XXV Seminarium

ZASTOSOWANIE KOMPUTERÓW W NAUCE I TECHNICE 2015

Oddział Gdański PTETiS

DYNAMIC RESISTANCE MEASUREMENTS OF MV SWITCH-DISCONNECTOR CONTACTS

Jędrzej BANASZCZYK[1], Piotr ORAMUS[1], Zbigniew DOMURAD[2], Piotr PIEKARSKI[2]

1. Corporate Research Centre ABB, Cracow, Poland
   tel.: +48 22 223 94 77 e-mail: jedrzej.banaszczyk@pl.abb.com
   tel.: +48 22 223 95 81 e-mail: piotr.oramus@pl.abb.com
2. ABB MV Products Technology Centre, Przasnysz, Poland
   tel.: +48 22 223 88 36 e-mail: zbigniew.domurad@pl.abb.com
   tel.: +48 22 223 88 97 e-mail: piotr.piekarski@pl.abb.com

Abstract: Dynamic Resistance Measurement (DRM) is an effective technique for diagnosing the condition of high power switch contacts. Moreover, the technique can be used to predict the allowable number of switching operations that can be carried out before maintenance of the apparatus is necessary. Since coating materials are characterized by different mechanical and electrical properties, the DRM method can help predict the performance and improve the design of existing high power switches. In this paper both static and dynamic contact resistance measurements for new and worn contact sets of a standard MV switch-disconnector are presented. The contact resistance was measured both in function of the DC injected current magnitude, as well as the number of executed switching operations. The measurements were performed by means of the 4-wire method, and a high speed acquisition digital oscilloscope was used to register the DRM curves.

Keywords: contact resistance, diagnostics methods, MV apparatus, resistance measurements, switch-disconnector.

1. INTRODUCTION

Energy losses always accompany electrical power distribution and consumption. These losses can be partly attributed to unwanted heating of current conducting elements, resulting from an increase in the resistance of the conductors themselves or in the contact resistance in conductor connections. The resistances of high current components are usually relatively small (10÷1000 μΩ), but their increase above acceptable values may give rise to serious issues in devices such as circuit breakers, switches or tap changers [1].

The quality of conductor connections has a significant impact on the efficiency of electricity distribution. Since power loss is determined by the resistance of the line conductor, the value of the contact resistance at each connection and by the magnitude of the current flowing in the line, increased contact resistance in the connections is undesirable [2, 3].

In order to transmit electrical current through a connection with a minimum voltage drop, the contact area (free of oxides, corrosion films, contaminants, etc.) between the two solid bodies has to be sufficiently large, which is usually realized by applying high contact pressures. In power applications copper contacts are usually coated with an electroplated silver layer, to prevent formation of a non-conducting copper oxide film [4]. The silver coated copper contacts are therefore subjected to high contact forces, typically 10÷100 N. Since silver and copper are soft materials, they deform plastically already when mated under stationary conditions. Subjecting them to an additional fretting motion can lead to severe surface damage and contact resistance increase [5].

When designing a new contact system it is important to be able to predict the rate at which the contacts will wear out in order to foresee the element lifetime, as well as to be able to optimize the coating properties and the normal contact forces.

In this article the contact resistance behavior of an MV switch-disconnector is investigated by means of static and dynamic contact resistance measurement techniques. The impact of both main contact and arcing contact wear, as well as the semiconducting grease applied on the main contacts is investigated. Advantages of high DC current dynamic measurements over low current static measurements are discussed.

2. MEASUREMENT TECHNIQUES

In general there are three methods of measuring contact resistance. The 2-wire method is the simplest one, and it is mostly used for measuring contact resistance in the range of 10 Ω÷10 MΩ, where the impact of the series lead resistance or the parallel leakage resistances on the accuracy of the measurement is negligible.

The 3-wire technique is suitable for measuring resistance above 10 MΩ. It is typically applied in measurements of high voltage equipment insulation, where the third wire acts as a guard against leakage currents, which would influence the measurement.

Finally, the 4-wire technique is the most accurate method when measuring contact resistances below 10 Ω, rendering it possible to avoid errors introduced by the lead and contact resistances [1]. Since, as mentioned before, the contact resistance in typical high power switches lies in the μΩ range, the 4-wire technique is the right choice.

