Installation Procedures & New Transformer Oil Processing

Minneapolis, MN RTS

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Josh Brown joined Prolec GE Waukesha in 2008 at the Goldsboro, North Carolina, location. Starting out as a manufacturing engineer, Josh held several engineering positions of increasing responsibility prior to joining the service team in 2014. He worked various jobs supporting eastern U.S. activity within the Service Group and was promoted to General Manager in 2017. As the general manager, Josh is responsible for leading the Waukesha® Service Group in providing and implementing creative field service solutions nationwide. He has a Bachelor of Science Degree in Systems Engineering from East Carolina University, where he remains an active member of the engineering advisory board. He is also an active member of industry committees and advisory boards.

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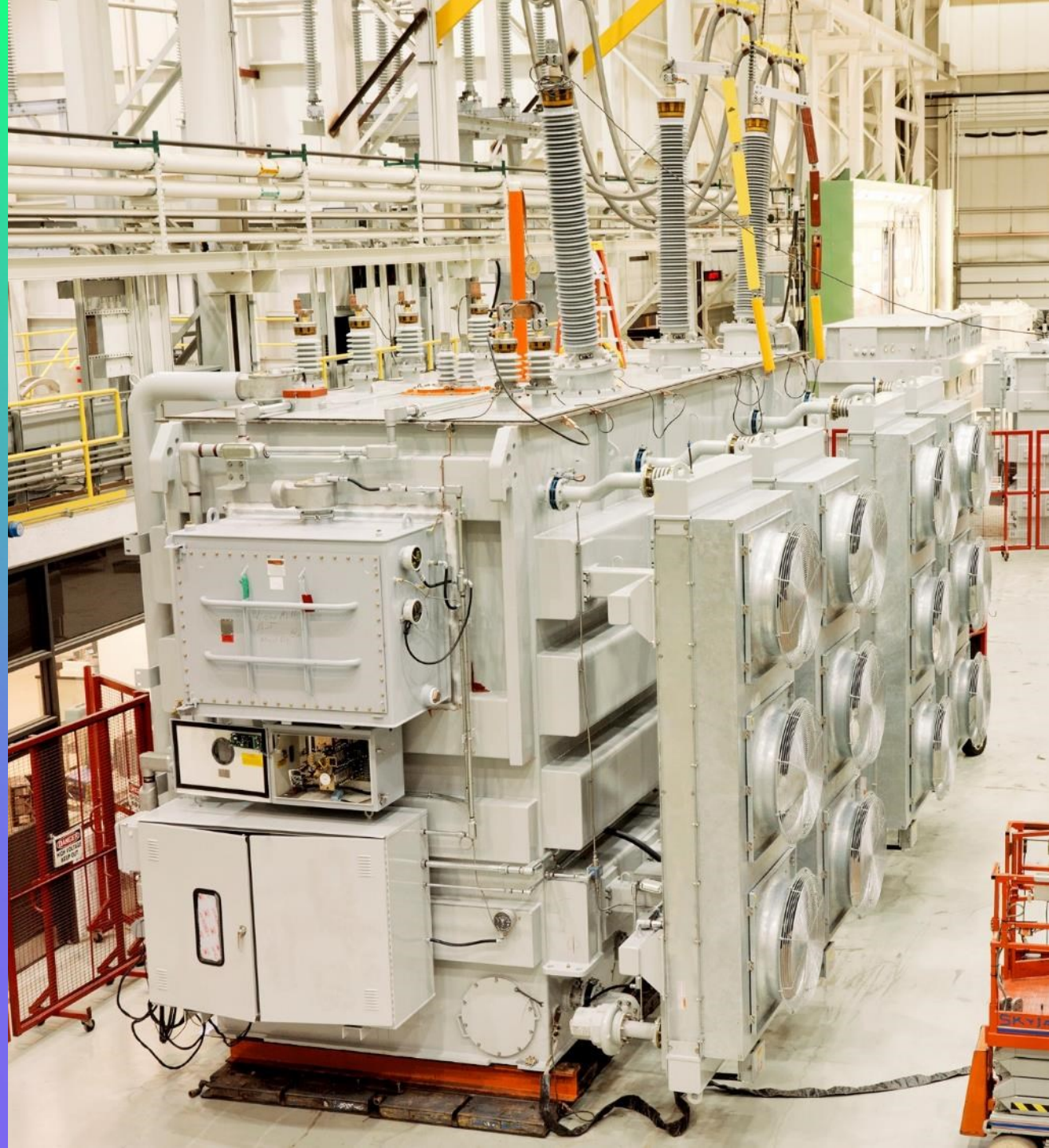


Agenda

- Receiving Inspection
- Unloading
- Field Assembly
- Oil Processing
- Vacuum Filling
- Energization

Introduction

- Develop a site installation plan
- Review OEM Instructions
- Review Applicable Standards
  - IEEE Guide for Installation of Liquid Immersed Power Transformers (C57.93-2019)
  - IEEE Guide for Maintenance and Acceptance of Insulating Oil in Equipment (C57.106-2015)
  - NETA Acceptance Testing Specification 2021
  - IEEE Guide for Diagnostic Testing of Fluid Filled Power Transformers, Regulator, and Reactors (C57.152-2013)
  - IEEE Guide for Failure Investigation, Analysis, and Documentation of Power Transformers and Shunt Reactors (C57.125-1991 Appendix A)

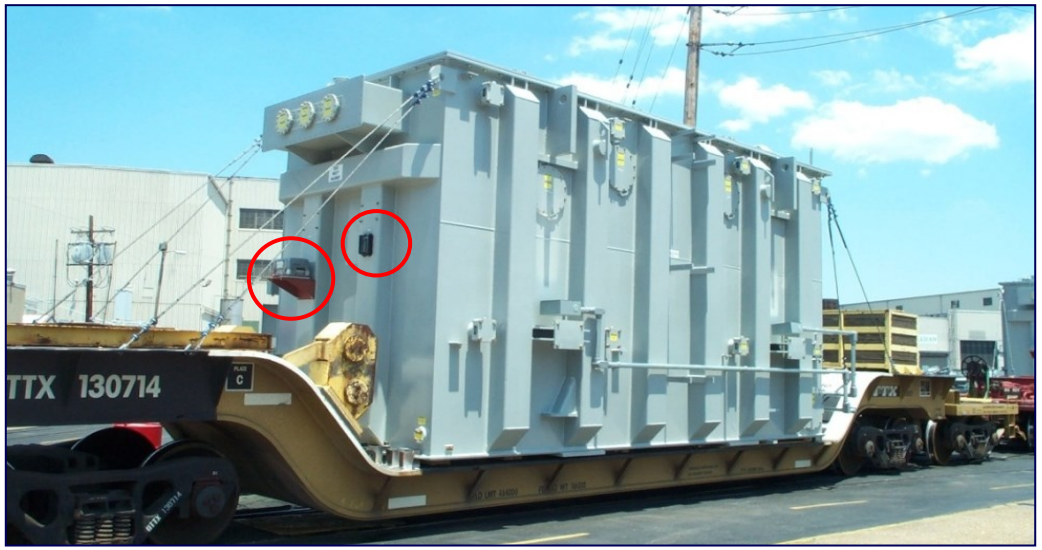
Receipt of Transformer

Receiving Inspection

- Complete visual inspection
- Check for movement, shifting, bent or broken tie down rods.
- Check for scratches, dents, broken accessory devices
- Check tank pressure
- Perform dew point measurement
- Perform core ground test
- Inventory and inspect accessories
- Review impact recorder

External Inspection

Impact Recorders



- There are several type of impact recorders
  - Strip Chart Recorder
  - Non-resettable
  - Resettable
  - Data Logging
  - GPS Data Logging
- Mount recorder directly on transformer
- Assure there is adequate battery life & recording paper
- Redundant recorders are recommended for critical shipments
- 2G impacts in lateral & vertical direction and 3G impacts in longitudinal direction warrant further inspection

Receiving Inspection

If damage is evident from visual inspection, impact recorder reading, or testing:

- Notify manufacturer
- Notify carrier
- Do not unload equipment
- Initiate any claim forms
- Perform an internal inspection

Receiving Inspection – Prevention Techniques

Unloading of Transformer

Methods

- Cranes
- Beams & hydraulic sliders
- Gantry cranes
- Winch lines/jacks

Unloading of Transformer

Precautions

- Verify use of proper lifting eyes and jacking lugs.
  - Lift angle should not exceed 60°
- Verify location of center of gravity
- Verify proper jacking points
- Verify proper base support locations
- Keep base level while handling
  - Never more than 15° vertical
- Block railcars and trailers to prevent tipping or collapse

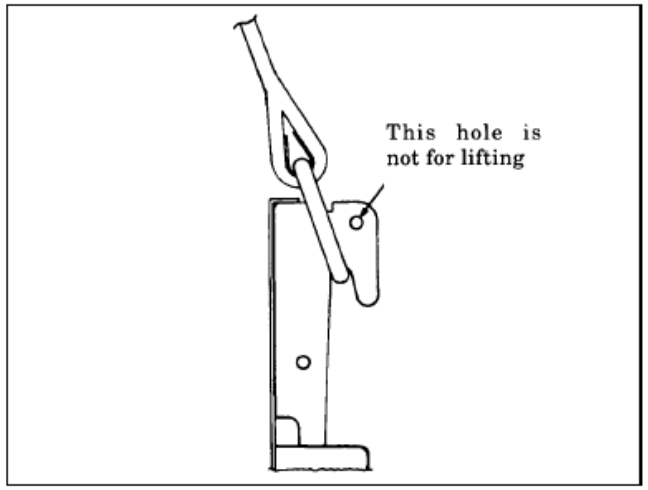


Figure 4-2.

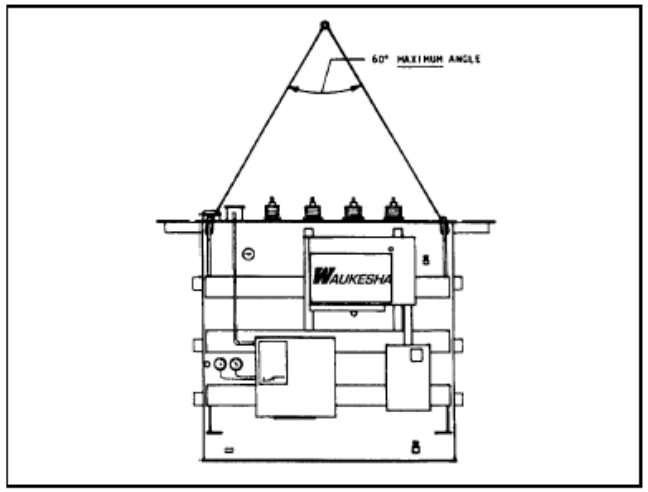


Figure 4-3.

