Technical Paper

A Systematic Approach to High-Voltage Circuit Breaker Testing

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Content

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1 Abstract

Understanding diagnostic testing of HV Circuit Breakers is essential. When diagnostic tests are performed on HV Circuit Breakers, valuable information can be extracted. From a technical maintenance perspective, these diagnostic tests provide critical information about the condition of the HV Circuit Breakers.

Standard field tests widely applied today in HV Circuit Breaker diagnostics include:

- Timing and Travel
- Power Factor
- Contact Resistance (Static and Dynamic)
- Minimum Pick-Up

These specific diagnostic tests have been selected as the primary focus for this paper and discussion.

This easy-to-follow paper and presentation focuses on how diagnostic techniques can be applied to HV circuit breakers as part of the standard condition assessment protocol. The audience will be provided with an understanding, application, and analysis of these tests, supported by case studies validating the value that these diagnostic tests bring to HV circuit breaker testing.

2 Introduction

Circuit breaker technology varies depending on the application. Also, the preferred technology is dependent on the geographical region in which it is applied. Case in point, Dead Tank SF6 Filled Circuit Breakers and Bulk Oil Circuit Breakers are primarily used in North America in HV applications, while the rest of the world prefers Live Tank Circuit Breaker technology.

Overall, circuit breakers, regardless of type and technology, are designed with the following three functions in mind:

- Direct current flow between desired sections of an electric power system
- Interrupt current flow under abnormal power system events and conditions, such as faults
- Carry load current under normal power system conditions with minimal losses

These three functions must be performed under both normal and abnormal (fault) conditions, and must perform under strict performance specifications.

Circuit breakers vary by subsystems:

- Insulation System
- Arc Quenching Method
- Mechanism
- Contact Technology
- Control Circuit Schemes
- CT's

These subsystems above need to be analyzed both separately and as a complete electro-mechanical system. Table 1, shown below, lists several different properties related to circuit breakers.

Table 1 – Circuit Breaker Classifications

BREAKER TYPES	MECHANISM TYPES
Bulk Oil Circuit Breaker (OCB)	Mechanical (Spring)
Dead Tank SF6 Breaker	Hydraulic
Live Tank Air Blast	Pneumatic
Live Tank SF6	Magnetic Actuator
Vacuum Breakers	
Air Magnetic	**INSULATION SYSTEMS**
Low Voltage Air Blast	Oil
Reclosers	SF6
Circuit Switchers	Air
Sectionalizers	Vacuum

The two types of dead tank breakers, highlighted in RED in Table 1, will be the main focus of this paper.

Diagnostic testing can be performed in either an on-line/in-service state or an off-line/de-energized state. The manufacturer's recommendations, duty, number of operations, and past experience should be considered when justifying the test and maintenance requirements.

Table 2 and Table 3 list recommended and commonly practiced on-line/in-service and off-line/de-energized tests, respectively.

Table 2 – Online/In-Service Testing Methodologies

Visual Inspection	Inspect External Physical Condition, Structure, Grounding, Gauges, Annunciators, and On-line Monitoring Devices
SF6 Gas Analysis	SF6 Density, SF6 Moisture, and SF6 Decomposition
SF6 and Air Leak Detection	Laser Imaging, Thermal Conductivity, Acoustic Emissions
Infrared (IR)	Thermal Imaging; Temperature Differential
Acoustic Emissions	Partial Discharge, Particles, Mechanical Defects
First Trip	Basic Operation and Timing, Control Circuit Performance, AC/DC Power Source Main contacts via Phase Currents, Lubrication
IED (Simple) Intelligent Electronic Device	First Trip, Basic Operation and Timing, Control Circuit Performance, AC/DC Power Source, Main Contacts via Phase Currents, Lubrication, Contact Wear (I^2t)
IED (Advanced) Intelligent Electronic Device	Acoustic Emissions (Partial Discharge, Particles, Mechanical Defects), Air and Gas Diagnostics (Density, Moisture, Pressure, Decomposition), Heaters, and Charging System (Air and Motors).

Table 3 – Offline/De-Energized Testing Methodologies

Visual Inspection	Inspect Internal and External Physical Condition, Structure, Grounding, Gauges, Annunciators, On-line Monitoring Devices
Contact Resistance	Static and Dynamic (DRM)
Insulation Integrity	Power Factor/Capacitance, Partial Discharge (PD), Insulation Resistance, Withstand (AC/DC High Pot), DGA & Oil Screen, and SF6 Quality
Timing	Control Circuit and Contacts, Verify TRIP, CLOSE, TRIP-FREE(Dwell-Time), and RECLOSE (Dead-Time)
Mechanism	Total Travel, Velocity, Over-Travel, Rebound, Contact Wipe, Stoke
Control Circuit	Minimum Pickup, Minimum Voltage, Insulation Resistance, Operation of Protective, and Alarm Devices
Instrument Transformers	CT Saturation, CT Polarity, CT Ratio, Burden, and Winding Resistance

3 Breaker Types

As indicated, this paper focuses on two circuit breaker types, Bulk Oil Circuit Breakers (OCB) and Dead Tank SF6 Circuit Breakers. These two types were selected because they are most popular in North America when used in HV applications. Both types are of the dead tank design. The OCBs are considered old technology, and have been steadily replaced by the newer Dead Tank SF6 Circuit Breakers. This change-over has been occurring for roughly 30 years. Figure 1 shows both circuit breaker types, coincidentally, side by side in the same substation.

