GENERAL MAINTENANCE, LIFE EXTENSION CONSIDERATIONS & SPARE TRANSFORMER MANAGEMENT

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Agenda

1. Life of a Transformer
2. Maintenance
3. Spare Transformer Management
4. Life Extension Considerations

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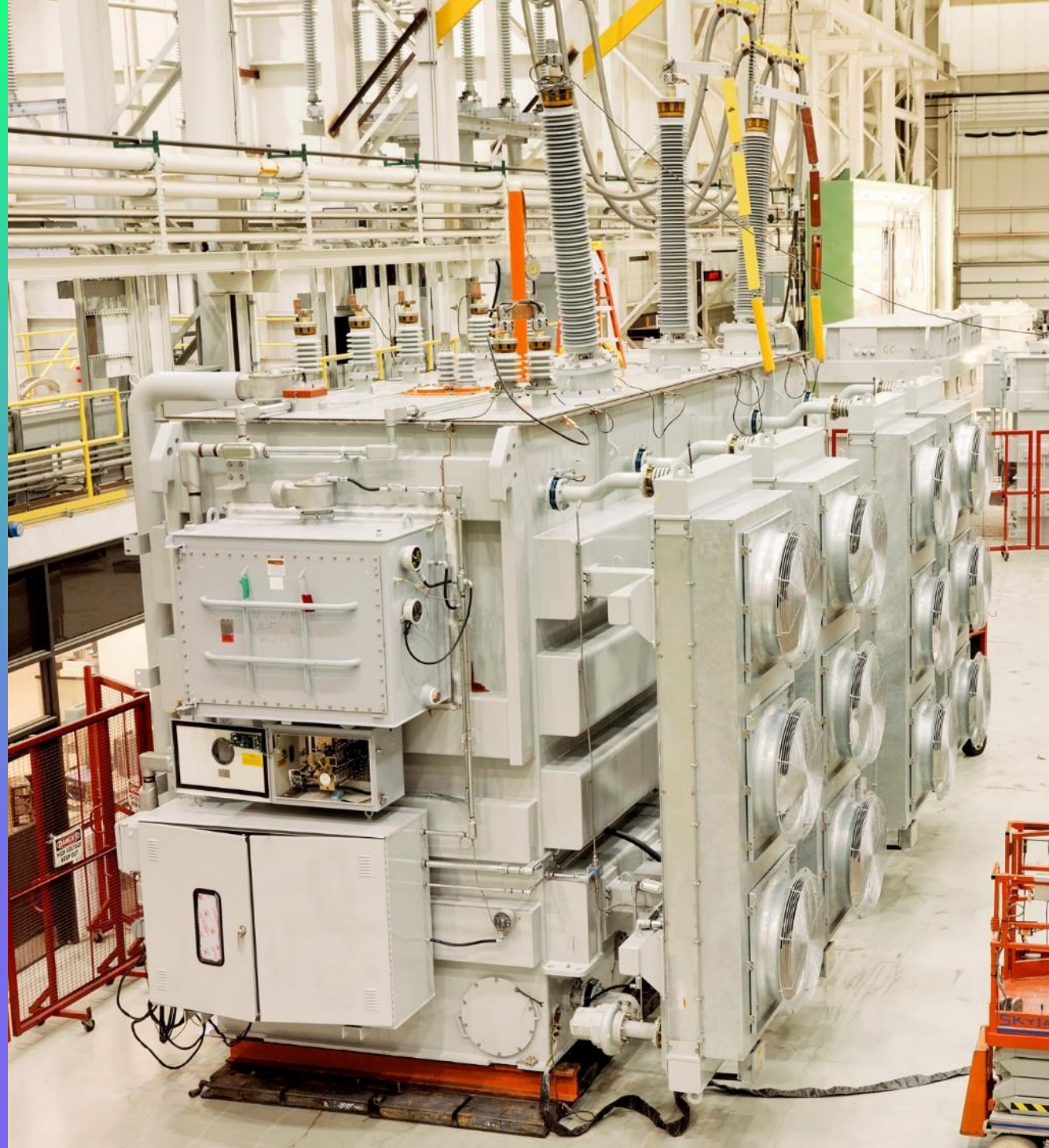
Life of a Transformer



Life of a Transformer

$$Life = \exp\left(\frac{15000}{HST + 273} - 27.604\right)$$

Where, Life = Life in hours at temperature HST
HST = Hot Spot Temperature in °C

Theoretical Life

Aging of insulation materials is caused by

- Moisture
- Oxygen
- Temperature
- Time

Proper application of oil preservation systems and maintenance can minimize the moisture and oxygen content

Cooling system is critical to operating temperatures

Life of a Transformer

$$Life = \exp\left(\frac{15000}{HST + 273} - 27.604\right)$$

Where, Life = Life in hours at temperature HST
HST = Hot Spot Temperature in °C

If this is the equation for transformer life, all we need to do is control hot spot temperature, right?

Why do transformers fail?

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Insulation Aging Estimates

Insulation Aging & Expected Life

Table 2—Normal insulation life of a well-dried, oxygen-free 65 °C average winding temperature rise insulation system at the reference temperature of 110 °C

Basis	Normal insulation life	
	Hours	Years
50% retained tensile strength of insulation (former IEEE Std C57.92-1981 criterion)	65 000	7.42
25% retained tensile strength of insulation	135 000	15.41
200 retained degree of polymerization in insulation	150 000	17.12
Interpretation of distribution Transformer functional life test data (former IEEE Std C57.91-1981 criterion)	180 000	20.55

NOTES:
1 — Tensile strength or degree of polymerization (D.P.) retention values were determined by sealed tube aging on well-dried insulation samples in oxygen-free oil.
2 — Refer to I.2 in annex I for discussion of the effect of higher values of water and oxygen and also for the discussion on the basis given above.

IEEE Loading Guide C57.12.90-1995

Theoretical Aging Calculation

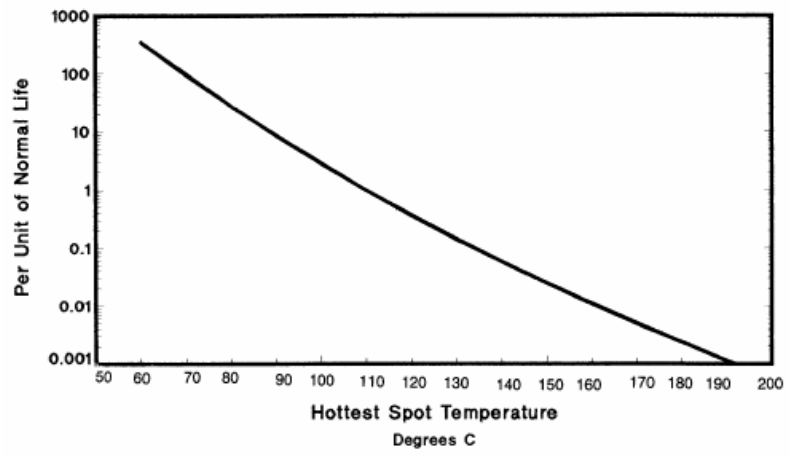


Figure 1—Transformer insulation life

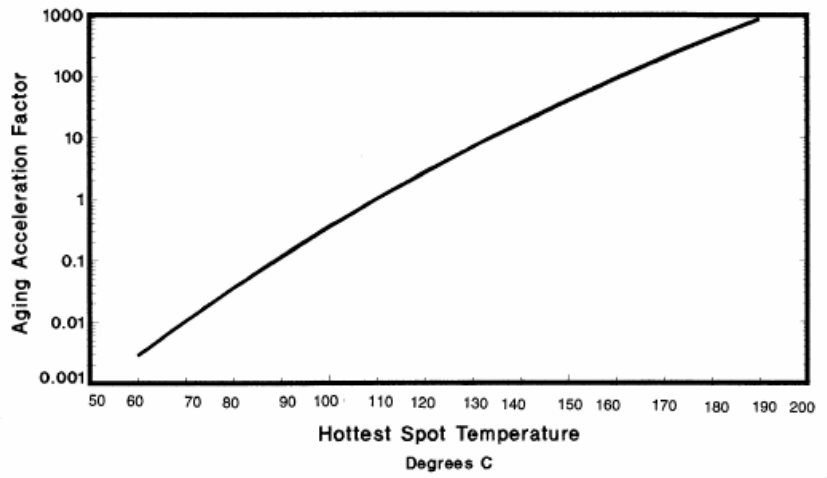


Figure 2—Aging acceleration factor (relative to 110 °C)

Table 1—Aging acceleration factor

Temperature °C	Age factor	Temperature °C	Age factor	Temperature °C	Age factor
<37	0.000 0	65	0.005 4	94	0.181 3
37	0.000 1	66	0.006 2	95	0.202 6
38	0.000 1	67	0.007 1	96	0.226 3
39	0.000 1	68	0.008 0	97	0.252 6
40	0.000 2	69	0.009 1	98	0.281 7
41	0.000 2	70	0.010 4	99	0.314 1
42	0.000 2	71	0.011 8	100	0.349 9
43	0.000 2	72	0.013 4	101	0.389 7
44	0.000 3	73	0.015 2	102	0.433 7
45	0.000 3	74	0.017 2	103	0.482 3
46	0.000 4	75	0.019 5	104	0.536 2
47	0.000 4	76	0.022 0	105	0.595 7
48	0.000 5	77	0.024 9	106	0.661 4
49	0.000 6	78	0.028 I	107	0.734 0
50	0.000 7	79	0.031 8	108	0.814 2
51	0.000 8	80	0.0358	109	0.902 6
52	0.000 9	81	0.0404	110	1.000 0
[illegible]	[illegible]001 1	82	0.[illegible]55	111	1.10[illegible]

Theoretical Aging Calculation

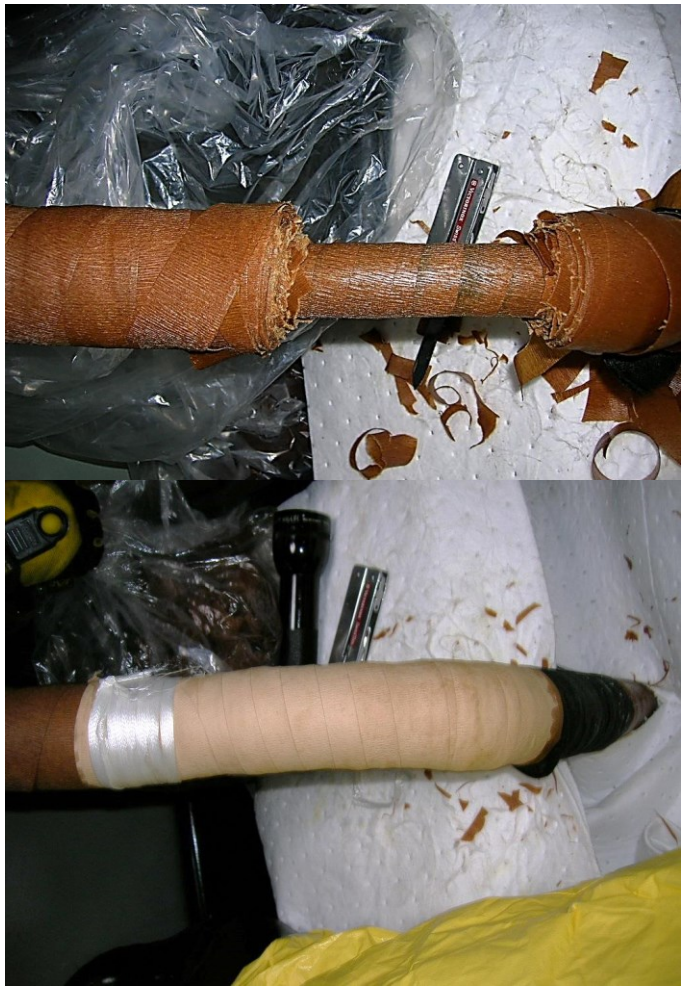
- Service Age
- Hot Spot Temperature
  - Real time recording
  - Loading profile
  - Approximation from ambient, average winding rise and hot spot gradient
- Aggregate Aging Factor
- Moisture Content Consideration

UNIT DESIGNATION	SERIAL NUMBER	Estimated Time in Service, Hours
TB	7001535	376,680

Avg. Ambient Temp (°C)	Avg. Ambient Temp (°F)	Number of Hours/Year	Est. Hot Spot Temp (°C)	Aging Factor
< 5	< 41	0	<75	0.0195
5 to 10	41-50	0	75-80	0.0358
10 to 15	51-59	3624	80-85	0.0649
15 to 20	60 to 68	4416	85-90	0.1156
20 to 25	69 to 77	720	90-95	0.2026
25 to 30	78 to 86	0	95-100	0.3499
30 to 35	87- 95	0	100-105	0.5957
		8760	Total	
		Avg. Aging Factor		0.1018
		Water Content Factor		1.5000

UNIT DESIGNATION	SERIAL NUMBER	Total Time in Service	Aging Hours	Percent Loss of Life*
TB	7001535	376,680	57,506	38.34%

Insulation Aging - DP



Degree of Polymerization

- Test Method is ASTM-4243
- New insulation measures 1000-1200
- End of life considered to be 200
- Direct measure of insulation aging.
- Paper is most aged at the hot spot location.
- Often impractical to retrieve sample from optimal location.

