SWITCHGEAR AND CIRCUIT BREAKERS

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1.0 SCOPE

This data sheet describes loss prevention recommendations for the basic operation, protection, inspection, maintenance, and testing of various types of switchgear and circuit breakers. “Switchgear” is a general term covering switching, interrupting, control, metering, protective, and regulating devices. It also includes assemblies of these devices with their associated interconnections, accessories, and supporting structures.

This data sheet is limited to switchgear and circuit breakers for use in applications above 1000 V AC. Data Sheet 5-20, *Electrical Testing*, addresses equipment used in applications below 1000 V AC.

1.1 Hazards

The primary purpose of switchgear and circuit breakers is to protect connected equipment and systems from electrical faults, which could result in equipment damage, arcing faults, fire, and widespread power outage.

1.2 Changes

October 2024. Interim revision. The scope of this data sheet was updated to clarify that it contains loss prevention recommendations related to the fire protection of **ALL** types of switchgear and circuit breakers.

2.0 LOSS PREVENTION RECOMMENDATIONS

The majority of losses involving switchgear and circuit breakers are related to deficient maintenance practices, operating conditions, environment, and human factors. Most of these losses can be prevented by following good design practices, regular inspection & testing, periodic preventive electrical and mechanical maintenance, and a robust management of change program.

2.1 Operation and Maintenance

Recommended routine preventive inspection, testing, and maintenance frequency and scope are general guidance. They should be adjusted depending on factors such as operating history, operating conditions, online monitoring systems, age, and criticality of the equipment.

Establish and implement a switchgear and/or circuit breaker inspection, testing, and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.1.1 Electrical Power System Studies

2.1.1.1 Complete the appropriate system studies (e.g., protection coordination, load flow, short circuit) for new installations and whenever any of the following electrical system expansions or modifications are carried out:

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 (e.g., closing a normally open tie-breaker or adding a new tie-breaker)

D. The addition of large motor(s) (e.g. >500 HP)

E. The addition of in-house power generation

2.1.1.2 Ensure switchgear and circuit breakers operate within their specified load ratings. If the load currents are not known, perform a load flow study.

2.1.1.3 Ensure switchgear and circuit breakers are adequately rated for the prospective fault levels. If prospective fault levels are not known, perform a short-circuit study.

2.1.1.4 Ensure switchgear and circuit breaker protection settings are appropriate to protect connected equipment. If appropriate settings are not known, perform a protection coordination study.

The protection coordination study should ensure all faults (thermal overload, short-circuit, arcing and ground) within the power system are detected and cleared as quickly as possible, whilst minimizing the level of interruption to the power system. An effective protection coordination study should be based on an accurate and up-to-date fault study for the power system. The protection study scope should include the point/s of supply from the utility, any fixed generators, motors with substantial fault contribution, and the first protection device downstream of each power transformer.

2.1.2 Visual Inspection

2.1.2.1 Conduct regular visual inspections of switchgear. Subject to the environmental and operating conditions, perform weekly to monthly inspections with the switchgear energized and in its normal operating condition. The switchgear should operate in a clean, cool, dry, and tight environment with no abnormal noises, smells, vibration, or heat.

2.1.3 In-Service Surveys

2.1.3.1 Perform online partial discharge surveys for switchgear and circuit breakers rated 4 kV and above on a routine basis such as every 1 to 3 years.

2.1.3.2 Perform thermographic surveys of switchgear and circuit breakers (of any size) on a routine basis every 1 to 3 years. Where equipment design makes thermographic surveys difficult, use one of the following options:

A. Thermographic inspection viewing ports. When installing thermographic viewing ports in arc-resistant switchgear, it is important to ensure the arc-resistant integrity of the switchgear is not compromised. Because viewing ports provide a limited view of the switchgear, they should be located in areas where problems are likely to occur (e.g., at bolted connections, switchgear contacts, and cable terminations).

B. Permanently installed temperature monitoring devices.

2.1.3.2.1 If thermographic surveys are not possible verify the tightness of accessible bolted electrical connections during scheduled maintenance. Apply a calibrated torque-wrench method in accordance with manufacturer’s published data. Also, perform low-resistance testing on accessible electrical connections.

2.1.4 Switchgear and Circuit Breakers Testing and Maintenance

2.1.4.1 Circuit Breakers

2.1.4.1.1 Mechanically exercise, inspect, service, lubricate, and test all critical circuit breakers every 3 to 5 years. In addition to the following activity, perform other maintenance activities in accordance with manufacture’s guidelines and/or industry standards as applicable.

A. Inspect and test circuit breakers for smooth operation, correct alignment, mechanical damage, overheating, binding of moving parts, condition of arc chutes, and condition of contacts.

B. Perform a functional test of the charging mechanism and various auxiliary features. Depending on the circuit breaker, these auxiliary features can include interlocks, trip-free, anti-pumping, trip indicators, and critical alarms.

C. Perform functional trip tests to verify the circuit breaker’s control circuit integrity and proper function. The trip test should be initiated by the electrical operation of the trip coil. Investigate any failure to trip.

D. Lubricate the circuit breaker in accordance with the manufacturer’s recommendations using only the manufacturer’s recommended lubricant.

E. Perform the testing per Table 1.

2.1.4.1.2 Internally inspect bulk oil circuit breakers on a three to five year interval. Also inspect bulk oil circuit breakers internally after the breaker has operated to interrupt three heavy faults (faults close to the rated interrupting capability of the circuit breaker).

Table 1a. General Tests for Circuit Breakers

<table>
<tr><th>Test</th><th>Comment</th><th colspan="2">Acceptance Criteria</th></tr>
<tr><td>Low resistance</td><td>Measure the resistance of bolted connections using a low resistance ohmmeter (Ductor R).</td><td colspan="2">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.</td></tr>
<tr><td>Contact resistance</td><td>Measure the contact resistance of each pole using a low resistance ohmeter.</td><td colspan="2">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.</td></tr>
<tr><td>Insulation resistance</td><td>Measure the phse-to-phse and phase-to-ground insulation resistance of each pole with the circuit breaker in the open and closed positions.</td><td colspan="2">The insulation resistance reading must be at least 100 Mohm.</td></tr>
<tr><td rowspan="6">Trip and close coil voltages</td><td rowspan="6">Measure the voltage required to operate the trip and close coils. Also verify the trip and close coils are functioning properly.</td><td colspan="2">The operating voltages must be withing the manufacturer’s recommended values. The following is some general criteria:</td></tr>
<tr><td>Norminal control voltage</td><td>Acceptable Voltage Range</td></tr>
<tr><td>24 V</td><td>14−28 V</td></tr>
<tr><td>48 V</td><td>28−56 V</td></tr>
<tr><td>125 V</td><td>70−140 V</td></tr>
<tr><td>250 V</td><td>140−280 V</td></tr>
<tr><td>Contact timing test</td><td>Measure moving contact travel with respect to time during opening and closing operations.</td><td colspan="2">Contact timing values should be in accordance with manufacturer’s published data and previous test data.</td></tr>
<tr><td>Power factor testing or dissipation test for condenser bushings[1]</td><td>Perform the tests on each bushing equipped with power factor tap.For bushings without test tap, perform hot-collar tests.</td><td colspan="2">Power factor reading should be within 100% increase of nameplate value. Hot collar value should be 0.1w or less at 10 kV testing voltage.</td></tr>
<tr><td>Dielectrical overpotential test (only after repair, modification or per OEM instruction)</td><td>Perform general overpotential test for circuit breakers.</td><td colspan="2">Perform the test in accordance with manufacturer’s recommendation[2]. Take care not to damage connected equipment such as cables and solid state relays.</td></tr>
</table>

Note 1. Condenser bushings are generally seen at breakers rated at 69 kV or above.
Note 2. Overpotential testing is generally recommended by most circuit breaker manufacturers. Insulation integrity of circuit breakers is very important, and it is common to perform routine DC overpotential testing to check the insulation.

Table 1b. Specific Tests for Different Types of Circuit Breakers

Test	*Air Circuit Breaker*	*Air Blast/ Compressed Air*	*Vaccuum*	*SF_6*	*Bulk Oil*
Dielectrical Overpotential testing for vaccum bottle	NA	NA	Perform a DC overpotential test on vacuum circuit breaker bottles to determine vacuum interity. Compare with the manufacturer's recommended value.	NA	NA
Liquid screen	NA	NA	NA	NA	Take oil samples to test the following markers: Dielectricl Strength: >25 kV Moisture level (<25ppm) PCBs: <50 ppm
Moisture in the air	NA	Check the dryness of compresssed air. Compare with manufacturer's recommended value.	NA	NA	NA
SF_6 gas analysis when provision is made for sampling	NA	NA	NA	Moisture: 200 ppm Decomposition products: 500 ppm Air: 5000 ppm Dielectrical Strength level: per OEM guidance	NA
Compressed air and gas systems condition check	NA	Study the number of compressor starts and the hours run compared with circuit breaker operation.	NA	Record pressure changes per operation, times to restore pressure. Compare with previous record.	NA
Slow open/close	Slowly operate the circuit breaker in one open/close operation, check for binding,and missalignment.	NA	Slowly operate the circuit breaker in one open/close operation, check for binding,and missalignment.	Slowly operate the circuit breaker in one open/close operation, check for binding,and missalignment.	Slowly operate the circuit breaker in one open/close operation, check for binding,and missalignment.

