Dynamic Resistance Measurement for Circuit Breakers Applying high DC current

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ABSTRACT

Presented is the dynamic resistance measurement (DRM) method for circuit breakers by using a high frequency DC/DC converter as a power source generating several hundred's amperes. Injecting high DC current through the breaker contacts and simultaneously monitoring the voltage drop across the main contact during the operation of the breaker was reported first in 1993[1][2].

The DRM test requires a circuit breaker analyzer with a high-resolution measurement. The point of a position change from main to arcing contacts can be observed from the resistance plot. The resistance curve, as a function of a contact travel can be used to reveal potential problems related to the arcing contact condition[3]. Also, the actual length of the arcing contacts can be calculated if measuring the motion.

This paper explains the benefit of injecting as high current as possible, but not less than 100A, to provide a reliable voltage drop reading, thus allowing exact detection of the arcing contact performance.

After reviewing the characteristics of the dynamic resistance curve, the measuring system and parameters, the paper deals with relevant values that can be extracted from the resistance curve for detecting contact anomalies, wear, and/or misalignment.

Finally, case studies are presented and test results are discussed.

Keywords: *HV Circuit Breaker testing, diagnostic, maintenance, dynamic resistance measurement, arcing contacts*

1. INTRODUCTION

A power circuit breaker (CB) is electromechanical device used in the transmission and distribution power systems, intended to switch on and off electric currents in "power on" state. Circuit breakers are used for routine operations and protection of other equipment.

Figure 1.1 shows a Generic component-oriented model of a high voltage (HV) circuit breaker[4]. This is a general model that can be used to represent different types of HV circuit breakers - from old bulk oil to modern SF6 single self-blast CB's.

There are many different types of circuit breakers, but, as presented model shows, all those different types consist of the same basic components: Breaker Control unit, Operating Mechanism and Interrupter Unit.

The interrupter consists of moving and stationary contacts (immersed in some kind of insulation media – oil, gas, etc). These parts are at high voltage potential and are the active part in the electric power network. Figure 1.2 shows moving and stationary contacts for SF6 circuit breaker.

Main requirements on the interrupter are:

- To act as much as possible as an ideal conductor in the closed position (Z_{CB}->0);
- To act as much as possible as an ideal insulator in open position (Z_{CB}->∞);
- To be capable to perform fast open / close operation when in the closed / open position, with:
  - Minimal damage to contacts
  - Minimal over-voltages produced during operation

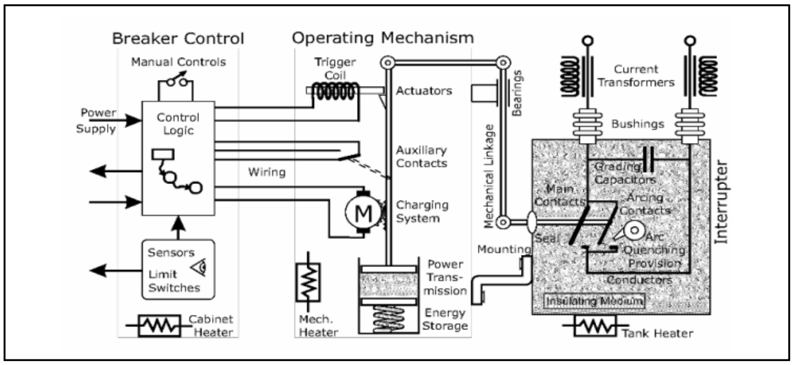
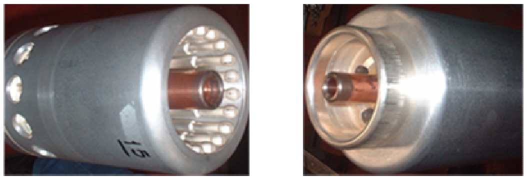


Figure 1.1. Generic component-oriented model of HV CB

Materials from which the contacts are made are subject to wear and erosion. A contact wear and erosion is unavoidable consequence of a current interruption process and formation of electrical arc.

An electric arc is a form of gas discharge – very complicated and complex electrical and thermal process, characterized by the appearance of plasma. Plasma refers to a state of matter and refers to electrically conductive ionized gas containing charged particles: electrons, positive and negative ions.



Stationary contact *Moving contact*

Figure 1.2 Moving and stationary contacts

Special attention should be paid to the chioce of materials in the CB contact design. The reasons are the HV CB needs to carry currents up to 4000 A (or even 40 kA for units installed in nuclear power stations), to withstand (up to 3 sec) and break currents of up to 100 kA with 250 kA_{peak} under abnormal conditions.