The 4-wire measurements require two current and two sensing leads as shown in Figure 1.

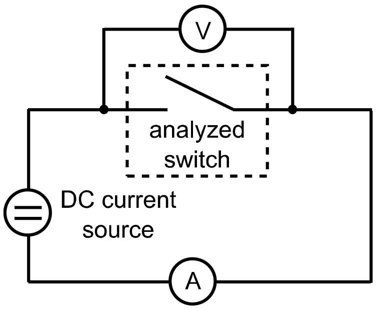


Fig. 1. Schematics the 4-wire method measurement setup assembly

3. DRM METHOD

In order to assess the condition of a high power switch contact set, the main contact resistance measurement is usually performed. While it is known that excessive arcing-contact wear may hamper the high power switch breaking capacity, the static contact resistance measured when the breaker remains in a closed position does not give any indication of the condition of the arcing contacts.

To verify the condition of the arcing contacts, it is possible to perform an internal inspection, but it is time-consuming and costly, because of the SF6 gas and arc byproducts. For this reason, the Dynamic Resistance Measurement method (DRM) was developed to render it possible to evaluate the condition of breaker contacts without disassembling the interrupting chamber, which is a crucial benefit.

DRM is an effective technique for verification of the main contacts and arcing contacts condition of electrical apparatus, such as power circuit breakers. It is based on the breaker contact resistance measurement during an opening operation. Analysis of the high power switch contact resistance measured in function of time or contact displacement renders it possible to assess the condition of both main and arcing contacts.

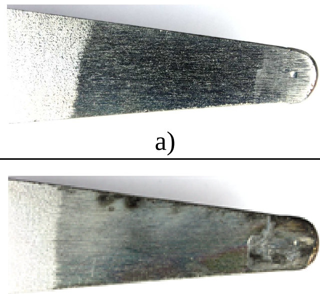
In order to enhance the accuracy of the measurements, it is beneficial to use possibly high DC currents, to trigger decomposition of the contaminants and oxides present on the surface of the contacts. This is particularly important when measuring contact resistance in SF6 insulated devices, where the presence of metallic fluorides deposited on contacts could mask the actual contact resistance for some breakers [6, 7].

4. TEST OBJECTS

To evaluate the effectiveness of the diagnostic method presented in section 3, dynamic and static resistance measurements have been performed for new and worn contact sets of a high power switch. Contact sets taken from an air insulated MV switch-disconnector (U_N = 12 kV, I_N = 400 A) were chosen for the analysis. Photographs of the main contacts of the analyzed object are presented in Figure 2, while arcing contacts are shown in Figure 3.


a) b)

Fig. 2. Silver plated copper switch-disconnector main contacts; new (a) and worn (b)


a)

b)

Fig. 3. Analyzed switch-disconnector arcing contacts; new (a) and worn (b)

The DRMs were carried out by means of the 4-wire method (setup diagram is presented in Figure 1), with 150 A DC injected current.

5. MEASUREMENTS RESULTS

5.1. Static contact resistance measurements

One of the simplest contact resistance measurement methods is based on an AC current source. However, the resistance measurement becomes impedance determination by dividing RMS values of voltage and current, and errors are inevitably introduced into the measurement, caused by inductive and capacitive components in the test circuit. This method can be acceptable if there is no need for high accuracy [1].

In Figure 4 the contact resistance in function of AC current is plotted for the lubricated worn and dry worn main contacts. No influence of the grease on the static contact resistance can be noticed from the measurement. The measured value decreases with the increased current, and a stable result is obtained for 2 A injected current and above. This is due to decomposition of oxides and contaminants on the contact surfaces while a purely metallic a-spot contact is formed [3].

