

Dynamic Contact Resistance Measurement

A Diagnostic Approach to Assessing Contact Condition and Performance of circuit breakers

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Abstract-Dynamic Contact Resistance Measurement (DCRM) is an advanced diagnostic technique used to assess the condition of circuit breaker main and arcing contacts during operation. Unlike traditional static contact resistance measurements, DCRM captures real-time resistance variations throughout the breaker's operation cycle, offering deeper insights into contact movement, wear, and timing. This paper presents a detailed analysis of DCRM signatures obtained from SF₆ circuit breakers under field conditions. By interpreting these waveforms, the study identifies key indicators of contact misalignment, erosion, and mechanical issues. The findings underline the importance of DCRM as a predictive maintenance tool that enhances reliability and minimizes unexpected failures in high-voltage switchyards

Keywords: DCRM, Circuit Breaker Testing, Contact Resistance, Predictive Maintenance, High Voltage, Condition Monitoring.

I. INTRODUCTION

Circuit breakers are essential elements in high-voltage transmission and distribution networks, acting as automatic switching devices designed to protect electrical equipment from over currents, short circuits, and system faults. These devices must operate with precision, speed, and reliability to isolate faulty sections and maintain system stability. Breakers are categorized based on arc-quenching mediums, including SF₆ (sulfur hexafluoride), vacuum, and air blast, with SF₆ and vacuum circuit breakers (VCBs) being the most widely used in modern AIS (Air Insulated Substations) and GIS (Gas Insulated Substations) due to their compactness and high dielectric strength. A typical high-voltage circuit breaker consists of **main contacts** (to carry rated current), **arcing contacts** (to withstand and extinguish arcs during fault interruptions), an **operating mechanism** (spring or hydraulic), and auxiliary components for control and monitoring. Over time, factors like frequent operations, contact erosion, misalignment, and mechanical wear can degrade breaker performance. Early detection of such issues is crucial to prevent catastrophic failures, unscheduled outages, and equipment damage.

Conventional diagnostic methods, such as timing analysis, contact resistance testing, insulation resistance, and motor current profiling, provide limited information about the internal contact conditions and mechanical behavior during dynamic operations. Static tests only reflect the contact health at a single position (closed state) and may miss intermittent faults or wear patterns that occur during breaker movement. To bridge this gap, **Dynamic Contact Resistance Measurement (DCRM)** has gained prominence as an advanced, non-intrusive diagnostic tool. DCRM captures millisecond-resolution resistance changes throughout the breaker's operation (typically during Close-Open or Open-Close cycles). These resistance curves—or "signatures"—offer deep insights into the contact travel path, timing, and health of arcing and main contacts. Any deviation from baseline waveforms can indicate issues such as sluggish contact travel, erosion, misalignment, or excessive contact bounce.

This research paper presents real-world DCRM signatures recorded on 145 kV and 245 kV SF₆ circuit breakers under field conditions using specialized breaker analysis equipment. Through waveform analysis, the study aims to correlate resistance profiles with mechanical conditions, validate the effectiveness of DCRM for predictive maintenance, and propose a diagnostic framework for condition-based maintenance (CBM). Ultimately, this approach enhances operational reliability, reduces forced outages, and supports life-cycle asset management in critical power infrastructure

II. OBJECTIVE

The primary objective of this paper is to evaluate the effectiveness of **Dynamic Contact Resistance Measurement (DCRM)** as a diagnostic tool for assessing the health of high-voltage circuit breakers under real-world conditions. Specifically, the study aims to:

1. **Analyze DCRM Signatures:**

Capture and interpret DCRM waveforms from SF₆ circuit breakers during Close-Open operations to identify patterns associated with healthy and faulty contact behavior.

2. **Detect Internal Contact Issues:**

Identify early signs of main and arcing contact degradation such as misalignment, erosion, contact bounce, slow movement, or sluggish operation—conditions often missed by traditional testing methods.

3. **Establish Baseline Characteristics:**

Define standard or healthy DCRM signatures to serve as reference benchmarks for various breaker types, ratings (e.g., 132 kV, 245 kV etc.), and technologies (AIS/GIS).

4. Compare Field vs Factory Conditions:

Evaluate how contact behavior changes under field conditions compared to factory settings or historical reference data, helping to determine degradation over time.