2.1.4.2 Switches and Fuses

2.1.4.2.1 Inspect, test, lubricate, and service the switches and fuses with automatic opening mechanisms every 3 to 5 years. Maintenance should include testing of interlocks. In addition to the testing in Table 2, perform other maintenance activities in accordance with manufacture's guidelines and/or industry standards as applicable.

2.1.4.2.2 Functionally test the control system on motor-operated switches by initiating an open and close operation at least every 3 to 5 years.

Table 2. Tests for Switches and Fuses

		Acceptance Criteria			
Test	*Comment*	Air	Vacuum	Oil	SF_6
Dielectric Overpotential (vacuum bottle integrity)	Perform a dc overpotential test on vacuum bottles to determine vacuum integrity.	Not applicable	Follow manufacturer's instructions and compare to manufacturer's values.	Not applicable	Not applicable
Liquid Screening	For oil-filled switches, take a sample of the oil and test for PCBs moisture, dielectric strength, and oil quality.	Not applicable	Not applicable	Dielectric strength: 26 kV Moisture: 25 ppm PCB: 50 ppm	Not applicable
Gas Analysis	For SF_6 switches, check the gas for moisture, dielectric strength, and contaminants.	Not applicable	Not applicable	Not applicable	Moisture: 200 ppm Decomposition products: 500 ppm Air: 5000 ppm Dielectric strength: 11.5-13.5 kV
Low Resistance	Measure the resistance of bolted connections using a low resistance ohmmeter.	Compare resistance readings between similar bolted connections. There must 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.			
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			
Fuse Resistance	Check fuse size and condition	This applies to fused switches only. Check that the fuses are in good condition and that the fuses are of the correct size and type for the switch. (Fuses can age and change their fusing characteristics. Some fuse manufacturers recommend that fuses are replaced after a certain service time.)			
Insulation Resistance	Apply a DC voltage for one minute with the contacts closed to measure phase to ground resistance for each pole.	Nominal Rating (kV)	Recommended Test Voltage (kV)	Minimum Resistance (MegaOhm)	
		1.0	1.0	100	
		2.5	1.0	500	
		5.0	2.5	1,000	
		8.0	2.5	2,000	
		15.0	2.5	5,000	
		25.0	5.0	20,000	
		35.0	15.0	100,000	
		46.0	15.0	100,000	
		69.0 and greater	15.0	100,000	
Dielectric Overpotential[1]	Apply a DC overvoltage for one minute with the contacts closed and measure leakage current for each pole.	Nominal Rating (kV)		Recommended DC Test Voltage (kV)	
		1.0 kV		8.5 kV	
		2.5		12.7	
		5.0		16.1	
		8.0		22.1	
		15.0		28.8	
		18.0		33.9	
		25.0		42.4	
		35.0		59.4	
		46.0		80.6	
		69.0 and greater		118.8	
		Take care not to damage connected equipment such as cables and solid state			

Note 1. Overpotential testing is generally recommended by most switch manufacturers. Insulation integrity of switches is very important and it is common to perform routine DC overpotential testing to check the insulation. relays.

2.1.4.3 Protection Relays

2.1.4.3.1 Perform routine testing and maintenance every 3 to 5 years. In addition to the following activity, perform other maintenance activities in accordance with manufacture's guidelines and/or industry standards as applicable

A. Inspect protection relays for physical damage and condition (cracked case, dirt, missing relays, uncleared semaphores or flags) as part of circuit breaker and switchgear inspection program.

B. Perform insulation resistance testing of control wire and trip circuits. (For solid state and microprocessor relays, check the manufacturer's recommended procedure for insulation resistance testing. These relays may be damaged by the voltages applied during insulation resistance testing).

C. Verify the settings of each protection relay are correct in accordance with most recent coordination study or register of original settings.

D. Perform a secondary injection test for each protection relay to verify correct operation of the relay. For electromechanical and solid state relays, perform a full calibration test (i.e. secondary current injection at multiple current levels to verify the accuracy of the relay's timing curve).

E. Test trip/close coil monitoring relays (if installed).

F. Where protection relays do not have a current transformer monitoring function, perform a continuity test for each current transformer.

G. Perform proof testing of field-mounted instrumentation associated with the circuit breaker trip function (e.g., sudden pressure relay, temperature transducer).

H. Perform a functional trip test to verify the operation of the trip coil circuit, including relays, control circuit, trip coils and circuit breaker.

I. Verify that all alarms (local and remotely monitored) are functioning correctly.

2.1.4.4 Batteries

2.1.4.4.1 Perfrom inspection, testing and maintenance for batteries and battery chargers in accordance with Data Sheet 5-28, *DC Batteries*.

2.1.4.5 Insulators and Busbars

2.1.4.5.1 Inspect outdoor open-air busbars and insulators for cleanliness and physical damage (insulation condition, corona damage, rodent damage, corrosion, leaks) once a month. Also check for alignment and foundation problems, and inspect the condition of grounding connections once a month.

2.1.4.5.2 For metal-enclosed or metal-clad switchgear, inspect the main breaker line side bus and feeder breaker load side bus for cleanliness and physical damage once a year whenever possible. For the primary bus sections with limited access, perform inspections for deterioration, corona damage, or contamination at intervals of between 3 and 5 years, or when the insulation resistance readings are less than the recommended values shown in Table 3.

2.1.4.5.3 Perform the tests in Table 3 every 3 to 5 years.

Table 3. Tests for Insulators and Busbars

Test	*Comments*	*Acceptance Criteria*		
Insulation resistance	Apply a DC voltage for one minute to measure phase-to-ground resistance for each phase.	Nominal Rating (kV)	Recommended Test Voltage (kV)	Minimum Resistance (Megaohms)
		1.0	1.0	100
		2.5	1.0	500
		5.0	2.5	1,000
		8.0	2.5	2,000
		15.0	2.5	5,000
		25.0	5.0	20,000
		35.0	15.0	100,000
		46.0	15.0	100,000
		69.0 and greater	15.0	100,000
Overpotential (only after repair or modification, or new installations)	Apply a DC overvoltage for one minute on each phase and measure leakage current.	Nominal Rating (kV)	Recommended Maximum DC Test Voltage (kV)	
		1.0	8.5	
		2.5	12.7	
		5.0	16.1	
		8.0	22.1	
		15.0	28.1	
		18.0	33.9	
		25.0	42.4	
		35.0	59.4	
		46.0	80.6	
		69.0 and greater	118.8	
Low resistance	Measure the resistance of bolted connections using a low-resistance ohmmeter.	Compare resistance readings between similar bolted connections. There must not be a difference greater than 50% between resistance readings. Also, check that the resistance readings are below the maximum value recommended by the manufacturer.		

2.1.4.6 Instrument Transformers

2.1.4.6.1 Inspect instrument transformers for physical damage (cleanliness, insulator damage, foundation condition, alignment, grounding and shorting connections, fuses) once a year.

2.1.4.6.2 Perform the tests in Table 4 at intervals of every 3 to 5 years.

Table 4. Tests for Instrument Transformers

<table>
<tr><th rowspan="2">Test</th><th rowspan="2">Comments</th><th colspan="4">Acceptance Criteria</th></tr>
<tr><th>Current</th><th>Inductive Voltage</th><th colspan="2">Capacitive Voltage</th></tr>
<tr><td>Excitation test</td><td>Measure the excitation current for each phase.</td><td>Compare the excitation current to the manufacturer’s value.</td><td>Not applicable</td><td colspan="2">Not applicable</td></tr>
<tr><td>Capacitance</td><td>Measure the capacitance of each capacitor section.</td><td>Not applicable</td><td>Not applicable</td><td colspan="2">Compare the capacitance to the nameplate value.</td></tr>
<tr><td>Power Factor</td><td>Measure the power factor of the instrument transformer.</td><td>Optional</td><td>Optional</td><td colspan="2">Compare the power factor to the nameplate value.</td></tr>
<tr><td>Fuses</td><td>Check fuse resistance and size.</td><td>Not applicable</td><td>Verify fuse sizes are correct and that the fuses are in good condition.</td><td colspan="2">Verify fuse sizes are correct and that the fuses are in good condition.</td></tr>
<tr><td>Test</td><td>Comments</td><td colspan="4">Acceptance Criteria (applies to all instrument transformer types)</td></tr>
<tr><td>Polarity test</td><td>Check transformer connection for correct polarity.</td><td colspan="4">Confirm that the instrument transformer is connected with the correct polarity and that the polarity matches the transformer markings.</td></tr>
<tr><td>Turns ratio</td><td>Check the transformer turns ratio at each tap position.</td><td colspan="4">There must not be a deviation greater than 0.5% between the measured ratio and the nameplate value.</td></tr>
<tr><td>Measure burden (i.e., secondary impedance at rated secondary current)</td><td>Measure transformer burden at the secondary terminals when drawing rated secondary current.</td><td colspan="4">The measured burden must agree with the nameplate values.</td></tr>
<tr><td>Dielectric overpotential</td><td>Apply a dc overvoltage for one minute while measuring leakage current.</td><td colspan="4">Perform dielectric withstand test in accordance with manufacturer’s recommendation or ANSI/IEEE C57.13, Standard Requirements for Instrument Transformers.</td></tr>
<tr><td>Low resistance</td><td>Measure the resistance of bolted connections using a low-resistance ohmmeter.</td><td colspan="4">Compare resistance readings between similar bolted connections. There must not be a difference greater than 50 between resistance readings. Also check that the resistance readings are below the maximum value recommended by the manufacturer.</td></tr>
<tr><td rowspan="5">Insulation resistance</td><td rowspan="5">Apply a dc voltage for one minute to measure the phase-to-ground resistance on each phase.</td><td rowspan="2">Rated Voltage</td><td rowspan="2">Recommended Test Voltage</td><td colspan="2">Minimum resistance (MegaOhm)</td></tr>
<tr><td>Dry</td><td>Liquid</td></tr>
<tr><td>Up to 600V</td><td>1000 V</td><td>500</td><td>100</td></tr>
<tr><td>Up to 5000V</td><td>2500 V</td><td>5000 Mohm</td><td>1000</td></tr>
<tr><td>Above 5000V</td><td>5000 V</td><td>25000 Mohm</td><td>5000</td></tr>
</table>