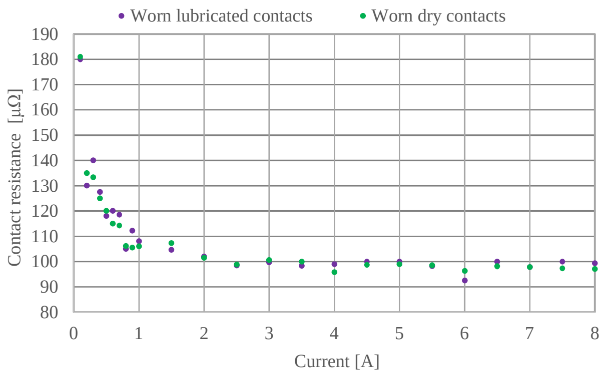


Fig. 4. Static contact resistance in function of the injected AC current, measured for a worn contact, with (purple) and without (green) grease

5.2. DC current static contact resistance measurement

In order to measure pure contact resistance it is best to use DC current. The results in function of the number of switching operations for a new and worn main contact are shown in the plot in Figure 5. First, it is clear that the DC measurement yields a lower contact resistance result than the AC measurement. Also, the contact resistance for the damaged contact is higher than for the new one. The contact resistance increases slightly with every switch operation, as the silver coating becomes worn due to fretting.

After each closing operation 10-15 s were waited before the measurement was taken in order to allow the voltage to go down to a stable value. During this time the contacts were heating up and the contact resistance was decreasing.

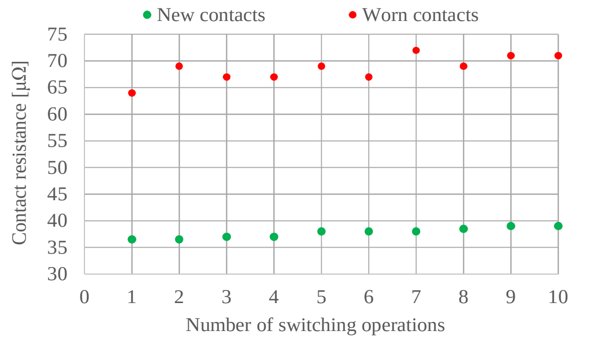


Fig. 5. Static contact resistance in function of the number of switching operations, measured for new (green) and worn (red) main contacts, with 2 A DC injected current

In Figure 6 the static contact resistance for the same pair of contact sets is plotted in function of the injected DC current. It is clearly visible that the measured static contact resistance decreases as the magnitude of the DC injected current is increased. At 6 A DC injected current the contact resistance becomes stable and the difference in the measured value between the new and worn contact sets becomes smaller. For these reasons, it is of advantage that the measurements should be performed with a possibly high DC injected current.

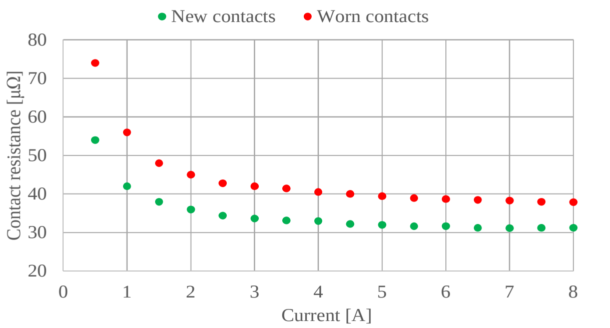


Fig. 6. Static contact resistance in function of the injected DC current, measured for new (green) and damaged (red) contacts

Measurements were performed for small current (less than 10 A) to indicate a significant difference in the values of the measured contact resistance. This dependence would not be observable for greater current values.

5.3. DRM Results

It is not always the case that the results of the DRM are noise free and easy to interpret. The main contact part of the curve may e.g. be impossible to distinguish from the arcing contact part. For this reason, different strategies including slowing down the contact movement during the switching operation of preheating the contacts can be employed [7]. However, it is the least intrusive policy to use a high DC injected current for carrying out the measurement. In the case of the tested MV switch-disconnector it was sufficient to use 150 A DC current to register very good quality dynamic contact resistance curves.

In Figure 7 the DRM results are shown for the MV switch-disconnector fitted with a new set of main contacts, and a worn set of arcing contacts. The red curve shows the measurement for dry contacts (no lubrication), while the green curve depicts a situation where the main contacts have been coated with semiconductive grease. The main contact parts of the two DRM curves look very similar, though very small fluctuations are noticeable for the lubricated contact set curve. In the arcing contact part there is a sharp peak visible for the dry contacts curve, but it is probably due to a random bounce of the arcing contacts.

