BUREAU OF RECLAMATION

Facilities Instructions, Standards and Techniques Volume 3-16

Maintenance of Power Circuit Breakers

Required periodicity is outlined in FIST 4-1B, *Maintenance Scheduling for Electrical Equipment*

U.S. Department of the Interior

(FIST 015) 06/05/2020
NEW RELEASE

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14. ABSTRACT
The Bureau of Reclamation (Reclamation) operates and maintains 53 hydroelectric powerplants and many switchyards, pumping plants, and associated facilities which are important to electric power and water delivery systems. These facilities house complex electrical and mechanical equipment; and circuit breakers play an essential role in protecting this equipment as well as the electric power system.

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Acronyms and Abbreviations

CC	Close Coil
CO_2	Carbon Dioxide
CT	Current Transformer
D&S	Reclamation Manual Directive and Standard
DGA	Dissolved Gas Analysis
DOT	Department of Transportation
DRM	Dynamic Resistance Measurement
FIST	Facilities Instructions, Standards, and Techniques
GCB	Gas Circuit Breakers
GICB	Gas Insulated Circuit Breakers
GIS	Gas Insulated Switchgear
HECP	Hazardous Energy Control Program
HEPA	High Efficiency Particulate Air
IEEE	Institute of Electrical and Electronics Engineers
IR	Infrared
JHA	Job Hazard Analysis
kV	Kilovolts
lbs	Pounds
MAC	Magnetron Atmosphere Condition
MCCB	Molded Case Circuit Breakers
NEMA	National Electrical Manufacturers Association
NERC	North American Electric Reliability Corporation
NETA	National Electric Testing Association
NFPA	National Fire Protection Association
O&M	Operation and Maintenance
PO&M	Power Operations and Maintenance
PPE	Personal Protective Equipment
PPMv	Parts per Million Volume
PRO	Power Resources Office
RCM	Reliability Centered Maintenance
Reclamation	Bureau of Reclamation

RM	Reclamation Manual
RSHS	Reclamation Safety and Health Standards
SDS	Safety Data Sheet
SF_6	Sulfur Hexafluoride
SO_2	Sulfur Dioxide
SOF_2	Thionyl Fluoride
TC	Trip Coil
TSC	Technical Service Center
UL	Underwriters Laboratory
V	Volts
WECC	Western Electricity Coordinating Council

1.0 Introduction

The Bureau of Reclamation operates and maintains 53 hydroelectric powerplants and many switchyards, pumping plants, and associated facilities in the 17 Western United States. These facilities are critical to the electric power and water delivery systems relied on by many. These facilities contain complex electrical and mechanical equipment that must be kept operational. Circuit breakers and their associated circuits play an essential role in protecting these facilities and complex equipment.

1.1 Purpose and Scope

This document defines Reclamation practices for operating, maintaining and testing low, medium, and high voltage circuit breakers used within the Bureau of Reclamation. The circuit breaker is a device which is required to perform a wide variety of functions. They are used for switching for operational configuration and they also provide for the protection of equipment and personnel. If the circuit breakers do not operate as designed, it could mean severe equipment damage or create a hazard to plant staff.

The National Fire Protection Association (NFPA), the Institute of Electrical and Electronics Engineers (IEEE™), and historic and current Reclamation practices are the basis of this FIST volume. Reclamation facilities following this FIST document on circuit breakers and their associated equipment, including testing and maintenance, will comply with North American Electric Reliability Corporation (NERC), Western Electricity Coordinating Council (WECC), NFPA, and FIST 4-1B standards.

Included in this document are standards, practices, procedures, and advice on day-to-day operation, maintenance, and testing of critical circuit breakers. The guidance (non-bold and bracketed) text included in this FIST should be considered for incorporation into job plans and compliance documentation.

FIST volumes are Reclamation documents that describe time-based activities used in the operation and maintenance (O&M) of Reclamation facilities. FIST volumes provide instructions, practices, procedures, and techniques useful in conducting O&M (collectively called 'power O&M activities'). FIST volume requirements or mandatory activities not included in a Reclamation Manual (RM) under the various Directives and Standards (D&S) are to be adopted by the respective local/area office. When permissible, the adoption of other techniques must be implemented via a variance. These other techniques must be consciously chosen, technically sound, effectively implemented, and properly documented. An alternative for non-NERC qualifying facilities might include a condition based maintenance program or a Reliability Centered Maintenance (RCM) based program that may justify longer (or shorter) time intervals. NERC qualifying facilities are required to be on a time based maintenance program. Guidance and recommendations herein are based on industry standards and experience in Reclamation facilities. However, equipment and situations vary greatly, and sound engineering and management judgement must be exercised when applying these diagnostics. All available information must be considered in conjunction with this document.

1.2 Reclamation Standard Practices

FIST manuals are designed to provide guidance for maintenance and testing on equipment in Reclamation's facilities. There may be multiple ways to accomplish tasks outlined in this document. Facilities may exercise discretion as to how to accomplish certain tasks based on equipment configurations and available resources.

Reclamation's regions, PRO, and TSC agree that certain practices are required to be consistent across all Reclamation facilities. Mandatory FIST procedures, practices, and schedules that appear in **{Red, bold, and bracketed}** or **[Black, bold, and bracketed]** text are considered Reclamation requirements for the O&M of equipment in power facilities. RM D&S FAC 04-14, *Power Facilities Technical Documents*, describes the responsibilities required by text designations: **{Red, bold, and bracketed}**, **[Black, bold, and bracketed]**, and plain text, within this technical document. Refer to RM D&S FAC 04-14 for more details concerning technical documents.

1.3 Condition Based Maintenance

Preventive maintenance activities for circuit breakers have historically been performed on a periodic basis. This is common for some low voltage circuit breakers. However, for medium and high voltage circuit breakers, a condition based maintenance program may be warranted. The main purpose of the overhauls of circuit breakers is to replace worn components. Through condition based maintenance, it may be possible to delay an overhaul to when it is necessary.

Normally, a circuit breaker overhaul is required when a specified number of operations, full load fault interruptions, or a recommended time interval has passed. The time interval may be recommended by either FIST 4-1B or the manufacturer's O&M manual. A manufacturer's requirement to perform maintenance based on time and number of operations is based on an expected lifespan of the breaker seals and other consumable components. Using this method will often result in maintenance being performed long before the breaker components are in need of replacement.

Ideally, Reclamation should be using condition based maintenance practices to determine when an overhaul, or at least an inspection, is required. Therefore, an overhaul is performed when the components of the breaker are actually worn and prior to a breaker failure.

A typical condition based maintenance program uses diagnostic testing to estimate the condition of the circuit breaker. By analyzing the results of the diagnostic tests and comparing the results over time, trends can be found and decisions made that may trigger specific maintenance procedures. These decisions are not based on any one diagnostic test. It could take several different tests to verify the decision to perform the maintenance.

When relying on condition based maintenance, it is very important that general maintenance and diagnostic testing are continued. The results obtained from performing these maintenance activities will be used to determine the condition of the breaker which will trigger a more extensive maintenance activity. In using condition based maintenance, the results of the diagnostic tests may trigger maintenance activities on only a specific part of the circuit breaker. As an example, if the results of the diagnostic testing for the internal contacts meet the manufacturer's requirements, but the timing and motion do not, an overhaul may be required on the operating mechanism but the internal components of the breaker contacts may be fine.

To implement a condition based maintenance program for circuit breakers, perform the normal periodic maintenance. On a periodic basis, the following diagnostic tests may also be performed based on the type and the style of breaker. This is not a complete list since other types of breakers may require more periodic tests. More breaker specific tests will be discussed in that type breakers section.

- Breaker timing
- Motion analysis
- Contact resistance
- Measurement

Out of the above diagnostic testing, breaker timing and motion analysis can determine the condition of the operating mechanism, and under some circumstances, can help assess problems with the main contacts. When breaker timing is greater than or less than the limits shown within the O&M manual, maintenance must be performed on the circuit breaker's operating mechanism.

Contact resistance can help assess the condition of the circuit breaker contacts. If contact resistance falls above the limits set by the circuit breaker O&M manual, an inspection must be performed on the contacts. This may mean opening the circuit breaker to inspect the condition of the contacts.

For this work to be effective in assessing the condition of the breaker, the data collected during these tests must be analyzed to verify that the readings meet the manufacturer's requirements as found in the O&M manual. If the results show signs that the breaker is not acting according to the manufacturer's requirements, the problem must be investigated and either repaired or an overhaul scheduled. The circuit breaker can be returned to service only when the breaker test results meet the requirements of the O&M manual.

Another sign that a breakers condition is beginning to degrade would be in a comparison of previous test results. If the trend shows signs of worsening test results, plans should be developed to inspect the breaker for problems. There is no need to pull the breaker out of service until the results of the testing falls outside the limits of the breaker's O&M manual.

1.4 Standards and References

The following are recommended standards and references. These documents were used in the creation of this FIST.

- NFPA 70B-2016, Recommended Practice for Electrical Equipment Maintenance
- NETA, Circuit Breaker Maintenance Handbook, Volume 1
- NETA, Circuit Breakers Handbook, Series II
- CEATI Report No. T103700-3068 and T093700-3065, Power Circuit Breaker Reference Document
- IEEE, Power Circuit Breaker Theory and Design, Revised Edition, Edited by C.H. Flurscheim
- Electrical Power Equipment Maintenance and Testing, Second Edition, By Paul Gill
- IET, High-Voltage Engineering and Testing, 3rd Edition, Edited by Hugh M. Ryan
- IET, Vacuum Switchgear, By Allan Greenwood
- Switching in Electrical Transmission and Distribution Systems, By Renè Smeets, Lou van der Sluis, Mirsad Kapetanović, David F. Peelo, Anton Janssen
- ANSI MTS-2015, Maintenance Testing Specifications for Electrical Power Equipment and Systems
- NEMA AB 4-2017, Guidelines for Inspection and Preventive maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications
- cigré 319, Circuit-Breaker Controls Failure Survey on Circuit-Breaker Controls Systems
- cigré 510, Final Report of the 2004 – 2007 International Enquiry on Reliability of High Voltage Equipment, Part 2 – Reliability of High Voltage SF6 Circuit Breakers
- cigré 513, Final Report of the 2004 - 2007 International Enquiry on Reliability of High Voltage Equipment, Part 5 – Gas Insulated Switchgear (GIS)
- Substation Operation and Maintenance, Alexander Publications
- EPRI Technical Report, Integrated Monitoring and Diagnostics, Maintenance Ranking and Diagnostic Algorithms for Circuit Breakers

1.5 Safety During Maintenance Activities

Safety is an essential part of circuit breaker maintenance. Identifying the hazards involved with working on or near circuit breakers is essential to create a safe working condition.

Electrical hazards are the most obvious hazards involved when working on or near circuit breakers. Circuit breakers can also store a lot of mechanical energy, whether it be spring, hydraulic, pneumatic energy, etc. It is important that all hazards be assessed prior to the start of work. All maintenance activities must be conducted in accordance with FIST Volume 1-1, Hazardous Energy Control Program (HECP), FIST Volume 5-14, Electrical Safety Program, and the Reclamation Safety and Health Standards (RSHS). A job hazard analysis (JHA) must be conducted as well.

The use of circuit breaker remote rack-in devices could reduce hazards to workers as circuit breakers are racked in and out. See Section 1.5.2 for more details in remote racking of circuit breaker.

1.5.1 Voltage Hazard Associated with use of circuit breakers having grading capacitors

It is possible to develop substantial sustained voltages on a bus which has connected potential transformers and is disconnected from the external system through an open air circuit breaker having grading capacitors. A sustained voltage of about one-half rated magnitude and one third normal frequency has been observed on a supposedly de-energized bus. We are not aware of any equipment failures that have resulted from this phenomenon, but safety is a concern due to the hot bus and shock hazard. This reemphasizes the necessity for strict adherence to approved grounding procedures in the Reclamation Operation and Maintenance Safety Standards when approaching and working on circuits and Instrumentation. The voltages observed in this phenomenon were caused by a ferro-resonant circuit consisting of the grading capacitors in the air circuit breaker and the magnetizing impedance of the potential transformers. The resonance can be suppressed through application of resistors or through use of capacitor potential devices instead of potential transformers. Where observed voltages are found to be objectionable, recommendations for corrective action should be obtained from the Technical Service Center, Code- 8400, Denver Office.

1.5.2 Breaker Remote Rack in Device

The use of circuit breaker remote rack-in devices could reduce hazards to workers as circuit breakers are racked in and out. Reclamation operations and maintenance personnel are required to rack in or remove circuit breakers from an energized bus during a regular maintenance. Hazards encountered during this process can be reduced by the use of control devices which allow an operator to stand several feet away from the breaker compartment and be able to rack in and out the circuit breaker.

Almost every breaker manufacturer and aftermarket manufacturer builds devices for racking in or out the breaker from a remote location. A control device is connected to the breaker via a cable so an operator can stand several feet away in a safe location or to the side when a breaker is being racked in or out.

These devices can reduce hazards to anyone required to rack in or remove a breaker from an energized bus. By allowing the operator to stand several feet away or to the side instead of directly in front of an open (or closed) breaker compartment, these devices keep the worker out of harm's way in the event of a failure resulting in an electrical explosion.

These devices may allow the worker to stand beyond the arc flash boundary, and therefore may eliminate the requirement for the operator to wear flash-protective clothing. Each case should be evaluated to see if the remote rack-in device would place the worker beyond the arc flash boundary.

The use of remote breaker rack-in devices is strongly suggested to eliminate potential safety hazards encountered when breakers are racked in and out. To obtain further information, contact the breaker manufacturer's representative with the model or type, and voltage. If you need assistance, please contact the Power Resources Office.

2.0 Maintenance Procedures and Diagnostic Tests

2.1 Breaker Operating Mechanism Maintenance and Lubrication

The operating mechanism is the device that controls the motion of the breaker contact. Maintenance is performed on the breaker operating mechanism to ensure that timing and speed of the contacts meet manufacturer's specifications. If timing and speed do not meet manufacturer's specifications, it may not clear a fault as designed or it may even produce a catastrophic failure of the breaker. Furthermore, if a breaker closes or opens too fast, it could damage the contact(s), linkage(s), or other parts of the breaker. Therefore, circuit breaker operating mechanism maintenance is critical to the health of the breaker.

The operating mechanism is a source of stored energy which can create a hazard to maintenance personnel. It is important that when performing any work on the operating mechanism, all energy within the operating mechanism must be discharged.

Note: Do not work on any part of the breaker operating mechanism without releasing the stored energy or blocking the breaker so it cannot operate or discharge.

There are four basic types of operating mechanisms:

- Pneumatic
- Spring charged
- Hydraulic
- Hydraulic-spring

The maintenance for these devices can vary slightly with the operating mechanism type, but many aspects are pretty much the same. The differences in maintenance of the operating mechanism types are based on the equipment which creates the energy to move the breaker contact. This may include general maintenance on motors, pressure vessels, checking for air or oil leaks, etc.

The main concern for maintaining the operating mechanism is cleanliness and lubrication. Aging or a lack of lubrication can be a major cause of binding within the operating mechanism which may cause a breaker failure. It is important to regularly inspect the operating mechanism for dust, accumulated oil or grease, and loose or broken parts. Dust and accumulated oil may be removed with a lint-free rag and a solvent which is approved by the manufacturer's O&M manual. In some cases, it may require some disassembly of equipment to completely clean the parts. Once cleaned, it is important to lubricate the operating mechanism according to the manufacturer's O&M manual using an approved lubricant. Enclosed dust-tight bearings should require less servicing.

It is important to note that each manufacturer may use different types of lubricant for their breaker's operating mechanism. Mixing different types of lubricant may negatively affect the lubrication of the operating mechanism.

If the O&M manual does not provide a recommendation for a lubricant, or the lubricant specified no longer exists, choose a lubricant that works best with the previous lubricant and works best under the conditions which it will be operating. Take into account the environment where the breaker is located (i.e. temperature swings, indoor, outdoor, moisture, dust, etc.), the component being lubricated, and longevity.

Note: Penetrating oils or sprays must not be used as a lubricant or a degreaser on any part of the operating mechanism. Penetrating oils such as WD-40 may work at the time of application, but the solvent portion will soon evaporate, leaving a residue which is quite viscous and will be worse than the existing lubricant.

It is important to follow the manufacturer's O&M manual for lubrication points. Some of the newer breakers use lubrication free parts. If this is the case, adding lubricant to these points can actually harm the operation of the breaker. If the O&M manual does not specify lubrication points, lubrication points should include all linkage pins, cams, bearings, slides, and guide rods.

2.2 Manual Operation

Many of our medium and high voltage circuit breakers are generator breakers and may operate many times a year. But some of our medium and high voltage circuit breakers may not operate for long periods of time, and some may only operate one time each year.

When the circuit breaker sits for long periods of time without operation, the lubricant will dry out and become viscous, which can cause the breaker to slow down. During the first trip of the circuit breaker, the circuit breaker can slow down enough that it no longer meets the specifications set by the manufacturer's O&M manual. However, after the first operation, it mixes the lubricant enough that the next operation of the breaker's timing may meet manufacturer's specifications. To ensure that the lubricant on the operating mechanism stays fresh, it is important that breakers be periodically operated. This will require three close-open operations to keep the circuit breaker operation free from binding.

2.3 First Trip Test

Due to the change in circuit breaker timing after a long period of inactivity between the first operation of opening a breaker to remove it from service and subsequent operations, a first trip test can provide critical information on the condition of your operating mechanism. The first trip test is performed while the breaker is still in operation and must be the very first open operation before taking the breaker out of service. All connections for the test are made inside the control panel while the breaker is still in service. Caution must be taken when connecting the test leads to the control circuits. There is live equipment within the control panel which can produce an electrical hazard. There may also be hazards from the operating mechanism since it is fully charged and may operate on an inadvertent trip or during a fault condition.

When performing the first trip test, the test set will be connected to the wiring of the breaker control circuits as shown in Figure 2-1 below. There is no need to wire to the close coil (CC) since a close operation will not be performed. Use test clips and clamp-on current meters to make connections so that there is minimal disturbance to the control circuits. Red lines indicate the test set connections.

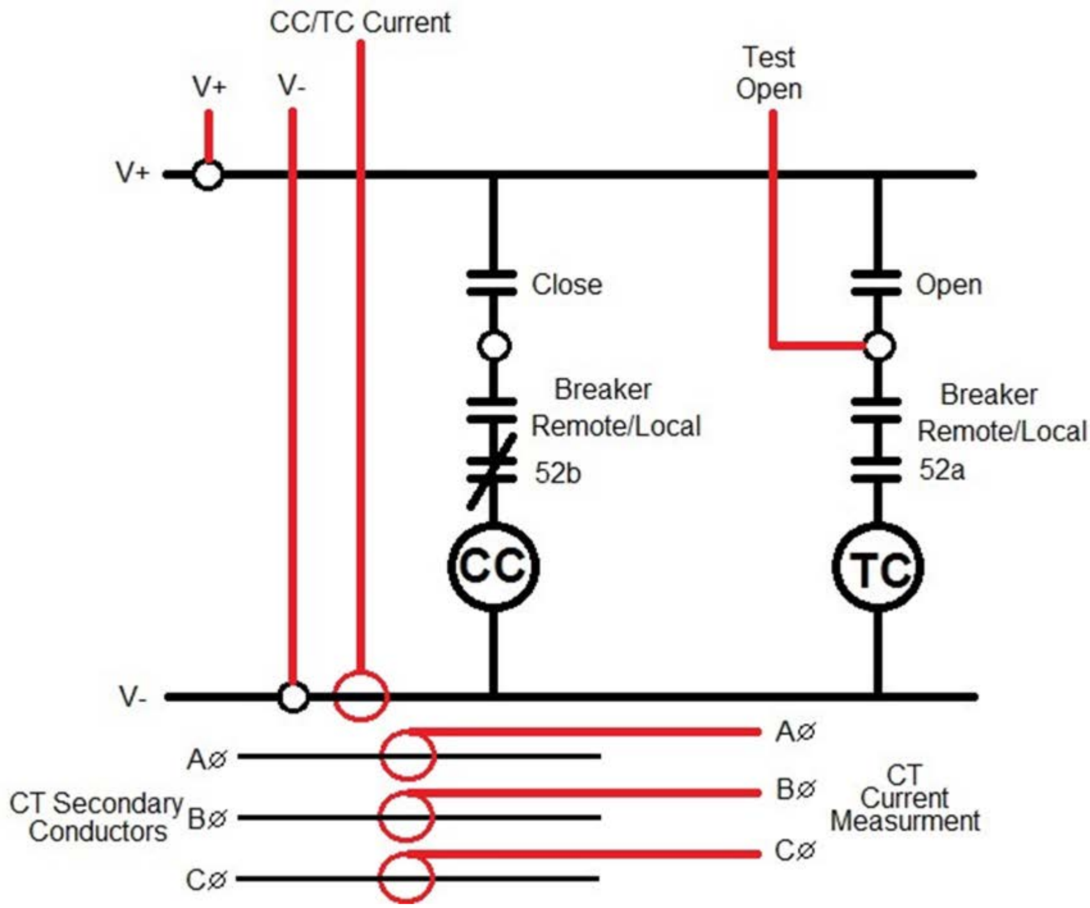

Figure 2-1. Breaker control circuit test (wiring connection)

The breaker timing can be determined by the length of time that current is flowing through the trip coil (TC) as shown in Figure 2-2. By using clamp-on current meters on the current transformer (CT) secondary circuits, a direct indication of the main contact open time can be achieved. However, for breakers that are carrying a load, arcing time will be included in the opening time.

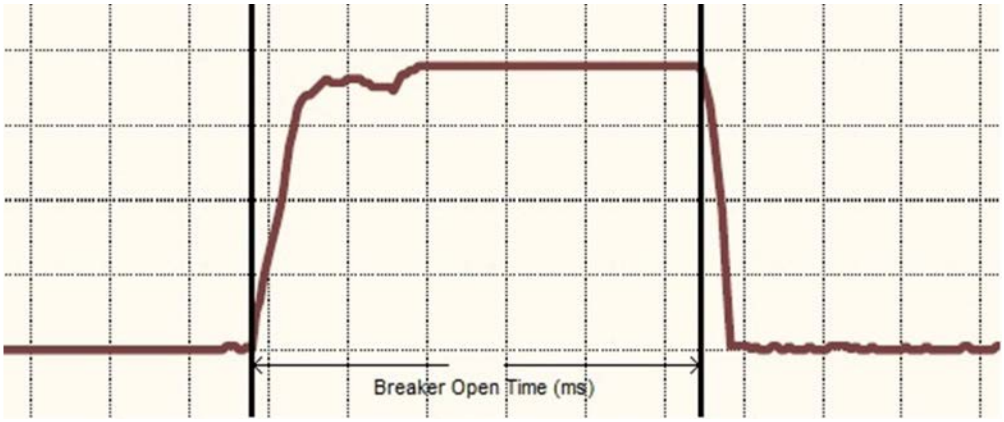

Figure 2-2. Breaker close-open-close timing

2.4 Contact Resistance Test

Contact resistance is a test in which a DC current is injected through the closed contact of the breaker. By measuring the resistance across a closed contact, a determination can be made as to its condition.