5. Support Predictive Maintenance Strategies:

Promote the use of DCRM in condition-based maintenance (CBM) programs to reduce unplanned outages, optimize maintenance schedules, and enhance operational reliability.

6. Enhance Breaker Lifecycle Management:

Demonstrate how regular DCRM testing contributes to asset health indexing, failure prediction, and improved decision making for repair, refurbishment, or replacement

III. PRINCIPLE OF DCRM

The DCRM test is based on injecting a constant DC current (typically 100A) through the breaker contacts while it operates (Close and Open). The voltage drop across the contacts is continuously recorded using high-speed data acquisition (generally at 10kHz or more). This voltage, when divided by the injected current, gives a resistance vs. time curve ($R = V/I$). A travel transducer is also used to capture the travel characteristics of the CB.[3]

The resulting time-resistance graph (DCRM signature) reveals:

1. Contact touch and separation points.
2. Transition zones (main to arcing contact).
3. Mechanical stroke variations.

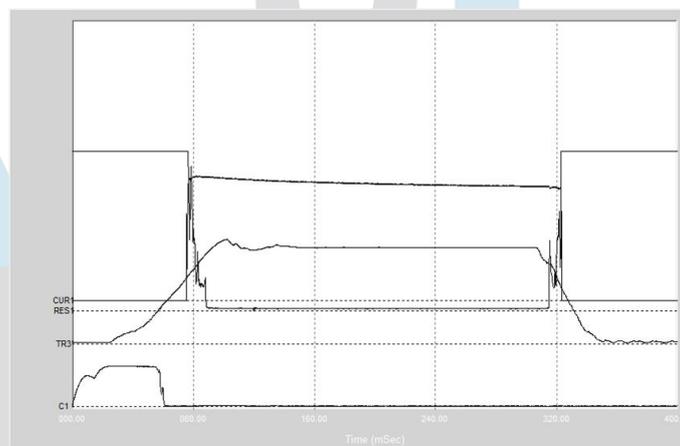


Fig.1 Normal DCRM signature.

IV. Test Setup and Procedure

1) Equipment Required

- DC current injection source (typically 100A).
- DCRM test kit (Table 1 contain details and specifications as per manufactures).
- High-Speed voltage measurement probes.
- Breaker Timing & Control Interface (to synchronize with CB operation).
- Laptop with analysis software.

Manufacturer	Model / Product Name	Key Features
SCOPE T&M (India)	CRM100B / SCOT Advanced Series	Especially designed for DCRM with timing and motion analysis. Widely used in Indian utilities.
OMICRON	CIBANO 500 (with DCRM module)	Multifunctional CB test set, timing + DCRM + resistance. Modular design.
Doble Engineering	TDR900 (or with DRM module)	Integrated breaker analyzer with DCRM functionality.
ISA (Altanova/GE)	CBA 3000	Advanced breaker analyzer with DCRM and timing test.
Megger	EGIL with DRM Module	Compact breaker analyzer with optional DCRM function.
Vanguard Instruments	CTT or CB Analyzer series	Optional DCRM module, suitable for high-voltage CB testing.

2) Connection Diagram

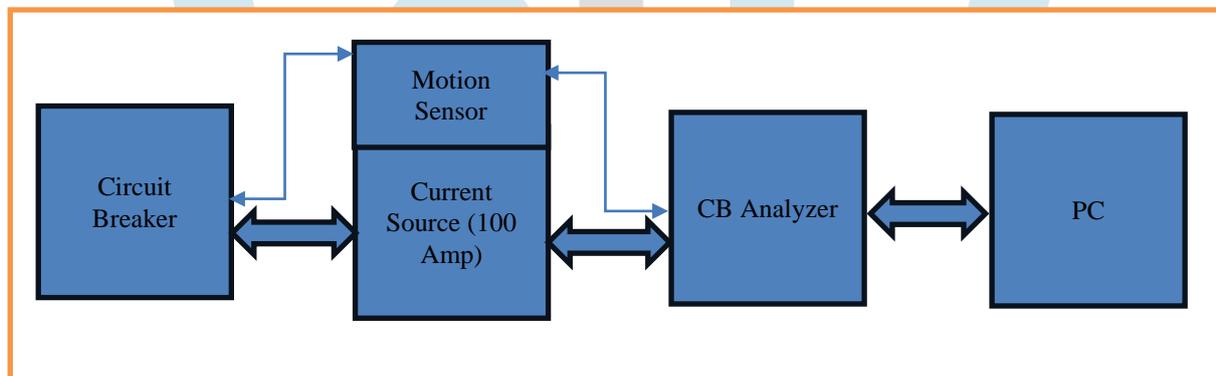


Fig.2 DCRM Connection block diagram

Step1. Test Setup

- CB should be isolated.
- Connect DCRM equipment across the breaker's main terminals i.e. CB Analyzer and Current Source.
- Attach motion sensor to breaker's moving mechanism.
- Connect DC source and shunt for current and voltage measurement.