2.1.4.7 Surge Arrestors

2.1.4.7.1 Inspect surge arrestors for physical damage (cleanliness, insulator damage, surge rings, foundation condition, alignment, grounding straps and connections) once a month.

2.1.4.7.2 Perform the tests in Table 5 at an interval of every 3 to 5 years.

Table 5. Tests for Surge Arrestors

<table>
<tr><th>Test</th><th>Comments</th><th colspan="3">Acceptance Criteria</th></tr>
<tr><td>Low Resistance</td><td>Measure the resistance of bolted connections using a low-resistance ohmmeter.</td><td colspan="3">Compare resistance readings between similar bolted connections. There must not be a difference greater than 50 between resistance readings. Also check that the resistance readings are below the maximum value recommended by the manufacturer.</td></tr>
<tr><td>Ground Integrity</td><td>Perform a fall-of-potential test to measure grounding resistance.</td><td colspan="3">The measured grounding resistance must not be greater than 5 ohms for commercial and industrial systems. The grounding resistance must not be greater than 1 ohm for power generating, transmission, and distribution systems.</td></tr>
<tr><td>Watts Loss</td><td>Measure the watts loss for each phase. This test is usually performed with a power factor test set.</td><td colspan="3">Compare the watts loss between phases. There must not be any significant differences in the watts loss reading.</td></tr>
<tr><td rowspan="8">Insulation Resistance</td><td rowspan="8">Apply a dc voltage for one minute to measure phase-to-ground resistance for each phase.</td><td>Nominal Rating (kV)</td><td>Recommended Test Voltage (kV)</td><td>Minimum Resistance (Megaohm)</td></tr>
<tr><td>1.0</td><td>1.0</td><td>100</td></tr>
<tr><td>2.5</td><td>1.0</td><td>500</td></tr>
<tr><td>5.0</td><td>2.5</td><td>1,000</td></tr>
<tr><td>8.0</td><td>2.5</td><td>2,000</td></tr>
<tr><td>15.0</td><td>2.5</td><td>5,000</td></tr>
<tr><td>25.0</td><td>5.0</td><td>20,000</td></tr>
<tr><td>>35.0</td><td>15.0</td><td>100,000</td></tr>
</table>

2.1.4.8 Motor Contactors

2.1.4.8.1 Mechanically exercise, inspect, service, lubricate, and test all critical motor contactor every 3 to 5 years . In addition to the testing per Table 6, perform other maintenance activities in accordance with manufacture's guidelines and/or industry standards as applicable.

Table 6. Electrical Tests for Motor Contractors

Test	*Comment*	*Acceptable Criteria*
Insulation resistance	Measure the phase-to-phase and phase-to-ground insulation resistance of each pole with contactor closed.	Compare to manufacturer's recommended value.
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.
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.

2.1.4.9 Gas-Insulated Switchgear or Substation (GIS)

2.1.4.9.1 On a monthly basis, inspect GIS for physical damage (cleanness, foundation condition, alignment, grounding straps, and connection) and malfunction of built-in indicators (gas pressure gauge, switching position indictors).

2.1.4.9.2 Perform tests for SF_6 gas leaks for each compartment annually.

2.1.4.9.2.1 When continuous online gas leaking monitoring is provided, perform calibration testing of the instrument on annual base or in accordance with OEM guidance.

2.1.4.9.3 Perform online PD testing annually.

2.1.4.9.4 Perform the testing and maintenance activities at intervals of three to five years in accordance with manufacturer’s guidelines or applicable industry standards. If there are no manufacturer’s guidelines or industry standards, use the following guidance:

A. Perform gas analysis to check moisture levels, decomposition by products and dielectric strength.

B. Perform proof tests to verify the operation of alarm, interlock, and built-in relay operation such as low-pressure lock-out relay.

C. Perform functional trip tests to verify the circuit breaker’s control circuit integrity and proper function. The trip test should be initiated by the electrical operation of the trip coil. Investigate any failure to trip.

D. Perform circuit breaker contact timing test

E. Measure the voltage required to operate the trip and close coils for the circuit breakers.

2.1.4.9.5 Lubricate, service, and test GIS (i.e., overhaul maintenance) following the manufacturer’ recommendations, which depend on the type of equipment, interrupter mechanism, number of switching operation, interrupted fault current, and inspection/testing results.

If there are no manufacturer guidelines, apply Table 7 for offline testing.

Table 7. Tests of GIS

Test[1]	*Comment*	*Acceptance Criteria*		
Conductor resistance	Conduct the test on all the bus, circuit breaker, disconnecting switches, grounding switches.	Compare resistance reading with manufacturer’s recommended values, taking into account the difference of the two test arrangements (number of components, contacts and connections, length of conductors, etc.). There must be no deviation of the resistance reading between phases greater than 50% of the lowest value.		
Insulation resistance	Apply a DC voltage for one minute oneach phase, phase-to- phase and phase-to-ground with switch or circuit breaker closed.	Nominal Rating (kV)	Minimum Test Voltage (kV)	Recommended Minimum Insulation Resistance (Megaohms)
		1.0	1.0	100
		2.5	1.0	500
		5.0	2.5	1,000
		8.0	2.5	2,000
		15.0	2.5	5,000
		25.0	5.0	20,000
		≥35	15.0	100,000
Dielectric over-potential test (only after repair or modification, or per OEM instructions)	Perform general overpotential testing.	Perform the test in accordance with the manufacturer’s recommended testing voltage and value.		
Dielectrical overpotential test for vacuum bottle[2]	Perform a DC overpotential test vacuum circuit breaker bottles to determine vacuum integrity.	Follow manufacturer’s instruction and compare to manufacturer’s values.		

Note 1. Ideally, the tests should be measured at individual component level. If live parts are inaccessible at this level, obtain the readings for several components connected in series. For conduct resistance, consult manufacturers to supply factory values of the accessible components in series as a base for verifying test results in the field.
Note 2. Vacuum bottle is usually used in medium voltage (up to 72 kV) GIS as the interrupter where SF_6 is used as insulation media.

2.1.4.10 Grounding Systems

2.1.4.10.1 Perform visual inspections of grounding conductors every year for physical and mechanical condition. Note that corrosion is most likely appearing a few inches below the soil surface where a grounding conductor attaches to ground mat or rod.

2.1.4.10.2 Perform ground earth resistance tests on ground connections when first installed, after soil conditions have stabilized and thereafter as needed depending upon conditions:

- Protective relays not operating properly for ground-faults
- Surge equipment failing to properly protect electrical circuits or equipment
- Step and touch potentials
- Signal noise on electronic and communication equipment
- Physical evidence of grounding conductor deterioration.

The resistance should not exceed 5 ohms. For large utility substations, a maximum resistance of 1 ohm is recommended.

2.1.4.10.3 Perform continuity tests (physical and/or electrical) of equipment grounding conductors to ensure adequate earthing bonding/connection between the main grounding system and all major electrical equipment frames, grounded system neutral and/or derived neutral points when first installed and thereafter as needed to ensure the vital protection remains intact.

The resistance between points should not exceed 0.5 ohm or the recommended value per applicable industry guidelines

2.1.5 General Safeguards

2.1.5.1 Keep switchgear separate from the equipment it controls and from any hazardous equipment or process. Ensure switchgear is accessible even if severe arcing, fire, or explosion occurs in the equipment it controls.

2.1.5.2 Arrange arc-resistant switchgear so the arcing vents do not expose cables and other combustible equipment. Provide adequate venting to prevent overpressure damage to the room.

