IEEE Std C57.93-1995
(Revision of
ASA C57.93-1958)

IEEE Guide for Installation of Liquid-Immersed Power Transformers

IEEE Power Engineering Society

Sponsored by the
Transformers Committee

IEEE Std C57.93-1995

IEEE

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IEEE Guide for Installation of Liquid-Immersed Power Transformers

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**Transformers Committee
of the
IEEE Power Engineering Society**

Approved 12 December 1995

IEEE Standards Board

Abstract: Guidance is given for the shipping, handling, inspection, installation, and maintenance of liquid-immersed power transformers rated 501 kVA and above with secondary voltage of 1000 V and above. The entire range of power transformers is covered, including EHV transformers, with distinctions as required for various sizes, voltage ratings, and liquid insulation types.
Keywords: installation, liquid-immersed, load tap changers (LTCs), transformers

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Introduction

(This introduction is not part of IEEE Std C57.93-1995, IEEE Guide for Installation 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 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.

This guide discusses two sizes of transformers:

— Clause 3: 501 kVA to 10 MVA (oil/air cooled [OA]) with primary windings less than 69 kV
— Clause 4: 10 MVA and above with high-voltage windings 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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Contents

CLAUSE PAGE

1. Scope 1

2. References 1

3. Liquid-immersed power transformers rated 501 kVA to 10 MVA (OA) with primary windings less than 69 kV 2

3.1 General 2
3.2 Inspection and receipt 2
3.3 Internal inspection 3
3.4 Handling 3
3.5 Assembly 4
3.6 Storage 4
3.7 Tests 5
3.8 Energization 6
3.9 Maintenance 7

4. Liquid-immersed power transformers rated 10 MVA and above with high-voltage windings 69 kV and above 8

4.1 General 8
4.2 Shipping 8
4.3 Inspection and receipt 11
4.4 Internal inspection 12
4.5 Handling 13
4.6 Preliminary liquid filling 13
4.7 Assembly 14
4.8 Vacuum treatment 15
4.9 Field drying of insulation 17
4.10 Recirculation 20
4.11 Tests 21
4.12 Energization 21
4.13 Maintenance 22

ANNEX

Annex A (informative) Bibliography 26

Annex B (informative) Figures and table 27

Annex C (informative) Field equipment for oil-filling EHV transformers and determination of insulation dryness 31

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IEEE Guide for Installation 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, with distinctions as required for various sizes, voltage ratings, and liquid insulation types.

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—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. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ASTM D877-95, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

ASTM D923-91, Standard Test Method for Sampling Electrical Insulating Liquids.[1]

ASTM D1816-84a (1990), Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.

ASTM D4559-92, Test Method for Volatile Matter in Silicone Fluid.

ASTM D4652-92, Standard for Specification for Silicone Fluid Used for Electrical Insulation.

[1]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

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ASTM D5222-92, Standard Guide for High Fire-Point Electrical Insulating Oils of Petroleum Origin.

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (ANSI).[2]

IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers, and Guide for Short-Circuit Testing of Distribution and Power Transformers (ANSI).

IEEE Std C57.104-1991, IEEE Guide for the Interpretation of Gasses Generated in Oil-Immersed Transformers (ANSI).

IEEE Std C57.106-1991, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment (ANSI).

IEEE Std C57.111-1989, IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers (ANSI).

IEEE Std C57.121-1988, IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers (ANSI).

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

3.1 General

In general, these transformers can be either of the station or pad-mount configuration. 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 and may have load-tap-changing (LTC) equipment.

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

Forced cooling (if present) normally use fans.

Transformers in this size range are usually shipped filled with insulating fluid and do not have shipping braces as such. Units rated 7.5–10 MVA (oil/air cooled [OA]) are sometimes shipped without liquid 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 are seldom utilized and most shipments are 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.

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Upon receipt, each transformer should be checked for evidence of damage or leaks, and internal pressure should be measured. A positive or negative pressure indicates that the tank did not leak. Zero gauge pressure should be investigated. The de-energized tap switch should be operated 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 the contact is in the high-voltage position, unless otherwise specified by the customer.

Prior to energization, 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 provided, core insulation should be tested.

In this size range, some tank designs may not be able to withstand a vacuum and must therefore be refilled inside a vacuum chamber. For this reason, removal of the insulating liquid in the field for any reason should be avoided.

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 air that has a minimum dew point of –62 °F at 30 °F ambient temperature.

CAUTION: *Verify that the internal atmosphere is nonhazardous and that the oxygen content of the gas in the tank is 19.5% or more before entering the tank.*

If there is no provision for an internal inspection, and there is evidence of internal damage, the transformer supplier should be contacted to arrange for field inspection by the manufacturer's representative or for return of the transformer to the manufacturer.

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 fork-lift truck. 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. Oth-

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erwise, 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 and that 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.

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 and the manufacturer's outline drawings should be consulted to determine if the lifting and jacking facilities are positioned for the assembled or disassembled 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 (OA), 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 clause 4. Pad-mounted 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 zone 2 or greater.

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, completely assembled with the insulating liquid at its proper level and the gas space pressurized at approximately 2 lbf/in^2 (14 kPa) at ambient temperature. Periodic inspection should ensure that the pressure gauge does not return to zero and that proper liquid level is maintained at all times.