Note: When performing a contact resistance test, a minimum of 100 Amps shall be used.

Contact resistance shall not exceed that which was set by the manufacturer's O&M manual. If the manufacturer's O&M manual is not available, the contact resistance shall not exceed 200% of the manufacturer's factory test data. If that information is not available, contact resistance of any one pole shall not exceed the lowest resistance value by 50%.

If any readings fail these conditions, further investigation shall be required to determine the root cause. This may require opening the breaker to inspect the contacts.

2.5 Breaker Timing Test

Breaker timing is the speed of the breaker contacts from the time it gets a signal to move, to the point where the contact changes state. Therefore, on a close signal, the breaker timing is from the point the close coil is energized to where the contacts first touch. On an open signal, the breaker timing is from the point the trip coil is energized to where the contacts separate. Unlike the first trip scenario where the timing of the breaker is determined by the trip coil current, this test determines the timing of the breaker by reading the resistance across the main contacts.
The timing tests should include a close, open, and close-open operation. If a breaker being tested has a recloser relay involved, then the timing test must include an open-close, and a close-open-close operation.

The breaker timing results shall not exceed the limits set by the manufacturer's O&M manual. It is also important that the breaker timing between phases shall not exceed 2 milliseconds (ms) for most breakers. If a breaker timing test fails these conditions, further investigation is required. Some operations like the close-open, open-close and open-close-open may not have values within the manufacturer's O&M manual. For these operations, the trending of the results is important.

When performing a breaker timing test, there are a number of features other than the timing of the open and close times which must be investigated as well. These can include auxiliary contact timing, close and trip coil currents, close and trip coil control voltage, close and trip coil resistance, and charging motor current. Wiring of the circuit breaker for the testing may look like Figure 2-3. Red lines indicate the test set connections.

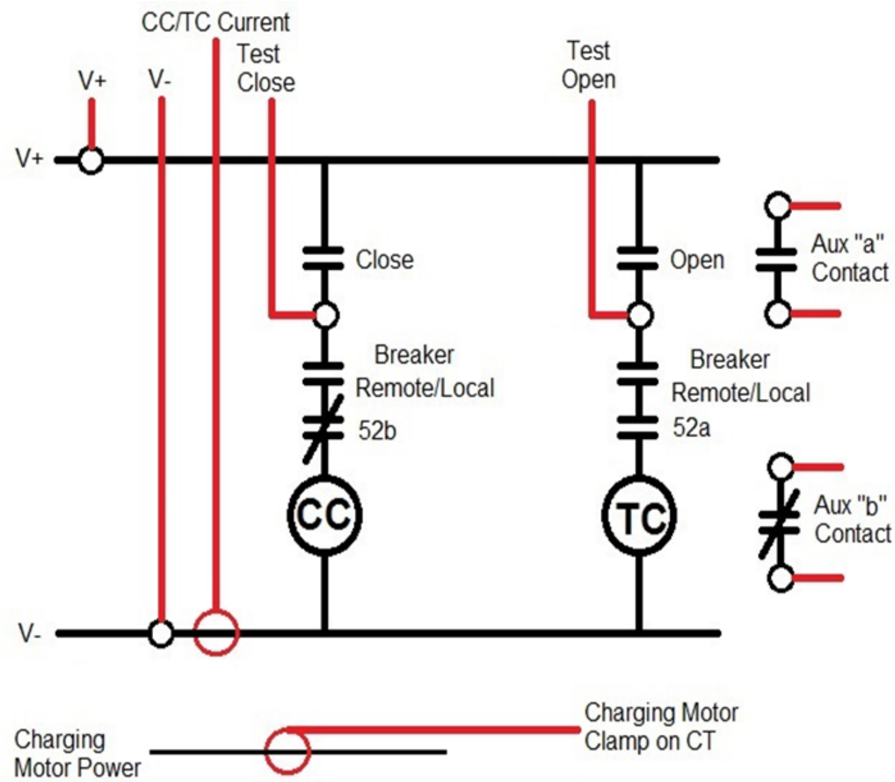

Figure 2-3. Breaker control circuit test (wiring connection)

There are usually no limits set by the manufacturer for the auxiliary contact timing as compared to the timing of the main contacts. However, since many of the auxiliary contacts have functions which are critical to the control and protection of the breaker and plant equipment, it is critical that the auxiliary contacts follow the main contacts as closely as possible.

The close and trip coil currents, along with voltage and resistance can show when the solenoids are starting to fail. Similar to the auxiliary contacts, there are no limits set on the solenoid current. However, there is usually a minimum pickup voltage for the close and trip coils within the manufacturer's O&M manual. If the voltage falls below this limit, the breaker may not trip or close. If the tests show that the voltage levels are starting to drop, it is important that the problem be investigated.

The charging motor current is similar to the close and trip coils in that this value can show when the motor is starting to fail.

2.6 Breaker Motion Analysis

A circuit breaker relies heavily on the operating mechanism to operate as it was designed or damage to the operating mechanism, breaker contacts, or other parts of the breaker may occur. Therefore, a breaker's motion analysis becomes critical to the testing of medium and high voltage circuit breakers.

When setting up the test set for a motion analysis, the transducer shall be placed at the location as specified within the manufacturer's O&M manual. This location usually will not be a straight 1:1 ratio for movement of the transducer to movement of the contact. The manufacturer's O&M manual should provide a ratio for transducer movement to contact movement. If a ratio is not given, the actual linear or rotational distance given by the transducer may be used and the results trended over time. Though the distance the contact travels will not be known, the value displayed may be used to trend motion over future tests.

From the motion curve, specific data can be collected which will assist in determining the health of the circuit breaker. Some of the data collected will include contact close and open speeds, stroke length, contact wipe or penetration, overtravel, undertravel, and rebound. Figure 2-4 is a typical graph showing the motion diagram of a close-open operation.

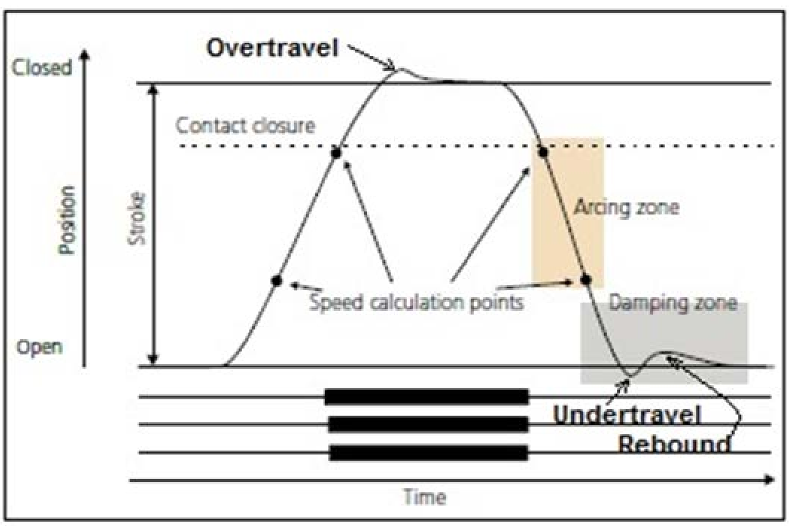

Figure 2-4. Illustration of overtravel and undertravel

Breaker speed is calculated through the arcing zone of the circuit breaker. The manufacturer's O&M manual will often give the location of the arcing zone as well as give limits for the high and low speeds of the breaker. The speed is extremely important since too slow means that the breaker may not interrupt the arc, and too fast means that damage may occur to the circuit breaker.

Stroke is the distance of contact travel from fully open to fully closed. There is usually no limit for stroke; the value given in the manufacturer's O&M manual is the nominal length of the stroke.

Contact wipe or penetration is the length the contact moves from contact closure to where the contact comes to rest. There is usually no limit set on contact wipe or penetration.

Contact overtravel or undertravel is the distance the contact travels beyond its final resting position. A limit for overtravel and undertravel is usually not set by the manufacturer's O&M manual.

Rebound is the bounce back towards closed after the breaker opens. If the rebound is too great, there is a chance for restrike which could cause problems interrupting the circuit.

The indicators for which the manufacturer does not give limit are for trending purposes only. There should be very little change over time for most of these indicators. If there is a change in the indicator values, an investigation must be performed to resolve what might have caused the change.

2.7 Breaker Control Functional Tests

The breaker control circuit can be a fairly complex circuit. It will usually have some permissive relaying and contacts to keep the circuit breaker from operating when there are problems. Similar to functional testing of the protection circuits, breaker control circuits must also be tested.

When performing functional testing of the breaker control circuits, it is not enough to open the circuit breaker from the lockout relay or open and close the circuit breaker from the control switch or auto synchronizer. All permissive contacts must be checked as well to make sure the breaker will not operate when there is a problem.

To perform circuit breaker control functional testing, a procedure must be created which will physically operate the permissive contacts and will test whether those permissive contacts operate as intended.

Note: All devices which physically affect the opening or closing of the circuit breaker must be verified.

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3.0 Molded Case Circuit Breaker Maintenance

3.1 General

3.1.1 Background

There are many critical circuits in Reclamation powerplants protected by molded case circuit breakers (MCCBs). Within our facilities, MCCBs can be used for the protection of AC or DC circuits from 115 to 1000 volts. Even though breakers are primarily designed to protect equipment, these breakers are the first line of defense against electrical shock in the event of ground faults which will energize motor frames, electrical enclosures, conduit, etc. Circuit breakers also limit arc flash energy from fault currents that are hazardous to personnel. Furthermore, the proper coordination and operation of critical control and protection circuit breakers can prevent a cascading outage of multiple circuits.

Note: Develop a list of critical MCCBs which are to be maintained and tested.

The list must be kept up to date within the CARMA system to ensure maintenance is scheduled and results recorded. There are hundreds if not thousands of MCCBs in Reclamation power facilities and it is virtually impossible to carefully maintain all of them. Critical control, protection, branch, and feeder breakers must be carefully maintained as outlined below.

Throughout this section, the term 'critical MCCB' is used to determine which breakers will be maintained. Critical MCCBs are AC or DC breakers which feed circuits that control or operate critical equipment (Refer to FIST 4-1B for the definition of critical equipment).

A failure of a critical MCCB may cause loss of generation or serious damage to critical equipment. It may also increase the hazards involved in performing a task. In 2011, there were two such events within Reclamation where the branch MCCB had failed to trip causing the trip of the feeder MCCB and the loss of control and protection power to operating generators.

In May 2011, an electrical short occurred on a unit control DC circuit. During the fault, the 70 amp MCCB in the control room failed to trip and protect the control wiring. There was no evidence that this MCCB had maintenance performed during its 60-year lifespan. The design of the distribution system for the DC control, protection, and annunciation circuits brought all these circuits for all four generators to one main MCCB. The main MCCB eventually tripped and left all four generators without control, protection, or annunciation power. At that time, there were three generators on-line. Two of the generators continued to run without control, protection, or annunciation power through the entire event.

In September 2011, there was a short on a protective device which led to the loss of DC control and protection power on an operating generator. In 2005, the facility had redesigned its DC distribution panels and MCCBs. However, a thorough coordination study of the new DC distribution system had not been performed. The main feeder MCCB had been installed with an improperly sized interrupting rating. At the moment of the fault, the feeder MCCB tripped rather than the branch

MCCB which provided DC power to most of the control and protection circuits for one generator. When the breaker tripped, the generator lost most of its control and protection circuits. As a result, extensive damage occurred to the slip rings and field leads of this unit. Due to the design of the DC distribution system, this was the only unit affected.

Critical MCCBs must be tested and maintained to ensure their proper operation when a crucial need arises.

3.1.2 Design and Operation

MCCBs are manufactured in single pole, double pole, and three pole configurations for both AC and DC applications. In some DC applications, a four pole configuration is available. MCCBs are manufactured in rated amperage from 15 amps to 6000 amps.

The voltage ratings can vary from 115 volts to 1,000 volts.

Figure 3-1 is a picture of the inside of a 115 VAC single pole breaker. More common in industrial facilities is the 3 phase, 600 VAC, MCCB (See Figure 3-2).

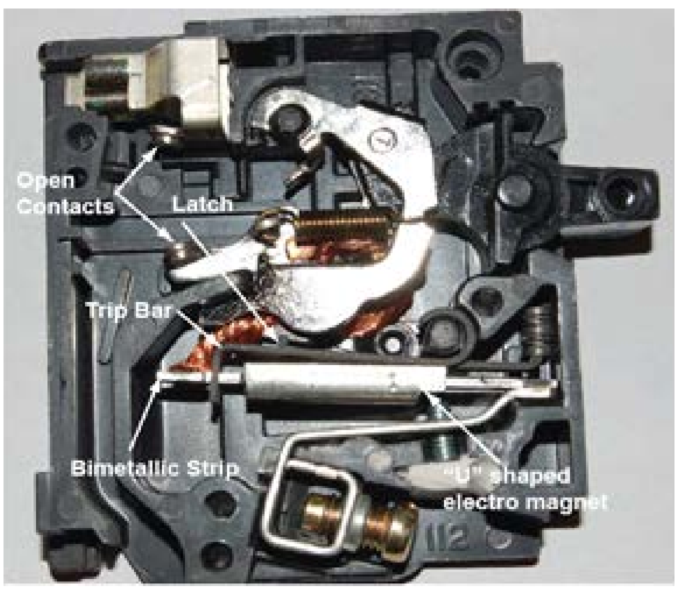

Figure 3-1. Single pole breaker with major parts labeled

The MCCB has two tripping mechanisms. One is the "inverse time" or "time overcurrent" trip. The second tripping mechanism is the "magnetic" or "instantaneous" trip.

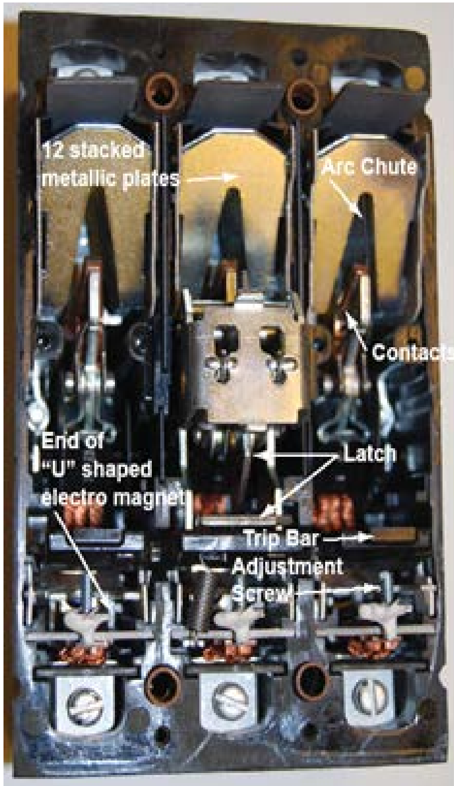

Figure 3-2. Three pole breaker with major parts labeled in the trip position

3.1.3 Time overcurrent trip

"Inverse time" or "time overcurrent" trip means the trip is time dependent, based on how much load current is flowing through the breaker and is designed to protect the circuit from overloads. This function operates through a bimetallic strip which is part of the normal current path within the MCCB. This trip device works by a current flow through the breaker which is greater than the continuous current rating of the breaker. This current will cause a build-up of heat within the bimetallic strip causing the strip to warp and eventually trip the breaker. Higher overload currents will shorten the tripping time due to the bimetallic strip heating faster.

3.1.4 Instantaneous trip

The "magnetic" or "instantaneous" trip is designed to protect against ground faults and short circuit faults. Fault current is typically much higher than overload current so the breaker must open much faster. This function operates by an electromagnet which is part of the normal current path within the MCCB. This trip device works by the fault current creating an electromagnetic field which will pull the trip bar (see Figure 3-3).

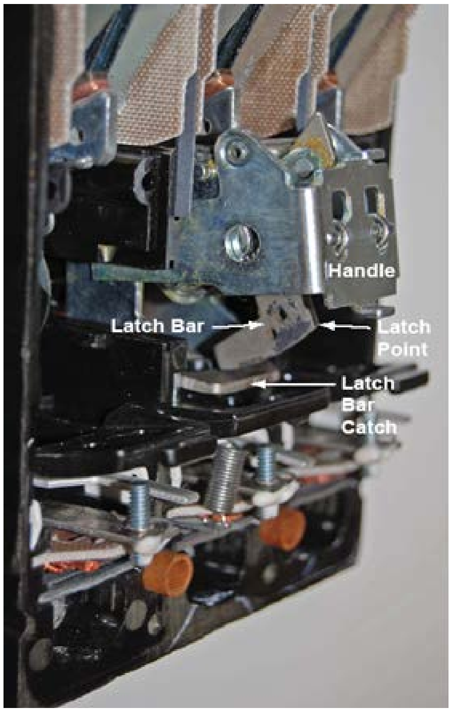

Figure 3-3. Three pole breaker in tripped position

3.1.5 Current interrupting rating

The current interrupting rating is the maximum current that a breaker can safely open. Any level of current above this rating may result in explosive destruction of the breaker, additional faults inside the breaker and/or the breaker enclosure, and damage or destruction of surrounding equipment. In addition, workers may be exposed to arc flash, shock hazards, and fires.

Breakers shown here in detail are basic fixed trip units for illustration of function. For example, the 3 pole breaker (Figures 3-2 and 3-3) is a "fixed trip" type breaker rated at 70 amps normal load. The instantaneous trip will be around 10 to 12 times this or 700 to 840 amps. This is a fixed multiple. Note that other breakers are available with adjustable trips. Also, there are modern electronic trip breakers which can be programmed to trip at various levels of current.

3.2 Breaker Specific Maintenance and Testing

The MCCB is a critical link in clearing fault events on branch and feeder circuits. During a fault condition, current must be interrupted quickly and reliably. Even though MCCBs are fairly stout devices and are designed for a long life with little maintenance, they do have some common problem areas which must be mitigated in order to keep them operating as designed. Regular maintenance will help to mitigate these common problems. Common problems that often affect MCCBs are:

- If a MCCB remains idle for years with no current interruptions or manual exercising, dust, corrosion, and oxidation accumulate on the latching mechanism. This can render the breaker inoperable, resulting in fault currents being allowed to continue without interruption.

See Figure 3-1 for the single pole breaker latch and Figures 3-2 and 3-3 for the three pole latch and internal moving parts.

- Contacts can become burned by too many fault interruptions or contact springs can become weak. Resistance across the contacts will rise which will generate more heat deteriorating the contacts further.

- Top or bottom wire connections can become loose due to temperature cycling or failure to properly tighten during installation. Loose connections generate heat, which further deteriorate connections generating more heat causing further deterioration. Heated bottom connections can affect tripping due to close proximity to the thermal tripping mechanism.

- Breaker cases can become cracked due to thermal or physical stress allowing increased penetration by dust/dirt moisture, etc. The case is an integral part of the structural strength of the breaker. The breaker must be replaced if a cracked case is found.

- The breaker operating handle can also become damaged or completely break, especially if it is difficult to change the position of the breaker. The breaker should be replaced if this type of damage is found as the breaker is not designed to be manually operated without a handle and it could be difficult to determine the position of a breaker without a switch handle.

- The internal mechanism of the breaker may fail and one or two contacts may remain closed while the other contact is open. In this scenario, the handle of the breaker may also show an open or tripped condition.

- Fault interruptions cause arcing and intense heat inside the breaker case. For a high current short circuit fault which trips the breaker on the instantaneous setting, internal arcing may burn the internal components of the breaker. Arcs may reach temperatures up to 35,000 °F and can damage or weaken the internal components of the breaker which may cause failure. For this reason, it is strongly recommended that MCCBs that have experienced two short circuit faults be replaced immediately and destroyed.

The maintenance of MCCBs can be divided into two categories: mechanical and electrical. Mechanical maintenance consists of an inspection of the breaker, maintaining its mounting and electrical connections, and manual operation of the breaker. Electrical maintenance consists of testing the trip elements, insulation resistance tests, and contact resistance tests. Refer to NEMA standard publication AB 4-2017, *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications*, for a more detailed list on preventive maintenance of MCCBs. AB 4-2017 is available for download at no cost from NEMA's website (http://www.nema.org).

***Note: If a MCCB is found to be faulty, damaged, or otherwise inoperable, that breaker must be destroyed or permanently marked as bad.* This will prevent a failed breaker from inadvertently being placed back into service.**

3.2.1 Visual Inspection

[Perform the following activities during the visual inspections of critical indoor and outdoor MCCBs.]

3.2.1.1 Signs of excessive heating

Excessive heat in the circuit breaker, mainly due to loose connections, can cause malfunctions in the form of nuisance tripping and possibly an eventual failure (see Figures 3-4 and 3-5).

