Impact of pre-strike arc on contacts degradation after short circuit current making operation in medium voltage air load break switches

Naghme Dorraki, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, naghme.dorraki@ntnu.no
Marius Strand, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, mstran@stud.ntnu.no
Kaveh Niayesh, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, kaveh.niayesh@ntnu.no

Abstract

Medium voltage load break switches are required to perform a number of making operation while passing of short circuit current that could be more than tens of kiloamperes. Using air-filled devices as an alternative to SF_6, which is a high impact greenhouse gas, makes the switch more environmentally friendly but leads to more challenging making operation due to higher arcing times and dissipated energies between the contacts. In this case, the pre-strike arc could lead to contacts welding and degradation, which is highly undesirable. This paper reports on an investigation of the pre-strike arc impact on erosion and welding of copper/tungsten (20/80) arcing contacts during short-circuit making operations. For this purpose, a synthetic test circuit consisting of a high current source in combination with a high voltage one is used. Experiments are conducted for different operation voltages, while the short circuit current is kept constant at 22 kA. Mass loss measurement and visual inspection of eroded/welded contacts are examined with regard to pre-strike arc impact on their degradation. The contacts are welded by three times repeating the test at operation voltage of 20 kV and short-circuit current of 22 kA and failed to re-open. Besides, an increase in the contacts' mass loss with arcing time is observed while the making current is constant. This is an indication that the pre-strike arc energy highly impacts the switch reliability and service life.

1 Introduction

Considering the crucial role of Load Break Switches (LBS) in Medium Voltage (MV) distribution networks, high reliable operation of MV-LBS is required [1, 2]. An MV-LBS must be able to interrupt load currents and close under fault conditions. Making of short circuit current results in fault current flow through the contacts while closing. Although MV-LBS are designed to carry fault currents of tens of kiloamperes up to few seconds in the closed position, we should consider that the current flow starts before contacts full touch moment when arc formation makes a bridge between the contacts, which will deteriorate the contacts' surfaces. The local electric field strength between the contacts increases while closing, which causes a breakdown in the insulation gas and arc burning before contacts' touch. The short circuit current flows through the pre-strike arc causes high energy dissipation between the contacts, which are partly absorbed by contact surfaces leading to their melting and evaporation. Closing the contacts with melted surfaces could lead to welding the contacts to each other and failure to re-open, which is one of the main reasons for failure in this type of switches. The stresses applied to the contact are expected to be higher during making operation compared to current interruption because of higher arc energy dissipation between the contacts [3]. The dissipated energy between contacts could be limited by arcing time, which is dependent on the dielectric strength of the insulation gas. Although SF_6 supports the design of compact, low cost, and reliable MV-LBS due to high dielectric strength, it has a high environmental impact, which put an end to using SF_6 in gas-insulated switchgear. Regarding cost-effective and environmentally friendly insulation gas, air or air mixtures could be an alternative to SF_6 [4]. However at the pressure of one bar, air with dielectric strength of 3 kV/mm causes higher arcing time compared to SF_6 with dielectric strength of 8.9 kV/mm at same making test condition which makes the switch operation even more challenging.

From the aspect of arcing contact erosion, several theoretical and experimental investigations have been done [5-7]. Simulation models have been developed based on arc-metal contacts interface to explain arc behavior under the injection of particles and metal vapors [8, 9]. Several parameters have been calculated,

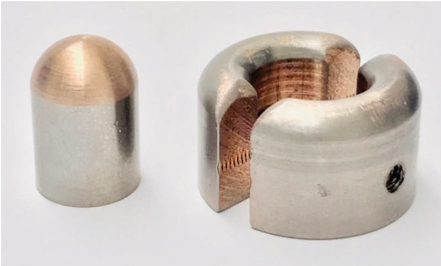

Fig 1. Electrical contacts made of W/Cu (80/20). Pin is the fixed contact (cathode) and split tulip is the dynamic one (anode).

such as contacts surface temperature, material transfer rate, arc temperature, thermal and electrical conductivity [10, 11].

It has been shown that the erosion mechanism at high current is different from the low current. Several factors affect the electrical contacts erosion in switching operation such as arc energy, arcing time, gap distance, closing velocity, contacts shape, and material properties [12]. Besides, there is still a lack of understanding of the impact of pre-strike arc on contacts erosion during making operation in fault conditions.

In this work, we focus on the impact of the pre-strike arc on the contacts degradation during making operation. A spring-type drive test object and a synthetic test circuit are employed. Arc electrical characterizations and mass loss measurement are used to find a meaningful relationship between the pre-strike arc parameters and the contacts degradation.

