ELECTRICAL TESTING

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1.0 SCOPE

This data sheet provides inspection, testing, maintenance, and testing interval guidance for low-voltage electrical equipment, including supply and/or distribution transformers 5MVA and below and their associated switchgear.

This data sheet does not apply to low-power devices such as data and communication systems or process controls. For loss prevention guidance on electrical equipment not covered by this data sheet, refer to the following: Data Sheet 5-4, *Transformers;* Data Sheet 5-12, *Electric AC Generators;* Data Sheet 5-17, *Motors and Adjustable Speed Drives;* and Data Sheet 5-19, *Switchgear and Circuit Breakers.*

1.1 Hazard

The majority of losses involving electrical equipment are related to poor operating conditions (e.g., overload, loose connections) or environment (e.g., poor ventilation, corrosion, contamination, combustible storage). Most of these losses can be prevented by conducting regular visual inspections, maintaining good housekeeping practices, and performing basic electrical tests such as infrared and insulation-resistance measurements.

1.2 Changes

October 2025. Interim revision. Major changes in this revision include the following:

A. Revised the guidance for thermograph/infrared scanning recommendations in Section 2.1.3.1:

1. Added a new table to assist field engineering with assessing the level of deficiency identified through infrared scanning.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Operation and Maintenance

Establish and implement an electrical inspection, testing, and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.1.1 Visual Inspections

2.1.1.1 Visually inspect electrical equipment on a regular basis, approximately monthly or quarterly depending on the environmental conditions (i.e., equipment exposed to dirty or humid atmospheres need to be inspected more frequently). Verify that electrical equipment is operating in a clean, cool, dry, and tight condition with no abnormal noises, smells, vibration, or heat.

See Section 3.6 for a detailed description of what is meant by “clean, cool, dry, and tight.”

2.1.1.2 Perform visual inspection of grounding conductors every 1 to 3 years. Note that corrosion is most likely to appear a few inches below the soil surface where a grounding conductor attaches to a ground mat or rod.

2.1.2 Electrical Connections

2.1.2.1 Ensure all bolted connections are properly tightened to the correct torque when they are assembled. Strictly follow the manufacturer’s recommended torque values and assembly instructions. Perform an infrared survey to check proper electrical connections.

2.1.3 Electrical Tests

Inspection, testing, and maintenance frequencies given in this section are a general guide. Adjust inspection and testing frequencies based on the particular type of equipment and its duty, failure history, criticality, and condition.

2.1.3.1 Thermography (Infrared Survey)

2.1.3.1.1 Perform infrared surveys on all electrical equipment annually.

The following table provides reference guidance for interpreting thermography results when no manufacturer's guidance or industry standards are available.

Table 2.1.3.1.1. Typical Actions Based on Temperature Difference from Infrared Thermographic Survey

Temperature difference based on comparison between similar components under similar loading	*Temperature difference based on comparison between component and ambient air temperature*	*Recommended Action*
< 6°F (3°C)	< 18°F (10°C)	Continue preventive IR scanning
7°F ~ 27°F (4°C ~ 15°C)	20°F ~ 36°F (11°C ~ 20°C)	Probable deficiency. Repair as time permits (e.g., shut down within months for repair)
	36°F ~ 72°F (21°C ~ 40°C)	Monitor until corrective measures can be accomplished (e.g., shut down within weeks for repair)
> 27°F (15°C)	> 72°F (40°C)	Major discrepancy, repair immediately, e.g., shut down within hours for repair

2.1.3.2 Low-Voltage Circuit Breakers

Due to the large number of circuit breakers at a typical facility, maintenance priority should be given to critical circuit breakers.

2.1.3.2.1 Mechanically exercise, inspect, service, lubricate, and test all critical/main low-voltage circuit breakers every 3 to 5 years in accordance with manufactures guidelines' and/or industry standards as applicable. If there are no manufacturer guidelines or industry standards, use Table 2.1.3.2.1 as a reference for testing low-voltage circuit breakers.

Common inspection and service activities include checking the circuit breaker for smooth operation, correct alignment, mechanical damage, overheating, binding of moving parts, condition of arc chutes, and condition of contacts. Also perform a functional check of the charging mechanism and various auxiliary features. Depending on the circuit breaker, these auxiliary features can include interlocks, trip-free, anti-pumping, and trip indicators.

Table 2.1.3.2.1. Electrical Tests for Low-Voltage Circuit Breakers

Test	*Comment*	*Acceptance Criterial*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There should not be any difference greater than 50% between resistance readings. Verify that resistance readings are below the maximum value recommended by the manufacturer.
Contact resistance	Measure the contact resistance of each pole.	Compare to manufacturer's recommended values. There should be no deviation of the contact resistance readings between poles greater than 50% of the lowest value.
Insulation resistance	Measure the phase-to-phase and phase-to-ground insulation resistance of each pole with the circuit breaker in the open and closed positions.	The insulation resistance reading should be at least 100 Mohm.
Trip and close coil voltages (optional)	Measure the voltage required to operate the trip and close coils. Also verify the trip and close coils are functioning properly.	The operating voltages should be within the manufacturer's recommended values.
Primary current injection testing[1, 2]	Verfiy proper operation and response of the protection functions of the breaker.	The protection relays should pick up and operate at currents within the tolerance band specified by the manufacturer.

Note 1. Circuit breakers with direct tripping can only be tested by primary current injection. Circuit breakers with discrete solid state protection relays may be tested by secondary current injection. A functional test should be included in addition to secondary current testing.
Note 2. If switchgear is equipped with ground fault protection, this protection should be tested periodically in accordance with the equipment manufacturer's guidelines and results documented as part of the switchgears routine service and test program.