Assembly of Transformer

Preparations

- Devise an assembly plan
  - Assure tool and material availability
  - Minimize potential damage to components
  - Minimize exposure time
- Transformer base should be level and supported per manufacturers instructions
- Transformer should be positioned for adequate air circulation
- Transformer tank should be grounded to system ground
- Verify mechanical pressure relief device is installed

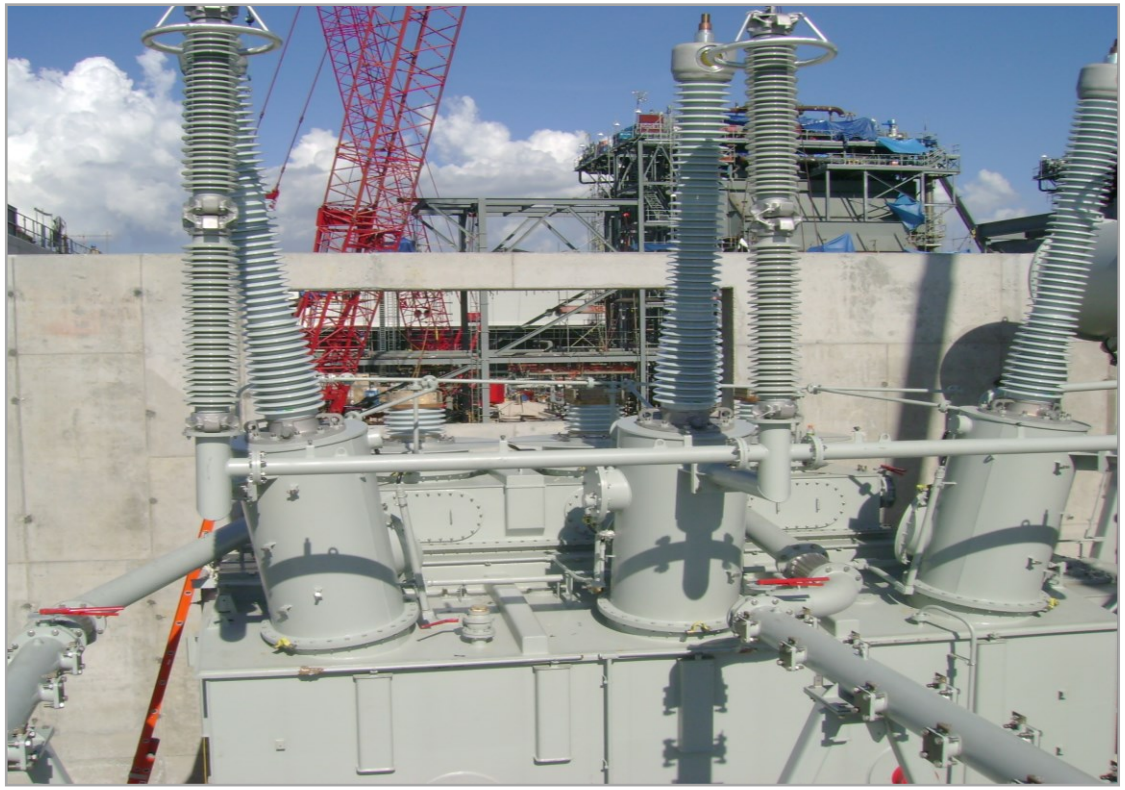
Assembly of Transformer

General Assembly Guidelines

- If supplied, use new gaskets for assembly. Nitrile gasket material can be reused if undamaged.
- Observe manufacturers match marks for component orientation.
- Seal all pipe fittings with Teflon tape or sealing paste.
- Gaskets should be glued on only one side. Petroleum jelly can be applied to minimize damage during assembly.
- Pull flash vacuum, pressurize, and seal transformer each evening.

Turrets and Bushings

- Remove any temporary braces and support
- Install all turrets & connect current transformers
- Perform power factor tests prior to installation of bushings
- Lift and install bushings per manufacturers instructions
- Make current carrying connections, torque, insulate, and install shields as specified
- Install grounding/bonding jumpers and static grounds

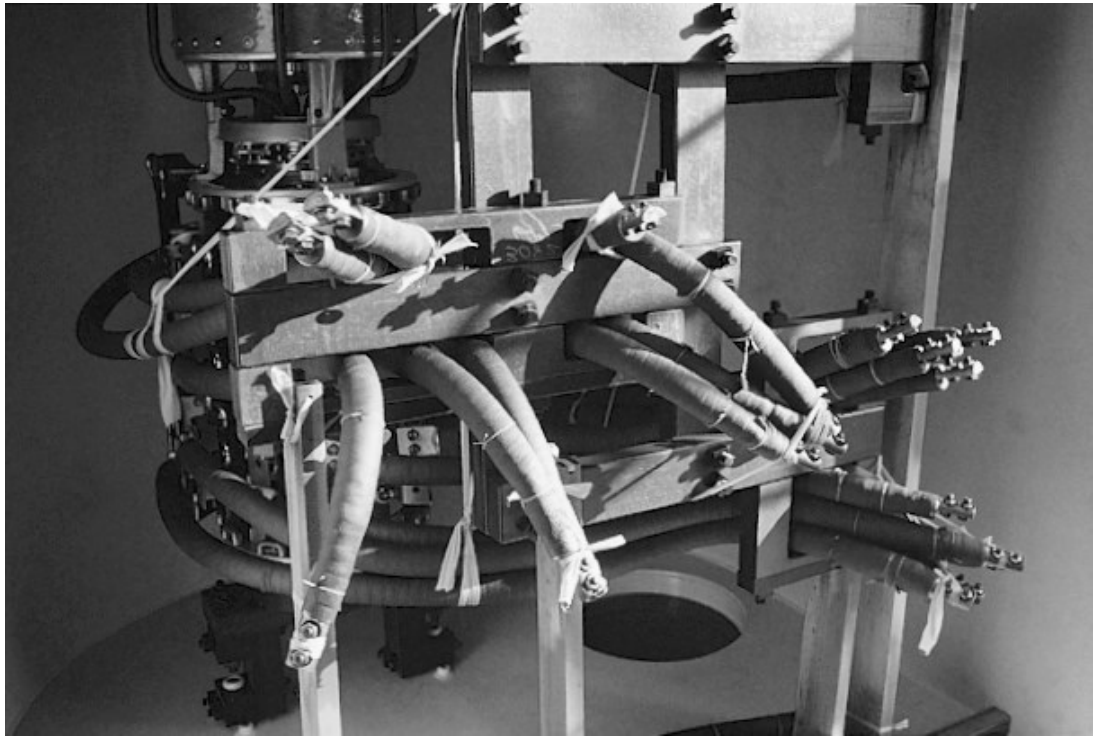


Cooling Equipment

- Cooling equipment should be inspected, cleaned, and flushed, if required
- Replace mounting gaskets and glue gaskets on one side only. Use petroleum to assist with installation
- Mount fans and fan guards
- Mount supports or seismic bracing
- Examine and tighten all packing glands
- Make electrical connections

Load Tap Changers

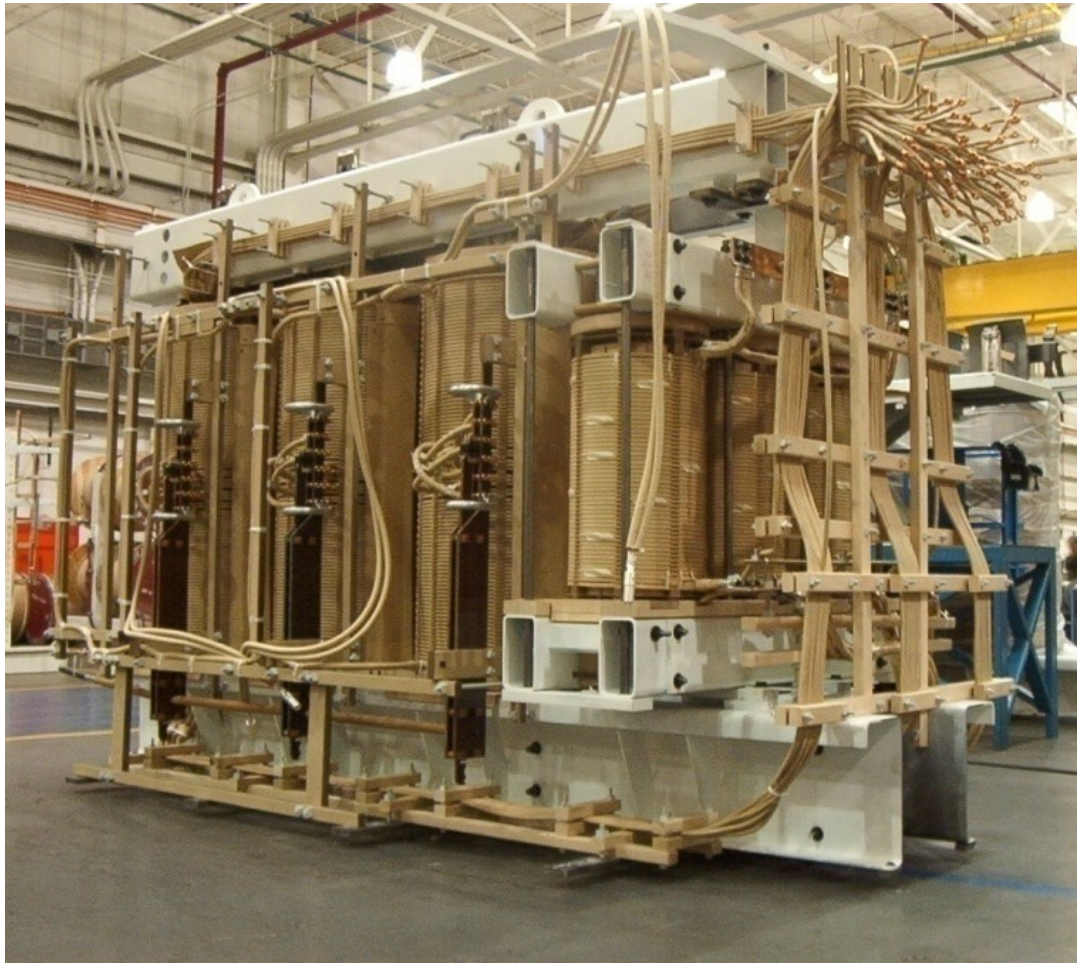
- Remove any shipping braces and supports
- Install motor drive and operating shafts
- If ULTC is removed for shipment, make lead connections to barrier board and insulate as necessary
- Manually and electrically operate ULTC
- Check alignment, timing, and contact pressure



Oil Preservation Systems

- Sealed system may need to be capped for vacuum filling
- Nitrogen systems will require piping connections and mounting of regulator cabinet. Regulator cabinet to be isolated for vacuum filling
- Conservators should be inspected and pressure tested
- Verify OEM requirements for conservator tanks capability to withstand vacuum

Final Internal Inspection



- Verify no foreign material, dirt, moisture present
- Verify all shipping braces removed
- Verify all bushing connections, corona shield, and insulation barriers installed correctly
- Verify all lead clearances
- Check for proper liquid level gauge operation
- Verify DETC and ULTC operation, timing, and alignment
- Check current transformer mounting and connections
- Inspect coil clamping, spacer alignment, phase barriers oil boxes, and coil wraps

Preliminary Tests

It is recommended that some preliminary tests be conducted prior to starting vacuum filling operations:

- Dew point
- Core insulation resistance
- Bushing power factor
- Transformer turns ratio
- Current transformer ratio and polarity tests