Theoretical Aging vs. Direct Measurements

SPX Transformer Solutions Inc
47300 KATO RD

FREEMONT, CA 94538 US
ATTN: STEPHEN COOLEY
PO#: 120954
Project ID:
Customer ID: SVPNRS/SPX

Serial#: 7001535
Location: SANTA CLARA CA
Equipment: TRANSFORMER
Compartment: MAIN(BOTTOM)
Breathing:
Bank: **Phase:**
Fluid: PAPER

Mfr: WESTINGHOUSE
kV:
kVA:
Year Mf'd:
Syringe ID:
Bottle ID:
Sampled By: LE

Control#: 6637092
Order#: 439523
Account: 3292
Received: 03/19/2014
Reported: 03/28/2014
INNER LAYER

Lab Control Number:	6637092
Date Sampled:	03/18/2014
Order Number:	439523
Oil Temp:	
Degree of Polymerization	
D-4243[5] **Average Degree of Polymerization (DPv):** (most recent sample)	655

Diagnostic Statement:

New insulation with a high degree of mechanical strength will typically have a Degree of Polymerization (DP) of 1000-1300. "Middle Aged" paper is approximately 500 and paper with less than 250 is in its "Old Age." Severely degraded insulation with a DP of 150 or less will have very little mechanical strength and may result in a transformer failure. The above estimations are based on a study by Chendong of GSU transformers filled with mineral oil.

Comment:

Challenges with Direct Measurement:

- Sample location often not at point of most severe aging(hot spot).
- Sample extraction in invasive and difficult to obtain.

Theoretical Aging vs. Indirect Measurements

	Serial#:	7001535	**Mfr:**	WESTINGHOUSE	**Control#:** 6637526
FIELD SERVICES	**Location:**	SANTA CLARA CA MAIN TANK	**kV:**		**Order#:** 439644
P.O. BOX 268	**Equipment:**	TRANSFORMER	**kVA:**		**Account:** 616
GOLDSBORO, NC 27533 US	**Compartment:**	MAIN(BOTTOM)	**Year Mf'd:**		**Received:** 03/21/2014
ATTN: STEVE CHICKI	**Breathing:**	SEAL	**Syringe ID:**	17642	**Reported:** 03/25/2014
PO#: BLANKET	**Bank:**	**Phase:**	**Bottle ID:**		
Project ID: 120954	**Fluid:** MIN		**Sampled By:**		

Furanic Compound	**2-Furaldehyde (ppb):**	< 10
D-5837	**5-Hydroxy-methyl-furaldehyde (ppb):**	< 10
	2-Acetylfuran (ppb):	< 10
	5-Methyl-2-furaldehyde (ppb):	< 10
	2-Furyl alcohol (ppb):	< 10

Furanic Compound Diagnostics (most recent sample):

New insulation with a high degree of mechanical strength will typically have a Degree of Polymerization (DP) of 1000-1300. "Middle Aged" paper is approximately 500 and paper with less than 250 is in its "Old Age." Severely degraded insulation with a DP of 150 or less will have very little mechanical strength and may result in a transformer failure. The above estimations are based on a study by Chendong of GSU transformers filled with mineral oil.

Estimated Average Degree of Polymerization (DP): >1003

Estimated Operating Age of the Equipment: <1.0

Notations:

Comment:

Challenges with Indirect Measurement:

- Oil maintenance/processing or replacement will remove aging compounds.
- Must track cumulative effects of aging between maintenance cycles.

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Moisture Content

How do we estimate water content?

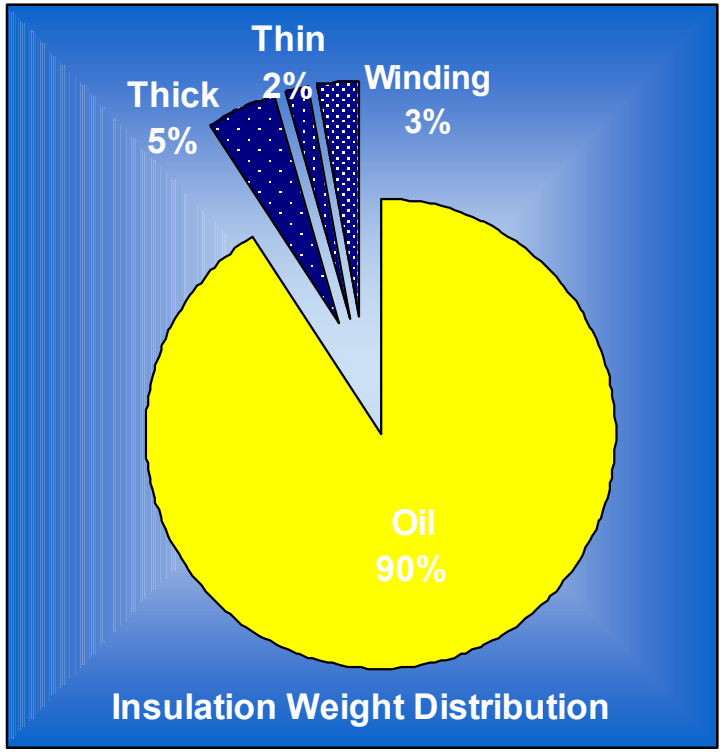
Dew point

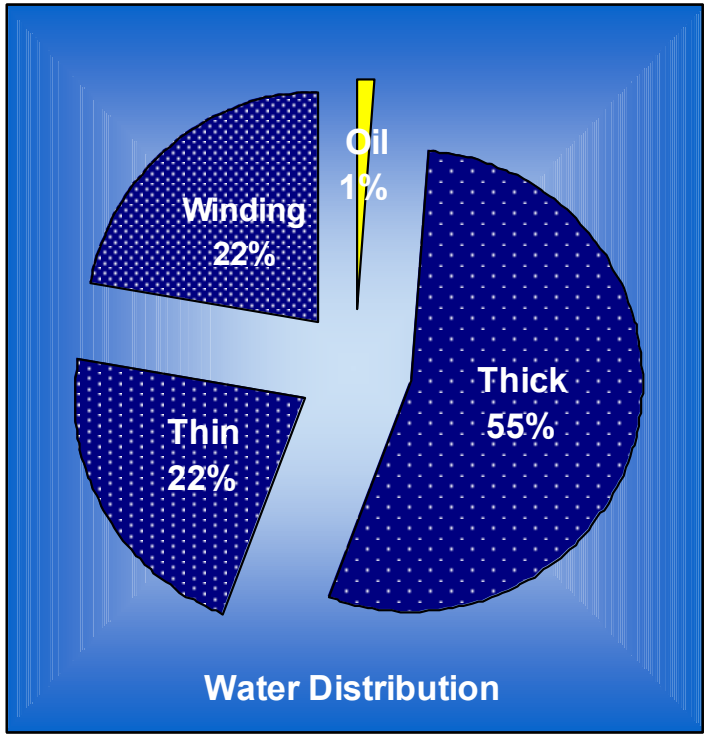
Moisture Equilibrium Curves

Power Factor

Recovery Voltage Method

Water in Transformers





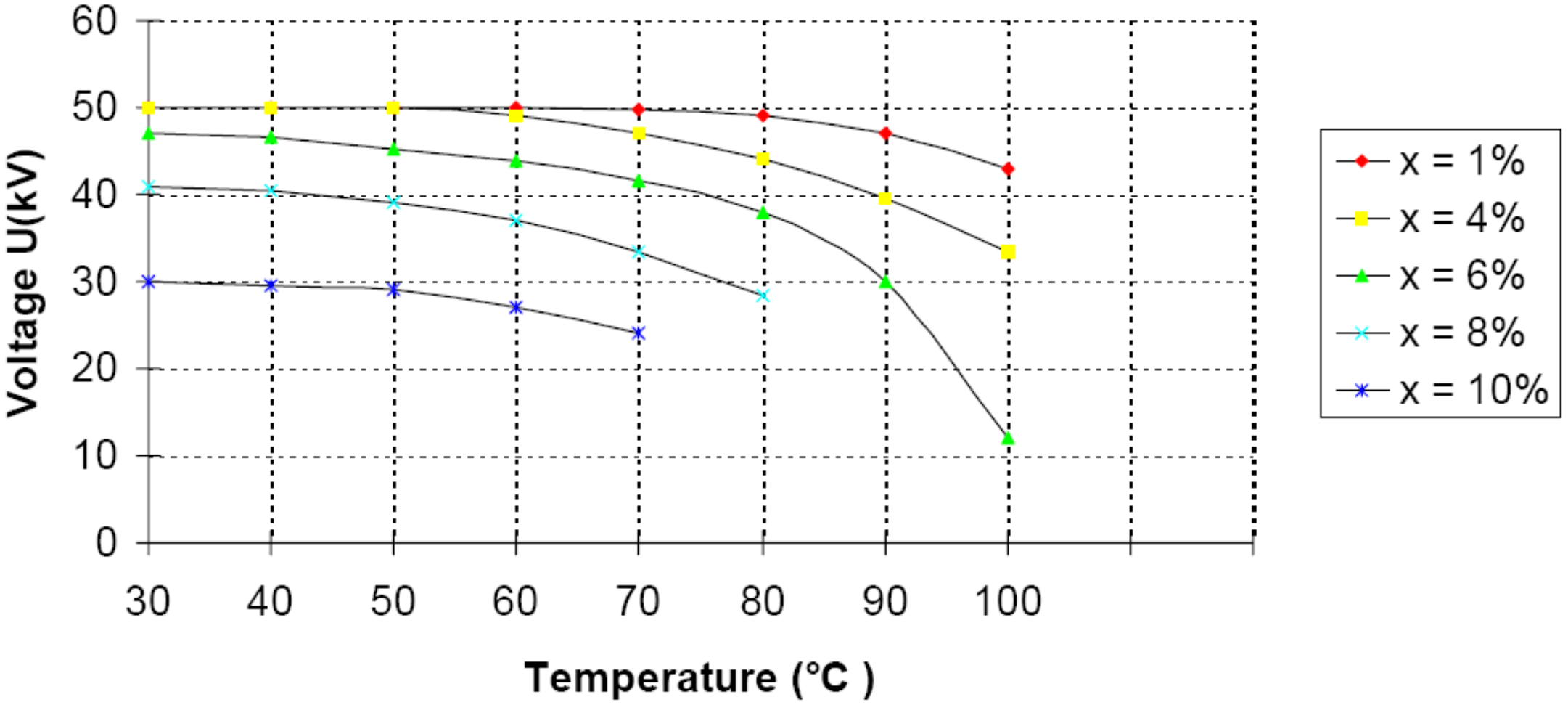
Source: J. Aubin, 2005 Weidmann-ACTI Conference, San Antonio, TX