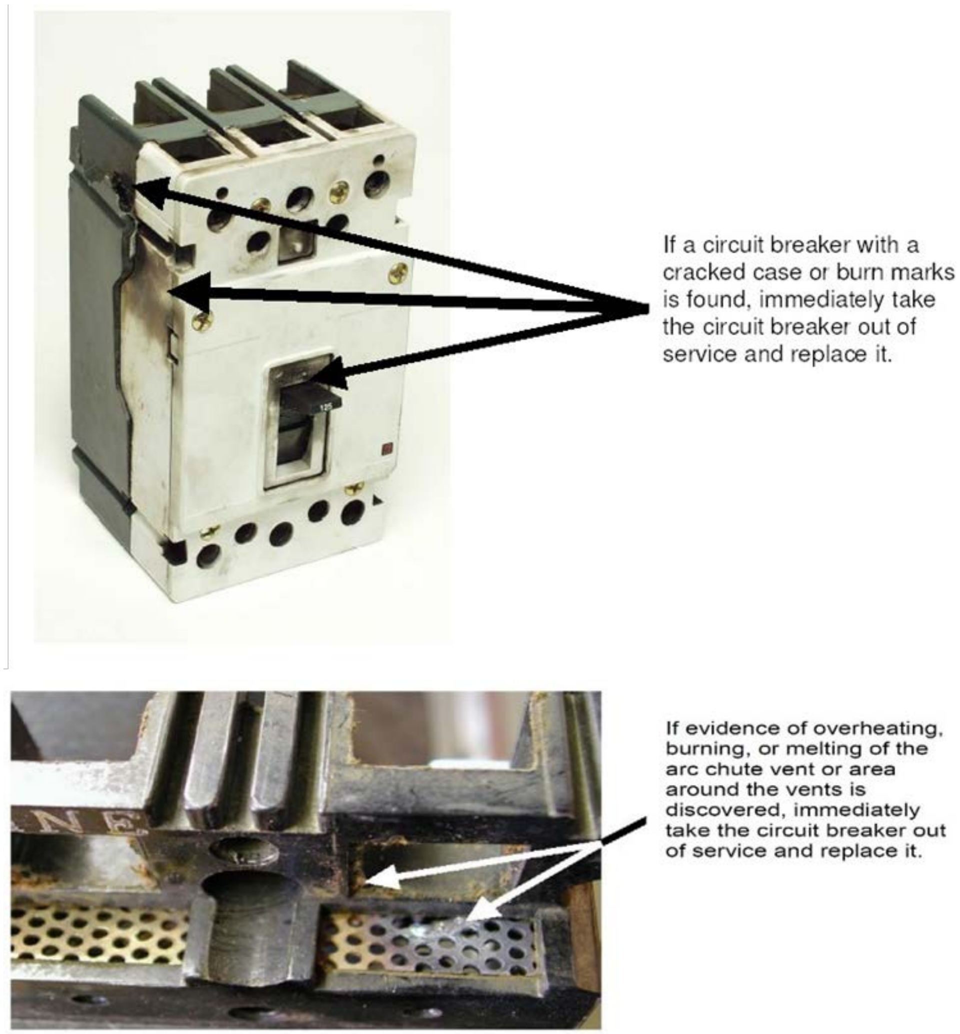

Figure 3-4. Examples of overheating

Figure 3-5. Additional examples of overheating

Periodic inspections should involve checking the breaker case or conductor for discoloration, flaking, or blistering which could be a sign of excessive heating. See the above figures for examples. All figures reprinted by permission from the National Electrical Manufacturers Association (NEMA). If any of these conditions are found, replace the affected breaker immediately. A thermographic camera is also an excellent method of checking for excessive heating on the face of the MCCBs. A temperature difference of just a couple of degrees C between similar breakers under similar loads or temperatures exceeding 54 °C (130 °F) may indicate a problem and should be investigated. See section on infrared scanning below.

3.2.1.2 External contaminants such as dust, soot, grease, or moisture

Breaker surfaces should be inspected for dust, soot, grease, or moisture. MCCBs should be kept clean of external contamination so internal heat can be dissipated and to reduce potential arcing. MCCBs may be cleaned by isolating the MCCB and then using a dry lint free cloth, brush, or vacuum. Avoid blowing contaminants into the MCCB or surrounding equipment. Commercial cleaners and lubricants may attack and damage the plastic insulating materials of the breaker and should not be used.

MCCBs that are known to have been subjected to water damage, e.g. by flooding or sprinkler discharge, should be replaced.

3.2.1.3 Warping or cracking

Cracks on the surface of a breaker may affect the structural integrity of a MCCB which is important in withstanding the stresses imposed during fault-current interruptions. Replace the breaker on any sign of cracking.

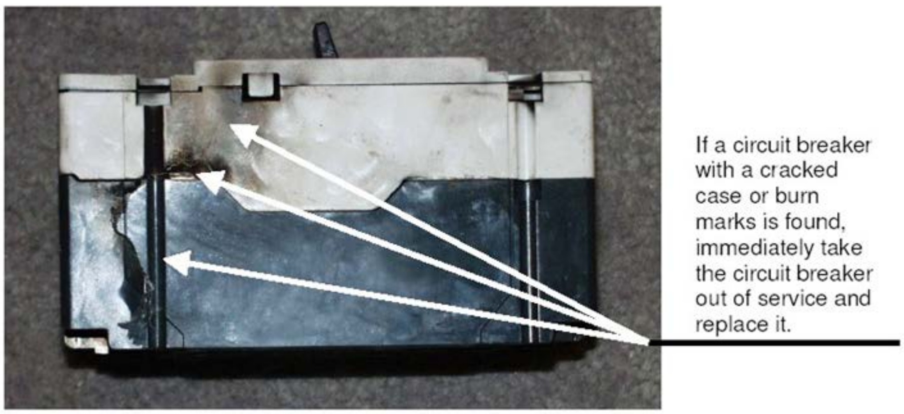

Figure 3-6. Example of cracks and burns

Reference - NEMA AB 4-2017, NFPA 70B-2016 Section 17, Annex L Table L.1.

3.2.2 Manual Operation

[Manually operate critical indoor and outdoor MCCBs, 'ON' and 'OFF' three times. If a push-to-test feature is present on the MCCB, the operation of the push-to-test feature must be used to trip the breaker as well as performing a manual operation of the breaker handle.]

During maintenance activities of the MCCBs, the manual operation of these circuit breakers is considered to be work being performed on energized parts and appropriate Personal Protective Equipment (PPE) must be used. If possible, an attempt should be made to electrically isolate the load from the breaker prior to any manual operation. The breaker handle should operate smoothly without binding. Although manual operation will exercise the breaker mechanism and help keep the contacts clean, the mechanical linkages in the tripping mechanism will not be exercised. Some circuit breakers have push-to-trip buttons that can be pushed to manually trip the MCCB. When performing a manual operation of an MCCB, it is preferred that a trip be performed by using the push-to-trip button as well as manually tripping a MCCB using the breaker handle. This will ensure that the tripping mechanism is exercised as well as the components involved in a manual operation.

Reference - NEMA AB 4-2017, NFPA 70B-2016 Section 17, Annex L Table L.1.

3.2.3 Electrical Testing

Electrical testing of critical MCCBs is important to ensure that the breaker operates as designed. Electrical operation of the breaker will also wipe the contact areas of the tripping mechanism which will help free the mechanism from any buildup of dust, corrosion, or oxidation. It is recommended that the listed electrical tests be performed based on the available functions of the breaker.

[Based on the available functions of the breaker, an inverse-time overcurrent test and/or an instantaneous trip test must be performed for both indoor and outdoor critical MCCBs.]

3.2.3.1 Inverse-Time Overcurrent Trip Test

For inverse-time overcurrent trip tests, the test should be performed on individual poles at 300% of trip rating. The 300% load is chosen as the test point because it is relatively easy to generate the required current in the field, and the wattage per pole from line to load is large enough that it is not significantly influenced by the dissipation of the heat in the non-active poles. Complete and detailed instructions for this trip test are given in NEMA AB 4-2017, Section 6.5. Individual manufacturers also publish recommended testing procedures as well as time-current characteristic tripping curves.

This test is not a destructive test for a MCCB. According to Underwriters Laboratory (UL) testing, these breakers can withstand hundreds of these types of trips without affecting the integrity of the breaker.

Values for inverse-time trip are given in the manufacturer's O&M manual or Table 3-1. Table 3-1 outlines the current and trip-time values as recommended by NEMA. The maximum values were developed to encompass most brands. Under normal test conditions, the circuit breaker will trip in less than the maximum values shown. Under improper test conditions, the maximum values can exceed those given. For more specific values, refer to the manufacturer's data for the circuit breaker being tested.

Table 3-1. Current and trip-time values recommended by NEMA

VALUES FOR INVERSE TIME OVERCURRENT TRIP TEST (At 300% of Rated Continuous Current of Circuit Breaker)		
Rated Current (Amperes)	**Maximum Trip Time* (Seconds)**	
	≤ 250V	**251-600V**
0-30	50	70
31-50	80	100
51-100	140	160
101-150	200	250
151-225	230	275
226-400	300	350
401-600	—	450
601-800	—	500
801-1000	—	600
1001-1200	—	700
1201-1600	—	775
1601-2000	—	800

VALUES FOR INVERSE TIME OVERCURRENT TRIP TEST (At 300% of Rated Continuous Current of Circuit Breaker)		
Rated Current (Amperes)	Maximum Trip Time* (Seconds)	
	≤ 250V	251-600V
2001-2500	—	850
2501-5000	—	900
6000	—	1000

* For integrally-fused circuit breakers, trip times may be substantially longer if tested with the fuses replaced by solid links (Shorting bars).

3.2.3.2 Instantaneous Trip Tests

Testing instantaneous trip points can be accomplished by using either the run-up or pulse method. Both methods require specialized test equipment to produce either a constant rate-of-rise or pulse current and accurate current monitoring equipment. Depending on the size of the breaker, a primary or secondary test set (such as a relay test set) may be used. Detailed instructions for the instantaneous trip test are given in NEMA AB 4 2017, Section 6.6. Individual manufacturers have also published recommended testing procedures.

Reference - NEMA AB 4-2017, NFPA 70B-2016 Section 17, Annex L Table L.1.

3.3 Other Specific Breaker Related Tests

3.3.1 Equipment Ratings Review

[Perform an equipment ratings review and coordination study of critical AC and DC MCCBs for a new installation or modification.]

An equipment ratings review of AC and DC distribution systems is critical to ensure the proper operation of protective devices, including MCCBs. A coordination study shall also be included with the equipment ratings review.

The results of this review should be used to help procure properly rated MCCBs. After installation and the as-built information is obtained, another equipment ratings review must be performed. The equipment ratings review of the MCCBs and the coordination study can easily be accomplished during the review of the Arc Flash Hazard Analysis.

Reference - NFPA 70B 2016, Section 9.

3.3.2 Infrared Scan and Thermal Analysis

Perform an infrared (IR) scan of critical AC and DC breakers while breaker is closed and in service.

An infrared scan is perhaps the most useful MCCB maintenance tool. It can quickly reveal loose connections, high internal resistance of individual contacts, and overloaded conductors. It is very important to note that the actual temperature within the breaker may be up to four times hotter than what is displayed on the outer case. So, it is very important that a hot spot found on an IR scan be investigated. It is also important that trending of the IR scans is performed.

While performing IR scans of MCCBs, they must be carrying normal load current or the scan must be done immediately after de-energizing. Due to rapid temperature decrease, an IR scan is useless if the circuit has been de-energized more than a few seconds prior to the scan.

Enclosures must be opened and/or panels removed so that breaker fronts and, if possible, connected conductors can be viewed directly. If there is more than 3 or 4 ºC difference between phases of a three pole MCCB or attached conductors there is a problem with the breaker such as high resistance contacts or loose connections. If re-torqueing the connections does not resolve the high heat levels, then the breaker contacts may be deteriorating and could fail at any time. The breaker should be immediately replaced.

The following guidelines are from NFPA 70B 2016 Edition, Section 11.17.5.6 and are based on National Electric Testing Association (NETA) standards. These are general guidelines for IR scanning of all electrical equipment. Temperature differences as listed below are referring to the temperature of the breaker poles and connected conductors to a nearby reference temperature. A point on the enclosure or different pole of the same breaker can act as the baseline for a temperature difference. It is very important to note that the actual temperature within the breaker may be up to four times hotter than what is displayed on the outer case.

- Temperature differences of 1 ºC (1.8 ºF) to 3 ºC (5.4 ºF) indicate possible deficiency and warrant investigation.

- Temperature differences of 4 ºC (7.2 ºF) to 15 ºC (27 ºF) indicate deficiency; repairs should be made as time permits.

- Temperature differences of 16 ºC (28.8 ºF) and above indicate major deficiency; repairs should be made immediately.

For more information on performing an IR scan, refer to FIST 4-13, "Thermal Analysis". Modern infrared equipment and trained thermographers are available from the TSC to perform IR scans of electrical and other plant equipment, if requested.

The first scan below (Figure 3-7) shows examples of both poor connections and overloaded conductors. Notice the breaker to the far right in the scan. The conductors are overloaded and the breaker contacts and connections are also deteriorated. This breaker was replaced and the conductors checked for overload.

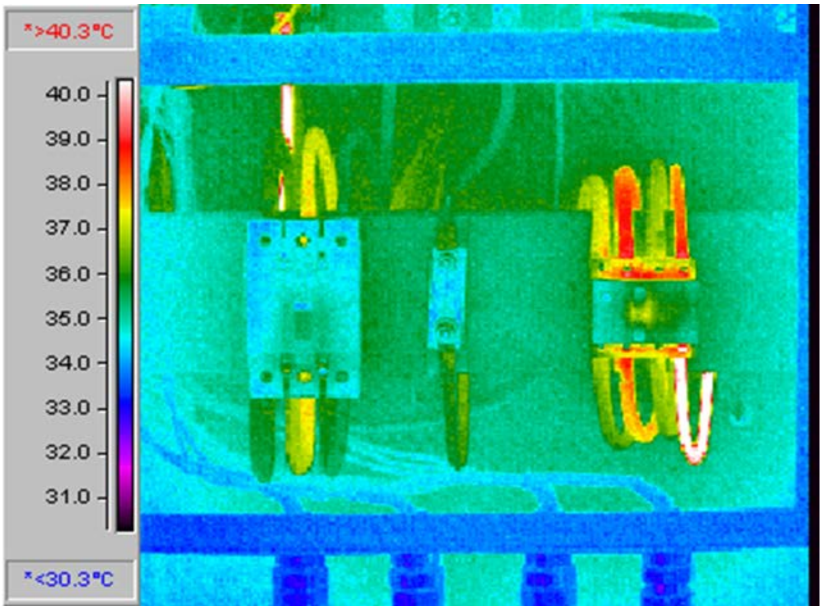

Figure 3-7. Infrared view of an electrical panel

The second example (Figure 3-8) is a panelboard; note the three pole breaker at the top left. This breaker must be replaced due to the hot spot on the breaker face which indicates that the breaker contacts have deteriorated, producing heat from the increased resistance across the contacts.

The breaker on the right side, of the panel shown below, has a bad connection (white spot) which is the hottest spot. This breaker must be replaced due to the heat which has also ruined the breaker contact inside the breaker as can be seen from the red and yellow spot in the center of the breaker.

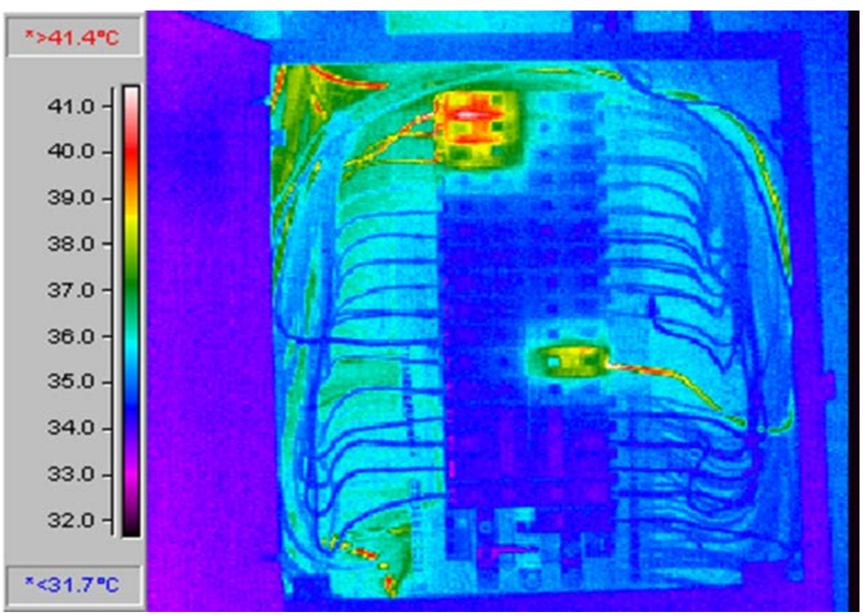

Figure 3-8. Infrared view of terminal box

The third example (Figure 3-9) shows either a bad connection on the center conductor or the center contact is bad. Notice the white spot at the left of the breaker handle, in the center. When any of the above problems are found, the breaker should be replaced and the conductors checked for overload. MCCBs cannot normally be repaired. They must be replaced when high resistance internal contacts or problems with tripping mechanisms are found. When a bad connection is found, sometimes it can be cleaned and retorqued; however it must be rescanned, under load, with the IR camera to ensure overheating has been resolved.

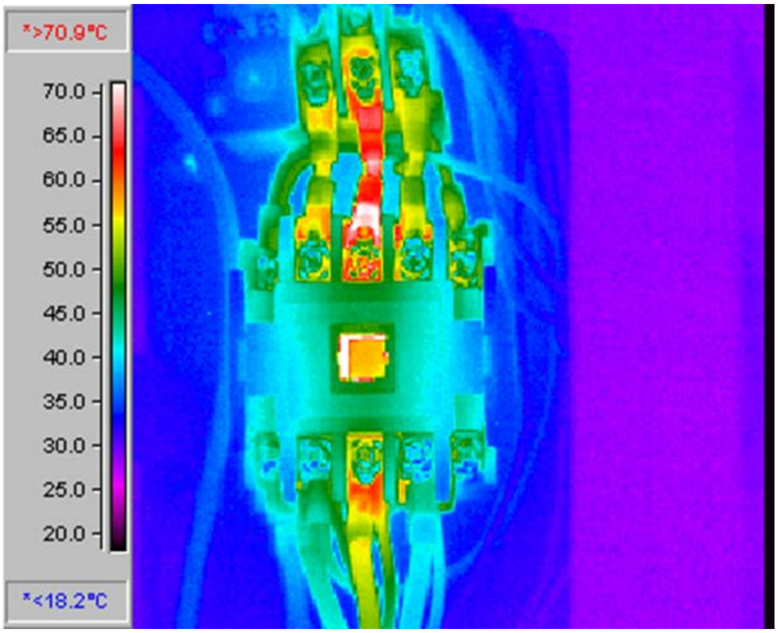

Figure 3-9. Infrared scan of MCCB

These examples show the value of IR scanning of MCCBs. NEMA standard AB-4 requires other tests such as contact resistance and insulation resistance. However, if the above tests and IR scans are conducted, these will show any deficiencies and determine whether or not further testing is necessary.

Reference - NEMA AB 4-2017, NFPA 70B-2016, Section 11.17.

3.3.3 Optional Electrical Testing

The following electrical tests are not required but are shown here as other tests that can help determine the condition of the breaker. These tests will help determine the condition of the contacts, and whether the insulation of the internal components of the breaker meets specifications. These tests are left as recommended since an infrared scan will locate breakers that are having problems with high contact or insulation resistance tests.

3.3.3.1 Insulation Resistance Tests

Measure the insulation resistance of each pole for 1 minute at an applied voltage that is in accordance with the manufacturer's data or at least 1,000 VDC. The test should be performed on individual poles with the breaker closed and the unused poles and frame grounded. An additional test should be performed with the breaker open and one side of the breaker grounded to measure the open poles. The insulation resistance test is a pass/fail test, however, at times the manufacturer may publish minimum resistance values within their O&M manual. If the O&M manual does not give a minimum value for its results, use a minimum value of 1 MΩ.

This test is recommended, but not mandatory, for critical indoor and outdoor MCCBs.

3.3.3.2 Contact Resistance Tests

Measure the resistance across each contact to verify the values are within manufacturer's specifications. The resistance values will vary dependent of the breaker type, rating, and manufacturer. A standard digital multimeter is not adequate to perform this type of test. A digital low resistance ohmmeter or 4-point tester should be used to obtain sufficient accuracy. Apply a test current across a pole equal to the breaker rating. If the breaker is rated at 500 Amps or greater, 500 Amps shall be used to perform this test. High resistance values indicate that there may be an oxide film on the contacts or there is a more serious issue with the contact or contact spring pressure that will require the breaker to be replaced.

4.0 Low Voltage (600 V and Less) Draw-Out Air Circuit Breaker Maintenance

4.1 General

4.1.1 Background

Low voltage (600 V and less) draw out air breakers are critical in the day-to-day operation of our plants. They can also be one of the more dangerous operational duties that our personnel will perform. Regular maintenance on these breakers is critical to the daily operation of our plants and safety of our staff.

4.1.2 Design and Operation

Low voltage air breakers are designed to be easy to maintain and operate. Older breakers are more difficult since test equipment must produce a current high enough to be able to test both the thermal overload function as well as the instantaneous trip function. This will create the need to acquire a very robust primary current injector to test those breakers.

Many of the newer low voltage breakers incorporate current transformers to step the current down to allow for a digital trip unit which is more accurate and can have more features which will add better protection, both to the equipment and the operator.

Many models of low voltage power circuit breakers have the slow-close feature and it makes the contact touch test possible.

The older low voltage breakers can be upgraded with new trip units which can add the protective features of the newer trip units. These breakers may be slower than the new breakers, but they are more robust and may be easier to maintain than the newer breakers.

4.2 Breaker Specific Maintenance and Testing

4.2.1 Visual Inspection

[Perform the following activities during the visual inspection:

- **Record operations counters**
- **Check circuit breaker panels and insulation material for cracks and cleanliness.**
- **Check condition of enclosing cabinets including hinges, latches, locks, and door gaskets.**
- **Check for loose or broken frame ground connections.**

- **Check that all power and control circuit switches are closed and fuses are in place. Inspect wiring for damaged insulation.]**

Reference - NFPA 70B-2016, Sections 11.10.6, 15.4, Table K.4(d), Table L.1.

