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Dynamic Contact Resistance Measurements on HV Circuit Breaker

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Abstract

Dynamic contact resistance measurement (DCRM) is advance technique for assessing the condition of power circuit-breaker (CB) main contacts and arcing contacts. In SF6 gas CB there can be abnormal wear and tear, excess pitting of arcing contact, mechanical weaknesses or deterioration of operating mechanism. In this paper, DCRM signature analysis through MATLAB program is studied. The resulting parameters are most relevant since it helps in assessing the status of circuit breaker.
Keywords — circuit breakers (CBs), dynamic contact resistance measurement, contact resistance, contact travel

I. INTRODUCTION

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. Second, following the main contact part, the tungsten-copper arcing contacts are finally opened, thus initiating arc quenching and current interruption. To assess the condition of the breaker contacts, the main contact resistance measurement is usually performed. However, the static resistance measured when the breaker remains in a closed position does not give any indication of the condition of the arcing contacts. To evaluate the latter's condition, an internal inspection can be done, but time consuming and costly maintenance procedures must be followed in order to securely handle the SF6 gas and arc byproducts. It should be remembered that excessive arcing contact wear and/or misalignment may result in a decrease of the circuit breaker's breaking capacity.

The dynamic contact resistance measurement (DRM) was developed over 10 years ago to assess the condition of the arcing contacts without dismantling the breaker. This paper presents a new dynamic-contact resistance measurement method that has been validated by field tests which were performed on SF6 gas circuit breakers. The new method is based on the breaker contact resistance measurement during an opening operation and closing operation. After reviewing the characteristics of the dynamic resistance curve and 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.

II. CIRCUIT BREAKER CONTACTS

The HV circuit breaker is the most important component of an HV substation, as it has the task to remove the fault, no matter what is the fault current. When a fault occurs, current must be interrupted quickly and reliably to avoid personal injuries and minimize damage. If a breaker fails to break the circuit, the resulting damage can be very serious indeed. Moreover, a needlessly large section of the power grid will have to be disconnected in order to interrupt the fault current. A circuit breaker is the active link in the fault-clearance chain. Even though circuit breakers are comparatively reliable, faults can and do occur. Circuit breakers must thus be tested and maintained to ensure operation when a crucial need arises. During its 40+ year service life, a circuit breaker must be constantly prepared to do its duty. Long periods of idleness often elapse during which the breaker's mechanical parts never move. There are many reasons to maintain and test a circuit breaker. Friction and wear can affect the performance of movable parts. Leaks can occur in the valves and seals used in arc-extinguishing chambers, damping devices, pneumatic and hydraulic operating mechanisms. Faults can occur in electrical control circuits, and the contact surfaces in current-carrying circuits can deteriorate, thus increasing the risk of excessive heat generation. The primary goal of circuit breaker testing is to determine the condition of the breaker. Breakers have moving parts which allow electrical contacts to separate (an 'open' or 'trip' operation) or to close. Whether those contacts are in a vacuum, in oil or in a gaseous medium, it makes sense to test the moving parts of the breaker. If the motion of the contact system is in accordance with manufacturer specifications then one can reasonably conclude that all mechanical parts, from the mechanism which provides the movement to the contacts themselves, are in good condition. A typical high voltage circuit breaker contact system consists of two sets of contacts, main contacts and arcing contacts. When a standard timing method is applied, arcing contact opening and closing time can be measured through changes in impedance. Because of the relatively small difference between arcing contacts impedance and main contacts impedance, the moment of change over between those two sets of contacts is not detected. One way to try and see the changeover is to inject a high DC current in to the breaker and, through a voltage drop measurement, determine the impedance and thus detects the moment of change over between the two sets of contacts. Contact resistance tests provide information about how healthy the contacts are and their ability to handle their rated current. The maximum contact resistance should be verified against manufacturer's specifications. Rated current should not be exceeded and testing at 10% of the rated current is recommended. The minimum DC test current should be used according to manufactures specification; however, the IEC and ANSI recommended levels are:

50 A IEC 60694

100 A ANSI

Static Contact resistance is measured by injecting a DC current through the breaker or device under test and measuring the voltage drop. The breaker must be in the closed position. If low resistance readings are obtained when testing the breaker contact resistance using a low current, then it is recommended to re-test the contacts at a higher current. A higher current have the ability to overcome connection issues and oxidation on terminals, where a lower current may produce false (higher) readings under these conditions. High contact resistance in circuit breakers is caused by high current breaking operations. Modern networks are carrying increasing loads requiring improved contact resistance.