Water in Transformers

Temperature (degrees C)	Water in Oil	Water in Paper
20°	1	3,000 times what is in the oil
40°	1	1,000 times what is in the oil
60°	1	300 times what is in the oil

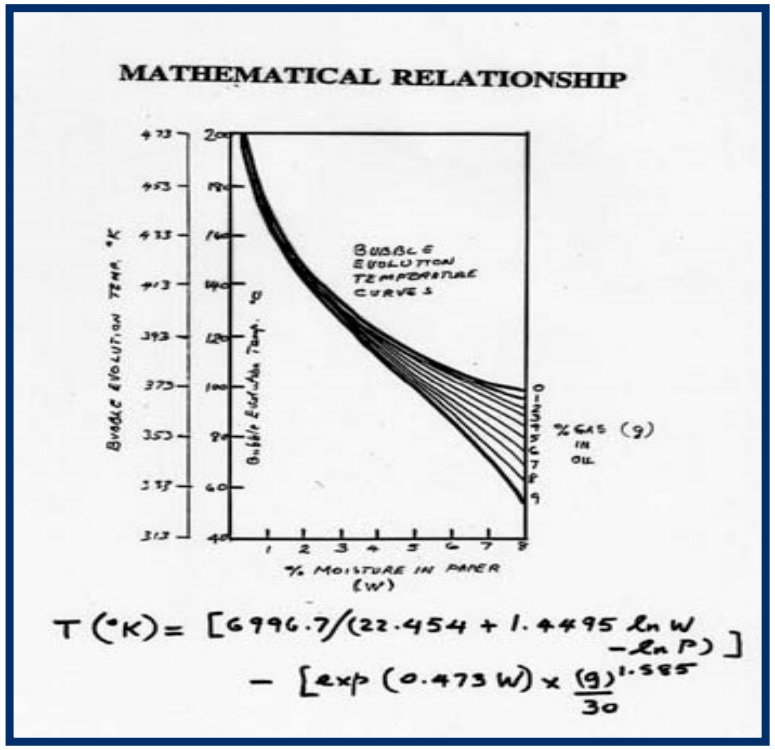
The table above shows the tremendous attraction that paper insulation has for water. The ppm of water in oil shown in the DGA is only a small part of the water in the transformer. It is important that, when an oil sample is taken, you record the oil temperature from the top oil temperature gage.

Effects of Moisture in a Transformer

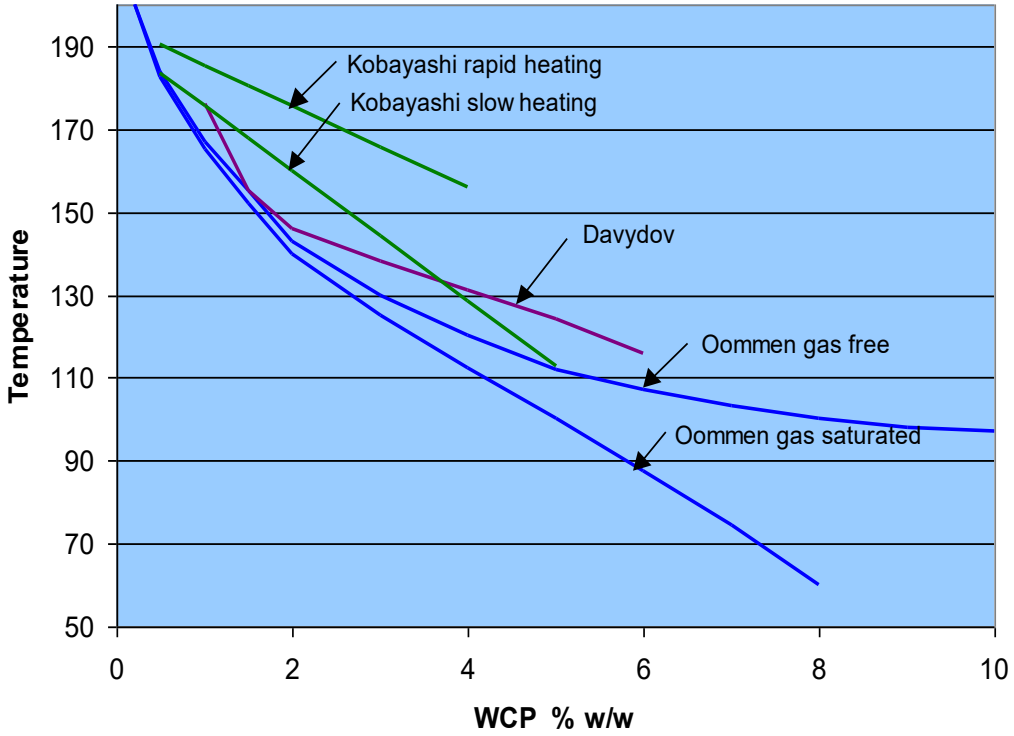


Effects of Moisture in a Transformer

Moisture lowers the lowest hot-spot temperature range for possible bubble formation.



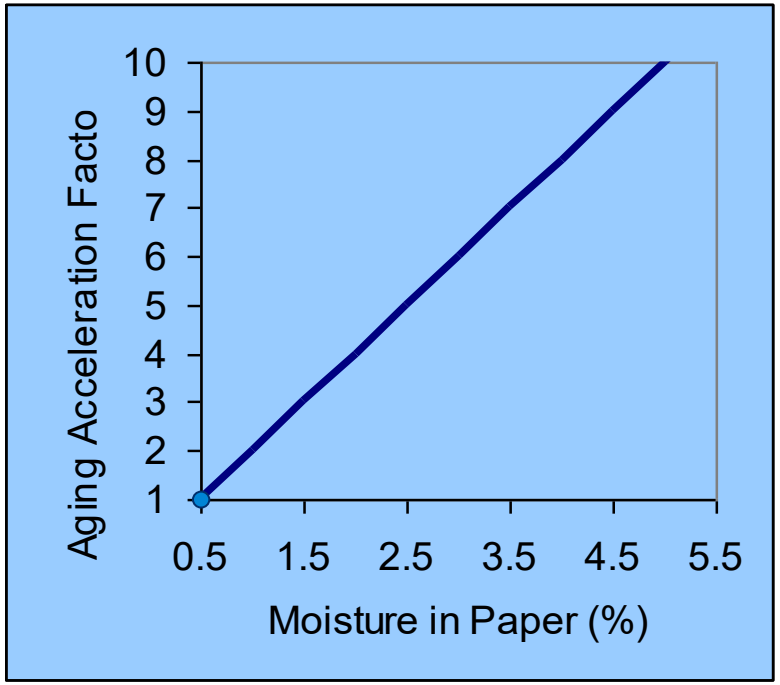
Source: TV Oommen, EPRI Reports:
EL-6761, March 1990; EL-7291, March 1992



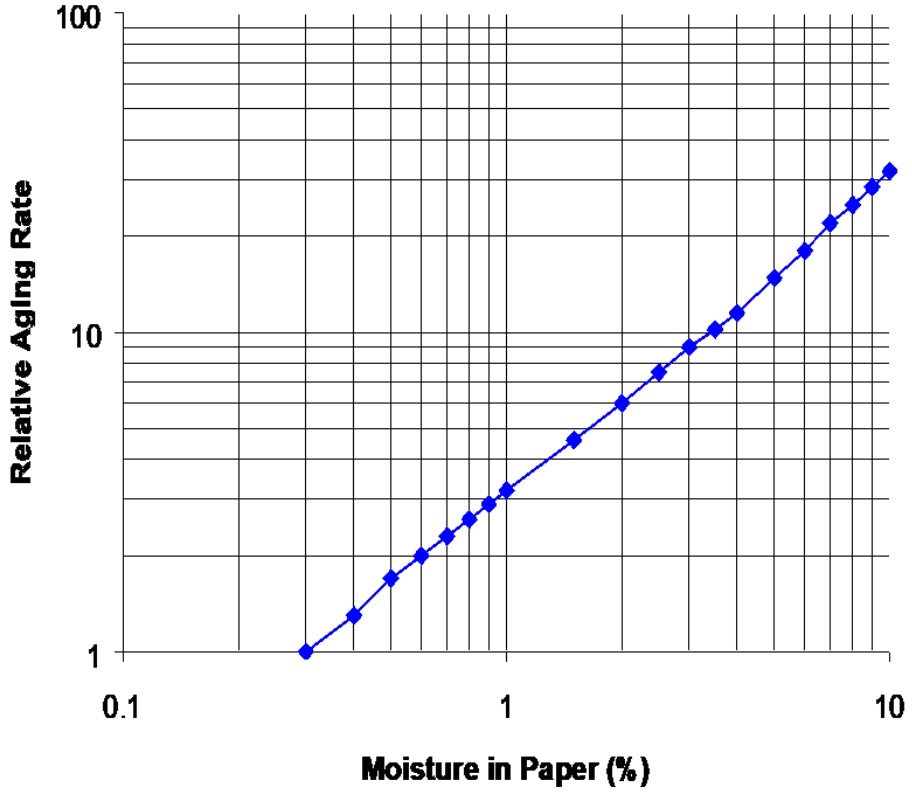
Comparison of “critical” bubble temperature vs. water content in paper by three researchers

Effects of Moisture in a Transformer

Moisture accelerates thermal aging of paper insulation.



IEEE Std C57.91-1995



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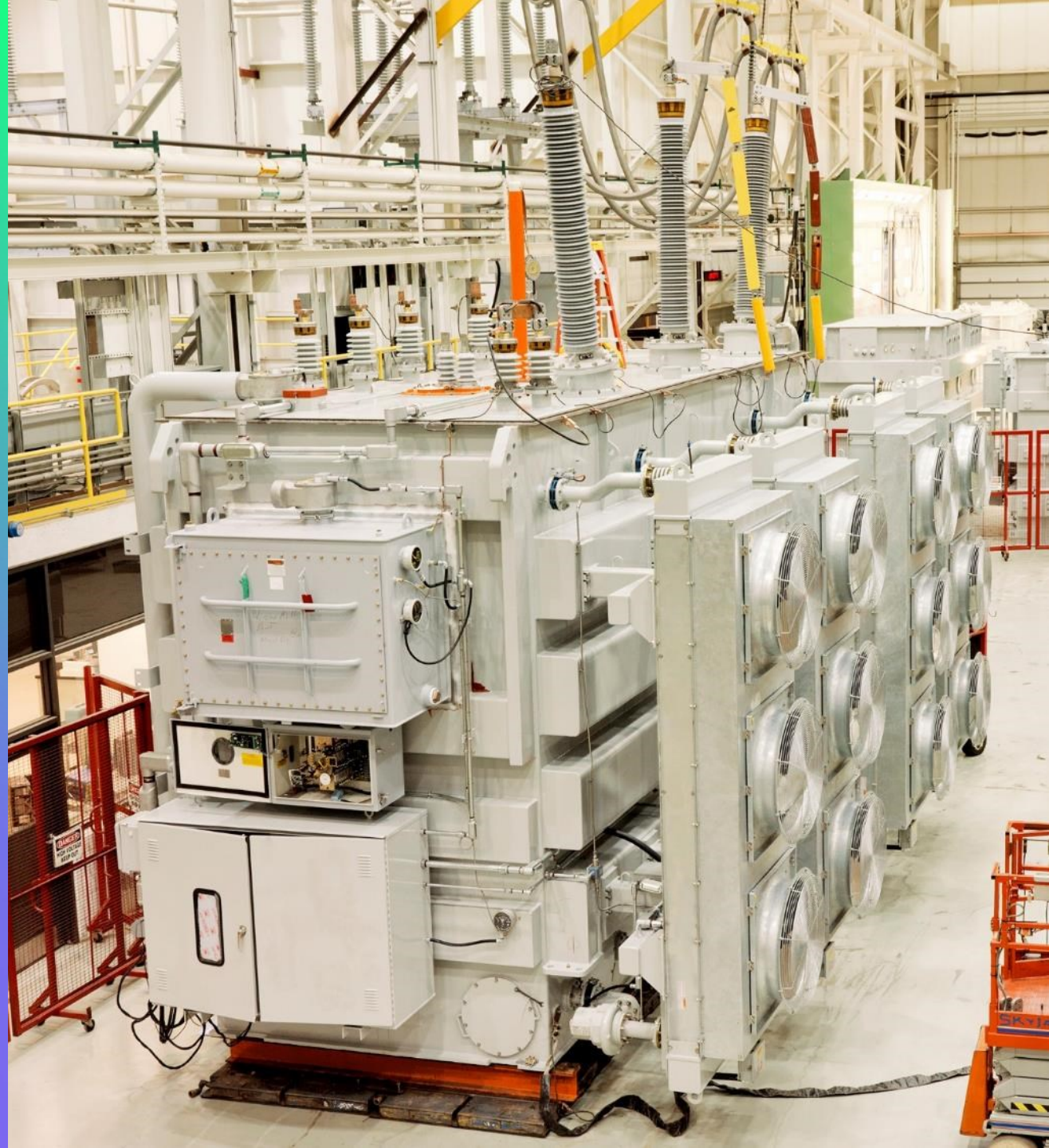
Maintenance



