Revisions to this document shall be communicated in accordance with program document AM-EU-P034 to ensure alignment between Maintenance Templates and field work procedures.

Power Transformer - Substation Class ≥ 200 MVA (> 230 kV, ≥115kV Phase Angle Regulators)								
Component Classification Categories								
Criticality	I	X						Nuclear Switchyards ≥220 kV as defined in the respective Nuclear Plant Interface Requirements (NPIRs).
	II		X					DC, SS, TDC, TSS locations that serve O'Hare & Midway Airports
	III			X				• Next Terminal Out [Equipment 220kV & Up] from Nuclear Switchyards (as defined in the respective NPIRs) • Critical Transmission Interconnections • Critical Equipment / Locations per AM-CE-P034-R0001
	IV				X			All other locations
Duty Cycle	Heavy Load	N/A	N/A	N/A	N/A	N/A		
	Normal load	N/A	N/A	N/A	N/A	N/A		
Service Condition	In-Service	X	X	X	X			
	Spare					X		Spare*
Condition Monitoring Tasks		**Task Frequencies**					**Failure Codes**	**Comments**
Monitor Nitrogen Pressure		**5W**	**5W**	**10W**	**10W**	**10W**	**3a-f, 3j**	
Monitor Oil Level		**5W**	**5W**	**10W**	**10W**	**10W**	**1e, 3a-e, 3g-h, 3j, 4b**	
Monitor Oil Temperature		**5W**	**5W**	**10W**	**10W**	**N/A**	**1a-d, 3g**	
Monitor Oil Flow Indicator		**5W**	**5W**	**10W**	**10W**	**N/A**	**1c**	
Monitor Winding Temperature		**5W**	**5W**	**10W**	**10W**	**N/A**	**1a-d, 4d**	
Monitor LTC Operations Counter		**5W**	**5W**	**10W**	**10W**	**N/A**	**6a-c**	This task applies only to transformers with LTC
Monitor LTC Filtration System		**5W**	**5W**	**10W**	**10W**	**N/A**	**6b**	This task applies only to transformers with LTC
Monitor Gas Accumulator as applicable		**5W**	**5W**	**10W**	**10W**	**N/A**	**4a, 4c-d, 5a**	Main Tank, Reactor compartment
Oil DGA - Main Tank		**3M**	**3M**	**3M**	**3M**	**N/A**	**2a-b, 4c-d, 6b**	
Oil DGA - LTC		**N/A**	**3M**	**3M**	**6M**	**N/A**	**2a-b, 4c-d, 6b**	This task applies only to transformers with LTC; Ferr-Pack and FPE LTC (quarterly); RMV-II (annual)
Oil Quality Test		**3M**	**3M**	**3M**	**3M**	**1Y**	**3a-b, 4a, 4c-d, 6b**	All oil filled compartments
Thermography		**3M**	**1Y**	**1Y**	**1Y**	**N/A**	**1a-f, 4b, 6b**	
LTC Run Thru Neutral		**N/A**	**6M**	**6M**	**6M**	**N/A**	**1f, 6b**	This task applies only to transformers with LTC
Power Factor Test		**4Y**	**4Y**	**4Y**	**4Y**	**6Y**	**2a, 4c-f**	Including CCVT used as voltage source for regulation, as applicable
High Voltage Excitation Test		**4Y**	**4Y**	**4Y**	**4Y**	**AR**	**2a-b, 4c-d**	
Winding Resistance		**4Y**	**AR**	**AR**	**AR**	**AR**	**1f-g, 2c-d**	For Transformers outside of the Nuclear Switchyard, this task applies only to transformers with LTC
Frequency Response Analysis		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**2a, 2e**	Sweep Frequency Method
Time Directed Tasks		**Task Frequencies**					**Failure Codes**	**Comments**
Maintenance Inspection		**4Y**	**4Y**	**4Y**	**4Y**	**6Y**	**1h, 3a-e, 4b-c**	
Clean Heat Exchangers		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**1a**	This task frequency applies only to FOA type transformers with coolers. Perform task As Required for other heat exchanger types. Perform task more frequently if environmental conditions warrant (e.g. cotton wood impacted locations).
LTC Mechanism Inspection		**N/A**	**4Y**	**4Y**	**4Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC
Flush LTC Compartments and Replace With New Oil		**N/A**	**4Y**	**4Y**	**4Y**	**N/A**	**6b**	This task applies only to transformers with LTC. Task is to performed along with the LTC Internal Inspection.
Failure Finding		**Task Frequencies**					**Failure Codes**	**Comments**
Check Cabinet Heaters		**5W**	**5W**	**10W**	**10W**	**10W**	**1d, 5a-b**	
Check Bushing Oil Level		**5W**	**5W**	**10W**	**10W**	**10W**	**4e**	
Check / Replace Desiccant		**5W**	**5W**	**10W**	**10W**	**10W**	**4a**	
Visual Inspection		**5W**	**5W**	**10W**	**10W**	**10W**	**1a-e, 3a-j, 4e, 6a**	
Functional Test, Cooling System, Alternate Lead/Lag Coolers		**5W**	**5W**	**10W**	**10W**	**N/A**	**1b-c**	Alternate not required for automated Dynamic Ratings Monitoring (DRMCC)
Functional Alarm Test		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**5b**	
Ultrasonic Bearing Wear Monitor		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**1c, 4c-d**	Pumps with Techsonics bearing wear monitor
Inspect Bushing Potential Tap		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**4e**	
Check / Verify Gauges and Alarms		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**1a-d, 3a-f, 4b, 4d, 5a-b**	
Check Automated Aux Power		**4Y**	**4Y**	**4Y**	**4Y**	**N/A**	**1d**	Where ATO installed at transformer
Check Geomagnetically Induced Current Monitor		**N/A**	**4Y**	**4Y**	**4Y**	**N/A**	**5e**	Where installed
Transformer Turns Ratio		**4Y**	**AR**	**AR**	**AR**	**AR**	**6a**	For Transformers outside of the Nuclear Switchyard, this task applies only to transformers with LTC
LTC Continuity Test		**N/A**	**4Y**	**4Y**	**4Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC
LTC Internal Inspection		**N/A**	**4Y**	**4Y**	**4Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC. In lieu of performing Winding Resistance and Transformer Turns Ratio tests, Flush LTC and replace with new oil to remove carbon buildup and perform internal inspection.
Condition Directed Tasks		**Task Frequencies**					**Failure Codes**	**Comments**
None		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**		

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Revisions to this document shall be communicated in accordance with program document AM-EU-P034 to ensure alignment between Maintenance Templates and field work procedures.