Tes	Tap	IEEE30 V/I	IEEE45 V/I	IEC 10/50 V/I	NP-Ratio	M-Ratio	% Error
1	X1-X2	0.00 / 0.0000	0.00 / 0.0000	0.00 / 0.0000	400/5.0	78.806	1.4930
2	X1-X3	0.00 / 0.0000	0.00 / 0.0000	0.00 / 0.0000	1200/5.0	238.323	0.6986
3	X1-X4	0.00 / 0.0000	0.00 / 0.0000	0.00 / 0.0000	1500/5.0	298.874	0.3753
4	X1-X5	859.28 / 0.0740	693.04 / 0.0570	918.16 / 0.0856	2000/5.0	400.558	0.1395

Oil Filling Procedures

- Oil-Filled Transformers
- Transformers shipped with dry gas

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Transformer Shipped Oil Filled

- Open bottom radiator valves and vent air through top bleeder plug
- Open top radiator valves
- If required, add make-up oil
- Test each individual container (drum, tanker, etc.)
- It is permissible to pump oil into the transformer through a filter press or degassing equipment
- During filling, the added oil should be pumped in at a level below current oil level in tank and should be directed horizontally over core and coil assembly
- It is ***not*** recommended to pull vacuum over the oil in the transformer
- Fill transformer to 25°C mark through upper filter press valve or manhole; attempt for horizontal oil flow to minimize bubbling
- Adjust oil level allowing for temperature compensation per nameplate instructions
- Purge gas space with nitrogen; maximum permissible O_2 is 1.2%
- Take final oil samples
- Observe proper set time for energizing

Transformers Shipped Dry Gas Filled Strategies

- Confirm main tank gas type before any internal work initiatives (N2/Dry Air/etc.)
- Ensure Dew point measurement is taken daily on main tank
- Record dry gas dewpoint *(utilized daily for internals work or tank pressurization at end of day)*
- Avoid internals activities on high humidity days
- Utilize “flash vacuum steps” for treatment on high humidity results during process
- Perform pressure test prior to initiating vacuum process
- Validate integrity of vacuum system utilizing “blank-off test” on processor unit

Vacuum Filling Preliminary Processes

Prior to beginning vacuum operations, operator must verify…

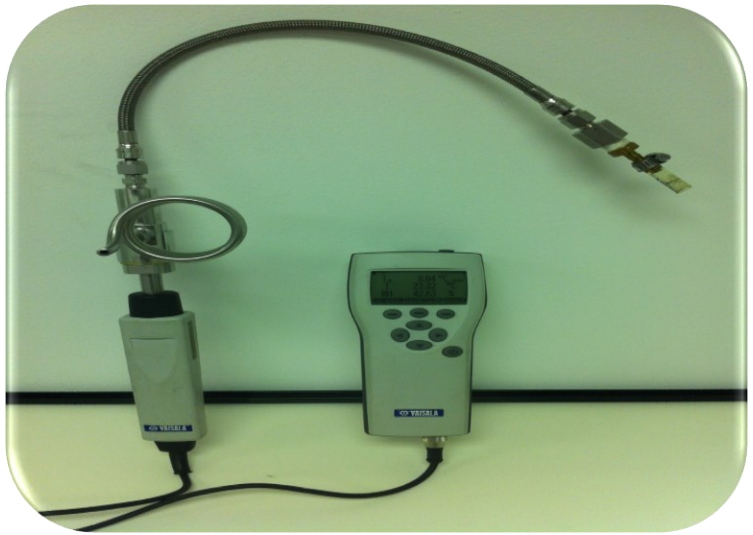
- Equipment preparations
- Determination of insulation moisture content
- Verification of tank leakage rates
- Field dry out methods
- Low ambient processing

Vacuum Preparations

When preparing for vacuum filling operations, there are several recommendations….

- Ground transformer tank, storage tanks, purification unit, and bushing terminals
- Disconnect any bushing terminations
- Cover transformer cover with tarp
- Isolate all devices not rated for vacuum
- Balance pressure on terminal boards or barriers
- Leave mechanical relief device in position

Insulation Moisture Content



Dew point measurement

- Introduce dry gas and stand idle for 12-24 hours
- Measure dew point of gas
- Record tank pressure
- Record insulation temperature
- Utilize Pieper curve information to calculate moisture content
- Most OEMs have an acceptance range between 0.5 and 1.0%

Insulation Moisture Content

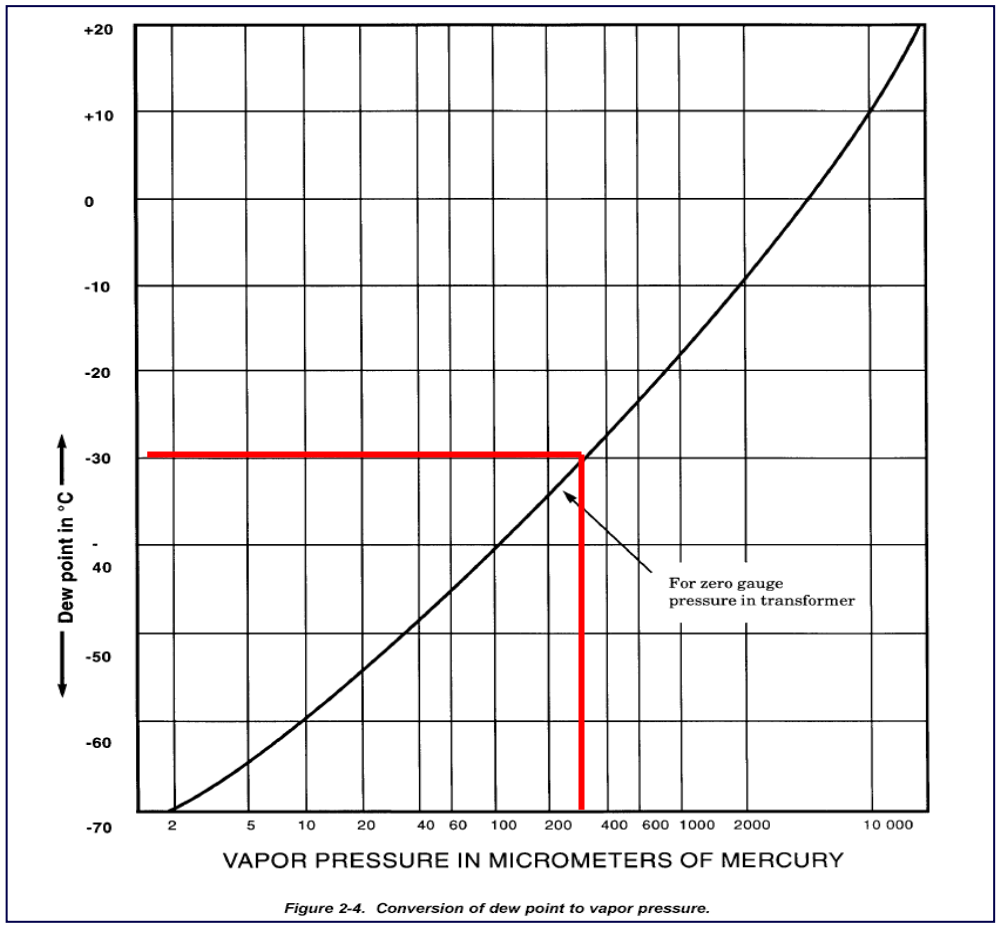


Figure 2-4. Conversion of dew point to vapor pressure.

- Dew point = -30°C
- Tank Pressure = 3 PSI
- Insulation Temp = 30°C

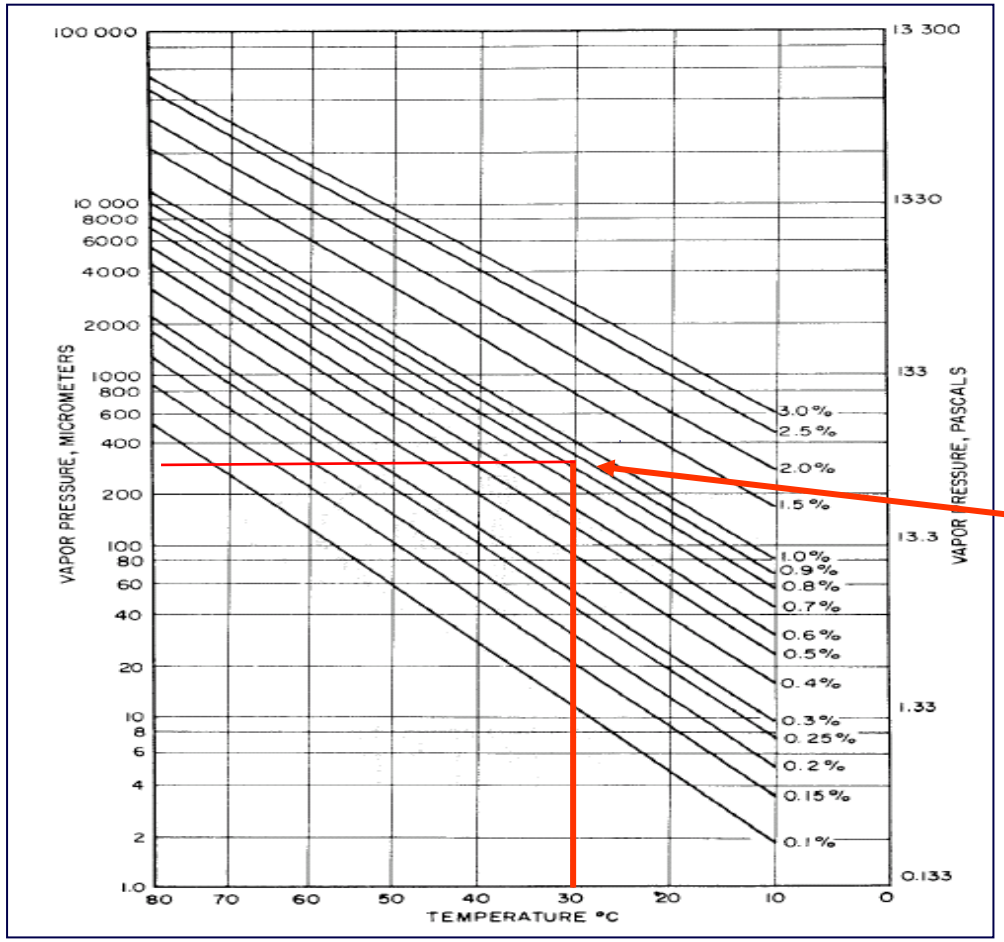
$$V_C = V_P \frac{(14.7 + T_P)}{14.7}$$

$$V_C = 300 \frac{(14.7 + 3)}{14.7}$$

$$V_C = 361.2$$

Source: IEEE C57.93-2019

Insulation Moisture Content



Moisture content is 0.9%.

