 0.1–0.3 bar (1.5–4.4 psi) at all times while in storage. Check the manufacturer's instructions for specific values. A reserve air supply >10 bar (150 psi) is required to be coupled with a pressure vacuum regulator. An elevated pressure should be initially applied for several hours and the unit checked for leaks. Both the reserve air supply and the tank pressure should be monitored and recorded daily during the first week or two as required by the manufacturer. These readings should be taken at approximately the same time each day and the time and temperature should also be recorded. If pressures remain stable, the interval between readings may be extended.

NOTE—For a transformer intended to be filled with ester-based fluid, storage under dry air may not be recommended. Follow the manufacturer's instruction.

Oil—Transformers received filled with oil from the factory may be stored without further attention.

4.14.1.2.2 Storage—up to six months

Some manufacturers permit storage in dry nitrogen for up to six months, but storage in oil is preferred.

An unassembled transformer can be vacuum filled with oil to its proper level and the space above the oil pressurized with dry air or nitrogen. An elevated pressure should be applied for several hours and the tank checked for leaks. Both the cylinder pressure and the tank pressure should be monitored and recorded daily during the first week or two as required by the manufacturer. These readings should be taken at approximately the same time each day and the time and temperature should also be recorded. If pressures remain stable, the interval between readings may be extended.

Alternatively, the transformer may be fully assembled; vacuum filled with oil and made operation ready. If the transformer is equipped with pumps, periodically (3–6 months) one half of the pumps should be run for thirty minutes followed by operation of the other half. Otherwise, the transformer should be tested and maintained as though operational.

4.14.1.2.3 Storage—more than six months

The transformer should be fully assembled; vacuum filled with oil and made operation ready. If the transformer is equipped with pumps, periodically (3–6 months) one half of the pumps should be run for thirty minutes followed by operation of the other half. On a monthly basis fans should be run for approximately 10 minutes and control cabinet heaters should be checked. Otherwise, the transformer should be tested and maintained as though operational including annual check of oil quality, condition of silica gel breathers, operational condition of relays, and cleanliness of the complete transformer.

4.14.2 Storage of transformer accessories and components

Transformer accessories and components include items such as radiators and coolers, tap-changers, bushings, pumps and motors, fans and motors, control cabinet, gaskets, connectors, tapes, relays, gauges, etc.

The objectives in storage of these accessories before they are installed on the transformer are to retain control of the accessories so that they are available when needed and to prevent deterioration and damage to the equipment.

Certain equipment should be stored in a clean and dry environment. This would include bushings, which should be stored in their shipping crates with their upper parts elevated from horizontal, and components such as relays, connectors, wiring, gaskets, gauges, etc. If adequate indoor storage is available, motors and control cabinet, if shipped loose, would benefit from indoor storage otherwise a silica gel basket should be placed in the control cabinet. Anything stored outdoors should be kept off the ground to keep it out of standing water and covered to protect it from weather. Fan motors are very susceptible to corrosion during storage if they are not properly stored. If received and stored with drain plugs installed, condensation may occur accompanied by heavy internal rusting. If received without drain plugs installed, the motors must be protected from water ingress. Openings (flanges and tapped holes) to oil cooling equipment, such as radiators, coolers and conservator tanks, should be sealed and if practical the equipment should be filled with dry gas or oil, particularly if storage for more than three months is anticipated.

Transformer mechanism cabinets or LTC mechanism cabinets should be stored indoors or should have their anti-condensation heaters connected to prevent internal moisture accumulation or corrosion.

Annex A

(informative)

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Annex B

(informative)

Figures and table

Annex B contains the following figures and table.

Figure B.1 shows the conversion of dewpoint or frost point to vapor pressure.

Figure B.2 illustrates the moisture equilibrium chart used to monitor the insulation drying process. Based on a set of temperature and vapour pressure readings, the moisture content in percent dry weight of insulation is determined.

Figure B.3 provides some examples of insulation characteristics with respect to drying time, vacuum penetration time, oil impregnation time, and absorption of air over time.

Table B.1 provides a tabular reference for vacuum-pressure conversion in various units.