2.1.3.3 Motor Contactors

2.1.3.3.1 Inspect, test, lubricate, and service as needed the motor contactors that are larger than 50 hp (37 kW), or that supply critical processes, every 3 to 5 year in accordance with the manufacturer's instructions and/or industry standards as applicable.

If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.3.1 as a reference for testing motor contactors.

Common inspection and service activities include checking the contactor for smooth operation, correct alignment, mechanical damage, overheating, binding of moving parts, condition of arc barriers, and condition of contacts. Also perform function checks of the contactor controls.

Table 2.1.3.3.1. Electrical Tests for Motor Contactors

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There should not be any difference greater than 50% between resistance readings. Verify that resistance readings are below the maximum value recommended by the manufacturer.
Contact resistance	Measure the contact resistance of each pole.	Compare to manufacturer's recommended values. There should be no deviation of the contact resistance readings between poles greater than 50% of the lowest value.
Insulation resistance	Measure the phase-to-phase and phase-to-ground insulation resistance of each pole with the circuit in the open and closed positions.	The insulation resistance reading should be at least 100 Mohm.

2.1.3.4 Switches, Fuses, and Fused Switches

Due to the large number of switches and fused switches at a typical facility, maintenance priority should be given to critical switches.

2.1.3.4.1 Mechanically exercise, lubricate, service, and test these switches every 3 to 5 years in accordance with the manufacturer's instructions and/or industry standards as applicable. If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.4.1 as a reference for testing fuses and fused switches. Common inspection of switches include checking for smooth operation during opening and closing to confirm that the mechanism is not binding.

Table 2.1.3.4.1. Electrical Tests for Fuses and Fused Switches

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There must not be any difference greater than 50% between resistance readings. Check that the resistance readings are below the maximum value recommended by the manufacturer.
Contact resistance	Measure the contact resistance of each pole.	Compare to manufacturer's recommended values. There must be no deviation of the contact resistance readings between poles greater than 50% of the lowest value.
Insulation resistance	Measure the phase-to-phase and phase-to-ground insulation resistance of each pole with the circuit breaker in the open and closed position.	The insulation resistance reading must be at least 100 Mohm.
Fuse Resistance	Measure the fuse resistance.	Fuse resistances must not deviate by more than 15% between phases.

2.1.3.4.2 During inspection, verify that fuses of the correct type and size are used. When replacing blown fuses, replace all three phases at the same time with like fuses.

2.1.3.5 Automatic Transfer Switches

2.1.3.5.1 Functionally test automatic transfer switches every 3 to 5 years by simulating loss of normal power and return of normal power.

Use an infrared survey to check for hot spots with the automatic transfer switch in both positions. Check the function of mechanical interlocks that prevent the operation of the switch during normal conditions.

2.1.3.5.2 Service and test automatic transfer switches every 3 to 5 years in accordance with the manufacturer's instructions. Use only the manufacturer's recommended lubricant because improper lubrication is a common cause of switch binding. If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.5.1 as a reference for testing automatic transfer switches.

Table 2.1.3.5.1. Electrical Tests for Automatic Transfer Switches

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There should not be a difference greater than 50% between resistance readings. Check that the resistance readings are below the maximum value recommended by the manufacturer.
Contact resistance	Measure the contact resistance of each pole.	Compare to manufacturer's recommended values. There should be no deviation of the contact resistance readings between poles greater than 50% of the lowest value.
Insulation resistance	Measure the phase-to-phase and phase-to-ground insulation resistance of each pole with the circuit in the open and closed position.	The insulation resistance reading should be at least 100 Mohm.

2.1.3.6 Bus Ducts and Cables

2.1.3.6.1 Perform electrical tests every 3 to 5 years for critical bus ducts and cables in accordance with the manufacturer's guidelines and/or industry standards. If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.6.1 as a reference for testing bus ducts and cables.

Table 2.1.3.6.1. Electrical Tests for Bus Ducts and Cables

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There must not be any difference greater than 50% between resistance readings. Check that the resistance readings are below the maximum value recommended by the manufacturer.
Insulation resistance	Measure the phase-to-phase and phase-to-ground insulation resistance. Apply a test voltage of 500 V for cables rated at 300 V, and 1000 V for cables rated at 600 V.	The insulation resistance reading must be at least 100 Mohm per 1000 ft of bus duct or cable.

2.1.3.7 Fluid-Filled Transformers

2.1.3.7.1 Carry out fluid screen tests and dissolved gas analysis (DGA) at least every 1 to 2 years, regardless of the fluid type. Keep a trend of DGA results for comparison and analysis and adjust the frequency of testing based on the results. Refer to Section 3.4 for additional details on transformer-fluid testing.

2.1.3.7.2 Check the PCB content of oil-filled PCB-contaminated or suspect PCB transformers once every 5 years. Periodic PCB testing is only needed for PCB-filled transformers that have been retro-filled with a PCB-free fluid, even if the fluid in these transformers has not been processed or topped up since the last PCB test. Ensure the PCB content does not exceeded 50 ppm. Refer to Data Sheet 5-4, *Transformers,* for detailed information on PCBs.

2.1.3.7.3 Perform the tests shown in Table 2.1.3.7.3 every 3 to 5 years in accordance with the manufacturer's guidelines and/or industry standards as applicable. If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.7.3 as a reference for testing fluid-filled transformers.