2.1.5.3 Maintain switchgear enclosures or switch rooms under a slight positive pressure from a filtered air source.

2.1.5.4 Do not store tools, supplies, or other materials in switch rooms or switchgear enclosures.

2.1.5.5 Take precautions against leakage of steam or chemicals, moisture, seepage, condensation, or breakage. Carefully check overhead areas and remove foreign objects that may fall onto switchgear. Enclose or seal any openings that could result in exposure to the switchgear or electrical components.

2.1.5.6 Install electrical space heaters in the switchgear if humidity is high.

2.1.5.7 Replace the circuit breaker and switchgear when their condition is not fit for service.

2.1.6 Contingency Planning

2.1.6.1 Equipment Contingency Planning

2.1.6.1.1 When a switchgear and/or circuit breaker breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable switchgear and/or circuit breaker equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

2.2 Fire Protection

2.2.1 Locate switchgear installations in rooms of noncombustible construction. Treat minimum oil circuit breakers as non-oil-filled equipment. These breakers do not require fire protection if they are installed in noncombustible rooms and there are no other combustibles in the area.

2.2.2 Provide protection for grouped combustible insulated wires and cables in accordance with Data Sheet 5-31, *Cables and Bus Bars*.

2.2.3 Apply the following recommendations to oil-filled switchgear or switchgear installation exposed to combustibles.

2.2.3.1 Protect indoor bulk oil circuit breakers containing ignitable liquid as follows:

A. Provide automatic sprinkler protection, a FM Approved inert gaseous extinguishing system, or, where applicable, an FM Approved water mist system listed in the *Approval Guide* for the protection of enclosures with machinery (refer to Data Sheet 4-1), where oil circuit breakers or other oil-insulated apparatus are installed.

B. Vent flammable vapor from the oil circuit breaker to the exterior of the building.

C. Recommend air, SF_6, or vacuum-type breakers in preference to the oil- type.

2.2.3.2 Where forced air-cooled bus ducts are used and cooling air is drawn from an area that is a potential location for fire (e.g., an outdoor oil-filled transformer area), interlock the air fan with the bus duct circuit breaker and remote area fire detection equipment to prevent drawing smoke from the remote area into the electrical equipment.

2.2.3.4 Provide portable extinguishers suitable for both class A and Class C fires.

2.2.4 Provide photoelectric or a combination of photoelectric and ionization smoke detectors in electrical rooms to sound an alarm at a constantly attended location, regardless of any automatic sprinkler protection or heat detection that may exist. Ensure response includes notification of personnel capable of de-energizing the electrical equipment. The presence or absence of smoke detectors does not change the need for sprinklers. Ensure smoke detector spacing is in accordance with Data Sheet 5-48, *Automatic Fire Detectors*.

In many electrical rooms it may not be practical to de-energize all electrical equipment. In such cases, ensure the response to the smoke detectors includes personnel capable of diagnosing the electrical condition.

2.2.5 Develop a pre-incident plan for fire and electrical response. Ensure electrical personnel are capable of responding at the same time as firefighting personnel, and are able to de-energize equipment so there is no delay in firefighting activities. An upstream (high side) breaker located outside the electrical room accessible during emergencies may be needed to accomplish this.

2.3 Equipment and Process

2.3.1 Where practical, equip circuit breakers that use battery power for tripping with a DC undervoltage tripping device that will trip the circuit breaker in the event of a loss of the battery supply. If these devices are used, place a warning at the trip circuit fuses to indicate the circuit breaker will trip if these fuses are removed.

2.3.2 Provide ground fault protection for solidly grounded and low resistance grounded systems. Provide ground fault detection for all high resistance systems.

2.3.3 Provide a low voltage alarm for a DC bus providing emergency power or switchgear protection power at a continuously monitored location.

2.3.4 Perform an acceptance test on all new switchgear installations including primary injection of protection relays before they are energized. Record the test results as benchmarks to be used for future reference.

2.3.5 Use arc-resistant switchgear, redundant switchgear, or physical separation at the tie bus coupler to prevent arcing faults exposing both sides of switchgear for all new electrical installations when the switchgear involved is critical.

Alternatively, when two breakers on different sides of the tie breaker feed the same (critical) load in a primary selective arrangement, arrange the proposed new breakers to maintain preferably five horizontal sections between any two breakers that feed the same critical load.

2.3.6 For gas-insulated switchgear, provide gas pressure monitoring with alarm function for each gas compartment. Provide low gas pressure lock-out relay for circuit breaker compartment where the gas is used as the interruption media.

2.3.7 Design Considerations to Support Preventive Maintenance

2.3.7.1 For facilities or certain systems in a facility that require continuous operation, they system should be designed such that maintenance work is permitted without load interruption or with only minimal loss of availability. Design examples include

- Double circuits to critical equipment
- Double ended substations
- Tie circuit breakers
- Redundancy utility feeds
- Maintenance bypass switches for uninterruptible power supply systems

2.3.7.2 Provide the following online monitoring for critical switchgear and circuit breakers:

- Thermal sensors for critical terminations
- Permanent online PD monitoring for High Voltage (72 kV and above) Gas-Insulated Switchgear

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Visual Inspections

Abnormal operating conditions, such as overheating, corona, partial discharge, and arcing, can be detected by operators using only their senses. Corona and partial discharge can be detected by the smell of ozone as well as by sound. Arcing can also be detected by sound as well as by voltage flicker. The presence of blistered or blackened paint, the smell of overheated plastic, and the visual condition of insulation are good indicators of overheating. Room temperature is also a good indication of general overheating.

Visual inspections are also useful in picking up general deficiencies, such as storage of combustibles near switchgear, damaged insulators, excessive vegetation growth, pooled water, leaks, rodents, and environmental contaminants. Visual inspections should include observations of relay indications (flags), voltage, and current readings.

3.2 Condition Monitoring and In-Servicing Testing

The following permanently installed online monitoring systems or in-servicing testing for switchgear are commercially available. A brief description and their typical applications are provided.

3.2.1 Infrared Thermographic Windows

Infrared thermographic windows are made from special optical fluoride glass which is transparent to infrared waves as well as the visual wavelength. They have high transmissivity for the infrared wavelength. The windows are permanently installed on switchgear panels thus allowing permanent inspection of the internal critical components like connections, switches, etc. to be conducted with safety at any time.

Examples of products (for reference only) include IRISS window, Fluke window, and Sorem Crystal window.

3.2.2 Continuous Thermal Monitoring System

Continuous thermal monitoring systems in high voltage switchgear to monitor temperature at critical electrical connections such as screw terminals, bus-bar joints, lugs or inaccessible connections for thermographic survey. Various temperature sensor technologies are commercially available including fixed thermal cameras, or non-conductive temperature sensors with either wired or wireless connections to transmit real data to local or remote stations for display and analysis.

Examples of online temperature monitoring system products (for reference only) include GraceSens temperature monitoring with fiber optic sensor, FLIR AX8 continuous thermal imaging camera, and IntelliSaw wireless temperature monitoring with passive surface acoustic wave sensors.

3.2.3 Continuous Partial Discharge Monitoring

Partial discharge and corona activity occur in switchgear rated 4 kV and above and is a good indicator of insulation issues due to incorrect installation of cable termination kits, air voids within cable insulation due to manufacturer defects, sharp edges or others left on the conductors, insufficient clearance between conductors and surrounding insulation, insulation cracks, foreign inclusions and insulation aging.

Many ways to detect and measure PD are available in the market either through continuous monitoring or periodic survey. Continuous PD monitoring systems can use high-frequency current transformers and capacitive couplers to detect current signal from partial discharge activity. Permanently installed PD monitoring sensor is most often used in high voltage gas-insulated switchgear.

3.2.4 In-Service PD Survey

Partial discharge and corona activity for switchgear rated 4kV and above also can be detected by using tools of different sensing technology through periodic survey. PD survey is very practical since this technique does not require direct line of sight or the opening of cabinet doors, as does infrared. When used in conjunction with infrared, a more thorough evaluation of an electrical system can be accomplished. However, the PD diagnosis can be challenging. A good PD survey requires the sensor connected to an instrument that displays the signal intensity and phase relationship of the signal to identify true PD activity. In addition, a good PD survey report includes the following elements:

- Background signal level for baseline reference
- Probable cause of signal difference and nature of activity
- Inaccessible or unobservable equipment
- System voltage and current at time of inspection
- Graphic or color-coded representation of the deficiencies
- Recommended action.

3.2.4.1 PD Survey Sensor Technologies

A. UHF Measurement

Partial discharge and corona activity emit broadband ultra-high frequency (UHF) radiation. This radiation can be detected by installing antennae in switchgear cubicles, or by using a hand-held UHF receiver.

B. Electromagnetic Interference Measurement (or high frequency current transformers)

It has long been known that faulty electrical equipment generates electrical noise that interferes with radio equipment. Modern electromagnetic interference measurement techniques use high-frequency current transformers to detect the UHF radiation generated by partial discharge and corona activity. An oscilloscope or spectrum analyzer is used in conjunction with a high-precision radio frequency receiver to measure and analyze the electromagnetic interference generated by partial discharge and corona activity.