It has been observed that the temperature at the center of the arc, when one is subjected to forced cooling, reaches up to 25,000°C (Just as a reference - the Sun surface temperature is approximately 5,500°C). It may sound like contradiction, but temperature at the center of the arc is lower (around 4 times) when there is no forced cooling. The reason is the forced cooling reduces arc diameter affecting current density of the plasma and increases the temperature[5].

Such a high temperature causes vaporization of the contact material which is the main reason for contact erosion. Contact erosion and wear occurs as a result of contacts bouncing when a circuit breaker change of state under normal load or a fault current interruption. Mechanical impact also causes deviations on the contacts.

Contact erosion process is too complex to be described mathematically. Such a description would require taking into account a large number of input parameters. On the other hand, considerable research, mainly of experimental nature, has been done in order to better understand and explain this phenomena.

Experimental results obtained show erosion of the contacts made of heterogeneous (sintered) materials is significantly smaller than in homogeneous (pure metal) materials.

For example, let’s compare contacts made of Copper/Tungsten (Cu/W) as heterogeneous material to pure Copper (Cu) contacts.

In pure Cu contacts a “pond” of melted material is formed around an arc root from which the metal vaporizes. Arc roots tend to avoid cooling blasts of vaporized metal. This results in a very unstable movement of arc roots on the molted surface of the electrode. Even without vaporization, this causes removal of the contact material in a liquid form. This process leads to intensive erosion.

At heterogeneous material, such as Cu/W, the arc forms its roots on the material with higher vaporization temperature. The fact that copper vaporizes before tungsten even starts to melt, leads to a conclusion that tungsten affects cooling of the arc root significantly. That is the reason there is no creation of a “pond” of a melted material on the electrode in this case and erosion of the contacts takes place mostly through vaporization, without droplets such as in homogeneous materials[6].

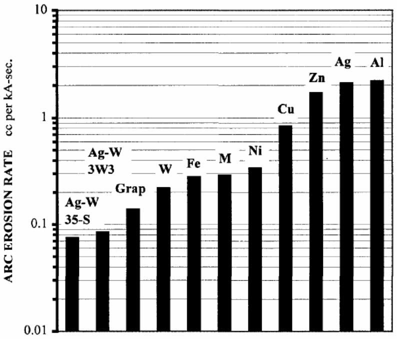


Figure 1.3 Measured materials rate of erosion due to arcing in SF6[5]

That is the main reason why the overall contact system of circuit breakers consists of two distinct contact elements: Main contacts with a primary role to conduct currents when the breaker is in a closed position and arcing contacts designed to be the first to touch and the last to part. Any electrical arc formed during the breaker operation will happen on the arcing contacts.

This is not a case for vacuum circuit breakers, due to arc’s specific behavior in a vacuum surrounding. In such an environment, there are no ionized gases from the arc’s surrounding ambient and the positive arc column is composed only of metal vapors that have been boiled off the electodes. That's the reason there is no need for separation of main and arcing contacts for the vacuum circuit breakers and DRM test will not provide any information regarding the state of the contacts.

On the other hand, the design of modern high-voltage puffer-type SF6 gas circuit breakers is based on the switching of two parallel contact sets.

First, the low-resistance silver-plated contacts, or the main contacts, are specifically designed to carry the load current without any excessive temperature rise.

The second, tungsten-copper arcing contacts operate at the breaker opening following the main contact part. The electrical arc starts after the separation of the arcing contacts. The tungsten-copper material is designed to carry the arc until it is cleared at the next zero–crossing.

Offline timing tests and static resistance measurement will provide some diagnostic information about the state of contacts.

By definition, a circuit breaker timing test is the process of measuring the mechanical operating times. These tests are also used to determine synchronization between phases, or within one phase for circuit breakers having more than one break unit per phase. Also, timing test on the circuit breaker can provide information about contacts bouncing.

Closing of the contacts is usually followed by several bouncing cycles before the two contacts settle down in a close position. During bouncing period, each contacts separation is followed by the appearance of an electric arc that causes erosion of the contacts.