Table 2.1.3.7.3. Electrical Tests for Fluid-Filled Transformers

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There should not be any difference greater than 50% between resistance readings. Also check that the resistance readings are below the maximum value recommended by the manufacturer.
Insulation resistance	Measure the winding-to-winding and winding-to-ground insulation resistance.	The insulation resistance reading should be at least 100 Mohm on the low-voltage winding and at least 5000 Mohm on the high-voltage winding.
Power factor	Measure the power factor for the transformer windings. For transformers with capacitance-type bushings, measure the power factor and capacitance of the bushing. If a power factor test tap is not provided, use the hot collar test and measure the watts-loss.	The winding power factor for fluid-filled transformers is less than 3% except for silicone transformers, which will have a typical power factor of 0.5%. The bushing power factor and capacitance should not vary from the nameplate by more than 10%. Bushing hot collar watts-loss readings should not exceed the manufacturer's factory test result.

2.1.3.8 Dry-Type Transformers

2.1.3.8.1 Inspect, clean, service, and test dry-type transformers every 3 to 5 years in accordance with the manufacturer's guidelines or industrial standards. Ensure cooling fans, temperature switches, and alarms are functioning properly. If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.8.1 as a reference for testing dry-type transformers.

Table 2.1.3.8.1. Electrical Tests for Dry-Type Transformers

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There should not be any difference greater than 50% between resistance readings. Also check that the resistance readings are below the maximum value recommended by the manufacturer.
Insulation resistance	Measure the winding-to-winding and winding-to-ground insulation resistance.	The insulation resistance reading should be at least 100 Mohm on the low-voltage winding, and at least 5000 Mohm on the high-voltage winding.
Polarization index	Extend the 1-minute spot insulation resistance test to include a 10-minute insulation resistance measurement.	Calculate the polarization index. This value should not be less than 1.0.
Power factor[1]	Measure the power factor for the transformer windings.	Power factor testing is most effective when results are compared to installation acceptance tests and/or recommended manufacturer values, if available. There should be no significant increase (e.g., >100%) compared with a baseline value. As a general guideline, CHL should be < 2% for power transformers, and < 5% for distribution transformers.

Note 1. Power factor tests are optional and normally used for diagnostics.

2.1.3.9 Emergency Generators

2.1.3.9.1 Start and run emergency generators once a month. Run diesel emergency generators for 30 minutes under load at a minimum of 30% nameplate rating or at the manufacturer's recommended minimum load, wichever is more severe.

Wet stacking is caused by operating diesel engines at no load or low loads for extended periods of time. This causes unburnt fuel residue to accumulate on the exhaust valve stem. These accumulations harden into a resin and can lead to stuck valves, bent push rods, and other mechanical damage. This can also occur if the diesel engine is not operated for a long enough time to allow the engine temperature to reach a sufficiently high value.

2.1.3.9.2 For automatic starting generators, functionally check the operation of the generators and associated automatic transfer switches by simulating loss of normal power and return of normal power. Perform these functional checks every 3 to 5 years. Where it is not possible to energize the emergency load during the test, use of a “dummy load” is acceptable.

2.1.3.9.3 Perform the tests shown in Table 2.1.3.9.3 every 3 to 5 years in accordance with the manufacturer’s instructions and/or industry standards as applicable. If there are no manufacturer’s guidelines or industry standards available, use Table 2.1.3.9.3 as a reference for testing emergency generators.

Table 2.1.3.9.3. Electrical Tests for Emergency Generators and Rotary Uninterruptible Power Supplies

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There must not be any difference greater than 50% between resistance readings. Check that the resistance readings are below the maximum value recommended by the manufacturer.
Insulation resistance	Measure the winding to ground insulation resistance.	The insulation resistance reading correct to 100°F (40°C) must be at least 5 Mohm.[1]
Dielectric Absorption (for generators with magnet wire windings)[2]	Calculate the dielectric absorption ratio (the ratio of the insulation resistance at 30 seconds to the insulation resistance at 60 seconds).	This value must not be less than 1.4. Dielectric absorption ratios higher than 2.0 may indicate a dry and brittle winding.

Note 1. Acceptance criteria applies to random-wound and form-wound generators.
Note 2. Generators will typically use magnet wire for the stator windings. Magnet wire is insulated by enamel or varnish and will not have any other insulation. There is little value in measuring the polarization index for magnet-wire windings.

2.1.3.10 Uninterruptible Power Supplies

2.1.3.10.1 Test the batteries in uninterruptible power supplies in accordance with Data Sheet 5-28, *DC Battery Systems.*

2.1.3.10.2 Functionally check the operation of the uninterruptible power supply by simulating loss of normal power and return of normal power. Perform these functional checks once every 3 to 5 years.

2.1.3.11 Rotary Uninterruptible Power Supplies

2.1.3.11.1 Functionally check the operation of rotary uninterruptible power supplies by simulating loss of normal power and return of normal power. Perform these functional checks once every 3 to 5 years.

2.1.3.11.2 Perform electrical tests as shown in Table 2.1.3.9.3 in accordance with the manufacturer’s guidelines and/or industry standards as applicable. If there are no manufacturer’s guidelines or industry standards available, use Table 2.1.3.9.3 as a reference for testing rotary uninterruptible power supplies.

2.1.3.11.3 Install vibration monitoring on the bearings arranged to alarm to a constantly attended location when high vibration levels are detected. Alternatively, perform regular vibration monitoring at least once per week to detect problems with the bearings.

2.1.3.11.4 For oil-lubricated bearings, perform annual lubrication analysis to detect wear or other problems with the bearings.

2.1.3.11.5 Check greased bearings on a daily basis to ensure the bearings are adequately lubricated.

2.1.3.11.6 Maintain the flywheel, bearings, synchronous clutch, and diesel engine in accordance with the manufacturer’s instructions.