Source: IEEE C57.93-2019

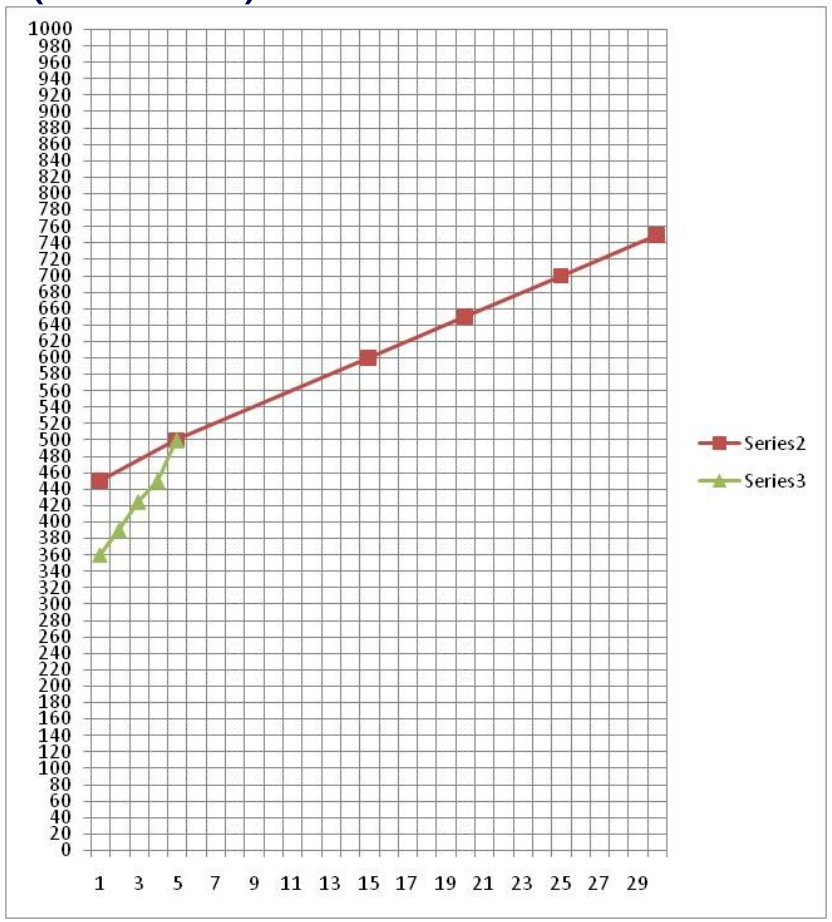
Verification of Leakage Rate

Leaks are detrimental to the vacuum process so it is necessary to verify tightness of transformer. Typically this is verified by:

- Pressure Check
- Vacuum Leak Check
  - Evacuate tank to 2 Torr
  - Isolate pump and take reading 5 minutes later(P1)
  - Take second reading 30 minutes later(P2)
  - Calculate leak rate

Verification Leakage Rate

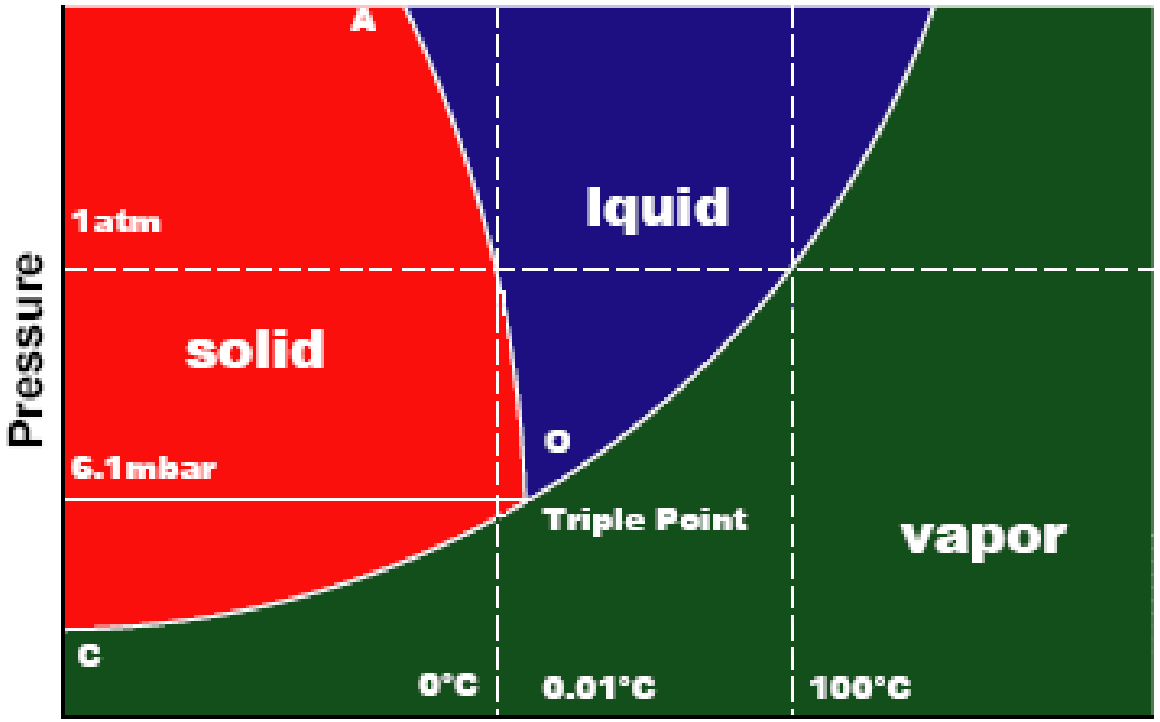
(P2 -P1) x V < OEM Value



Leak Rate Chart

Tank Oil Volume (Gallons)	Maximum Allowable Leak Rate (Torr Rise in 10 Minutes)
Less than 5000	0.80
5001 – 7500	0.53
7501 – 10000	0.40
10001 – 12500	0.32
12501 – 15000	0.27
15001 – 17500	0.23
17501 - 20000	0.20
20001 - 22500	0.17

Field Dry Out Methods



the phase diagram of water

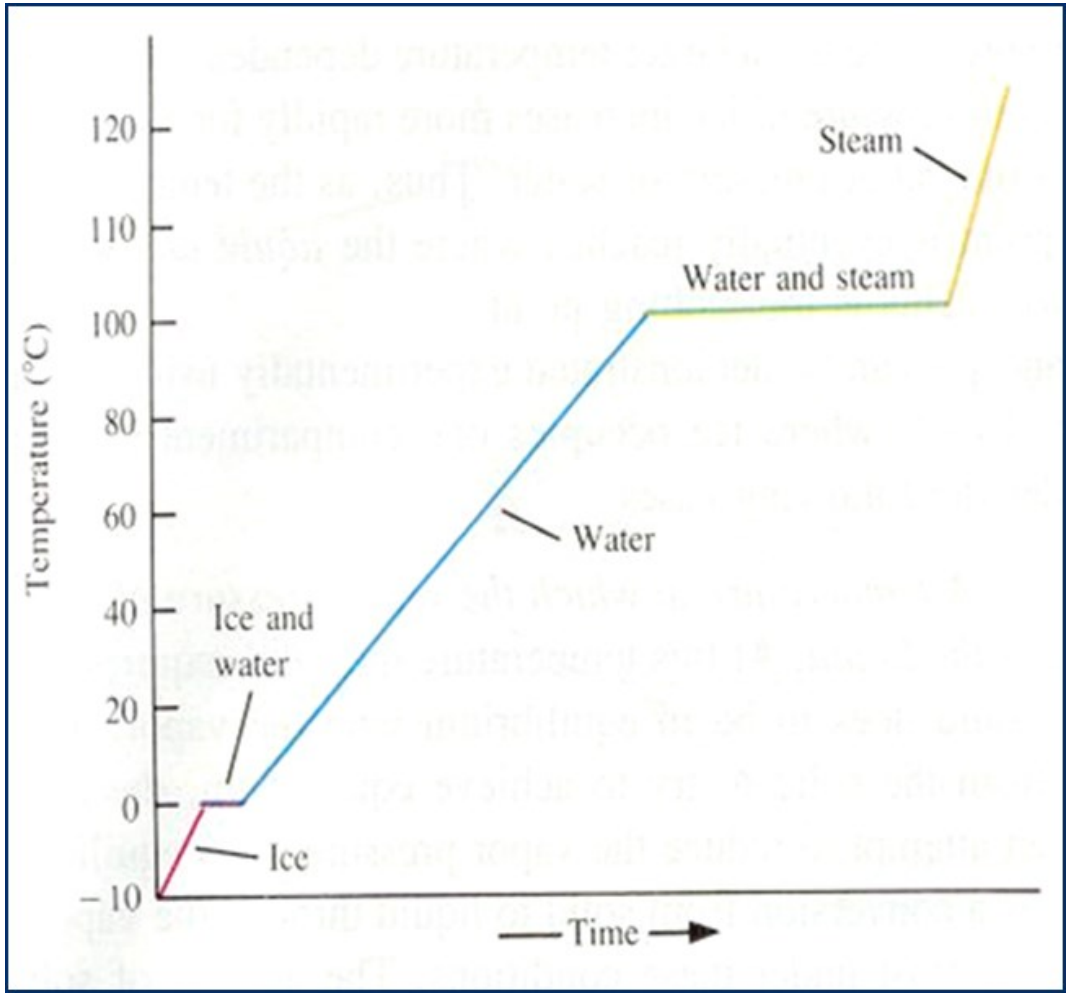
There are multiple methods for field drying of a transformer if the moisture content is found to be above an acceptable limit.