C. Transient Earth Voltage (TEV)

When PD occurs in the phase to earth insulation, electromagnetic waves propagate away from the discharge site. The wave can generate a transient earth voltage (TEV) on the metal surface due to discontinuity caused by gasketed joints. TEV method uses handheld devices to detect the transient voltage.

D. Acoustic Measurement, Ultrasonic Scanning

Ultrasonic listening devices (portable hand-held scanners and/or touch probes) are used to pick up high-frequency sounds generated by arcing, corona, and partial discharge (PD activities) associated with indoor and outdoor switchgear and substations. For example, the ionization of microscopic air and gaseous voids within deteriorating solid insulation can be detected along with arcing without having to open cabinet doors. The method is most applicable for equipment operating at voltages at or above 4 kV where the voltage stress across insulation is greater and PD is most prevalent, but can also be useful at voltages less than 4 kV to detect arcing.

Ultrasound scanning is well suited for detecting partial discharge (PD) activity because PD emissions produce sound frequencies in the ultrasonic range. Ultrasonic instruments can sense between 20 and 100 kHz and use internal heterodyning signal processing to translate the ultrasonic emissions into the audible range.

A trained operator will scan around the door seams and air vents of enclosed electrical switchgear cabinets with a portable ultrasonic scanning device while listening through headphones and viewing the intensity (typically in decibels) of any airborne sound waves being generated on the devices display screen. The operator will listen for distinct sound patterns associated with arcing, tracking, and corona. If there are no apparent seams or vents in the switchgear cabinet, the operator can use a touch probe device in contact with the cabinet walls to listen for structurally induced sounds. If any suspect areas need to be analyzed further, the sounds can be recorded and viewed on spectral analysis computer software. This software allows the sound patterns to be heard in real time and also viewed. Subtle problems can be more thoroughly analyzed and compared to known sound wave patterns associated with PD activity and/or arcing. Printed images of the suspect patterns can be generated and included in a report.

E. Ozone Sniffers (Air-Insulated Switchgear)

Partial discharge and corona activity in air-insulated switchgear generates ozone gas. Ozone sniffers sample the air around switchgear to detect trace quantities of ozone. This is used to indicate the presence of partial discharge and corona activity.

F. Corona Cameras (Outdoor Switchgear)

A corona camera detects the light emitted by corona and partial discharge activity. It is most often used to survey outdoor switchgear such as busbars, insulators, instrument transformers, and transmission lines.

3.2.5 Power-Factor Monitoring (Current Transformers)

Online power-factor monitoring is provided on instrument transformers to detect changes in the internal insulation condition. This tool is normally used on oil-impregnated paper current transformers that are showing signs of deterioration.

3.2.6 Leakage-Current Monitoring (Outdoor Insulators)

Leakage-current monitoring is provided on outdoor insulators to determine the level of contaminants on the surface of the insulator and to decide when insulator cleaning is required. Typically, one test insulator is placed in an outdoor switchyard and the leakage current is monitored to indicate if the insulators in the rest of the switchyard need cleaning.

3.2.7 Circuit Breaker Monitoring (High-Voltage Circuit Breakers)

Circuit breaker travel, contact temperature, contact pressure, gas pressure and temperature (in gas-insulated switchgear), optical emissions from the arc, radio frequency emission, vibration signature, current, and voltage measurements can be provided for circuit breakers. This allows continuous monitoring of circuit breaker condition. Because of cost, its use has so far been limited to high-voltage circuit breakers in critical applications.

3.3 Failure Modes

3.3.1 Deterioration of Dielectric Media

Circuit breakers and switchgear are designed to interrupt an arc under normal and fault conditions. Dielectric-filled switchgear relies on the properties of the dielectric media (such as oil, SF_6, compressed air, and vacuum) to help extinguish the arc.

If the dielectric media used in switchgear deteriorates to a point where it is no longer able to extinguish the arc effectively, the circuit breaker or switch will fail as a result of sustained arcing at the contacts.

The dielectric strength of oil can deteriorate due to the ingress of moisture, contamination by arcing products, contamination by other material, such as fibers from the tank lining, and degradation of the oil from partial discharge, arcing, and overheating.

The dielectric strength of SF_6 can deteriorate due to the ingress of moisture, SF_6 leaks, and contamination by arcing products and conducting particles.

The dielectric strength of compressed air is significantly deteriorated by moisture. Contamination of air, especially by conducting particles, can also reduce its ability to extinguish an arc.

The dielectric strength of vacuum is lost if there is a leak in the vacuum interrupter bottles.

3.3.2 Deterioration of Solid Insulation

Deterioration of solid insulation, such as standoff insulators, bushings, tank linings, and bus bar shrouding, will result in tracking, which eventually leads to phase-to-phase or phase-to-ground arcing faults that will damage the switchgear and ignite combustibles in the area.

Moisture, environmental pollution, partial discharge, corona and overheating can result in deterioration of solid insulation.

3.3.3 Degradation in Performance

The following are some causes of performance degradation.

3.3.3.1 Operating Mechanism Failures

The operating mechanism of circuit breakers and switches can bind or become misaligned due to high mechanical and electrical forces experienced during operation. In other words, the condition of mechanism is affected by number of operations. Other causes of operating mechanism failure are environmental surroundings and the period of maintenance servicing.

Deterioration of the operating mechanism will affect the circuit breakers' arc interrupting capability. For example, a sluggish mechanism will allow sustained arcing to occur at the contacts. This can result in circuit breaker burn-down or an electrical explosion. Maloperation can result in circuit breaker poles operating out of phase or some poles not operating at all. This can cause single phasing to occur and may also result in electrical system instability.

3.3.3.2 Tripping Circuit Failures

The circuit breaker tripping circuit consists of tripping power, wiring, and trip coils. Failure of tripping power can prevent the circuit breaker from operating to clear a fault. Short circuits or open circuits in the trip circuit wiring will prevent the circuit breaker from operating. Damage to the trip coils, such as shorted turns, will also have the same effect.

Failure of the circuit breaker to trip will allow an electrical fault to persist and cause damage to downstream equipment as well as electrical system instability.

3.3.3.3 Contact and Arc-Control Device Failures

Circuit breaker and switch contacts and arc-control devices will wear through use and normally depend on the number of operations performed by a circuit breaker and whether such operations are load or fault current breaking. It will assist scheduling the maintenance activity if a log of switching operation is kept. Onerous duty, such as frequent operations and frequent clearing of heavy faults, will cause the contacts to wear more quickly. If the contacts are excessively worn, the circuit breaker or switch may not be able to effectively interrupt an arc or carry load current. This will result in a burn-down of the switchgear or an electrical explosion. Overheating of loose or worn contacts can also result in deterioration of the dielectric medium and solid insulation.

3.3.3.4 Misapplication

Misapplication of switchgear is a significant cause of failure. Circuit breakers misapplied for the short circuit current will fail explosively.

However, properly applied switchgear may become inadequate if there are significant changes in the short circuit fault level. Large changes in short circuit fault levels are typically due to the following:

A. Changes in the utility short circuit contribution caused by the following:

- The installation of additional transformers at the substation feeding the plant
- The replacement of existing transformers with larger units at the substation feeding the plant
- The installation of additional feeders to the plant or the substation feeding the plant
- The installation of additional generation close to the plant
- Changes in the plant short circuit contribution caused by:
  - The installation of large motors
  - The installation of large generators connected to the grid
  - The installation of additional transformers
  - The replacement of existing transformers with larger units
  - the installation of additional feeders
  - Changes in the distribution system, such as the closing of bus-ties, the closing of ring mains, and parallel operation of transformers

B. Properly select and apply new switchgear after taking into account the following factors:

- Maximum service voltage
- Insulation level
- Short circuit fault levels (taking future load growth and system changes into consideration)
- Switching conditions (e.g., load currents, capacitive and inductive currents from transmission lines,

cables, generators, motors, transformers, reactors, capacitors)
- Special duties (e.g., re-closing, closing on fault, phase opposition)
- Special applications (e.g., generator circuit breaker, furnace transformer control, hazardous locations)
- Environmental conditions (e.g., high altitude, ice, wind, earthquake, corrosive atmosphere, marine application, isokeraunic level, harmonics)

3.3.3.5 Human Error

Human error is another significant cause of switchgear failure. Some examples of human error include the following:

- Not following proper procedures for maintenance, testing or recommissioning.
- Leaving tools and parts inside switchgear cubicles
- Incorrectly wiring protection devices (e.g., wrong polarity on instrument transformers)
- Improperly installing equipment
- Modifying protection relay settings without authorization
- Setting protection relays incorrectly
- Using the wrong circuit breaker in a switchgear cubicle

Proper training is critical for persons operating, maintaining, and testing electrical equipment.

3.4 Switchgear Tests

Table 8 lists the recommended switchgear tests discussed in the preceding sections, as well as the failure mode each test is capable of detecting.