Figure 1 - Bulk OCB vs. Dead Tank SF6

The following should be noted:

3.1 Bulk Oil Circuit Breakers (OCB)

> Bulk OCBs use a large volume of oil to extinguish the arc.
> Arcing occur in oil, which creates gases (hydrocarbons).
> Though the use of a vented interrupter chamber, gas bubbles create pressure that forces the arc to expand further into the vents, until it is able to extinguish itself at a zero crossing current.
> The interrupter chambers often attract moisture.
> Bulk OCBs often use condenser type bushings, resin or oil, that are equipped with tap electrodes. These bushings can be isolated and tested. These bushings often have CTs mounted on the lower ground sleeve.

3.2 Dead Tank SF6 Circuit Breakers

> Dead Tank SF6 Circuit Breakers can utilize three different methods for arc extinction. Each of these methods utilizes SF6 gas pressure to "blow-out" or extinguish the arc.

a. SF6 Puffer Circuit Breaker - Mechanical compression of the arcing chamber generates SF6 gas pressure.
b. SF6 Self-Extinguishing Circuit Breaker - Heat generated in the arcing chamber generates SF6 gas pressure.
c. SF6 Double (Dual) Pressure Circuit Breaker - Uses a pressurized SF6 gas chamber that is released in the arcing chamber during operation.

> Dead Tank SF6 Circuit Breakers are often equipped with SF6 gas-filled bushings that cannot be isolated for field testing. The bushings often have CTs mounted on the upper external ground sleeve near the mounting flange.

4 Timing and Travel

Circuit breaker timing and travel measurements entail three steps:

1. Perform a dynamic timing and travel measurement
2. Calculate performance characteristics
3. Compare results to the manufacturer's recommendations or user-defined limits

Table 4 provides the fundamentals tests and calculations involved in circuit breaker timing measurements and diagnostics.

Table 4 – Circuit Breaker Timing Fundamentals

CONTROL	MEASUREMENT	CALCULATIONS
Trip (O)	Displacement	Main Contact Timing
Close (C)	Contact State (O-R-C)	Resistor Switch Timing
ReClose (O-C)	Command Coil Current	Delta Timing (Pole Spread)
TripFree (C-O)	Auxiliary Contact State (OW-OD-C)	Velocity
(O-CO)	Battery Voltage	Total Travel
(O-CO-CO)	Phase Currents (First Trip)	Over Travel
Slow Close (C)	Dynamic Resistance (DRM)	Rebound
First Trip (O)		Stroke
		Contact Wipe
		Dwell Time (TripFree C-O)
		Dead Time (ReClose O-C)

Most breakers utilize a 125 VDC control circuit. However, 48 VDC, 250 VDC, 120 VAC, and 240 VAC control circuits are not uncommon. Table 5 lists typical control signal timing values used in performing timing and travel tests.

Table 5 – Typical Signal Timing Values

	Trip Coil	Close Coil	Delay
Trip (O)	66.6 ms (4 cycles)		
Close (C)		133.3 ms (8 cycles)	
ReClose (O-C)	66.6 ms (4 cycles)	Standing	> 300.0 ms
TripFree (C-O)	Standing	133.3 ms (8 cycles)	8.3 ms (1/2 cycles)

4.1 Measured Signal

When performing circuit breaker timing and travel measurements, there are five primary signals that are of interest.

1. Displacement
2. Contact State (Open-Resistor-Close)
3. Command Coil Current
4. Auxiliary Contact State (OW-OD-C)
5. Battery Voltage

It is worth noting that the main contacts can take on three different states, OPEN, CLOSE, and RESISTOR, because some breaker applications require Pre-Insertion Resistors (PIRs). When the breaker performs a CLOSE operation, a resistor will be placed across the open contacts for a few to several milliseconds in order to limit potential overvoltage associated with long transmission line applications. It is important to capture the operation; specifically, the timing of this resistor switch.

Also, depending on the use and availability of the auxiliary contacts, such as 52a and 52b, etc., these contacts may be wet (voltage present) or dry. The measurement must be configured for such conditions.