- Vacuum
- Vacuum with Hot Air
- Short circuit and Vacuum
- Vacuum with Hot Oil

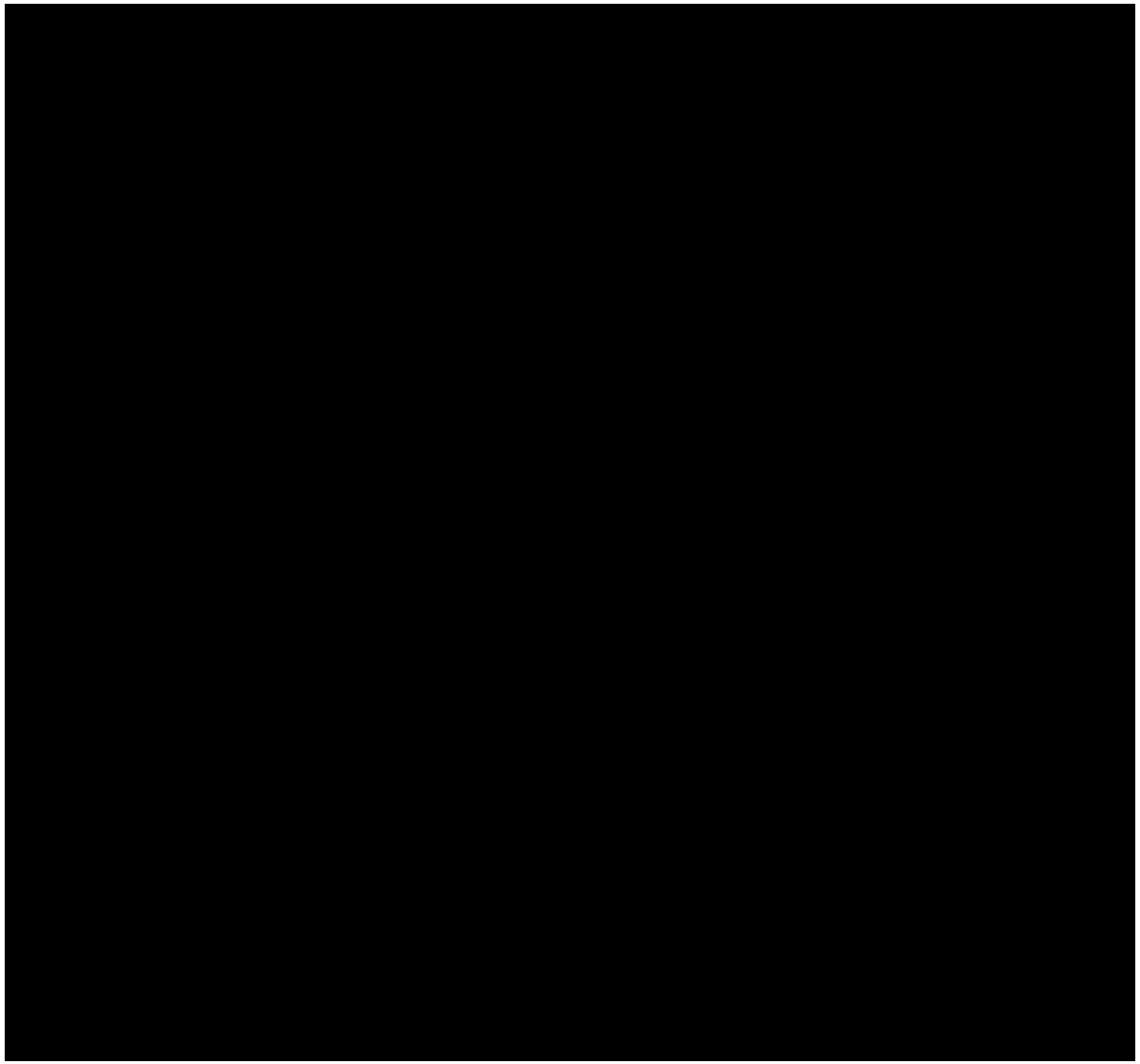
Transformer Drying

Importance of Temperature

- Heat required for a phase change comes from the surrounding oil and transformer parts
- As heat moves from the insulation into the water, the temperature of the insulation and transformer drops
- Therefore, replacement heat is added by continuously reheating the oil and pumping it into the transformer
- If the heat is not replaced, freezing can eventually occur



Transformer Drying



Video courtesy of Baron USA, LLC

Transformer Dry Out Method

Vacuum

- Good method for removing small amounts of residual moisture
- Transformer is subjected to high vacuum and held for a period of time
- Efficiency of method is increased at higher temperatures
- Cold traps can be used in vacuum line to measure moisture extraction

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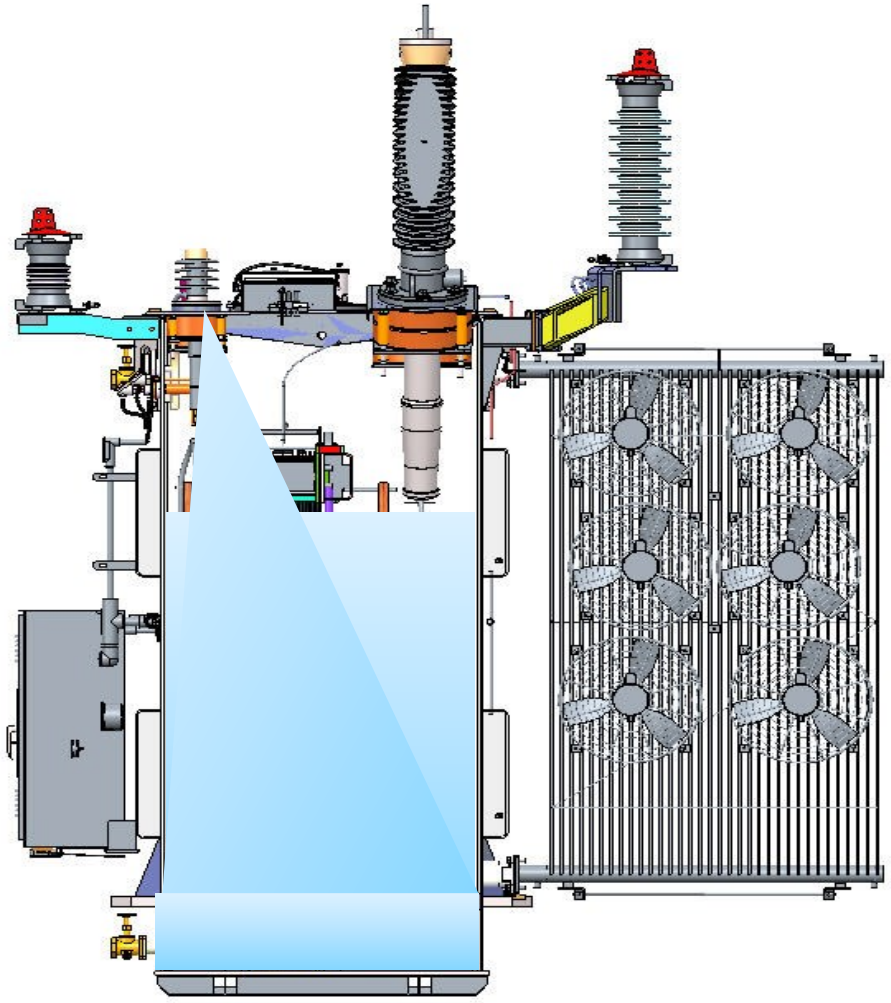
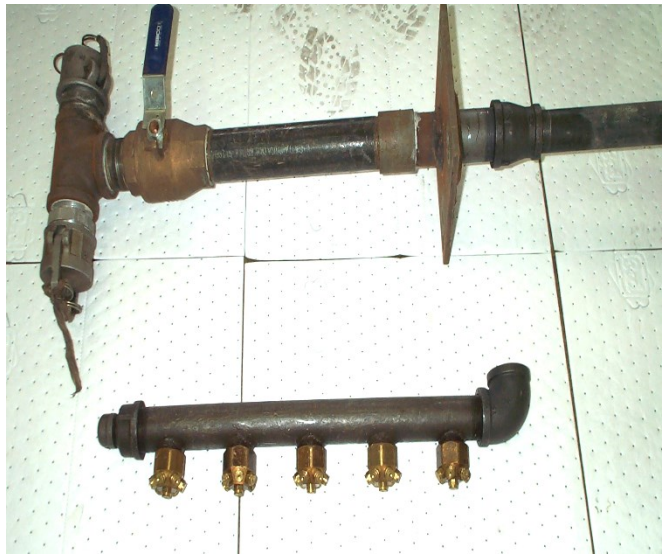
Transformer Dry Out Methods



High Vacuum and Hot Oil

- Evacuate tank
- Introduce oil to heat core/coil assembly
  - If capable, limit oil volume to 10% of total or enough to establish oil circulation
  - Otherwise, cover core/coil assembly
- Circulate oil under vacuum until outlet oil temperature reaches desired temperature, typically 50-70°C
- Drain oil from transformer
- Continue to pull vacuum and monitor moisture through cold trap, if desired

Transformer Dryout Methods



High Vacuum and Hot Oil Circulation

Process is more effective when heat is introduced to increase the vapor pressure of the moisture:

1) Evacuate tank to 2 Torr of less
2) While maintaining vacuum, introduce oil with inlet temperature of 70°C ± 5°C
3) Oil volume to be no less than 10% of total or enough to establish oil circulation
4) Circulate oil under vacuum until outlet oil temperature reaches 50°C
5) Optionally, Monitor moisture extraction through cold trap and cease drying when cold trap is less than 1 oz./hr.
6) Alternatively, monitor with vapor pressure equilibrium chart and cease when vacuum level corresponds to 0.75% at applicable temperature
7) Drain oil from transformer
8) Continue to pull vacuum and monitor moisture through cold trap until moisture extraction rate achieved
9) Confirm result via dew point measurement

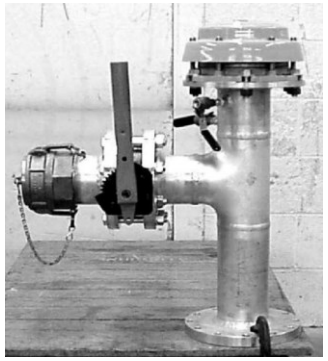
Low Ambient Processing

Vacuum is ineffective when the insulation temperature approaches the freezing point.

Therefore, the insulation temperature must be elevated…

- Evacuate tank to 10 Torr of less
- While maintaining vacuum, introduce oil with inlet temperature of 70°C ± 5°C
- Circulate oil under vacuum until outlet oil temperature reaches 10°C
- Drain oil from transformer
- Immediately begin vacuum operations

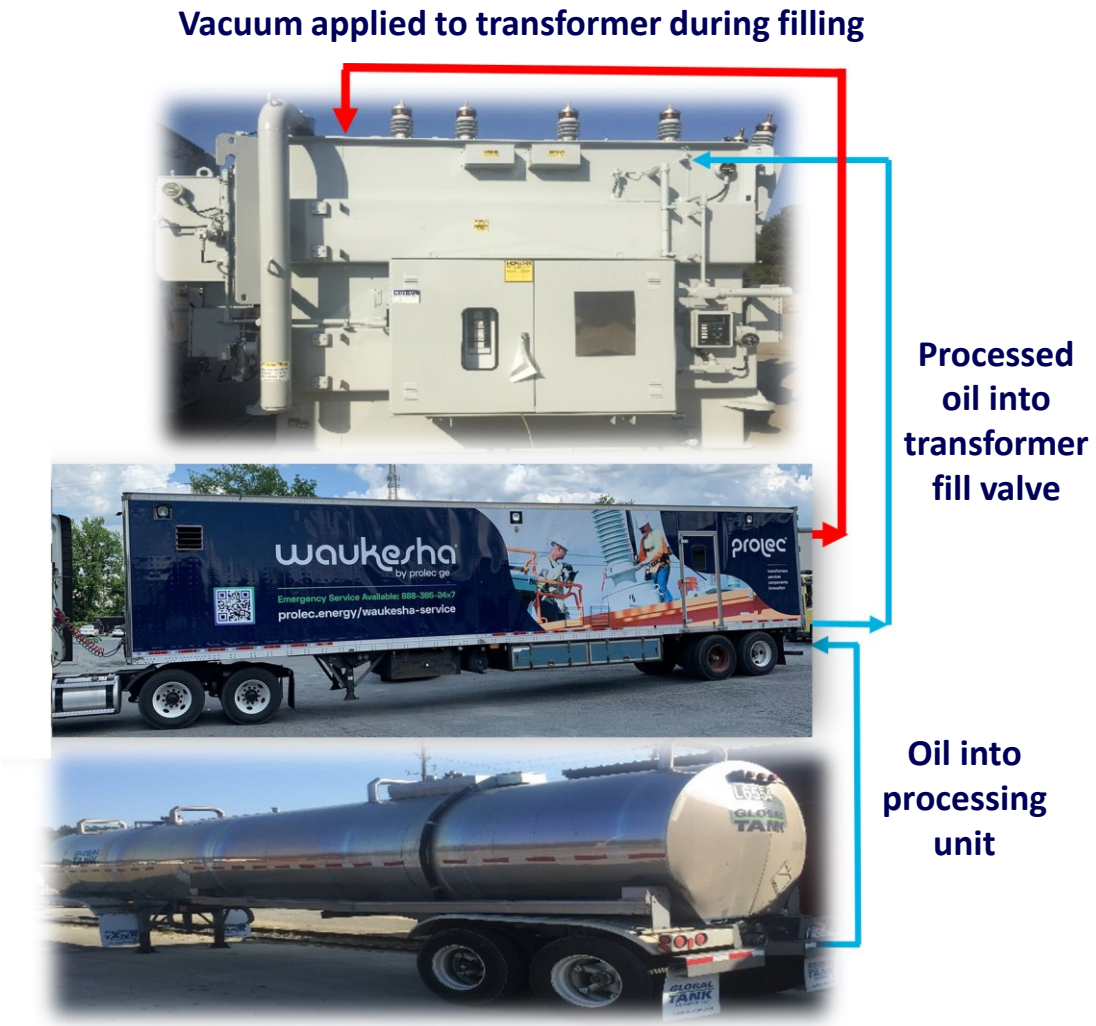
Vacuum Preparations



When preparing for vacuum filling operations, we can offer several recommendations:

