Overview of Testing Methods Required to Maintain Electrical Power Equipment

Engineers Joint Committee of Long Island

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Megger

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LEGAL DISCLAIMER

- This presentation is offered for informational purposes only and shall not be relied upon for any work in the field
- Only fully qualified personnel shall work on electrical equipment
- Electrical equipment shall only be worked on in a de-energized state
- All tables have accompanying footnotes that have been removed for brevity

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QUESTIONS

- What is an acceptable power reliability?
- What are some of the things that could interrupt the continuous flow of power?
- Is maintenance an income or an expense?
- Why do we test?
- Who should test?

WHAT IS AN ACCEPTABLE POWER RELIABILITY?

- Only one acceptable answer to the consumer – continuous power
- To the facility manager – cost of maintaining a bullet proof system vs. cost of an outage
- P.S. As I'm typing this, the power goes out at the Super Bowl – what did this cost?

WHAT COULD INTERRUPT POWER?

- GENERATION – loss of cooling, electrical shutdown, etc.
- TRANSMISSION – Lightning, protective device malfunction, overload?
- DISTRIBUTION – animal contact, car pole accident, storms, lightning, overload!
- UTILIZATION – lack of maintenance, inadvertent operation, ground fault, human error

IS MAINTENANCE INCOME OR EXPENSE?

- To the bean counters – an expense?
- To the maintenance technician – a necessity since the flow of power = the flow of business?

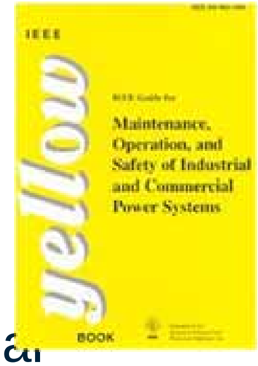
WHY DO WE TEST?

- Personnel safety – arc flash protection assumes equipment will interrupt precisely as intended
- Fire safety – NFPA National Electrical Code
- Insurance company required
- Regulatory – NERC/FERC
- Aging infrastructure
- Equipment manufactured to precise specifications (i.e. no fluff)
- Increase life cycle and defer the need for capital investment

WHO SHOULD TEST?

- Hospitals
- Data centers
- Utilities
- Industrials
- Commercial
- Everyone should have some form of testing to ensure safety

RESOURCES



- AVO Training Institute - Substation Maintenance
- IEEE - Color Book Series (Yellow Book - Guide for Maintenance, Operation, & Safety of Industrial & Commercial Power Systems)
- NETA – Standard for Acceptance/Maintenance Testing Specifications
- NETA Level II, III and IV test technicians
- NFPA 70B: Recommended Practice for Electrical Equipment Maintenance
- ANSI, NEMA, IEC
- Manufacturers of apparatus
- Authors such as Paul Gill - Electrical Power Equipment Maintenance and Testing

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RESOURCES (Continued)

- Manufacturers of test equipment:
  - Megger
  - Doble
  - Omicron
  - Vanguard
  - Flir
  - Fluke
  - Many more

REGULATORY

- NFPA – National Fire Protection Association
- NFPA 70: NEC – National Electrical Code
- NFPA 70E: Standard for Electrical Safety in the Workplace

- NESC – National Electrical Safety Code
- OSHA – Occupational Safety & Health Administration

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ELECTRICAL PREVENTIVE MAINTENANCE (EPM)

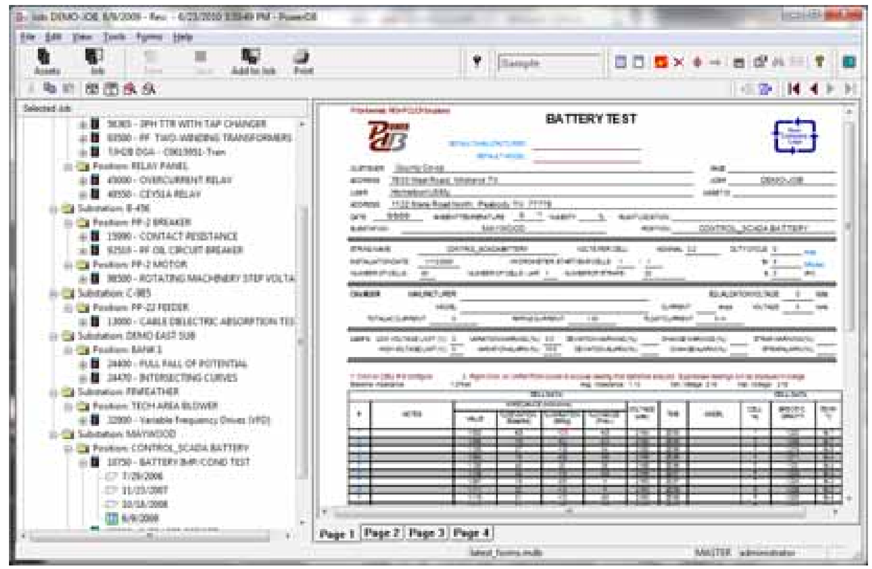
- Let's start with Acceptance Testing – Startup & Commissioning
  - Establish baseline data for future trending
  - Ensure compliance of equipment to specifications
  - Check "full" range of apparatus, not just operating range
  - Confirm that equipment installed without damage

ELECTRICAL PREVENTIVE MAINTENANCE (Continued)

- Let's proceed to Maintenance Testing
  - Traditionally these programs were time based
  - Preventive vs. Predictive
  - Reliability Centered Maintenance (RCM)
  - Condition Monitoring – online
  - Historical performance of different assets
  - Whichever method works best – a Computerized Maintenance Management System should be utilized

CMMS

- Computerized Maintenance Management Systems
  - Manage work orders
  - Track PM
  - As found & as left data
  - Asset management
  - Inventory control
  - Root cause analysis
  - Trending
  - Regulatory reporting
  - Advanced analysis



- Example: PowerDB, Maximo, Cascade, Pow-R-Test

PERSONNEL QUALIFICATIONS

- Technicians must be trained and experienced for apparatus being tested
- Only qualified persons should attempt maintenance
- NETA - Levels II, III and IV test technician
  - www.netaworld.org/certification
- Manufacturer certified
- Union specific training

MAINTENANCE & TESTING

- This presentation is going to focus on the electrical testing aspect of a maintenance program

- There are many more steps involved with:
  - Mechanical testing
  - Visual inspections
  - Verifications
  - Terminations
  - Sequencing
  - Levels
  - Etc.