A sealed tank unit, supplied without insulating liquid, can be stored for a maximum period of six months without inspection, or as otherwise instructed by the manufacturer, providing a positive pressure is maintained. Inspection and drying should precede extended storage if required. It is desirable that the transformers be stored undercover. Transformers stored outside a fenced area should be secured and barricaded.

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Insulating liquid supplied in drums or other containers should be placed in a dry location with moderate temperature variation and must comply with the insulating liquid supplier's instructions. 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 head. 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 bung spaces. Covers are available to protect drums from moisture ingress. All insulating liquids should be tested prior to use.

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, with a megohmmeter, the winding resistance should be measured. For larger units, 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 of the insulating liquid prior to placing the transformer into service. If a core ground lead is available, the core insulation should be tested.

When sampling facilities are available, the liquid sample should be taken when the temperature of the unit is equal to or warmer than the surrounding air to avoid condensation of moisture on the liquid.

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. Cold insulating liquid is much slower in settling. Liquid samples from the transformer should be taken from the sampling valve at the bottom of the tank in accordance with the requirements of ASTM D923-91.[3]

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 field work 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 for the application.

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

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

The dielectric strength of the oil sample should not be less than 30 kV, according to ASTM D877-87, and not less than 26 kV using the 0.04 in gap or 40 kV using the 0.08 in gap, according to ASTM D1816-84a. ASTM D877-87 is recommended for testing new oil as received from the refinery. ASTM D1816-84a is recommended for oil shipped within new equipment.

3.7.3 Other insulating liquids

Refer to the supplier's instructions for applicable tests, sampling positions, and acceptability of levels.

[3]Information on references can be found in clause 2.

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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 is properly grounded, and that proper precautions have been taken.

3.8.1 Connections

Make sure that the de-energized tap connection is proper for the required voltage.

NOTE—Changes in tap connections must be done only with the transformer high-voltage and low-voltage circuits completely de-energized.

Transformers equipped for dual-voltage or delta-wye (reconnectable winding) operation usually have an externally operable switch mounted on the face plate in the high-voltage terminal compartment. Units combining dual-voltage and delta-wye features may have two separate switches.

The transformer shall be de-energized before dual-voltage or delta-wye switches are operated. Attempting to change dual-voltage or delta-wye switches on an energized transformer could result in damage to the equipment and serious personal injury.

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, unless otherwise specified by the customer.

3.8.2 Connecting to bushings

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

3.8.3 Energization under cold conditions

IEEE Std C57.12.00-1993 considers starting temperatures below –20 °C as unusual service.

Three characteristics of the insulation/coolant system must be considered relative to cold start. 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. If, at any temperature, the density of the insulating oil is greater than the density of water, free ice or free water could exist in the system and cause dielectric discontinuity and possible failure. 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. These transient conditions are readily tolerated by a properly designed transformer. 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, energize the transformer, and hold at no-load for at least 8 h.

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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 Insulating liquid

Critical transformers should have their insulating liquid tested frequently for the first few weeks of operation to make sure that no gas or moisture is being driven from the solid transformer insulation into the liquid. The unit should be thoroughly tested after the first three months, six months, and subsequently at one-year intervals. If at any time this liquid should test below values specified in IEEE Std C57.104-1991 or IEEE Std C57.106-1991, it should be processed until a satisfactory value is obtained.

3.9.2 External inspection

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, blowing snow, 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 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:

   1) Operate fans (check if direction of rotation is correct).

   2) Operate pumps and check liquid-flow indicator.

i) If the transformer has a load tap changer (LTC), refer to 4.13.3.

j) Retrofilled transformers may require special attention relating to different fluid viscosities, flammability, specific gravity, and lubricating properties.

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4. Liquid-immersed power transformers rated 10 MVA and above 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. New transformers are being designed with reduced BIL, at lower primary voltages than has been the practice in the past. Installation and handling requirements become more stringent for these units, and 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. The relatively large investment in high-voltage transformers and their importance to the power system demonstrates the need for rigorous refinements in transformer preparation.

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 nitrogen under pressure.

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 will not be necessary to drain this liquid from the transformer except as required for inspection and repair.

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, and testing the transformer should be developed, and agreement between all parties concerned should be obtained. Manufacturers require some degree of vacuum treatment before filling with dielectric liquid, specify the vacuum to be maintained during filling, and recommend limits on residual moisture, gas content, and dielectric strength of the liquid after filling. Limiting values for each transformer will be supplied by the manufacturer. Only the general order of magnitude of limits and the means required to reach these values are covered in this guide.

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 in annex B.)

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.

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When shipping weight permits, the transformer may be shipped filled with insulating liquid. For larger units shipped by rail, the transformer is usually shipped filled with commercially dry nitrogen or dry air, with the insulating liquid shipped separately. For personnel safety, dry air is recommended. 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.

4.2.1.1 Transformers shipped FOB 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 purchaser may be assisted by the manufacturer in this effort.

4.2.1.2 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 manufacturer may be assisted in this effort by the purchaser. The manufacturer must initiate filing of the necessary claim forms and obtain proof that any damage occurred as a result of shipment.

4.2.2 Railroad shipments

4.2.2.1 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.

4.2.2.2 Acceptance by carrier

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

4.2.2.3 Rail cars

Various types of rail cars are available for special shipments. Rail cars with lowered centers 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 Schnabel 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.

