



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

IEEE Power Engineering Society

Sponsored by the
Transformers Committee



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

Sponsor
Transformers Committee
of the
IEEE Power Engineering Society

Approved 5 December 2007
IEEE-SA Standards Board

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

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

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Introduction

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

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

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

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

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

This guide discusses the following two sizes of transformers:

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

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

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IEEE Guide for Installation and Maintenance of Liquid Immersed Power Transformers

1. Scope

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

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

NOTE 1—For transformers with primary voltages that are less than 69 kV and larger than 10 MVA, users should follow Clause 4.¹

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

2. Normative references

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

~~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 D1816-2004, Standard Test Method for Dielectric Breakdown Voltage of Insulating ~~Liquids~~ Oils of Petroleum Origin Using ~~Disk~~VDE Electrodes.²

¹ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

² ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

[ASTM D2668-2002, Standard Test Method for 2,6-Di-tertiary-Butyl-Para-Cresol and 2,6-Ditertiary-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption.](#)

[B1] ASTM D877- 2002e1, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes

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

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

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

[IEEE Std 62™-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus](#)

[IEEE Std 693™-2005, IEEE Recommended Practices for Seismic Design of Substations.](#)

3. Liquid-immersed power transformers rated 501 kVA to 10 MVA ~~(OA)~~₁ or with primary windings less than 69 kV

3.1 General

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

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

Forced cooling (if present) normally uses fans.

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

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

3.2 Inspection and receipt

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

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

~~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~~

³ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08854, USA.

⁴ The IEEE products referred to in this clause are trademarks belonging to the Institute of Electrical and Electronics Engineers, Inc damage to tank, radiators, bushings or any external accessories. Upon receipt, each transformer should be checked for evidence of damage or leaks, and the internal gas pressure should be measured. A positive or negative pressure indicates that the tank has not developed any leak. Zero gauge pressure should be investigated. A small valve or a plug fitting could be opened slightly to check for the internal gas pressure. The de-energized tap switch should be operated and if necessary (provided that the bushings are installed or the winding leads are accessible), a ratio test may be carried out to ensure that it is functional.

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

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

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

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

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

3.2.1 Station-type configuration

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

3.2.2 Pad-mount configuration

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

3.3 Internal inspection

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

3.3.1 General practices for internal inspection

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

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

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

WARNING

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

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

3.3.2 Atmospheric conditions

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

3.3.3 Inspection

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

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

3.4 Handling

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

CAUTION

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

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

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

3.4.1 Pad-mount configuration

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

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

3.5 Assembly

Since transformers in this size range are normally shipped fully assembled and ready for service, there is little field assembly required. Units may be shipped filled with insulating liquid, but with the high-voltage bushings and fans removed for shipment. Above 7.5 MVA ~~(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 4.8. Padmount transformers are normally shipped fully assembled with the insulating liquid in the transformer and under positive gas pressure, ready for service. Transformers should be mounted on a level pad that is strong enough to support the total weight involved. The transformer should be secured to the pad, especially in seismic "[Moderate Zone](#)" or greater. [Refer to IEEE Std 693.⁵](#)

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

3.6 Storage

The transformer should be stored upright and completely assembled.

Sealed-tank units should be filled with the insulating liquid at its proper level and the gas space pressurized at approximately 14 kPa (2 lbf/in²) at ambient temperatures [between 10 °C and 30 °C \(50 °F and 86 °F\)](#). Periodic inspection should ensure that [positive gas](#) pressure ~~gauge does not return to zero~~ and proper liquid level ~~is~~ [are](#) maintained at all times.

~~A sealed tank unit;~~ [Conservator type units should be stored with proper liquid level in the conservators.](#)

[Transformers](#) supplied without insulating liquid, can be stored [under nitrogen](#) for a maximum period of six months ~~without inspection~~, or as otherwise instructed by the manufacturer, provided a positive pressure is maintained. Inspection and drying should precede extended storage if required. ~~It is desirable that the transformers be stored undereover.~~ Transformers stored outside a fenced area should be secured and barricaded. [All bushing terminals should be solidly grounded to protect the transformer terminals and windings in the event of a lightning strike. Heaters in the control cabinets and motor drive housings of LTCs should be connected to a power supply and turned on to prevent condensation.](#) Insulating liquid supplied in drums or other containers should be placed in a dry location with moderate temperature variation ~~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-cover~~. The insulating liquid would then be susceptible to water contamination due to expansion and contraction of the liquid, which can create suction causing water seepage into the drum through the [bungs](#). [Drums may be covered to protect drums from reduce the risk of moisture ingress.](#) All insulating liquids should be tested prior to use. [Oil with poor test results shall be processed before use. Testing of oil in drums can be difficult; therefore, if possible, place the oil in bulk containers and allow it to settle before testing. If a test sample is required from the drums, the drums should be tilted for several minutes to allow any water to settle at the low point. A sample may than collected at the lowest point.](#)

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

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 insulation resistance should be measured with a megohmmeter. For ~~larger~~ units equipped with de-energized tap changers and/or dual voltage switch, it is desirable to check the ~~tumsturns~~ ratio at all de-energized taps and dual voltage switch (or series -parallel terminal board) positions and to check the dielectric strength and water content of the insulating liquid prior to placing the transformer into service. If access to a core ground lead is available, the core insulation should be tested.

~~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.~~

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

3.7.1 Pad-mount configuration

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

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

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

Refer to Table 7 of IEEE Std C57.106. The dielectric strength of the oil sample should not be less than ~~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 2 mm gap, according to ASTM D1816-843. ASTM D877-87 is recommended for testing new oil as received from the refinery. ASTM D1816-843 is recommended for oil shipped within new equipment method.

3.7.3 Other insulating liquids

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

3.8 Energization

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

³~~Information on references can be found in clause 2-~~

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.~~

WARNING

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

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

Transformers equipped for dual-voltage or delta-wye (reconnectable winding) configurations usually have an externally operable switch mounted on the 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. Refer to the nameplate for information on adjusting these devices.~~

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

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

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

3.8.2 Connecting to bushings

Connections to bushings ~~must be made 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, adequately supported, and with allowance for expansion and contraction.

3.8.3 Energization under cold conditions

IEEE Std C57.12.00 considers ~~starting~~ energization at temperatures below $-20\text{ }^{\circ}\text{C}$ ($-4\text{ }^{\circ}\text{F}$) as unusual service.

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

Dielectric liquids may exhibit a drop in dielectric strength at lower temperatures if moisture precipitates out ~~if, at any temperature, the density, and even at high relative saturation levels of the insulating moisture in oil is greater than the density of water prior to precipitation.~~ At colder temperatures, free ice or free water could exist in the system and could cause a dielectric discontinuity and possible failure. If an outside power source is available, consideration should be given to preheat the transformer in extreme cold weather prior to energization. Insulating the coolers/radiators to reduce heat loss should also be considered. In consideration of viscous insulating fluid in cold temperatures below $-20\text{ }^{\circ}\text{C}$ ($-4\text{ }^{\circ}\text{F}$), it is prudent to energize any extremely cold