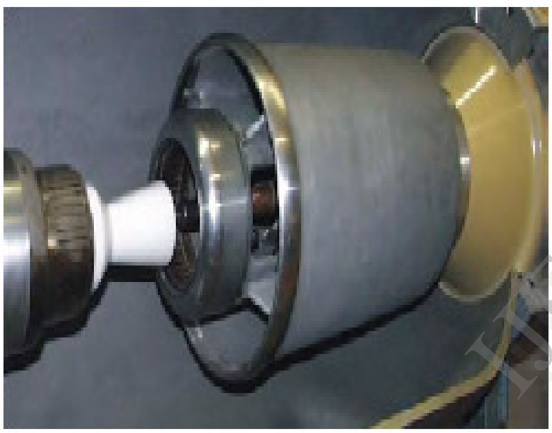

Figure 1: Cut-away view of SF6 circuit breaker

Here is a cut-away view of the inside of an Arcing Chamber of an SF6 Breaker. The white nozzle is the Arc Chute for the arcing contact. The right side of the picture is the stationary part of the contact and the left side with the white nozzle is the moving contact. The arcing contact is the metal rod (copper, tungsten, etc.) that is inserted into the nozzle and is designed to take the brunt of the arcing during close and open operations. The ring around the arcing contact is the main contact (silver, silver plated copper, etc.) and it functions to carry the load while the breaker is in the closed position. The arcing contact is the first to make contact during a close operation and the last to break contact during an open operation. If the arcing contact is too short or otherwise in bad condition, then the breaker soon becomes unreliable. Main contact surfaces can be deteriorated by arcing resulting in increased resistance, excessive heating and in worst-case explosion. The main contact resistance is measured dynamically over an open or close operation and the arcing contact length can be reliably estimated. The only real alternative in finding the length of the arcing contact is dismantling the circuit breakers arcing chamber. Reliable interpretation requires high test current and a circuit breaker analyzer with good measurement resolution.

III. DYNAMIC CONTACT RESISTANCE MEASUREMENT

Dynamic Contact resistance measurement, commonly known as "DCRM" is a test method used as a diagnostic and analysis tool. It is a comparative test and as such will not necessarily yield results the first time it is performed. The measurement is performed by injecting DC current through the breaker and simultaneously monitoring the voltage drop as well as current flow during the operation of the breaker. From these two parameters a resistance value can be calculated. Also Dynamic Contact resistance Signature is a non –invasive diagnosis measurement which indicates the erosion of arcing and main contacts looseness, damage, misalignment and helps to measure length of arcing tip. DCRM signature with travel curve gives fairly good idea about healthiness of main and arcing contacts. The abnormal wear and tear or excessive pitting of arcing contact is indicated in the signature. Certain mechanical weaknesses, undetected by travel measurement are reflected in DCRM signature. It also gives prior indication of deterioration of operating mechanism linkages. Comparison with old signature makes condition monitoring and corrective measure possible.

In the figure below the resistance trace starts out as a straight line before the breaker starts to move, this is DLRO value. As the breaker starts to move, the resistance increases slightly. At the main contacts part, there is a spike in the resistance curve and at the arcing contact ,the resistance goes to infinity and when the current flow stops the breaker is open.

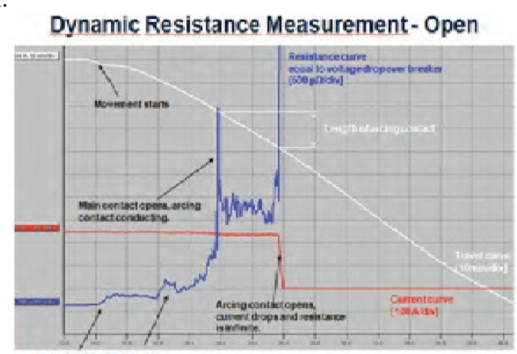

Figure 2: Dynamic resistance measurement signature

IV. TYPICAL DCRM SIGNATURE

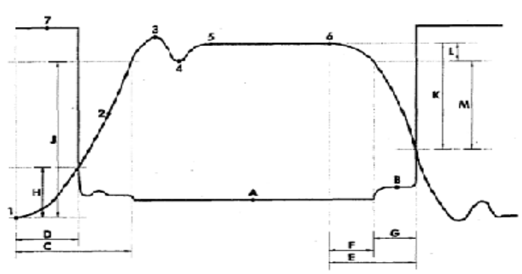

Figure 3: DCRM Signature

Where
A Main contact resistance
B Arcing contact resistance
C Time for main contacts to make
D Time for arcing contacts to make
E Time for arcing contacts to break
F Time for main contacts to break
G Time arcing contact made
H Distance for arcing contacts to make
J Distance for main contacts to make
K Distance for arcing contacts to break
L Distance for main contacts to break (wipe of main contact)
M Distance arcing contacts made (wipe of arcing contact)
And
Where
1 Start of mechanism movement for closing sequence
2 Travel curve
3 Mechanism overtravel for closing sequence
4 Mechanism rebound for closing sequence
5 Mechanism fully closed position
6 Start of mechanism movement for opening sequence
7 Contact resistance waveform