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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 floor boards 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. If so, 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.

4.2.2.4 Block and tie-down

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

b) 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.

c) 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.

d) 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.

e) When using steel-floor cars, 1 in × 6 in or larger wood planks or sheathing should be placed under the transformer weight-bearing surfaces to provide cushioning.

4.2.2.5 Rail car loading standard

The Association of American Railroads has published a standard for loading rail cars. See [B8].[4]

4.2.2.6 Travel recorders

An impact meter which records impacts should be affixed firmly to the transformer main tank. For large transformers, this should record longitudinal, vertical, and if possible, latitudinal impacts. This 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 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.

4.2.2.7 Personal escort, special freight team service

For critical shipments, particularly where transit time is important, an escort familiar with railroad operations may accompany the shipment. The escort can attest to how the load was handled and minimize delays at switching points. Daily phone reports on shipping progress can be provided.

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.

4.2.3 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.

[4]The numbers in brackets correspond to those of the bibliography in annex A.

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Tie down and blocking procedures should be similar to that used for rail shipment but normally chains and chain blocks are used to secure the transformer to the truck bed. Travel recorders suitably calibrated for truck shipment are available but seldom used since, in general, truck shipments impose smaller impact loads on the transformer than rail shipments.

4.2.4 Water shipment

These can be in the hold of a ship or on the top of barges. 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, sea water, 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 at the site location. For smaller transformers in this size range, this may not be considered necessary.

NOTE—Rough handling, for which the railways are responsible, generally begins at 5 g, horizontal impact.

Check the impact recorder charts for accelerations in excess of the manufacturer's recorded limits. The hauling agent should be present when the seal is broken. 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) and more than 10% (if shipped in dry air). 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.

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

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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 bleed the pressure to zero before opening the access opening. Check the core ground, reseal the opening, and then introduce dry air until the desired positive pressure is reached.

Dry air should be continuously supplied into the transformer while the manhole cover is removed. Extreme care must be taken that the oxygen content is 19.5% or more whenever anyone is inside. 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.

If the delivering carrier will not permit internal inspection of the transformer on the car, note 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 location 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 Special considerations for different types of tanks

If the transformer is of the split-tank-type construction or has removable bushing pockets and has been shipped with the upper section of the tank or pockets removed, it will be necessary to remove the temporary covers before assembly of the tank to the final configuration. Because of the different types of internal construction and the different ways of joining tank sections together used by the various manufacturers, detailed instructions for performing this operation will be furnished by the transformer manufacturer.

4.4.3 Inspection

If the transformer was shipped in its permanent tank, access for internal inspection and assembly is obtained through a manhole.

CAUTION: *After the manhole cover is removed, the transformer should not be entered until the shipping gas (including dry air) is completely purged with breathable dry air, making sure the oxygen content is at least 19.5%. This replacement of gas with dry air is necessary to provide sufficient oxygen to sustain life. If the unit was initially shipped in nitrogen, there is a possibility of trapped nitrogen pockets, unless a vacuum is applied prior to purging.*

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.

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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, line-up, and 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.

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 Preliminary liquid filling

This step is optional, performed when required either by the manufacturer or user. This clause is usually applicable to EHV transformers.

4.6.1 Oil filling

Install valves and fittings which are located lower than the top of the core and coils. If the high-voltage lead is connected below the top section of a winding, install bushing, using dry air as described in 4.4.3. Immediately evacuate the tank to 2 mmHg (260 Pa) or below and hold the vacuum for 4 h, or more if required by the manufacturer. Fill the transformer under vacuum with dried, filtered, degassed dielectric fluid to approximately 5 cm above the top of the winding insulation or a few centimeters below the temporary shipping cover, if one is used. Break the vacuum with dry bottled gas or its equivalent. (See also IEEE Std C57.106-1991.)

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4.6.2 Less-flammable liquid filling

The two general types of less-flammable insulating liquids are high molecular weight hydrocarbon (HMWH) and silicone (PDMS). If these liquids are used, the manufacturers recommended instructions and filling procedures should be followed. These procedures may vary from those used for conventional transformer oil.

4.7 Assembly

4.7.1 General

The transformer should be securely grounded before the start of installation.

Moisture ingress should be minimized by opening only tank access ports necessary at any time. After the internal inspection has been completed, the bushings and radiators or unit coolers 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. Many different types and shapes of gaskets may be used in assembling the various components. Specific instructions for these are usually provided by the manufacturer. If a temporary shipping cover or bushing pockets are used, remove and replace them with the permanent device and pressure test the transformer. The manufacturer may require liquid filling prior to removing the shipping cover. Evacuate the transformer and fill with dry air making certain that the oxygen content of the entire gas space is at least 19.5%. During the following internal work, maintain a continuous supply of dry air for the safety of personnel and the minimization of the entrance of moisture. If internal work will take more than one day, the transformer should be sealed under positive pressure overnight. The transformer should then be purged with dry air before work is resumed.

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, except that cone-disk washers, if used to maintain bolt pressure, should be depressed 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. Mechanical loading on ends of bushings should not exceed design limits. The bushing should undergo power factor or dissipation factor testing prior to its installation onto the transformer.