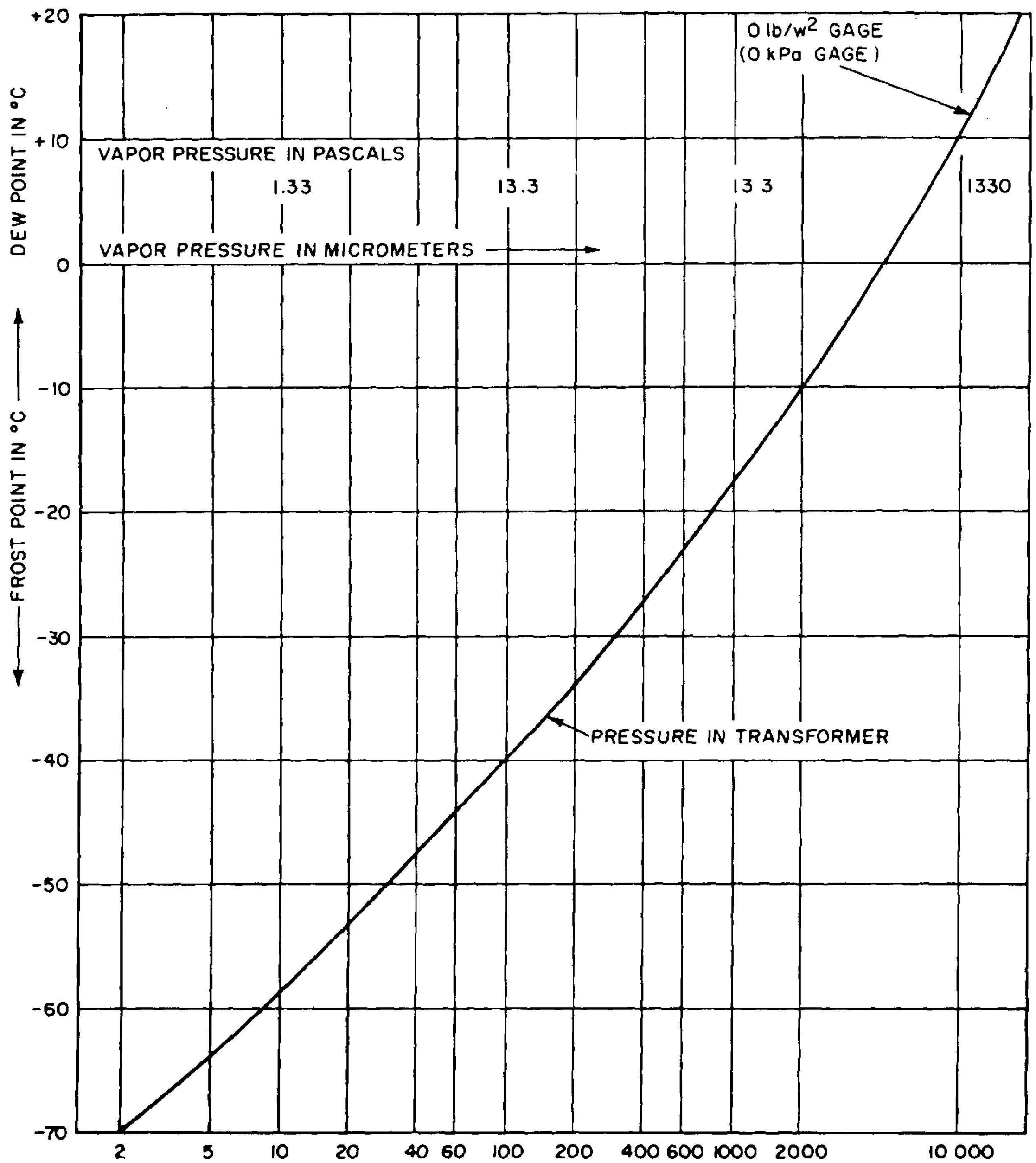
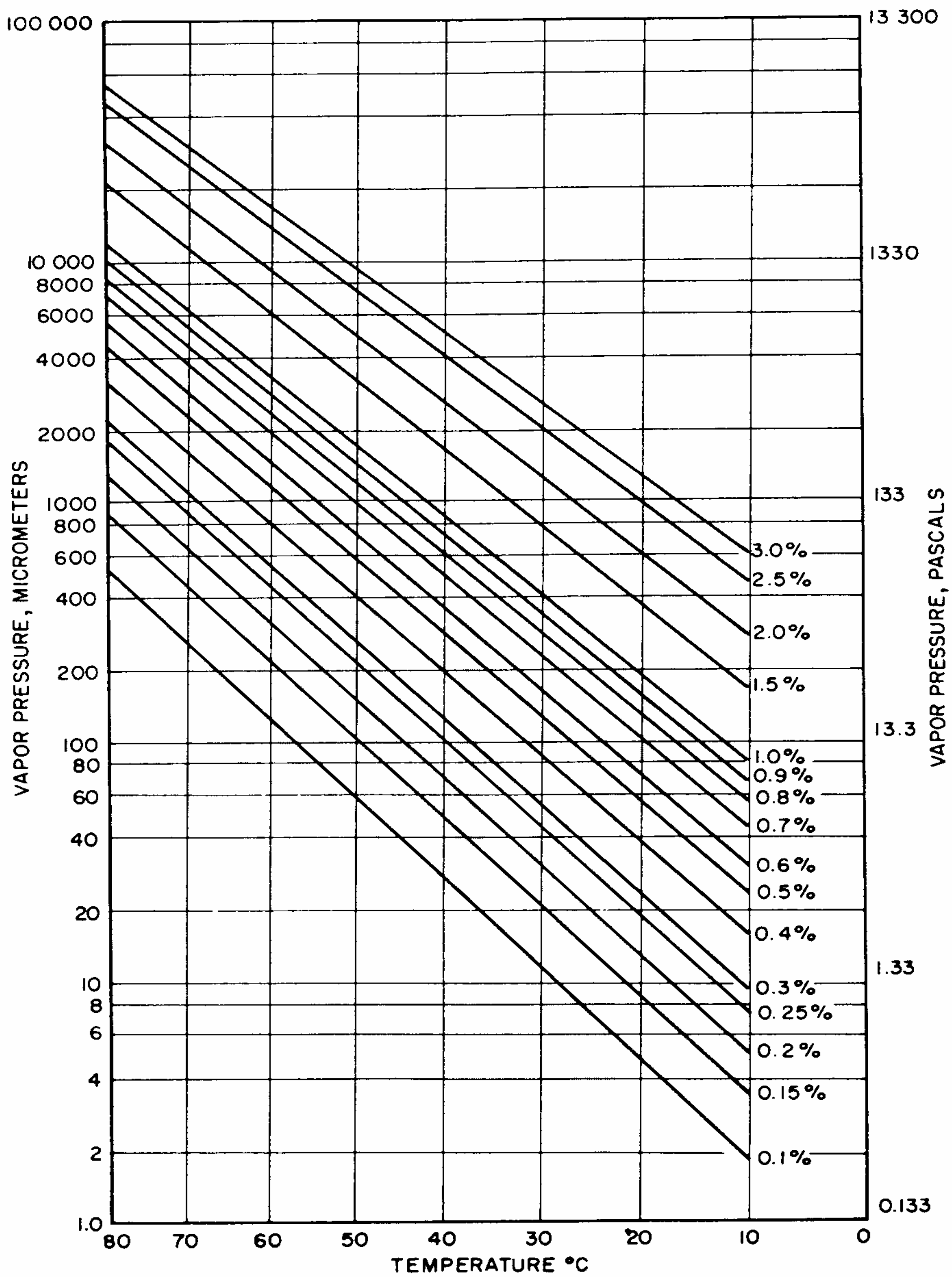
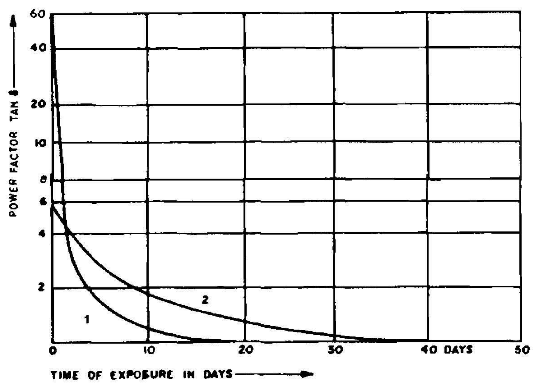