3 Biggest Enemies of a Transformer

- Heat
- Water
- Oxygen

Maintenance

Extending the functional life of the transformer involves many activities:

- Control Of Aging Factors
  - Oil Quality
  - Cooling
  - Oil Preservation System
- Monitoring

Reactive vs. Proactive

Preventative Maintenance Program

Key Items:

Maintaining Cooling System

Maintaining Leak Free Unit

Monitoring

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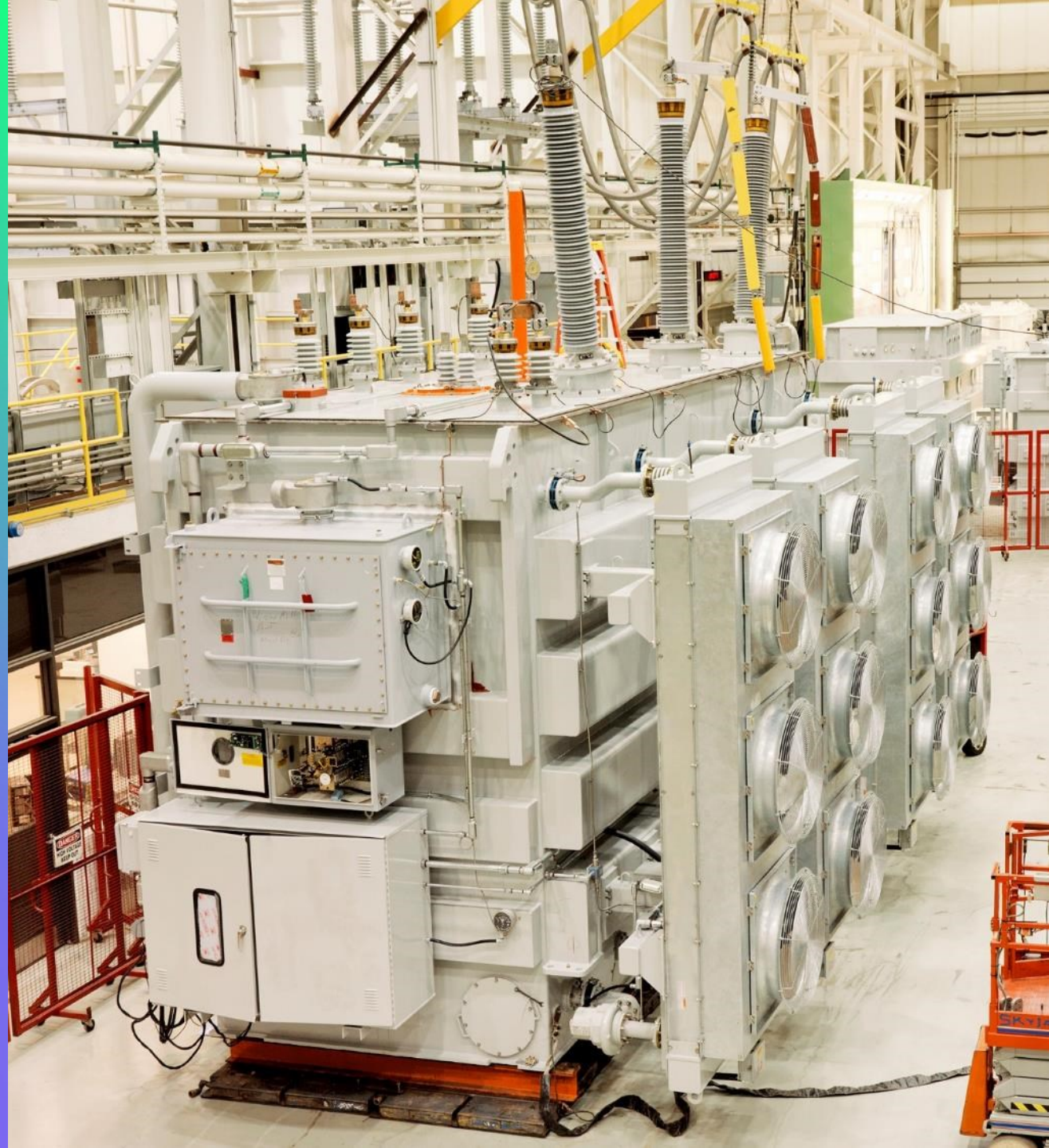
Visual Inspections



Visual and Mechanical Inspection

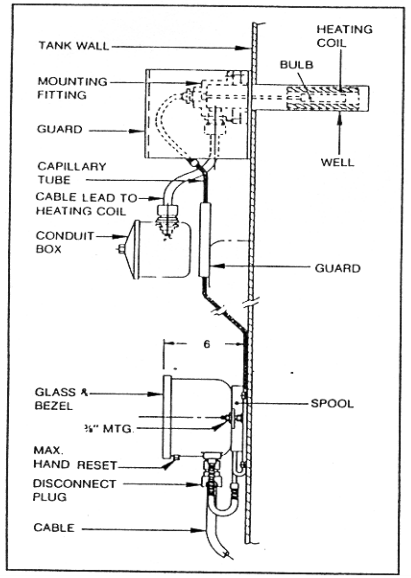
- Inspect physical and mechanical condition
- Verify that alarm, control, and trip settings on temperature indicators are as specified
- Verify that cooling fans and/or pumps operate correctly
- Verify operation of all alarm, control, and trip circuits from temperature and level indicators, pressure relief device, and fault pressure relay
- Inspect all bolted electrical connections for high resistance using a thermographic survey

Visual and Mechanical Inspection

- Verify correct liquid level in all tanks and bushings
- Verify that positive pressure is maintained on nitrogen-blanketed transformers
- Perform specific inspections and mechanical tests as recommended by the manufacturer
- Verify correct equipment grounding
- Verify the presence of transformer surge arresters

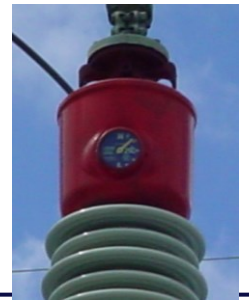
Transformer Maintenance – Inspection & Repair

- Gauges & Devices
  - Levels & Indicators *(Reset)*
    - Winding Temperature
    - Oil Levels
    - LTC Position(s)

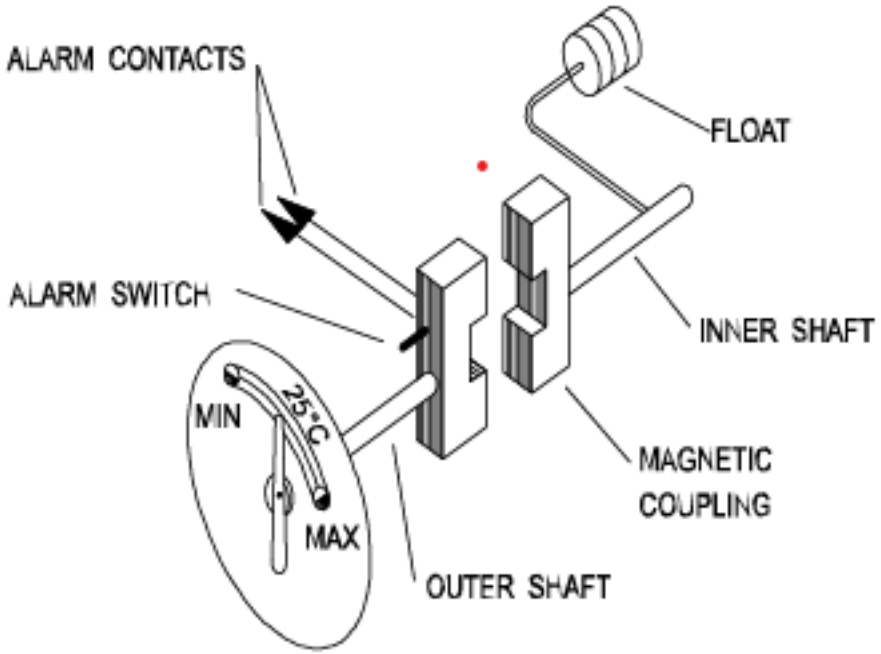


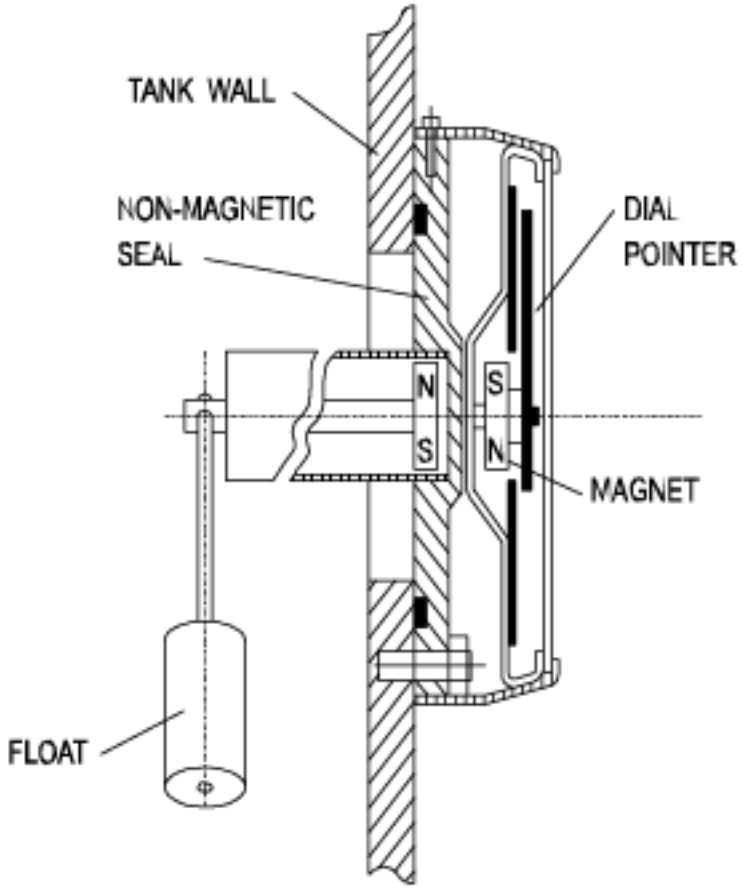
Transformer Maintenance – Inspection & Repair

- Gauges & Devices *(cont.)*
  - Alarms *(Indicators)*
  - Gas Accumulators
  - Bushing Sight Glasses