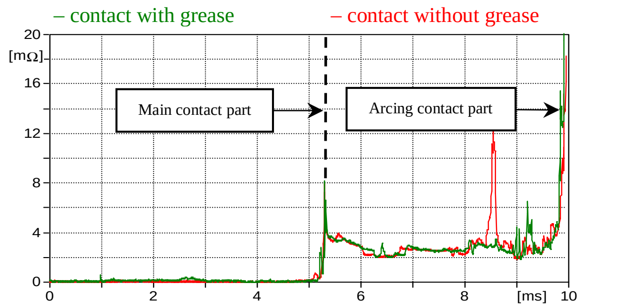


Fig. 7. DRM curves for the new main contact set with (green) and without (red) grease, and worn arcing contact set

In Figure 8 the results of a similar measurement are plotted, where the MV switch-disconnector comprised a set of worn main contacts and a set of new arcing contacts. Again, the red curve represents a situation where the main contacts were dry, while the green curve corresponds to main contacts lubricated with the semiconductive grease. The main contact part for the worn contact set exhibits a significant increase of the contact resistance (fluctuations in the plot).

As far as the arcing contact part is concerned, the average contact resistance of the new arcing contacts is about 1.5 mΩ, while for the worn arcing contacts in Figure 7 it is 3.0 mΩ. It is also noticeable that the duration of the arcing contact part of the curves is about 0.5 ms less for the worn arcing contacts (Figure 7) compared to the new arcing contacts (Figure 8). This indicates that the worn arcing contacts became shorter as a result of multiple switching operations accompanied by electrical arcing.

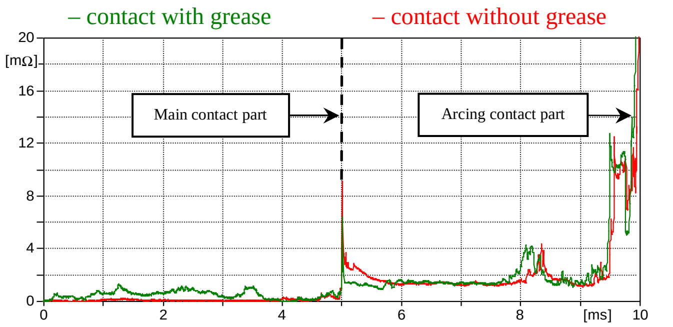


Fig. 8. DRM curves for the worn main contact set with (green) and without (red) grease, and new arcing contact set

Interesting observations can be made by analyzing graphs of the cumulative area under the contact resistance curves [8]. The impact of the semiconducting grease on the contact resistance of the main contacts was not visible from the low current static AC measurements shown in Figure 4. However, after looking at the plot in Figure 9 the impact of grease becomes clear.

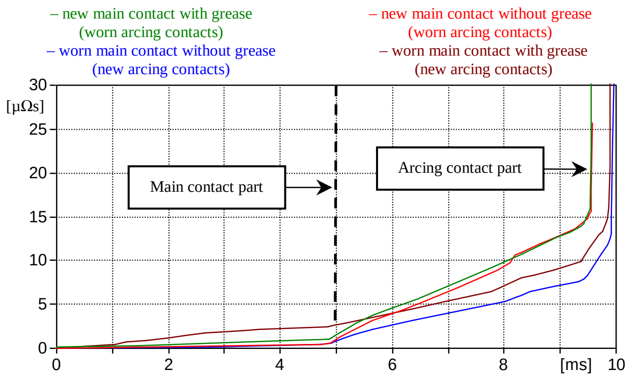


Fig. 9. Comparison of the cumulative area under the DRM curves for all measurements

The areas under the contact resistance curves plotted in Figure 9 can be calculated for both the main contact and the arcing contact parts, to give a clear indication of the contact condition. The calculated values of this cumulative area are gathered in Table 1.

Table 1. Calculated cumulative area under the resistance curves

Main	Arcing	Grease	ΣR main contacts	ΣR arcing contacts
			[μΩ·s]	
New	Worn	No	0.55	14.30
New	Worn	Yes	0.98	14.32
Worn	New	No	0.44	12.52
Worn	New	Yes	2.46	12.63

In the column named "ΣR main contacts" of Table 1 the cumulative contact resistance for all four configurations of the main contact sets is listed. It is clear that the application of the grease significantly increases the main contact resistance. This effect is particularly pronounced for the worn contact set. In the column named "ΣR arcing contacts" of Table 1 the cumulative contact resistance for the arcing contacts is presented. Clearly, worn arcing contacts have a higher contact resistance, even though their arcing time is 0.5 ms shorter.