Figure B.1— Conversion from dew point or frost point to vapor pressure

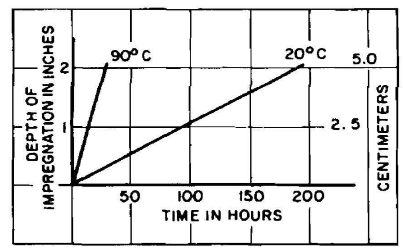


NOTE—This chart was prepared using information from a Piper Chart, which was extrapolated and interpolated from published data on cotton paper. Piper gave a multiplication factor of 1.7 to use for Kraft paper (non-thermally upgraded). This chart incorporates the 1.7 factor, and the values obtained need to be corrected. It should be noted that equilibrium moisture content of cellulose is dependent on whether equilibrium is approached by absorption or desorption, since there is a hysteresis effect.

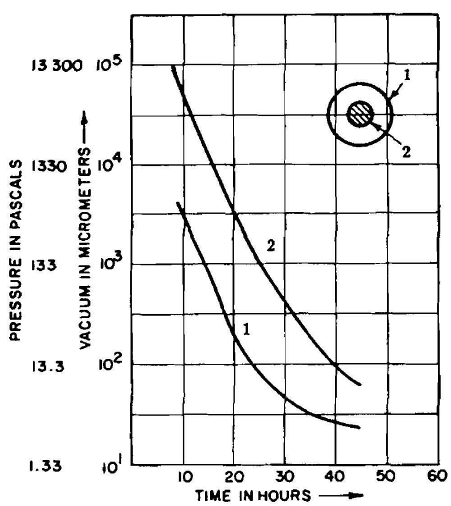
Figure B.2— Moisture equilibrium chart (with moisture content in percent of dry weight of insulation) Piper [B19]



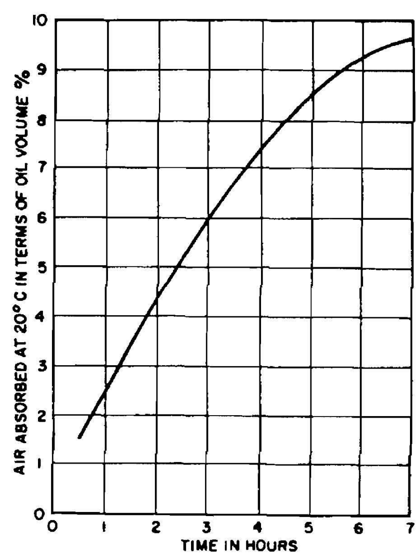
(a) Drying of moistened oil-impregnated and non-impregnated paper
Curve 1—non-impregnated paper
Curve 2—oil-impregnated paper



(c) Oil-impregnated depth of press-board versus time after vacuum application and immersion in transformer oil



(b) Vacuum penetration of cable insulation
Curve 1—vacuum in drying tank
Curve 2—vacuum at conductor surface



(d) Absorption of air by degassed transformer oil

NOTE—Curves illustrate trend of certain characteristics for components of conventional oil-immersed insulation system under specific test conditions.

Figure B.3— Some examples of insulation characteristics (See Moser [B1] and [B10], Martin and Thompson [B18], Russek [B21])

Table B.1— Vacuum-pressure conversion based on atmospheric pressure of 759.95 mm (29.92 in) Hg at 15.6 °C (60 °F)

Vacuum				Absolute pressure		
Pascals (Pa)	Millimeters of mercury (mmHg)	Inches of mercury (in Hg)	Pound-force per square inch (lbf/in^2)	Millimeters of mercury (mmHg)	Inches of mercury (in Hg)	Pascals (Pa)
0	0	0	0	760	29.92	101 323
33 864	254	10	4.9	506	19.92	67 460
67 728	508	20	9.8	252	9.92	33 597
98 205	736.6	29	14.2	23.4	0.92	3120
99 992	750	29.53	14.50	10	0.39	1333
101 192	759	29.88	14.68	1	0.039	133
101 318	759.95	29.92	14.70	0.05	0.002	6.7