4.7.3 Heat exchangers and piping

Radiators or heat exchangers, liquid piping, valves, and fittings should be thoroughly cleaned and flushed (if contaminated) with clean, warm 25–35 °C (80–100 °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.

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4.7.4 Other accessories

The tap changers, liquid-level gauge, temperature gauges, and other accessories should be installed in accordance with manufacturer's instructions. 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. The current transformer should be checked for ratio and polarity before filling the transformer.

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.

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 drawing vacuum. In some transformers the barriers between the main tank and other compartments will not withstand full vacuum on one side with atmospheric pressure on the other side. Where such conditions prevail, 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, tank-mounted arresters, or insulators during vacuum operation. Tank deflections to these items with rigid connections to the porcelains could result in porcelain breakage. 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 5 lbf/in^2 (35 kPa). 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 panel, 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.

NOTES

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. If short-circuit current is used, the current must be held to a value to prevent hot spots in the windings, which could easily damage the insulation. Recommendations of the manufacturer regarding the maximum allowable temperature should not be exceeded.

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

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.

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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. The vacuum treatment is generally recommended when the temperature of the core and coils is above 50 °F.

The degree of vacuum required depends on the design 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 (absolute) may suffice for transformers rated below 138 kV. For higher voltage transformers, vacuum treatment at pressures less than 1 mmHg 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 fill 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 than 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 in a period of 30 min.

4.8.3 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 C57.106-1991.

The ability of the filter press to remove water from the liquid depends upon the dryness of the filter papers. Filter papers should be oven-dried immediately before being inserted into the filter press. The filter should be changed frequently, with a hygrometer used to measure its effectiveness.

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 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*

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accessible transformer terminals, as well as the tank and liquid filtering equipment, should be properly grounded during filling.

4.8.4 Vacuum filling

After attaining the required vacuum and holding for 4 h or more, 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 and 80 °C 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 1/2 in/min (1.25 cm/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 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 2–5 lbf/in^2 (15–35 kPa).

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. Extreme caution must be taken with the pressure-relief device blanked off. Overfilling without pressure relief can cause tank damage. 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 for at least 12 h to allow the insulating oil to absorb residual gas and thoroughly impregnate the insulation.

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—Short-circuited windings (oil-filled), vacuum (without oil).* A low value of residual moisture can be obtained by this method.

— *Method 3—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 4—Hot air.* The method is not as effective as the vacuum methods.

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Other methods or combinations of these methods may be used where facilities are available. The equipment detailed in annex C 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, either 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 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 either the filter-press valve and drain valve or through top and bottom radiator valves. Wherever possible, to reduce heat losses due to radiation, the oil should be prevented from circulating through 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.

Another version of the method is to circulate hot oil to heat the unit. When the core and coils reach 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. If an unacceptable dew point is obtained, the process is repeated.

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 (130 Pa) above the oil during the above heating cycle, although a low positive gauge pressure 1–2 lbf/in^2 (7–14 kPa) 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.

4.9.2 Method 2—Short-circuited windings, vacuum

The transformer should be filled with dielectric liquid to the normal level. This method requires a source of energy to heat the transformer by circulating current through the windings plus a suitable vacuum pump to extract moisture from the insulation. A refrigerated condenser trap in the vacuum line to collect water is also required. If possible, install the refrigerated condenser, such as a dry ice and antifreeze cold trap (see annex C), on the top cover with a short, large-diameter (4–8 in [10–20 cm] or more) connection. Since these traps may be heavy, check with the manufacturer to make sure that the tank, when under full vacuum, can support this weight without special bracing; if not, brace as required. Insulate the outside of the transformer tank to reduce the heating required. Connect the vacuum pump to a suitable valve at the top of the tank.

Care must be exercised to prevent the temperature of the windings and insulation from reaching a value which causes excessive aging to the insulation. The temperature of the windings should not exceed 95 °C, and the liquid 85 °C. Frequent measurements of the resistance of the windings and of the liquid temperature should be made.

The power supply may be connected to either winding, with the other winding short-circuited. The secondaries of any current transformers in the tank should also be short-circuited. All tap coils should be connected in the windings.

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For forced-oil-cooled transformers, the oil pumps should be operating while the transformer is being heated, but the cooling medium, either air or water, should be shut off. Short-circuit currents up to full rated current can be used to heat forced-oil-cooled transformers for a short period of time. For self-cooled transformers, up to full rated current may be used while the transformer is cold, then reduced as the transformer approaches rated temperature. The voltage required to circulate this current will depend upon the impedance of the transformer.

After the desired winding and liquid temperatures have been reached, disconnect the power supply and drain the dielectric liquid from the transformer tank. When the liquid has been drained from the tank, close the valves and start the vacuum pump. Continue pulling vacuum on the transformer until water extraction stops. This procedure may be repeated as many times as necessary to attain the desired degree of dryness. The minimum water content in the insulation can be estimated from table B.1). Water extraction from the insulation will stop when the vapor pressure of water in the insulation at the temperature and pressure equals the partial pressure of water vapor prevailing in the tank at this temperature and pressure.

4.9.3 Method 3—High vacuum

This method requires the use of a suitable vacuum pump, capable of pumping down to an absolute pressure of 0.05 mmHg (7 Pa) or lower, and a 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 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 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 is recommended. The knowledge of vapor pressure and of the insulation temperature can be used with the moisture equilibrium chart shown in figure B.2 to determine insulation dryness and to provide an intelligent determination of the vacuum treatment endpoint.