- Complete preliminary testing
- Ground transformer tank, storage tanks, purification unit and bushing terminals
- Disconnect any bushing terminations
- Cover transformer cover with tarp
- Isolate all devices not rated for vacuum
- Balance pressure on terminal boards or barriers
- Leave mechanical relief device in position

Vacuum Oil Filling



- Evacuate tank hold for specified duration
- Pretest oil
- Fill transformer under vacuum
- Verify inlet oil temperature
- Verify positive head pressure an inlet valve
- Monitor oil level during fill
- Fill at specified fill rate

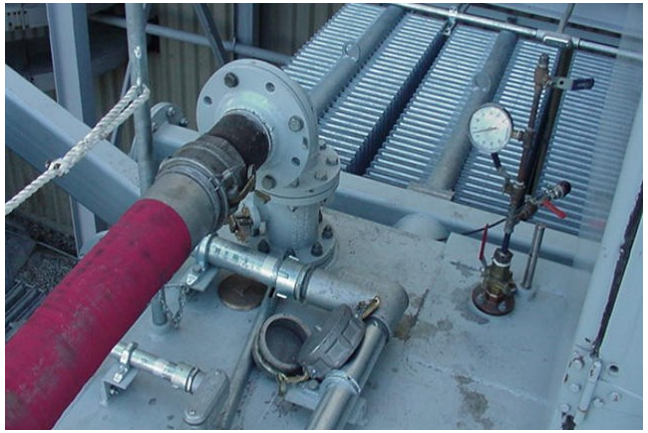
Vacuum & Oil Filling Specifications

	Voltage, kV	≤ 69 kV	138 kV	230 kV	345 KV	500 kV	765 kV
Preparation	Complete all assembly	yes	yes	yes	yes	yes	yes
	Dew point measurement	yes	yes	yes	yes	yes	yes
	Core & Coil minimum temperature, Celsius	10	10	10	10	10	10
	Drain all oil prior to final vacuum	yes	yes	yes	yes	yes	yes
	Close oil preservation system valve	yes	yes	yes	yes	yes	yes
	Open all cooler equipment	yes	yes	yes	yes	yes	yes
Vacuum	Final Leak Test	yes	yes	yes	yes	yes	yes
	Absolute Pressure Maximum, Torr	2	2	1	0.75	0.5	0.5
	Vacuum Hold Time, Hrs.	12	24	48	48	60	72
Oil Filling	Fill from Top or Bottom	T/B	T/B	T/B	T/B	T/B	T/B
	Oil Temp Minimum, Celsius	50	50	50	50	50	50
	Oil Temp Maximum, Celsius	80	80	80	80	80	80
	Degasser required or Filter Press only	D/F	D/F	D	D	D	D
	Vacuum during filling Maximum, Torr	1	1	1	0.75	0.5	0.5
	Rate of filling, GPM Maximum	30	30	30	30	30	30
	Oil Recirculation, # of passes	2/3/4	2/3/4	2/3/4	2/3/4	2/3/4	2/3/4
	Minimum Stand Time, hrs	12	24	24	48	48	72

*Retain a copy of all Certificates of Authenticity for each tanker arriving at site to support oil filling operations

Source: IEEE Guide C57.93-2019

Vacuum Filling Instructions



- In inclement weather, take necessary precautions to prevent moisture intrusion should a leak develop
- Make connections from pumping system to transformer as short as possible to increase efficiency
- Make sure there are no low spots in hoses for moisture to collect
- Use large diameter hoses (4”) to increase pumping efficiency

Vacuum Filling Instructions (cont.)

- Conduct vacuum leak test
- Pull vacuum per OEM specifications
- Prior to adding oil to transformer, the oil should be tested to verify OEM specifications are met:
  - Moisture content: 30 PPM maximum value
  - Dielectric strength (ASTM-877): 30 kV minimum value
  - Power factor: 0.05% @ 20°c maximum value
  - Interfacial tension: –40 dynes/cm minimum value

Vacuum Oil Filling

Once the prescribed vacuum hold time is completed, the transformer is filled:

- Verify proper acceptance criteria of oil
- Fill oil into upper fill valve or bottom fill valve
- Validate that inlet temperature meets minimum specification
- Verify positive fill pressure at fill location
- Fill at specified flow rate or liquid level change
- Monitor level through site glass

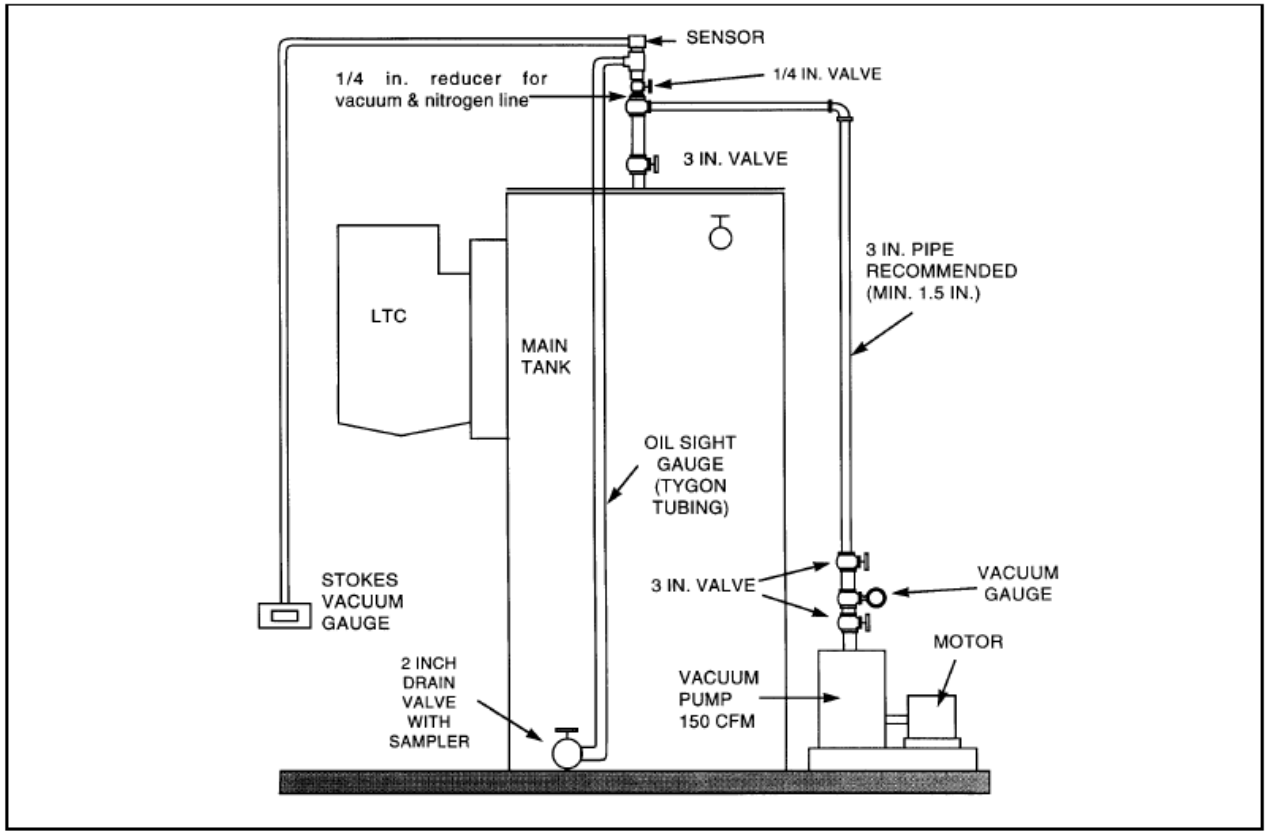


Figure 5-1. Typical piping arrangement for vacuum-filling.

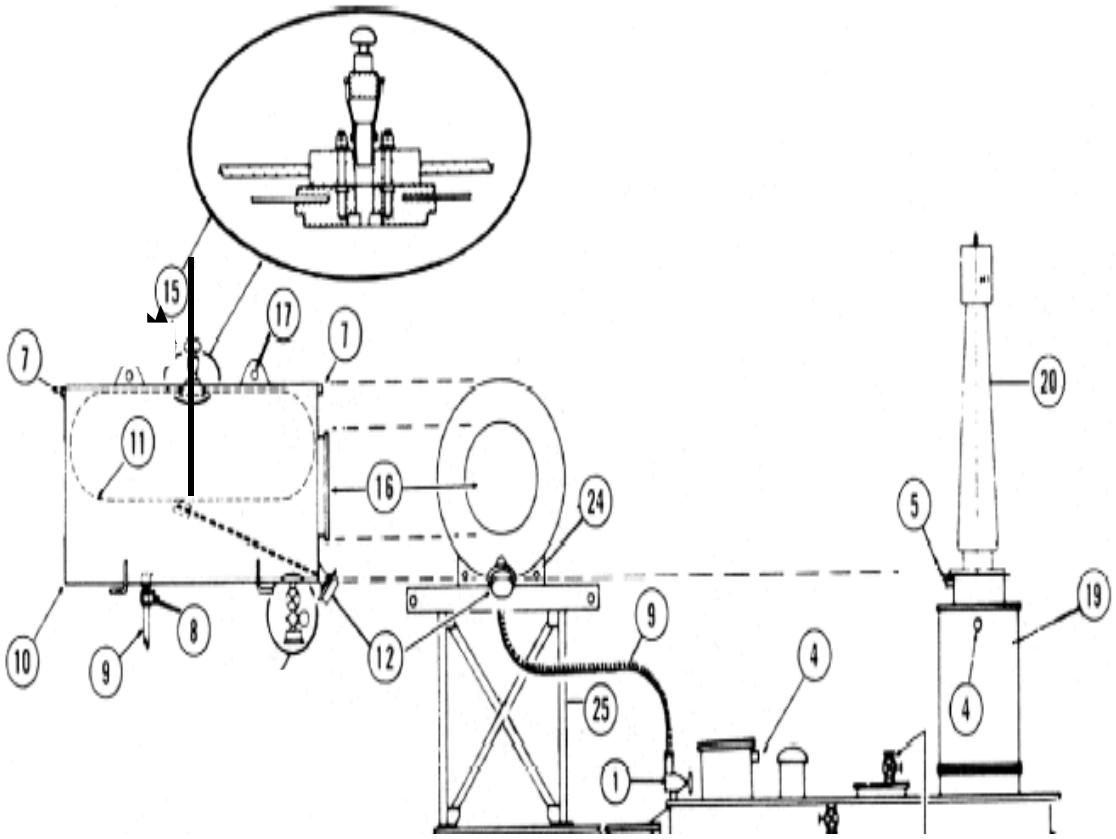
Oil Filling (cont.)