MAINTENANCE & TESTING (Continued)

- Tests **should** be done on deenergized equipment
- Test equipment should be calibrated to NIST

- Short circuit and coordination studies should be provided
- Equipment should be inspected for conformance with studies and settings

- Arc flash study should be completed and equipment properly labeled

TEST EQUIPMENT TO BE COVERED

- Low Resistance Ohmmeter (Ductor)
- Insulation Resistance Tester (Megger)
- Dielectric Withstand (Hi-Pot)
- Transformer Turns Ratio (TTR)
- Power Factor (Doble)
- Transformer Ohmmeter – Winding Resistance
- Vacuum Bottle Integrity Tester
- Ground Resistance Tester
- High Current Injection
- Circuit Breaker Analyzer

TEST EQUIPMENT TO BE COVERED (Continued)

- Battery Capacity (Load) Tester
- Battery Impedance Tester
- Relay Test Set
- Oil Dielectric Test Set

LOW RESISTANCE OHMMETER

- Ductor, Digital Low Resistance Ohmmeter (DLRO) or micro-ohmmeter
- Measure contact resistance, bus joints, etc.
- Applies DC Current
- Measures Voltage Drop
- Calculates (Low) Resistance in $\mu\Omega$
- Utilizes Kelvin connections
- $R = \frac{V}{I}$

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INSULATION RESISTANCE TESTER

- Megger or Megohmmeter
- Applied at or above rated voltage
- Affected by temperature, humidity, test voltage
- Should be normalized to 20°C
- Comparison test
- Used for Polarization Index
  - Ratio of $IR\ @\ 10\ minutes\ / IR\ @\ 1\ minute$
- Applies DC Voltage up to 15kV
- Measures Leakage Current
- Calculates (High) Resistance in MΩ

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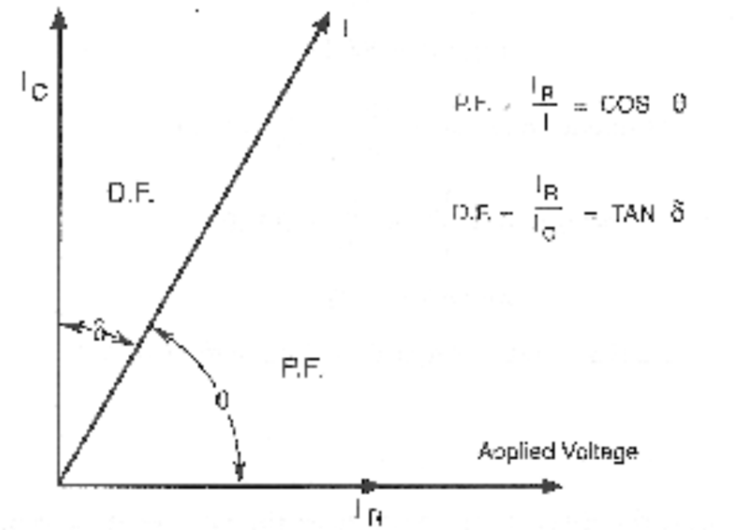
DIELECTRIC WITHSTAND

- High Potential, Hi-Pot
- DC test applied at 60Hz crest voltage $\sqrt{2}$ X RMS
- Overpotential – Go / No Go or Pass/Fail test
- Used for dielectric absorption
  - Good insulation should show increase in resistance
  - Because absorption current decreases
- Used for step-voltage test
- DC not recommended for cables
- AC test applied at 60Hz
- Used for testing bucket trucks

TRANSFORMER TURNS RATIO

- TTR
- Determines ratio of transformer
- $\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$
- Applies voltage to one winding and measures the other and calculates the ratio
- Used in both power and control transformers
  - 1∅ and 3∅
  - CTs and PTs

POWER FACTOR



- Doble test
- Dissipation Factor (tan δ)
- AC test
- Non destructive
- $PF = \dfrac{watts\ absorbed\ in\ insulation}{applied\ voltage\ X\ charging\ current}\ X\ 100$
- $DF = {}^{I_R}/_{I_C}$
- Perfect insulation would have PF of 0%
- Must be corrected to 20°C

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POWER FACTOR (Continued)

- Also used for excitation test
- Checks for:
  - Defects in manufacturing
  - Faults in windings
  - Problems with Load Tap Changers
  - Abnormal core grounds
- AC voltage applied to a transformer winding creates a magnetizing current
- This is recorded as excitation current
- Comparative test

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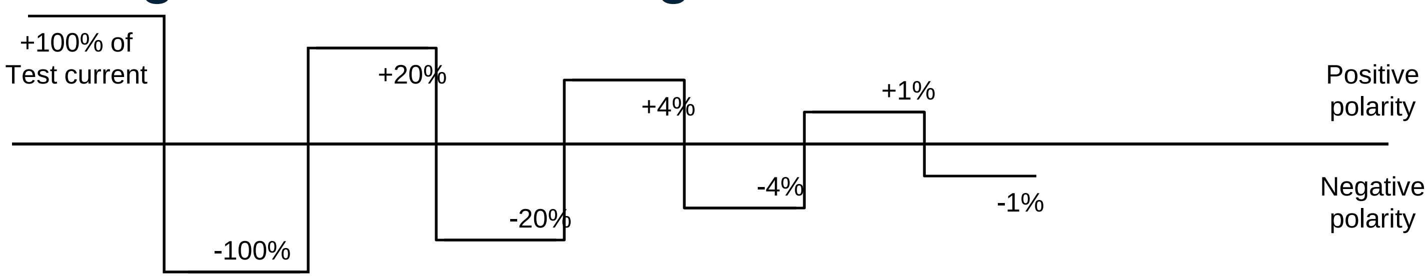
TRANSFORMER OHMMETER – WINDING RESISTANCE

- Apply a DC current and measure voltage drop
- Calculate resistance
- $\mathrm{V} = RI + L\frac{\partial I}{\partial t}$
- Need to saturate the core so the $L\frac{\partial I}{\partial t}$ goes to zero
- DC current magnetizes the core
- Demagnetize to avoid high inrush currents



VACUUM BOTTLE INTEGRITY TESTER

- Check integrity of vacuum
- AC Hi-Pot test
- DC Hi-Pot test

GROUND RESISTANCE TESTER

- National Electrical Code 250.56
  - A single electrode > 25Ω is to be augmented by one additional electrode
- Fall-of-potential test measures R of earth electrode
- Injects AC current at fixed point
- Measures voltage at multiple points, graphed and accepted where curve is flat

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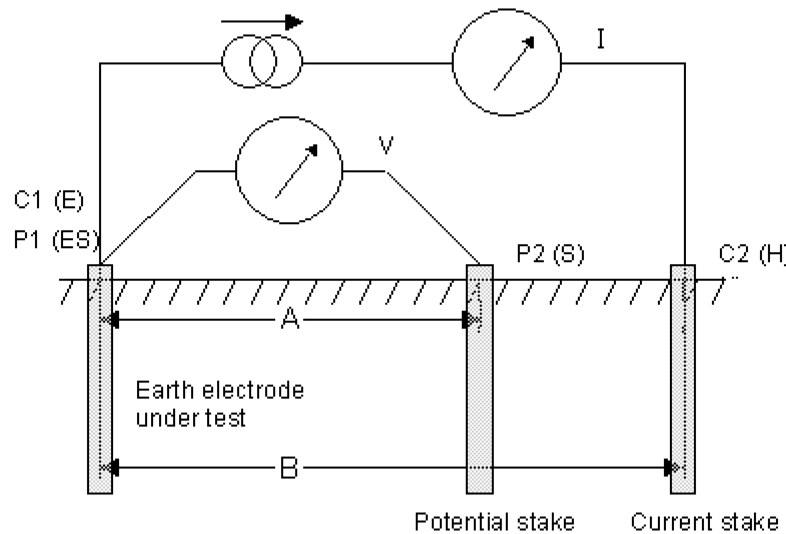
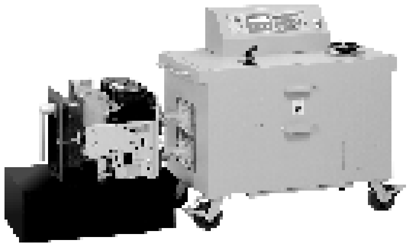