Not all of the above signals are always included; however, as signals are omitted, it limits the effectiveness of the analysis. Figure 2 and Figure 3 illustrate various signals associated with circuit breaker timing and travel measurements.

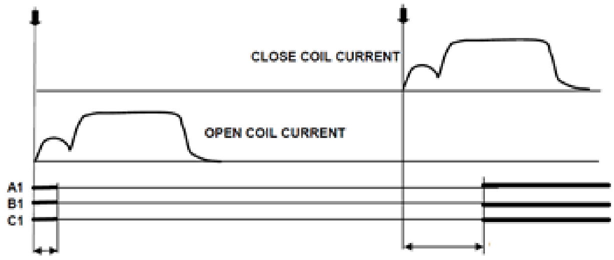


Figure 2 - Command Coil Currents and Main Contact State

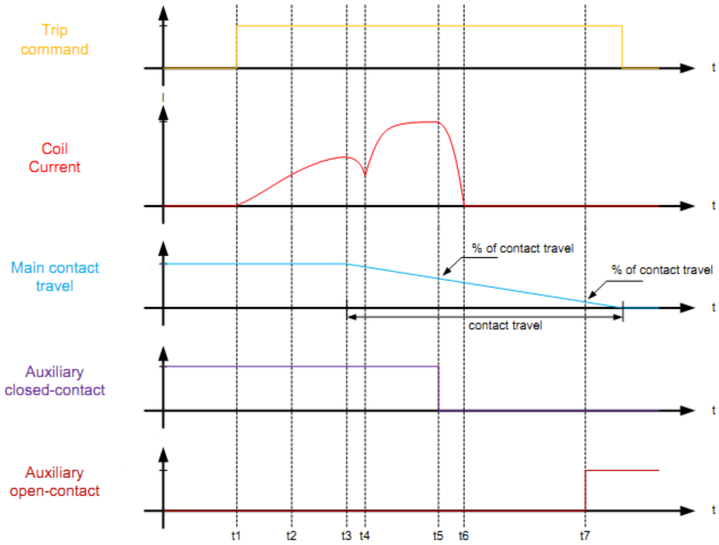
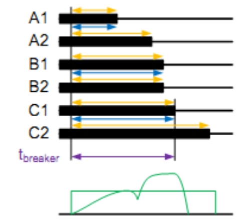
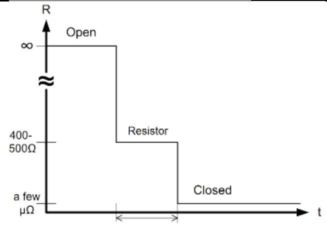
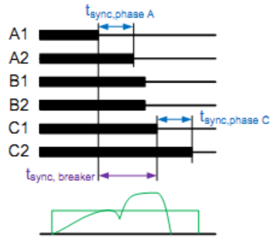
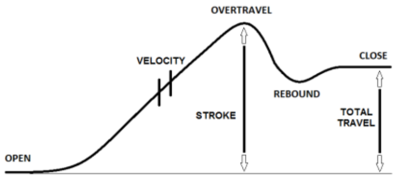
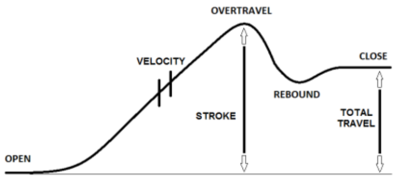
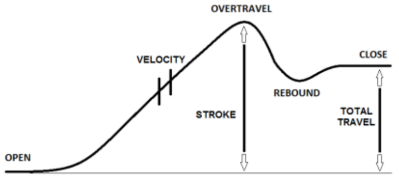
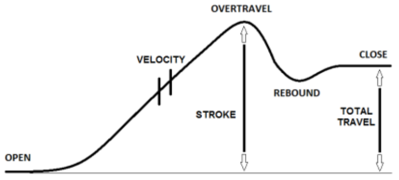


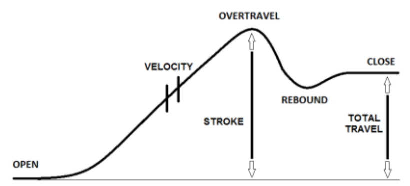
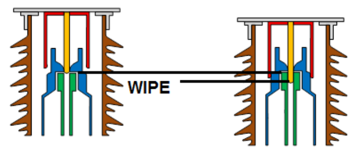
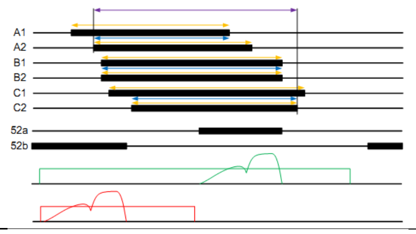
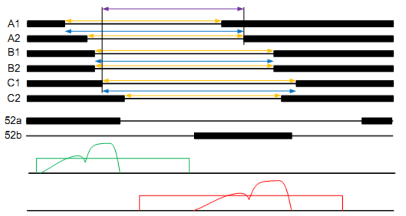
Figure 3 - Trip Operation Signals

4.2 Performance Characteristics

Table 6 lists all of the pertinent circuit breaker characteristics. There are 11 in all, including 5 related to timing, 5 related to displacement, and 1 for velocity.