4.9.4 Method 4—Hot air

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.

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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. (**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. Fire extinguishers, preferably the carbon dioxide type, should be located near the transformer before beginning the drying.*)

The volume of air required to obtain minimum drying time varies with the size of the tanks. The following is an approximate guide:

Area of tank base	(ft^2)	30	60	100	125	150
	(m^2)	2.8	5.6	9.3	11.6	14.0
Volume of air	(ft^3/min)	1000	2000	3000	4000	5000
	(m^3/min)	28	56	85	114	140

4.9.5 Completion of the drying

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

Recirculation may not be necessary for all transformers in this size range. Check with the manufacturer. If required, circulate insulating liquid continuously through a vacuum oil treatment plant for at least 8 h, or 2 volumes, to remove remaining moisture and dissolved gases. If allowed by the instruction book, all transformer pumps, but not fans, should be operated during this circulation process. The recirculation time may vary, depending upon manufacturers recommendations, voltage, and BIL. Moisture and dissolved gas content should be monitored regularly. Recirculation may not be necessary where proper vacuum oil treatment

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and degassification equipment have been used in filling the transformer. Upon completion of this process, the transformer should not be energized for approximately 24 h.

4.11 Tests

After the transformer has been assembled and filled with dielectric liquid, tests should be made and the test reports preserved to ensure that the transformer is ready for service and to provide a basis for comparison with 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. 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.

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, magnetization current, and impedance.

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

l) Test bushings.

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

4.12 Energization

Perform the selected tests of those listed in 4.11. Set cooling controls to automatic (if possible), energize the transformer, and hold at rated voltage and no-load for at least 8 h. Test gas blanket for oxygen and combustible gas. Check operation of LTC mechanism and auxiliary equipment during this time. Note excessive audible noise and vibration.

The transformer is now ready for service. However, observe the transformer carefully (particularly in critical low ambient temperature areas) for the first few hours after load is applied.

After several days, retest the dielectric liquid for moisture and dissolved gas, and the gas blanket for oxygen, carbon dioxide, and combustible gas.

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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 so that the level falls below the top of the core and coil assembly, all of the liquid should be removed and the transformer vacuum-filled, as described in 4.8.4.

It is important that the LTCs be maintained in accordance with the manufacturer's recommendations. 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.

4.13.1.1 Maintenance—station inspection interval (at least monthly)

Inspections of power plant transformers should be made weekly.

a) Check the liquid level.

b) Record hot-spot and top liquid temperatures (both instantaneous and maximum values).

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

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

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

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

h) Check liquid levels of liquid-filled bushings.

NOTE—It may be necessary to use field glasses or de-energize to properly verify the level.

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

j) Operate fans.

k) Operate pumps and check liquid-flow indicator.

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

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

a) Test the transformer insulating liquid for dielectric strength. Additional tests, such as moisture content, interfacial tension, or acid value, may be appropriate.

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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.

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

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

Performance of the following maintenance requires that the transformer be removed from service. Perform the maintenance as listed in 4.13.2.2, 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 insulation system 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.

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

Regardless of the measured arcing contact wear, most LTC manufacturers set a limit in the number of years of operation between inspections. This limit may vary between three and five years.

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.

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

a) Test the insulating liquid for dielectric strength and acidity.

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

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

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

a) Measured arcing contact wear after the first year of service 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 changer, 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 changer 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 changer 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 changer and change-over selector are located in the main transformer oil, the manufacturer's instructions should be followed.

IMPORTANT: *If the inspection of the tap changer 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 selector switches 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.

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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.

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.

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Annex A

(informative)

Bibliography

[B1] Discussion by H. P. Moser of CIGRE Transformer Papers 110, 135, and 142, CIGRE, vol. I, pp. 317–320, 1966.

[B2] Discussion by H. P. Moser of CIGRE Transformer Study Committee Report 135, vol. I, CIGRE, pp. 252–258, 1962.

[B3] EEI Electrical System and Equipment Committee, "Guide For Receiving, Installing, and Maintaining Large Power Transformers," Edison Electric Institute, Jan. 1983.

[B4] Heighes, J., "High Voltage Transformer Insulation and Its Processing," *AEI Engineering*, pp. 84–87, Mar./Apr. 1966.

[B5] Hurter, T. and Erb, W., "Treatment of Insulation in EHV Transformers and Reactors," *Proceedings of the 8th Electrical Insulation Conference*, pp. 169–172, 1968.

[B6] Martin, R. G. and Thompson, C. N., "A Vacuum Pre-Treatment Apparatus for Filtering, Dehydrating and Degassing Oil," *British Journal of Applied Physics*, p. 222, 1951.

[B7] Piper, J. D., "Moisture Equilibrium Between Gas Space and Fibrous Materials in Enclosed Electric Equipment," *AIEE Transactions*, vol. 65, pp. 791–797, 1946.

[B8] "Rules Governing the Loading of Miscellaneous Commodities On Open Top Cars and Trailers," Association of American Railroads, Revised 1995.[5]

[B9] Russek, R. M., "Drying and Impregnation of Paper Insulated Power Cables," *IEEE Transactions on Power Apparatus and Systems*," pp. 34–52, Jan. 1967.