HIGH CURRENT INJECTION



- Primary Injection through low voltage circuit breakers
- Injects full current through circuit breaker
- Allows measurement of instantaneous, long time, short time and ground fault
- Provides complete check of breaker and protective circuit
  - CTs
  - Control wiring
  - Relay
  - Trip Unit

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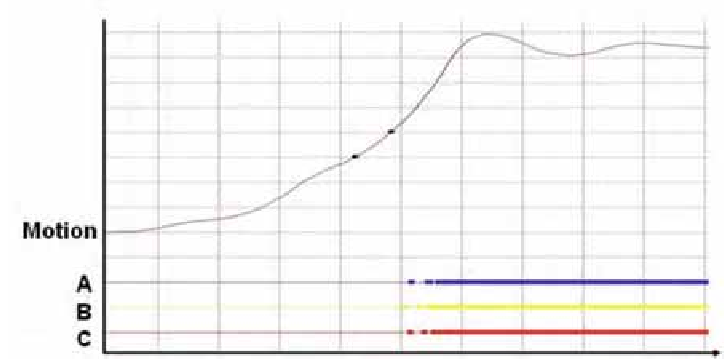
CIRCUIT BREAKER ANALYZER



- Time-Travel
- Measures
  - Closing & opening time
  - Contact bounce
  - Opening & closing synchronization
  - Closing and opening velocity
  - Trip operation
  - Trip-free operation
  - Close operation
  - Trip-close operation
- First trip

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BATTERY CAPACITY TESTER

- Load testing
- IEEE 450 for flooded lead-acid
- IEEE 1188 for sealed lead-acid
- IEEE 1106 for nickel-cadmium
- The only way to get an accurate value on the actual capacity of the battery
- Puts a resistive load on the in-service bank and measures Amp-hours the battery can deliver before the terminal voltage drops to a specified point
- Constant current

BATTERY IMPEDANCE TESTER

- Injects an AC current
- Measures AC voltage drop across each cell
- Calculates impedance
- Also calculates strap resistance
- Compare cells to one another
- Trending

- NERC PRC-005

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BATTERY GROUND FAULT FINDER

- Inject an AC signal – 20Hz
- Superimposed over DC without interruption
- Follow the path through ground
- Temporarily isolate ground fault monitors

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RELAY TEST SET

- High compliance voltage and high current test
- Test electromechanical, solid-state and microprocessor relay
- Timed outputs until relay trips
- End to end test with GPS
- IEC 61850 & GOOSE protocol
- Generic Object Oriented Substation Events

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OIL DIELECTRIC TEST SET

- Liquid dielectric breakdown testers
- Determines the dielectric strength of high voltage insulating liquids
- Measures voltage at breakdown
- Measures the insulating ability of a liquid to withstand electrical stress
- Different electrodes for different standards
- Gap is set with spacer
- Some standards call for stirring

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SWITCHGEAR/SWITCHBOARD

- Thermographic survey under full load

DANGER!!!

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value
- Test insulation resistance for each section of bus – phase-to-phase and phase-to-ground
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Conduct dielectric withstand for each section of bus - phase-to-ground with phases not under test grounded (optional)
  - Only if insulation resistance levels are acceptable
  - Compare to manufacturers requirements or NETA Table 100.2
  - Run test for 1 minute
  - Pass / Fail or Go / No Go

SWITCHGEAR/SWITCHBOARD (Continued)

- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
- Test instrument transformers (detailed in a later section)
- Test ground resistance (detailed in a later section)
- Test control power transformers for insulation resistance – winding-to-winding and each winding-to-ground
  - Compare to manufacturers requirements or NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14

NETA TABLE 100.1

Insulation Resistance Test Values
Electrical Apparatus and Systems

Nominal Rating of Equipment (Volts)	Minimum Test Voltage (DC)	Recommended Minimum Insulation Resistance (Megohms)
250	500	25
600	1,000	100
1,000	1,000	100
2,500	1,000	500
5,000	2,500	1,000
8,000	2,500	2,000
15,000	2,500	5,000
25,000	5,000	20,000
34,500 and above	15,000	100,000

NETA TABLE 100.2

Switchgear Withstand Test Voltages

Type of Switchgear	Rated Maximum Voltage (kV) (rms)	Maximum Test Voltage (kV)	
		AC	DC
Low-Voltage Power Circuit Breaker Switchgear	.254/.508/.635	1.6	2.3
Metal-Clad Switchgear	4.76	14	20
	8.25	27	37
	15.0	27	37
	27.0	45	a
	38.0	60	a
Station-Type Cubicle Switchgear	15.5	37	a
	38.0	60	a
	72.5	120	a
Metal-Enclosed Interrupter Switchgear	4.76	14	20
	8.25	19	27
	15.0	27	37
	27	45	a
	38.0	60	a

NETA TABLE 100.5

Transformer Insulation Resistance Maintenance Testing

Transformer Coil Rating Type (Volts)	Minimum DC Test Voltage	Recommended Minimum Insulation Resistance (Megohms)	
		Liquid Filled	Dry
0 – 600	1000	100	500
601 – 5000	2500	1000	5000
Greater than 5000	5000	5000	25000

NETA TABLE 100.14

Insulation Resistance Conversion Factors (20° C)

Temperature		Multiplier	
° C	° F	Apparatus Containing Oil Immersed Insulation	Apparatus Containing Solid Insulation
-10	14	0.125	0.25
-5	23	0.180	0.32
0	32	0.25	0.40
5	41	0.36	0.50
10	50	0.50	0.63
15	59	0.75	0.81
20	68	1.00	1.00
25	77	1.40	1.25
30	86	1.98	1.58
35	95	2.80	2.00
40	104	3.95	2.50
45	113	5.60	3.15
50	122	7.85	3.98
55	131	11.20	5.00
60	140	15.85	6.30
65	149	22.40	7.90
70	158	31.75	10.00
75	167	44.70	12.60
80	176	63.50	15.80
85	185	89.789	20.00
90	194	127.00	25.20
95	203	180.00	31.60
100	212	254.00	40.00
105	221	359.15	50.40
110	230	509.00	63.20