Table 6 – Timing and Travel Performance Characteristics

Main Contact Timing	Time between test initiation (energization of command coil) and change of main contact state (make or break)	
Resistor Switch Timing	Time involving the resistor switch in the circuit.	
Delta Timing (Pole Spread)	The time duration between first contact to change state and the last contact to change state, within a breaker, within a phase, or within a module.	
Velocity (Average and Instantaneous)	Average Velocity is measured during referenced times, measured points in the displacement, or events (contact make or break). Time to Time, Time to Distance, Distance to Distance, Time to Contact Make/Break, and Distance to Contact Make/Break are examples of some combinations. Instantaneous Velocity is the measured velocity at a signal point. This can be defined as a specific time, distance, or when a contact makes or a contact breaks.	
Total Travel	The distance traveled by the contacts from the initial starting position to the final resting position	
Over Travel	The distance traveled by the contacts that exceeds the final resting position. Over Travel & Rebound are measured to verify the proper operation of damping assemblies within the breaker.	
Rebound	The distance traveled by the contacts beyond the final resting position after returning from over travel.	

Stroke	The maximum distance traveled by the contacts during an operation (Travel + Over Travel)	
Contact Wipe	The distance the contacts travel during a close operation from initial contact make to the final resting position.	
Dwell Time (TripFree C-O)	The time duration that the main contacts remain open during the Trip-Free operation.	
Dead Time (ReClose O-C)	The time duration that the main contacts remain closed during the Re-Close operation.	

4.3 Analysis of Results

Timing and travel results are directly compared to the manufacturer's performance specifications and previous results [1]. All of the performance characteristics listed above will have pass/fail criteria. Table 7 illustrates typical performance characteristics. It should be noted that not all manufacturers document all performance characteristic limits; it may be worthwhile to baseline any missing limits with commissioning tests.

Table 7 – Typical Performance Limits Provided by the Manufacturer

Identification	**CB1**
Control Circuit Open	70-140 VDC / 6.0 A
Control Circuit Close	90-140 VDC / 6.0 A
Opening Time	17-30 ms
Opening Velocity	3.8 m/s minimum
Pole Spread Open	2.7 ms
Closing Time	50-85 ms
Closing Velocity	1.7 to 2.3 m/s
Pole Spread Close	2.7 ms
Overtravel	4.0 mm maximum
Rebound	6.5 mm maximum
Stroke	113 mm maximum
Dwell Time	20-38 ms
Reclose Time (Dead Time)	300 ms minimum

A few diagnostic indicators, such as contact bouncing, dashpot damping, and command coil signatures are obtained by analyzing the recordings.

> Contact Bouncing – Main Contacts, Resistor Switches, and Auxiliary Contacts can be analyzed for undesired bouncing. Phase A in Figure 4 illustrates unusual bouncing of a main contact. The measurement should be repeated, and all connections should be checked. It may be worthwhile to verify the presence of interference. If this problem is validated, it is recommended to follow-up with resistance measurements, both static and dynamic; see the contact resistance section for more information.

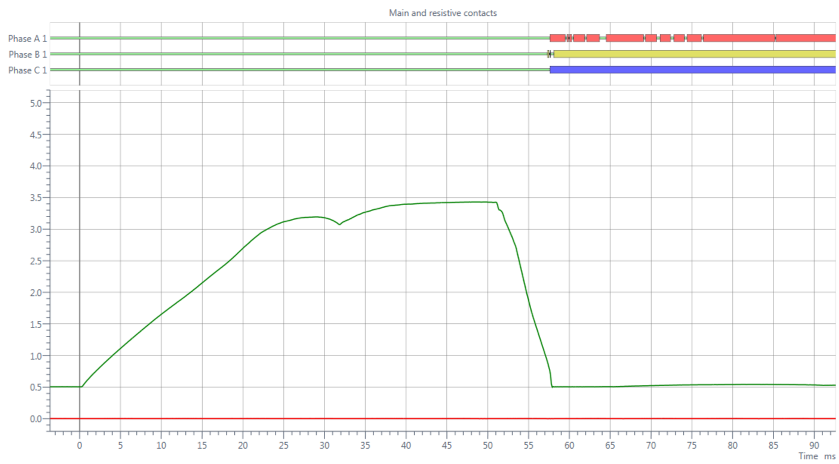


Figure 4 – Unusual Contact Bouncing

> Dashpot Damping – Just as a circuit breaker is expected to accelerate quickly upon command, it must slowdown just as efficiently. A damping device, something like a shock absorber, is used to slow the mechanism as it approaches the final resting position. It can utilize the dynamic effects of oil or air. The motion recording is analyzed for proper deceleration near the final resting position. As the dashpot becomes worn, it can affect the contact's performance. These motion recordings can be compared and trended over time.