Annex C

(informative)

Field equipment for oil-filling EHV transformers and determination of insulation dryness

C.1 Recommended minimum equipment ratings (for new transformers)

C.1.1 Oil-processing equipment (preferably an integrated trailer unit)

Specifications may vary based on size of the transformer and ambient temperatures.

a) Degassification trailer capable of delivering 1.2 L/s (1.9 L/s (1800 gal/h) at 70 °C (158 °F) at less than 10 mg/kg (10 ppm) water, 190 kW heating capacity. Trailer intake filter 5.0 micron, trailer discharge filter 0.5 micron.

NOTE—The oil heating should be done with heaters of 0.5 W/cm^2 (3.20 W/in^2) to avoid damaging the oil [or other limitation as discussed with the manufacturers].

b) Positive displacement pump [2.5 L/s (2400 gal/h) or more] for oil discharge from the main transformer tank.

c) Portable oil storages tanks [20 000 L (5000 gal)each].

C.1.2 Vacuum pumps

a) Vacuum pump with 70 × 10^{-3} m^3/s to 140 × 10^{-3} m^3/s (150cfm to 300 cfm) capacity or greater with attainable blank off pressure of 0.02 Torr or less. A 0.57 m^3/s to 0.76 m^3/s (1200 cfm to 1600 cfm) booster pump is an additional option.

b) “Cold trap,” the vapor pumping capability of a combination of special vacuum pumps, will not normally exceed the condensate pumping rate of a suitably sized dry ice and antifreeze trap.

C.1.3 Dry gas

The source of dry air supply may be obtained from a commercial supply of bottled nitrogen and air of a dew point of –50 °C (–58 °F) or lower, or alternatively, a low-pressure air compressor and dryer capable of continuously producing at least 9.438 L/s (20 ft^3/min) at a dew point of –50 °C (–58 °F) or lower.

C.1.4 Test equipment

a) Air dew point test set capable of operating at low or negative inlet pressure at climatic conditions and with good resolution to –60 °C (–76 °F) dew point or lower.

b) Oxygen in gas by volume.

c) Oil dielectric test set, preferably including capability specified in ASTM D1816.

d) Suitable vacuum-measuring instrumentation.

e) Insulation temperature bridge as described in or suitable alternatives for determining insulation temperature if vacuum dry out is required.

f) Gas in oil by volume test set.

g) Optional moisture in oil by weight test set or equivalent.

C.2 Determination of insulation dryness

During field installation, vital parts of a transformer are often subjected to inadvertent exposure. The danger of moisture pickup by the insulation structure is generally recognized, and precautions are taken to avoid the entrance of humid air into the transformer. Perhaps the most difficult source of moisture to control is that from expiration, transpiration, and perspiration of individuals who enter the tank for inspection and fitting operations. Continuous purging with dry air during working hours is usually practiced. Even with these precautions, it is not certain that transformer dryness is maintained.

There is no practical field procedure for measuring with absolute accuracy the all-important average moisture content of the transformer's complex oil-impregnated insulation structure. However, there are procedures, which, if clearly understood and followed with care, can be used to determine with adequate accuracy the dryness of the transformer. It is imperative to confirm the dryness of the transformer by the best practical method of measurement.

C.2.1 Moisture determination of cellulose insulation

Two applicable methods of moisture determination in cellulose insulation are discussed in order of preference.

C.2.1.1 Dew point measurement

During recent years, the potential of the dew point measurement technique has become recognized. Enough experience has been gained to say that the technique provides an accurate and reliable method of moisture determination in a gas space. When used with proper understanding, it can be a very useful tool.

The dew point within a closed vessel is responsive to the surface moisture on the insulation. A reliable measurement requires that a state of equilibrium be achieved between the surface moisture level and that of the surrounding gas space. Equilibrium is reached in 6–12 h. When the insulation atmospheric environment is changed, for example, by the introduction of dry air or dry nitrogen following an installation or internal inspection, a new period of equilibration must occur for the dew point to adequately represent the surface moisture. Equilibrium exists when, in an otherwise static condition, the moisture content is constant for 6–12 h.