DRY TYPE TRANSFORMERS - Small ≤500kVA

- Thermographic survey under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance winding-to-winding and each winding-to-ground
  - Compare to manufacturers requirements or NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - Perform Polarization Index and compare to prior values; should not be < 1
- Test turns ratio on in-service tap (all taps on first test) (optional)
  - Should not deviate more than ½% from average or from calculated ratio

DRY TYPE TRANSFORMERS - Large >500kVA

- Thermographic survey under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance winding-to-winding and each winding-to-ground
  - Compare to manufacturers requirements or NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - Perform Polarization Index and compare to prior values; should not be < 1
- Perform power factor test on all windings
  - Power transformers should expect ≤ 2%
  - Distribution transformer should expect ≤ 5%
  - Consult Doble, Megger, etc. or transformer manufacturer
- Test turns ratio on in-service tap (all taps on first test)
  - Should not deviate more than ½% from average or from calculated ratio

DRY TYPE TRANSFORMERS - Large >500kVA (Continued)

- Perform an excitation current test on each phase
  - Typically two similar current readings and one lower
- Measure winding resistance on in-service tap (all taps on first test) (optional)
  - Correct readings for temperature
  - Compare to prior values and should be within 1%
  - Demagnetize when done
- Verify secondary voltages (600V and less)
- Test surge arresters (detailed in a later section)

OIL FILLED TRANSFORMERS

- Thermographic survey under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance winding-to-winding and each winding-to-ground
  - Compare to manufacturers requirements or NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - Perform Polarization Index and compare to prior values; should not be < 1
- Test turns ratio on in-service tap (all taps on first test)
  - Should not deviate more than ½% from average or from calculated ratio
- Perform power factor test on all windings & bushings
  - Correct to 20°C
  - Consult Doble, Megger, etc. or transformer manufacturer
  - Representative values from NETA Table 100.3
  - Investigate bushing values differing by more than 10%

OIL FILLED TRANSFORMERS (Continued)

- Perform an excitation current test on each phase
  - Typically two similar current readings and one lower
- Measure winding resistance on in-service tap (all taps on first test)
  - Correct readings for temperature
  - Compare to prior values and should be within 1%
  - Demagnetize when done
- Remove oil sample and send for complete tests per ASTM D 923
  - Dielectric breakdown voltage: ASTM D 877 and/or ASTM D 1816
  - Acid neutralization number: ANSI/ASTM D 974
  - Specific gravity: ANSI/ASTM D 1298 (optional)
  - Interfacial tension: ANSI/ASTM D 971 or ANSI/ASTM D 2285
  - Color: ANSI/ASTM D 1500
  - Visual Condition: ASTM D 1524
  - Water in insulating liquids: ASTM D 1533. (Required on 25 kV or higher voltages and on all silicone-filled units.) (optional)
  - Measure power factor or dissipation factor in accordance w/ASTM D 924 (optional).
  - ~~Compare values to NETA Table 100.4~~

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OIL FILLED TRANSFORMERS (Continued)

- Send oil sample for dissolved gas analysis (DGA)
- Test instrument transformers (detailed in a later section)
- Test surge arresters (detailed in a later section)
- Test neutral grounding resistor
  - Compare with prior results

LOAD TAP CHANGERS

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance winding-to-winding and each winding-to-ground for any off-neutral positions
  - Compare to manufacturers requirements or NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - Perform Polarization Index and compare to prior values; should not be < 1
- Test turns ratio at all positions
  - Should not deviate more than ½% from average or from calculated ratio
- Perform power factor test in off neutral position
  - Correct to 20°C
  - Consult Doble, Megger, etc. or transformer manufacturer
  - Representative values from NETA Table 100.3
  - Investigate bushing values differing by more than 10%

LOAD TAP CHANGERS (Continued)

- Measure winding resistance (optional)
  - Correct readings for temperature
  - Compare to prior values and should be within 1%
  - Demagnetize when done
- Remove oil sample and send for complete tests per ASTM D 923
  - Dielectric breakdown voltage: ASTM D 877 and/or ASTM D 1816
  - Color: ANSI/ASTM D 1500
  - Visual Condition: ASTM D 1524
  - Compare values to NETA Table 100.4
- Send oil sample for dissolved gas analysis (DGA)
- Conduct vacuum integrity test across each bottle with contacts open
  - Pass / Fail or Go / No Go

NETA TABLE 100.3

Maintenance Test Values
Recommended Dissipation Factor/Power Factor at 20° C
Liquid-Filled Transformers, Regulators, and Reactors

	Oil Maximum	Silicone Maximum	Tetrachloroethylene Maximum	High Fire Point Hydrocarbon Maximum
Power Transformers	1.0%	0.5%	3.0%	2.0%
Distribution Transformers	2.0%	0.5%	3.0%	3.0%

NETA TABLE 100.4.1

Suggested Limits for Class I Insulating Oil

Mineral Oil [a]				
		Acceptable Values		
Test	ASTM Method	69 kV and Below	Above 69 kV - Below 230 kV	230 kV and Above
Dielectric breakdown, kV minimum [b]	D 877	26	26	26
Dielectric breakdown, kV minimum @ 1 mm (0.04 inch) gap	D 1816	23	28	30
Dielectric breakdown, kV minimum @ 2 mm (0.08 inch) gap	D 1816	40	47	50
Interfacial tension mN/m minimum	D 971 or D 2285	25	30	32
Neutralization number, mg KOH/g maximum	D 974	0.20	0.15	0.10
Water content, ppm maximum @ 60° C [c]	D 1533	35	25	20
Power factor at 25° C, %	D 924	0.5	0.5	0.5
Power factor at 100° C, %	D 924	5.0	5.0	5.0
Color [d]	D 1500	3.5	3.5	3.5
Visual Condition	D 1524	Bright, clear and free of particles	Bright, clear and free of particles	Bright, clear and free of particles
Specific Gravity (Relative Density) @ 15° C Maximum [e]	D 1298	0.91	0.91	0.91

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NETA TABLE 100.4.2

Suggested Limits
for Less-Flammable Hydrocarbon Insulating Liquid

Test	ASTM Method	Acceptable Values
Dielectric breakdown voltage, kV minimum	D 877	24
Dielectric breakdown voltage for 1 mm (0.04 inch) gap, kV minimum	D 1816	34
Dielectric breakdown voltage for 2 mm (0.08 inch) gap, kV minimum	D 1816	24
Water content, ppm maximum	D 1533 B	35
Dissipation/power factor, 60 hertz, % max. @ 25° C	D 924	1.0
Fire point, ° C, minimum	D 92	300
Interfacial tension, mN/m, 25° C	D 971	24
Neutralization number, mg KOH/g	D 664	0.20