Power Transformer - Substation Class ≥ 9375 kVA, <200 MVA (≤ 138kV)									
Component Classification Categories									
Criticality	I	X							DC, SS, TDC, TSS locations that serve O'Hare & Midway Airports
	II		X						• 138kV Transformers at Critical Transmission Interconnections • Critical Equipment / Locations per AM-CE-P034-R0001
	III			X					Locations exclusive of ≤ 34 kV ESS, DCs and Criticality I & II locations
	IV				X				DC locations
	V					X			≤ 34kV ESS locations
Duty Cycle	Heavy Load	N/A	N/A	N/A	N/A	N/A	N/A		
	Normal load	N/A	N/A	N/A	N/A	N/A	N/A		
Service Condition	In-Service	X	X	X	X	X			
	Spare						X		Spare*
Condition Monitoring Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
Monitor Nitrogen Pressure		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**3a-f, 3j**	
Monitor Oil Level		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1e, 3a-e, 3g-h, 3j, 4b**	
Monitor Oil Temperature		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**1a-d, 3g**	
Monitor Oil Flow Indicator		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**1c**	
Monitor Winding Temperature		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**1a-d, 4d**	
Monitor LTC Operations Counter		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**6a-c**	This task applies only to transformers with LTC
Monitor LTC Filtration System		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**6b**	This task applies only to transformers with LTC
Monitor Gas Accumulator as applicable		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**4a, 4c-d, 5a**	
Oil DGA - Main Tank		**6M**	**6M**	**1Y**	**1Y**	**1Y**	**N/A**	**2a-b, 4c-d, 6b**	
Oil DGA - LTC		**6M**	**6M**	**6M**	**6M**	**6M**	**NA**	**2a-b, 4c-d, 6b**	This task applies only to transformers with LTC; Ferr-Pack and FPE LTC (quarterly); RMV-II (annual)
Oil Quality Test		**6M**	**6M**	**1Y**	**1Y**	**1Y**	**1Y**	**3a-b, 4a, 4c-d, 6b**	All oil filled compartments
Thermography		**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**N/A**	**1a-f, 4b, 6b**	
LTC Run Thru Neutral		**6M**	**6M**	**6M**	**6M**	**6M**	**N/A**	**1f, 6b**	This task applies only to transformers with LTC
Power Factor Test		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**2a, 4c-f**	including CCVT used as voltage source for regulation, as applicable
High Voltage Excitation Test		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**2a-b, 4c-d**	
Winding Resistance		**AR**	**AR**	**AR**	**AR**	**AR**	**AR**	**1f-g, 2c-d**	This task applies only to transformers with LTC
Time Directed Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
LTC Overhaul		**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**N/A**	**6b**	Ferranti-Packard and Federal Pacific load tap changers only
Maintenance Inspection		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**1h, 3a-e, 4b-c**	
Clean Heat Exchangers		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**1a**	This task frequency applies only to FOA type transformers with coolers. Perform task As Required for other heat exchanger types. Perform task more frequently if environmental conditions warrant (e.g. cotton wood impacted locations).
LTC Mechanism Inspection		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC
Flush LTC Compartments and Replace With New Oil		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**6b**	This task applies only to transformers with LTC. Task is to performed along with the LTC Internal Inspection.
Failure Finding		**Task Frequencies**						**Failure Codes**	**Comments**
Check Cabinet Heaters		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1d, 5a-b**	
Check Bushing Oil Level		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**4e**	
Check / Replace Desiccant		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**4a**	
Visual Inspection		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1a-e, 3a-j, 4e, 6a**	
Functional Test, Cooling System, Alternate Lead/Lag Coolers		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**1b-c**	Alternate not required for automated Dynamic Ratings Monitoring (DRMCC)
Functional Alarm Test		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**5b**	
Ultrasonic Bearing Wear Monitor (Pumps)		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**1c, 4c-d**	Pumps with Techsonics bearing wear monitor
Inspect Bushing Potential Tap		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**4e**	
Check / Verify Gauges and Alarms		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**1a-d, 3a-f, 4b, 4d, 5a-b**	
Check Automated Aux Power Throw-over Switch		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**1d**	Where ATO installed at transformer
Transformer Turns Ratio		**AR**	**AR**	**AR**	**AR**	**AR**	**N/A**	**6a**	This task applies only to transformers with LTC
LTC Continuity Test		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC
LTC Internal Inspection		**8Y**	**8Y**	**8Y**	**8Y**	**8Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC. In lieu of performing Winding Resistance and Transformer Turns Ratio tests, Flush LTC and replace with new oil to remove carbon buildup and perform internal inspection.
Condition Directed Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
None		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**		

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Power Transformer - Substation Class 34kV High Side Transformers with LTC [Power range > 2500 kVA, < 9375kVA]									
Component Classification Categories									
Criticality	I	X							DC, SS, TDC, TSS locations that serve O'Hare & Midway Airports
	II		X						Critical Equipment / Locations per AM-CE-P034-R0001
	III			X					Locations exclusive of ≤ 34 kV ESS, DCs and Criticality I & II locations
	IV				X				DC locations
	V					X			≤ 34kV ESS locations
Duty Cycle	Heavy Load	N/A	N/A	N/A	N/A	N/A	N/A		
	Normal load	N/A	N/A	N/A	N/A	N/A	N/A		
Service Condition	In-Service	X	X	X	X	X			
	Spare						X		Spare*
Condition Monitoring Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
Monitor Nitrogen Pressure		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**3a-f, 3j**	
Monitor Oil Level		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1e, 3a-e, 3g-h, 3j, 4b**	
Monitor Oil Temperature		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**1a-d, 3g**	
Monitor LTC Operations Counter		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**6a-c**	This task applies only to transformers with LTC
Oil DGA		**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**N/A**	**2a-b, 4c-d, 6b**	Main Tank, LTC
Oil Quality Test		**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**3a-b, 4a, 4c-d, 6b**	All oil filled compartments
Thermography		**1Y**	**1Y**	**1Y**	**1Y**	**4Y**	**N/A**	**1a-f, 4b, 6b**	
LTC Run Thru Neutral		**AR**	**AR**	**AR**	**AR**	**AR**	**AR**	**1f, 6b**	This task applies only to transformers with LTC
Power Factor Test		**16Y**	**16Y**	**16Y**	**16Y**	**16Y**	**8Y**	**2a, 4c-f**	
High Voltage Excitation Test		**16Y**	**16Y**	**16Y**	**16Y**	**16Y**	**AR**	**2a-b, 4c-d**	
Winding Resistance		**AR**	**AR**	**AR**	**AR**	**AR**	**AR**	**1f-g, 2c-d**	This task applies only to transformers with LTC
Time Directed Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
Maintenance Inspection		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**8Y**	**1h, 3a-e, 4b-c**	
Flush LTC Compartments and Replace With New Oil		**16Y**	**16Y**	**16Y**	**16Y**	**16Y**	**AR**	**6b**	This task applies only to transformers with LTC. Task is to performed along with the LTC Internal Inspection.
Failure Finding		**Task Frequencies**						**Failure Codes**	**Comments**
Check Cabinet Heaters		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1d, 5a-b**	
Check Bushing Oil Level		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**4e**	
Check / Replace Desiccant		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**4a**	
Visual Inspection		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1a-e, 3a-j, 4e, 6a**	
Functional Test, Cooling System, Alternate Lead/Lag Coolers		**5W**	**10W**	**10W**	**3M**	**N/A**	**N/A**	**1b-c**	
Functional Alarm Test		**8Y**	**8Y**	**16Y**	**16Y**	**N/A**	**N/A**	**5b**	
Check / Verify Gauges and Alarms		**8Y**	**8Y**	**16Y**	**16Y**	**AR**	**N/A**	**1a-d, 3a-f, 4b, 4d, 5a-b**	
Transformer Turns Ratio		**AR**	**AR**	**AR**	**AR**	**AR**	**N/A**	**6a**	This task applies only to transformers with LTC
LTC Internal Inspection		**16Y**	**16Y**	**16Y**	**16Y**	**16Y**	**N/A**	**6a-b**	This task applies only to transformers with LTC. In lieu of performing Winding Resistance and Transformer Turns Ratio tests, Flush LTC and replace with new oil nto remove carbon buildup and perform internal inspection.
Condition Directed Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
None		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**		