4.2.2 Preventive Maintenance

[Perform the following preventive maintenance of indoor and outdoor low voltage draw-out air circuit breakers:

- **Check frame, panel, and cabinet condition of paint and repaint as necessary. Tighten bolts to recommend specifications. Clean exterior of cabinet.**

- **Clean porcelain of bushings or insulators with water or a suitable cleaner. Repair chipped spots by painting with enamel such as 1201 glyptal. Tighten bolts to recommended specifications.**

- **Perform in-depth bushing inspection for any carbon tracking, leaks, and cracks.**

- **Clean, repair chipped spots, remove and clean interphase barriers.**

- **Check main connections for loose or overheating terminals.**

- **Remove arc chutes so that the contacts can be inspected. Dress contacts, if rough, with a fine file. It is necessary to carefully remove only the projecting beads. Pits in a flat, smooth surface are not objectionable.**

- **Check contact springs for loss of temper, breaks, or rust deterioration.**

- **Check flexible shunts at contact hinges for overheating and fraying. Tighten connections to recommended specifications.**

- **Verify breaker fit and racking mechanism operation.**

- **Check operating rods, shafts, and bell cranks for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc. Clean moving parts of rust, dirt, and accumulated grease and oil. Wash out bearings, pivots, and gears with a suitable cleaner. Lubricate with new grease or oil with the type required by the application being used. In cold climates, it is important to use lubricant that will not stiffen with cold. Wipe off excess lube. Enclosed dust-tight bearings should require less servicing. For more information on breaker lubrication, see Section 2.1.**

- **Observe closing solenoid motor or spring during several closing operations to see that everything is in proper working order. Check solenoid plunger for sticking in guides.**

- **Check close coil resistance with an ohmmeter and insulation resistance with an appropriate insulation tester.**

- **Observe latch and trip mechanism during several tripping operations to see that everything is in working order.**

- **Check latch and trip assembly pins, bearings, and latches for wear, binding, and misalignment.**

- **Clean and lubricate latch and trip assembly. Check latch carefully to see that it is not becoming worn so that it would unlatch from vibration or stick and fail to trip. Tighten bolts and screws to recommended specifications.**

- **Observe tripping operation during electrical operation. See that full energy action of plunger is obtained. Check plunger for sticking in guides.**

- **Inspect digital or electronic trip mechanisms for the power light and any possible error codes.**

- **Check condition of auxiliary contacts and refinish with burnishing tool if burned or corroded.**

- **Check auxiliary contact springs, operating rods, and levers. Check closing and opening position with respect to main contacts while breaker is being slowly closed and opened manually. Certain auxiliary contacts used for special purposes may require adjustment for the closed position.**

- **See that position indicator or semaphore is properly indicating the breaker position. Check operating rods or levers for loose parts.]**

Reference - NFPA 70B-2016, Section 11, 15.

4.2.3 Manual Operation

[Manually operate the indoor and outdoor low voltage draw-out air circuit breaker, 'CLOSE' and 'OPEN' three times.]

Many breakers sit without any operation for long periods of time. This can be very harmful to the breakers operating mechanism and lead to faulty operations. This operation is best performed at the breaker with the local switch. Ensure the breaker is de-energized prior to operating. See Section 2.2 for further information.

Reference - NFPA 70B-2016, Section 11.10.6.

4.2.4 Breaker Timing Test

[Complete timing tests for both indoor and outdoor circuit breakers.]

Test all trip functions available. This may include long-time pickup and delay, short-time pickup and delay, instantaneous, and ground-fault pickups.

The timing test for low voltage, draw out, circuit breakers may require current injection for all trip functions unless an electronic or digital trip unit is used.

Note: If an electronic or digital trip unit is in place, the first trip test of each phase must be performed by current injection through the contact. It is then possible to test the remaining functions of the trip mechanism through secondary current injection directly into the trip mechanism.

Performing the current injection test for the initial test will ensure the CTs within the circuit breaker are operating as designed.

Reference - NFPA 70B-2016, Section 11.10.6.

4.2.5 Insulation Resistance Test

[Complete an insulation resistance test for both indoor and outdoor low voltage draw-out air circuit breakers.]

Measure the insulation resistance of each pole for one minute at an applied voltage that is in accordance with the manufacturer's O&M manual or at least 1,000 VDC. The test should be performed on individual poles with the breaker closed and the unused poles and frame grounded. An additional test should be performed with the breaker open and one side of the breaker grounded to measure the open poles. The insulation resistance test is a pass/fail test; however, at times the manufacturer may publish minimum resistance values within their O&M manual. If the O&M manual does not give a minimum value for its results, use a minimum value of 1 MΩ.

Reference - NFPA 70B-2016, Sections 11.10.6, 11.16.1.2.1-11.16.1.2.4,
Table K.4(d), Table L.1.

4.2.6 Contact Resistance Test

[Complete a contact resistance test for both indoor and outdoor low voltage draw-out air circuit breakers.]

For more details on contact resistance testing, see Section 2.4.

Reference - NFPA 70B-2016, Section 11.16.1.2.2, Table K.4(d), Table L.1.

4.2.7 Equipment Rating Review

[Perform an equipment ratings review and coordination study for both indoor and outdoor low voltage draw-out air circuit breaker.] An equipment ratings review of AC and DC distribution systems is critical to ensure the proper operation of protective devices, including low voltage circuit breakers. A coordination study shall also be included with the equipment ratings review.

The results of this review should be used to help procure properly rated low voltage breakers. After installation and the as-built information is obtained, another equipment ratings review must be performed. The equipment ratings review of the breakers and the coordination study can easily be accomplished during the review of the Arc Flash Hazard Analysis.

Reference - NFPA 70B 2016, Section 9.

4.2.8 Infrared Scan and Thermal Analysis

Perform an infrared scan while the breaker is in service and closed.

Infrared scan or thermal scan/analysis allows for nonintrusive analysis of temperature and thermal characteristics or thermal patterns of circuit breaker and its components. Infrared scan may dynamically detect abnormal thermal conditions or changes in temperature that may indicate problems in circuit breakers in their incipient stages. Different technologies are available in the industry to detect dynamic changes in heating; however, using thermal imaging cameras is preferred. Identifying and remedying problems early by the infrared scan may avoid serious failures and costly outages. Early detection permits more effective maintenance planning and scheduled outages. Thermal analysis can be used to troubleshoot, perform pre- and post-outage thermal comparisons, verify successful installation or repair, and predict problems with the circuit breakers.

Note: Opening panel doors or removing panels which may expose maintenance personnel to live parts while the breaker is in service is considered as work on live parts. This type of work may expose maintenance personnel to an arc flash hazard.

For more information on performing an infrared scan and thermal analysis, see FIST 4-13.

Reference - NFPA 70B, Section 11.17.

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5.0 Medium Voltage (601 V – 15kV) Air and Air Blast Breaker Maintenance

5.1 General

5.1.1 Background

Air and air blast circuit breakers were designed as a replacement for oil circuit breakers being used indoors or in sensitive locations. This was due to the oil circuit breakers' inherent hazards and smaller footprint than the typical oil breaker.

5.1.2 Design and Operation

Air and air blast circuit breakers are very similar in design and operation. The difference is air blast circuit breakers use compressed air to blow out the arc, while typical air breakers use different technologies to extinguish the arc, from lengthening the arc to splitting the arc into many smaller arcs.

5.2 Breaker Specific Maintenance and Testing

5.2.1 Visual Inspection

[Perform the following activities during the visual inspection:

- **Record operations counter.**
- **Check air circuit breaker panels and insulation material for cracks and cleanliness.**
- **Check condition of enclosing cabinets including hinges, latches, locks, and door gaskets.**
- **Check bushings and insulators for chipped or broken porcelain, excessive dirt/film, visible cracks, contamination, and oil level.**
- **Check breaker frame, tanks, and valves for loose or broken parts.**
- **Check frame, tanks, and valves for air leaks and note air pressure reading.**
- **Drain condensation from air system.**
- **Check fuses and mountings for general condition and tightness.**
- **Check main terminals and ground connections for loose or overheating contacts; and loose or broken frame ground connections.**

- **Perform a visual inspection of the closing solenoid, motor, or spring to see that equipment is in operating condition.**

- **Drain condensation from air cylinder if applicable.**

- **Perform a visual inspection of the breaker position indicating light if the breaker is closed to ensure the solenoid trip device is in operating condition.**

- **Check the operating mechanism cabinet metal and hardware for condition. Check door gaskets for tightness and that they properly exclude dust and dirt.**

- **Check cabinet heaters and see that they are in service in cold weather.**

- **Replace burnt-out lamps.**

- **See that all power and control circuit switches are closed and fuses are in place.**

- **Inspect wiring for damaged insulation.]**

Reference - NFPA 70B-2016, Sections 11.16.1, 15.4, Table K.2(e), Table L.1.

5.2.2 Preventive Maintenance

[The following preventive maintenance must be performed on indoor and outdoor Air and Air Blast Circuit Breakers. Add other activities as required by the breakers O&M manual:

- **Check condition of frame, panels, and cabinets for the condition of the paint and repaint as necessary.**

- **Tighten frame, panels, and cabinet bolts to recommended specifications.**

- **Clean exterior of cabinets.**

- **Clean bushing or insulator porcelain with water or a suitable cleaner. Repair chipped spots by painting with lacquer such as 1201 glyptal. Tighten bolts to recommended specifications.**

- **Test bushings for capacitance, dielectric loss, power factor/dissipation factor, partial discharge, insulation resistance.**

- **Perform in-depth bushing inspection for any carbon tracking, leaks, and cracks.**

- **Clean, repair chipped spots, remove and clean interphase barriers.**

- **Tighten all bus and ground connections to recommended specifications and inspect for heating.**

- **Refinish all bus and ground contact surfaces if they have been overheating.**

- **Inspect ground cable to see that it is not loose or broken.**
- **Remove arc chutes so that the contacts can be inspected. Dress contacts, if rough, with a fine file. It is necessary to carefully remove only the projecting beads. Pits in a flat, smooth surface are not objectionable.**
- **Check contact pressure springs for loss of temper, breaks, or rust deterioration.**
- **Check flexible shunts at contact hinges for overheating and fraying. Tighten connections to recommended specifications.**
- **Check arc-rupturing blowout coils, magnetic circuit, arc chutes, de-ion grids, air-puffer, or other interrupters for proper operation.**
- **Perform a leak test on air system to check seals and piping.**
- **Check contact crosshead for misalignment, breaks, bends, or looseness on lift rod.**
- **Check contact lift rods for breaks, weakening, or warping, and pulling out at ends. Check adequacy of guides.**
- **Check operating rods, shafts, and bell cranks for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc.**
- **Clean moving parts of rust, dirt, and accumulated grease and oil.**
- **Wash out bearings, pivots, and gears with a suitable cleaner; and operate breaker several times to work out dirt and old lubricant. Lubricate with new grease or oil.**
- **In cold climates, it is important to use lubricant that will not stiffen with cold. Wipe off excess oil.**
- **Observe mechanism during several closing operations to see that everything is in proper working order. Check solenoid plunger for sticking in guides.**
- **Check coil resistance with an ohmmeter and insulation resistance with an appropriate insulation tester.**
- **Dismantle air cylinder and clean and lubricate. Check motor. Check closing springs for proper tension and closing energy.**
- **Observe latch and trip mechanism during several tripping operations to see that everything is in working order.**
- **Check latch and trip mechanism pins, bearings, and latches for wear, binding, and misalignment.**

- **Clean and lubricate latch and trip mechanism pins.**
- **Check latch carefully to see that it is not becoming worn so that it would unlatch from vibration or stick and fail to trip.**
- **Tighten bolts and screws of the latch and trip mechanism to recommended specifications.**
- **Electrically trip breaker and observe operation. See that full energy action of plunger is obtained.**
- **Check tripping solenoid plunger for sticking in guides.**
- **Check trip solenoid coil and insulation resistance.**
- **Check condition of auxiliary contacts and refinish with burnishing tool if burned or corroded.**
- **Check auxiliary contact springs, operating rods, and levers.**
- **Check closing and opening position with respect to main contacts while breaker is being slowly closed and opened manually. Certain auxiliary contacts used for special purposes may require close adjustment in this respect.**
- **Check dashpots or snubbers for proper setting and adjust as necessary.**
- **Clean dashpot or snubber liquid or oil and replenish if necessary.**
- **Verify calibration of any pressure meters and pressure switches to manufacturer's requirements.**
- **Check position indicator or semaphore is properly indicating the breaker position. Check operating rods or levers for loose parts.]**

Reference - NFPA 70B-2016, Section 11, 15.

5.2.3 Manual Operation

[Manually operate the indoor and outdoor Air and Air Blast Circuit Breaker, 'CLOSE' and 'OPEN' three times.]

Many breakers sit without any operation for long periods of time. This can be very detrimental to the breakers operating mechanism and lead to faulty operations. This operation is best performed at the breaker with the local switch. Ensure the breaker is de-energized prior to operating. See Section 2.2 for further information.

Reference - NFPA 70B-2016, Section 11.16.1.

5.2.4 Insulation Resistance Test

[Perform an insulation test of indoor and outdoor Air and Air Blast Circuit Breakers.]

Measure the insulation resistance of each pole for 1 minute at an applied voltage that is in accordance with the manufacturer's O&M manual or a minimum of two times the rated voltage plus 1,000 volts, up to 10 kV. The test should be performed on individual poles with the breaker closed and the unused poles and frame grounded. An additional test should be performed with the breaker open and one side of the breaker grounded to measure the open poles. The insulation resistance test is a pass/fail test, however, at times the manufacturer may publish minimum resistance values within their O&M manual. If the O&M manual does not give a minimum value for its results, use a minimum value of 1 MΩ.

A power factor test may be performed for this type of breaker as well. Refer to the DOBLE Test-Data Reference Book for more information on the specific type of breaker being tested.

> Reference - NFPA 70B-2016, Sections 11.9, 11.16.1.2.1 - 11.16.1.2.4,
> Table K.2(e), Table L.1.

5.2.5 Contact Resistance Test

[Perform a contact resistance test of indoor and outdoor Air and Air Blast Circuit Breakers.]

For more details on contact resistance testing, see Section 2.4.

> Reference - NFPA 70B-2016, Section 11.16.1.2.2, Table K.2(e), Table L.1.

5.2.6 Breaker Timing Test

[Perform timing tests of indoor and outdoor Air and Air Blast Circuit Breakers.]

Test all trip functions available. This may include long-time pickup and delay, short-time pickup and delay, instantaneous, and ground-fault pickups.

Medium voltage draw out circuit breakers may require current injection for all trip functions. If an electronic or digital trip unit is used, the first trip test of each phase must be performed by current injection through the contact. It is then possible to test the trip mechanism's remaining functions through secondary current injection directly into the trip mechanism. If it is not feasible to inject current across the contacts to test the trip mechanism, the breaker's CTs must be tested as well.

For more information on timing testing, see Section 2.5.

> Reference - NFPA 70B-2016, Section 11.16.1.2.7, Table K.2(e), Table L.1.

5.2.7 Breaker Motion Analysis Test

[Perform a motion analysis test of indoor and outdoor Air and Air Blast Circuit Breakers.]

On some of the smaller, rack out medium air circuit breakers, this test may not be recommended by the manufacturer's O&M manual. However, a motion analysis is always a benefit to the breakers normal maintenance. For more information on motion analysis testing, see Section 2.6.

Reference - NFPA 70B-2016, Section 11.16.1.2.7, Table K.2(e), Table L.1.

5.2.8 Breaker Control Functional Testing

[Perform functional testing of the breaker control circuits of indoor and outdoor Air and Air Blast Circuit Breakers.]

For more information on breaker control functional testing, see Section 2.7.

5.2.9 Equipment Ratings Review

[Perform an equipment ratings review and coordination study of both indoor and outdoor Medium Voltage Air and Air Blast Circuit Breakers.]

An equipment ratings review of electrical equipment is critical to ensure the proper operation of protective devices, including medium voltage circuit breakers. A coordination study shall also be included with the equipment ratings review.

The results of this review should be used to help procure properly rated medium voltage breakers. After installation and the as-built information is obtained, another equipment ratings review must be performed. The equipment ratings review of the breakers and the coordination study can easily be accomplished during the review of the Arc Flash Hazard Analysis.

Reference - NFPA 70B-2016, Section 9.

5.2.10 Infrared Scan and Thermal Analysis

Perform an infrared scan.

For more information on performing an infrared scan, see FIST 4-13.

Reference - NFPA 70B-2016, Section 11.17.

6.0 Medium Voltage (601 V – 15kV) Vacuum Breaker Maintenance

6.1 General

6.1.1 Background

The first experimentation with vacuum circuit interrupters (Figure 6-1) occurred in the mid-1920s, but a suitable commercial vacuum interrupter was not available until the late 1950s. The vacuum circuit breaker market continues to grow due to its simple design, low maintenance requirements, and being environmentally safe compared to sulfur hexafluoride (SF_6) circuit breakers.

Figure 6-1. Vacuum circuit breakers

6.1.2 Design and Operation

The vacuum circuit breaker design is fairly basic compared to most other breakers. Getting beyond the science of the contacts in a vacuum, it's basically a flat movable disk pressing against a flat stationary disk. The movement of the contacts is no more than 10 to 20 mm. Furthermore, there is no other medium that must be dealt with. Vacuum circuit breakers have approximately a 20 to 30 year life expectancy. With these breakers having a potential to operate beyond their designed life expectancy, it is extremely important that a regular maintenance program be established.

Dependent on the voltage class and current rating of the vacuum circuit breaker, the breaker may have a larger footprint and may cost more than a comparable SF_6 breaker. However, they benefit from requiring less maintenance than most circuit breakers and are environmentally friendly compared to SF_6 circuit breakers.

Vacuum circuit breakers' primary points of weakness are the operating mechanism and the bellows which is attached to the moving contact on the vacuum bottle (Figure 6-2). Due to the number of operations of some of our generator breakers, the bellows can start to crack which can impact the vacuum of the breaker. The operating mechanisms for vacuum circuit breakers are typically spring operated. This also simplifies the maintenance of these breakers.

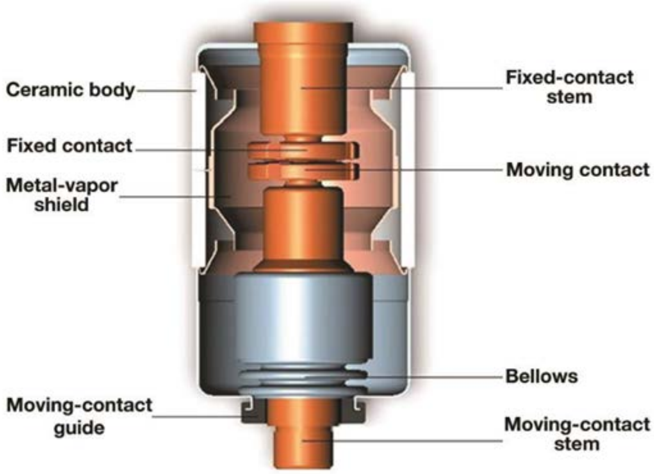

Figure 6-2. Operating mechanism of vacuum circuit breaker

6.2 Breaker Specific Maintenance and Testing

6.2.1 Visual Inspection

[Perform the following activities during the visual inspection:

- **Record operations counter.**
- **Check circuit breaker frame and insulation material for cracks and cleanliness.**
- **Check bushings and insulators for chipped or broken porcelain and excessive dirt or film, visible cracks, contamination, and oil level.**
- **Check main terminals and ground connections for loose or overheating contacts and loose or broken frame ground connections.**
- **Perform a visual inspection of the closing solenoid, motor, and springs to ensure the equipment is in operating condition.**
- **Perform a visual inspection of the trip solenoid and springs to ensure the equipment is in operating condition.**
- **Check condition of enclosing cabinets including hinges, latches, locks, and door gaskets.**
- **Check operation of cabinet heaters and lamps.**

- **Check the general condition and tightness of power and control circuit switches, fuses, and mountings. Inspect wiring for damaged insulation. Inspect and torque terminal points.]**

Reference - NFPA 70B-2016, Sections 11.16.3, 15.5, Table K.2(e), Table L.1.

6.2.2 Preventive Maintenance

[Perform the following preventive maintenance tasks on indoor and outdoor vacuum circuit breakers:

- **Observe mechanism during several closing and opening operations to see that everything is in proper working order.**
- **Tighten all bus and ground connections to recommended specifications and inspect for heating. Refinish contact surfaces if they have been overheating. Inspect ground cable to see that it is not loose or broken.**
- **Clean bushing or insulator porcelain with water or a suitable cleaner. Repair chipped spots by painting with lacquer such as 1201 glyptal. Tighten bolts to recommended specifications.**
- **Test bushings for capacitance, dielectric loss, power factor/dissipation factor, partial discharge, insulation resistance.**
- **Perform in-depth bushing inspection for any carbon tracking, leaks, and cracks.**
- **Clean, repair chipped spots, remove and clean interphase barriers.**
- **Inspect vacuum bottle for signs of heating or other damage. Inspect vacuum bottle connections.**
- **Measure contact stroke.**
- **Check close and trip coil resistance with an ohmmeter. Some timing test sets will perform this function during a timing test.**
- **Check operating mechanism springs for loss of temper, breaks, or rust deterioration.**
- **Check charging motor for proper operation.**
- **Check operating rods, shafts, and bell cranks for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc. Clean moving parts of rust, dirt, and accumulated grease and oil.**
- **Lubricate operating mechanism with new grease or oil as required by the manufacturer's O&M manual. (Do not use penetrating oil on any part of the breaker operating mechanism.)**

- **Check dashpots or snubbers for proper setting and adjust as necessary. Clean out and replenish liquid in liquid dashpots.**
- **Check the breaker position indicator is properly indicating the breaker position.**
- **Check contact-erosion indicator, see Section 6.3.1 below for more details.**
- **Clean racking mechanism and lubricate jack screws and gears.**
- **Check condition of enclosure and clean if necessary. Repaint enclosure if needed. Tighten loose bolts to recommended specifications.]**

Reference - NFPA 70B-2016, Section 11.16.3, Table K.2(e), Table L.1.

6.2.3 Manual Operation

[Manually operate the indoor and outdoor medium voltage vacuum circuit breaker, 'CLOSE' and 'OPEN', three times.]

Many breakers sit without any operation for long periods of time. This can be very harmful to the breaker's operating mechanism and lead to faulty operations. This operation is best performed at the breaker with the local switch. Ensure the breaker is de-energized prior to operating. See Section 2.2.

Reference - NFPA 70B-2016, Section 11.10.6.

6.2.4 Insulation and Vacuum–integrity Test

[Perform a hi-pot test to determine insulation and vacuum-integrity of indoor and outdoor Vacuum Circuit Breakers.]

A power factor or watt-loss test is not a test that will adequately test the insulation or the vacuum-integrity of a vacuum circuit breaker. A hi-pot test is required for this purpose.

For more information on insulation and vacuum-integrity testing for vacuum circuit breakers, see Section 6.3.2, below.

Reference - NFPA 70B-2016, Sections 11.9, 11.16.3, Table K.2(e), Table L.1.

6.2.5 Contact Resistance Test

[Perform contact resistance test of indoor and outdoor Vacuum Circuit Breakers.]
For more details on contact resistance testing, see Section 2.4.

Reference - NFPA 70B-2016, Section 11.16.3, Table K.2(e), Table L.1.