- When oil reaches 6” to 8” from cover, stop filling and isolate vacuum pump
- For sealed or nitrogen blanketed systems, displace vacuum with dry nitrogen
- For COPS* system, displace vacuum with dry gas or oil
- Fill COPS* system once tank pressure reaches slight positive pressure

**COPS = Conservator Oil Preservation System, often referenced as COPS tank*

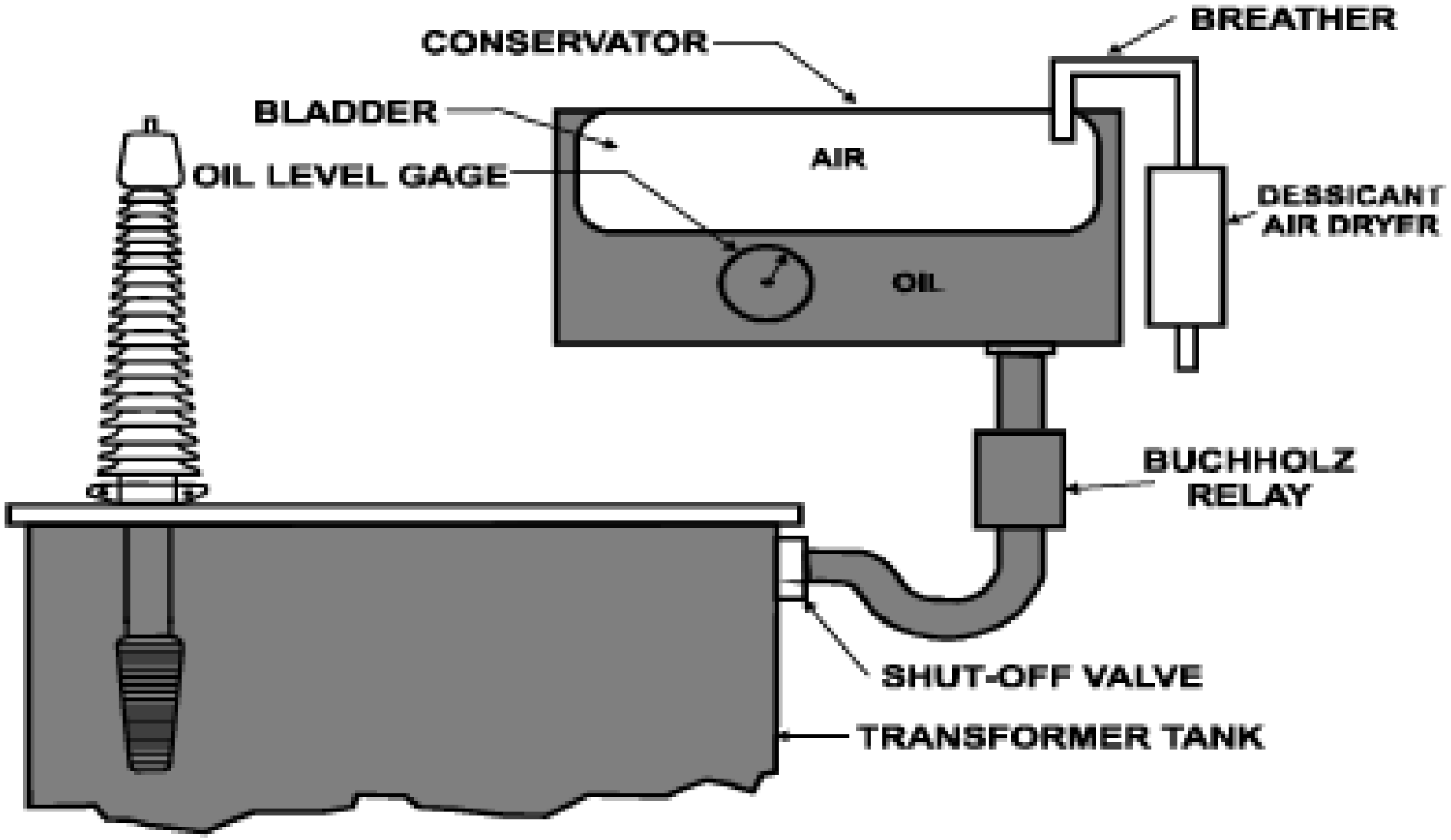
Vacuum Oil Filling

- For sealed or nitrogen blanketed systems, displace vacuum with dry nitrogen
- For conservator system, displace vacuum with dry gas or oil
- Fill conservator system once tank pressure reaches slight positive pressure

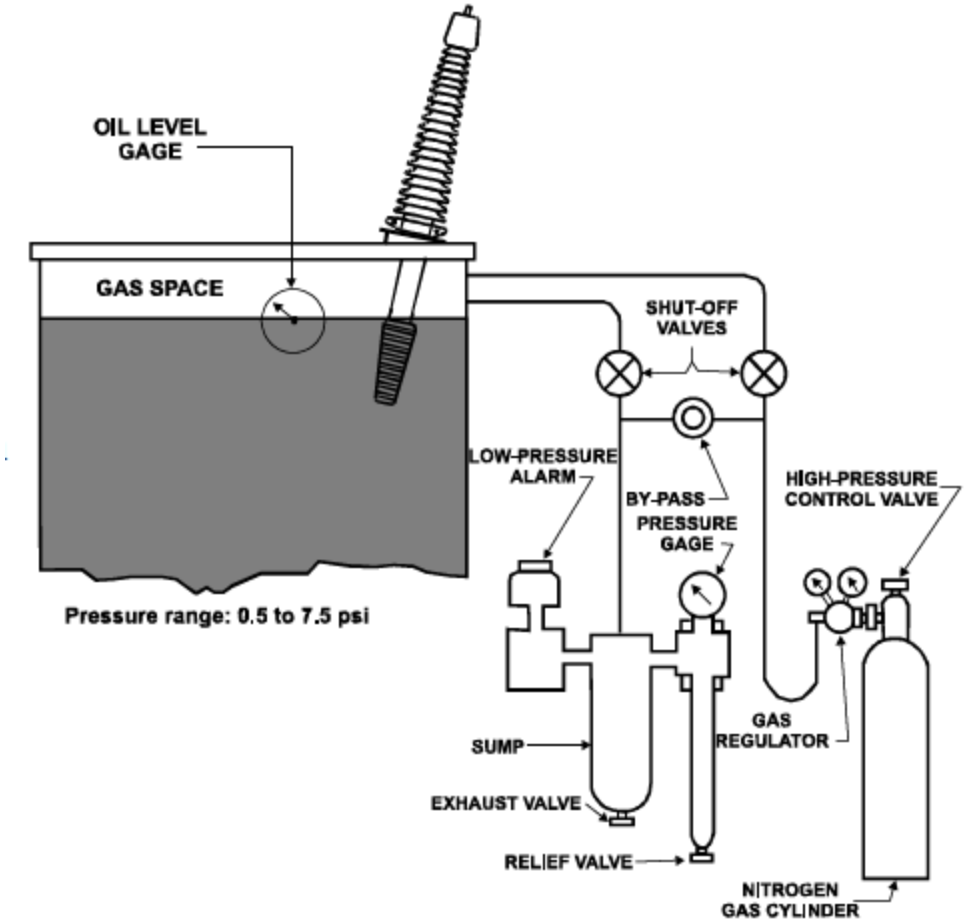


Vacuum Oil Filling

- Adjust oil level in accordance with OEM instructions for given average oil temperature
- If required by OEM specification, perform oil circulation process
- Bleed all vent locations and reactivate isolated devices
- Observe stand time
- Confirm oil quality

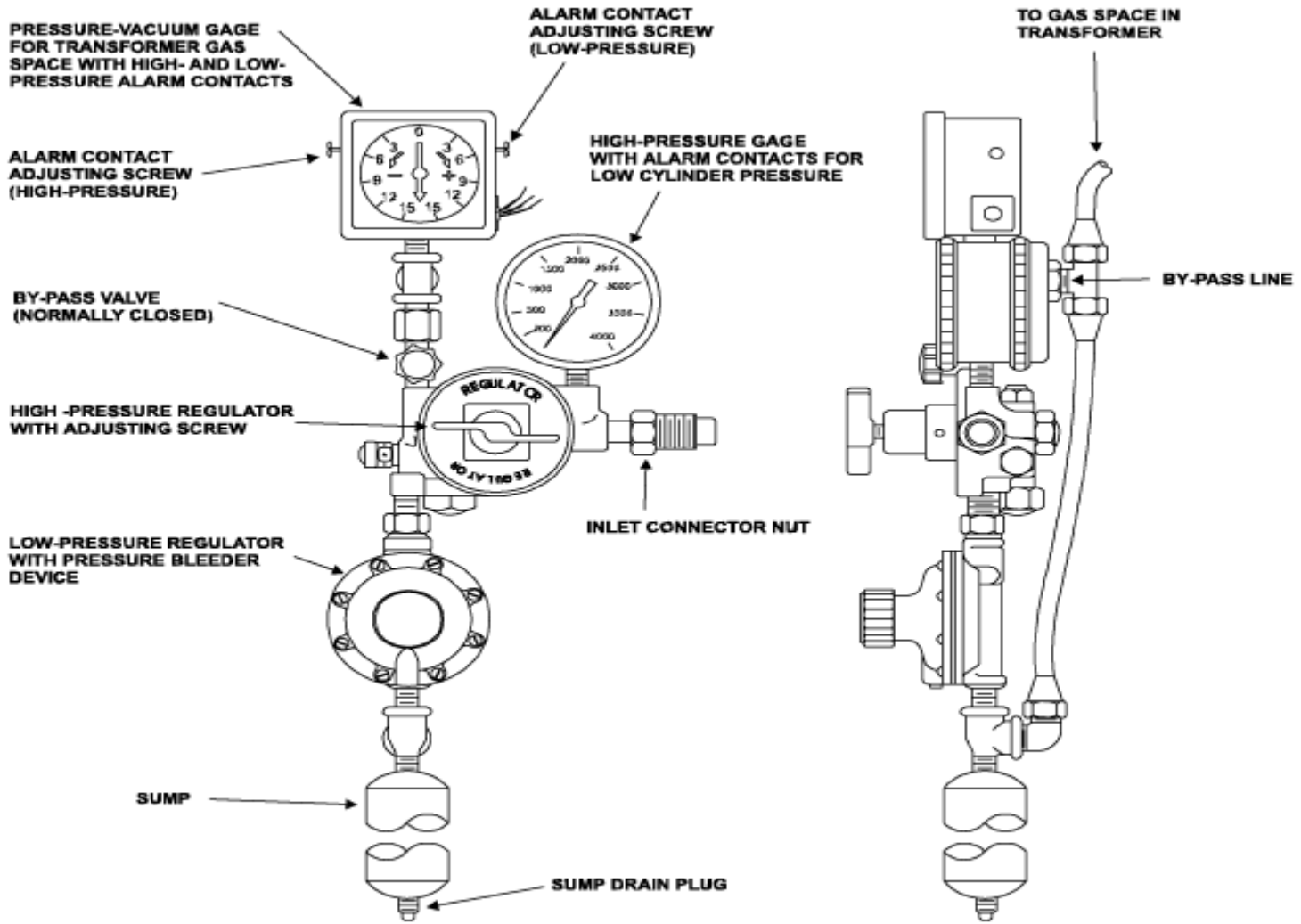

CONSERVATOR
BREATHER
BLADDER
AIR
OIL LEVEL GAGE
DESSICANT
AIR DRYER
OIL
BUCHHOLZ
RELAY
SHUT-OFF VALVE
TRANSFORMER TANK

Oil Filling (cont.)