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Power Transformer - Substation Class > 2500 kVA, < 9375kVA [Exclusive of 34kV High Side Transformers with LTC]									
Component Classification Categories									
Criticality	I	X							DC, SS, TDC, TSS locations that serve O'Hare & Midway Airports
	II		X						Critical Equipment / Locations per AM-CE-P034-R0001
	III			X					Locations exclusive of ≤ 34 kV ESS, DCs and Criticality I & II locations
	IV				X				DC locations
	V					X			≤ 34kV ESS locations
Duty Cycle	Heavy Load	N/A	N/A	N/A	N/A	N/A	N/A		
	Normal load	N/A	N/A	N/A	N/A	N/A	N/A		
Service Condition	In-Service	X	X	X	X	X			
	Spare						X		Spare*
Condition Monitoring Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
Monitor Nitrogen Pressure		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**3a-f, 3j**	
Monitor Oil Level		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1e, 3a-e, 3g-h, 3j, 4b**	
Monitor Oil Temperature		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**1a-d, 3g**	
Monitor LTC Operations Counter		**5W**	**10W**	**10W**	**3M**	**6M**	**N/A**	**6a-c**	This task applies only to transformers with LTC
Oil DGA		**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**N/A**	**2a-b, 4c-d, 6b**	Main Tank, LTC
Oil Quality Test		**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**1Y**	**3a-b, 4a, 4c-d, 6b**	All oil filled compartments
Thermography		**1Y**	**1Y**	**1Y**	**1Y**	**4Y**	**N/A**	**1a-f, 4b, 6b**	
LTC Run Thru Neutral		**AR**	**AR**	**AR**	**AR**	**AR**	**AR**	**1f, 6b**	This task applies only to transformers with LTC
Power Factor Test		**16Y**	**16Y**	**AR**	**AR**	**AR**	**8Y**	**2a, 4c-f**	
~~Low~~ High Voltage Excitation Test		**16Y**	**16Y**	**AR**	**AR**	**AR**	**AR**	**2a-b, 4c-d**	
Winding Resistance		**AR**	**AR**	**AR**	**AR**	**AR**	**AR**	**1f-g, 2c-d**	
Time Directed Tasks		**Task Frequencies**						**Failure Codes**	**Comments**
Maintenance Inspection		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**8Y**	**1h, 3a-e, 4b-c**	
Flush LTC Compartments and Replace With New Oil		**16Y**	**16Y**	**AR**	**AR**	**AR**	**AR**	**6b**	This task applies only to transformers with LTC. Task is to performed along with the LTC Internal Inspection.
Failure Finding		**Task Frequencies**						**Failure Codes**	**Comments**
Check Cabinet Heaters		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1d, 5a-b**	
Check Bushing Oil Level		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**4e**	
Check / Replace Desiccant		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**4a**	
Visual Inspection		**5W**	**10W**	**10W**	**3M**	**6M**	**10W**	**1a-e, 3a-j, 4e, 6a**	
Functional Test, Cooling System, Alternate Lead/Lag Coolers		**5W**	**10W**	**10W**	**3M**	**N/A**	**N/A**	**1b-c**	
Functional Alarm Test		**8Y**	**8Y**	**16Y**	**16Y**	**N/A**	**N/A**	**5b**	
Check / Verify Gauges and Alarms		**8Y**	**8Y**	**16Y**	**16Y**	**AR**	**N/A**	**1a-d, 3a-f, 4b, 4d, 5a-b**	
Transformer Turns Ratio		**AR**	**AR**	**AR**	**AR**	**AR**	**N/A**	**6a**	This task applies only to transformers with LTC
LTC Internal Inspection		**16Y**	**16Y**	**AR**	**AR**	**AR**	**N/A**	**6a-b**	This task applies only to transformers with LTC. In lieu of performing Winding Resistance and Transformer Turns Ratio tests, Flush LTC and replace with new oil to remove carbon buildup and perform internal inspection.
Condition Directed Tasks	**Task Frequencies**							**Failure Codes**	**Comments**
None		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**		

*** Designated Spare Equipment** that is covered by this PM program is defined as Transformers placed in long-term, outdoor storage in substation yards and designated for use as replacements for Transformers in previously defined applications or positions. Examples of equipment excluded from this PM program are: Transformers stored for ongoing or future projects or installations, Transformers removed from service and retired on-site, and Transformers stored temporarily to be re-delivered to other locations.

TRANSFORMER FAILURE MODES

FAILURE MODE:	FAILURE CAUSES:	MAINTENANCE TASKS:
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Visual Inspection
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Power Wash
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Monitor Oil Temperature
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Monitor Winding Temperature
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Thermography
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Check / Verify Gauges and Alarms
1. Fails to Provide Adequate Capacity	1a. Clogged / Corroded Coolers/ Radiator/ Piping	Power Wash Heat Exchanger
1. Fails to Provide Adequate Capacity	1b. Fan / Motor Failure	Visual Inspection
1. Fails to Provide Adequate Capacity	1b. Fan / Motor Failure	Monitor Oil Temperature
1. Fails to Provide Adequate Capacity	1b. Fan / Motor Failure	Monitor Winding Temperature
1. Fails to Provide Adequate Capacity	1b. Fan / Motor Failure	Functional Test
1. Fails to Provide Adequate Capacity	1b. Fan / Motor Failure	Check / Verify Gauges and Alarms
1. Fails to Provide Adequate Capacity	1b. Fan / Motor Failure	Thermography
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Visual Inspection
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Monitor Oil Temperature
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Monitor Winding Temperature
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Monitor Oil Flow Indicator
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Functional Test
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Check / Verify Gauges and Alarms
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Thermography
1. Fails to Provide Adequate Capacity	1c. Pump / Motor Failure	Ultrasonic Bearing Wear Monitor (Pumps)
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Visual Inspection
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Monitor Oil Temperature
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Monitor Winding Temperature
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Check / Verify Gauges and Alarms
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Thermography
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Check Cabinet Heaters
1. Fails to Provide Adequate Capacity	1d. Cooler Control Circuit Failure	Check Automated Aux Power Throw-over Switch
1. Fails to Provide Adequate Capacity	1e. Loss of Oil	Monitor Oil Level
1. Fails to Provide Adequate Capacity	1e. Loss of Oil	Thermography
1. Fails to Provide Adequate Capacity	1e. Loss of Oil	Visual Inspection
1. Fails to Provide Adequate Capacity	1f. High Resistance Connection Failure	Winding Resistance
1. Fails to Provide Adequate Capacity	1f. High Resistance Connection Failure	Thermography
1. Fails to Provide Adequate Capacity	1f. High Resistance Connection Failure	LTC Run Thru Neutral
1. Fails to Provide Adequate Capacity	1g. Open Connection in Winding	Winding Resistance
1. Fails to Provide Adequate Capacity	1h. Loose or Frayed Connection	Maintenance Inspection
2. Fails to Transform Voltage/ Current	2a. Winding Failure	Oil DGA
2. Fails to Transform Voltage/ Current	2a. Winding Failure	Oil DGA - LTC (Non-Vacuum)
2. Fails to Transform Voltage/ Current	2a. Winding Failure	Power Factor Test