6. CONCLUSIONS

For the proper functioning of high power switches it is necessary to monitor the contact resistance of both main contacts and arcing contacts. Static methods can only give a rough indication of the main contact state and do not yield any information regarding the arcing contacts. The DRM method renders it possible to extract more information regarding the condition of both main contacts and arcing contacts.

In order to obtain accurate measurements it is best to use high DC injected current. High current magnitude renders it possible to decompose the contaminations from the surface of the contacts, which would otherwise obscure the result of the measurements.

The presence of semiconductive grease affects the contact resistance of the main contacts, but this increase is difficult to detect with low current static measurements. However, the contact resistance difference becomes very clear when the DRM is performed.

The DRM method can be useful for developing new coatings and greases for switch-disconnector main contacts. The condition of the contacts after repetitive switching operations is easier to verify with the DRM method.

7. LITERATURE

[1] Stanisic Z.: Method for Static and Dynamic Resistance Measurements of HV Circuit Breaker, 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe), Manchester, 5-7 Dec.2011

[2] Holm R.: Electric Contacts, Theory and Applications, Ber1in, Springer-Verlag, 1967

[3] Kassman Rudolphi A.; Jacobson, S.: The contact resistance of rolling silver coated copper contacts, Electrical Contacts, 1997., Proceedings of the Forty-Third IEEE Holm Conference on , pp. 33-40, 20-22 Oct. 1997

[4] Khayam U., Risdiyanto A., Suwarno: Reducing Electrical Contact Resistance at Highly Loaded Copper Conductor using Nickel and Silver Coating, 2013 Joint International Conference on Rural Information & Communication Technology and Electric-Vehicle Technology (rICT & ICeV-T), Bandung, 26-28 Nov. 2013

[5] Kassman Rudolphi A., Jacobson S.: Gross plastic fretting-mechanical deterioration of silver coated electrical contacts, Wear Vol. 201, pp. 244-254, 1996

[6] Tingting C., Wenjun Z., Guangyao J., Zhiyong Y., Gao W.: Influence of the Injected Current on Dynamic Contact Resistance Measurements of HV Circuit Breakers, 2014 China International Conference on Electricity Distribution (CICED 2014), Shenzhen, 23-26 Sep. 2014

[7] Landry M., Turcotte O., Brikci F.: A complete strategy for conducting dynamic contact resistance measurements on HV circuit breakers, Power Delivery, IEEE Transactions on, vol. 23, pp. 710-716, 2008

[8] Landry M., Caron J., Ouellet G., Bastien R.: A new method for measuring the main contact resistance of 25 kV SF Gas FB4-type circuit breakers, the Circuit Breaker Test Maintenance Conf., Jackson, MS, Sep. 6–8, 1999

POMIARY DYNAMICZNEJ REZYSTANCJI PRZEJŚCIA DLA ROZŁĄCZNIKA ŚREDNIEGO NAPIĘCIA

Pomiar dynamicznej rezystancji styków jest skuteczną metodą diagnostyki stanu aparatu zestykowego. Metoda ta może być wykorzystana do przewidywania możliwej liczby operacji łączeniowych, które mogą być przeprowadzone przed wymaganym przeglądem technicznym urządzenia. Z uwagi na fakt, iż różne materiały stykowe charakteryzują się zróżnicowanymi parametrami mechanicznymi i elektrycznymi, metoda pomiarowa zaprezentowana w artykule może zostać użyta do poprawy istniejących konstrukcji łączników elektroenergetycznych. Niniejszy artykuł przedstawia wyniki pomiarów statycznej oraz dynamicznej rezystancji styku przeprowadzonych dla rozłącznika średniego napięcia. Rezystancję styku zmierzono w funkcji prądu przepływającego przez badany zestyk oraz w funkcji liczby przeprowadzonych operacji łączeniowych, odpowiednio dla nowego i eksploatowanego układu stykowego. Pomiary wykonano przy użyciu czteroprzewodowej metody, z wykorzystaniem cyfrowego oscyloskopu zapewniającego wysoką częstotliwość próbkowania.

Słowa kluczowe: aparaty elektryczne, metody diagnostyczne, pomiary rezystancji, rezystancja styku, rozłącznik.