2.1.3.12 Induction Motors

2.1.3.12.1 Visually inspect the motor foundations, shaft alignment, bearings, grounding connections, fans, air filters, and baffles (if applicable) once per month.

2.1.3.12.2 For oil-lubricated bearings, perform annual lubrication analysis to detect wear or other problems.

2.1.3.12.3 Check greased bearings on a monthly basis to ensure the bearings are adequately lubricated.

2.1.3.12.4 Where a viable motor equipment contingency plan is not in place, perform the tests shown in Table 2.1.3.12.4 every 3 to 5 years in accordance with the manufacturer's guidelines or industry standards. If there are no manufacturer's guidelines or industry standards available, use Table 2.1.3.12.4 as a reference for testing induction motors. See Data Sheet 9-0, *Asset Integrity*, and Data Sheet 5-17, *Motors and Adjustable Speed Drives*, for equipment contingency planning guidance.

Table 2.1.3.12.4. Electrical Tests for Induction Motors

Test	*Comment*	*Acceptance Criteria*
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter (Ductor®).	Compare resistance readings between similar bolted connections. There must not be any difference greater than 50% between resistance readings. Check that the resistance readings are below the maximum value recommended by the manufacturer.
Insulation resistance	Measure the winding to ground insulation resistance for each phase.	The insulation resistance reading correct to 40°C must be at least 100 Mohm.
Dielectric absorption	Calculate the dielectric absorption ratio (the ratio of the insulation resistance at 30 seconds to the insulation resistance at 60 seconds).	This value must not be less than 1.4. Dielectric absorption ratios higher than 2.0 may indicate a dry and brittle winding.

2.1.3.13 Grounding Connections

2.1.3.13.1 Perform ground-earth resistance tests on ground connections to earth when first installed, after soil conditions have stabilized. Further testing should be performed as needed based on the following conditions:

A. Protective relays not operating properly for ground-faults

B. Surge equipment failing to properly protect electrical circuits or equipment

C. Step and touch potentials present

D. Signal noise on electronic and communication equipment

E. Physical evidence of grounding conductor deterioration

The resistance should not exceed 1 ohm or the recommended value per applicable industry guidelines.

2.2 System Studies

2.2.1 Verify that load flow, fault current, and protection coordination studies have been completed. For systems with dedicated ground fault protection, include ground fault protection coordination as applicable when fault current and protection coordination studies are performed.

2.2.2 Perform fault current and protection coordination studies whenever any of the following electrical system expansions or modifications are conducted:

A. The addition of a utility feeder

B. The addition of transformers or an increase in installed transformer capacity

C. The paralleling of existing transformers

D. The addition of motor(s) with individual or combined ratings larger than 50 hp (37 kW)

E. The addition of in-house generation sources, including renewables and traditional energy sources, larger than 50 hp (37 kW)

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Failure Modes

3.1.1 Insulation Breakdown

Insulation breakdown of electrical equipment is the primary failure mode of concern in commercial and industrial buildings. Insulation breakdown is typically caused by one or more of the following:

- Contamination
- Overheating
- Over-voltage
- Vermin
- Human error

Insulation breakdown can cause electrical arcing, short circuits, and ground faults.

Operating electrical equipment in clean, cool, dry, and tight conditions will significantly reduce the risk of insulation breakdown.

3.1.2 Faulty Operation

Faulty operation of circuit breakers is another common failure mode. Failure of circuit breakers to open, slow operation of circuit breakers, misalignment of circuit breaker contacts, and unintentional operation of circuit breakers can have severe consequences. These can range from a destructive failure of the circuit breaker to unintentional power loss to critical processes.

Failures of circuit breakers can be reduced by routinely inspecting, exercising, and lubricating the breakers. This ensures the mechanisms operate freely and do not bind.

3.1.3 Transformer Explosion and Fire

The greatest hazard with mineral oil-filled transformers is internal arcing causing the transformer to explode. Internal arcing occurs when the winding insulation breaks down due to over-voltage, mechanical forces from electrical faults, overload, excessive moisture, or age.

Because it is not possible to completely prevent internal arcing, oil-filled transformers should be arranged per DS 5-4 so they do not expose other equipment or buildings in the event of an explosion and fire. It is not prudent to rely completely on electrical testing, maintenance, and electrical protection to prevent transformer explosions.

3.2 Electrical Connections

When properly made, an electrical connection should not require retightening. Studies show that terminal torque reduces somewhat from initial values due to creep or cold flow, but contact resistance remains essentially unchanged. Since contact resistance is a determining factor in contact heating, as long as resistance remains low, overheating should not occur.

Most switchgear manufacturers advise that connections requiring retightening be entirely reworked. This means a connection must be taken apart and cleaned, often with a specific cleaning compound. Parts such as spring washers must be replaced, and the connections reassembled and re-torqued to the proper value.

Studies show that installers usually under-torque connections when they fail to use a torque wrench or screwdriver.

An excellent method for detecting improperly-made electrical connections is infrared thermography.

3.3 Aluminum Conductors

Although there have been some large losses involving aluminum conductors, the *National Electrical Code®* currently allows their use if the following rules are followed:

A. Aluminum conductors and connectors need to be made of an acceptable electrical-grade aluminum alloy. In the United States, this refers to AA-8000 series material.

B. Aluminum conductors need to be sized larger than copper conductors for the same service.

C. The connectors for dissimilar metals (e.g., copper and aluminum) have to be specifically designed for this use.

3.4 Transformer Oil Testing and Dissolved Gas Analysis

3.4.1 Transformer Oil Testing

Transformer oil should be checked to ensure it is in good condition for continued service. The transformer oil provides cooling and insulation. It also protects the paper insulation.