TRANSFORMER FAILURE MODES

FAILURE MODE:	FAILURE CAUSES:	MAINTENANCE TASKS:
2. Fails to Transform Voltage/ Current	2a. Winding Failure	Low Voltage Excitation Test
2. Fails to Transform Voltage/ Current	2a. Winding Failure	Frequency Response Analysis
2. Fails to Transform Voltage/ Current	2b. Preventive Auto Failure	Oil DGA
2. Fails to Transform Voltage/ Current	2b. Preventive Auto Failure	Oil DGA - LTC (Non-Vacuum)
2. Fails to Transform Voltage/ Current	2b. Preventive Auto Failure	Low Voltage Excitation Test
2. Fails to Transform Voltage/ Current	2c. High Resistance Connection Failure	Winding Resistance
2. Fails to Transform Voltage/ Current	2d. Open Connection in Winding	Winding Resistance
2. Fails to Transform Voltage/ Current	2e. Winding Looseness	Frequency Response Analysis
3. Fails to Maintain Boundary Integrity	3a. Gasket Failure	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3a. Gasket Failure	Visual Inspection
3. Fails to Maintain Boundary Integrity	3a. Gasket Failure	Monitor Oil Level
3. Fails to Maintain Boundary Integrity	3a. Gasket Failure	Check / Verify Gauges and Alarms
3. Fails to Maintain Boundary Integrity	3a. Gasket Failure	Oil Quality Test
3. Fails to Maintain Boundary Integrity	3a. Gasket Failure	Maintenance Inspection
3. Fails to Maintain Boundary Integrity	3b. Weld Failure	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3b. Weld Failure	Visual Inspection
3. Fails to Maintain Boundary Integrity	3b. Weld Failure	Monitor Oil Level
3. Fails to Maintain Boundary Integrity	3b. Weld Failure	Check / Verify Gauges and Alarms
3. Fails to Maintain Boundary Integrity	3b. Weld Failure	Oil Quality Test
3. Fails to Maintain Boundary Integrity	3b. Weld Failure	Maintenance Inspection
3. Fails to Maintain Boundary Integrity	3c. Main Tank Coolers, Fins, Cooler Corrosion	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3c. Main Tank Coolers, Fins, Cooler Corrosion	Visual Inspection
3. Fails to Maintain Boundary Integrity	3c. Main Tank Coolers, Fins, Cooler Corrosion	Monitor Oil Level
3. Fails to Maintain Boundary Integrity	3c. Main Tank Coolers, Fins, Cooler Corrosion	Check / Verify Gauges and Alarms
3. Fails to Maintain Boundary Integrity	3c. Main Tank Coolers, Fins, Cooler Corrosion	Maintenance Inspection
3. Fails to Maintain Boundary Integrity	3d. Loose Mechanical Connection	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3d. Loose Mechanical Connection	Visual Inspection
3. Fails to Maintain Boundary Integrity	3d. Loose Mechanical Connection	Monitor Oil Level
3. Fails to Maintain Boundary Integrity	3d. Loose Mechanical Connection	Check / Verify Gauges and Alarms
3. Fails to Maintain Boundary Integrity	3d. Loose Mechanical Connection	Maintenance Inspection
3. Fails to Maintain Boundary Integrity	3e. Valve Leakage	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3e. Valve Leakage	Visual Inspection
3. Fails to Maintain Boundary Integrity	3e. Valve Leakage	Monitor Oil Level
3. Fails to Maintain Boundary Integrity	3e. Valve Leakage	Check / Verify Gauges and Alarms
3. Fails to Maintain Boundary Integrity	3e. Valve Leakage	Maintenance Inspection
3. Fails to Maintain Boundary Integrity	3f. Main Tank Over pressurization	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3f. Main Tank Over pressurization	Visual Inspection
3. Fails to Maintain Boundary Integrity	3f. Main Tank Over pressurization	Check / Verify Gauges and Alarms
3. Fails to Maintain Boundary Integrity	3g. Main Tank / Tap Changer Internal Compartment	Monitor Oil Temperature

TRANSFORMER FAILURE MODES

FAILURE MODE:	FAILURE CAUSES:	MAINTENANCE TASKS:
3. Fails to Maintain Boundary Integrity	3g. Main Tank / Tap Changer Internal Compartment	Monitor Oil Levels
3. Fails to Maintain Boundary Integrity	3g. Main Tank / Tap Changer Internal Compartment	Visual Inspection
3. Fails to Maintain Boundary Integrity	3h. Main Tank/ Tap Changer External Compartment	Monitor Oil Levels
3. Fails to Maintain Boundary Integrity	3h. Main Tank/ Tap Changer External Compartment	Visual Inspection
3. Fails to Maintain Boundary Integrity	3h. Main Tank/ Tap Changer External Compartment	Replace Gaskets
3. Fails to Maintain Boundary Integrity	3i. Pressure Relief Failure	Visual Inspection
3. Fails to Maintain Boundary Integrity	3j. Tank Corrosion	Monitor Nitrogen Pressure
3. Fails to Maintain Boundary Integrity	3j. Tank Corrosion	Visual Inspection
3. Fails to Maintain Boundary Integrity	3j. Tank Corrosion	Monitor Oil Level
3. Fails to Maintain Boundary Integrity	3j. Tank Corrosion	Paint
4. Fails to Provide Adequate Electrical Insulation	4a. Insulating Oil Breakdown	Oil Quality Test
4. Fails to Provide Adequate Electrical Insulation	4a. Insulating Oil Breakdown	Check / Replace Desiccant
4. Fails to Provide Adequate Electrical Insulation	4a. Insulating Oil Breakdown	Acoustical Testing for Internal PD
4. Fails to Provide Adequate Electrical Insulation	4a. Insulating Oil Breakdown	Monitor Gas accumulator
4. Fails to Provide Adequate Electrical Insulation	4b. Loss of Oil	Monitor Oil Level
4. Fails to Provide Adequate Electrical Insulation	4b. Loss of Oil	Check / Verify Gauges and Alarms
4. Fails to Provide Adequate Electrical Insulation	4b. Loss of Oil	Maintenance Inspection
4. Fails to Provide Adequate Electrical Insulation	4b. Loss of Oil	Thermography
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Oil DGA
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Oil DGA - LTC (Non-Vacuum)
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Oil Quality Test
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Power Factor Test
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Low Voltage Excitation Test
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Maintenance Inspection
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Ultrasonic Bearing Wear Monitor (Pumps)
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Acoustical Testing for Internal PD
4. Fails to Provide Adequate Electrical Insulation	4c. Solid Insulation Failure	Monitor Gas accumulator
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Monitor Winding Temperature
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Oil DGA
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Oil DGA - LTC (Non-Vacuum)
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Oil Quality Test
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Check / Verify Gauges and Alarms
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Power Factor Test
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Low Voltage Excitation Test
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Ultrasonic Bearing Wear Monitor (Pumps)
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Acoustical Testing for Internal PD
4. Fails to Provide Adequate Electrical Insulation	4d. Winding Insulation Failure	Monitor Gas accumulator
4. Fails to Provide Adequate Electrical Insulation	4e. Bushing Failure	Power Factor Test
4. Fails to Provide Adequate Electrical Insulation	4e. Bushing Failure	Check Bushing Oil Level