> Command Coil Signatures – By analyzing the command coil signatures, information regarding lubrication, electrical coil performance and latch operation can be extracted. However, this diagnostic is most effective when it is performed as a "First Trip" activity. First Trip is performed when the circuit breaker is in-service, and has not been operated for a long time. Lubrication problems are easiest to identify in this scenario. As the armature of the command moves, an expected command coil signature is generated. Figure 5 illustrates a typical coil current signature. These signatures can be compared and trended over time.

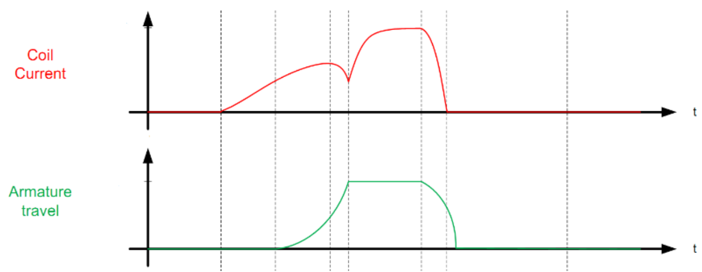


Figure 5 – Command Coil Current vs. Plunger Movement

5 Power Factor

Power factor and capacitance testing provides means of verifying the integrity of the insulation of circuit breaker components. Problems that impair the insulation integrity and can be detected by measuring the power factor and capacitance include:

- Deterioration of entrance bushing insulation
- Deterioration of interrupter assemblies, insulated operating rods and support insulators due to arcing by-products
- Presence of particles, impurities and contamination of insulating medium
- Moisture ingress due to leaks or inaccurate cleaning and drying
- Damages resulting from corona discharge due to voids within the internal insulation system

5.1 Test Procedure

Power factor and capacitance test procedures depend on the design and type of apparatus. The following test procedures are those required to test Bulk Oil Circuit Breakers (OCB) and SF6 Dead Tank Circuit Breakers. However, these test procedure concepts apply to a number of different breaker types.

The applied test voltage should not exceed the line-to-ground rating of the test specimen, or otherwise stated by the manufacturer. The test specimen should be solidly grounded for safety and proper measurement.

5.1.1 Bulk Oil Circuit Breaker (OCB)

A total of nine tests are performed on a Bulk Oil Circuit Breaker, including six in the open state and three in the closed state. By varying the breaker state, we are attempting to isolate various components. Table 8 provides a list of the nine tests.

Table 8 – Recommended Tests: Bulk Oil Circuit Breaker

Test	Insulation Tested	Breaker Position	HV	IN A	IN B	Test Mode
1	C_{1G}	Open	Bushing 1	-	-	GST
2	C_{2G}	Open	Bushing 2	-	-	GST
3	C_{3G}	Open	Bushing 3	-	-	GST
4	C_{4G}	Open	Bushing 4	-	-	GST
5	C_{5G}	Open	Bushing 5	-	-	GST
6	C_{6G}	Open	Bushing 6	-	-	GST
7	$C_{1G}+C_{2G}$	Closed	Bushing 1&2	-	-	GST
8	$C_{3G}+C_{4G}$	Closed	Bushing 3&4	-	-	GST
9	$C_{5G}+C_{6G}$	Closed	Bushing 5&6	-	-	GST

NOTE: All unused bushing should be left floating

Although all components influence power factor and capacitance measurements, open breaker tests (Test 1-6) primarily isolate the respective bushing being energized, interrupter assemblies, and the lift rod guide. Closed breaker tests (Test 7-9) isolate both phase bushings being energized, tank oil/liner, and lift rod.

If the Bulk Oil Circuit Breaker is equipped with condenser type bushings, C1 and C2 should be performed and evaluated. These tests are similar to bushing tests performed on power transformers.

5.1.2 Dead Tank SF6 Breakers

There are nine recommend and three optional tests performed on Dead Tank SF6 Breakers. Table 9 shows the 12 tests.