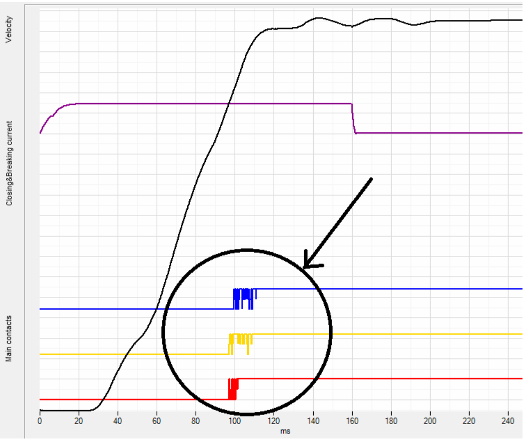


Figure 1.3 Increased contacts bouncing – timing test on SF6 circuit breaker 123kV, manufactured in 1970s

Contacts bouncing should be reduced to a minimum by proper design since it directly affects contact's erosion.

Several standards (IEC 60694, ANSI C37.09) are suggesting the measurement of the circuit breaker main contacts static resistance as a part of standard offline diagnostic test procedure.

Collected results are providing information on state of the main contacts (damaged contacts, contact force lower then specified, polluted isolation medium, malfunction – breaker is not in fully closed position, etc).

Unfortunately, these tests on the circuit breaker interrupter unit do not provide any information about state of the arcing contacts.

That's the reason for introducing a dynamic-contact resistance measurement method to be used as a tool to diagnose the condition of arcing contacts. The method has been validated by field tests performed on SF6 gas circuit breakers[7][8]. The new method is based on the breaker contact resistance measurement during an opening operation at rated contact speed.

2. MEASUREMENT TECHNIQUES

2.1 Battery as a power source for DRM test

Regular 12 V car-batteries can be used as a source for current injection. Voltage drop measurement across breaker terminals was measured with the Circuit Breaker Analyzer instrument (analog channel - range 1 V). It is recommended to perform a trip-free test without battery to see if everything is connected properly and the breaker operates trip free.

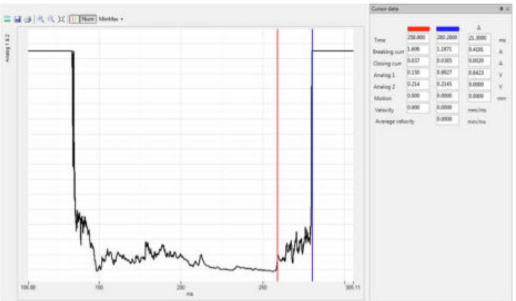


Figure 2.1 145 kV SF6 circuit breaker car battery was used as a power source for high current injection. *Voltage drop was measured across breaking elements during trip-free operations.*

Disadvantages of this solution are weight, possibility of accidental battery short-circuiting as well as a poor contact connection.

Deployment of the lead acid or other rechargeable batteries as a source presents technical problems that will prevent their use in practice.

In addition, lack of current regulation makes it difficult to establish similar testing conditions, in different time intervals or on different CB phases, as well as later comparison of the results.

2.2 DRM at low contact speed

There is an alternative method using a slow motion of the circuit breaker when a DC current is injected. The results of this approach do not represent a real situation because there are no breakers that will operate with such a low speed.

Under this simulation the contact system will not behave as when the breaker is operated at normal velocity.

Additional disadvantage is that this method is intrusive for some breaker mechanisms, since an adjustment to the operating mechanism is required.

There is a potential risk of damaging the operating mechanism when restoring it back to service.

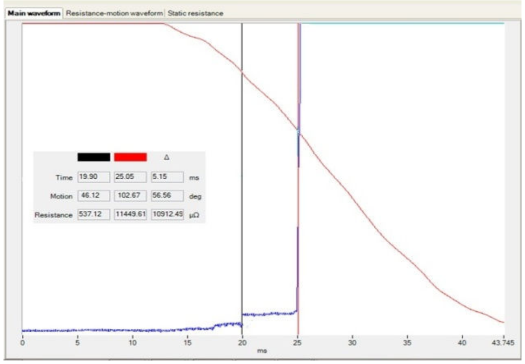
2.3 DRM at rated contact speed using micro ohmmeter as the power source

Another successfully used strategy was performing the DRM tests at rated opening speed while simultaneously injecting current of at least 100 A.

The Circuit Breaker Analyzer and Timer was used as both, the power source, the current and voltage drop recorder. Test object was 145 kV SF6 dead tank circuit breaker.

Technical characteristics of a 200 A micro ohmmeter used as a power source were: load voltage of up to 7 V, and measuring accuracy of ±(0.1 % reading + 0.1 % full scale).

Linear to rotary converter was used for a digital rotary transducer T1, with transfer function: 1 mm at contacts = 2.79 deg at transducer. Measured static resistance of the CB is 88.9 μΩ and this value shows no damage on the main contacts.