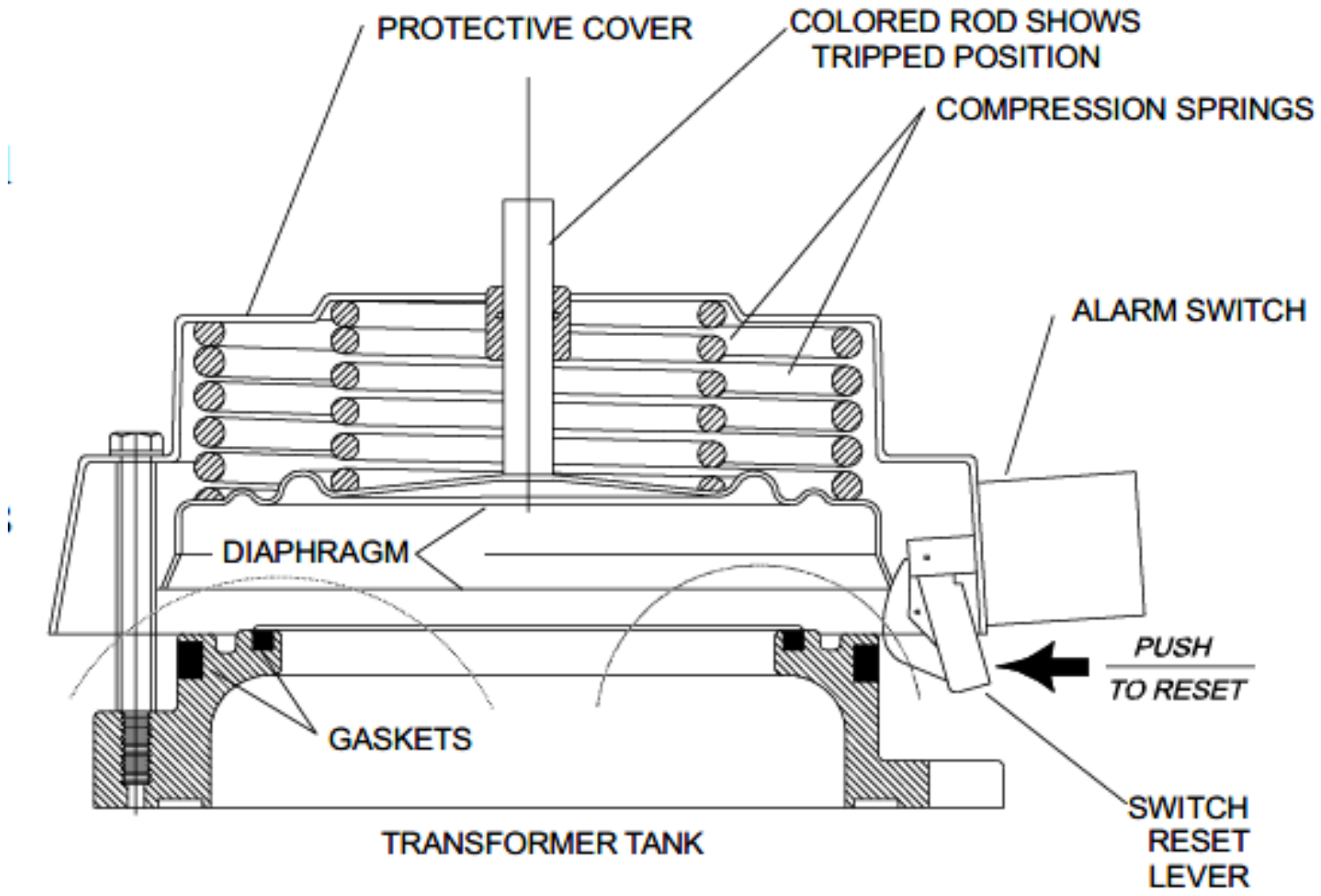


Devices

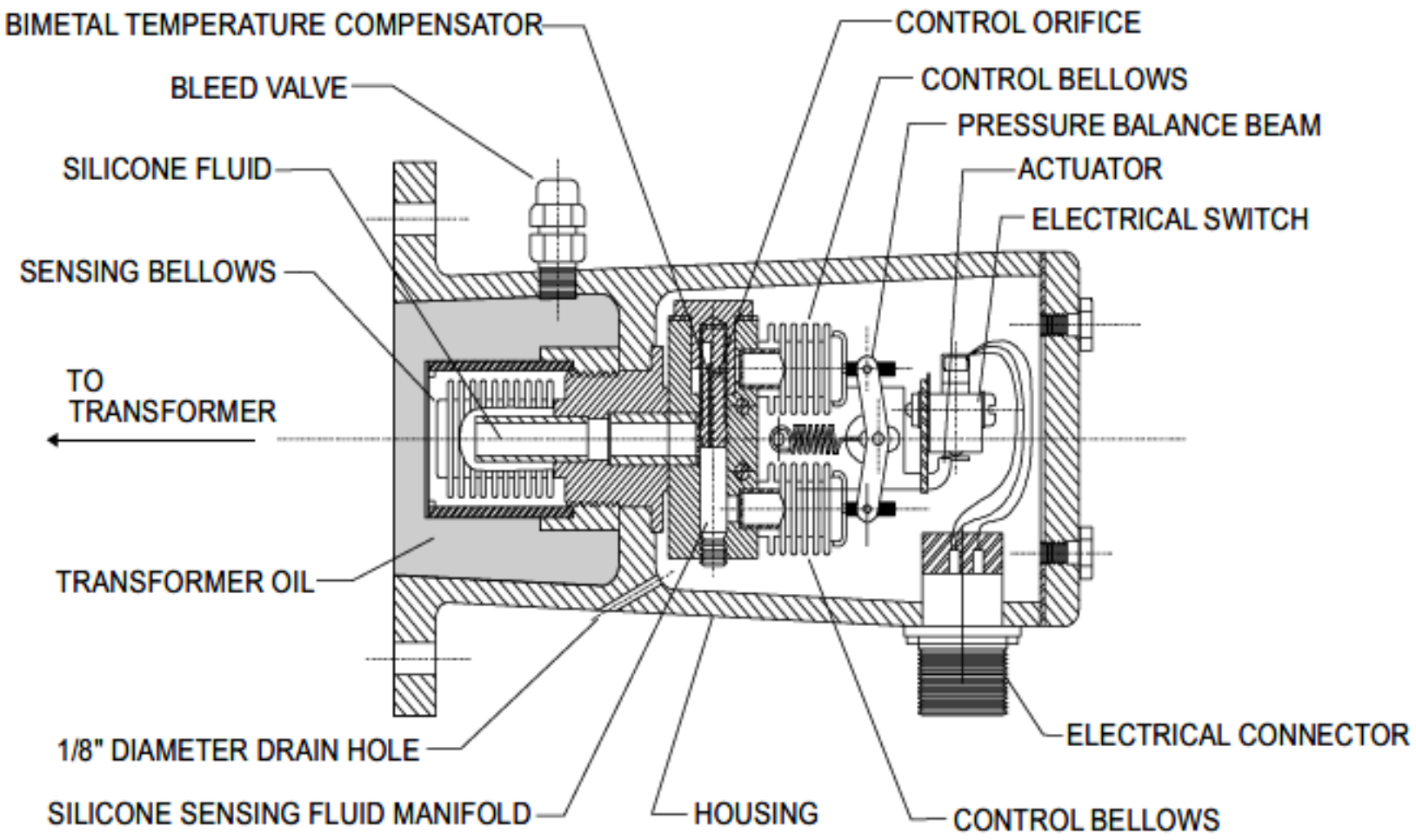

ALARM CONTACTS
FLOAT
ALARM SWITCH
INNER SHAFT
MIN
25°C
MAX
MAGNETIC
COUPLING
OUTER SHAFT


TANK WALL
NON-MAGNETIC
SEAL
DIAL
POINTER
N
S
S
N
MAGNET
FLOAT

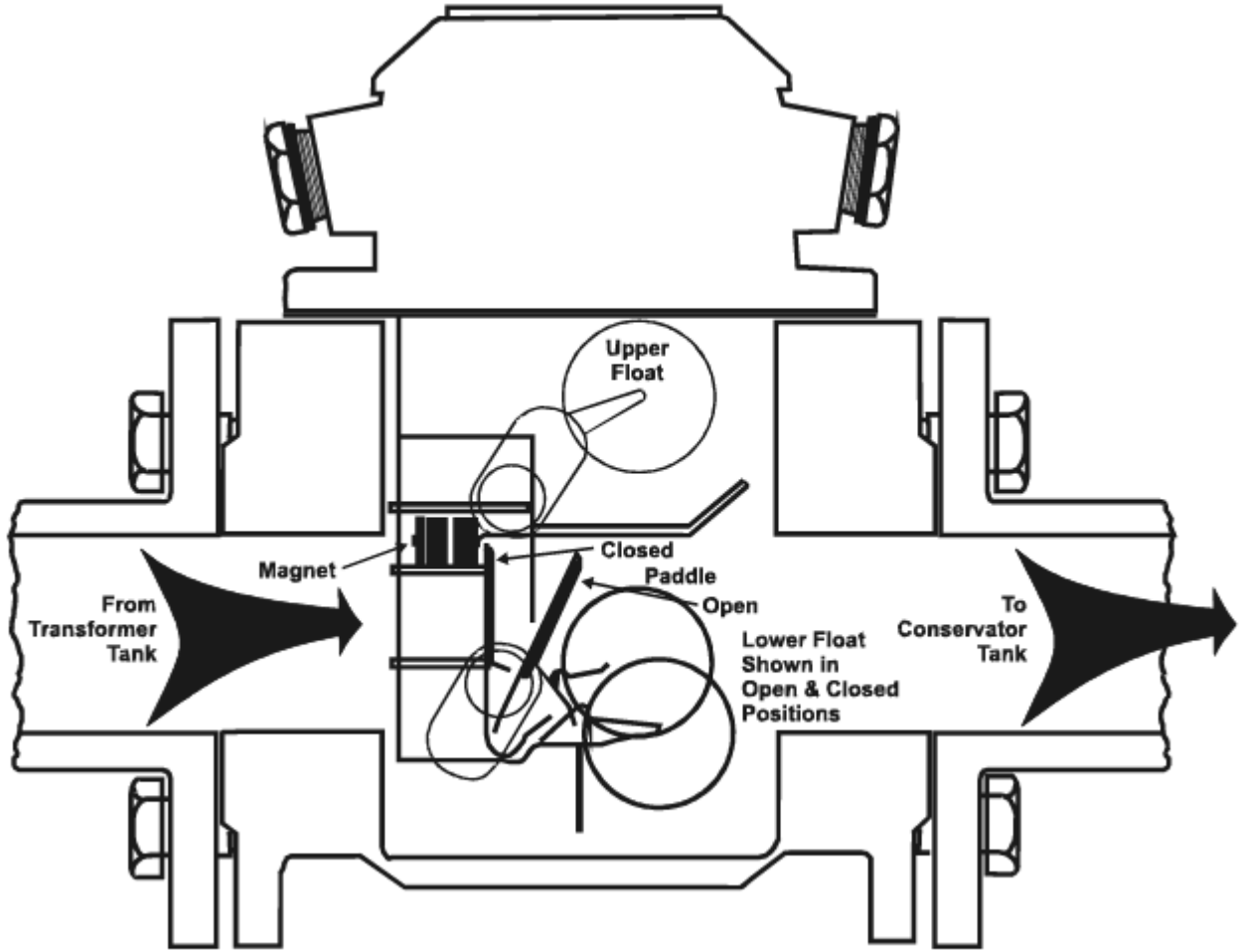
Devices


PROTECTIVE COVER
COLORED ROD SHOWS TRIPPED POSITION
COMPRESSION SPRINGS
ALARM SWITCH
DIAPHRAGM
PUSH
TO RESET
GASKETS
SWITCH RESET LEVER
TRANSFORMER TANK