Table 9 – Recommended and Optional Tests: Dead Tank SF6 Breakers

Test	Insulation Tested	Breaker Position	HV	IN A	IN B	Test Mode
1	C_{1G}	Open	Bushing 1	-	-	GST
2	C_{2G}	Open	Bushing 2	-	-	GST
3	C_{3G}	Open	Bushing 3	-	-	GST
4	C_{4G}	Open	Bushing 4	-	-	GST
5	C_{5G}	Open	Bushing 5	-	-	GST
6	C_{6G}	Open	Bushing 6	-	-	GST
7	C_{12}	Open	Bushing 1	Bushing 2	-	UST-A
8	C_{34}	Open	Bushing 3	Bushing 4	-	UST-A
9	C_{56}	Open	Bushing 5	Bushing 6	-	UST-A
10	$C_{1G}+C_{2G}$	Closed	Bushing 1&2	-	-	GST
11	$C_{3G}+C_{4G}$	Closed	Bushing 3&4	-	-	GST
12	$C_{5G}+C_{6G}$	Closed	Bushing 5&6	-	-	GST

NOTE: All unused bushing should be left floating

Tests 1-6 primarily measures the insulation integrity of the energized bushing and also include any insulated support structure, operating rod and SF6 gas.

Tests 7-9 assess the condition of the contact assembly and SF6 gas within the interrupter chamber.

Tests 10-12 are optional tests that are performed on circuit breakers with more than one contact chamber per phase. This test mode helps stress the additional support structures that will not be seen while the circuit breaker is in the open position.

5.2 Analysis of Results

5.2.1 Bulk Oil Circuit Breaker (OCB)

Power factor and capacitance measurements are used cautiously to determine the overall condition of the insulation. OCBs, in general, especially the interrupter assemblies, are prone to moisture. Elevated power factor measurements are not uncommon. Comparisons can be made against previous data, similar units and phases on the same units. From a single measurement, it is difficult to determine the cause or source of elevated power factor. As stated above, caution should be used when analyzing elevated power factors.

Because open and closed breaker tests influence individual components differently, a special comparison can be performed. This comparison, known as Tank Loss Index (TLI), includes three measurements from each phase (two open breaker tests and one closed breaker test). The losses (in Watts) generated from different components for each tests are weighted against each other. TLI is calculated as follows:

TLI = (closed breaker test in Watts) – (sum of open breaker losses in Watts)

The polarity sign of the TLI calculation helps determine the questionable circuit breaker components. General guidance for investigating abnormal TLI values for dead tank oil circuit breakers is given in Table 10, shown below.

Table 10 – Tank Loss Index: Component vs Polarity

Negative TLI (-)	Positive TLI (+)
Lift Rod Guide	Lift rod
Interrupter Assembly	Oil
	Tank Liner

Limits for TLIs vary depending on OCB design. As a general statement, HV OCBs should be investigated when TLIs exceed +/- 150 mW [2].

5.2.2 Dead Tank SF6 Breakers

For low capacitance specimens like Dead Tank SF6 Breakers it is generally recommended to assess losses (in Watts) instead of power factor. As stated in IEEE C57.152-2013 [3]:

"PF calculations should not be used to determine the integrity of insulation if the measured current is less than 0.3 mA. At low measured currents, PF calculations are susceptible to large swings, which could be misleading. Therefore, in those cases, the test results should be evaluated based on current and loss readings".

Not all Dead Tank SF6 Breakers are assessed according to measured losses, just those units with very low capacitance.

Elevated power factor or loss readings can indicate degradation of bushings, the insulated support structure, operating rod, contact assembly, and/or SF6 gas.

On circuit breakers with grading capacitors Tests 7-9 are dominated by the grading capacitors. High power factor or loss readings may indicate deteriorated capacitors. An unexpected increase in capacitance may indicate short-circuited capacitance layers.

Figure 6 illustrates typical results obtained from a Dead Tank SF6 Breaker. It can be seen that tests [1 3 5], tests [2 4 6], tests [7 8 9] can be compared, respectively.

No.	Measurement	Breaker position	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	Cap. meas	PF meas
1	C1G	Open	GST	None	10.00 kV	60.00 Hz	10.00 kV	0.55 mA	1.68 mW	141.9 pF	0.0306 %
2	C2G	Open	GST	None	10.00 kV	60.00 Hz	10.00 kV	0.37 mA	1.40 mW	96.3 pF	0.0379 %
3	C3G	Open	GST	None	10.00 kV	60.00 Hz	10.01 kV	0.53 mA	1.67 mW	138.5 pF	0.0316 %
4	C4G	Open	GST	None	10.00 kV	60.00 Hz	10.00 kV	0.36 mA	1.41 mW	93.5 pF	0.0392 %
5	C5G	Open	GST	None	10.00 kV	60.00 Hz	10.01 kV	0.54 mA	1.64 mW	139.2 pF	0.0303 %
6	C6G	Open	GST	None	10.00 kV	60.00 Hz	10.01 kV	0.36 mA	1.37 mW	93.4 pF	0.0380 %
7	C12	Open	UST-A	None	10.00 kV	60.00 Hz	10.01 kV	0.01 mA	0.05 mW	3.4 pF	0.0459 %
8	C34	Open	UST-A	None	10.00 kV	60.00 Hz	10.01 kV	0.01 mA	0.06 mW	3.0 pF	0.0587 %
9	C56	Open	UST-A	None	10.00 kV	60.00 Hz	10.01 kV	0.01 mA	0.05 mW	3.0 pF	0.0519 %