Table 8. Switchgear tests and failure modes

Test	*Tested Components*	*Failure Mode*
Thermography	Dielectric medium, solid insulation, bolted connections, switchgear contacts	Detects overheating due to overloading, loose bolted connections, worn contacts, or inadequate contact pressure. Overheating causes deterioration of solid insulation and degradation of dielectric medium.
Circuit breaker control circuit functional trip test	Control circuit from relays output to circuit breakers	Detects broken or loose control wires in the trip control circuit from relay to circuit breaker.
Insulation resistance	Dielectric medium and solid insulation	Detects degradation of solid insulation and dielectric media.
Insulation resistance	Tripping circuit insulation	Detects defects such as short circuit and open circuits in the tripping circuit.
Low resistance	Bolted connections	Detects inadequately tightened bolted connections that could lead to overheating.
Contact resistance	Contacts	Detects worn contacts, contact misalignment and inadequate contact pressure.
Dielectric overpotential	Dielectric medium and solid insulation	A definitive test of the switchgear's insulation integrity.
Dielectric overpotential	Vacuum interrupter bottles	The only method of checking the integrity of vacuum interrupter bottles.
Slow open/close	Circuit breaker mechanism	Detects friction, binding, inadequate lubrication, and misalignment of the circuit breaker operating mechanism.
Time travel	Circuit breaker mechanism	Functionally checks the speed, travel, and damping action of the circuit breaker mechanism.
Power factor	Solid insulation and dielectric medium	Provides information about internal defects that will also affect the integrity of insulation. It is a complement to insulation-resistance testing and overpotential testing.
Power factor	Bushing	Checks the insulation integrity of switchgear bushings. It is a complement to insulation-resistance testing and overpotential testing.
Liquid screening	Dielectric medium	Performed on oil-filled switchgear to determine if there has been any deterioration of the dielectric medium.
Moisture analysis	Dielectric medium	Performed on the compressed air used in air-blast circuit breakers to determine if moisture has compromised the arc-extinguishing ability of the circuit breaker.
Gas analysis	Dielectric medium	Gas analysis of SF_6 switchgear is carried out to determine if there has been any contamination of the gas that could degrade its arc extinguishing ability.
Watts loss	Solid insulation	Tests the capability of the surge arrestor to act as an insulator. It does not test the surge arresting capability of the surge arrestor.
Tank loss index	Solid insulation	Measures the condition of the auxiliary insulation (tank liner) in bulk oil circuit breakers.

4.0 REFERENCES

4.1 FM

Data Sheet 1-1, *Firesafe Building Construction and Materials*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-28, *DC Battery Systems*
Data Sheet 5-31, Cables and Bus Bars

4.2 Other

ANSI International (ANSI). ANSI C37.24, *Guide For Evaluating the Effect of Solar Radiation*.

ANSI International (ANSI). ANSI C37.20, *Switchgear Assemblies Including Metal Enclosed Bus*.

Institute of Electrical and Electronics Engineers (IEEE). IEEE C37.122.1, *Guide for the Application of Gas-Insulated Substation Rated Above 52 kV*.

Institute of Electrical and Electronics Engineers (IEEE). IEEE C37.122.2, *Guide for the Application of Gas-Insulated Substation Rated 1kV to 52 kV*.

International Electrical Testing Association. ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*.

National Fire Protection Agency (NFPA). NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces*.

APPENDIX A GLOSSARY OF TERMS

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource FM Approvals, for a complete list of products and services that are FM Approved.

Gas insulated switchgear or substation (GIS): A compact, multi-component assembly, enclosed in a grounded metallic housing in which the primary insulating medium is compressed gas of sulfur hexafluoride (SF_6), and that normally consists of buses, switchgear and associated equipment.

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 2024. Interim revision. The scope of this data sheet was updated to clarify that it contains loss prevention recommendations related to the fire protection of **ALL** types of switchgear and circuit breakers.

January 2024. Interim revision. Minor editorial changes were made.

January 2022. Interim revision. Minor editorial changes were made.

October 2021. Interim revision. Removed the guidance on battery inspection, testing and maintenance (ITM), and referenced Data Sheet 5-28, *DC Battery Systems*, for battery ITM guidance.

October 2020. This document has been completely revised. Significant changes include the following:

A. Revised the inspection, testing, and maintenance (ITM) frequency recommendations to align with other electrical equipment ITM throughout the whole document. Consolidated ITM scope to be more concise and have better focus on key loss drivers.

B. Expanded the guidance on electrical system studies.

C. Added in-service partial discharge survey testing recommendation for system rated 4kV and above.

D. Added guidance on maintainability and redundancy for new installations.

E. Changed the offline electrical testing and maintenance recommendations for gas insulated switchgear (GIS) compartments from time-based to condition-based approach.

F. Added equipment contingency planning guidance.

October 2014. The following major changes were made:

A. Added guidance on gas-insulated switchgear.

B. Clarified recommendations related to batteries, including battery monitoring systems and battery charger maintenance.

C. Added recommendations related to lube-oil supply reliability (electrical aspects).

D. Clarified various testing recommendations.

January 2006. This document has been extensively revised. It no longer refers to Data Sheet 5-20, *Electrical Testing.* All electrical testing and maintenance recommendations for switchgear are now addressed in this document.

September 2005. This document has been extensively revised. It no longer refers to Data Sheet 5-20, *Electrical Testing.* All electrical testing and maintenance recommendations for switchgear are now addressed in this document.

January 2001. The recommendation for the smoke detection for electrical rooms was revised to provide consistency within 5-series data sheets.

May 2000. This revision of the document was reorganized to provide a consistent format.

The changes include rewording of the Section 1.0, Scope, to emphasize that the data sheet for electrical switchgear includes motor control center (MCC), load center and unit substation. The only category excluded is ''local operator control stations''.

Recommendations for fire detection of electrical rooms with an alarm at a constantly attended location, prefire plan for fire and electrical response and the possible requirement of an upstream breaker outside of the electrical room to ensure prompt de-energization were added.

The term ''Motor Control Center'' was defined in the Data Sheet Appendix.

January 2000. This document was re-structured.

November 1988 — the principal changes include the addition of the following:

- Current limiting circuit breaker description and application information.
- Application precautions for vacuum circuit breakers.
- Revised recommendations for new equipment installations.
- Maintenance recommendations for batteries used to supply circuit breaker tripping power.
- Ground fault protection for new 480-600 V switchgear equipment.
- Reference to high resistance grounding as a means for preventing burndowns in 480-600 V switchgear equipment.

APPENDIX C SUPPLEMENTAL INFORMATION

C.1 Description

C.1.1 Switchgear Assemblies

The following sections on metal-enclosed power switchgear and metal-enclosed bus (including Figure 1) are excerpts from ANSI C37.20, *Switchgear Assemblies Including Metal-Enclosed Bus,* which describes the different types of switchgear used for the control and protection of apparatus.

- Metal-enclosed power switchgear. A switchgear assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) containing primary power circuit switching or interrupting devices, or both, with buses and connections and may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors or removable covers.
- Metal-clad switchgear (Figs. 2 and 3). Metal-enclosed power switchgear characterized by the following necessary features:

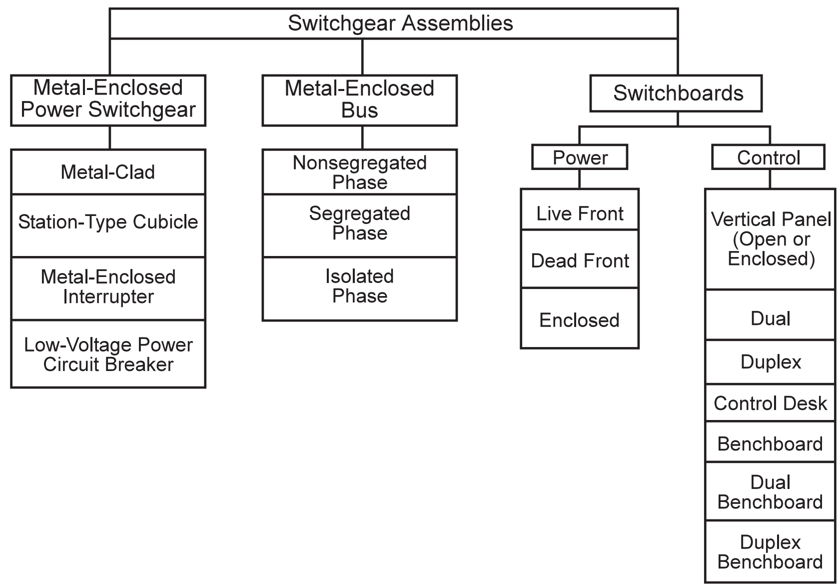

Fig. 1. Types of switchgear assemblies

1. The main switching and interrupting device is a removable type arranged with a mechanism for moving it physically between connected and disconnected positions and equipped with self-aligning and self-coupling primary and secondary disconnecting devices.