The qualities of transformer oil shown in Table 3.4.1 should be checked at each test.

Table 3.4.1. Oil Quality Analysis Criteria for Mineral, Silicone, Ester Oil (Valid only for Transformers with Primary Voltage of 69 kV and Below)

<table>
<tr><th>Quality Test</th><th>Purpose</th><th colspan="3">Mineral Oil</th><th>Silicone Oil</th><th>Natural Ester</th></tr>
<tr><td rowspan="2">Dielectric Strength (ASTM D 1816)</td><td rowspan="2">Checks whether the insulating property of the fluids has been degraded by contaminants, primarily moisture.</td><td colspan="3">23 kV minimum for a 0.04 in. (1 mm) test gap</td><td>23 kV minimum for a 0.04 in. (1 mm) test gap</td><td>23 kV minimum for a 0.04 in. (1 mm) test gap</td></tr>
<tr><td colspan="3">40 kV minimum for a 0.08 in. (2 mm) test gap</td><td>40 kV minimum for a 0.08 in. (2 mm) test gap (<30kV per D 877)</td><td>40 kV minimum for a 0.08 in. (2 mm) test gap</td></tr>
<tr><td rowspan="2">Dissipation factor</td><td rowspan="2">Determines how badly the oil has been contaminated by substances other than water, including carbon, metal, soaps, and products of oxidation.</td><td colspan="3">0.5 maximum at 77°F (25°C)</td><td rowspan="2">0.2 maximum at 77°F (25°C)</td><td rowspan="2">Follow manufacturer’s guidance</td></tr>
<tr><td colspan="3">5.0% maximum at 210°F (100°C)</td></tr>
<tr><td>Interfacial tension</td><td>Checks for contaminants in the fluid, primarily particles generated by the oxidation of the fluid and paper insulation.</td><td colspan="3">25 mN/m minimum</td><td>Na</td><td>Na</td></tr>
<tr><td>Neutralization number</td><td>Determines the acidity of the fluid, which indicates how much the fluid and paper insulation has deteriorated.</td><td colspan="3">0.20 mg KOH/g maximum</td><td>0.20 mg KOH/g maximum</td><td>Na</td></tr>
<tr><td>Oxygen inhibitor content</td><td>Added to some oils to help protect the paper insulation from oxidation.</td><td colspan="3">0.09% (only valid for inhibited oils)</td><td>Na</td><td>Na</td></tr>
<tr><td rowspan="4">Water content</td><td rowspan="4">The amount of water in transformers is critical. Too much water can cause the paper insulation to degrade much quicker than normal and cause bubbling inside the transformer during high load</td><td>Oil Temp</td><td>Water Content</td><td>Relative Saturation</td><td rowspan="4">100 ppm</td><td rowspan="4">Follow manufacturer’s guidance</td></tr>
<tr><td>120°F (50°C)</td><td>27 ppm</td><td>15%</td></tr>
<tr><td>140°F (60°C)</td><td>35 ppm</td><td>15%</td></tr>
<tr><td>160°F (70°C)</td><td>55 ppm</td><td>15%</td></tr>
</table>

Note: 1 ppm = 1 mg/kg
Transformer oil that does not meet the acceptance criteria in this table may need to be replaced or treated by filtering the oil.

3.4.2 Dissolved Gas Analysis

Dissolved gas analysis (DGA) is the process of using a gas chromatograph to determine the concentration of dissolved gases in a sample of transformer oil. The key gases that are measured during DGA testing, and their most likely causes, are shown in Table 3.4.2.

Table 3.4.2-1. Key Gases in Transformer Fluids

Key Gas	*Most Likely Cause*
Hydrogen H_2	**Partial discharge** – Hydrogen is generated for almost all faults. If it is the predominant gas, the most likely cause is partial discharge.
Methane CH_4	**Overheating** – Methane is the first gas to appear when there is overheating. It will be present at even low levels of overheating; around 300°F (150°C).
Acetylene C_2H_2	**Arcing** – Acetylene is typically associated with arcing; however, localized overheating above 930°F (500°C) but below 1300°F (700°C) can generate low concentrations of acetylene without any arcing being present.
Ethylene C_2H_4	**Localized overheating** – Ethylene is generated at temperatures above 350°C. It is generally associated with localized overheating of windings and core.
Ethane C_2H_6	**General overheating** – Ethane is generated at temperatures above 250°C. It is associated with overload and poor cooling if no higher temperature gases are present.
Carbon Monoxide CO	**Cellulose overheating** – Faults involving oil do not generate carbon monoxide. It is only produced when paper insulation is involved.
Carbon Dioxide CO_2	**Oil and/or cellulose overheating** – Carbon dioxide is produced by faults involving both paper and oil.

There is greater value in observing the trends in gas generation rates than in just looking at the key gas concentrations. Changes in gas generation rates are more and sensitive to and indicative of incipient problems than absolute gas concentration levels.

Proper oil-sampling technique is critical to ensuring the reliability of oil testing and dissolved gas analysis results. The slightest error in oil sampling can have a significant effect. Some common errors include accidentally touching the mouth of the sampling bottle with a bare hand, not properly flushing the oil sampling valve and/or the oil collection bottle and syringe, exposing oil samples to light and heat, not using a syringe to collect oil samples for DGA testing, and allowing the oil sample to be contaminated. A reputable professional transformer oil-testing company will carefully adhere to the latest industry standards when collecting oil samples.