[5]This publication is available from the Association of American Railroads, Mechanical Division, 1920 L St., NW, Washington, DC 20036.

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Annex B

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Figures and table

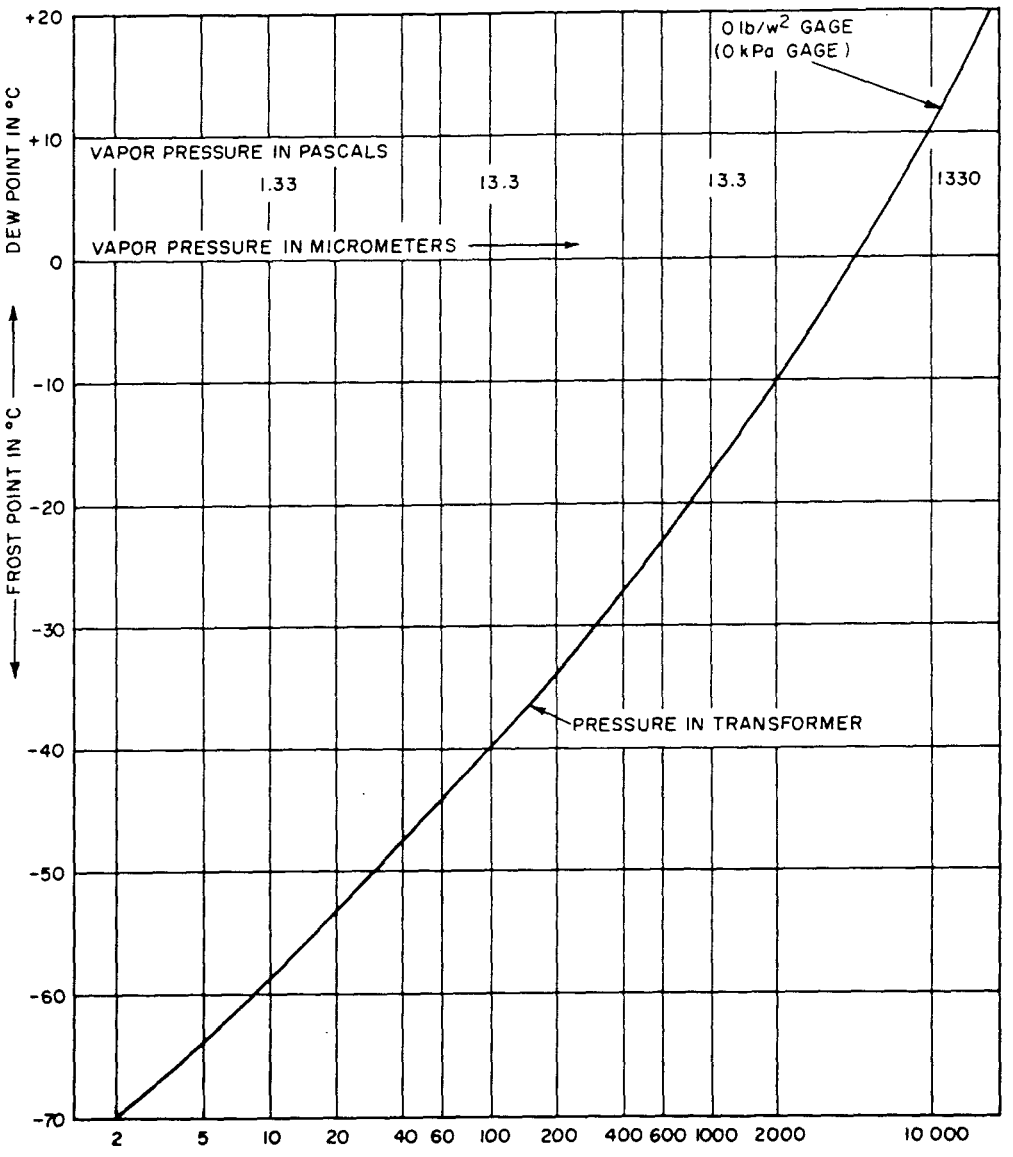
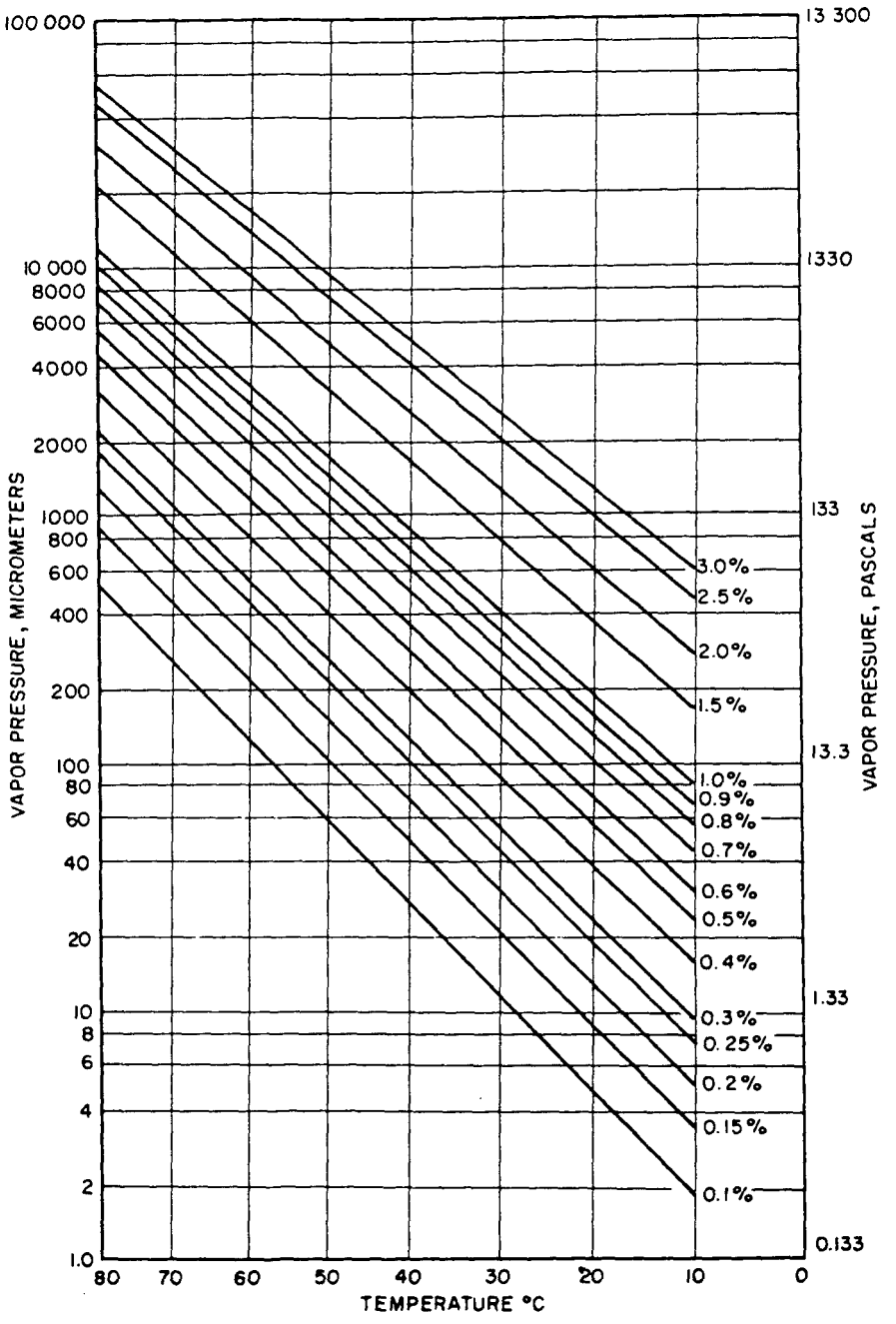