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NETA TABLE 100.4.3

Suggested Limits
for Service-Aged Silicone Insulating Liquid

Test	ASTM Method	Acceptable Values
Dielectric breakdown, kV minimum	D 877	25
Visual	D 2129	Colorless, clear, free of particles
Water content, ppm maximum	D 1533	100
Dissipation/power factor, 60 hertz, maximum @ 25° C	D 924	0.2
Viscosity, cSt @ 25° C	D 445	47.5 – 52.5
Fire point, ° C, minimum	D 92	340
Neutralization number, mg KOH/g max.	D 974	0.2

NETA TABLE 100.4.4

Suggested Limits for Service-Aged Tetrachloroethylene Insulating Fluid

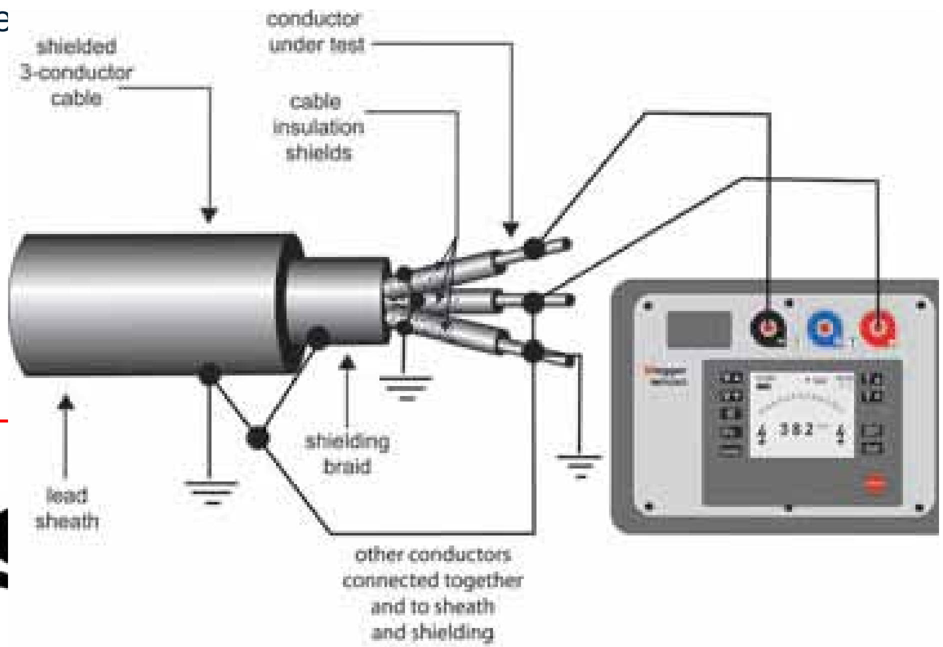
Test	ASTM Method	Acceptable Values
Dielectric breakdown, kV minimum	D 877	26
Visual	D 2129	Clear with purple iridescence
Water content, ppm maximum	D 1533	35
Dissipation/power factor, % maximum @ 25° C	D 924	12.0
Viscosity, cSt @ 25° C	D 445	0
Fire point, ° C, minimum	D 92	-
Neutralization number, mg KOH/g maximum	D 974	0.25
Neutralization number, mg KOH/g maximum	D 664	-
Interfacial tension, mN/m minimum @ 25° C	D 971	-

LOW VOLTAGE CABLES $\leq$600V

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each conductor between ground and adjacent conductors
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results and similar circuits but not less than 2MΩ
- Verify uniform resistance of parallel conductors
  - Deviations should be investigated

MEDIUM- AND HIGH-VOLTAGE CABLES

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance individually on each conductor with all other conductors and shields grounded
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Verify continuity of shield
  - Investigate values > 10Ω / 1000' cable



MEDIUM- AND HIGH-VOLTAGE CABLES (Continued)

- PREFERRED METHOD TO BE DETERMINED BY ALL PARTIES
  - Dielectric withstand (Pass / Fail or Go / No Go)
    - DC
    - VLF
    - 60Hz
  - Diagnostic (Test equipment manufacturer dictated)
    - Power Factor/Dissipation Factor (tan δ)
    - 60Hz
    - VLF
  - DC insulation resistance
  - Partial discharge
    - Online
    - Offline

INSULATED-CASE & MOLDED-CASE CIRCUIT BREAKERS

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with breaker closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Test contact resistance with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar breakers
- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
  - Disconnect solid state components

INSULATED-CASE & MOLDED-CASE CIRCUIT BREAKERS (Continued)

- Primary current injection for long-time, short-time, instantaneous and ground fault pickup (Note: very rarely done)
  - Compare to manufacturers requirements or NETA Table 100.7 and 100.8
- Secondary injection for trip units (optional) (Note: more common)
- Check minimum pickup voltage for shunt trip
  - NETA table 100.20
- Check auxiliary functions

NETA TABLE 100.20.1

Rated Control Voltages and Their Ranges for Circuit Breakers

Operating mechanisms are designed for rated control voltages listed with operational capability throughout the indicated voltage ranges to accommodate variations in source regulation, coupled with low charge levels, as well as high charge levels maintained with floating charges. The maximum voltage is measured at the point of user connection to the circuit breaker [see notes (12) and (13)] with no operating current flowing, and the minimum voltage is measured with maximum operating current flowing.

(11) Rated Control Voltage	Direct Current Voltage Ranges (1)(2)(3)(5) (8)(9) Closing and Auxiliary Functions		Opening Functions All Types	Rated Control Voltage (60 Hz)	Alternating Current Voltage Ranges (1)(2)(3)(4)(8) Closing, Tripping, and Auxiliary Functions
	Indoor Circuit Breakers	Outdoor Circuit Breakers		Single Phase	Single Phase
24 (6)	--	--	14–28	120	104–127 (7)
48 (6)	38–56	36–56	28–56	240	208–254 (7)
125	100–140	90–140	70–140		
250	200–280	180–280	140–280	Polyphase	Polyphase
--	--	--	--	208Y/120	180Y/104–220Y/127
--	--	--	--	240	208–254

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NETA TABLE 100.20.2

Rated Control Voltages and Their Ranges for Circuit Breakers Solenoid-Operated Devices

Rated Voltage	Closing Voltage Ranges for Power Supply
125 dc	90 – 115 or 105 – 130
250 dc	180 – 230 or 210 – 260
230 ac	190 – 230 or 210 – 260

NETA TABLE 100.7

Molded-Case Circuit Breakers
Inverse Time Trip Test
(At 300% of Rated Continuous Current of Circuit Breaker)

Range of Rated Continuous Current (Amperes)	Maximum Trip Time in Seconds for Each Maximum Frame Rating [a]	
	$\leq$250 V	251 – 600 V
0-30	50	70
31-50	80	100
51-100	140	160
101-150	200	250
151-225	230	275
226-400	300	350
401-600	- - - - -	450
601-800	- - - - -	500
801-1000	- - - - -	600
1001 – 1200	- - - - -	700
1201-1600	- - - - -	775
1601-2000	- - - - -	800
2001-2500	- - - - -	850
2501-5000	- - - - -	900
6000	- - - - -	1000