Table 3.4.2-2 lists the dissolved gas concentrations for assessment of a gassing condition on a mineral oil-filled transformer with no previous history (e.g., a new or repaired transformer). They are consensus values based on IEEE C57.104: *IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.* Users may decide to use different dissolved gas concentrations for a transformer based on experience with other similar transformers. Conditions 2, 3, and 4 indicate problem may exist and re-sampling is needed to establish a trend for further investigation.

Table 3.4.2-2. Typical DGA Values for Transformers (with No Previous History) Filled with Mineral Oil

Status	*H_2 (Hydrogen)*	*CH_4 (Methane)*	*C_2H_2 (Acetylene)*	*C_2H_4 (Ethylene)*	*C_2H_6 (Ethane)*	*CO (Carbon Monoxide)*	*CO_2 (Carbone Dioxide)*	*TDCG*
Condition 1, typical value, ppm	<100	<120	<1	<50	<65	<350	<2500	<720
Condition 2, higher than normal value, ppm	<700	<400	<10	<100	<100	<570	<4000	<1920
Condition 3, high level, ppm	<1800	<1000	<35	<200	<150	<1400	<10000	<4630
Condition 4 excessive value, ppm	>1800	>1000	>35	>200	>150	>1400	>10000	>4630

Table 3.4.2-3 provides reference guidance for gas generation rates when there are no manufacturer's guidelines or industry standards available.

For silicon oil-filled transformers, refer to Table 3.4.2-4. See Table 3.4.2-5 for ester oil-filled transformers.

Table 3.4.2-3. Gas Generation Rate for Transformers Filled with Mineral Oil

Status	*H_2 (Hydrogen)*	*CH_4 (Methane)*	*C_2H_2 (Acetylene)*	*C_2H_4 (Ethylene)*	*C_2H_6 (Ethane)*	*CO (Carbon Monoxide)*	*CO_2 (Carbone Dioxide)*
Generation rate G1, ppm limit per month[1]	<10	<8	<3	<8	<8	<70	<700
Generation rate G2, ppm limit per month[2]	<50	<38	<3	<38	<38	<350	<3500

[1] G1 limit means: If one or more gas generation rate exceeds G1 limits, further investigation is needed.

[2] G2 limit means: If one or more gas generation rate exceeds G2 limits, the unit is considered in critical condition.

Table 3.4.2-4. Typical Gas Values and Generation Rate for Transformers (with No Previous History) Filled with Silicon Oil

Status	*H_2 (Hydrogen)*	*CH_4 (Methane)*	*C_2H_2 (Acetylene)*	*C_2H_4 (Ethylene)*	*C_2H_6 (Ethane)*	*CO (Carbon Monoxide)*	*CO_2 (Carbone Dioxide)*	*TDCG (Total dissolved combustible gas)*
Typical value (ppm)	<200	<100	<1	<30	<30	<3000	<30,000	<3360
Generation rate G1 limit* (ppm per month)	<20	<10	<1	<3	<3	<300	<1500	<na
Generation rate G2 limit** (ppm per month)	<100	<50	<1	<15	<15	<1,500	<15,000	<na

*G1 limit means: if one or more gases generation rates exceed G1 limits, further investigation is needed.

**G2 limit means: if one or more gases generation rate exceed G2 limits, the unit is considered in critical condition.

Table 3.4.2-5. Typical Dissolved Gas Concentration Value for Transformers (with No Previous Sample History) Filled with Ester Oil

Ester Fluid Type	*H_2 (Hydrogen)*	*CH4 (Methane)*	*C_2H_6 (Ethane)*	*C_2H_4 (Ethylene)*	*C_2H_2 (Acetylene)*	*CO (Carbon Monoxide)*	*CO_2 (Carbone Dioxide)*
Soybean based, (ppm)	<115	20	<235	20	<2	<170	na
High Oleic Sunflower based (ppm)	<35	<25	<60	<20	<1	<500	na
Synthetic (ppm)	<65	<105	<125	<150	<15	<1400	na

3.5 Ultrasonic Scanning

Online ultrasonic scanning can be performed while equipment is energized using a portable handheld scanning device. A trained technician can listen around switchgear enclosure door seals and vents with the scanning device or a touch/contact probe attachment to the device that can be used to listen through the enclosure itself. This method can detect possible arcing in low-voltage electrical equipment circuit breakers, switches, and contacts. Ultrasonic scanning is most effective when used with sound imaging (spectral) software to help analyze and prioritize ultrasonic scan results.

Ultrasonic scanning will only detect arcing in low-voltage switchgear. If buzzing sounds are detected they are likely due to loose connections vibrating at the electrical system frequency or possible tracking.

3.6 Visual Inspections

3.6.1 Inspection Frequency

Having visual inspections made by qualified personnel is the best overall method of detecting electrical deficiencies and determining when other supplementary electrical tests need to be performed.

Visual inspections do not require electrical equipment to be de-energized, dismantled, or opened. These inspections are performed with equipment in normal operating condition using only human senses (sight, sound, smell, and touch). It should not take a long time to perform visual inspections. As an example, it should take no more than 10 minutes to walk through the average main electrical room for an office building, warehouse, or factory.

3.6.2 Operating Temperature of Electrical Equipment

Heat is a significant factor in the deterioration of electrical insulation. In general, for every 18°F (10°C) rise above the rated operating temperature, a halving of insulation life can be expected. Loss of insulation life will lead to electrical breakdown.

Typically, the ambient temperature in switchrooms should be maintained at no higher than 86°F (30°C), or between 68°F (20°C) and 77°F (25°C) if electronic components such as solid state relays, process controllers, and VRLA batteries are present. A high ambient temperature in the switchroom indicates equipment is either being overloaded or the ventilation in the room is inadequate. This increases the risk of failure.