Figure 6 – Power Factor and Capacitance Results

6 Contact Resistance

Contact Resistance can be a complicated subject. Contact assemblies can consist of both main and arcing contact components. To see both main and arcing contact components, the Contact Resistance is analyzed, both statically and dynamically, respectively.

6.1 Static

The micro ohm measurement or static contact resistance measurement determines the continuity integrity of the main contact components. Abnormal readings may indicate improper alignment, pressure, or damaged contact surfaces, such as plating or coating.

This is the standard test that is performed to measure the actual resistance value of contact continuity and associated series components, such as bushing connections and tulips. The static measurement produces a single, temperature dependent value in Ohms (Ω).

A static contact measurement is to be performed on each phase, using a DC current source. Typical measurements are less than 100 μΩ; however, the manufacturer's literature should be used to determine the actual expected value. Considering all breaker types, experience has shown measurements range from 10 μΩ to 150 μΩ depending on the type, with low voltage vacuum breakers associated with very low measurements, and higher voltage SF6 Dead Tank Breakers producing the higher measurements. It is recommended that at least 100A DC is injected for this test [2]. Also, it should be noted that if the breaker is equipped with CTs, it may take several seconds to saturate the opposing effects. Precautions should be taken to ensure that the injected high primary current does not affect protection circuits.

Due to the very low resistances, in the μΩ range, it is recommended that a high DC current source be used in conjunction with a Kelvin connection. The Kelvin 4-wire method is the most effective method used to measure very low resistance values. The Kelvin 4-wire method will exclude the resistance from the measurement circuit leads and any contact resistance at the connection points of these leads. The concept of the Kelvin 4-wire method is to apply the voltage and current leads separately. This is shown in Figure 7.

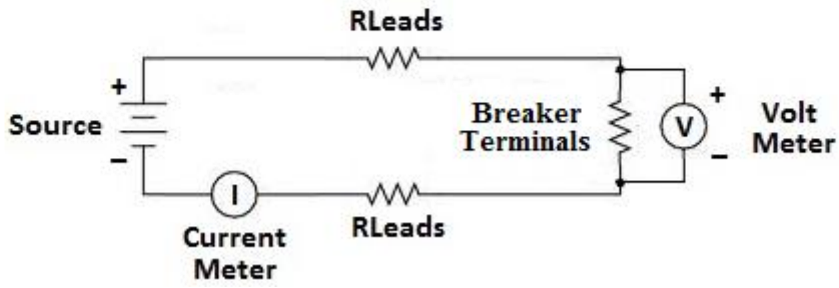


Figure 7 - Kelvin Connection Used for Contact Resistance Measurement

6.2 Dynamic (DRM)

The dynamic resistance measurement is a diagnostic tool to assess the condition of the arcing contacts in SF6 nozzle style interrupters. By measuring the current, voltage, and displacement associated with the contact assembly, it is possible to determine the wear level and integrity of the arcing contact. This measurement, like the static contact resistance measurement, requires high current injection to be successful. Common practice is to use at least 100A DC. Caution must be taken when analyzing the results. As implied by the name (DRM), "resistance" is being isolated and measured. However, in actuality, due to the speed of the contact interaction (roughly 15-20 ms), it is impedance, which includes both real and reactive components, that drives the response. Source leads, CT's, and capacitances, both stray and fixed, contribute to the unexpected reactance.

Figure 8 illustrates a typical dynamic resistance measurement. Motion and the resistance (impedance) response are plotted together. The length of what is left of the arcing contact is determined by comparing it to the distance traveled.