6.2.6 Breaker Timing Test

[Perform a circuit breaker timing test of indoor and outdoor Vacuum Circuit Breakers.]

For more information on circuit breaker timing testing, see Section 2.5.

Reference - NFPA 70B-2016, Section 11.16.3, Table K.2(e), Table L.1.

6.2.7 Breaker Motion Analysis Test

It is recommended that a motion analysis test be performed for both indoor and outdoor vacuum circuit breakers.

A motion analysis on vacuum circuit breakers is not normally recommended by breaker manufacturers due to their short operating stroke, usually between 10 and 20 mm. However, a motion analysis can become valuable in finding problems with the breaker operating mechanism that might not show up on a timing test.

In one circumstance, it was noted that due to a problem with a bad dampening device, the velocity of the breaker on a trip command was well beyond its recommended velocity and there would be a bounce back to nearly 80% closed. This caused severe vibrations within the breaker which created problems with connection stab alignment, operating mechanism damage, and possible contact damage. It is also possible that a restrike could have occurred within the breaker. A regular motion analysis of this breaker would have caught the problem before this damage had occurred.

For more information on breaker motion analysis testing, see Section 2.6.

Reference - NFPA 70B-2016, Section 11.16.3, Table K.2(e), Table L.1.

6.2.8 Breaker Control Functional Testing

[Perform functional testing of the breaker control circuits.]

For more information on breaker control functional testing, see Section 2.7.

6.2.9 Equipment Ratings Review

[Perform an equipment ratings review and coordination study for both indoor and outdoor Medium Voltage Vacuum Circuit Breakers.]

An equipment ratings review of electrical equipment is critical to ensure the proper operation of protective devices, including medium voltage vacuum circuit breakers. A coordination study shall also be included with the equipment ratings review.

The results of this review should be used to help procure properly rated medium voltage vacuum circuit breakers. After installation and the as-built information is obtained, another equipment ratings review must be performed. The equipment ratings review of the breakers and the coordination study can easily be accomplished during the review of the Arc Flash Hazard Analysis.

Reference - NFPA 70B-2016, Section 9.

6.2.10 Infrared Scan and Thermal Analysis

Perform an infrared scan and thermal analysis.

For more information on performing an infrared scan, see FIST 4-13.

Reference - NFPA 70B-2016, Section 11.17.

6.3 Other Specific Breaker Related Tests

6.3.1 Contact-erosion Indicator Check

As a vacuum circuit breaker's contacts wear, material from the contact faces are lost. As this happens, the position of the moving contact stem will begin to recede into the vacuum bottle. Most vacuum circuit breakers have a procedure that can be used to verify contact wear. Each manufacturer has a different way of checking contact-erosion. Refer to the manufacturer's O&M manual for a detailed procedure outlining the steps necessary to perform this task.

6.3.2 Insulation and Vacuum–integrity Test

An insulation test will check for possible shorts to ground. A vacuum-integrity test will check the pressure of the vacuum bottle. These tests are critical to the continued safe operation of the circuit breaker.

There are several different methods to perform an insulation test. An AC or DC hi-pot test or a power factor (watt-loss test) will check the integrity of the circuit breaker insulation. The hi-pot test is a pass/fail test and the power factor test will give a value which will usually allow trending. However, the test result of the power factor test is so low that the value obtained may not be able to show a meaningful trend. The power factor test will not give meaningful results pertaining to vacuum-integrity due to the circuit breakers high insulation values.

There are two tests that will give a vacuum-integrity test. A hi-pot test and a Magnetron Atmosphere Condition (MAC) Assessment. The MAC test will give an actual pressure within the vacuum bottle.

To perform an insulation and a vacuum-integrity test, the following tests must be performed:

1) With the breaker closed, test between each phase to ground.

2) With the breaker open, test across the contact of each phase.

Note: Some vacuum interrupters have an exposed mid-band ring on the exterior of the vacuum bottle that may retain voltage after testing. After completion of a test and prior to handling or making any change of the test leads, touch each pole and the mid-band ring with a grounding stick.

6.3.2.1 AC or DC Hi-Pot Test

The hi-pot test is the best way to check the insulation and perform a vacuum-integrity test within one set of tests. It is also the quickest and easiest to perform. The hi-pot test is strictly a pass/fail test. An AC hi-pot is preferred due to possible x-ray emissions which can be produced by some DC hi-pot test sets when testing is performed at voltages higher than rated voltage with the contacts open.

Note: A DC hi-pot may create hazardous x-ray exposure. To mitigate this exposure, perform the following steps:

- *Place the breaker in an isolated area such that no personnel can approach within 15 feet (set-up red danger tape at this barrier).*
- *Test personnel must not enter or be within the danger tape area while the vacuum interrupters are being tested.*

The voltages and procedures used during the tests should be provided within the manufacturer's O&M manual. If that is not available, the insulation and vacuum-integrity test voltage is dependent upon the rated voltage of the breaker and whether the test is performed with an AC or DC test set. See Table 6-1 for recommended test voltages.

Table 6-1. Recommended test voltages

Rated Voltage (kV)	Field Test Voltage (kV AC)	Field Test Voltage (kV DC)
3.6	7.5	10.6
4.76	14.3	20.2
7.2	15	21.2
8.25	27	38.2
12	21	29.7
15	27	38.2

6.3.2.2 Power Factor or Watt-Loss Test

The power factor test is specifically used to determine the condition of the surface insulation of the breaker, it will not give the condition of the vacuum interrupter. The power factor test is normally performed by a DOBLE M4000 test set. This test is to be used with a baseline and the results trended over time.

The results obtained can be between 0.002 to 0.25 Watt-Loss dependent on the manufacturer and type of breaker. As an example, the GE VB1 vacuum circuit breaker typically has had a Watt-Loss value from .002 to 0.020, the Siemens-Allis SDV vacuum circuit breaker has had Watt-Loss results vary from 0.021 to 0.200, and the Siemens-Allis FCV vacuum circuit breaker has had Watt-Loss results from 0.002 to 0.030.

The results are so low for this test, that there may be large increases in values with each subsequent test performed mainly due to age of the breaker, cleanliness of the surface of external parts, and calibration and accuracy of the DOBLE M4000 itself.

6.3.2.3 Magnetron Atmospheric Condition (MAC) Assessment

The MAC (Figure 6-3) is a fairly new test which will measure the internal pressure of the vacuum interrupter. This test is performed by producing a high potential across an open contact while surrounded by a magnetic field. The results of this test appears to be an accurate method for determining the condition of the pressure within the vacuum interrupter.

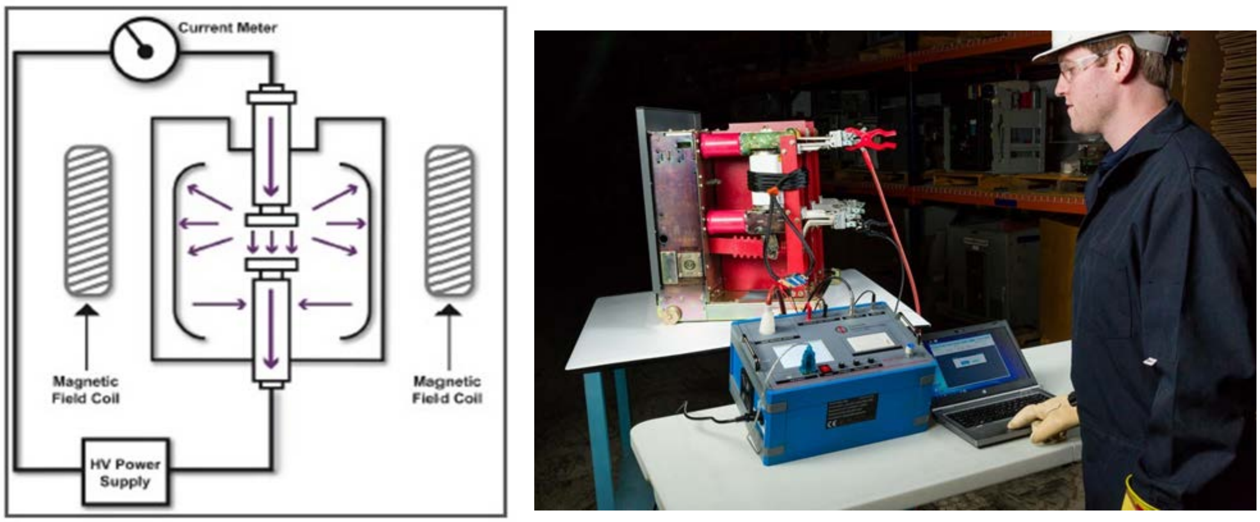

Figure 6-3. Principle of magnetron atmospheric condition (MAC) assessment (left) and a MAC assessment being performed

A normal hi-pot test across an open contact will provide a pass/fail for the condition of the vacuum interrupter. A pass/fail may not always provide enough information to accurately assess the condition of the vacuum interrupter while the MAC will give more details into its condition.

7.0 Medium and High Voltage Oil Circuit Breaker Maintenance

7.1 General

7.1.1 Background

Since oil circuit breakers can hold substantial amounts of oil, a catastrophic failure could mean a rupture of the tank causing an oil spill and/or a fire which can produce a very hazardous situation

Figure 7-1. Oil circuit breaker

If oil circuit breakers are not properly maintained, they may fail to operate when required or they may fail catastrophically. For this reason, preventive maintenance is crucial to assure safe and proper operation.

7.1.2 Design and Operation

Oil circuit breakers can be classified in two different styles. In one style, the tank of the breaker is grounded (dead tank); in the other style the tank of the breaker is at the potential of the circuit in which it is connected (live tank or minimum oil). Most Reclamation facilities utilize the dead tank style. In a dead tank oil circuit breaker, the oil is not only used to extinguish the arc, but it is also used as an insulator between the energized parts and the outer tank. A live tank oil circuit breaker is also known as a minimum oil breaker since the oil is primarily used to extinguish the arc and not as an insulator. This FIST focuses on testing procedures required for dead tank oil circuit breakers, but testing on live tank oil circuit breakers should be similar. In either case, always refer to the breakers Operation and Maintenance Manual for specific maintenance procedures that may not be covered in this document.

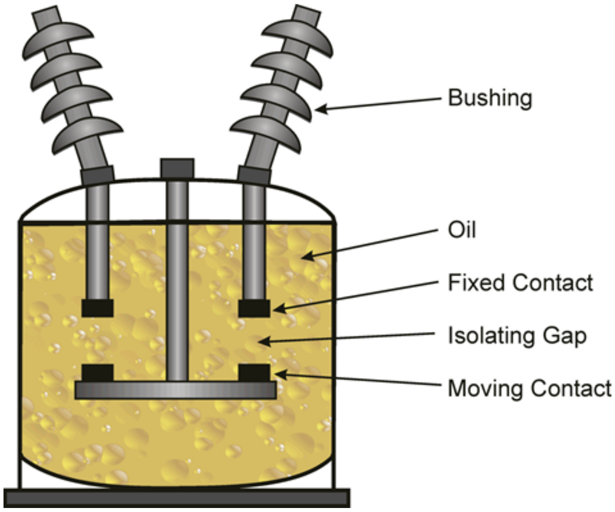

Figure 7-2. Oil circuit breaker design

When an oil circuit breaker has a high interrupting rating, it will normally utilize multiple interrupters in series to break the arc. When multiple interrupters are designed into the breaker, a voltage grading device is often used in parallel with the contacts. A high ohmic resistor or grading capacitor in parallel with each interrupter is often used as a grading device. These devices help to stabilize the voltage between the contacts during contact opening.

The majority of breaker failures are due to high mechanical resistance of the operating system. Some breakers, particularly those with high current levels, have a tendency to develop contact heating if left closed for long periods. The operating mechanism may also develop a high mechanical resistance which will prevent the breaker from operating according to the breaker specifications. Opening and closing the breaker several times at scheduled intervals, as system operation permits, may reduce contact and operating mechanism resistance. Lubrication of the operating system along with its moving parts and linkages will also ensure continued operation according to initial specifications. For more information on breaker lubrication, see Section 2.1.

7.2 Breaker Specific Maintenance and Testing

7.2.1 Insulating Oil Inspection and Tests

[Perform the following activities on the breaker insulating oil.

- **Check oil level of the breaker and bushings.**
- **Check oil visual condition and color.**
- **Perform a dissolved gas analysis (DGA) on the insulating oil.]**

DGA on an oil circuit breaker at first seems contrary to everything we understand about the use of the DGA since there is arcing within a breaker when it is operated. However, the DGA on an oil circuit breaker can be an important diagnostic tool in pointing out problems with your breaker. As with transformer oil, the important thing to watch for is a continuing rise in oil contamination. The results of the insulating oil tests should rise to a specific point when new, then stabilize. If these values continue to rise, it could mean problems are beginning to occur. This testing will also help determine when the oil should be reclaimed. For more information about insulating oil testing, see FIST 3-30, Section 4.4 "Transformer Oils", and FIST 3-31, Sections 5 "Dissolved Gas Analysis", and 6 "Oil Physical/Chemical Tests".

The tests that should be performed along with the DGA should consist of a particulate count and sizes, water content, neutralization or acid number, total metals, interfacial tension, dielectric breakdown or power factor.

The amount of combustible gases produced through normal operation of the breaker is fairly constant and should not continue to climb. Like a DGA on the insulating oil of an oil filled transformer, it is important to be watching for upward trends of the combustible gases. The DGA will show when there is overheating or excessive arcing within the circuit breaker. This test will help determine that these problems exist and ensure that the level of these gases do not climb to dangerous levels. The combustible gases and their levels of concern will be similar to those of the insulating oil of an oil filled transformer.

The particulate count is used to detect problems with oil contamination as well as the possible wear and tear of materials and equipment inside the breaker. If the quantity of particulates is rising, an analysis of the makeup of the particles should be obtained to help determine the cause of the contamination.

The water content determines the amount of free moisture within the insulating oil of the breaker. Water in insulating oil could mean a problem with a gasket or seal. Water will break down the oils dielectric strength. Excessive water in oil may mean a bad seal, gasket, breather, or vent.

The neutralization or acid number measures the acidity level of the oil. Organic acids can form as the insulating oil ages due to oxidation. If the acid number gets too high, sludge can form which can affect the operation of the breaker.

A total metals test will give an indication of both the amount of metal particulates and of dissolved metals contained within the insulating oil. This test is a good indication to the condition of the contacts. An increasing amount of metal within the oil could mean a problem is developing with the breaker contacts and should be inspected as soon as an outage can be scheduled.

The interfacial tension, when compared with the acid number, is an indication that sludge is forming within the oil.

The dielectric breakdown test or power factor of the oil is a method of determining the condition of the oil as an insulating medium.

7.2.2 Visual Inspection

[Perform the following activities during the visual inspection.

- **Observe and record the operation counter.**

- **Check foundation for cracks and settling.**
- **Check for oil leaks and loose or broken parts.**
- **Check oil level gauges of tanks and oil-filled bushings.**
- **Check panels for cracks and cleanliness.**
- **Check condition of enclosing cabinets including hinges, latches, locks, and door gaskets.**
- **Check bushings and/or insulators for chipped or broken porcelain, excessive dirt, and oil leaks.**
- **Check main terminals and ground connections for presence of foreign materials, birds' nests, etc., in or near connecting buswork; loose or overheating connections; and loose or broken frame ground connections.**
- **Check control cabinets for condition of metal and hardware.**
- **Check that control cabinet door gaskets are tight and properly exclude dust and dirt.**
- **Check control cabinet heaters and ensure they function in cold weather.**
- **Inspect control cabinet wiring for damaged or burned insulation.**
- **Check control cabinet for loose or hanging conductors.**
- **Check fuses and fuse mountings for general condition and tightness.]**

Reference - NFPA 70B-2016, Sections 11.16.2, 15.6, Table K.2(e), Table L.1.

7.2.3 Preventive Maintenance

[Perform the following activities during the preventive maintenance.

- **Prior to opening the breaker to perform preventive maintenance, perform a first trip test if the breaker has not operated for more than one year without an operation. For more information on the first trip test, see Section 2.3.**
- **Clean exterior of tanks and cabinets.**
- **Tighten bolts to recommended specifications, as necessary.**
- **Check condition of paint and repaint as necessary.**
- **Inspect tank interior for moisture and rust; clean and repaint as necessary.**

- **Check tank liners and interphase barriers.**
- **Clean oil level gauge glass and connections into tank.**
- **Check vents and breathers to see that screens and baffles are not obstructed or broken.**
- **Check gaskets for flexibility and cracking.**
- **Clean bushings or insulator porcelain with water or a suitable cleaner.**
- **Repair chipped spots on bushings or insulators by painting with lacquer such as 1201 glyptal.**
- **Inspect bushings or insulator gaskets for leaks. Tighten bolts to recommended specifications, if necessary.**
- **Test bushings for capacitance, dielectric loss, power factor/dissipation factor, partial discharge, insulation resistance.**
- **Perform in-depth bushing inspection for any carbon tracking, leaks, and cracks.**
- **Clean, repair chipped spots, remove and clean interphase barriers**
- **Check power factor with hot collar or Hipot on bushings or insulators. See FIST 3-31 for instructions.**
- **Replenish oil filled bushings with oil if necessary.**
- **Tighten all bus and ground connections and inspect for heating.**
- **Refinish bus and ground connection contact surfaces if there are signs of overheating.**
- **Inspect ground cable to see that it is not loose or broken.**
- **Drain oil and inspect the breaker contacts.**
- **Dress contacts, if rough, with a fine file. It is necessary to carefully remove only the projecting beads. Pits in a flat, smooth surface, are not objectionable.**
- **Check springs for loss of temper, breaks, or rust deterioration.**
- **Check flexible shunts at contact hinges for overheating and fraying. Tighten connections to recommended specifications.**

- **Check arc-rupturing blowout coils, arc chutes, de-ion grids, oil blast, or other interrupters for proper operation.**
- **Check contact crosshead for misalignment, breaks, bends, or looseness on lift rod.**
- **Check contact lift rods for breaks, weakening, or warping, and pulling out at ends.**
- **Check adequacy of guides.**
- **Check operating rods, shafts, and bell cranks for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc.**
- **Clean operating rods, shafts, and bell cranks moving parts of rust, dirt, and accumulated grease and oil.**
- **Lubricate operating mechanism with new grease or oil as recommended by manufacturer's O&M manual. Wipe off excess oil. For more information on breaker lubrication, see Section 2.1.**
- **Observe close and trip coil mechanisms during several close and open operations to see that everything is in proper working order.**
- **Check close and trip coil resistance with an ohmmeter.**
- **Check operating mechanism charging or compressor motor.**
- **Check position indicator or semaphore is properly indicating the breaker position.**
- **Check operating rods or levers on position indicator for loose parts. Clean and lubricate if necessary.**
- **Check auxiliary contacts cand refinish with burnishing tool if burned or corroded.**
- **Check auxiliary contact springs, operating rods, and levers.**
- **Verify calibration of pressure meters and pressure switches to manufacturer's requirements.**

- **Check closing and opening position with respect to main contacts while breaker is being slowly closed and opened manually or through timing test. Certain auxiliary contacts used for special purposes may require close adjustment in this respect.]**

Reference - NFPA 70B-2016, Sections 11 and 15.

7.2.4 Manual Operation

[Manually operate the medium and high voltage oil circuit breaker, 'CLOSE' and 'OPEN', three times.]

Many breakers sit without any operation for long periods of time. This can be very harmful to the breakers operating mechanism and lead to faulty operations. This operation is best performed at the breaker with the local switch. Ensure the breaker is de-energized prior to operating. See Section 2.2 for more details.

Reference - NFPA 70B-2016, Section 17.10.

7.2.5 Insulation Test

[Perform an insulation test (power factor) on the breaker and bushings]

Measure the insulation resistance for 1 minute with a Hypot® at an applied voltage that is in accordance with the manufacturer's O&M manual. The test should be performed on individual poles to ground with the breaker closed and an additional test with the breaker open across the contacts. The Hypot® test is a pass/fail test, however, at times the manufacturer may publish minimum resistance values within their O&M manual. If the O&M manual does not give a minimum value for its results, use a minimum value of 1 MΩ.

A power factor test is recommended for this type of breaker as well. Refer to the DOBLE Test-Data Reference Book for more information on the specific type of breaker being tested. Perform a power factor test on the bushings with a hot collar.

Reference - NFPA 70B-2016, Sections 11.9, 11.16.2.2.1 - 11.16.2.2.4,
Table K.2(e), Table L.1.

7.2.6 Contact Resistance Test

[Perform contact resistance test.]

For more details on contact resistance testing, see Section 2.4.

Reference - NFPA 70B-2016, Section 11.16.2.2.2, Table K.2(e), Table L.1.

7.2.7 Breaker Timing Test

[Perform breaker timing test.]

For more details on breaker timing test, see Sections 2.5.

Reference - NFPA 70B-2016, Section 11.16.2.2.6, Table K.2(e), Table L.1.

7.2.8 Breaker Motion Analysis Test

[Perform breaker motion analysis test including timing of the breaker auxiliary "a" and "b" contacts.]

For more details on motion analysis testing, see Section 2.6.

Reference - NFPA 70B-2016, Section 11.16.2.2.6, Table K.2(e), Table L.1.

7.2.9 Breaker Control Functional Testing

[Perform functional testing of the breaker control circuits.]

For more details on breaker control functional testing, see Section 2.7.

7.2.10 Equipment Ratings Review

[Perform an equipment ratings review and coordination study for Medium and High Voltage Oil Circuit Breakers.]

An equipment ratings review of electrical equipment is critical to ensure the proper operation of protective devices, including medium and high voltage oil circuit breakers. A coordination study shall also be included with the equipment ratings review.

The results of this review should be used to help procure properly rated medium and high voltage oil circuit breakers. After installation and the as-built information is obtained, another equipment ratings review must be performed. The equipment ratings review of the breakers and the coordination study can easily be accomplished during the review of the Arc Flash Hazard Analysis.

Reference - NFPA 70B-2016, Section 9.

7.2.11 Infrared Scan and Thermal Analysis

Perform an infrared scan and thermal analysis.

For more details on performing an infrared scan, see FIST 4-13.

Reference - NFPA 70B-2016, Section 11.17.

7.3 Condition Based Maintenance

To implement a condition based maintenance program for oil circuit breakers, perform the following diagnostic tests which will help to evaluate the condition of the breaker:

- Breaker timing
- Motion analysis
- Contact resistance measurement
- Insulating oil tests and DGAs
- Power Factor

Breaker timing, motion analysis, and contact resistance were discussed in Section 1.3.