Step2. Breaker Operation

- Operate breaker (close/Open cycle).
- During operation, the DCRM unit measures **voltage drops** across contacts and **current** through the breaker.

Step3. Resistance Calculation

- Uses Ohm's Law: $R=V/I$
- Plots resistance vs. time, travel, or contact position

V. DCRM Signature Analysis

The resistance curve is analyzed to detect anomalies:

A. Normal Signature: as shown in figure 3

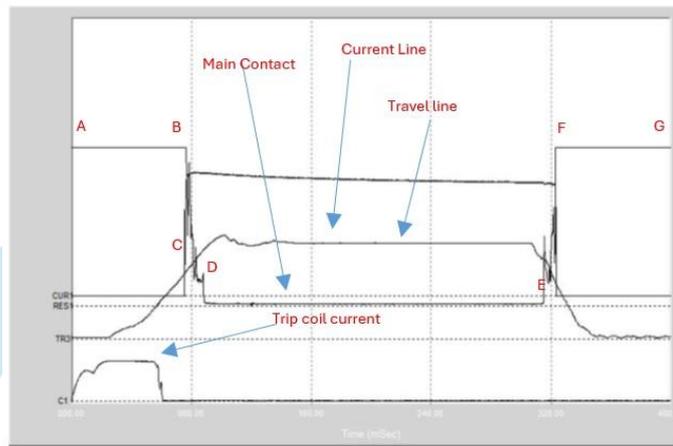


Fig.3 Detailed Segment Analysis

1. Initial Flatline (~0–60 ms) from point A to B

- Observation: Resistance is infinite or off-scale.
- Interpretation: Breaker contacts are fully open, no conduction. This is normal.

2. Arcing Contact Engagement (~60–90 ms) from point B to C

- Observation: Resistance drops gradually from open circuit to a few hundred milliohms, forming a sloped region.
- Interpretation:
 - Arcing contacts are now closing.
 - The slopes is relatively smooth, indicating that arcing contacts are intact and making contact correctly.
 - Peak resistance is seen before the main contact closes.
- Health: Arcing contact behavior looks normal.

3. Main Contact Touch Point (~90–100 ms) from point C to D

- Observation: Sharp drop to low resistance (flat, around ~50–70 mΩ).
- Interpretation:
 - Main contacts are fully engaged.
 - The flatness shows good surface condition.
 - No significant bouncing or irregularities visible.
- Health: Main contacts appear healthy with proper seating and engagement.

4. Steady Closed State (~100–320 ms) from point D to E

- Observation: Resistance is steady and low (~50–70 μΩ).
- Interpretation: This is the period when the breaker is closed, and current is flowing through both arcing and main contacts.
- Health: Consistent low resistance indicates clean and aligned contacts.

5. Opening Operation (~320–340 ms) from point E to F

- Observation:
 - Sudden resistance rises.
 - Slight bouncing or noise in the curve near the transition.
- Interpretation:
 - Main contacts open first → sharp increase in resistance.
 - Arcing contact opens last → gradual resistance increase.
 - Minor bounce could be from mechanism movement.

Note: Small oscillations are acceptable unless they are excessive or prolonged.

6. Final Open (~340+ ms) from point F to G

- Observation: Resistance again reaches high/off-scale.
- Interpretation: Breaker is fully open.

7. Final Health Summary

Table 2. CB Health summary

Component	Condition	Remarks
Arcing Contact	Good	Smooth slope, gradual resistance drop
Main Contact	Good	Sharp drop, flat low-resistance region
Mechanism	Slight bounce seen	Not alarming; watch in future tests
Resistance Value	Acceptable	~50–70 mΩ flat zone, within healthy range

8. Recommendations

- No immediate action is required.
- Monitor slight bounce in future tests.
- Maintain test history to track wear or degradation trends.