Caution: When replacing nitrogen cylinders, do not just order a "nitrogen cylinder" from the local welding supplier. Nitrogen for transformers should meet ASTM D-1933 Type III with - 59 °C dew point as specified in IEEE C-57.12.00-1993, paragraph 6.6.3 [27, 2].

Oil Filling (cont.)



Oil Level Verification

N2 Blanketed Unit

OIL LEVEL BELOW TOP SURFACE OF THE HIGHEST POINT OF THE HIGHEST MANHOLE FLANGE AT 25°C IS 8.5 INCHES.
OIL LEVEL CHANGES 0.81 INCHES PER 10°C CHANGE IN OIL TEMPERATURE.
INHIBITED OIL 0.30 % DBPC
OPERATING PRESSURE OF OIL PRESERVATION SYSTEM IS 8 LBF/IN^2 POSITIVE TO 3.0 LBF/IN^2 NEGATIVE.
TANK DESIGNED FOR 10 LBF/IN^2 POSITIVE AND FULL VACUUM FILLING.
CONTAINS NO DETECTABLE LEVEL OF PCB (LESS THAN 1 PPM) AT THE TIME OF MANUFACTURE.
DESIGN ALTITUDE OF 3300 FEET AMSL.

Oil Level Verification

N2 Final Level

Oil Level Verification

Conservator Unit

MAIN TANK DESIGNED FOR 10 LBF/IN^2 POSITIVE AND FULL VACUUM FILLING.
CONSERVATOR TANK WITH AIR FILLED BLADDER NOT DESIGNED FOR FULL VACUUM.
OIL LEVEL CHANGES 2.9 INCHES PER 10°C CHANGE IN OIL TEMPERATURE.
INHIBITED OIL 0.30 % DBPC
LIQUID LEVEL 25 INCHES BELOW TOP OF CONSERVATOR BREATHER MOUNTING FLANGE AT 25°C.
CONTAINS NO DETECTABLE LEVEL OF PCB (LESS THAN 1 PPM) AT THE TIME OF MANUFACTURE.
DESIGN ALTITUDE OF 3300 FEET AMSL.

Oil Level Verification

Conservator Final Level

Oil Temperature Verification

Determining Average Oil Temperature

- Take oil temperature from liquid temperature gauge.
- Using infrared gun or tape on thermometer, record oil temperature at bottom of unit.
- Average the two readings.
- Determine correction factor measurement for each unit based on nameplate data as shown on previous slides.

NOTE:

- On the N2 unit, measure from the PRD to the top of the oil as indicated earlier.
- On the conservator unit, stick a dowel through the breather opening and determine where it lands on top of the bag which indicates oil level. Put a piece of tape on the dowel after calculating level.

Vacuum Filling Instructions

- Vacuum and oil filling is meant to be a continuous process
- If power interruption occurs during filling process, isolate transformer; after restoring power, you can resume process if vacuum level did not exceed 10 mm of hg, but if vacuum level exceeded 10 mm of hg, the transformer must be drained and process restarted
- If criteria is not met while filling, entire tank must be drained and process restarted beginning with dry vacuum
- Verify process in OEM manual in the event of process interruption

Field Acceptance Testing – Overview

- Power Factor Testing
- Transformer Turn Ratio
- Insulation Resistance
- Current Transformer Testing
- Excitation Testing
- Winding Resistance Testing
- Frequency Response Analysis
- Controls Testing
- Oil Testing

Suggested Test Sequence

Prior to Oil Filling

- Dew point
- Core megger
- TTR
- Bushing power factor
- CT ratio & polarity

After Oil Filling

- A/C test first
- D/C test last

Processed Oil in New Transformer

Test	Standard	Unit	Voltage	Value
Dielectric Breakdown	ASTM-D1816 w/ 1mm gap	min, kV	< 69 kV	25
			> 69 - <230 kV	30
			> 230 kV	35
Neutralization Number	ASTM-D974	max, mg KOH/g	< 69 kV	0.03
			> 69 - <230 kV	0.03
			> 230 kV	0.03
Interfacial Tension	ASTM-D971	min, Dynes/cm	< 69 kV	38
			> 69 - <230 kV	38
			> 230 kV	38
Moisture Content	ASTM-D1533	max, PPM @ 60°C Avg. Oil Temp.	< 69 kV	20
			> 69 - <230 kV	10
			> 230 kV	10
Power Factor	ASTM-D924	max, % @ 25°C	< 69 kV	0.05
			> 69 - <230 kV	0.05
			> 230 kV	0.05

Take baseline DGA prior to energization

Field Acceptance Testing

Test	Type of Faults Detected	Good	Caution	Concern
Bushing Power Factor (% at 20°C)	Bushing insulation defect	<0.5%	0.5%-1%	>1%
Bushing Capacitance	Shorted condenser or test tap problems	<10% change from baseline		>10% change from baseline
Winding Power Factor (% at 20°C)	Defects in winding insulation or moisture	<0.5%	0.5%-1%	>1%
Winding Capacitance	Winding deformation / Open core ground	<10% change from baseline		>10% change from baseline
Leakage Reactance/LV Impedance	Winding deformation / Through fault damage	<3% change from baseline		>3% change from baseline
Transformer Turns Ratio	Open or shorted windings / improper polarity	< 0.5% standard deviation		>0.5% standard deviation
Winding Insulation Resistance (20°C)	Defects in winding insulation or moisture	> 1000 MΩ		< 1000 MΩ
DC Winding Resistance	Poor connections - winding, bushings, tap changer	<2% phase to phase deviation	2-5% phase to phase deviation	>5% phase to phase deviation
Winding Excitation	Core problems /shorted turns	<10% change from baseline		>10% change from baseline
Core Insulation Resistance (20°C)	Shorted core/damaged core insulation	> 100 MΩ		< 100 MΩ

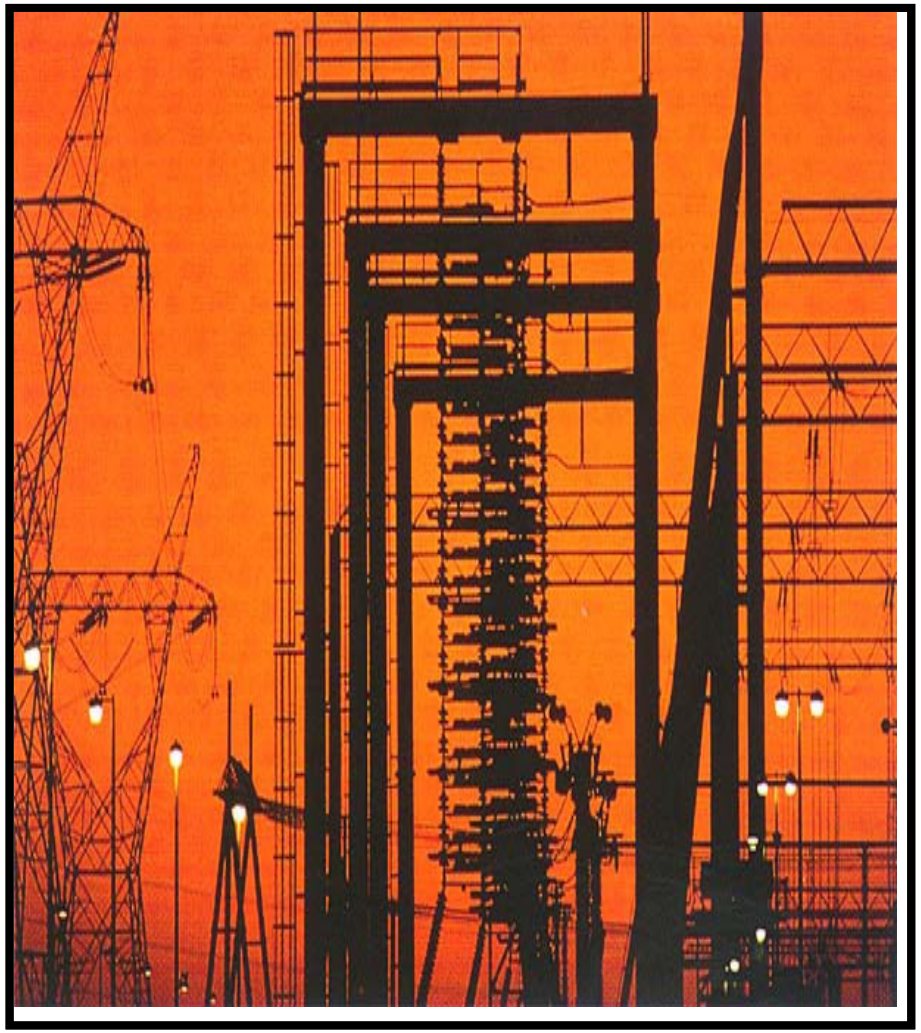
Energization Procedures

- Prior to energizing transformers, verify the following
  - Electrical and oil tests have been complete and have met minimum standards
  - Stand time after oil filling has been met
  - Cooling controls have been set to automatic operation
  - All temporary grounds and shorting wire have been removed
- Energize the transformer with no load from either the high voltage or low voltage side. If possible, it is recommended that voltage be raised in increments.
- Based upon primary voltage class, IEEE recommends a soak period before an operator begins to pick up load on a transformer.

Voltage Class	Suggested Minimum Energizing Period (hours)
230 ≥ 800 kV	12
0 < 230 kV	8

Source: IEEE C57.93-2019

Energization Procedures



- **During the energization period without load, it is recommended that close observation of the transformer be made.**
  - Excessive audible noise
  - Check of liquid temperatures, winding temperatures, and ambient temperature
  - Check of tank pressure
  - Check of oil level indicators
  - Check of gas detector relay.
- **Within the first month of operation, a DGA sample should be taken for baseline analysis**

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Questions?

Thank you!

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