If the above test results are within the acceptable limits of the manufacturer's O&M manual, performing preventive maintenance may be modified to areas of the breaker which are showing signs of deterioration. As an example, maintenance on the operating mechanism may be required, but internal maintenance on the circuit breaker, which may include draining and filtering the oil and any internal breaker maintenance activities which requires entering the breaker, may not.

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8.0 Medium and High-Voltage SF_6 Circuit Breaker Maintenance

8.1 General

8.1.1 Background

SF_6 gas was originally developed as an interrupting medium in 1938, and the first industrial use of SF_6 gas as an interrupting agent for an arc was in 1953. The first high voltage circuit breaker using SF_6 was released in 1956. SF_6 gas circuit breakers have since become the breaker of choice for both indoor and outdoor circuit breakers. Reclamation facilities have more than 1,000 power circuit breakers; the most modern of them use SF_6 gas as an arc-interrupting/quenching and insulating agent.

8.1.2 Design and Operation

SF_6 circuit breakers are also known as gas insulated circuit breakers (GICB) or gas circuit breakers (GCB). Occasionally the term gas insulated switchgear (GIS) will be used. GIS is defined as a substation which consists of multiple bays of GCBs and disconnects in which all components are gas insulated.

The earliest GCBs utilized a double pressure system which used high pressure SF_6 gas to blow out the arc similar to an air blast circuit breaker. Current GCBs use a puffer method that uses the motion of the moving contact to create a puff of SF_6 gas which will help extinguish the arc. This design is less complex than the double pressure system due to fewer components required to compress and store the SF_6 gas.

The drawbacks of GCBs are the impact of SF_6 gas on the environment and the hazards involved with working with the gas. These drawbacks have created special handling requirements for SF_6 gas. These requirements are covered in more depth in Directive and Standard FAC 04-13 for Reporting Procedures of SF_6 Gas and Section 9 of this document for safe handling procedures.

The environmental hazards of SF_6 gas are extensive. SF_6 is not an ozone-depleting gas, but one of the most powerful global warming gases known. It is nearly 24,000 times more effective at trapping infrared radiation than an equivalent amount of CO_2. Furthermore, where CO_2 has a 90 year lifespan when released into the atmosphere, it is estimated that SF_6 gas has a lifespan of 3,200 years. As an example of the power of SF_6 as a greenhouse gas, opening an SF_6 cylinder for approximately 10 seconds will have an equivalent effect as letting two cars idle, non-stop, for one year. Due to the severe environmental damage SF_6 gas can cause, strict reporting procedures have been created to track the amount of SF_6 gas released into the atmosphere. Reclamation Manual Directive and Standard FAC 04-13 contains requirements that Reclamation facilities are to use for tracking and reporting SF_6 gas usage.
SF_6 gas in its pure state is relatively non-toxic. However, when SF_6 gas is exposed to extreme heat, it can produce hazardous by-products which can cause severe injuries. See Section 9 for more information on safe handling procedures of SF_6 gas.

8.2 SF_6 Gas Insulated Breaker Specific Maintenance and Testing

Due to the environmental and safety concerns of SF_6 gas, GCBs are designed to require very little maintenance. However, this does not mean that these breakers can be ignored. There are a number of components which can fail, so regular maintenance is still required. According to a survey performed by CIGRE and summarized in the CIGRE technical brochure 510, most major failures of SF_6 gas circuit breakers are caused by the operating mechanism of the circuit breaker. Other systems which are a major cause of failures within SF_6 gas insulated circuit breakers include the electrical control system and the SF_6 gas insulating system. The goal of preventive maintenance is to prevent these failures from happening. See Section 8.3 for more information.

Due to the potentially hazardous nature of working in or near faulted SF_6 gas it is extremely important that individuals working on gas insulated circuit breakers, where there is a chance that SF6 gas may be released, receive SF_6 awareness training. See Section 9 for more information.

8.2.1 Visual Inspection

[Perform the following activities during the visual inspections of medium and high voltage GCBs.

- **Record gas pressure and gas or tank temperature; compare tolerance and prior readings.**
- **Compare gas pressure reading with the temperature vs. pressure graph supplied by the manufacture. Ensure that the gas pressure is within the breakers limits.**
- **Record operations counter**
- **Check equipment heaters**
- **Check operating mechanism condition according to Section 8.2.2.3.**
- **Verify breaker position indicating lights to mechanical indicator**
- **Check foundation, equipment grounds, breaker frame, paint, breaker housing, breaker bushings, and gas piping.**
- **Perform Visual Inspection of bushing for visible cracks, contamination, and oil level.]**

Reference - NFPA 70B-2016, Sections 11.16.4, 15.8, Table K.2(e).

8.2.2 SF_6 gas pressure and gas tank temperature

CIGRE technical brochure 510 states that SF_6 gas system leaks have created a large number of failures. In most cases, this can be found by regular readings of the SF_6 density or temperature corrected pressure gauge.

All gases expand and contract with temperature so the pressure in an enclosed space will fluctuate dependent on the temperature of the gas. Some of the newer SF_6 gas circuit breakers come with density gauges which factor in temperature to give a true indication of the amount of gas within the breaker. However, many SF_6 gas circuit breakers use a pressure gauge to measure the amount of SF_6 gas. Since the temperature of the gas will affect the pressure in the breaker, the temperature must be factored into the reading on the pressure gauge.

Circuit breaker manufacturers will include an SF_6 gas pressure vs. temperature characteristic curve in their Operation and Maintenance manual (see SF_6 pressure vs. temperature curve below). The pressure vs. temperature characteristic curve will typically give the rated density curve, alarm density curve, and breaker lockout density curve. The rated density curve on the SF_6 pressure vs. temperature curve (Curve 1) is the filling pressure of SF_6 gas. The alarm density curve on the SF_6 pressure vs. temperature curve (Curve 2) is the point where an alarm will be generated when the gas density drops to that curve. The lockout density curve on the SF_6 pressure vs. temperature curve (Curve 3) is the point where the breaker will lockout all close and open operations. It is very important that the breaker not open if the density of SF_6 gas falls below the breaker lockout curve. At this point, enough of the SF_6 gas has escaped where it may produce a catastrophic failure upon opening. The SF_6 liquefaction curve on the SF6 pressure vs. temperature curve (Curve 4) is the density where SF_6 gas will liquefy.

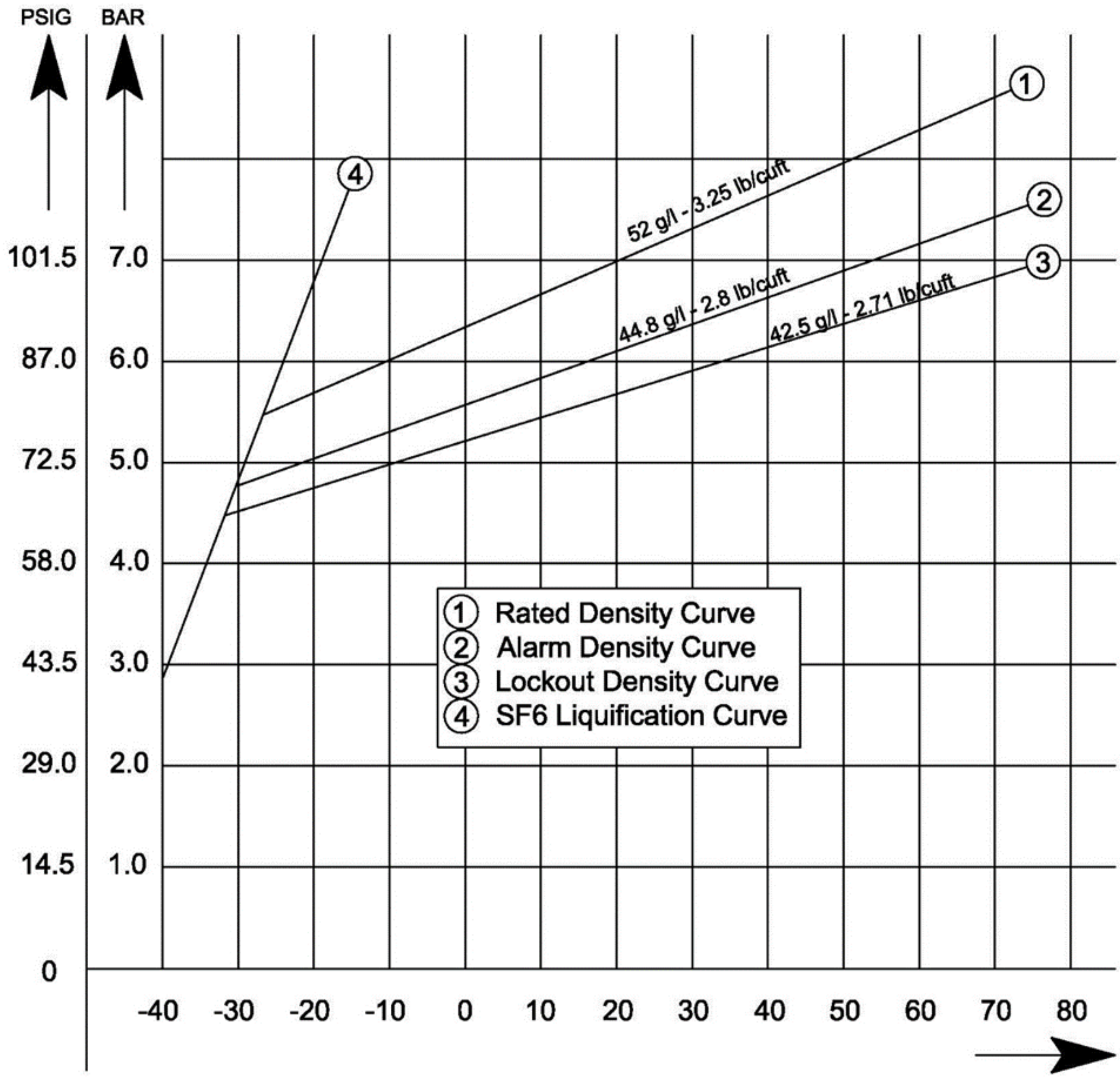


Figure 8-1. Pressure versus temperature graph

8.2.2.1 Record operations counter

Record the number of operations of the circuit breaker. This information is helpful in determining the condition of the breaker, as well as is required for some operational checks.

8.2.2.2 Check equipment heaters, cabinet and SF_6 tank heaters (if installed), for proper operation

It is important that equipment heaters operate as designed to limit damage due to moisture, and in extreme cold climates, heaters may be used to keep SF_6 gas from liquefying. SF_6 gas will liquefy at low temperatures and will affect the ability of the gas to interrupt the arc.

8.2.2.3 Check operating mechanism condition

The operating mechanism is the external equipment which provides energy to open and close the breaker. This equipment is the most common point of failure for SF_6 breakers. These operating mechanisms can consist of a spring charged operating mechanism, a pneumatic operating mechanism, a hydraulic operating mechanism, and a hydraulic-spring operating mechanism.

The spring charged operating mechanism uses a DC motor to physically charge the closed spring. The trip spring is charged as the breaker closes. For this type of operating mechanism, there is nothing that can be seen or checked during a monthly inspection.

The pneumatic operating mechanism uses compressed air to operate the breaker. Pneumatic systems are vulnerable to air leaks as well as corrosion due to moisture. Record the air pressure and verify that it is at the rated operating pressure. Record number of compressor operations if available and compare this to past readings. Make sure there is not an excess amount of compressor operations. This could point to an air leak or to an accumulator problem. Open the compressed air drain valve to remove any moisture.

The hydraulic operating mechanism uses a nitrogen gas accumulator and hydraulic oil to provide the operating energy for the breaker. Problems can arise from leaking hydraulic fluid and accumulator pressure. Record the hydraulic fluid pressure and verify that it is at the rated pressure. Check the hydraulic oil level.

The hydraulic-spring operating mechanism is similar to the hydraulic operating mechanism, except it uses a spring to pressure the hydraulic fluid rather than an accumulator. Check hydraulic oil level.

8.2.2.4 Check foundation, equipment grounds, breaker frame, and paint

Check the condition of the concrete foundation, check for cracking, loose bolts, signs of rust, condition of the paint, and check that equipment grounds are attached and secure.

8.2.2.5 Check breaker housing

Check for loose bolts, cracks, signs of rust, and protruding or misaligned gaskets and flanges. Check any problem areas for SF_6 gas leaks with a SF_6 gas detector.

8.2.2.6 Check operating mechanism condition

Check for loose bolts, slack in the operating rods, and signs of wear. Calibrate gauges that may be attached to the operating mechanism. Check condition of auxiliary switches. If necessary, calibrate auxiliary switches.

8.2.2.7 Check SF_6 gas piping

Check gas piping for looseness, cracks, rust, and check pipe fittings. If there are signs of wear, check any problem areas for SF_6 gas leaks with a SF_6 gas detector or dish soap and water.

8.2.3 Preventive Maintenance

[Perform the following activities during the preventive maintenance of medium and high voltage GCBs:

- **Prior to tripping the breaker to perform preventive maintenance, perform a first trip test if the breaker has not operated for more than one year. For more information on the first trip test, see Section 2.3.**

- **Check condition of frame, panels, and cabinets. Check paint and repaint as necessary. Tighten bolts to recommended specifications.**

- **Clean exterior of cabinets.**

- **Clean bushing or insulator porcelain with water or a suitable cleaner. Repair chipped spots by painting with lacquer such as 1201 glyptal. Tighten bolts to recommended specifications.**

- **Perform in-depth bushing inspection for any carbon tracking, leaks, and cracks.**

- **Clean, repair chipped spots, remove and clean interphase barriers.**

- **Tighten all bus and ground connections to recommended specifications and inspect for heating. Refinish contact surfaces if they have been overheating.**

- **Inspect ground cable to see that it is not loose or broken.**

- **Check operating rods, shafts, and bell cranks for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc.**

- **Clean moving parts of rust, dirt, and accumulated grease and oil.**

- **Wash out bearings, pivots, and gears with a suitable cleaner as specified by the manufacturer's O&M manual; and operate breaker several times to work out dirt and old lubricant. Lubricate with new grease or oil as specified in the manufacturer's O&M manual. In cold climates, it is important to use lubricant that will not stiffen with cold. Wipe off excess oil. Enclosed dust-tight bearings should require less servicing. For more information on breaker lubrication, see Section 2.1.**

- **Observe closing solenoid air cylinder, motor, or spring mechanism during several closing operations to see that everything is in proper working order.**

- **Check close solenoid plunger for sticking in guides.**

- **Check close coil resistance with an ohmmeter and insulation resistance with an appropriate insulation tester.**

- **Dismantle air cylinder and clean and lubricate if applicable.**

- **Check charging motor.**

- **Check closing springs for proper tension and closing energy.**

- **Observe latch and trip mechanism during several tripping operations to see that everything is in working order.**

- **Check latch and trip mechanism pins, bearings, and latches for wear, binding, and misalignment.**

- **Clean and lubricate latch and trip mechanism if required by manufacturer's O&M manual.**

- **Inspect latch carefully to see that it is not becoming worn so that it would unlatch from vibration or stick and fail to trip.**

- **Tighten latch and trip mechanism bolts and screws to recommended specifications.**

- **Observe tripping solenoid operation during electrical tripping. See that full energy action of plunger is obtained. Check plunger for sticking in guides.**

- **Check trip coil and insulation resistance.**

- **Check condition of auxiliary contacts and refinish with burnishing tool if burned or corroded.**

- **Check auxiliary contact springs, operating rods, and levers.**

- **Check closing and opening position of auxiliary contacts with respect to main contacts while breaker is being slowly closed and opened manually. Certain auxiliary contacts used for special purposes may require close adjustment in this respect.**

- **Check dashpots or snubbers for proper setting and adjust as necessary**

- **Clean dashpot or snubber liquid or oil and replenish if necessary**

- **Check position indicator or semaphore is properly indicating the breaker position. Check operating rods or levers for loose parts.**

- **Calibrate the SF_6 gas pressure meter and alarm and lockout pressure switches**

- **Verify calibration of any pressure meters and pressure switches to manufacturer's requirements.]**

Reference - NFPA 70B-2016, Section 11.16.4, Table K.2(e).

8.2.4 SF_6 Gas Analysis

[Perform a gas analysis on SF_6 gas. Check moisture, Sulphur Dioxide (SO_2), and purity.]

Perform an SF_6 gas analysis as discussed in Section 8.3.1, below.

8.2.5 Manual Operation

[Manually operate the medium and high voltage GCBs breaker, 'CLOSE' and 'OPEN', three times.]

Many breakers sit without any operation for long periods of time. This can be very harmful to the breaker's operating mechanism and lead to faulty operations. This operation is best performed at the breaker with the local switch. Ensure the breaker is de-energized prior to operating. See Section 2.2 for further information.

Reference - NFPA 70B-2016, Section 11.16.4, Table K.2(e).

8.2.6 Insulation Resistance Test

The insulation resistance test is a test that is replaced by the SF_6 gas analysis. Since the SF_6 gas is the insulation of the breaker, the gas analysis will provide a good indication to the quality of the insulating condition of the gas. See Section 8.3.1, below for a more detailed discussion.

8.2.7 Contact Resistance Test

[Perform circuit breaker contact resistance test of medium and high voltage GCBs.]

Circuit breaker contact resistance tests are to be performed according to Section 2.4.

Reference – NFPA 70B-2016, Section 11.16.4, Table K.2 €.

8.2.8 Breaker Timing Test

[Perform a circuit breaker timing test of medium and high voltage GCBs.]

Circuit breaker timing tests are to be performed according to Section 2.5.

Reference – NFPA 70B-2016, Section 11.16.4, Table K.2 €.

8.2.9 Breaker Motion Analysis Test

[Perform a circuit breaker motion analysis tests of medium and high voltage GCBs. Include timing of the breaker auxiliary "a" and "b" contacts.]

Circuit breaker motion analysis is to be performed according to Section 2.6.

Reference – NFPA 70B-2016, Section 11.16.4, Table K.2 €.

8.2.10 Breaker Control Functional Testing

[Perform functional testing of the breaker control circuits.]

For more information on breaker control functional testing, see Section 2.7.

8.2.11 Equipment Ratings Review

[Perform an equipment ratings review and coordination study for Medium and High Voltage Gas Circuit Breaker.]

An equipment ratings review of electrical equipment is critical to ensure the proper operation of protective devices, including medium and high voltage gas circuit breakers. A coordination study shall also be included with the equipment ratings review.

The results of this review should be used to help procure properly rated medium and high voltage gas circuit breakers. After installation and the as-built information is obtained, another equipment ratings review must be performed. The equipment ratings review of the breakers and the coordination study can easily be accomplished during the review of the Arc Flash Hazard Analysis. Reference – NFPA 70B-2016, Section 9.

8.2.12 Internal Circuit Breaker Inspection or Overhaul

[Perform an inspection or overhaul of the internal components every 12 years, or 5,000 operations, or three high current interruptions, whichever occurs first. Include contacts, nozzles, seals, and the operating mechanism. Replace seals, desiccant bag, and all worn parts.]

A periodic inspection or overhaul of the internal components and the operating mechanism is critical to the continued operation of the circuit breaker. Instead of a complete overhaul, it is beneficial to perform an inspection of the internal components and replace only those components that are necessary. When the breaker is opened, it is very important that the seals and desiccant bag are replaced. An option to using the time based requirement for an inspection or overhaul is to perform this task based on the condition of the breaker using Condition Based Maintenance as described in Section 8.4, below.

It is strongly recommended that an office not attempt this type work if they are not experienced with opening an SF_6 breaker. There can be some extreme consequences, as well as safety related consequences, if the maintenance personnel are not familiar with this type of work.

8.2.13 Dynamic Resistance Measurement

It is recommended that a dynamic resistance measurement be performed as described in Section 8.3.2, below.

8.2.14 Radiography Inspection

It is recommended that a radiography inspection be performed as described in Section 8.3.3, below.

8.3 Specific Breaker Related Tests

8.3.1 SF_6 Gas Analysis

An SF_6 gas analysis is extremely important to determine the condition of your breaker. Similar to the Dissolved Gas Analysis (DGA) for oil used for transformers and oil circuit breakers, this test can uncover possible problems with the breaker seals and gaskets. It may also help determine other problems that may be occurring inside the breaker.

Moisture within SF_6 gas can be the most critical contaminant within the breaker. When SF_6 gas and moisture are heated it will create many hazardous and destructive contaminants, the most common being SO_2. SO_2 is an acid which can affect the insulating surfaces of the breaker and the insulative quality of the gas.

Purity of SF_6 gas is the amount of air mixed with the gas. The usual cause of low purity in SF_6 gas is not following proper procedures for installing gas into the breaker. It can also be caused by faulty gas carts or filtering equipment.

When examining a gas analysis, similar to a DGA, it is important to ensure that the values are within the limits shown in the tables below, and the amount of contaminant does not continue to increase over time.

[Follow established limits for SF_6 gas contaminants for moisture, SO_2, and purity as shown in the tables below or within the manufacturer's O&M manual.]

In-service is based on gas which has been sampled from a breaker which is still in-service. Reclaimed gas is a gas which has been filtered and dried and will be placed back in-service. When new gas is added to a breaker, wait 72 hours prior to performing a gas analysis.

Table 8-1. Limits of moisture for In-Service gas

Limit	Condition
0 – 200 Parts per Million Volume (PPMv)	Acceptable
201 – 250 PPMv	Perform gas dry out during next outage.
Greater than 250 PPMv	Perform gas dry out immediately. Investigate cause and correct.

Table 8-2. Limits of SO_2 or In-Service gas

Limit	Condition
0-250 ppm	Acceptable
251-500 ppm	Filter gas during next outage.
Greater than 500 ppm	Filter gas immediately. Investigate cause and correct.

Table 8-3. Limits of gas purity for In-Service gas

Limit	Condition
97% and above	Acceptable
90% - 96.9%	Replace gas during next outage.
Below 89.9%	Replace gas immediately. Investigate cause and correct.

Table 8-4. Limits of contaminants for new and reclaimed gas

Contaminant	New Gas Limits	Reclaimed Gas Limits
Moisture	8 PPMv	50 PPMv
SO2	0 PPMv	0 PPMv
Purity	99.8%	99%

8.3.2 Dynamic Resistance Measurement

The Dynamic Resistance Measurement (DRM) is a test which will measure contact resistance while the breaker is in motion, closing or opening. The GCB has two current carrying contacts, the main and the arcing contacts. See Figure 8-2 below.

