METHODS FOR POWER TRANSFORMER CONDITION DIAGNOSTICS

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ABSTRACT

The paper gives an overview of methods for diagnostics of oil-filled power transformer functional parts (windings, bushings, oil, core, conservator, tank and accessories and cooling system). An overall transformer condition assessment methodology, linking routine maintenance and diagnostics is given. For each method list of problems that can be detected is quoted. For three reliability levels (low, medium and high) and for three equipment condition levels (poor, average, good) a preventive maintenance frequency matrix and values of multiplier for inspections and tests are given.

1. AN OVERVIEW OF METHODS

"Ideal" maintenance program is reliability-based, unique to each substation and to each peace of equipment. In the absence of this information and in response to requests for a maintenance timetable, following time-based maintenance schedule and matrix can be used.
A preventive maintenance frequency matrix is given in Table 1.

TABLE 1 Maintenance Frequency Matrix

		Equipment Condition		
		POOR	**AVERAGE**	**GOOD**
EQUIPMENT RELIABILITY REQUIREMENT	**LOW**	1.0	2.0	2.5
	MEDIUM	0.50	1.0	1.5
	HIGH	0.25	0.50	0.75

Values of multiplier for inspections and tests are given in Table 2. Each of these values is an interval duration (in months) between preventive maintenance actions for a medium reliability level and for an actual average equipment condition.
Table 1 is to be used in conjunction with Table II. For example: if we want to maintain average reliability level of oil power transformers for their actual average condition, we should perform visual, mechanical and electrical tests each 24 months. But, if we want to have high reliability power transformers, in an average condition, period between two inspections should be $24 \cdot 0.5 = 12$ months.

TABLE 2 Multiplier for Inspections and Tests (Frequency in Months)

Description	Visual	Visual & Mechanical	Visual & Mechanical & Electrical
Switchgear & Switchboard Assemblies	12	12	24
Transformers			
Small Dry-Type Transformers	2	12	36
Large Dry-Type Transformers	1	12	24
Liquid-Filled Transformers	1	12	24
Sampling	-	-	12
Cables			
Low-Voltage Cables	2	12	36
Medium- and High-Voltage Cables	2	12	36
Metal-Enclosed Busways	2	12	24
Infrared Only	-	-	12
Switches			
Low-Voltage Air Switches	2	12	36
Medium-Voltage Metal-Enclosed Switches	-	12	24
Medium- and High-Voltage Open Switches	1	12	24
Medium-Voltage Oil Switches	1	12	24
Medium-Voltage Vacuum Switches	1	12	24
Medium-Voltage SF_6 Switches	1	12	24
Circuit Breakers			
Medium-Voltage Oil CB	1	12	36
Sampling	-	-	12
High-Voltage Oil CB	1	12	12
Sampling	-	-	12
Medium-Voltage Vacuum CB	1	12	24
Protective Relays			
Electrical/Mechanical and Solid State	1	12	12
Microprocessor-Based	1	12	12
Instrument Transformers	12	12	36
Metering Devices	12	12	36
Regulating Apparatus			
Step-voltage Regulators	1	12	24
Sample liquid	-	-	12
Load-Tap-Changers	1	12	24
Sample Liquid	-	-	12
Surge Arresters			
Low-Voltage Devices	2	12	24
Medium- and High-Voltage Devices	2	12	24
Capacitors and Reactors			
Capacitors	1	12	12
Capacitors Control Devices	1	12	12
Reactors-Dry-Type	2	12	24
Reactors-Liquid-Filled	1	12	24
Sampling	-	-	12
Uninterruptible Power Systems	1	12	12
Telemetry/Pilot Wire SCADA	1	12	12

Automatic Circuit Reclosers, Oil/Vacuum	1	12	24
Automatic Line Sectionalizers, Oil	1	12	24

2. TRANSFORMER CONDITION ASSESSMENT METHODOLOGY

This part addresses specific testing and diagnostic techniques and tools used to assess the condition of oil-filled power transformers. These processes are often above and beyond routine maintenance work on a regular basis to keep transformer operational.
Table 3 shows the overall transformer condition assessment methodology, linking routine maintenance and diagnostics.