3.6.3 Clean, Cool, Dry, and Tight

The following are examples of clean, cool, dry, and tight conditions for various types of electrical equipment (and their relation to Equipment Factors).

3.6.3.1 Circuit Breakers

A. Clean (Environment)

1. There should be no product or environmental dust in switchgear cubicles or covering the circuit breaker.
2. There should be no trash or other debris in the circuit breaker cubicle or on top of the cubicle.
3. There should be no combustible material stored within 5 ft (1.5 m) of the switchgear cubicle.

B. Cool (Operating Condition or Environment)

1. The switchgear cubicle should be cool.
2. Circuit breakers should not show signs of overheating (e.g., discoloration or warping of the plastic casing and blackening or blistering of the paint).
3. The switchroom temperature should be no higher than 86°F (30°C), or 77°F (25°C) if solid state relays, electronic process controls, and VRLA batteries are present.
4. Temporary fans should not be used to cool equipment.
5. Doors should not be kept propped open to keep the switchroom cool.
6. Doors on switchgear cubicles should not be left open to keep equipment cool.

C. Dry (Environment)

1. There should be no rust stains on the inside or outside surfaces of switchgear cubicles.
2. Check for watermarks on the switchroom walls, floors, or ceilings, which may indicate previous incidents of flooding or leaks.

3. Tarpaulin or plastic sheeting draped over switchgear may indicate a problem with roof leaks.

4. There should be no condensation on the inside or outside surfaces of circuit breaker cubicles. (Condensation inside the cubicles can be prevented by installing switchgear cubicle heaters.)

5. The bases of circuit breaker cubicles should not be corroded. This could indicate that hoses are used for cleaning in the switchroom or that there is standing water in the area.

6. Water and sewage pipes should not run through the switchroom or over switchgear.

7. Condensation from air conditioning should not be allowed to drip onto switchgear.

D. Tight (Environment)

1. All switchgear cubicle doors should be closed.

2. Circuit breaker casings should not show any signs of cracking or breakage.

3. There should be no signs of vermin. Look for nests, dead animals, holes, rodent traps, or bite marks that indicate the presence of vermin. Rats can chew through cables, and snakes frequently cause electrical faults inside switchgear cubicles.

4. Product dust and dust from the environment should not be allowed to enter the switchgear cubicle or the switchroom. Ideally, the switchroom should be maintained under positive pressure.

5. All cable penetrations should be properly fire stopped.

3.6.3.2 Transformers

A. Clean (Operating Condition or Environment)

1. For liquid-filled transformers, ensure there are no leaks from the transformer tank or its bushings. Check for evidence of stains on the transformer as well as on the floor.

2. For dry-type transformers, ensure the transformer is not covered with product dust or dust from the environment.

3. There should be no vegetation in the transformer compound. Plant roots can damage the earth grid, and if vegetation is allowed to grow too tall it will present a risk of electrical fault.

4. There should be no debris or trash in the transformer compound or the transformer room.

5. Combustible material should not be stored in the transformer compound or the transformer room.

B. Cool (Operating Condition or Environment)

1. The gages on liquid-filled transformers should show the following temperature readings:

a. Temperature rise: 130°F to 150°F (55°C to 65°C)
b. Oil temperature: 180°F to 190°F (80°C to 90°C)
c. Hot spot temperature: 220°F to 250°F (105°C to 120°C)

2. The gages on dry-type transformers should show the following temperature readings:

a. Temperature rise: 180°F to 300°F (80°C to 150°C)
b. Hot spot temperature: 280°F to 390°F (140°C to 200°C)

3. The transformer may be overloaded if these temperatures are exceeded.

C. Dry (Environment)

1. For dry-type transformers, ensure there are no watermarks on the room walls, floors, or ceilings, which may indicate previous incidents of flooding or leaks.

2. There should be no tarpaulin or plastic sheeting over dry-type transformers. This may indicate there are roof leaks over the transformer.

3. The bottoms of dry-type transformer cubicles and oil-filled transformer tanks should not be corroded. This indicates the area around the transformer is subject to regular hosing or there is frequently standing water in the area.

4. Water and sewage piping should not be run through rooms housing dry-type transformers.

5. Condensation from air conditioning in the transformer room should not be allowed to drip onto dry-type transformers.

6. If the transformer is free breathing, ensure the desiccant in the transformer breather has not expired. Desiccant should be partly blue or orange. (Blue desiccant turns pink when it has expired; orange desiccant turns white when it has expired.)

D. Tight (Environment)

1. All cable penetrations from the transformer should be fire stopped.

2. Oil-filled transformers should be provided with adequate containment to prevent an oil spill exposing adjacent equipment and buildings.

3. There should be no signs of vermin. Look for nests, dead animals, holes, rodent traps, or bite marks that indicate the presence of vermin.

4. Rooms housing dry-type transformers should be protected from ingress of product and environmental dust.

3.6.3.3 Cables

A. Clean (Environment)

1. Cable trenches and basements should be free of trash and debris.

2. Cable trays should be clean and not covered with trash and dust.

3. Cable trays should not be overloaded with cables. (As a general rule, the number of cables in the tray should not be more than the depth of the tray.)

4. Pitch-filled and oil-filled cables should not leak, especially at the cable terminations.

B. Cool (Operating Condition)

1. Cables should be warm but not hot.

C. Dry (Environment)

1. Indoor cable trays should not be exposed to water leaks or other corrosive liquids and vapors. Certain solvents and oils can corrode cable insulation.

D. Tight (Environment)

1. Cable penetrations should be properly fire stopped.

2. Conduits in which cables are run should be waterproofed so water does not enter the conduit.

3. There should be no signs of vermin. Look for nests, dead animals, holes, rodent traps, or bite marks that indicate the presence of vermin.