V. RESULT ANALYSIS

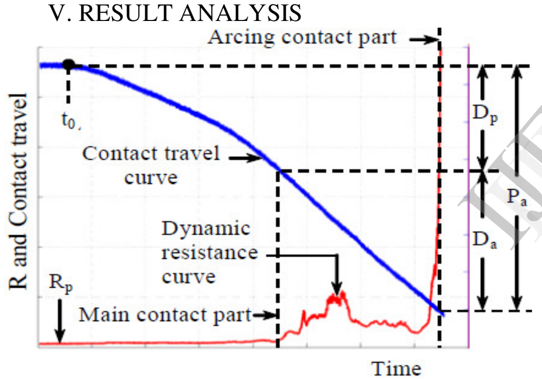

Figure 4: DCRM curve to extract parameters

Figure.4 depicts a typical dynamic resistance curve during an opening operation where t0 corresponds to the beginning of the breaker contact motion. It is always relevant to superimpose the travel curve of the breaker contact in order to extract diagnostic parameters related to the position of both the main contacts and the arcing contacts. These parameters are:

- Rp (μΩ): Average main contact resistance
- Dp (mm): Main contact wipe
- Da (mm): Arcing contact wipe
- Pa (mm): Position of the breaker contacts at the arcing contact part.

The two additional parameters for diagnosing the arcing contact conditions:

- Ra (μΩ): Average arcing contact resistance = $(\sum R_{i=1,N})/N$ N= Number of samples in the interval D_a
- Ra*Da (mΩ. mm): Area beneath the resistance curve as a function of the contact travel.

The latter parameter provides a criterion for evaluating the global breaker contact wear and/or contact alignment status.

Once the graph is plotted, all diagnostic parameters can be deduced. Since this graph can be considered as complete for diagnosing the breaker contact condition as given in following section.

a) Result analysis of circuit breaker A

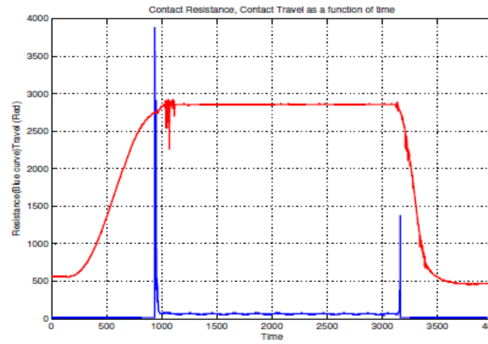

Figure 5: DCRM curve for circuit breaker A

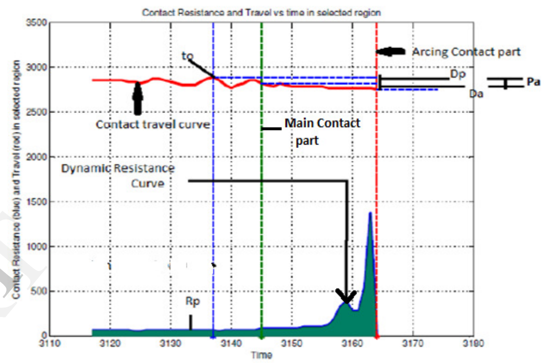

Figure6: Parameters to be extracted from dynamic resistance curve of circuit breaker A

b) Result analysis of circuit breaker B

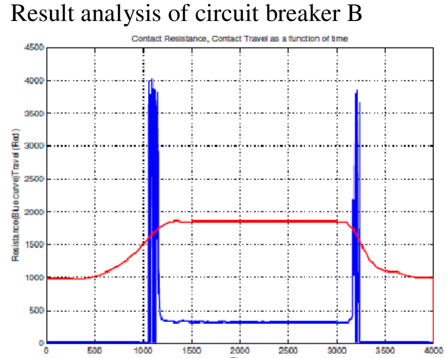

Figure 7: DCRM curve for circuit breaker B

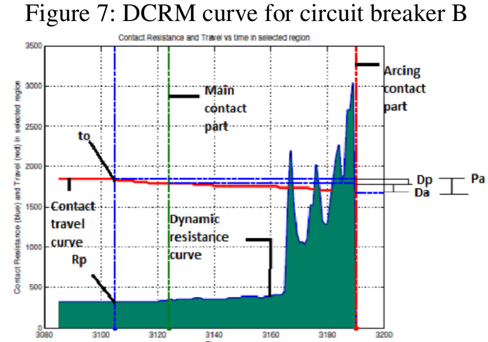

Figure 8: Parameters to be extracted from dynamic resistance curve of circuit breaker B