TABLE 3 An overall transformer condition assessment methodology

Windings	DC Resistance
	Turns Ratio
	Percent Impedance/Leakage Reactance
	Sweep Frequency Response Analysis (SFRA)
	Doble Tests (for windings and oil): Capacitance Excitation Current and Watts Loss Power Factor/Dissipation Factor
Bushing and Arresters	Capacitance (Doble Tests)
	Dielectric Loss (Watts)
	Power Factor
	Temperature (Infrared camera)
	Oil Level (bushings only)
	Visual Inspection for Porcelain Cracks and Chips
Insulating Oil	Dissolved Gas Analysis
	Dielectric Strength
	Metal Particle Count (if transformer has pump problems)
	Moisture
	Power Factor/Dissipation Factor (Doble)
	Interfacial Tension
	Acid Number
	Furans
	Oxygen Inhibitor
Core	Insulation Resistance
	Ground Test
Conservator	Visual (oil leaks and leaks in diaphragm)
	Inert Air System (desiccant color)
	Level Gauge Calibration
Tanks and Auxiliaries	Fault Pressure Relay (functional test)
	Pressure Relief Device (visual)
	Buchholz Relay (visual check for gas)
	Top Oil Temperature Indicator
	Winding Temperature Indicator
	Infrared Temperature Scan
	Fault Analyzer (ultrasonic)
	Sound Analyzer (sonic)
	Vibration Analyzer
Cooling System	Clean (fan blades and radiators)
	Fans and Controls (check fan rotation)
	Oil Pumps (check flow indicators, check rotation)
	Pump Bearings (vibration, sound and temperature)
	Check Radiator (valves open)
	Check Cooling System with Infrared Camera

Sequence of methods and procedures performing in order of power transformer condition evaluation is as follows:

- Step 1: Routine tests and inspections (DGA, Doble, visual inspection, IR analysis, Temperature and level indicators etc). If all indices are inside the limits of normal values procedure is over. If value of some, anyone, index is out of the limits go to the Step 2.
- Step 2: Repeat DGA, all physical and Furan tests and/or physical inspection, emphasis on oil temperatures and levels and/or ultrasonic and sonic contact and non-contact fault detection and/or IR analysis and/or vibration analysis and/or review operating history and/or corona measurements.). If all indices are inside the limits of normal values procedure is over. If value of some, anyone, index is out of the limits go to the Step 3.
- Step 3: Routine Doble tests, SFRA and leakage reactance and/or transformer turns ratio and/or across-winding DC resistance measurements and/or core ground tests (if available outside tank).). If all indices are inside the limits of normal values procedure is over. If value of some, anyone, index is out of the limits go to the Step 4.
- Step 4: Core ground tests (if available outside tank) and/or inspect and tests for bad connections on bushings, leads and tap-changer and/or take paper sample for degree of polymerization test and/or look for oil sludging, displacement or loose windings or wedges and debris, evidence of hot-spots etc.). If all indices are inside the limits of normal values procedure is over. If value of some, anyone, index is out of the limits consider major rehabilitation of replacement.

A summary of diagnostic techniques is given Table 4.

TABLE 4 A summary of diagnostic techniques

Tests	**Defects**
On-line tests	
Dissolved Gas Analysis (Laboratory and Portable)	Measures dissolved gasses: to detect arcing, bad electrical contacts, hot spots, partial discharges, overheating of conductors, oil, tank, paper insulation
Oil physical and chemical tests	Moisture, interfacial tension, acidity, furans, dissolved metals and metal particles count (indicates pump problems)
Physical inspection-external	Oil leaks, broken parts, worn paint, defective support structure, malfunctioning temperature and level indicators, cooling problems, pump and radiator problems, bushing and lightning arrester porcelain cracks etc.
Infrared scan	Hot spots, localized heating, bad connections, circulating currents, blocked cooling, tap changer problems, bushing and lightning arrester problems.
Ultrasonic and sonic contact fault detection	Internal partial discharge, arcing, sparking, pump impeller and bearing problems, mechanical noises, loose parts (blocking, deflectors etc.)
Ultrasonic non-contact and contact fault detection	Nitrogen leaks, vacuum leaks, corona at bushings, pump mechanical and bearing problems, cooling fan problems
Vibration analysis	Internal core, shield problems, loose parts vibration.
External temperatures (main tank)	Temperature monitoring with changes in load and ambient temperature.
Sound level	Internal and external noises to compare to baseline and other vibration tests
Corona	Compare bushings and lightning arresters and all high voltage connections with sister units
Off-line tests	
Doble power factor	Loss of winding insulation integrity, loss of bushing insulation integrity, winding moisture.
Excitation current	Shortened turns in windings
Turns ratio	Shortened windings
Leakage reactance	Measures percent impedance, to be compared to name plate after moving or through fault.
Sweep Frequency Response Analysis	Structural problems, core and winding problems, movement of core and windings. Run this test before and after moving and after a through fault.

Across winding resistance measurements	Broken strands, loose connections, bad contacts in tap-changer.
Winding DC resistance to ground	Winding low resistance to ground (leakage current)
Core to ground resistance	Bad connection on intentional core ground or existence of unintentional grounds
Internal inspections and tests	Oil sludging, displaced winding or wedging, loose windings, bad connections, burned conductors
Degree of polymerization	Insulation condition (life expectancy)

Key words: Transformer- Condition- Methods- Assessment- Reliability- Defects.

3. REFERENCES

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