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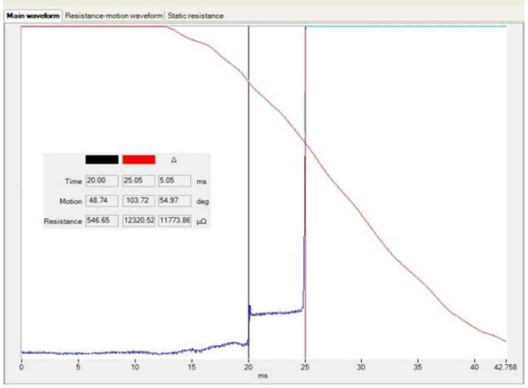
Time	19.90	25.05	5.15	ms
Motion	46.12	102.67	56.56	deg
Resistance	537.12	11449.61	10912.49	μΩ

Figure 2.2 DRM graph at 100A on 145 kV SF6 circuit breaker. It is often difficult to identify the point of main contact parting. The main contact separation point is not as obvious as in the second approach with 200A.



	■	🟥	Δ	
Time	20.00	25.05	5.05	ms
Motion	48.74	103.72	54.97	deg
Resistance	546.65	12320.52	11773.86	μΩ

Figure 2.3 DRM graph at 200A on 145 kV SF6 circuit breaker. The graph is far smoother and the point of main contact parting can be easily identified.

The DRM results obtained at 200 A current indicated the main contacts separation at 19.6 ms. It means the arcing contact overlapping time is approximately 5.2 ms which is the expected time, and overlapping length is approximately 20.6 mm*.

Resistance value obtained is around 1400 μΩ after the main contacts open. This resistance value is common for arcing contacts. First step noticed on the graph at 15 ms is probably due to a fact that the main contact resistance increases as the contacts start moving.

Note: *Measured lenght of the arcing contact is approximatly 20,6 mm (57,6 deg), from 19,6 ms to 24,9 ms. Transducer: Emeta, MA306-10-2500-3, Model: #S108-B 2500

3. DYNAMIC RESISTANCE MEASUREMENT ON CIRCUIT BREAKER GROUNDED ON BOTH SIDES (BSG)

Testing a high voltage circuit breaker which is not grounded on both sides can be hazardous due to high electric potential presence.

DRM measurement can also be performed on a circuit breaker grounded on both sides. In this way higher level of personal safety and protection is achieved.

Voltage drop across arcing contacts, in case of circuit breaker grounded on both sides, will be lower due to presence of parallel resistance that comes from the grounding cables and ground resistance.

Even with decreased total resistance in cases when both sides of the circuit breaker are grounded, overlapping time does not change.

Overlapping length of the main and arcing contacts is calculated manually, based on the obtained motion diagram and previously determined overlapping time.

Considering the overlapping time is not changed, one can conclude grounding does not affect DRM results.

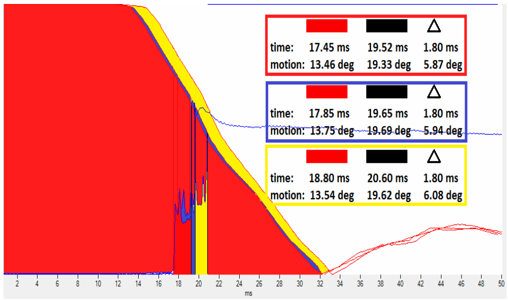


Figure 3.1 Overlapped DRM results on the same phase of CB, once without grounding and with ground resistance of 20 mOhm and 10mOhm.

4. CONCLUSION

Preventive maintenance on a high voltage (HV) breaker consists of several routine tests. The timing and motion tests are methods used to assess the breaker mechanical condition.

When the timing and motion results indicate an abnormality, the DRM test can be an effective way to further diagnose the internal condition of the breaker contacts.

Figure 2.3 depicts an example of a dynamic resistance measurement on a high voltage circuit breaker where transition from static resistance value to open contact is shown.

Based on the above graphs (Fig 2.2 and Fig 2.3), it becomes clear that interpreting the DRM curve at 100 A may lead to a wrong diagnostic conclusion, especially for the main contact separation which occurs at approximately 19 ms.

As the injected current is increased from 100 A to 200 A, the graph is far smoother and the main contact separation can be easily identified, as shown in Fig. 2.3.

In view of these results, it is recommended to apply an injected current of at least 200 A when performing DRM tests at the rated contact speed on the 145 kV SF6 circuit breakers.

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