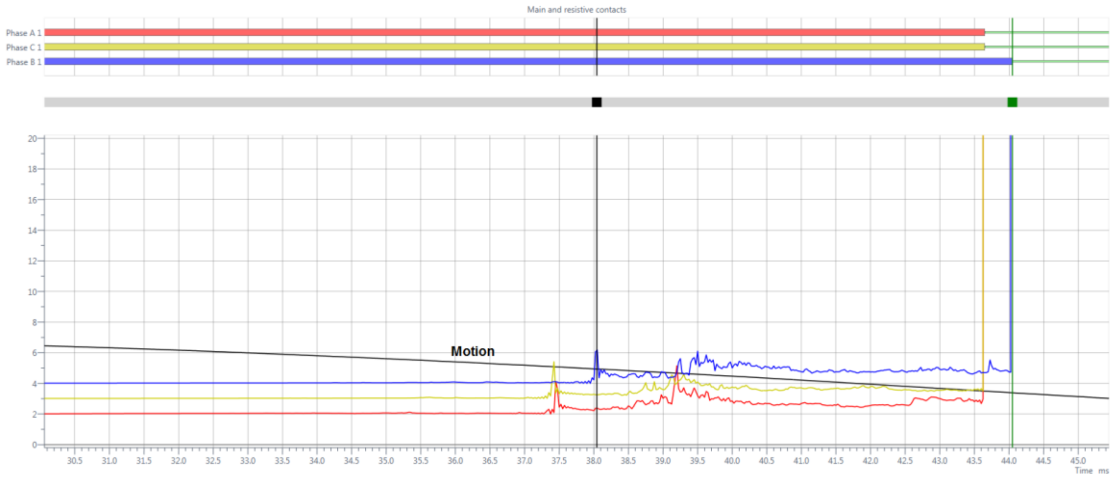


Figure 8 - Typical Dynamic Resistance Measurement

7 Minimum Pick-Up

The minimum pick-up measurement is performed to determine the minimum command coil (trip or close) voltage required to operate the circuit breaker. This is the minimum energy need for the command coil to release the "latch". The latch can either be a mechanical release mechanism or a value used to control a pneumatic or hydraulic system.

This test is done for each control coil of a circuit breaker. Different considerations must be given to ganged versus independent pole operation (IPO) circuit breakers. The test needs to be done for all command coils independently. The IPO breaker may require several more tests to include all command coils.

The test procedure includes the following:

- Determine the command coil parameters and ratings, AC or DC, and operating voltage.
- Determine a start and stop voltage for the command coil under test. Example, 125 VDC command coil, Start [10 VDC] – Stop [125 VDC]
- Determine pulse time: the pulse time should be limited so the command coil does not overheat, 300 ms is the default starting point.
- Determine dead time: this is the time that the command coil pauses between pulses. The dead time should be long enough to assist in cooling of the command coil. Two seconds is a reasonable starting point.
- Determine the voltage step increment: This is the amount that the voltage is increased between command coil pulses. 5V DC is a reasonable starting point.

The voltage is increased linearly until the command coil operates. This behavior is illustrated in Figure 9, shown below. The blue response is current (A), and the purple response is voltage (V).

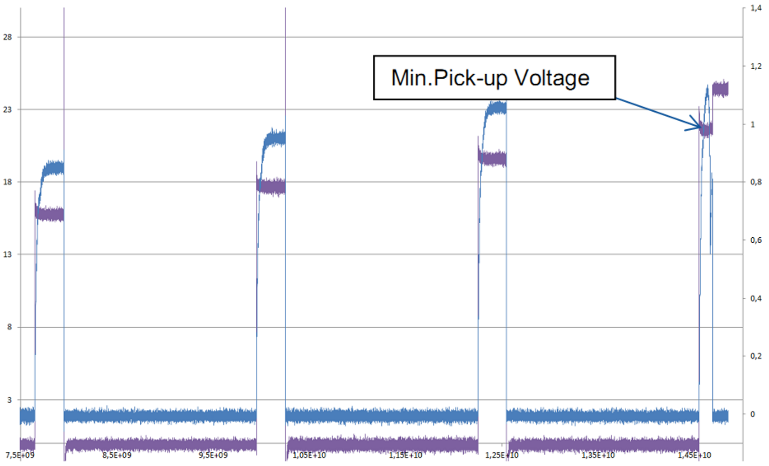


Figure 9 - Minimum Pick: Voltage and Current Responses

The smaller the steps, the more accurate the test result. In general, experience has shown that most healthy command coils will operate at less than 50% of rated voltage. However, this is not an official limit.

8 Conclusion

- Timing and Travel measurements determine and validate the performance characteristics of circuit breakers. The control coils, mechanical linkages, energy storage device, contacts, and dashpots are all monitored for proper operation.
- Power factor and capacitance testing provides means for verifying the integrity of the insulation of circuit breaker components. Depending on the type of breaker and the insulation components that are present, the proper test procedure and analysis strategy must be implemented.
- Contact Resistance measurements can be performed in either the static mode or the dynamic mode. Traditionally, static measurements have been performed allowing only the main contacts to be assessed. With the introduction of DRM, the integrity of the arcing contacts on SF6 nozzle style contacts can be determined.
- The minimum pick-up measurement is performed to determine the minimum command coil (trip or close) voltage required to operate the circuit breaker. This will ensure that the circuit breaker will operated at a specified reduced voltage.

9 References

[1] ANSI/NETA MTS-2011, "Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems"

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[3] IEEE C57.152-2013, "IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors".

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