TRANSFORMER FAILURE MODES

FAILURE MODE:	FAILURE CAUSES:	MAINTENANCE TASKS:
4. Fails to Provide Adequate Electrical Insulation	4e. Bushing Failure	Visual Inspection
4. Fails to Provide Adequate Electrical Insulation	4e. Bushing Failure	Inspect Bushing Potential Tap
4. Fails to Provide Adequate Electrical Insulation	4f. Lightning Arrester Failure	Power Factor Test
5. Fails to Alarm	5a. Gauge / Pressure Switch Failure	Check Cabinet Heaters
5. Fails to Alarm	5a. Gauge / Pressure Switch Failure	Check / Verify Gauges and Alarms
5. Fails to Alarm	5a. Gauge / Pressure Switch Failure	Monitor Gas accumulator
5. Fails to Alarm	5b. Control Circuit Failure	Check Cabinet Heaters
5. Fails to Alarm	5b. Control Circuit Failure	Functional Alarm Test (Direct Wired)
5. Fails to Alarm	5b. Control Circuit Failure	Check / Verify Gauges and Alarms
5. Fails to Alarm	5c. Fuse Failure	Functional Alarm Test (Aux Relay Installations)
5. Fails to Alarm	5d. Aux Relay Failure	Functional Alarm Test (Aux Relay Installations)
5. Fails to Alarm	5e. Sensor / Monitor Failure	Check Geomagnetically Induced Current Monitor
6. Fails to Regulate Voltage	6a. Drive Train Failure	LTC Mechanism Inspection
6. Fails to Regulate Voltage	6a. Drive Train Failure	Visual Inspection
6. Fails to Regulate Voltage	6a. Drive Train Failure	Monitor LTC Operations Counter
6. Fails to Regulate Voltage	6a. Drive Train Failure	Transformer Turns Ratio
6. Fails to Regulate Voltage	6a. Drive Train Failure	LTC Continuity Test
6. Fails to Regulate Voltage	6a. Drive Train Failure	LTC Inspection
6. Fails to Regulate Voltage	6b. Contact Failure	Thermography
6. Fails to Regulate Voltage	6b. Contact Failure	Oil DGA
6. Fails to Regulate Voltage	6b. Contact Failure	Oil DGA - LTC (Non-Vacuum)
6. Fails to Regulate Voltage	6b. Contact Failure	Monitor LTC Operations Counter
6. Fails to Regulate Voltage	6b. Contact Failure	LTC Overhaul
6. Fails to Regulate Voltage	6b. Contact Failure	Oil Quality Test
6. Fails to Regulate Voltage	6b. Contact Failure	LTC Mechanism Inspection
6. Fails to Regulate Voltage	6b. Contact Failure	Flush LTC Compartments and Replace With New Oil
6. Fails to Regulate Voltage	6b. Contact Failure	Monitor LTC Filtration System
6. Fails to Regulate Voltage	6b. Contact Failure	LTC Run Thru Neutral
6. Fails to Regulate Voltage	6b. Contact Failure	LTC Continuity Test

TRANSFORMER MAINTENANCE TASK DEFINITIONS

Task	DEFINITION
Check / Verify Gauges and Alarms	Check accuracy of installed gauges and alarms. Verify switch pick up and drop out values against a calibrated instrument or gauge. Verify set points are correct and equipment operates as designed. (e.g. coolers turns on, alarm / trip is set at correct reading, gas accumulator is working properly.)
Check Automated Aux Power Throw-over Switch	Verify operation of automated auxiliary power throw-over switches located in the transformer control cabinet.
Check Bushing Oil Level	Visual verification that bushing oil levels are appropriate. This task applies only to bushings where level indication is available.
Check Cabinet Heaters	Visual/physical verification that cabinet heaters are operational.
Check Geomagnetically Induced Current	Check functionality of installed GIC monitor.
Check / Replace Desiccant	Visual verification that Main tank and LTC desiccant is clean and dry.
Flush LTC Compartments and Replace With New Oil	Flush the LTC and replace with new oil to remove carbon buildup. Task is performed along with the LTC Internal Inspection.
Frequency Response Analysis	Electrical test using Sweep method. Perform test per test equipment manufacturer. Record data for trending.
Functional Alarm Test (Aux Relay Installations)	Verify alarm at transformer is sent to substation control house and System Operations. Test should be performed by bringing up an alarm at the equipment and verifying it is received in the substation control house and System Operations.
Functional Alarm Test (Direct Wired)	Verify alarm at transformer is sent to substation control house and System Operations. Test should be performed by bringing up an alarm at the equipment and verifying it is received in the substation control house and System Operations.
Functional Test, Cooling System, Alternate Lead/Lag Coolers	Alternate lead/lag coolers to switch the cooler group that operates first. Additionally, if the coolers are not running during the inspection, they should be run manually one at a time to verify proper operation.
Inspect Bushing Potential Tap	Inspect the potential tap for loose or burned connections and ensure they are filled with the appropriate fluid. The BPD cable should be visually inspected for mechanical damage, also making sure the cable is adequately supported by attachments on the transformer tank. The cable should be replaced if damaged or frayed. The cabinet should be cleaned and inspected.
High Voltage Excitation Test	Electrical test usually performed with a Doble power factor test set that will indicate health of the magnetic circuit within the transformer. The highest possible safe voltage is applied to the single phase high-voltage winding and the current in that winding is measured.
LTC Continuity Test	Current path continuity check to ensure circuit is not interrupted during tap changer operation.

TRANSFORMER MAINTENANCE TASK DEFINITIONS

Task	DEFINITION
LTC Internal Inspection	Flush and filter the LTC or replace with new oil to remove carbon buildup and perform internal inspection.
LTC Mechanism Inspection	Off-line detailed inspection of the operating mechanism. Checks include: - Operating tap changer from local control - Check electrical interlocks - Check solenoids - Limit switches - Dash pots - Position indicators and counter for proper operation - Verify all clearance dimensions (Stops, latches, rollers, switches and links) - Check wiring terminal blocks for tightness - Inspect desiccant systems and replace desiccant on the LTC - Apply approved lubricants to bearings and other specified areas on mechanism including linkage wear points - Remove, clean, and verify operation of breather
LTC Overhaul	Minimum scope includes: - Check contacts for damage and pitting. Clean or replace as required. - Check for loose, missing or damaged hardware and components - Test vacuum bottles for integrity (if applicable) (hi-pot test) - Check alarms operate correctly - Perform a functional test of the LTC - Ensure oil is clean and has appropriate dielectric strength - Inspect gaskets and replace as necessary
LTC Run Thru Neutral	Pass through neutral to wipe carbon buildup from the reversing switch
Maintenance Inspection	Check condition of all grounds, clean and inspect all bushings for oil leaks, damage and contamination. Inspect all line connections for discoloration, frayed or damaged links and correct torque. Inspect the secondary cable bond connections for jacket slippage. Inspect and replace gaskets as necessary. Inspect hardware fittings and supports, tighten as required. Inspect control cabinet for cleanliness and overall condition. Inspect oil and air filled cable entry compartments and clean as required. Replace desiccant in Main tank systems. (Oil filled compartments that require vacuum filling should be inspected only if oil samples indicate a problem).
Monitor LTC Operations Counter	Record current operations count as indicated on mechanism counter. Reset drag hands after taking reading.
Monitor LTC Filtration System	Verify LTC filter system is operational. Monitor and record filter differential pressure, where filter system installed. Replace filter as required.