Devices


BIMETAL TEMPERATURE COMPENSATOR
BLEED VALVE
SILICONE FLUID
SENSING BELLOWS
TO
TRANSFORMER
TRANSFORMER OIL
1/8" DIAMETER DRAIN HOLE
SILICONE SENSING FLUID MANIFOLD
HOUSING
CONTROL BELLOWS
CONTROL ORIFICE
CONTROL BELLOWS
PRESSURE BALANCE BEAM
ACTUATOR
ELECTRICAL SWITCH
ELECTRICAL CONNECTOR

Devices


Upper
Float
Magnet
Closed
Paddle
Open
From
Transformer
Tank
Lower Float
Shown in
Open & Closed
Positions
To
Conservator
Tank

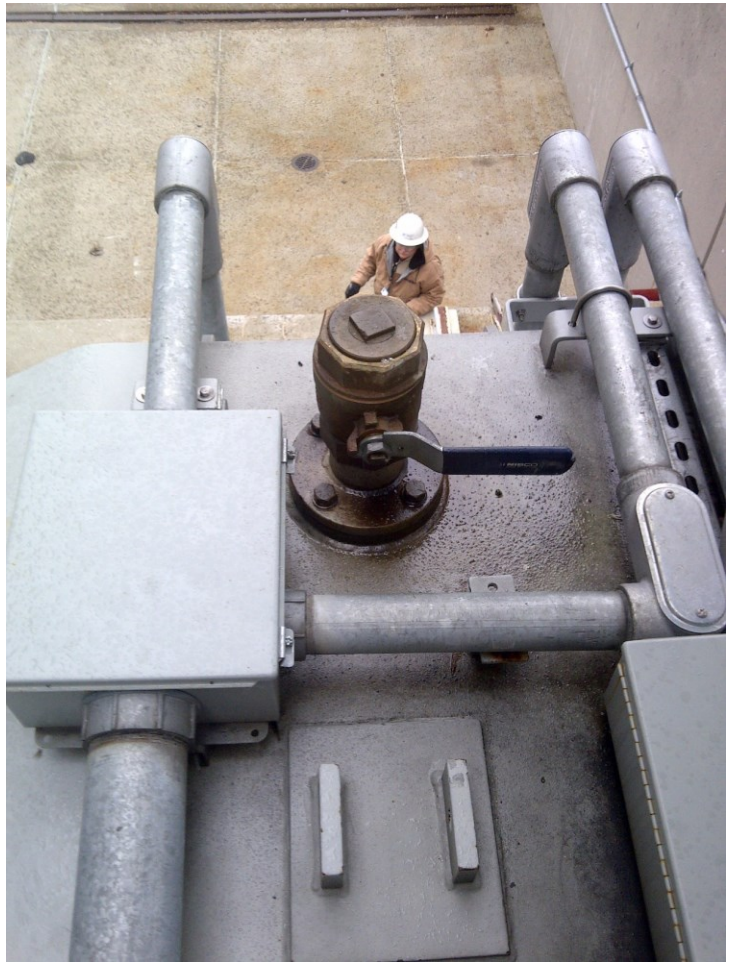
Transformer Maintenance

- Surface Conditions
  - Paint/Galvanizing/Plating
  - Rust
  - Water collection

Transformer Maintenance

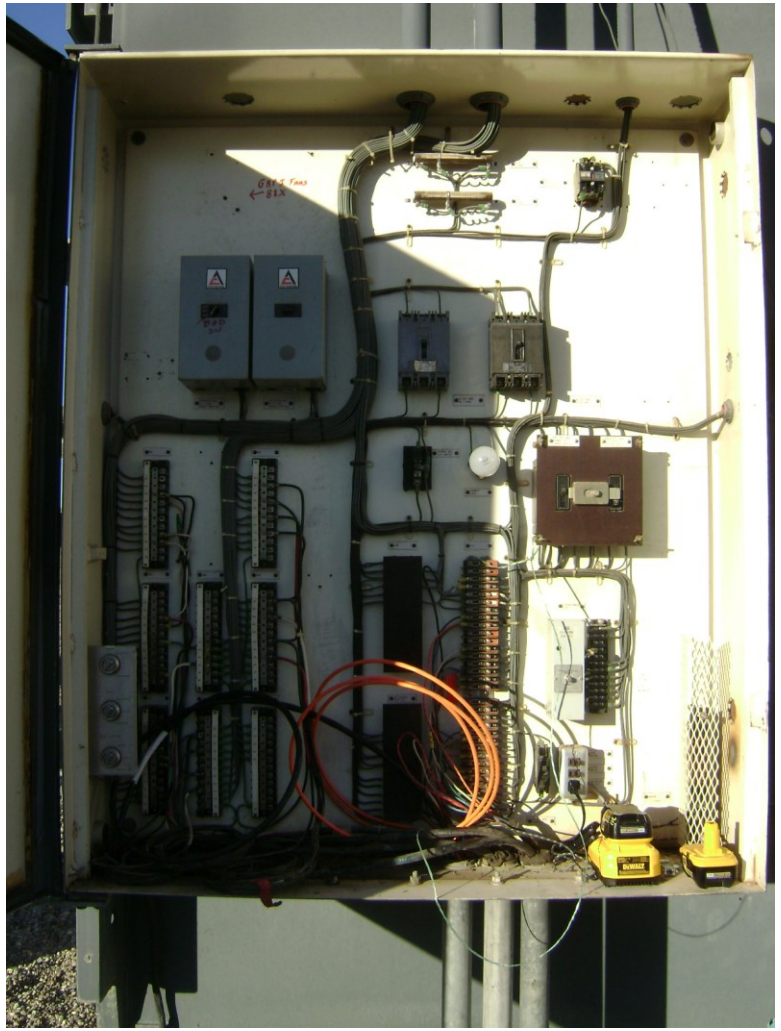
Blocked Cooling Fins

Oil Leaks



Transformer Maintenance

- Controls & Wiring
  - Degradation/Insulation
  - Infestation
  - Disconnected/loose wires
  - Proper labeling
  - Overheating



Preventative Maintenance

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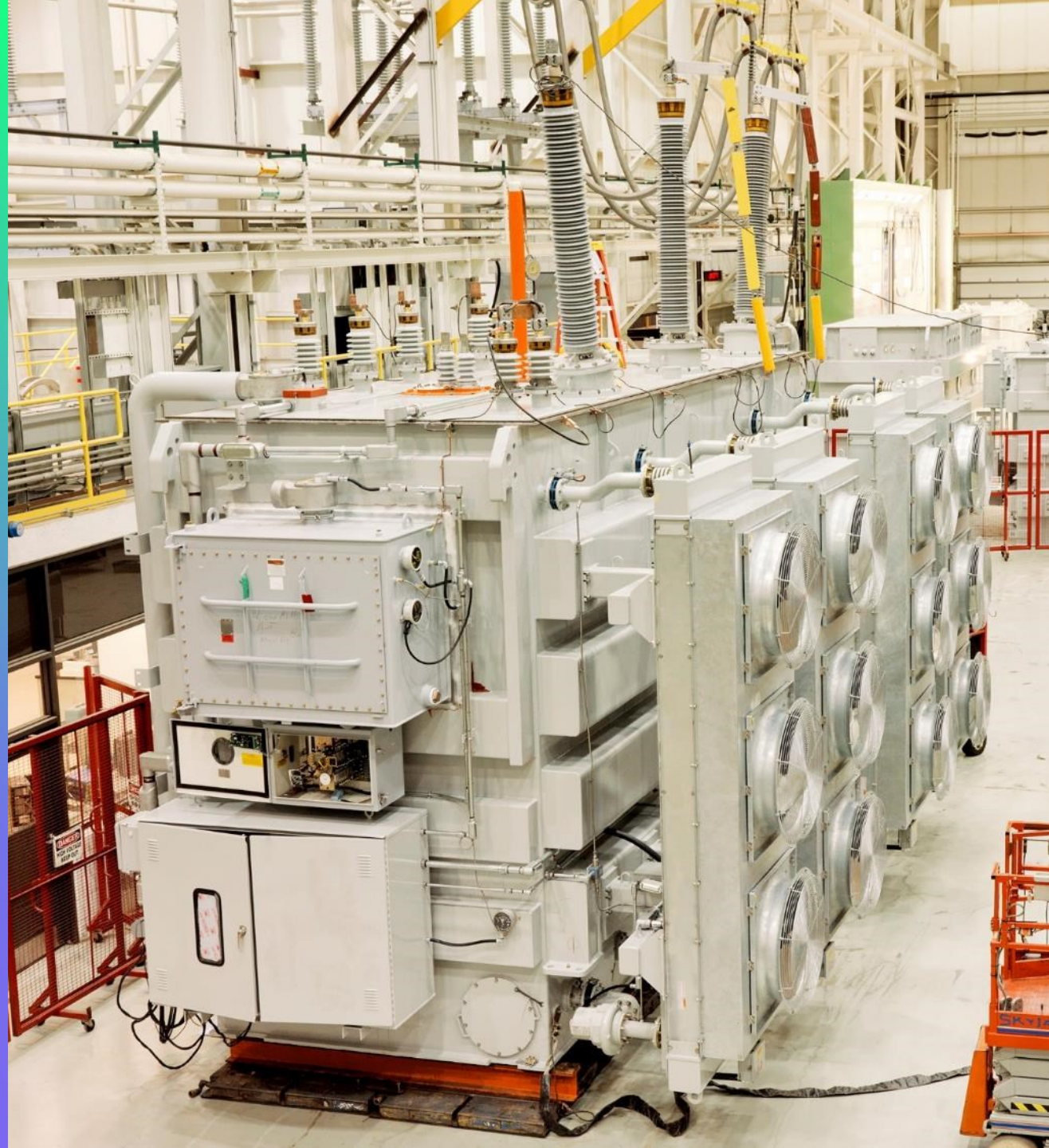
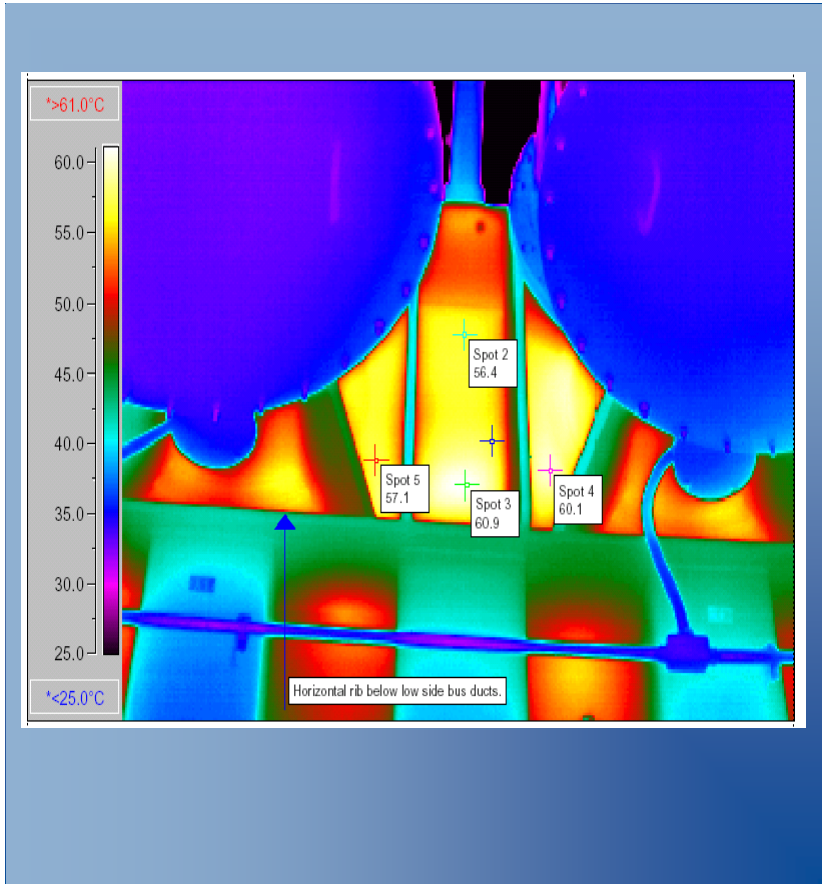
Testing & Monitoring



Thermography



Annual thermographic testing is helpful detecting:

- Bushing Problems/hotspots
- Stray flux heating/shield issues
- LTC/Main tank oil temperature differential
- Oil level problems
- Blocked or closed cooling loops
- Fan motor problems
- Control device problems.