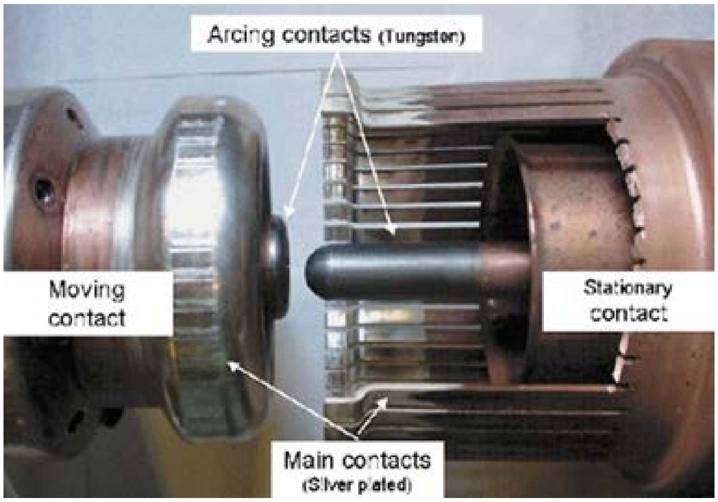


Figure 8-2. GCB current carrying contacts

As the breaker opens, the main contact releases, then the arcing contact. This makes the arcing contact the device which will take the majority of the damage when interrupting a fault. This test will give an indication as to the condition of the arcing contact by measuring the distance of the arcing contact beyond the main contact.

The DRM is meant to be a comparison between past measurements. A sudden decrease in arcing contact length should be investigated. However, in some cases, the results can indicate other contact problems, including broken contact fingers.

A typical result of a DRM is shown in the figure below. The DRM is always taken with a motion analysis. By showing both graphs on the same plot, the length the arcing contact protrudes beyond the main contact can be determined.

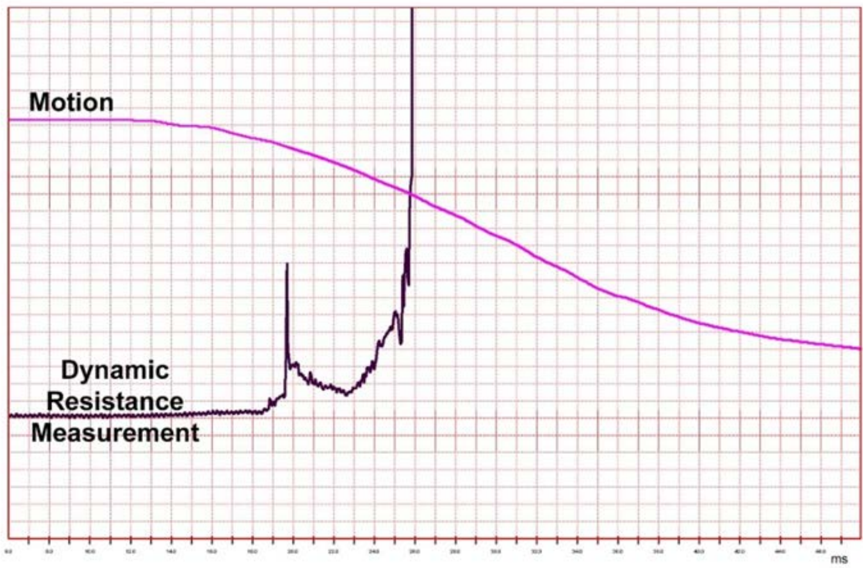


Figure 8-3(a). Dynamic Resistance Measurements

When the contact is closed, the resistance will be constant. See figure below.

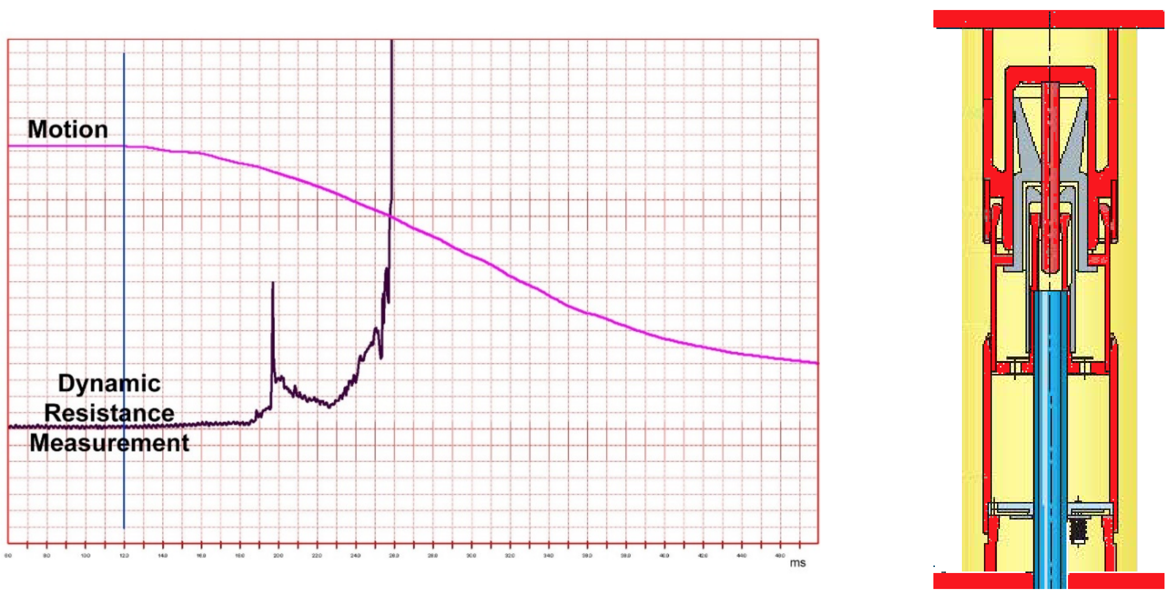
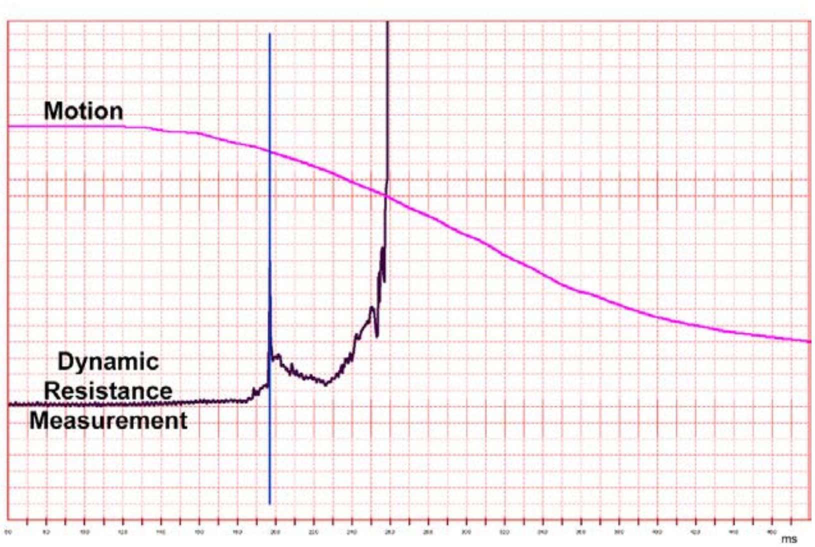


Figure 8-3(b). Dynamic resistance measurements

As the contact begins to move, there will be a slight increase in resistance. When the main contact opens, there will be a spike in resistance. See figure below.



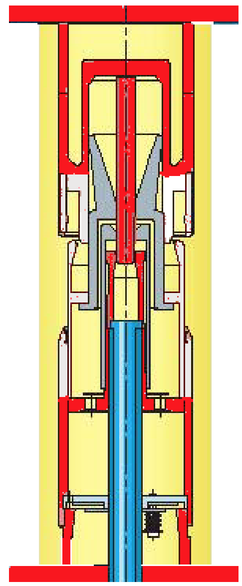
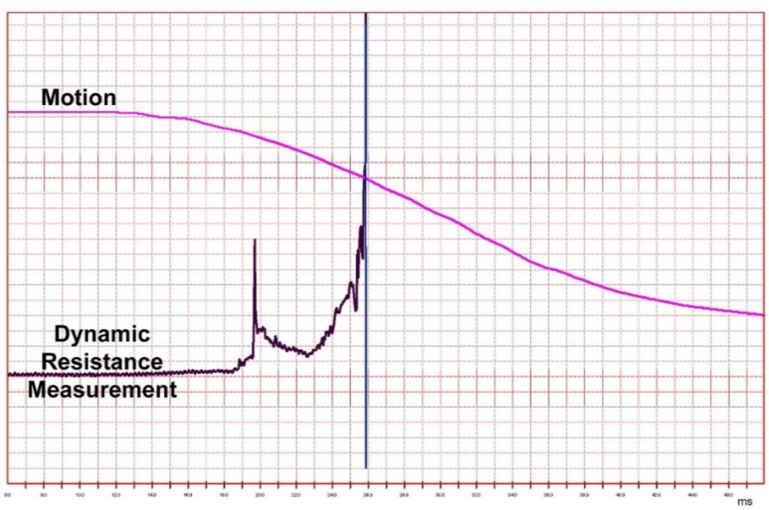


Figure 8-3(c). Dynamic resistance measurements

At this point, the resistance is through the arcing contact. As the contact continues to open, the resistance will be higher than previously recorded. Once the arcing contact opens, the resistance measurement will rise to infinity. See figure below.



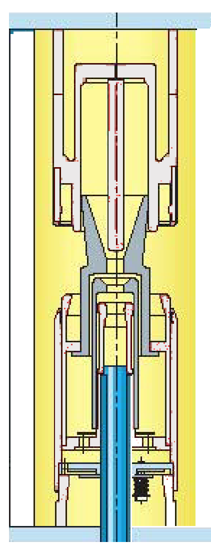


Figure 8-3(d). Dynamic resistance measurements

To determine the length of the arcing contact, the location measured where the main contact opens and where the arcing contact opens are compared to the motion analysis. See figure below.

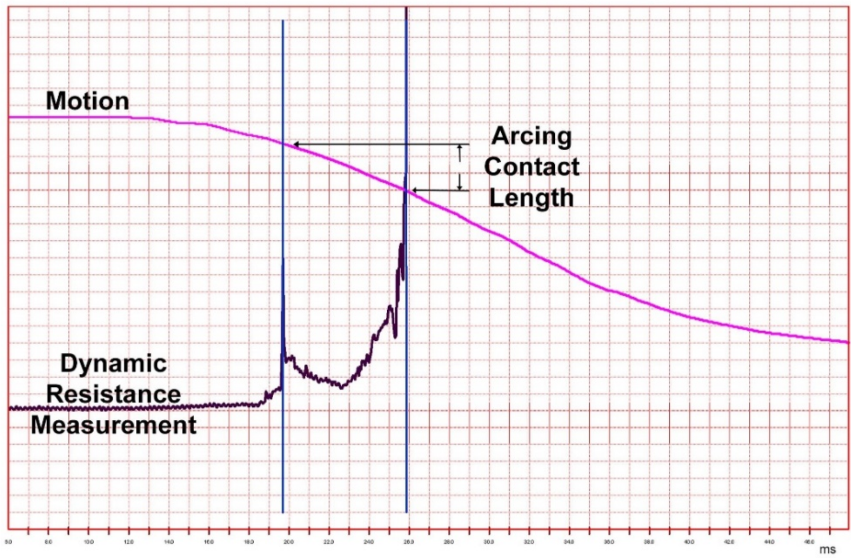


Figure 8-3(e). Dynamic resistance measurements

This test requires test equipment which can take a micro-ohm reading while the breaker is in motion and record the motion analysis at the same time. It is best to schedule this test when the timing and motion analysis tests are being performed.

8.3.3 Radiography Inspection

Radiography inspections allow for the inspection of internal parts of a GCB without opening the breaker. Radiography can use an X-ray device, but mostly it will use Ir192 or Co60 to expose a reusable film. The film is then scanned and the image is inspected and analyzed to manufacturer's specifications. The whole process can take just a few hours or less on a single breaker, depending on the size. When compared to opening a breaker for an inspection, this process can save days of work as well as avoiding all the other problems associated with opening a GCB.

An image produced by radiography is very similar to an X-ray of the human body, except it shows the internal components of the breaker.

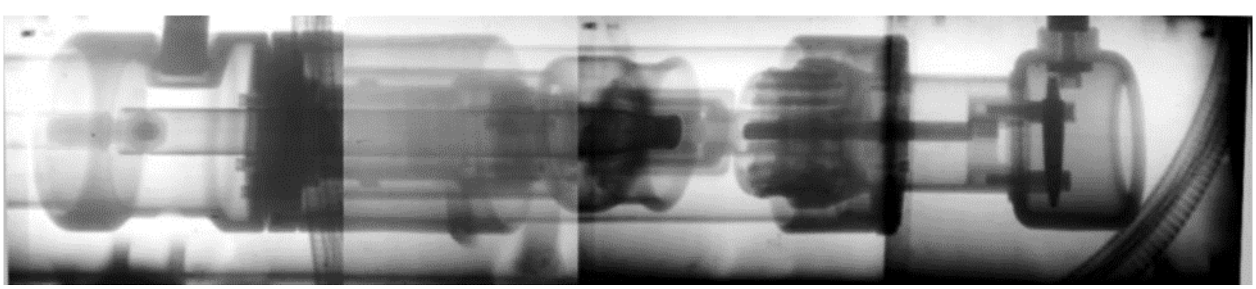
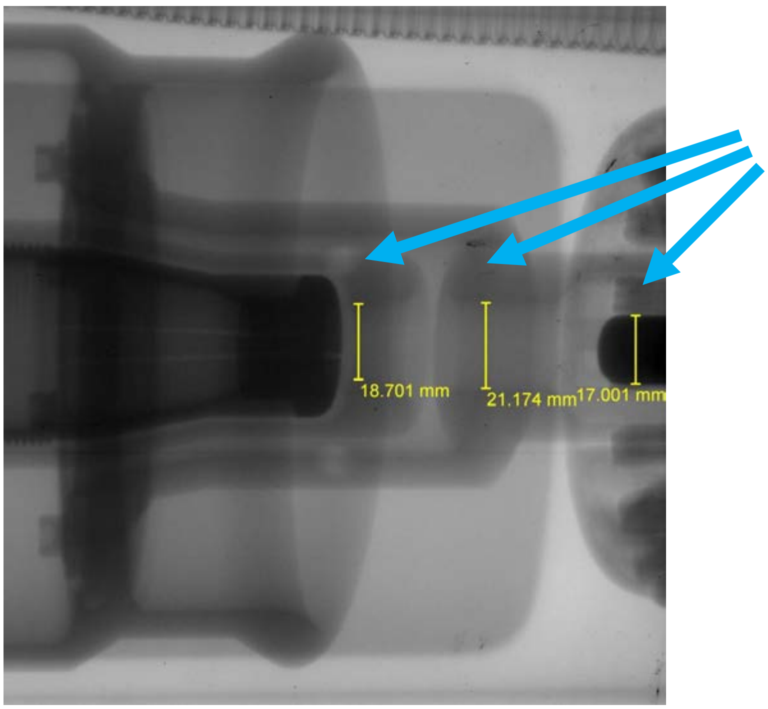


Figure 8-4. Radiographic image of a circuit breaker

This picture is actually a number of shots, digitally combined to form one complete unit. Using the images, a detailed evaluation of the breaker's internal components can be made which will avoid the need for an internal inspection on the GCB.

Radiography inspections can be performed on breakers of almost any material, including aluminum, ceramic, or steel. Radiography imaging is typically focused on the arcing contacts, contact fingers, Teflon nozzle, and in some circuit breakers, a complete picture of the inside of the entire breaker, as shown above, may be possible. Measurements are taken of internal components to verify they meet manufacturer's specifications. In this picture, the diameters of the internal components are measured and compared to manufacturer's specifications. The inspection can identify damaged, missing, or loose parts.



Critical measurements of the arcing contact and the nozzle compared to manufacturer's specifications.

Figure 8-5. Radiographic image of a circuit breaker (closer view)

Radiography will not show any wear that may be on the silver plating of the contacts, any bolts that may be out of torque, or condition of the breaker seals.

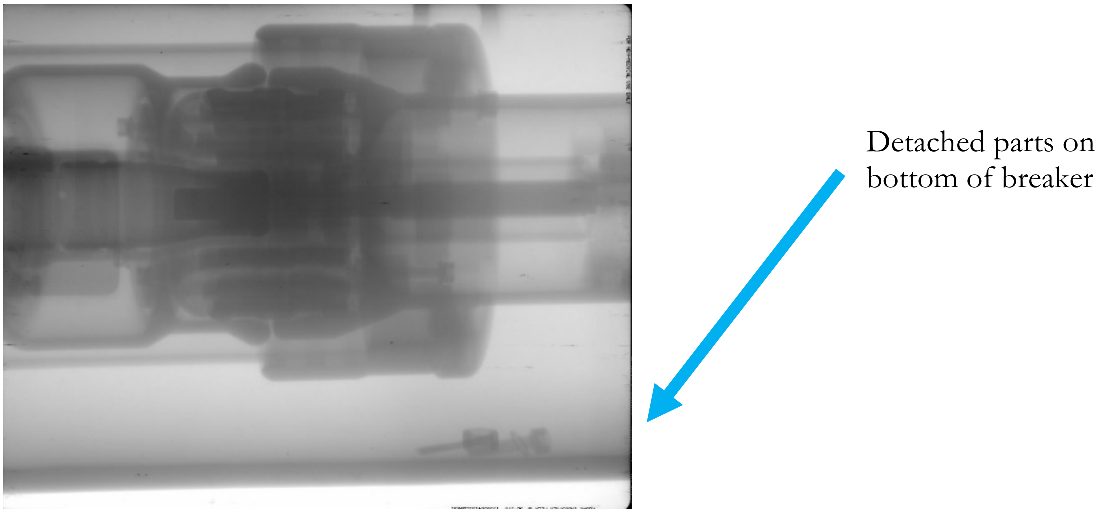


Figure 8-5. Detached parts seen in the radiographic image

This type of inspection is best used as a periodic 12 year inspection or when another test is indicating a problem may exist inside the breaker that must be investigated.

8.4 Condition Based Maintenance

To implement a condition based maintenance program for GCB, perform the normal periodic maintenance. On a periodic basis, the following diagnostic tests shall be performed which will help to evaluate the condition of the breaker:

- Breaker timing
- Motion analysis
- Contact resistance measurement
- Dynamic resistance measurement (DRM)
- SF_6 gas analysis
- Radiography inspection

Breaker timing, motion analysis, and contact resistance were discussed in Section 1.3.

The DRM will show a measurement of the length of the arcing contact over time. It is important that this measurement be tracked over time and compared to the baseline. The results of the DRM can assist in reviewing the timing and motion analysis results in certain circumstances. The results of this test will assist in making a decision to perform an internal inspection. The Radiographic Inspection will assist in making a decision whether an internal inspection or overhaul of the internal components is required. The SF_6 gas analysis can help determine the condition of the breaker seals.

If the amount of contaminants within the breaker continue to be a problem or the breaker is leaking gas, it is a good sign that the seals need to be replaced.

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9.0 Safe Handling Procedures for SF_6 Gas

9.1 General

SF_6 gas was originally developed as a current interrupting medium in 1938, and the first industrial use of SF_6 as a current interrupting agent was in 1953. In 1956, the first high voltage circuit breaker using SF_6 was released. SF_6 circuit breakers have since become the breaker of choice. Reclamation facilities have more than 1,000 power circuit breakers; the most modern of them use SF_6 gas as an arc-interrupting and insulating agent.

SF_6 gas in its pure state is relatively non-toxic. However, when exposed to extreme heat, SF_6 gas can produce many hazardous by-products which can cause severe injuries. These injuries can become more severe with prolonged exposure. Due to the properties of SF_6 gas and its decomposition products, it is highly recommended that work requiring the breakdown and overhaul of SF_6 breakers be performed by staff well trained and experienced in working with faulted SF_6 gas.

Arcing which occurs during a trip function of SF_6 breakers will produce the heat necessary to create hazardous by-products. Other forms of heat such as smoking, welding, space heaters, open flames, or any other high-temperature heat source may also create hazardous SF_6 by-products.

Note: Smoking, welding, space heaters, open flames, or any other high-temperature heat sources are prohibited when working on equipment where there is a possibility that SF_6 gas may be present.

SF_6 by-products are numerous and are created from a mixture of SF_6 gas, heat, and moisture. To limit most of these by-products, it is important to limit the amount of moisture within the breaker. Many of the gases are very unstable and will recombine back to SF_6 gas when the heat is removed. The most stable gases which can be present are sulfur dioxide (SO_2) and thionyl fluoride (SOF_2). Solids, known as metal fluorides, may also form. These solids may include aluminum fluoride (AlF_3) and copper fluoride (CuF_2). Solids may appear as a white, tan or grey powder, depending on the makeup of the components. They may be extremely fine and may not always be visible, especially when airborne.

SF_6 gas has a vapor density five times that of air. Even though SF_6 gas can be inhaled in its pure state, it will displace oxygen. This may create an engulfment hazard if it accumulates in enough quantity as within a confined space. Therefore, where SF_6 may be present, confined-space entry protocols must be observed. This involves verifying that enough breathable air is present.

SF_6 gas is the most potent greenhouse gas known. It is 24,000 times more effective at trapping infrared radiation over a 100-year period than carbon dioxide (CO_2) and is stable in the atmosphere for 3,200 years. CO_2 is stable for 90 years. Venting one pound of SF_6 gas, which is equivalent to opening a cylinder of SF_6 gas for 10 seconds, has the same environmental impact as more than 11 tons of CO_2. Eleven tons of CO_2 is equivalent to two cars left in idle for one year. Due to the environmental impacts of SF_6 gas, Reclamation has instituted a policy (FAC 04-13) to track and report SF_6 inventory. This policy may be found on the Bureau of Reclamation web site http://www.usbr.gov/recman/fac/fac04-13.pdf.

Note: Do not manually vent SF_6 gas to atmosphere. Venting SF_6 gas to atmosphere will only be acceptable in those cases where there is no other option due to the style or age of the breaker. Style and age of test equipment is not an acceptable reason to vent SF_6 gas. It is understood that during testing, there may be a small amount released. Any release of SF_6 gas must be kept to a minimum.