TRANSFORMER MAINTENANCE TASK DEFINITIONS

Task	DEFINITION
Monitor Nitrogen Pressure	Visual verification of proper Nitrogen pressure by monitoring the Nitrogen Pressure in the main tank and nitrogen bottle (If so equipped.) Add nitrogen as required and record amount added for trending purposes. (Note Nitrogen pressure may be connected to conservator tank but is still reading main tank pressure.)
Monitor Oil Flow	Visual verification that pumps are moving oil.
Monitor Oil Level	Visual verification of proper oil level in all oil filled compartments. Record oil level. Correct level as required and record amount added/removed for trending.
Monitor Oil Temperature	Record present top oil and maximum top oil temperatures.
Monitor Winding Temperature	Record present hot spot and maximum hot spot temperatures.
Oil DGA - Main Tank / LTC Tank (Non-Vacuum)	Take syringe samples. Follow sampling procedures for appropriate sample quantity. Data to be trended. Oil DGA Lab Analysis: Perform per ASTM D3612. The minimum scope for analysis and trending includes: Hydrogen, Carbon Monoxide, Ethylene, Ethane, Methane, Acetylene, Total Dissolved Combustible Gas, Oxygen, Nitrogen, and Carbon Dioxide. Moisture test should also be performed.
Oil Quality Test	Take 1 quart sample for voltage class < 220 kV. Take 2 quart sample for voltage class >= 220 kV. Reference sampling procedures. Oil Quality Lab Analysis per sample on Nuclear Transformers: • Dielectric Strength (ASTM D1816) • Power Factor (ASTM D924) • Interfacial Tension (ASTM D971) • Color (ASTM D1500) • Sediment (ASTM D1698 or visual), • Moisture Content (ASTM D1553) • Acid Number (ASTM D974). Oil Quality Lab Analysis per sample on Non-Nuclear Transformers: • Dielectric Strength (ASTM D1816 for ≥ 200MVA Transformers and Phase Shifters; ASTM D877 for all other transformers) • Moisture Content (ASTM D1553) • Color (ASTM D1500) • Sediment (ASTM D1698 or visual) Oil Quality Lab Analysis performed at least annually on Non-Nuclear Transformers: • Interfacial Tension (ASTM D971) • Acid Number (ASTM D974). • Power Factor @100 deg C (ASTM D924) • For breathable non-vacuum LTCs, Power Factor and Interfacial tests can be excluded.
Power Factor Test	Electrical loss measurement, usually performed using Doble power factor equipment, which helps to prove the insulation level of the device.

TRANSFORMER MAINTENANCE TASK DEFINITIONS

Task	DEFINITION
Power Wash Heat Exchangers	Remove foreign material and debris from coolers and radiators using soap and high pressure washing equipment.
Thermography	Infrared inspection of electrical equipment and power path components to identify any hot spots that may exist either in the contacts, bus connections or within control cabinets. Comparisons should be made phase to phase or on tank walls to determine if contact heating can be found or to determine oil levels within all tanks and verify level gauge.
Transformer Turns Ratio	Electrical test to verify transformer ratio. Test should be performed on all tap positions. Leave no load tap changer in as found position.
Ultrasonic Bearing Wear Monitor (Pumps)	Measure bearing wear in pumps that have Harley Techsonics bearing wear monitor.
Visual Inspection	This inspection approximates real-time condition monitoring that can detect developing problems and degradation, and provides condition data used to initiate corrective actions. These items should be checked: - Check for unusual noises and smells - Check LTC range of operation and present tap position - Verify alarm status and relay flags - Visually inspect for damage, cracked or chipped porcelain insulators - Check for signs of oil leakage from bushings, tank penetrations, gasket and flanges - Check secondary cable bond connections for jacket slippage - Check for loose, missing or damaged hardware - Check condition of grounding connections - Check coolers for debris and general cleanliness - Inspect air filters (where readily accessible) on all air filled compartments
Winding Resistance	Electrical test performed to identify high resistance connections. Test shall be performed on both primary and secondary winding connections. Test should be performed on the existing no load tap position. Test should be performed on the 3 positions of the LTC side to include neutral 1 position above and 1 Position below, 1 even and 1 odd. This test is a 'go / no go' test to indicate gross problems in the mechanical / electrical connections of the transformer.

Transformer Template Summary

The Preventive Maintenance program is documented via Maintenance Templates. Templates have been developed that address all transmission, substation, and distribution equipment that is owned, and / or, maintained by EED. Each template documents the program tasks, frequencies, failure modes, and maintenance basis for the associated equipment. Tasks and associated frequencies are designed to address known failure modes of the equipment covered by the template. In general, the tasks included in the maintenance templates are the result of good industry practices, industry experience, and manufacturer recommendations.

References:

Internal failure reports

OEM Maintenance Manuals and Interviews

EPRI 000000000001001779 Guidelines for the Life Extension of Substations

EPRI 1002913 Power Transformer Maintenance and Application Guide

IEEE Standard C57.104 IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers

IEEE Standard C57.106 IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment

IEEE Std C57.152-2013 IEEE Guide for Diagnostic Field Testing of Fluid-filled Power Transformers, Regulators and Reactors

EPRI TR-105070 Guidelines for the Life Extension of Substations

CM-ED-020010 T&S Insulating Oil Handling – Testing, Cleaning and Filling in Substation Equipment

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Boundary Definition

The boundary of a substation type, oil immersed transformer is defined from bushing terminal to bushing terminal, including:

- Pumps
- Controls
- Fans
- Radiators
- LTC (On-Load and De-energized)
- Surge Arresters

Pressure Relief Valves and Sudden Pressure (Rapid Rise) Relay
Sensors, Monitors, Alarms, and Current Transformers
Air and Oil Filled Compartments

Excluded from this treatment are: protective, timing, and control relays, iso-phase bus, duct and cooling, conductors, and fire suppression equipment.

Failure Experiences
Transformer failures are subject to ACE/RCI investigation. Findings/recommended corrective actions are incorporated into the template as required.

Vendor Recommendations
OEM manuals were referenced and interviews conducted during the development of this template.

Disposition of Vendor Recommendations
Recommendations were incorporated into the template as deemed necessary.

Basis For Template Tasks

Check / Replace Desiccant: Task intended to ensure designed systems are operating properly to prevent moisture intrusion into the transformer compartments.

Check / Verify Gauges and Alarms: IEEE Standard C57.152 identifies calibration as a tool for identifying problems with the various controls and indicators. EPRI 106857-V38 identifies the importance of controls and indications to the operator and system engineer in monitoring the performance of a transformer, and the importance of periodic calibration to ensure proper operation.

Check Automated Aux Power Throw-over Switch: Some transformer control cabinets on the system have been designed and installed with a main and emergency source of auxiliary power. These designs typically contain a throw-over switch located in the same control cabinet. This task is to verify operation of the throw over switch associated with this configuration. Failures of this scheme and type of equipment have been identified on the Exelon system.

Check Bushing Oil Level: Oil filled bushings normally have a means to check the level inside the bushing. Failure modes have been identified on the Exelon system that indicate failure of gasket material which causes loss of oil and eventual failure due to the decrease in dielectric strength associated with the loss of insulating fluid.

Check Cabinet Heaters: Task intended to ensure designed systems are operating properly to prevent moisture intrusion into the transformer control cabinets. Moisture in these areas have been known to cause corrosion damage to transformer control and alarm circuits.