3.6.3.4 Batteries

A. Clean (Operating Condition or Environment)

1. Battery rooms and cabinets should be free of trash and debris.

2. Battery chargers should be properly separated from combustibles.

3. There should be no electrolyte leaks from the battery banks.

4. Battery terminals and connections should be free from corrosion.

B. Cool (Environment)

1. Batteries should be maintained at approximately 77°F (25°C) (i.e., room temperature).

2. Battery cabinets housing batteries should not be warm. There should be vents in the battery cabinet to allow cooling.

3. Battery chargers should be warm but not hot. There should be vents in the battery charger cubicle to allow cooling.

C. Dry (Environment)

1. There should be no tarpaulin or plastic sheeting over battery chargers. This may indicate there are roof leaks over the charger.
2. Condensation from air conditioning should not be allowed to drip onto battery chargers.

D. Tight (Operating Condition or Environment)

1. Battery rooms should be properly ventilated to prevent a buildup of hydrogen gas.
2. Battery rooms and cabinets housing vented batteries should be arranged so electrolyte spills do not expose equipment or buildings.
3. There should be no signs of vermin. Look for nests, dead animals, holes, rodent traps, or bite marks that indicate the presence of vermin.
4. There should be no signs of battery casing bulging, cracking, or distortion.
5. Battery connections should be tight. An infrared camera or non-contact thermometer can be used to check the tightness of connections.

3.7 Infrared View Port

When installing any type of infrared view port in arc-resistant switchgear, it is important to ensure the arc-resistant integrity of the switchgear is not compromised.

To some degree, all view ports have a limited field of view within the switchgear enclosure. To maximize the effectiveness of an infrared scanning program using view ports, the ports should be placed strategically in areas where problems are likely to occur or have occurred in the past. These locations often include the rear panels of switchgear enclosures where main bus bar bolted connections, main circuit breaker/switchgear contacts, and/or cable terminations can be viewed.

4.0 REFERENCES

4.1 FM

Data Sheet 5-4, *Transformers*
Data Sheet 5-12, *Electric AC Generators*
Data Sheet 5-17, *Motors and Adjustable Speed Drives*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-28, *DC Battery Systems*
Data Sheet 9-0, *Asset Integrity*

4.2 Other

ASTM International (ASTM). D2668, *Standard Test Method for 2,6-di-tert-Butyl-p-Cresol and 2,6-di-tert-Butyl Phenol in Electrical Insulating Oil by Infrared Absorption.*

ASTM International (ASTM). D974, *Standard Test Method for Acid and Base Number by Color-Indicator Titration.*

ASTM International (ASTM). D1816, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.*

ASTM International (ASTM). D924, *Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.*

ASTM International (ASTM). D971, *Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method.*

Institute of Electrical and Electronics Engineers (IEEE). C57.121, *IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers.*

Institute of Electrical and Electronics Engineers (IEEE). C57.111, *IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers.*

Institute of Electrical and Electronics Engineers (IEEE). *Standard 141, Recommended Practice for Electric Power Distribution for Industrial Plants.*

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Institute of Electrical and Electronics Engineers (IEEE). IEEE C57.104, *Guide for the Interpretation of Gases in Oil Immersed Transformers.*

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Institute of Electrical and Electronics Engineers (IEEE). IEEE C57.155, *Guide for the Interpretation of Gases Generated in Natural Ester and Synthetic Ester Immersed Transformers.*

International Electrical Testing Association (NETA). *Maintenance Testing Specifications for Electrical Power Equipment Distribution and Systems.*

National Fire Protection Association (NFPA). NFPA 70, *National Electrical Code®.*

United States Department of the Interior, Bureau of Reclamation, Facilities Instructions, Standards and Techniques (FIST). FIST 3-3-, *Transformer Maintenance.*

APPENDIX A GLOSSARY OF TERMS

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide* for a complete listing of products and services that are FM Approved.

Low voltage: The definition of "low voltage" varies among industry standards. Per IEEE 141-1993, low voltage means ≤ 600V. IEC 60038 defines low voltage as system voltage less than 1000 V for AC and 1500 V for DC.

Supply and distribution transformers: These transformers generally are less than 10 MVA (per IEEE C 57.12.36) and are primarily used for voltage step-down purposes.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

October 2025. Interim revision. Major changes in this revision include the following:

A. Revised the guidance for thermograph/infrared scanning recommendations in Section 2.1.3.1:

1. Added a new table to assist field engineering with assessing the level of deficiency identified through infrared scanning.

October 2024. Interim revision. Minor editorial changes were made for this revision.

July 2023. Interim revision. Provided clarity on emergency generator wet stacking inspection, testing and maintenance.

October 2021. Interim revision. Updated diesel generator recommendation and battery testing reference.

July 2020. Interim revision. Updated contingency planning and sparing guidance.

October 2016. This document has been completely revised. The following major changes were made:

A. Clarified the scope, which now applies to low-voltage electrical equipment, including supply and/or distribution transformers and their associated switchgear.

B. Consolidated and clarified the guidance on inspections, tests, and testing intervals to improve the alignment with common industrial practice.

C. Added guidance on inspection and testing for ground fault protection and grounding conductors.

September 2007. The scope of this operating standard has been substantially changed and now applies only to electrical equipment less than or equal to 600 V in commercial and industrial buildings, and privately owned, pad-mount transformers greater than 600 V and their associated switchgear.

May 2001. Revisions were made to Table 1, Electrical Test Matrix.

January 2000. The document has been reorganized to provide a consistent format.