Electrical Test Condition Ratings

Test	Type of Faults Detected	Good	Caution	Concern
Bushing Power Factor (% at 20C)	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 20C)	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	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
Frequency Response Analysis	Winding deformation	< 2 dB amplitude deviation / resonant point shift from baseline		> 2 dB amplitude deviation / resonant point shift from baseline

Preventative Maintenance

Electrical Testing Every 1 to 3 Years

- Perform insulation-resistance tests, winding-to-winding and each winding-to-ground. Polarization index can be calculated.
- Perform turns-ratio tests at the designated tap position.
- Perform insulation power-factor on all windings and bushings and correct to 20°C in accordance with test equipment manufacturer's published data.
- Perform excitation-current tests in accordance with test equipment manufacturer's published data.
- Measure the resistance of each winding at the designated tap position.
- If core ground strap is accessible, measure core insulation resistance at 500 volts dc.
- Measure the percentage of oxygen in the nitrogen gas blanket.

Preventative Maintenance

Oil Testing - Annually

Remove a sample of insulating liquid in accordance with ASTM D923; sample shall be tested in accordance with the referenced standard.

- Dielectric breakdown voltage: ASTM D1816
- Acid neutralization number: ASTM D974
- Specific gravity: ASTM D1298
- Interfacial tension: ASTM D971
- Color: ASTM D1500
- Visual Condition: ASTM D1524
- Moisture Content: ASTM D1533.
- Power factor: ASTM D924
- Dissolved gas analysis (DGA): ASTM D3612
- Furan Analysis

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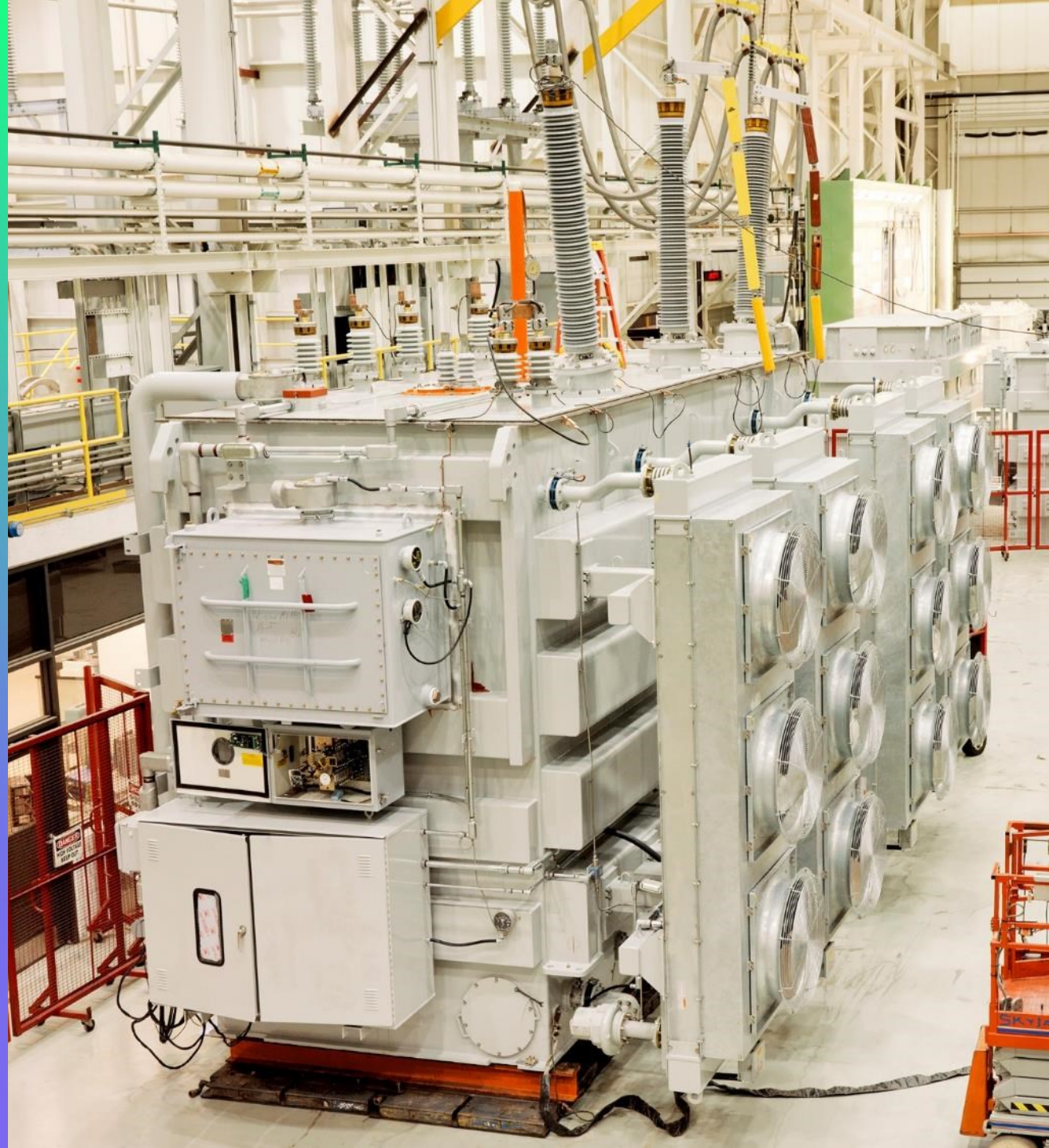
Cooling Systems



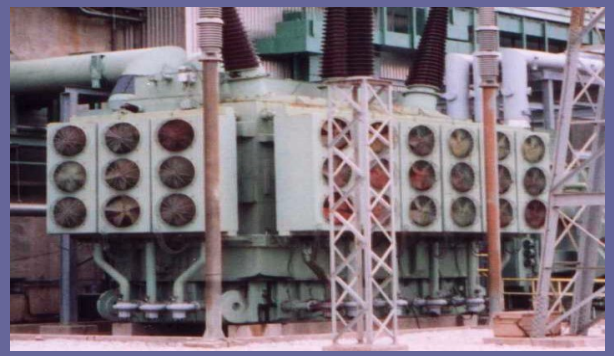
Cooling Maintenance

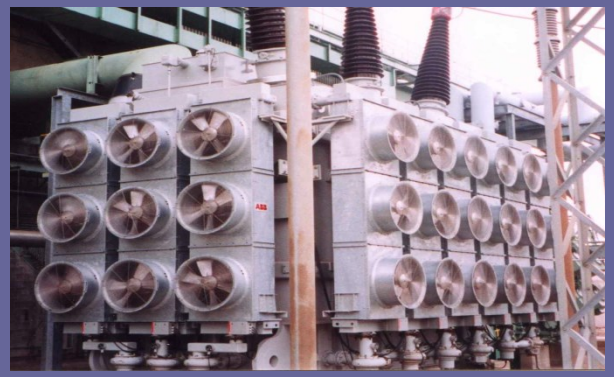
Issue:

- High liquid & winding temperatures
- Cooling Fans Inoperative
- Inoperative Controls
- Fouled cooling equipment and/or mineral deposits
- Air recirculation obstructions

Solution:

- Cleaning of cooling equipment
- Repair Fans
- Repair Controls
  - Fans
  - Radiators





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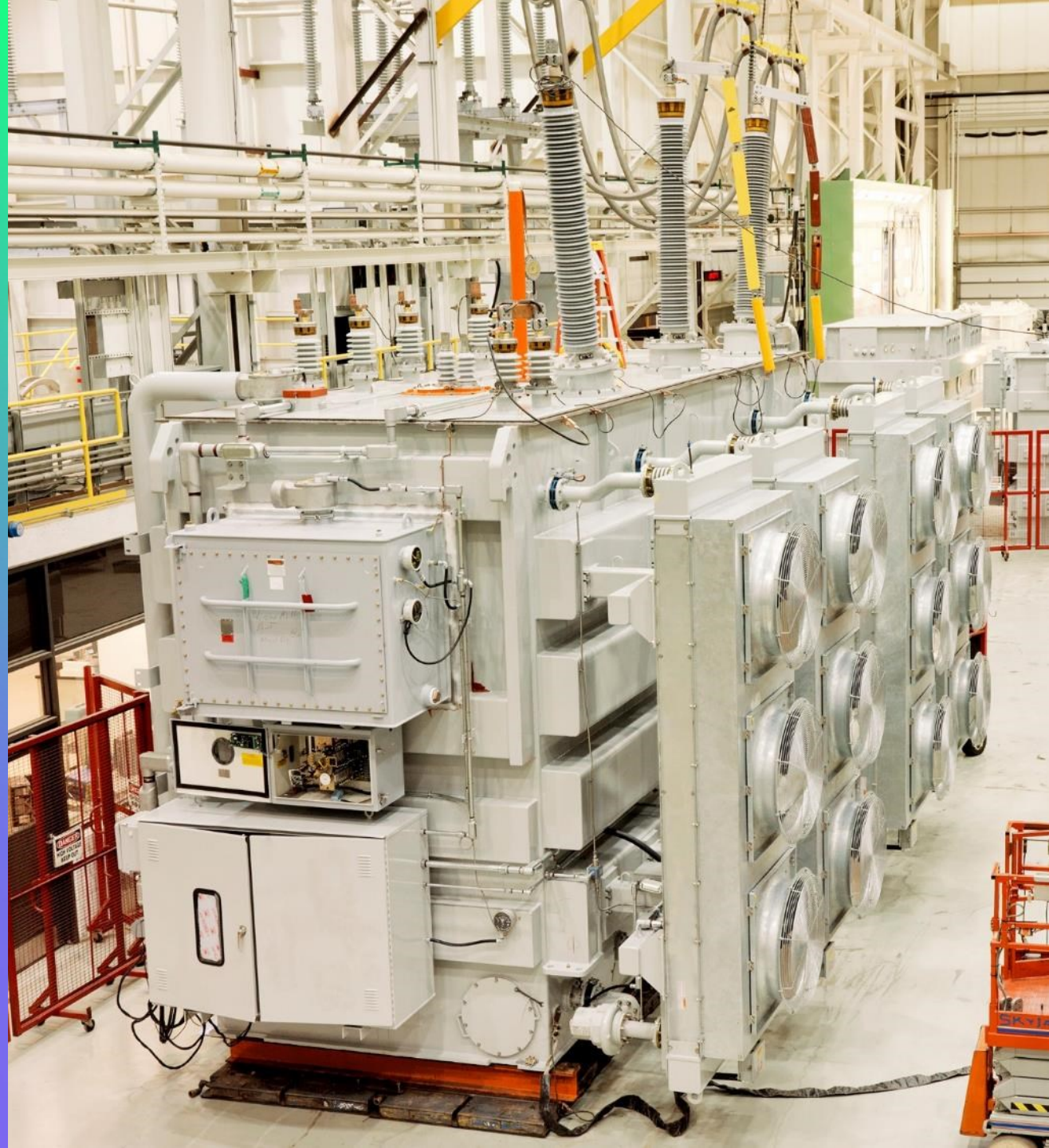
Oil Preservation System



Sealed and Nitrogen Blanket Systems

Issue:

High moisture content and/or oxidation byproduct from improper operation of oil preservation systems