Check Geomagnetically Induced Current Monitor - Solar flares may result in geomagnetically induced current (GIC) flow in transformer windings. Task is intended to ensure GIC monitor is operational.

Flush LTC Compartments and Replace With New Oil: Carbon is generated from operation of tap changers in normal service. This carbon can become attached to contacts and cause high resistance connections that begin to heat up and cause damage. Compartment must be flushed to remove carbon buildup and the tap changer needs to be refilled with New Oil. Task is a candidate for extension on transformers with known non-arcing type tap changers such as vacuum type that would not normally produce carbon products. Oil sample results must be reviewed and conditions proven to be clean and free of carbon.

Frequency Response Analysis: IEEE Standard C57.152 identifies electrical testing as a key diagnostic technique for identifying issues with the core, coils and bushings of a transformer. EPRI 106857-V38 identifies electrical testing as a key tool for evaluating the condition of the transformer. Sweep Frequency Response Analysis (SFRA) utilizes the natural inductance and capacitance of the transformer windings and plots a characteristic response curve from about 10 Hz to 2 MHz. If a change in the physical relationship between the windings occurs, then the response curves will change, indicating a need to do further inspections or evaluations. This test should be performed to obtain a baseline, after moving a transformer, and concurrent with electrical tests when the transformer is isolated. This is a relatively new technology that has successfully been used within Exelon to identify internal issues with transformers. SFRA testing is suggested as a post-event diagnostic tool by most OEMs. There are software programs available for automated analysis of SFRA test results.

Functional Alarm Test: EPRI 106857 identifies functional testing of control circuits to verify proper operation of the auxiliary systems.

Functional Test, Cooling System, Alternate Lead/Lag Coolers: Transformers with two stages of cooling will have the first stage of cooling either operating continuously or coming on at a lower temperature than the second stage. Alternating lead/lag coolers will switch the cooler group that operates first. This action assures even wear on all cooler group components and provides assurance that all coolers are operating properly. Additionally, if the coolers are not running during the inspection, they should be run manually one at a time to verify proper operation.

Inspect Bushing Potential Tap: Potential tap failures have been experienced on the system. These failures cause significant damage and result in extended outages. This task is a result of analysis of data that identified a recurring problem on the system. Transformer bushings many times have potential taps that may be used to provide voltage for relaying schemes or power for auxiliary equipment. Additionally, this tap is used to measure power factor of the bushing. When not in use these taps must be grounded. These taps need to be filled with oil or a dielectric grease.

High Voltage Excitation Test: IEEE Standard C57.152 identifies electrical testing as a key diagnostic technique for identifying issues with the core, coils and bushings of a transformer. EPRI 106857-V38 identifies electrical testing as a key tool for evaluating the condition of the transformer. The low voltage excitation test provides indication of defects in the magnetic circuit, shifting of windings, failures in turn-to-turn winding insulation, and problems in the tap changer circuit.

LTC Continuity Test: Test to determine if tap change operation is smooth and does no break load during operation. Tap changers are designed to change taps within the transformer in response to changing load conditions. Ultimately keeping the voltage within tariff requirements. A common failure mode with tap changers is failure of the mechanism to properly shunt in resistors or shunting windings to carry the load while the tap changer contacts are in motion, resulting in dropping load during the tap changer operation.

LTC Mechanism Inspection: Load tap changer mechanisms have been the cause of many priority emergent work requests. A review of work history within the Exelon system has indicated that periodic inspections are required to ensure the gears, electrical limit switches, braking systems and drive motors operate as designed.

LTC Internal Inspection: Carbon is generated from operation of tap changers in normal service. This carbon can become attached to contacts and cause high resistance connections that begin to heat up and cause damage. Compartment must be flushed to remove carbon buildup and the tap changer needs to be refilled with New Oil. Alternatively, performing Winding Resistance and Transformer Turns Ratio tests along with oil DGA/Quality results will determine impending issues.

Power Factor Test for ≥9375kVA Transformers (excluding Auto Transformers), Maintenance frequency of ≤6Y is acceptable for Transformers with known industry Bushing issues. Industry known bushing failures include, but not limited to, General Electric U models, Trench COTA models, etc. More frequent testing / trending of the Bushing can lead to early detection of Bushing issues.

LTC Overhaul: EPRI 106857-V38 identifies this maintenance to detect problems with tap changer contacts due to wear and high resistance connections that result in coking or thermal failure of the contacts. Due to success with the monitoring and diagnostic testing performed on this equipment; this task has been deemed a condition directed task. Analysis of oil DGA and oil quality, combined with periodic inspections, thermography and various time based electrical and mechanical tests, relative health of the tap changer contacts can be determined with enough lead time to order parts and schedule outages without impacting system reliability.

LTC Run Thru Neutral Oil quality and DGA analysis have been proven to identify tap changes with contacts that have degraded and started the coking process but these tasks identify a failed condition. Running the LTC thru neutral will wipe the reversing switch contacts and prevent the coking from starting. This task will be on different frequencies East and West as a result of the condition of the tap changers in each area.

Maintenance Inspection: Time based periodic detailed inspection of transformer to address and repair items that fail or degrade over time.

Monitor LTC Operations Counter: Collection of this data is required to assess the condition of the tap changer. This data is also used to determine if the tap changer has gone thru neutral.

Monitor LTC Filtration System: Collection of this data is required to assess the condition of the tap changer filter system.

Monitor Nitrogen Pressure: Collection of this data is required to ensure proper head pressure is maintained. This nitrogen pressure is intended provide an inert atmosphere above the oil level that acts to prevent corrosion of the internal components, prevent oxidation of the oil and act as a buffer to allow for thermal expansion and contraction of the oil.

Monitor Oil Flow Indicator: Ensures proper pump operation through indication of oil flow.

Monitor Oil Level: Oil level is required to maintain the design properties of the insulating systems, provide cooling to the winding and core. Loss of oil will result in equipment failure. Minor loss of oil will result in environmental cleanup.

Monitor Oil Temperature: Oil and winding temperature measurement are a result of the load current, ambient temperature and effectiveness of the cooling systems. Temperatures of the oil and winding are directly related to the transformer life. Tracking the actual and maximum temperatures seen can provide insight into the condition of the transformer and correlate to dga oil samples.

Monitor Winding Temperature: Oil and winding temperature measurement are a result of the load current, ambient temperature and effectiveness of the cooling systems. Temperatures of the oil and winding are directly related to the transformer life. Tracking the actual and maximum temperatures seen can provide insight into the condition of the transformer and correlate to dga oil samples.

Oil DGA - Main Tank / LTC (Non-Vacuum): IEEE Standard C57.152 identifies dissolved gas analysis as a primary troubleshooting tool for a range of electrical faults in the transformer, as well as the condition of the insulating oil. EPRI TR-106857-V38 identifies dissolved gas analysis as a tool for detecting electrical degradation of the coils, core, cooling system and insulating system. EPRI 1002913 identifies dissolved gas analysis as an excellent method of assessing transformer condition. The minimum scope for analysis and trending includes: Hydrogen, Carbon Monoxide, Ethylene, Ethane, Methane, Acetylene, Total Dissolved Combustible Gas. Additionally, the following are included in the minimum scope to trend insulation degradation, identify leaks, monitor the integrity of the oil preservation system and verify the quality of the oil sample: Oxygen, Nitrogen, Carbon Dioxide. Moisture test should also be performed.