Figure B.1—Conversion from dew point or frost point to vapor pressure

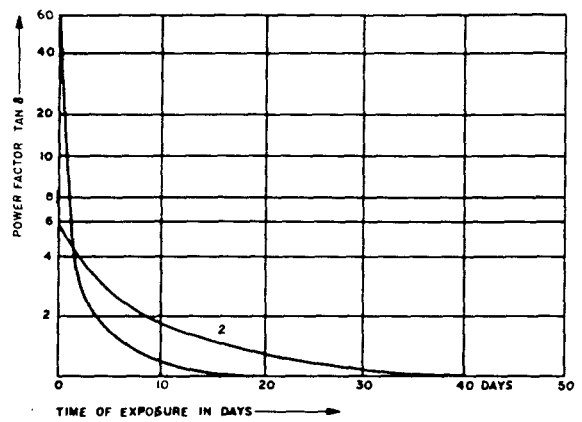
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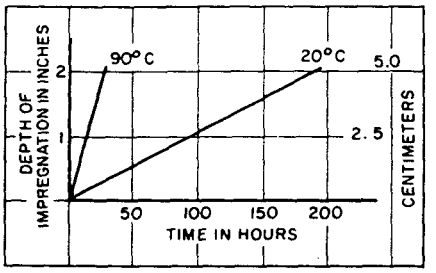
NOTE—This chart was prepared using information from a Piper Chart, which was extrapolated and interpolated from published data on cotton paper. Piper gave a multiplication factor of 1.7 to use for Kraft paper (non-thermally upgraded). This chart incorporates the 1.7 factor, and the values obtained need 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)