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NETA TABLE 100.8

Instantaneous Trip Tolerances for Field Testing of Circuit Breakers

		Tolerances of Manufacturer's Published Trip Range	
Breaker Type	Tolerance of Settings	High Side	Low Side
Electronic Trip Units [(1)]	+30%	- - - - -	- - - - -
Adjustable [(1)]	+40% -30%	- - - - -	- - - - -
Nonadjustable [(2)]	- - - - -	+25%	-25%

LOW-VOLTAGE POWER CIRCUIT BREAKERS

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with breaker closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Test contact resistance with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar breakers
- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
  - Disconnect solid state components

LOW-VOLTAGE POWER CIRCUIT BREAKERS (Continued)

- Primary current injection for long-time, short-time, instantaneous and ground fault pickup (Note: not always done)
  - Compare to manufacturers requirements
- Secondary injection for trip units (optional)
- Check minimum pickup voltage for shunt trip
  - NETA table 100.20
- Check auxiliary functions

MEDIUM-VOLTAGE AIR CIRCUIT BREAKERS

- Thermographic survey of connections under full load
- Perform first trip test (optional)
  - Compare trip time and trip-coil waveform to manufacture data and prior results
- Perform time-travel analysis (optional)
  - Compare travel and velocity to manufacture data and prior results
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with breaker closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14

MEDIUM-VOLTAGE AIR CIRCUIT BREAKERS (Continued)

- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
  - Disconnect solid state components
- Test contact resistance with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar breakers
- With breaker in "Test" position
  - Trip & Close with control switch
  - Trip via relay
  - Verify mechanism charge, trip-free and anti-pump functions
- Check minimum pickup voltage for trip and close (optional)
  - NETA table 100.20

MEDIUM-VOLTAGE AIR CIRCUIT BREAKERS (Continued)

- Power factor test with breaker open and closed (optional)
  - Compare with prior test results of similar breakers or manufacturers data
  - Bushing values should be within 10% of nameplate ratings
- Conduct dielectric withstand test with breaker closed and poles not under test grounded (optional)
  - Use voltage from manufacturers or NETA Table 100.19
  - Pass / Fail or Go / No Go
- Test instrument transformers (detailed in a later section) (optional – for medium voltage - why is it only required for vacuum breaker???)
- Check auxiliary functions

NETA TABLE 100.19

Dielectric Withstand Test Voltages for Electrical Apparatus Other than Inductive Equipment

Nominal System (Line) Voltage [a] (kV)	Insulation Class (kV)	AC Factory Test (kV)	Maximum Field Applied AC Test (kV)	Maximum Field Applied DC Test (kV)
1.2	1.2	10	6.0	8.5
2.4	2.5	15	9.0	12.7
4.8	5.0	19	11.4	16.1
8.3	8.7	26	15.6	22.1
14.4	15.0	34	20.4	28.8
18.0	18.0	40	24.0	33.9
25.0	25.0	50	30.0	42.4
34.5	35.0	70	42.0	59.4
46.0	46.0	95	57.0	80.6
69.0	69.0	140	84.0	118.8

MEDIUM VOLTAGE VACUUM CIRCUIT BREAKERS

- Thermographic survey of connections under full load
- Perform first trip test (optional)
  - Compare trip time and trip-coil waveform to manufacture data and prior results
- Perform time-travel analysis (optional)
  - Compare travel and velocity to manufacture data and prior results
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with breaker closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14

MEDIUM VOLTAGE VACUUM CIRCUIT BREAKERS (Continued)

- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
  - Disconnect solid state components
- Test contact resistance with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar breakers
- With breaker in “Test” position
  - Trip & Close with control switch
  - Trip via relay
  - Verify mechanism charge, trip-free and anti-pump functions
- Check minimum pickup voltage for trip and close (optional)
  - NETA table 100.20

MEDIUM VOLTAGE VACUUM CIRCUIT BREAKERS (Continued)

- Power factor test with breaker open and closed (optional)
  - Compare with prior test results of similar breakers or manufacturers data
  - Bushing values should be within 10% of nameplate ratings
- Conduct vacuum integrity test across each bottle
  - AC HiPot test??? X-Rays???
  - Pass / Fail or Go / No Go
- Conduct dielectric withstand test with breaker closed and poles not under test grounded (optional)
  - Use voltage from manufacturers or NETA Table 100.19
  - Pass / Fail or Go / No Go
- Test instrument transformers (detailed in a later section) (for medium voltage - why is it only required for vacuum breaker???)

MEDIUM- AND HIGH-VOLTAGE OIL CIRCUIT BREAKERS

- Thermographic survey of connections under full load
- Perform first trip test (optional)
  - Compare trip time and trip-coil waveform to manufacture data and prior results
- Perform time-travel analysis (unlike air & vacuum breakers, this test required) Why?
  - Compare travel and velocity to manufacture data and prior results
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with breaker closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Test contact resistance with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar breakers

MEDIUM- AND HIGH-VOLTAGE OIL CIRCUIT BREAKERS (Continued)

- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
- Remove oil sample and send for complete tests per ASTM D 923
  - Dielectric breakdown voltage: ASTM D 877
  - Color: ANSI/ASTM D 1500
  - Power factor: ASTM D 924 (optional)
  - Interfacial tension: ANSI/ASTM D 971 or ANSI/ASTM D 2285 (optional)
  - Visual condition: ASTM D 1524 (optional)
  - Compare values to NETA Table 100.4
- With breaker in “Test” position
  - Trip & Close with control switch
  - Trip via relay
  - Verify trip-free and anti-pump functions

MEDIUM- AND HIGH-VOLTAGE OIL CIRCUIT BREAKERS (Continued)

- Check minimum pickup voltage for trip and close (optional)
  - NETA table 100.20
- Power factor test with breaker open and closed (unlike air & vacuum breakers, this test required)
  - Compare with prior test results of similar breakers or manufacturers data
  - Bushing values should be within 10% of nameplate ratings
- Conduct dielectric withstand test with breaker closed and poles not under test grounded (optional)
  - Use voltage from manufacturers or NETA Table 100.19
  - Pass / Fail or Go / No Go
- Test instrument transformers (detailed in a later section) (optional – for medium voltage - why is it only required for vacuum breaker???)

SF6 CIRCUIT BREAKERS

- Thermographic survey of connections under full load
- Perform first trip test (optional)
  - Compare trip time and trip-coil waveform to manufacture data and prior results
- Perform time-travel analysis (unlike air & vacuum breakers, this test required) Why???
  - Compare travel and velocity to manufacture data and prior results
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with breaker closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Test contact resistance with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar breakers

SF6 CIRCUIT BREAKERS (Continued)

- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
- Remove a sample of SF6 (optional)
  - NETA Table 100.13
- With breaker in “Test” position
  - Trip & Close with control switch
  - Trip via relay
  - Verify trip-free and anti-pump functions
- Check minimum pickup voltage for trip and close (optional)
  - NETA table 100.20

SF6 CIRCUIT BREAKERS (Continued)

- Power factor test with breaker open and closed (unlike air & vacuum breakers, this test required)
  - Compare with prior test results of similar breakers or manufacturers data
  - Bushing values should be within 10% of nameplate ratings
- Conduct dielectric withstand test (optional)
  - Per manufacturer
  - Pass / Fail or Go / No Go
- Test instrument transformers (detailed in a later section) (optional – for medium voltage - why is it only required for vacuum breaker???)