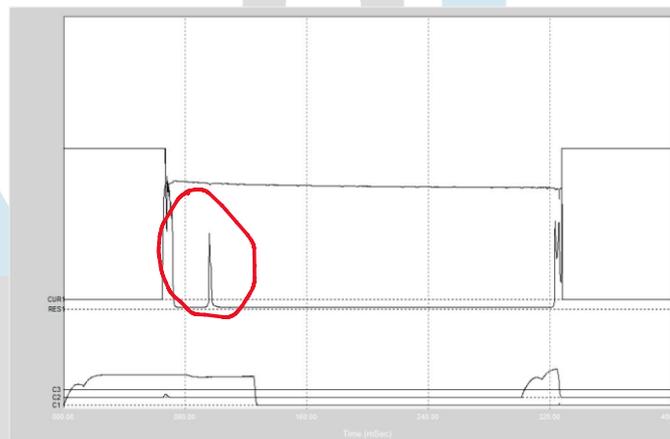
B. Abnormal Signature: as shown in figure 3

Fig.4 Abnormal DCRM signature

- **Observation:** Resistance suddenly change (~50–1800 mΩ), and a **spike** appears around ~120 ms after main contact touch (mark in red circle).
- **⚠️ Concern:**
 - This sharp spike after main contact engagement is likely due to **contact bounce**.
 - Could indicate **loose contact, mechanical misalignment, or dirty contact surface**.
- **Recommendations**
 1. **Inspect arcing contacts:**
 - Could be misaligned, eroded, or disconnected.
 2. **Clean and tighten main contacts:**
 - Bounce may be caused by loose or contaminated contacts.
 3. **Check operating mechanism:**
 - Check for slow movement, wear linkages or spring fatigue.
 4. **Repeat DCRM after maintenance** to compare signatures.

VI. Conclusion

Dynamic Contact Resistance Measurement (DCRM) signatures serve as a valuable diagnostic tool to predict emerging faults in circuit breaker contacts. By carefully analyzing resistance variations over time, specific fault modes can be identified. Contact wear is typically indicated by a gradual increase in the overall resistance trend, reflecting erosion or surface degradation of the main contacts. Misalignment manifests as sudden spikes or dips in the resistance curve, corresponding to irregular seating or delayed engagement of contacts. Contamination, such as oxidation or deposition on contact surfaces, produces fluctuating resistance even during static contact regions, where resistance should otherwise remain flat and stable. In severe cases, welded contacts are detected when the resistance curve fails to exhibit separation at the open command, indicating that the contacts remain physically stuck despite the operation mechanism. Such predictive interpretation of DCRM

graphs enables early detection of abnormalities, supports targeted maintenance, and enhances circuit breaker reliability in high-voltage networks.

- **Contact Wear:** Gradual increase in resistance over time
- **Misalignment:** Sudden spikes or dips in the curve
- **Contamination:** Fluctuating resistance in static contact regions
- **Welded Contacts:** No contact separation or sudden drop at open command
- **Benefits of DCRM**
 - Non-invasive and highly sensitive
 - Detect faults not visible in timing tests
 - Prevents catastrophic failures
 - Extends equipment life through early maintenance

VII. Future scope

While Dynamic Contact Resistance Measurement (DCRM) has already established itself as a reliable diagnostic technique for circuit breakers, there is significant potential for further research and development in this field:

1. Integration with Online Monitoring Systems

Developing sensors and algorithms that allow *real-time* DCRM-based monitoring without taking the breaker out of service.

2. Data Analytics and AI Applications

Using *machine learning* and *pattern recognition* techniques to classify DCRM signatures, predict failure modes, and generate automated health assessments.

3. Standardization and Benchmarking

Establishing **international standards** for acceptable resistance values, transition times, and diagnostic criteria to ensure uniformity across utilities and manufacturers.

4. Correlation with Other Diagnostic Methods

Combining DCRM results with *vibration analysis*, *timing tests*, and *partial discharge measurements* to provide holistic **health assessment** of circuit breakers.

5. Development of Portable and Automated Tools

Designing lightweight, fully automated DCRM test kits that reduce testing time and operator dependency.

VIII. ACKNOWLEDGMENT

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