Oil Quality Test: IEEE Standard C57.152 identifies oil quality tests as a tool for monitoring aging and condition of the insulating system. Follows ASTM standards as prescribed therein. Oil quality tests provide indication of oil condition and long term paper degradation. EPRI 1002913 identifies oil analysis as a primary tool for determining transformer condition. Insulating oil is a significant element in the insulating system. These tests assess the condition of the oil and the cellulose insulation system. EPRI TR-106857-V38 recommends periodic insulating oil quality tests. The scope of testing includes: Dielectric Strength (ASTM D1816 is the preferred method for HV/LV Transmission Transformers), Power Factor, Interfacial Tension, Color, Sediment, Moisture Content, Acid Number. It is important to obtain the temperature of the equipment at the time of the sample to ensure accurate calculation of H_2O saturation. Conditional Testing: PCB Test on any equipment >45 ppm. Transformers newer than 1980 are exempt.

Option at OpCo Discretion:
Power Factor, Interfacial Tension and Acid Number can be tested annually if trending results indicate no significant change over time that could result in equipment failure. For breathable non-vacuum LTCs, Power Factor and Interfacial tests can be excluded. Due to Nuclear Switchyard criticality, all prescribed tests shall be performed per sample.

Power Factor Test: (including bushings and arresters) IEEE Standard 62 identifies electrical testing as a key diagnostic technique for identifying issues with the core, coils and bushings of a transformer. EPRI 106857-V38 identifies electrical testing as a key tool for evaluating the condition of the transformer. Power Factor test provides indication of insulation degradation in the main tank or in the bushings and arresters. Best applied as a trending tool.

Power Wash Clean Coolers/Radiators: EPRI 106857-V38 identifies the fact that periodic cleaning of fin-type or honeycomb radiators is extremely important in ensuring proper operation of the transformer cooling system. Experience has shown that the transformer radiators need to be cleaned on a periodic basis to keep them performing at an optimum condition. The proper cleaning is to perform bi-directional cleaning to assure the coolers are clean for the summer. In the West, cleaning is required post cottonwood bloom in affected areas.

Thermography: IEEE Standard C57.152 identifies thermography as a primary tool for detection of connection issues, bushing issues, and issues with the cooling systems. EPRI 1002913 identifies thermography as a tool for detection of connection issues, insulator degradation and cooling system operation. EPRI TR-106857-V38 Identifies thermography as a tool for detection of loose electrical connections, LTC contact problems, local flux current heating, proper cooler operation, bearing wear in pump and fan motors.

Transformer Turns Ratio: IEEE Standard C57.152 identifies electrical testing as a key diagnostic technique for identifying issues with the core, coils and bushings of a transformer. EPRI 106857-V38 identifies electrical testing as a key tool for evaluating the condition of the transformer. The turns ratio test provides indication of winding failures, and correct operation of the LTC.

Ultrasonic Bearing Wear Indicator: Applicable to Harley oil pumps that have an integral Tecsonics bearing wear monitoring system installed. Oil pump bearings will wear out over time. The wear needs to be trended to detect incipient failure. The pumps need to be replaced before the bearings fail due to the difficulty of replacing a pump and the consequences of an on-line failure (metal wear products spread throughout the transformer with significant impact on the strength of the insulating system). This check is performed with the transformer and pumps in service; it requires specialized test equipment.

Visual Inspection: (Operator Rounds) This inspection approximates real-time condition monitoring that can detect developing problems and degradation, and provides condition data used to initiate corrective actions.

Winding Resistance: IEEE Standard C57.152 identifies electrical testing as a key diagnostic technique for identifying issues with the core, coils and bushings of a transformer. EPRI 106857-V38 identifies electrical testing as a key tool for evaluating the condition of the transformer. The winding resistance test provides indication of loose connections and high contact resistance.

TRANSFORMER TEMPLATE DEVELOPMENT HISTORY

	Revision 0	**Date 12/22/2006**
Writer	George Leinhauser (Strategic Programs)	
Reviewer(s)		
Approver(s)	Kathy McHugh (FAM Maintenance Planning)	
Reason Written	To document the maintenance program tasks, frequencies, failure modes, and maintenance basis	

	Revision 1	**Date 01/26/2007**
Writer	George Leinhauser (Strategic Programs)	
Reviewer(s)		
Approver(s)	Kathy McHugh (FAM Maintenance Planning)	
Reason Written	Visual Inspection and Maintenance Inspection Tasks Definitions updated to add additional clarity associated with secondary cable bond connections.	

	Revision 2	**Date 11/30/2010**
Writer	Chris Stefanski	
Reviewer(s)	Ken Wendt (Mgr. Material Condition)	
Approver(s)	Bill Fluhler , Bill Gannon, Nitin Patel, Jim Crane, Bill Sullivan	
Reason Written	Added note to ensure template changes are communicated to affected work groups.	

	Revision 3	**Date 04/29/2011**
Writer	Chris Stefanski (Material Condition)	
Reviewer(s)	Ken Wendt, Drew Reindel, Jim Crane	
Approver(s)	Bill Fluhler (ComEd) , Bill Sullivan (PECO)	
Reason Written	Modified criticality definitions and incorporated 10-week and 3-month inspection task frequencies. Created separate tabs by transformer size.	

	Revision 4	**Date 04/28/2014**
Writer	Steven Scalcucci (Material Condition)	
Reviewer(s)	Ken Wendt, Kushal Singh, Ty Lutes, Charles McDonald	
Approver(s)	Michael Moy (ComEd UFAM)	

TRANSFORMER TEMPLATE DEVELOPMENT HISTORY

Reason Written	3 year review, reformat document, frequency changes to align with 4 year FEG cycles. Remove sudden pressure relay test, will be incorporated in relay protection template.

	Revision 5 **Date 01/09/2015**
Writer	Chris Stefanski (Exelon Utilities)
Reviewer(s)	Ken Wendt, Kushal Singh, Ty Lutes, Charles McDonald
Approver(s)	Michael Moy (ComEd UFAM)
Reason Written	In support of maintenance alignment effort at the Nuclear Switchyards, adjusted criticality definitions and added TTR, low voltage excitation and winding resistance tests for transformers at Nuclear Switchyards. Added check of Geomagnetically Induced Current Monitor.

	Revision 6 **Date 03/02/2016**
Writer	Hugo Castaneda (Material Condition)
Reviewer(s)	Ken Wendt, Kushal Singh, Ty Lutes, Charles McDonald, Nitin Patel
Approver(s)	Michael Moy (ComEd UFAM)
Reason Written	Updated template tasks to align with new EU standard. Included new tab for 34kV Small Power Transformers with LTC.

	Revision 7 **Date 10/27/2017**
Writer	Hugo Castaneda (Material Condition)
Reviewer(s)	Ty Lutes (ComEd), Kushal Singh (ComEd), Brian Chapman (ComEd), Dale Player (ComEd), Nitin Patel (ComEd), Ismael Rivera Jr (Dresden Nuclear Station Systems Engineer), Kent Nelson (LaSalle Nuclear Station Systems Engineer)
Approver(s)	Michael Moy (ComEd UFAM)
Reason Written	Revised to reflect recommended changes from the EU Transformer PM Template Effectiveness Review that includes updates to Oil Quality tests, LTC internal inspection and other clarifications. In addition, added new criticalities to align with AM-CE-P034-R0001.