The migration of moisture internal to oil-impregnated insulation is slow and may require many days, and in some cases weeks, to equalize with the surface moisture. See Figure B.2. At a uniform temperature, moisture migration can be accelerated somewhat by creating a "super-dry" surface moisture condition. Some manufacturers use the stability of this super-dry surface moisture level over a period of 12–24 h to judge whether the internal moisture level is excessively high. A surface moisture level that remains approximately constant at 0.2% during the 24-hour period has been found to imply that the average moisture level of the insulation is probably no greater than the desired 0.5%. Some knowledge of the duration of the exposure to moisture must enter into the determination of the vacuum processing period used to remove the surface moisture prior to measurement. It is definitely not suggested, however, that the user try to duplicate the manufacturer's attainment of 0.2% surface moisture. On the contrary, it is important that the user not dry the transformer to a greater degree than was done at the factory. This could result in shrinkage and physical loosening of the insulation. A surface moisture determination of 0.5% in the stage of equilibrium is completely satisfactory for EHV transformers.

The manufacturer's instructions for the dew point measurement should be followed. Knowing the dew point in degrees Celsius, Figure B.1 can be used to obtain the vapor pressure. If the total pressure at the dew point instrument is different from the tank pressure, the measured vapor pressure must be corrected by multiplying the measured value by the ratio of the absolute tank pressure to the absolute pressure at the dew point instrument. Winding resistance can be measured and converted to winding temperature. The insulation temperature is assumed to be equal to the winding temperature. The average surface moisture content of the insulation structure can be found using Figure B.2, based on the insulation temperature and the vapor pressure of the insulation environment.

An example using the following measured conditions illustrates this procedure:

Dew point	–40°C (–40°F)
Insulation temperature	20°C (68°F)
Tank gauge pressure	14 kPa (2 lbf/in^2)
Pressure at dew point instrument	0 kPa (0 lbf/in^2)
Atmospheric pressure	101.35 kPa (14.7 lbf/in^2)

On Figure B.1, read the vapor pressure as 100 μm (13.3 Pa). Correct this vapor pressure to tank conditions:

On Figure B.2, read the moisture content 0.75% of the dry weight of insulation at the junction of 114 μm (15.2 Pa) vapor pressure and the insulation temperature of 20 °C.

Local "wet spots" in the insulation cannot be detected readily, although they will raise the measured moisture level. It is advisable to measure pressure, temperature, and dew point several times during the equalizing period (12–24 h) to assure that equilibrium is achieved. Equilibrium exists when, in an otherwise static condition, the moisture content remains constant for at least 12 h.

The following four precautions need emphasis when making a dew point measurement:

a) Equilibrium conditions must be reached.
b) Insulation temperature must be known accurately.
c) The measuring equipment shall be properly calibrated, and be in good working order.
d) It may be necessary to remove the dew point probe or other detector after each use to minimize the risk of contamination from oil vapor and splashed oil. Contamination will destroy its calibration.

C.2.1.2 Cold weather dew point testing

Special considerations are required for the testing of dew point in cold weather conditions.

C.2.1.3 Cold trap technique

The requirement for better vacuum during the field processing cycle has made the application of a cold trap indispensable. A cold trap serves two purposes. First, the contamination of the vacuum pump oil is minimized, increasing the efficiency of the pump so as to produce the low-vacuum level necessary. Second, it provides the operator with the opportunity to determine the condition of the transformer by measuring the quantity of condensate removed from the transformer. The total quantity of water in the insulation can be estimated by knowing both the weight of the insulation and its moisture content in percent by dry weight of insulation. This may be difficult to estimate for an oil-impregnated insulation in a field-exposed situation, but can be done with adequate accuracy. Upon comparing the accumulated weight of condensate against the estimate, the condition of dryness can be determined. A comparison of condensate weights by six-hour periods will reveal the rate of water removed and can suggest a termination point.