NETA TABLE 100.13

SF_6 Gas Tests

Test	Method	Serviceability Limits [a]
Moisture	Hygrometer	Per manufacturer or ≥ 200 ppm [b]
SF_6 decomposition byproducts	ASTM D 2685	≥ 500 ppm
Air	ASTM D 2685	≥ 5000 ppm [c]
Dielectric breakdown hemispherical contacts	2.54 mm (0.10 inch) gap at atmospheric pressure	11.5 – 13.5 kV [d]

MEDIUM VOLTAGE METAL ENCLOSED SWITCHES

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test contact resistance with low resistance ohmmeter
  - Switchblade assembly & fuse holder
  - Investigate values which deviate >50% from lowest value of similar breakers
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground with switch closed and across each open pole
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14

MEDIUM VOLTAGE METAL ENCLOSED SWITCHES
(Continued)

- Conduct dielectric withstand on each pole with switch closed and phases not under test grounded
  - Only if insulation resistance levels are acceptable
  - Compare to manufacturers requirements or NETA Table 100.2
  - Pass / Fail or Go / No Go
- Measure fuse resistance

METAL ENCLOSED BUSWAY

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each pole, phase-to-phase and phase-to-ground
  - Run test for 1 minute
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
  - Minimum values for 1000’ run
  - $R_{1000ft} = Measured\ Resistance\ X\ {}^{Length\ of\ Bus}/_{1000}$

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METAL ENCLOSED BUSWAY

- Conduct dielectric withstand on each busway with phases not under test grounded
  - Only if insulation resistance levels are acceptable
  - Compare to manufacturers requirements or NETA Table 100.17
  - Run test for 1 minute
  - Pass / Fail or Go / No Go
- Test contact resistance with low resistance ohmmeter (optional)
  - Each accessible connection point
  - For inaccessible points, measure sections
  - Investigate values which deviate >50% from lowest value of similar breakers
- Make sure heaters work!!!

NETA TABLE 100.17

Metal-Enclosed Bus Dielectric Withstand Test Voltages

Type of Bus	Rated kV	Maximum Test Voltage (kV) AC	DC
Isolated Phase for Generator Leads	24.5	37.0	52.0
	29.5	45.0	--
	34.5	60.0	--
Isolated Phase for Other than Generator Leads	15.5	37.0	52.0
	25.8	45.0	--
	38.0	60.0	--
Nonsegregated Phase	0.635	1.6	2.3
	4.76	14.2	20.0
	15.0	27.0	37.0
	25.8	45.0	63.0
	38.0	60.0	--
Segregated Phase	15.5	37.0	52.0
	25.8	45.0	63.0
	38.0	60.0	--
DC Bus Duct [a]	0.3	1.6	2.3
	0.8	2.7	3.9
	1.2	3.4	4.8
	1.6	4.0	5.7
	3.2	6.6	9.3

BATTERIES

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Check charger float and equalizing voltages
- Measure each cell and total string voltage while in float mode
  - For flooded lead acid & vented nickel-cadmium should be within .05V of each other
  - For valve-regulated lead-acid per manufacturers data
- Measure intercell connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Perform internal ohmic measurement
  - Should not vary by more than 25%
- Perform load (capacity) test
  - For flooded lead-acid per manufacturers data or ANSI/IEEE 450 (optional)
  - For vented nickel-cadmium per manufacturers data or ANSI/IEEE 1106 (optional)
  - For valve-regulated lead-acid per manufacturers data or ANSI/IEEE 1188 (required annually)

BATTERIES

- For vented nickel-cadmium measure voltage positive-to-ground and negative-to-ground
  - Voltages should have the same magnitude
- For VLRA - measure negative post temperature
  - Temperature should be per manufacturers data or ANSI/IEEE 1188

- NERC/FERC now weighing heavily and differing requirements

- Battery Ground Faults

PROTECTIVE RELAYS

- Test insulation resistance on each circuit to frame
  - Follow manufacturers requirements
- Check functional operation
  - 2/62 Timing Relay
  - 21 Distance Relay
  - 24 Volts/Hertz Relay
  - 25 Sync Check Relay
  - 27 Undervoltage Relay
  - 32 Directional Power Relay
  - 40 Loss of Field (Impedance) Relay
  - 46 Current Balance Relay
  - 46N Negative Sequence Current Relay
  - 47 Phase Sequence or Phase Balance Voltage Relay
  - 49R Thermal Replica Relay
  - 49T Temperature (RTD) Relay
  - 50 Instantaneous Overcurrent Relay

PROTECTIVE RELAYS (Continued)

- Check functional operation (continued)
  - 51 Time Overcurrent
  - 55 Power Factor Relay
  - 59 Overvoltage Relay
  - 60 Voltage Balance Relay
  - 63 Transformer Sudden Pressure Relay
  - 64 Ground Detector Relay
  - 67 Directional Overcurrent Relay
  - 79 Reclosing Relay
  - 81 Frequency Relay
  - 85 Pilot Wire Monitor
  - 87 Differential

CURRENT TRANSFORMERS

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance of each CT and wiring-to-ground and winding-to-winding
  - 1000V
  - Run test for 1 minute
  - NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - For solid-state components follow manufacturers recommendations for applied voltage
- Conduct dielectric withstand on primary winding with secondary winding grounded
  - NETA Table 100.9
  - Pass / Fail or Go / No Go
- Perform power factor test (optional)

CURRENT TRANSFORMERS (Continued)

- Check polarity (optional)
- Check ratio (optional)
  - Errors per NETA Table 100.21
- Perform an excitation test when used in relay applications (optional)
- Measure burden (optional)

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NETA TABLE 100.9

Instrument Transformer Dielectric Tests
Field Maintenance

Nominal System (kV)	BIL (kV)	Periodic Dielectric Withstand Test Field Test Voltage (kV)	
		AC	DC [b]
0.6	10	2.6	4
1.1	30	6.5	10
2.4	45	9.7	15
4.8	60	12.3	19
8.32	75	16.9	26
13.8	95	22.1	34
13.8	110	22.1	34
25	125	26.0	40
25	150	32.5	50
34.5	150	32.5	50
34.5	200	45.5	70
46	250	61.7	a
69	350	91.0	a
115	450	120.0	a
115	550	149.0	a
138	550	149.0	a
138	650	178.0	a
161	650	178.0	a
161	750	211.0	a
230	900	256.0	a
230	1050	299.0	a

NETA TABLE 100.21

Accuracy of IEC Class TP Current Transformers Error Limit

Class	At Rated Current		At Accuracy Limit Condition
	Ratio Error (%)	Phase Displacement Minimum	Peak Instantaneous Error (%)
TPX	± 0.5	± 30	10
TPY	± 1.0	± 60	10
TPZ	± 1.0	180 ± 18	10 (see note)
NOTE – Alternating current component error.			