2. Major parts of the primary circuit, that is, the circuit switching or interrupting devices, buses, voltage transformers, and control power transformers, are completely enclosed by grounded metal barriers, which have no intentional openings between compartments. Specifically included is a metal barrier in front of or a part of the circuit interrupting device to ensure that, when in the connected position, no primary circuit components are exposed by the opening of a door.

3. All live parts are enclosed within grounded metal compartments.

Automatic shutters prevent exposure of primary circuit elements when the removable element is in the disconnected, test, or removed position.

4. Primary bus conductors and connections are covered with insulating material throughout.

5. Mechanical interlocks are provided to ensure a proper and safe operating sequence.

6. Instruments, meters, relays, secondary control devices, and their wiring are isolated by grounded metal barriers from all primary circuit elements with the exception of short lengths of wire, such as at instrument transformer terminals.

7. The door through which the circuit interrupting device is inserted into the housing may serve as an instrument or relay panel and may also provide access to a secondary or control compartment within the housing.

Note: The term ‘metal-clad’ (as applied to switchgear assemblies) is correctly used only in connection with switchgear conforming fully to the definition for metal-clad switchgear given in C.1.1.2. Metal-clad switchgear is metal-enclosed, but not all metal-enclosed switchgear can be correctly designated as metal-clad.

Fig. 2. Front view of typical indoor metal-clad switchgear
"Images of Typical Masterclad Metal-Clad Switchgear Assembly and Masterclad Two Bay Assembly—Rear View used with permission from SchneiderElectric. © Schneider Electric. All Rights Reserved. www.schneider-electric.com ".

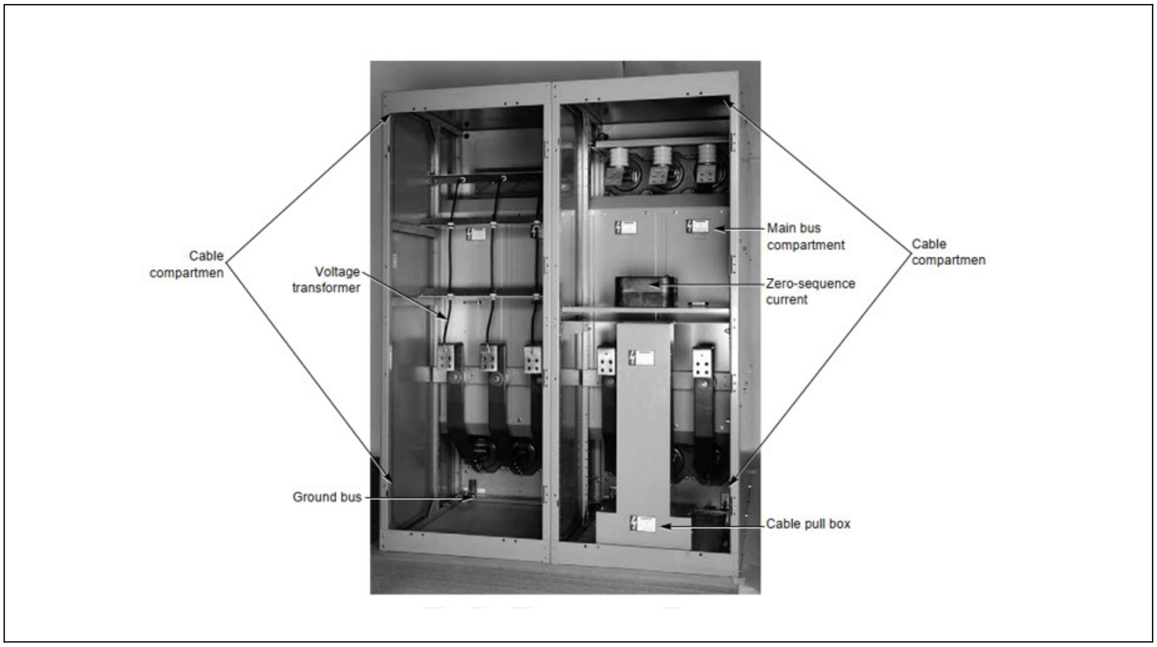

Fig. 3. Rear view of typical indoor metal-clad switchgear
"Images of Typical Masterclad Metal-Clad Switchgear Assembly and Masterclad Two Bay Assembly—Rear View used with permission from SchneiderElectric. © Schneider Electric. All Rights Reserved. www.schneider-electric.com ".

• Station-type cubicle switchgear. Metal-enclosed power switchgear comprised of the following equipment:

1. Primary power equipment for each phase segregated and enclosed by metal
2. Stationary mounted power circuit breakers
3. Group-operated switches, interlocked with the circuit breakers, for isolating the circuit breakers
4. Bare bus and connections
5. Instrument transformers
6. Control wiring and accessory devices

• Metal-enclosed interrupter switchgear (Fig. 4). Metal-enclosed power switchgear includes the following equipment as required:

1. Interrupter switches
2. Power fuses
3. Bare bus and connections
4. Instrument transformers
5. Control wiring and accessory devices

The interrupter switches and power fuses may be stationary or removable type. When removable type, mechanical interlocks are provided to ensure a proper and safe operating sequence.

Maintenance of metal-enclosed interrupter switchgear is relatively simple. There are no relays to be calibrated and no circuit breakers with associated battery banks to be maintained. The condition of the bare bus can be determined by visual inspection.

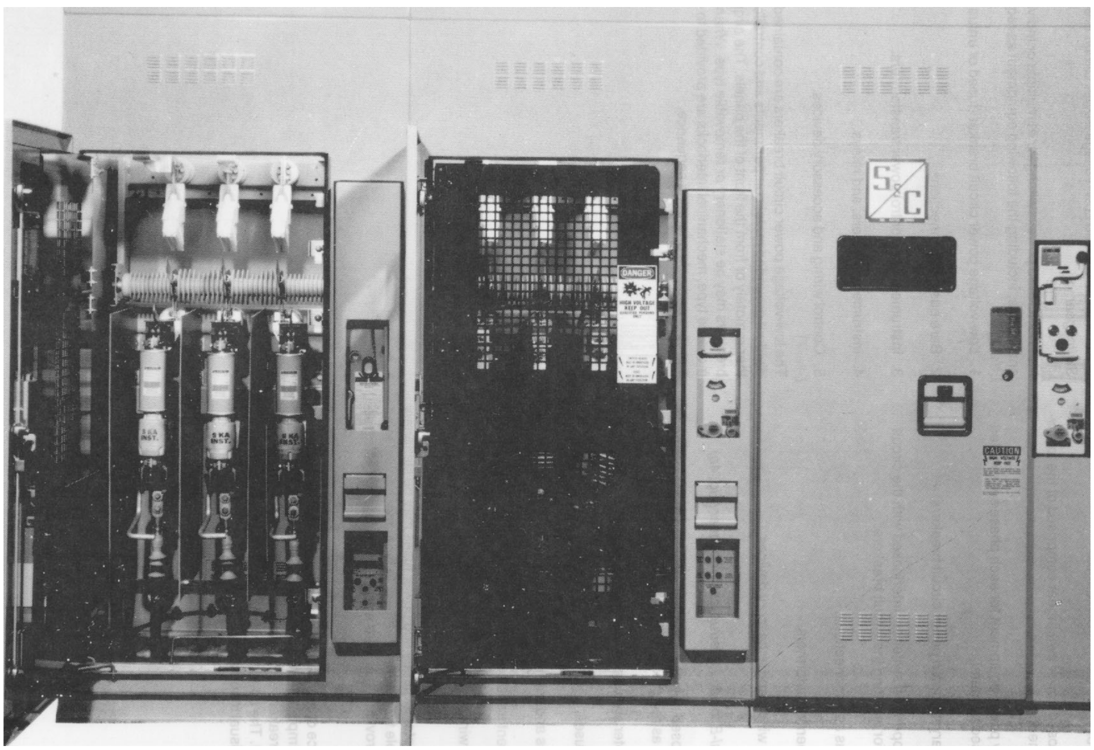

Fig. 4. Metal-enclosed interrupter switchgear (courtesy of S&C Electric Co., Chicago, IL)

C.1.2 Metal-Enclosed Bus

A metal-enclosed bus is an assembly of rigid conductors with associated connections, joints, and insulating supports within a grounded metal enclosure.

• Non-segregated phase bus. One in which all phase conductors are in a common metal enclosure without barriers between the phases.

Note: When associated with metal-clad switchgear, the primary bus conductors and connections are covered with insulating material throughout.

- Segregated phase bus. One in which all phase conductors are in a common metal enclosure, but are segregated by metal barriers between phases.
- Isolated phase bus. One in which each phase conductor is enclosed by an individual metal housing separated from adjacent conductor housings by an air space. (See Data Sheet 5-31, *Cables and Bus Bars*.)

C.1.3 Enclosures

An enclosure is a surrounding case or housing to protect the contained equipment and personnel working nearby.

- A ventilated enclosure is provided with a means to permit circulation of sufficient air to remove an excess of heat, fumes, or vapors.