- Plugged bleeders
- System leaks
- Defective regulator

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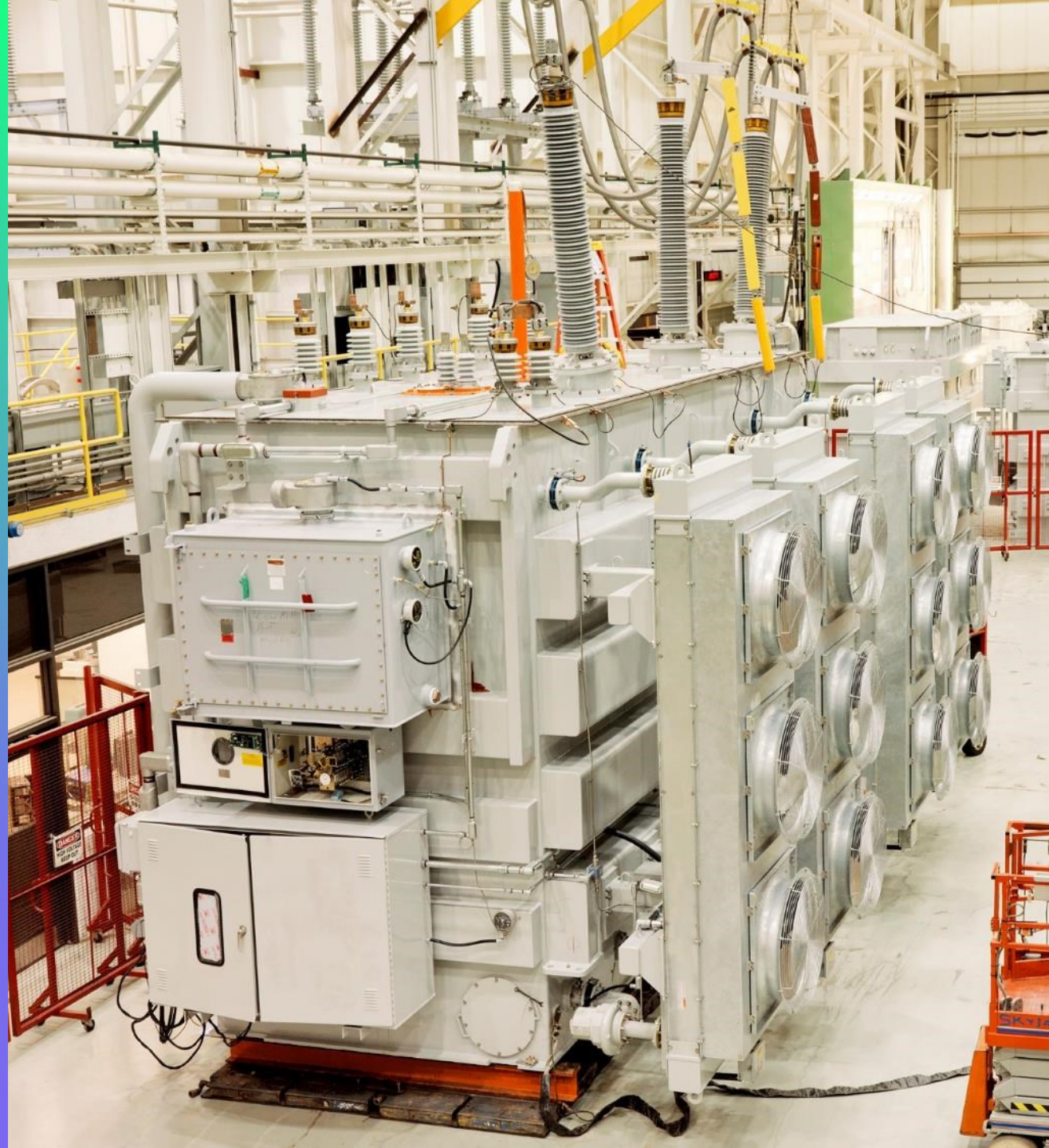
Components



Protective Surge Arresters

Transformer should be protected from overvoltages resulting from external or internal events, such as lightning, switching, faults, resonance, or loss of ground.

Consider:

- Replacement of rod gap or silicon carbide arresters
- If not present, addition of arresters at transformer terminals
- Coordination of remote mounted arresters with the transformer terminal winding BIL

Protective Relaying

A. Differential Protection
B. Sudden Pressure Relay
C. Instantaneous Overcurrent
D. Time Overcurrent
E. Ground relaying

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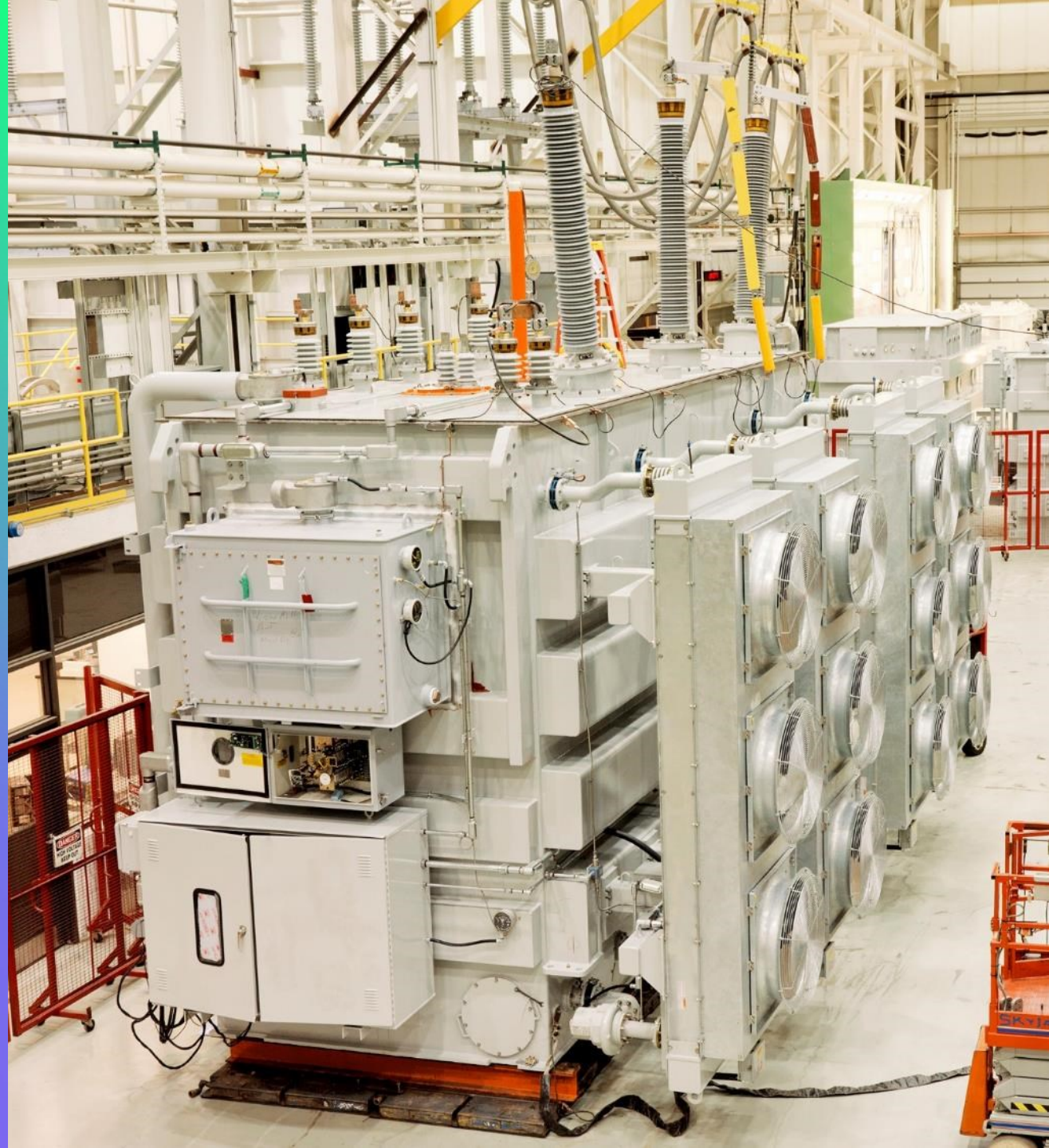
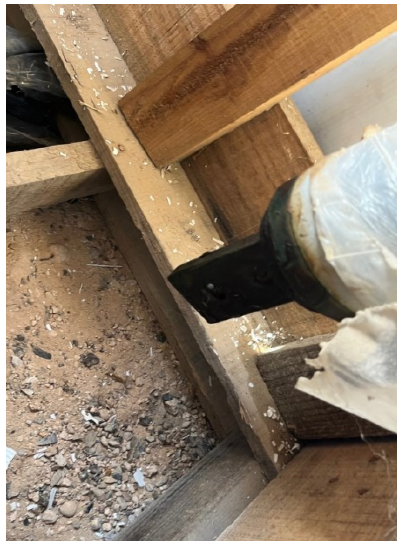
Transformer Storage Considerations



Spare Transformer Management

What could go wrong?




Transformer Storage Considerations

First Things First

- Make sure the unit is grounded
- Cabinet heaters should be energized Control Cabinet and Tap Changer Cabinet
- Accessories
  - *Mounted to the transformer*
  - *Stored Inside*
- Install Pressure Relief Device

Determining Duration of Storage

- Starts the day of shipment
- All transit time as well as all time consumed in the receiving process should be included in storage time
- Validate the OEM requirements on storage conditions & timelines

Transformer Storage Considerations

References for storage activities

- **Storage Period** – Time starts at shipment, the day the unit leaves the factory
- **Dry Nitrogen** - Nitrogen meeting or exceeding Dew Point -60 Deg. Centigrade and in compliance of AST Standard D1933 Type-I
- **Dry Air** – ISO8573-1 Class 1.1.1

Transformer Main Tank Storage Considerations

Storage less than 90 days

Dry Air (Good)

To be connected to the transformer via regulator.

Pressurize to 2-3 PSI

Monitored Daily for 7 days at the same time each day

If holding consistent pressure then monitoring cycle may be extended.

Nitrogen (Better) *[always mark units filled with N2 for safety purposes]*

To be connected to the transformer via regulator

Pressurize to 2 PSI - If above 80F pressurize to 3 PSI

Monitored Daily for 7 days at the same time each day

If holding consistent pressure then monitoring cycle may be extended.

Oil Fill (Best)

Transformers received with oil from the factory can be kept “as received” for 90 days

Transformer Storage Considerations

Storage 90 days to 18 months

Good

- Accessories stored in covered location
- Unit filled with oil to the proper lever
  - Cops tank unit filled to within 20 inches from cover.
  - Pressurized with dry gas

Best

- Fully assemble and fill transformer.

Transformer Storage Considerations

18 months or Longer

Fully Assemble and Fill Transformer

Start maintenance program as if in service

Reference OEM Manual for requirements

Typical items to address:

- Control Cabinet Heaters energized & active w/ set points
- Unit grounded
- Insulation Package impregnated & under oil
- Tank Base >60-70% coverage of support (timbers/temp. pad)
- Breathers functional for maintaining head space integrity
- Oil Level verified & noted w/ unit records
- Shipment Cover plates stored for future relocation needs

Proper Storage Prevents Moisture Ingress & Deterioration/Degradation

Spare Transformer Management

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Removal from Storage

- During storage moisture may accumulate in the transformer insulation if it is not properly stored.
- Stored Dry – Measure Dew Point – 1% moisture or better, compare with as received to storage results
- Stored Oil Filled – Oil Sample “Water Content Test” < 15ppm

Items to support removal from storage:

- **“As-shipped” drawing** w/ shipment dimensions *(validates parts required to be removed for transit)*
- **Cover Plates**, if components are installed and must be moved for relocation you will need to identify cover plates for removal of those components.
- **Crates** – specifically bushing crates as required, including balance of accessories
- **Oil Storage Plan** – how will you manage relocation of the oil if drained for relocation
- **Inspection Report** – validate unit integrity, including accessories & dryness

Contact

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