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POTENTIAL TRANSFORMERS

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance of each PT winding-to-winding and winding-to-ground
  - Run test for 1 minute
  - NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - For solid-state components follow manufacturers recommendations for applied voltage
- Conduct dielectric withstand on primary winding with secondary winding grounded (optional)
  - Run test for 1 minute
  - NETA Table 100.9
  - Pass / Fail or Go / No Go
- Perform power factor test (optional)

POTENTIAL TRANSFORMERS (Continued)

- Check polarity (optional)
- Check ratio
  - Error for revenue metering ≤ ± .1% for ratio and ≤ ± .9mrad (3 minutes) for angle
  - Error for other ≤ 1.2% for ratio and ≤ ± 17.5mrad (one degree) for angle
- Perform an excitation test when used in relay applications (optional)
- Measure burden (optional)

CCVT TRANSFORMERS

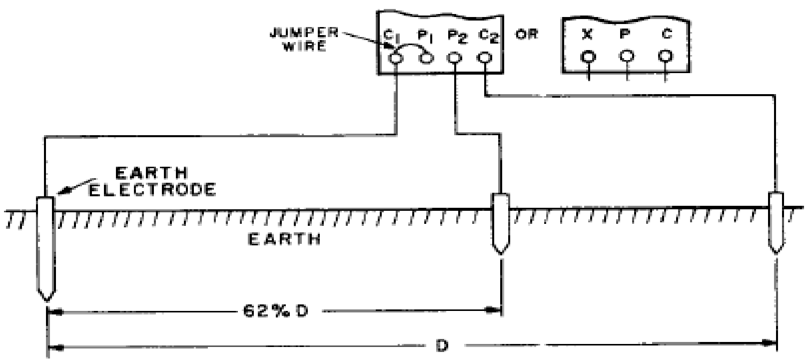
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance of each CCVT winding-to-winding and winding-to-ground
  - Run test for 1 minute
  - NETA Table 100.5
  - Correct to 20°C per NETA Table 100.14
  - For solid-state components follow manufacturers recommendations for applied voltage
- Conduct dielectric withstand on primary winding with secondary winding grounded (optional)
  - Run test for 1 minute
  - NETA Table 100.9
  - Pass / Fail or Go / No Go
- Measure capacitance

CCVT TRANSFORMERS (Continued)

- Perform power factor test (optional)
- Check polarity (optional)
- Check ratio
  - Error for revenue metering ≤ ± .1% for ratio and ≤ ± .9mrad (3 minutes) for angle
  - Error for other ≤ 1.2% for ratio and ≤ ± 17.5mrad (one degree) for angle
- Perform an excitation test when used in relay applications (optional)
- Measure burden (optional)

GROUNDING SYSTEMS

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Fall-of-potential (three terminal) test on main grounding electrode
  - IEEE Standard 81
  - NETA: Resistance ≤ 5Ω for commercial/industrial
  - NETA: Resistance ≤ 1Ω for generating or transmission stations
  - NEC: Single electrode with Resistance > 25Ω should be augmented by one additional electrode
- Perform point-to-point tests on all ground connections
  - Values should be ≤ .5Ω



GROUND FAULT SYSTEMS

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance neutral-ground with link removed
  - Should be not less than 1MΩ
- Test insulation resistance on all control wiring (optional)
  - 1000V for 600V cable; 500V for 300V cable
  - Run test for 1 minute
  - Compare with prior results but not less than 2MΩ
  - Disconnect solid state components
- Primary current injection for ground fault pickup
  - Should be > 90% of pickup setting and < 1200A or 125% of pickup
  - Measure time delay at value $\geq$ 150% of pickup
- Verify capability to trip at reduced voltage
  - 55% for AC
  - 80% for DC

SURGE ARRESTERS

- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance on each arrester from terminal-to-ground
  - Compare to manufacturers requirements or NETA Table 100.1
  - Correct to 20°C per NETA Table 100.14
- Test ground resistance (detailed in an earlier section)
  - Values should be < .5 Ω
- For medium- and high-voltage arresters (optional)
  - Perform a watts-loss test per manufacturer data and similar units

AC MOTORS & GENERATORS

- Thermographic survey of connections under full load
- Test bolted electrical connections with low resistance ohmmeter
  - Investigate values which deviate >50% from lowest value of similar connections
- Test insulation resistance
  - Correct to 40°C
  - per ANSI/IEEE Standard 43
  - > 200HP run test for 10 minutes and calculate polarization index
  - Perform Polarization Index and compare to prior values; should not be < 1
  - ≤ 200HP run test for 10 minutes and calculate dielectric absorption ratio
- Conduct DC dielectric withstand on machines > 2300V
  - per ANSI/IEEE Standard 95
- Measure phase-to-phase stator resistance on machines > 2300V
  - Investigate values which deviate >5%

AC MOTORS & GENERATORS

- Perform power factor test (optional)
- Perform power factor tip-up test (optional)
  - Should indicate no significant increase in power factor
- Perform surge comparison test (optional)
- Test insulation resistance on insulated bearings
- Test surge protective devices (detailed in an earlier section)
- Test motor starter
- Test resistance on RTDs
- Perform vibration analysis (optional) more of a mechanical test???
  - NETA Table 100.10

AC MOTORS & GENERATORS – Synchronous

- ADDITIONAL TESTS:
- Test insulation-resistance on main rotating field winding, exciter-field winding, and exciter-armature winding in accordance
  - Correct to 40°C
  - Per ANSI/IEEE Standard 43.
- Test AC voltage-drop on all rotating field poles (optional)
- High-potential test on excitation system
  - Per ANSI/IEEE Standard 421.3
- Measure resistance of machine-field winding, exciter-stator winding, exciter-rotor windings, and field discharge resistors
- Test front-to-back resistance on diodes and gating tests of silicon-controlled rectifiers for field application semiconductors (optional)

NETA TABLE 100.10

Maximum Allowable Vibration Amplitude

RPM (at 60 Hz)	Velocity (in/s peak)	Velocity (mm/s)	RPM (at 50 Hz)	Velocity (in/s peak)	Velocity (mm/s)
3600	0.15	3.8	3000	0.15	3.8
1800	0.15	3.8	1500	0.15	3.8
1200	0.15	3.8	1000	0.13	3.3
900	0.12	3.0	750	0.10	2.5
720	0.09	2.3	600	0.08	2.0
600	0.08	2.0	500	0.07	1.7

ADDITIONAL INFORMATION

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