Most cold traps consist of two containers. One is located inside the other. The inside container is filled with a coolant of dry ice and a suitable low-temperature antifreeze. Some utilities have used acetone and others have used trichloroethylene for the antifreeze, but most of these are somewhat hazardous. Presently, methanol and isopropyl alcohol are recommended. The outside container has two connections that permit installation of the cold trap in the vacuum line between the transformer and the vacuum pump. Vapors extracted from the active parts of the transformer are brought in contact with the super-cooled surface of the cold-trap where they condense. For efficient moisture removal, the necessity for a low vacuum and the desirability of the addition of heat is again emphasized. Refer to Figure B.3 (b) and Figure B.3 (c). To obtain a moisture content below 0.5% (by dry weight) of the insulation, it will be necessary to use equipment that will either provide a vacuum below 100 μm (13.33 Pa) at 30°C or provide hot-oil-circulating equipment that will raise the insulation temperature. Figure B.3 (b) shows that there is a partial pressure differential between the surface and the inner portions of the insulation. This is true for transformer insulation as well as for cable insulation. Field experience demonstrates that these inner regions contain 50% more moisture than Figure B.3 shows, depending upon the length of the moisture exposure time, transformer insulation design, the design and effectiveness of the cold trap, the vacuum line arrangement, and the weather conditions at the time of processing.

C.2.2 Moisture determination of transformer oil

In general, transformer oil received directly from the refinery is not ready to be pumped into a completely processed EHV transformer. Refineries usually supply oil having a moisture content of approximately 30 mg/kg (30 ppm). Oil that has been degassed, and with a moisture content below 10 mg/kg (10 ppm) at the refinery, will usually be contaminated during the loading and shipping procedures and from the condition of the tank car and other exposures so that dehydration, degassification, and filtering are necessary before the oil can be pumped into the transformer. See Figure B.3. It is prudent to check the moisture condition of the oil before it is placed in the transformer. The generally used "Karl Fischer method" is a delicate process that, under the best conditions of laboratory testing of samples taken in the field and transported to the laboratory, often produces differences of ±10 mg/kg, which are unacceptable. Laboratory repeatability is difficult to achieve. It is desirable to perform the test in the field immediately after the oil sample is taken, using a portable Karl Fischer test set, photo volt aqua test, parametric hygrometer, or comparable measuring equipment. This can eliminate several factors that lead to inaccuracies.

C.3 Shipping terminology

The trade terms used in domestic trade within the U. S. are based on the American Uniform Commercial Code (UCC). In international trading abbreviations, such as terms published by the International Chamber of Commerce, the INCOTERMS are used. Even though the abbreviations are often identical, they have different meanings. The trade terms used in this document are based on UCC.

The INCOTERMS advise where the title will pass and who is responsible for arranging the transport, freight charges, insurance and others. The terms are arranged in four groups according to the parties' obligations.

— "**C" Group:** Seller is responsible to arrange and pay for carriage and to deliver goods to a carrier

— **"D" Group:** Seller is responsible to deliver the goods to the buyer's country.

— **"E" Group:** Buyer is required to take delivery of the goods at the buyer's premises

— **"F" Group:** Buyer is required to arrange and pay for carriage. Seller is responsible to deliver goods to a carrier

The best overview of the Incoterms is provided in the "ICC Official Rules for the Interpretation of Trade Term INCOTERMS 2000" [B14]. The following 13 INCOTERMS are most relevant when discussing transformer shipping terminology.

— **"C" Group: Seller is responsible to arrange and pay for carriage and to deliver goods to a carrier.**

CFR Cost and Freight (….named port of destination)

CIF Cost, Insurance and Freight (….named port of destination)

CPT Carriage Paid To (….named place of destination)

CIP Carriage and Insurance Paid To (….named place of destination)

— **"D" Group: Seller is responsible to deliver the goods to the buyer's country.**

DAF Delivered At Frontier (….named place)

DES Delivered Ex Ship (….named port of destination)

DEQ Delivered Ex Quay (….named port of destination)

DDU Delivered Duty Unpaid (….named place of destination)

DDP Delivered Duty Paid (….named place of destination)

— **"E" Group: Buyer is required to take delivery of the goods at the buyer's premises**

EXW Ex Works (….named place)

— **"F" Group: Buyer is required to arrange and pay for carriage**

Seller is responsible to deliver goods to a carrier

FCA Free Carrier (….named place)

FAS Free Alongside Ship (….named port of shipment)

FOB Free on Board (….named port of shipment)