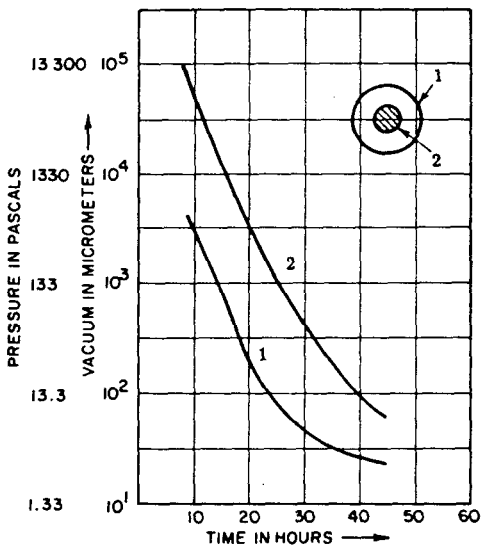
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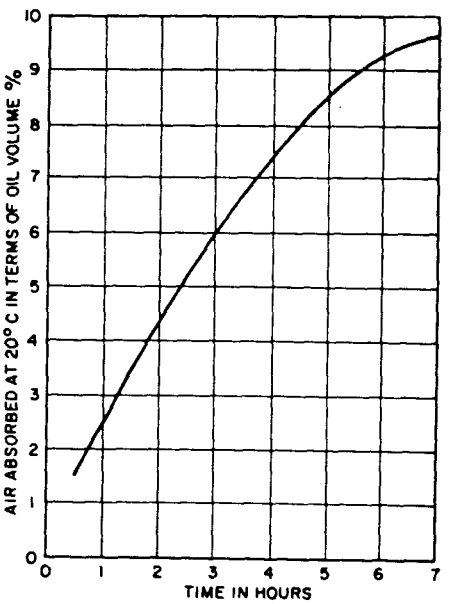
(a) Drying of moistened oil-impregnated and non-impregnated paper
Curve 1—non-impregnated paper
Curve 2—oil-impregnated paper



(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

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Table 1—Vacuum-pressure conversion based on atmospheric pressure of 29.92 inHg at 15.6 °C (60 °F)

Vacuum				Absolute pressure		
Pound-force per square inch (lbf/in^2)	Inches of mercury (inHg)	Millimeters of mercury (mmHg)	Pascals (Pa)	Inches of mercury (inHg)	Millimeters of mercury (mmHg)	Pascals (Pa)
0	0	0	0	29.92	760	101 323
4.9	10	254	33 864	19.92	506	67 460
9.8	20	508	67 728	9.92	252	33 597
14.2	29	736.6	98 205	0.92	23.4	3 120
14.46	29.526	750	99 992	0.394	10	1 333
14.63	29.88	759	101 192	0.0394	1	133
14.65	29.918	759.95	101 318	0.00197	0.05	7

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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)

a) Oil pumps and hoses with a mechanical filter capable of 10 (preferably 5) μm retention at a flow rate of at least 1200 gal/h (1.3 L/s).
b) Oil heating equipment to suit climatic conditions preferably capable of at least +50 °C oil output at 1200 gal/h (1.3 L/s).
c) Oil degassifier with a final stage operating below 1 mmHg (130 Pa) at a design flow of at least 1200 gal/h (1.3 L/s).
d) Bulk oil storage facilities including heated tanks for cold weather conditions.

The processing equipment above should be capable of reducing water content of oil to 10 ppm and the dissolved gas content to 0.5%.

C.1.2 Vacuum pumps

a) Mechanical vacuum pump capable of at least 0.05 mmHg (7 Pa) blank-off and a displacement of at least 350 ft^3/min; the use of a high-capacity mechanical booster vacuum pump should be considered.
b) Vacuum pumps with interstage cooling should be considered.
c) "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. See C.2.

C.1.3 Dry gas

Commercial supply of bottled nitrogen and air of a dew point of –50 °C or lower, or preferably a low-pressure air compressor and dryer capable of continuously producing at least 20 ft^3/min (0.01 m^3/s) at a dew point of –50 °C 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 dew point or lower.
b) Oxygen in gas by volume.
c) Oil dielectric test set, preferably including capability specified in ASTM D1816-84a.
d) Suitable vacuum-measuring instrumentation.
e) Insulation temperature bridge as described in C.2 or suitable alternatives for determining insulation temperature if vacuum dryout is required.
f) Gas in oil by volume test set.
g) Optional moisture in oil by weight test set or equivalent.

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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 cellulosic insulation

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

a) *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 (annex B). 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-h 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 (annex B) 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

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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 (annex B), 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
— Insulation temperature	20 °C
— Tank gauge pressure	2 lbf/in^2 (14 kPa)
— Pressure at dew point—instrument	0 lbf/in^2 (0 kPa)
— Atmospheric pressure	14.7 lbf/in^2 (103 kPa)

On figure B.1 (annex B), read the vapor pressure as 100 μm (13 Pa). Correct this vapor pressure to tank conditions:

$$\frac{14.7 + 2}{14.7} \cdot 100 = 114 \text{ μm (15 Pa)}$$

On figure B.2 (annex B), read the moisture content 0.75% of the dry weight of insulation at the junction of 114 μm (15 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.

Four precautions need emphasis when making a dew point measurement:

1) Equilibrium conditions must be reached
2) Insulation temperature must be known accurately
3) The measuring equipment shall be properly calibrated, and be in good working order
4) 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.

b) *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 6 h 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

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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) (annex B). 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 Pa) at 30 °C or provide hot-oil-circulating equipment that will raise the insulation temperature. Figure B.3(b) (annex 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.2 (annex B) 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

Frequently, opinion prevails that transformer oil received directly from the refinery is ready to be pumped into a completely processed EHV transformer. Refineries usually supply oil having a moisture content of approximately 30 ppm. Oil that has been degassed, and with a moisture content below 10 ppm at the refinery, will usually be contaminated during the loading and shipping procedures 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(d) (annex B). 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 which, under the best conditions of laboratory testing of samples taken in the field and transported to the laboratory, often produces differences of ±10 ppm, 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, photovolt aquatest, panametric hygrometer, or comparable measuring equipment. This can eliminate several factors that lead to inaccuracies.

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