9.1.1 Definitions

Faulted Gas – Unfiltered SF_6 gas which has been in electrical equipment, or exposed to an electric arc, corona, or extreme heating at 250°C (480°F) or above.

Non-faulted Gas – SF_6 gas which has not been in electrical equipment or exposed to extreme heating, an electric arc, or corona. This can include SF_6 gas which has been filtered so that contaminants no longer exist.

9.1.2 Training

[SF_6 awareness training must be provided for those that will be performing work on gas insulated circuit breakers where there is a chance that SF_6 gas may be released.]

SF_6 awareness training may be performed by a qualified person who has been trained to understand the potential hazards and handling of SF_6 gas. The qualified person must also understand the requirements of Section 9 of this FIST, Safe Handling Procedures for SF_6 Gas. The training will contain information that is relevant to the work being performed.

9.1.3 Storage

SF_6 gas is supplied in pressurized cylinders, which like any gas cylinder, is capable of being damaged or ruptured by careless handling. Cylinders should never be left standing without being secured. Cylinders should be stored in a well-ventilated location.

9.1.4 Transportation

Department of Transportation (DOT) regulations consider SF_6 gas as a class 2.2, non-poisonous, non-flammable, compressed gas. DOT regulations require that any storage container with a pressure 29 Pounds per Square Inch Gauge (PSIG) at 68°F and greater must be transported in approved high pressure cylinders.
A Safety Data Sheet (SDS) and a shipping manifest is required when transporting SF_6 gas in an approved container that weighs more than 220 pounds (lbs.), and/or a combined cylinder weight greater than 440 lbs. The total shipment weight cannot exceed 1,001 lbs.

When shipping SF_6 gas with a combined cylinder weight greater than 1,001 lbs, along with the MSDS and a shipping manifest, class 2.2 placarding is required on all sides of the vehicle and the driver must have a HazMat endorsed license.

9.1.5 Personal Protective Equipment

Taking appropriate protective measures means wearing and using proper personal protective equipment (PPE). Appropriate PPE shall be used when working with SF_6 gas. This PPE is not only designed to protect the worker, but also designed to prevent the worker from taking the hazardous materials off the job site and affecting others. PPE will vary dependent upon whether working with faulted or non-faulted SF_6 gas.

9.2 Faulted SF_6 gas

[When working with faulted SF_6 gas, it must be assumed that SF_6 by-products exist. The following PPE must be used when working with faulted SF_6 gas:

- **Hooded disposable coveralls such as polylaminated Tyvek.**
- **Disposable neoprene or chlorinated polyethylene (CPE) gloves (must be securely taped to the coveralls to prevent entry of by-products between glove and hand).**
- **Disposable rubber boots.**
- **Full-face respirator or a half-face respirator with chemical safety goggles. The respirators shall have twin HEPA cartridges for organic vapors and acid gases. For work performed within a confined space, supplied air-line full face pressure demand respirator NIOSH/MESA approval TC-19C-93 with clean, oil-free dry air supply or a self-contained breathing apparatus (SCBA). OSHA regulations require that personnel wearing respiratory protective equipment are trained in its use, medically qualified, and mask fit tested.]**

9.3 Non-Faulted SF_6 Gas

When working with non-faulted SF_6 gas, direct contact with liquid SF_6 may cause severe tissue burns and there is also an engulfment hazard. **[The following PPE must be used when working with non-faulted SF_6 gas within a confined space: supplied air-line full face pressure demand respirator NIOSH/MESA approval TC-19C-93 with clean, oil-free dry air supply or a SCBA. OSHA regulations require that personnel wearing respiratory protective equipment are trained in its use, medically qualified, and mask fit tested.]**

9.4 Required Equipment

9.4.1 Eye Wash Station

[A portable eye wash station is required near the work site while working near faulted SF_6 gas.]

9.4.2 Vacuum Cleaner

An industrial wet or dry vacuum cleaner using a dust class H rated High Efficiency Particulate Air (HEPA) single use filter and disposable bags.

9.4.3 Multi-gas Meter

A calibrated multi-gas meter which will sense levels of oxygen, carbon monoxide, hydrogen sulfide, and flammable gas limits.

9.4.4 SF_6 Gas Detector

A calibrated meter which will sense SF_6 gas will help determine if SF_6 gas is still present prior to entry of the gas compartment.

9.4.5 Gas Cart

Gas carts are designed and constructed to safely handle and process SF_6 gas. To further enhance the safe handling and processing of SF_6 gas and prevent the cart from getting contaminated with faulted gas, the carts will be equipped with a pre-scrubber, Teflon-lined hose, and approved high-pressure fittings.

[Gas carts shall be properly maintained and operated according to manufacturer's recommendations. PPE for non-faulted SF_6 gas must be worn during the operation of gas carts. Ear protection is required if sound levels exceed 85 dB.]

9.5 Pulling Samples of SF_6 Gas for Testing

9.5.1 SF_6 Gas Testing

The SF_6 gas analysis may be performed using an SF_6 gas analyzer, or by using a lab which will require a sample of the gas be pulled and sent to the lab. Prior to drawing gas, make sure all hoses and connector surfaces are clean and dry. It is best to draw SF_6 gas on a warm dry day. Moisture within the breaker can condense or freeze and give an inaccurate moisture reading. The ambient temperature when the sample was taken should always be recorded. This may help clarify specific changes in the gas analysis from sample to sample.

[Do not manually vent SF_6 gas to atmosphere. Venting SF_6 gas to atmosphere will only be acceptable in those cases where there is no other option due to the style or age of the breaker. Style and age of test equipment is not an acceptable reason to vent SF_6 gas. It is understood that during testing there may be a small amount released. Any release of SF_6 gas must be kept to a minimum.]

[SF_6 Gas shall never be removed from a gas insulated circuit breaker while the circuit breaker is energized.]

9.6 Removal of SF_6 Gas from Equipment Gas Compartment to Access Internal Components

9.6.1 Remove Gas

[Do not manually vent SF_6 gas to atmosphere. Venting SF_6 gas to atmosphere will only be acceptable in those cases where there is no other option due to the style or age of the breaker. Style and age of test equipment is not an acceptable reason to vent SF_6 gas. It is understood that during testing, there may be a small amount released. Any release of SF_6 gas must be kept to a minimum.]

Use a gas cart to remove SF_6 gas from equipment down to a final vacuum of less than 0.29 psi (2 kPa) or that required by the breaker manufacturer's O&M manual. This will minimize the amount of SF_6 gas released into the atmosphere. Filter the used gas using the gas cart filtration system or an inline scrubber. Make sure air is not drawn into the gas cart during this procedure. **[If removing SF_6 gas from within a confined space, PPE for faulted SF_6 gas must be worn. Ear protection is required if sound levels exceed 85 dB.]**

9.6.2 Add Dry Air

Slowly backfill the breaker SF_6 compartment with dry air or dry nitrogen so that it does not agitate SF_6 by-products. Avoid damp or wet air or nitrogen as it can endanger the integrity of insulating materials, and prolong dry out and reconditioning time.

9.6.3 Open Equipment Gas Compartment

After SF_6 electrical apparatus has been in service, it should be assumed that hazardous by-products will be present. After evacuation of the SF_6 gas and the gas compartment has reached atmospheric pressure, the gas compartment can be disassembled and opened according to the breaker manufacturer's O&M manual. **[PPE for faulted gas must be worn when opening a SF_6 gas insulated breaker.]**

9.6.4 Remove contaminated powder

Use an approved vacuum cleaner to remove contaminated powder within the equipment gas compartment. Be gentle when using a vacuum cleaner so the powder does not become airborne. The vacuum cleaner must meet the requirements described in Section 9.4.2. **[PPE for faulted gas must be worn while vacuuming the interior gas compartment. The vacuum cleaner must meet the requirements discussed above.]**

Note: The powder by-products may not always be visible within the equipment gas compartment. Always assume that the powder exists and take appropriate precautions.

Remove the desiccant bag located inside the equipment gas compartment. This bag must be considered hazardous waste and disposed of according to Section 9.7, below. Wipe any remaining residue with clean, lint free, dry rags. Only use solvents recommended by the manufacturer's O&M manual. Denatured alcohol is one solvent that many recommend, but make sure that this meets the manufacturer's recommendations prior to use. There are some style breakers where the manufacturer requires a different solvent between metallic surfaces and insulators. Using the wrong type of solvent or water on the internal components of a breaker or its insulators may cause permanent damage.

9.6.5 Ventilate Equipment Gas Compartment

Ventilate equipment gas compartment thoroughly with dry air from a suitable source. Avoid ventilating with very damp or wet air as it can endanger the integrity of insulation materials, and prolong dry out and reconditioning time.

Always assume that there will be dangerous by-products present when performing this work. **[PPE for faulted gas must be worn while setting up for the venting process.] [A barrier shall be placed during the venting process to keep personnel from entering the area.] [Smoking, welding, and the use of open flames or high-temperature heat sources are prohibited in this area.]** Be sure to include wind direction in placing the safety barrier.

Allow venting to continue for a time period sufficient to ensure a minimum of 10 complete air changes before working on the equipment (at least ½ hour). If it is not possible to evacuate the SF_6 from the apparatus prior to venting a minimum of 100 air changes shall be employed (at least 5 hours).

9.6.6 Test Air Supply

Once venting has been completed, test the air inside equipment gas compartment with a calibrated multi-gas meter. Verify minimum 19.5% oxygen with no combustible gases or carbon monoxide. After it has been determined that the air supply is normal, use the SF_6 gas detector to test for residual SF_6 gas. Residual SF_6 gas may still contain hazardous gases which must be removed before entry can be made. If SF_6 gas is detected continue venting compartment until the SF_6 gas detector shows no trace of SF_6 gas. **[PPE for faulted gas must be worn while testing the internal air supply.]**

9.7 Disposal of SF_6 By-Products

All SF_6 by-products and contaminated material shall be considered hazardous waste and disposed of according to local regulations. **[While handling SF_6 by-product waste, PPE for faulted gas must be worn.]** Materials contaminated with SF_6 gas by-products shall include but is not limited to:

- Desiccant bags
- Vacuum cleaner bags and contents
- Vacuum filter elements
- Cleaning rags
- Plastic bags used to hold the contaminated material
- Disposable protective equipment worn while work was being performed

- Other disposable equipment contaminated during the cleanup of SF_6 by-products

- An alternative method is to place all waste material in a plastic or metal container and pour a neutralizing solution over the contents. The neutralizing solution should be a mixture of water and soda ash mixed at a ratio of 10 gallons water to 1 lb of soda ash. Completely submerge all waste material into the solution and agitate contents. Corrosive or toxic fumes may be created from a reaction with the neutralizing solution so this work must be performed outdoors. The solution may also bubble for a while until all products have been sufficiently neutralized. Let the waste material stand for approximately one hour and test the pH of the solution to ensure the contents have completely neutralized. Once all materials have been neutralized, the solution and waste materials are no longer considered hazardous and may be disposed of according to local regulations.

- All non-disposable hand tools, protective gear, and equipment used in the clean-up of the gas compartment shall be cleaned with a neutralizing solution. Rinse with clean water. All rags used to clean the non-disposable equipment shall be considered hazardous waste and disposed of as recommended above. The neutralizing solution should be a mixture of water and soda ash mixed at a ratio of 10 gallons water to 1 lb of soda ash.

9.8 Filling & topping off breaker with SF_6 Gas

If topping off the breaker with SF_6 gas, see Section 9.8.3 below. **[SF_6 gas shall not be added to a gas insulated circuit breaker while the circuit breaker is energized.]**

9.8.1 Seal Equipment Gas Compartment

Moisture is one of the most prevalent contaminants within SF_6 gas, and it is also a primary ingredient in SF_6 by-products. To help keep moisture levels low, it is important that the equipment gas compartment contains a new bag of desiccant. If the equipment manufacturer's O&M manual does not require a desiccant bag, then this step may be ignored. The desiccant shall meet the requirements of the breaker's O&M manual. Reassemble and seal equipment's gas compartment according to the breaker manufacturer's O&M manual.

9.8.2 Evacuate Air

Evacuate air from the SF_6 gas compartment. Draw a vacuum meeting the manufacturer's recommended vacuum pressure and hold that pressure for the recommended duration. Due to the equipment gas compartment being under a vacuum, the moisture left in the container will become a gas and will be absorbed by the desiccant.

9.8.3 Fill Equipment SF_6 Gas Compartment

It is very important to refill the equipment with clean, dry SF_6 gas. The more impurities that are in the SF_6 gas, the more hazardous by-products will be created. **[Test the SF_6 gas prior to filling the breaker. The gas must meet the recommended levels of impurities as shown in Table 9.1 for reclaimed SF_6 gas or Table 9.2 for new gas.]** **[SF_6 gas shall not be added to a gas insulated circuit breaker while the circuit breaker is energized.]**

Table 9-1. Limits of impurities for reclaimed SF_6 gas

Impurities	Recommended Limit *
SF_6 Purity	99% Vol. (Lower Limit)
Moisture	50 PPM_V (Upper Limit)
Total reactive gaseous decomposition products (SO_2/SOF_2)	0 PPM_V (Upper Limit)
Mineral oil **	0 PPM_V (Upper Limit)

* This data is based on IEC and IEEE standards. Reference the equipment Operation and Maintenance Manuals for manufacturer specific requirements.
** Necessary only if SF_6 handling equipment uses oil in its pumps and/or compressors.

Table 9-2. Limits of impurities for new SF6 gas

Impurities	Recommended Limit *
SF_6 Purity	99.8% Vol. (Lower Limit)
Moisture	8 PPM_V (Upper Limit)
Total reactive gaseous decomposition products (SO_2/SOF_2)	0 PPM_V (Upper Limit)
Mineral oil **	0 PPM_V (Upper Limit)

* This data is based on IEC and IEEE standards. Reference the equipment Operation and Maintenance Manuals for manufacturer specific requirements.
** Necessary only if SF_6 handling equipment uses oil in its pumps and/or compressors.

Fill and pressurize the equipment SF_6 gas compartment with dry SF_6 gas to the rated pressure as required by the equipment's O&M manual. Ensure that the gas compartment is not over-pressurized. If the pressure becomes too high, it may blow the rupture disc of the breaker or damage the equipment seals and vent SF_6 gas into the atmosphere.

If the breaker is being refilled in a moist environment, to ensure that moisture is removed from the gas compartment, gas scavenging may be used to remove as much moisture from inside the gas compartment as possible. In gas scavenging, after the gas compartment has sat under vacuum as described above, it will be filled with an extremely dry gas to atmospheric pressure. The gas can be dry air or nitrogen. The gas is left in the gas compartment for a period of time to allow it to absorb any remaining moisture. The equipment gas container is then evacuated back to a vacuum as before, then refilled with dry SF_6 gas and pressurized to the rated pressure.

9.9 Catastrophic Failure Procedures

A condition where a pressure relief device of an SF_6 breaker opens due to a high current fault or worse yet, but extremely rare, is a complete catastrophic failure. Gas-insulated generator circuit breakers may be located within a power plant. In the event of a gas release or a catastrophic failure of one of these circuit breakers, much of the gas and by-products will be released into the atmosphere of the facility. Even for an outdoor breaker, SF_6 gas and the SF_6 by-products will be released into the air. Specific cautionary procedures must be followed to help keep personnel in the area safe.

9.9.1 Evacuate Area

Upon the release of SF_6 gas due to a failure of a pressure relief device or a catastrophic failure, all employees within the facility must evacuate according to that facilities evacuation policies. All personnel must be kept from reentering the facility until it has been confirmed safe to do so or 30 minutes after the incident.

9.9.2 Determine Condition of Site

After this type of an event, SF_6 gas and faulted SF_6 decomposition gases and powders are released. The decomposition gases will dissipate rather quickly. However, the breaker and the surrounding area may contain decomposition powders. Extreme care must be taken to prevent the decomposition powders from becoming airborne. To enter the area, PPE for faulted SF_6 gas must be worn.

SF_6 will displace oxygen and create an asphyxiation hazard. Due to the size of most in-door gas insulated circuit breakers; the potential for asphyxiation is low. However, the air must be checked with a multi-gas meter in all areas where SF_6 gas can accumulate. Small, enclosed areas would be the most susceptible for this type of hazard. For outdoor equipment, the quantity of SF_6 gas can be greater, but the potential for SF_6 gas to accumulate in an area that can reach a hazardous level is remote. However, there is a possibility that some nearby confined spaces may be affected. A multi-gas meter must be used to verify the air quality when entering all areas where SF_6 gas can accumulate. All readings must be normal prior to entry.

9.9.3 Attend to Affected Area

The SF_6 decomposition powders will have settled on the breaker, floor, and all nearby equipment. All contaminated areas must be thoroughly vacuumed and washed with a neutralizing solution (mixed 10 gallons water to 1 lb soda ash). If the area of the failure is outdoors over soil, rinse the ground with the same solution. Once the entire area has been washed with the neutralizing solution, rinse the area and all equipment with water. Dispose of all materials used in the cleanup per the requirements in Section 9.7.

9.10 Treating Exposure to SF_6 Gas and its By-Products

Exposure to faulted SF_6 gas and its by-products can lead to severe health problems and must be treated as soon as possible. Prolonged exposure may cause permanent damage to affected organs. Seek medical attention as soon as possible when exposed to SF_6 gas by-products.

9.10.1 Asphyxiation Due to Lack of Oxygen

SF_6 gas, being much denser than air, will accumulate in enclosed or low lying areas. Since SF_6 gas will displace oxygen in those areas, a worker may become asphyxiated by a lack of oxygen. The worker must be treated for oxygen deprivation and seek immediate medical attention.

9.10.2 Contact with Skin

Contact with faulted SF_6 by-products may not be immediately noticed. The by-products may not always be visible, and the symptoms may not be present right away. If skin comes into contact with SF_6 by-products, the location of contact can experience redness, irritation, swelling, and pain. If signs of exposure to the skin are found, remove exposed personnel from the area and remove any contaminated clothing. Flush irritated skin with cool running water and seek medical attention.

9.10.3 Contact with Eyes

SF_6 by-products are all very acidic. They act very quickly with the moisture in the eyes. Some of the symptoms that may be experienced include irritation, redness, blurred vision, and stinging pain. If SF_6 by-products come into contact with the eyes, flush with cool running water for 15 minutes, cover eyes with sterile bandages, and seek medical attention immediately.

9.10.4 Inhalation

SF_6 by-products produce a very strong odor of rotten eggs. If inhaled, the moisture in the lungs absorbs the SF_6 by-products producing an acid which can irritate or damage lung tissue. If the exposure to these by-products is short, the damage to the respiratory system may not be permanent. However, in the case of prolonged exposure, permanent respiratory damage may occur. Symptoms of SF_6 gas by-product inhalation can include chest tightness, shortness of breath, a dry or burning throat, and possibly loss of consciousness.

Treat inhalation by first moving the victim away from the contaminated area, remove any contaminated clothing, and immediately seek medical attention.

9.11 Gas Carts

Gas carts are used to help store, refill, and recover SF_6 gas from SF_6 gas circuit breakers and other SF_6 equipment. SF_6 gas carts are also used to clean and filter SF_6 gas for reuse after maintenance has been performed. By using SF_6 gas carts, it allows for the recovery and refill of SF_6 gas from equipment and limits the amount of SF_6 gas lost to atmosphere to a negligible amount.

Gas carts mainly consist of filters, compressors, vacuum pumps, piping, and hoses. Most of this equipment on a gas cart can go long periods of time before requiring maintenance. Those items that require the most amount of maintenance are the filters, compressors, and vacuum pumps.

When removing SF_6 gas from a breaker, the SF_6 gas will be drawn through either one or two filters within a gas cart. Those filters will eventually become saturated and will need to be changed. Some gas carts have gauges which will help determine when filters need to be changed. Another method is by the quality of the SF_6 gas. If the SF_6 gas quality won't improve with filtering, then it is time to change the filters. Refer to the gas cart's operation and maintenance manuals for specific information on when these filters must be changed. **[At a minimum, the filters must be changed when the quality of the SF_6 gas does not improve when filtered.]**

Most compressors in gas carts are oil-less, so these devices can go long periods of time without maintenance, even when the cart has regular operation. The maintenance required really depends on the model of the gas cart. At the very least, functional test the compressors prior to use of the gas cart. This may be accomplished when performing an evacuation function of the gas cart system before use.

Oil within SF_6 gas can be very destructive to a gas analyzer and will plug desiccant bags within a breaker and cause moisture to accumulate within the breaker. Some of the older gas carts have compressors that use oil as their lubrication. If the gas cart owned is of a type that uses oil as a lube, it would be strongly advised to have an oil filter as part of the gas filtering system. To further reduce the chance of oil being transmitted into the gas, it is important to keep the oil and compressor in good condition. **[The vacuum pump oil must be changed annually or prior to use if it hasn't operated during that time.]**

While the gas cart sits, moisture, dust, and other contaminants can accumulate within the gas cart. **[Run an evacuation function of the gas cart for 15 minutes before using the gas cart if it hasn't been operated in more than a month.]**

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Bureau of Reclamation

RECLAMATION
Managing Water in the West

RECLAMATION MANUAL TRANSMITTAL SHEET

Effective Date: **06/05/2020** Release No. **FIST 015**

Ensure all employees needing this information are provided a copy of this release.

Reclamation Manual Release Number and Subject

FIST 3-16, Maintenance of Power Circuit Breakers

Summary of Changes

The major revision of Reclamation Manual Release, FIST 3-16, Maintenance of Power Circuit Breakers replaces the previous manual that was released in January 1992. Also, as a result of the release of this FIST 3-16, the following documents will retire.
1) FIST 5-10 Voltage Hazard Associated with the use of Circuit breakers having grading capacitor
2) PEB 45 Periodic testing and preventive maintenance of critical AC/DC Molded case circuit breaker
3) PEB 47 Air, Air Blast and Oil Circuit breaker Preventive Maintenance
4) PEB 55 Appendix 7, 8, and 9.
5) PEB 25 Circuit Breaker Remote Rack-In Device
This release provides sound engineering guidance to ensure the proper maintenance of Power Circuit Breakers that have evolved in design, operation, safety, and technology over the last three decades.

NOTE: This Reclamation Manual release applies to all Reclamation employees. When an exclusive bargaining unit exists, changes to this release may be subject to the provisions of collective bargaining agreements.

Filing instructions

Remove Sheets	Insert Sheets
FIST 3-16 pp 1-143	**FIST 3-16 1-99**

All Reclamation Manual releases are available at http://www.usbr.gov/recman/

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