c) Result analysis of circuit breaker C

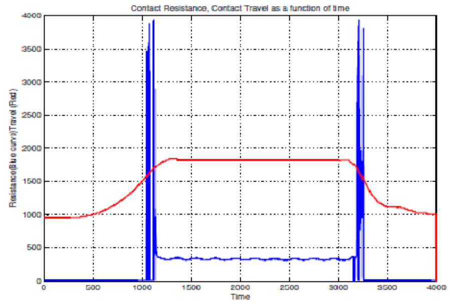

Figure 9:DCRM curve for circuit breaker C

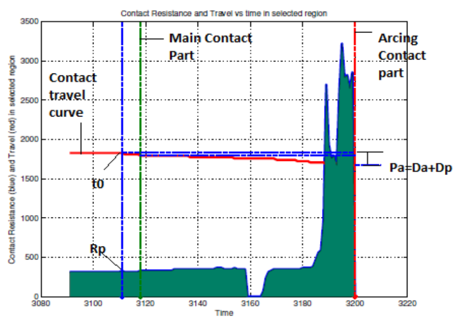

Figure 10: Parameters to be extracted from dynamic resistance curve of circuit breaker C

d) Result analysis of circuit breaker D

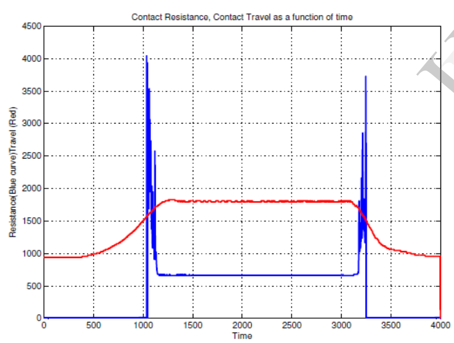

Figure 11:DCRM curve for circuit breaker D

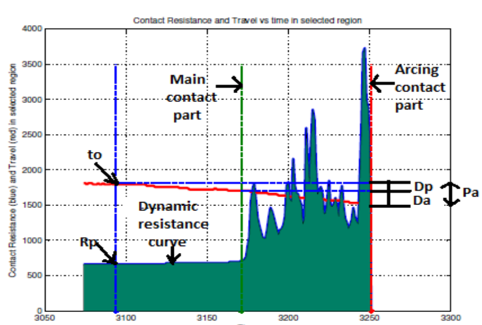

Figure 12: Parameters to be extracted from dynamic resistance curve of circuit breaker D

Tabel 1 – Summary of DCRM results

VI. CASE STUDIES

Circuit Beaker	T0 (ms)	Rp (μΩ)	Ra (μΩ)	Dp (mm)	Da (mm)	Pa (mm)	Ra*Da (mΩ.mm)
A	3137	69.47	163.7	70	70	140	11.459
B	3105	321.9	808.5	52	123	175	**99.44**
C	3111	315.91	576.93	34	123	157	70.96
D	3094	661	1567.43	105	209	314	**328**

Case study No. 1: Figure 6 presents DCRM result of 400kV gas SF6 circuit breaker A. It has performed 65 operations. Based on this signature and result listed in table 1, it can be deduced that the arcing contact are in good condition. The Ra value of 163μΩ is almost constant throughout the contact motion. Area (Ra*Da) is also relatively low i.e 11.45mΩ.mm.

Case study No. 2: DCRM signature of 245kV SF6 gas circuit breaker B, shown in figure 8.The result listed in table 1 for this circuit breaker indicates that Ra value is high, which shows that arcing contacts are abnormal. Ra*Da value i.e area under contact resistance curve for this circuit breaker is high.

Case study No. 3: Figure 10 shows the DCRM result of 400 kV SF6 gas circuit breaker C. Based on the curve and the extracted value listed in table 1, indicates that the breaker is in normal condition as Ra value and Ra*Da value are normal.

Case study No. 4: DCRM signature shown in figure 12 is of 400 kV SF6 gas circuit breaker D.The Ra*Da of 328mΩ.mm is the high value obtained during dynamic contact resistance measurement for this breaker.

VII. CONCLUSION

This paper presents a new dynamic contact resistance measurement method performed during opening operations aimed at evaluating the breaker condition without dismantling it. To extract the diagnostic parameters, a dedicated MATLAB software program was developed in order to plot the dynamic resistance curve as a function of the contact travel, i.e. μΩ versus mm. Six vital diagnostic parameter values are therefore determined:

- average main contact resistance;
- average arcing contact resistance;
- main contact wipe;
- arcing contact wipe;
- position of the breaker contact at the arcing contact part;
- the cumulative area beneath the resistance curve.

The last parameter is the most relevant one since it allows the overall contact wear and/or contact alignment status to be assessed. For example, values of about 11mΩ.mm indicate healthy breaker contacts while values of about 328mΩ mm indicate faulty contacts. The four case studies presented in this paper reveals that the DCRM provides vital information about the breaker contact condition. Without dismantling the breaker, the maintenance crew can thus plan maintenance work for specific breakers for which the DRMs reveal contact anomalies.

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