Note: For outdoor applications, ventilating openings or louvers are usually filtered, screened, or restricted to limit the entrance of dust, dirt, or other foreign material.

- An explosionproof enclosure is capable of withstanding an explosion of a specified gas or vapor that may occur within it and of preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosion of the gas or vapor within. The enclosure maintains an external temperature such that a surrounding flammable atmosphere will not be ignited.
- A nonventilated enclosure is so constructed as to provide no intentional circulation of external air through the enclosure. Doors or removable covers are usually gasketed; humidity control may be provided by filtered breathers.
- A drip-proof enclosure, usually for indoor application, is so constructed or protected that falling drops of liquid or solid particles that strike the enclosure at any angle within a specified deviation from the vertical shall not interfere with the successful operation of the enclosed equipment.
- A weatherproof enclosure is for outdoor application and is designed to protect against weather hazards such as rain, snow, or sleet. Condensation is minimized by the use of space heaters.
- A dustproof enclosure is so constructed or protected that any accumulation of dust that may occur within the enclosure will not prevent the successful operation of, or cause damage to, the enclosed equipment.
- A dust-tight enclosure is so constructed that dust will not enter the enclosing case.

C.1.4 Circuit Breakers

C.1.4.1 Types of Circuit Breakers

High-voltage circuit breakers are available in four main types: oil, air, vacuum, and gas-filled (SF_6). These circuit breakers are applied in circuits above 1000 V.

C.1.4.1.1 Oil Circuit Breakers

In an oil circuit breaker (Fig. 5), the contact parting takes place submersed in oil. The oil serves to cool the arc and to introduce a gas (hydrogen) that hinders the arc. The most commonly used oil circuit breakers are of two main types: bulk oil and minimum oil. Minimum-oil circuit breakers were developed (mainly in Europe) to reduce the quantity of oil (about 10% of the bulk oil quantity) in switchgear to an amount that would not cause hazards. Oil circuit breakers are not now ordinarily used for new indoor installations. The present practice is to install new oil circuit breakers indoors only where required to match existing equipment. Minimum-oil circuit breakers are not in widespread use in North America; however, minimum-oil circuit breakers of up to 34.5 kV can be found in extensive use in metal-clad switchgear in Europe and in other parts of the world.

C.1.4.1.2 Air Circuit Breakers

Magnetic air circuit breakers are usually operated by a stored energy device, and they interrupt the current in normal atmosphere. This type of circuit breaker makes use of a magnetic field to force the arc deep into a specially designed arc chute. The chute cools and lengthens the arc to the point of extinction.

Fig. 5. Bulk Oil circuit breaker

C.1.4.1.3 Vacuum Circuit Breakers

Vacuum circuit breakers (Fig. 6) utilize contacts enclosed in a vacuum bottle. The vacuum circuit breaker is presently the most popular power circuit breaker being specified for use in industrial plants in the United States, England, and Japan. The hermetically sealed vacuum interrupter is relatively noise-free and presents no explosion hazard.

Fig. 6. 34.5kV vacuum circuit breaker with and without out-phase barriers (courtesy of Siemens Energy & Automation, Inc., Raleigh, NC)

Vacuum circuit breakers are sometimes provided with an X-ray radiation warning. Again, ensure appropriate precautions are taken.

In the early years of vacuum technology, vacuum circuit breakers were found to create higher than normal voltage during opening. Transient overvoltage was caused in part by the premature suppression of current before the sinusoidal current reached normal current zero. This high voltage was capable of causing damage to the insulation of the more vulnerable pieces of equipment (i.e., dry-type transformers and motors). Problems were also encountered in switching capacitor banks. The development of new surge suppression technology has resulted in the resolution of these earlier problems.

At the present time, application principles for vacuum circuit breakers are well defined, and there should be no special concern associated with the use of these devices. Adherence to the manufacturer's instructions should ensure trouble-free operation.

It is crucially important that the surge protection recommendations of the equipment manufacturers be followed when applying vacuum circuit breakers. Follow the surge protection instructions of the manufacturers of both the vacuum circuit breakers and the equipment that is being switched.

C.1.4.1.4 Gas-filled (SF_6) Circuit Breakers

Gas-filled circuit breakers employ sulphur hexafluoride (SF_6) (Fig. 7) to extinguish the arc when the contacts are separated. SF_6 is an inert, nontoxic, and odorless gas with excellent insulating properties. SF_6 circuit breakers are available for voltages ranging from 2.4 kV to 765 kV, with continuous current ratings of up to 4000 A and interrupting capabilities of up to 63 kA.

Fig. 7. SF_6 Circuit breaker rated at 145 kV (Courtesy of Siemens)

Even though SF_6 is nontoxic, harmful by-products are produced when this gas is exposed to arcing. Accordingly, ensure appropriate precautions are taken when visiting sites where the SF_6 container has ruptured.

The life expectancy and required maintenance of SF_6 circuit breakers are about the same as that previously described for vacuum circuit breakers. In some instances, SF_6 circuit breakers are larger and more expensive than vacuum breakers of similar rating; however, there is measurable evidence that the SF_6 circuit breakers do not produce the transient overvoltage problems associated with vacuum circuit breakers.

C.2 Application

C.2.1 Fault Ratings

In order to minimize equipment damage, it is absolutely essential to use equipment with short circuit ratings equal to or greater than the available short circuit current to which the equipment will be subjected. ANSI/NFPA 70, Section 110-9, states that devices intended to break current shall have an interrupting capacity sufficient for the voltage employed and the current that must be interrupted.

It is also necessary to identify the short circuit rating of circuit conducting components, such as bus structures within switchgear and insulated conductors. The short circuit rating refers to the ability of the equipment to withstand the available short circuit current at the location where it is connected. The fact that the fault interrupting devices within a switchboard are capable of interrupting the available fault current does not guarantee that the switchboard is suitable for use at that fault current level or that the National Electrical Code has been complied with. Switchboards do not interrupt current: the devices mounted in or on the switchboard do interrupt fault currents. Accordingly, switchboards do not have interrupting ratings, but they do have short circuit withstand ratings.

The Underwriters Laboratories Standard for Dead Front Switchboards (UL 891) has been amended to include requirements that switchboards be tested for their short circuit withstand rating and that this rating be marked on a switchboard label or nameplate. These provisions became effective on September 30, 1982. This labeling assures that the entire switchboard, together with its fault protective devices, will withstand the rated fault current with the associated heating and magnetic forces. The labeling assists the inspection authorities in determining that the requirements of the National Electrical Code are followed.

To determine the adequacy of an interrupting device under fault conditions, the maximum fault currents that the device will be called upon to withstand and interrupt must be determined. The method in which the interrupting device is rated and the time after the inception of the fault at which the device operates are factors in determining the method of calculating the required fault capability of the device. Fault current calculation methods are found in the Standards tabulated below (Table 9).

Table 9. Standards Used for Determining Required Fault Capability of Circuit Breakers and Fuses

Device	*Standard for Fault Current Calculation*
High Voltage Circuit Breakers Rated on a Total Current Basis	ANSI C37.5
High Voltage Circuit Breakers Rated on a Symmetrical Current Basis	ANSI C37.010
Low Voltage AC Power Circuit Breakers Used in Enclosures	ANSI C37.13
Low Voltage Power Circuit Breakers	NEMA SG.3
Molded Case Circuit Breakers	NEMA AB1
Molded Case Circuit Breakers and their Application	NEMA AB1 NEMA AB3
Fuses	ANSI C37.41

C.2.2 Basic Impulse Insulation Level (BIL)

The Basic Impulse Insulation Level rating for switchgear is a measure of the capability of the equipment to withstand voltage surges of high magnitude but short duration. These overvoltages are typically produced by momentary system disturbances and lightning. The BIL rating is important when selecting surge arresters for the equipment.

C.2.3 Location of Equipment

In nonhazardous areas where power demands are heavy, metal-enclosed switchgear with nonflammable or dry, stepdown transformers are used. They are located indoors in unit substations near the center of the load.

Special precautions are usually unnecessary. Exceptions, however, are dusty occupancies such as cement plants, steel mills, and foundries. Locations where conductive dusts or corrosive atmospheres may be present need special attention. Flashovers may occur, especially where conducting dusts are present.

Maintain the switchgear rooms under a light positive pressure from a filtered air supply, minimizing the exposure to contaminants in the atmosphere. Special precautions such as air conditioning may be needed if humidity or high ambient temperatures exist.

Although most installations are indoors, switchgear is available with weatherproof enclosures for outdoor installations.

Switchgear assemblies conforming to ANSI Standard C37.20 are suitable for operation at nameplate rating provided that:

1. The temperature of the air surrounding the switchgear enclosure is within minus 30°C and plus 40°C;

2. Altitude is less than 1000 m (3300 ft) for all types of switchgear, with the exception of metal-enclosed low voltage power circuit breaker switchgear;

3. Altitude is not more than 2000 m (6600 ft) for low voltage power circuit breaker switchgear;

4. The effect of solar radiation is not substantial (see ANSI C37.24 for effects of solar radiation).