2 Experimental set-up

For the test type switch, the stationary contact is a pin with a diameter of 10 mm, and the dynamic one is a split tulip with an outer diameter of 20 mm and an inner diameter slightly less than 10 mm. The contacts are shown in figure 1. The pin is the anode and the split ring is the cathode with an inner diameter slightly smaller than the pin to provide fully touch of the contacts in closed position. The contacts are made of copper-tungsten (20/80), and the closing velocity is 3 m/s. The closing speed and the material type are chosen not to differ too much from the commercial product. The test circuit is a synthetic making circuit based on the IEC 62271 standard [13]. The circuit includes two parts; high current and high voltage sources. The high voltage circuit supplies the test voltage for dielectric breakdown while the switch is closing. Once the breakdown happens, a signal is sent to the high current source to initiate the flow of the transient making current. A schematic of the synthetic circuit is shown in figure 2 (a). The test object is a spring-type switch with axisymmetric arcing contacts. The synchronization between the time of breakdown by the synthetic circuit and closing the test object is achievable through the time setting for the release of the dynamic contact by a solenoid magnet (figure 2 (b)) A sensor records the position of the dynamic contact over time, making it possible to record the arcing time and length while contacts are closing. A Pearson current probe measures the arc current and a 6015A Tektronix voltage probe measures the arc voltage. To avoid the interference of electromagnetic noises, an optical system transmits the measured data to record them.

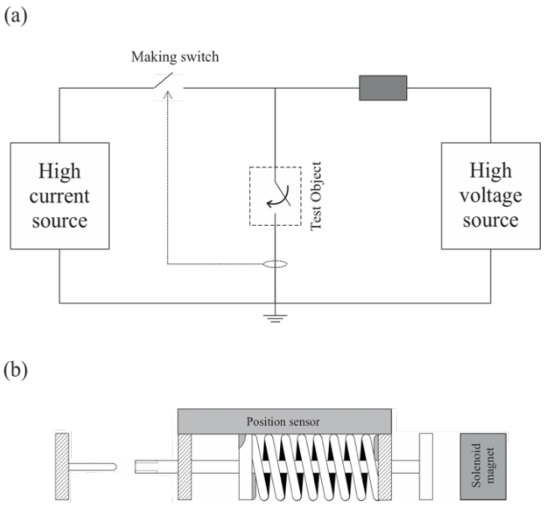

Fig 2. Schematic of the synthetic circuit (a), and the test-object.

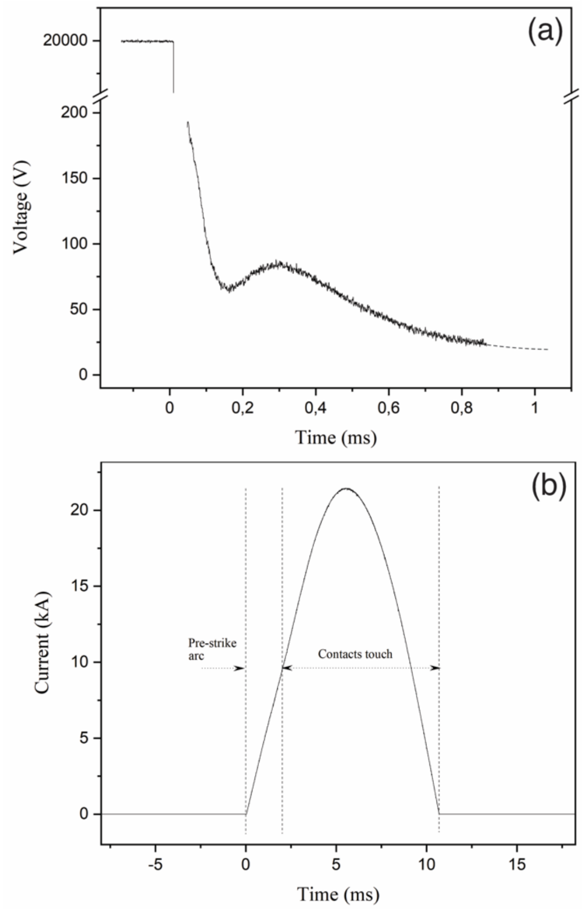

Fig 3. Arc voltage at 20 kV test voltage(a) and 50 Hz half-cycle short circuit current (b).

To make different arcing times to investigate the impact of pre-strike arcing on the contacts erosion and welding, two test voltages of 10 kV and 20 kV are applied to the test object with a short circuit current of 22kA. The fault currents duration has a tolerance of one to two milliseconds because of inaccuracy in the control system for the synthetic circuit. The difference does not make significant changes in the pre-strike arc current since di/dt is approximately constant in all the tests.

In order to figure out how long the eroded contacts can withstand fault conditions, each test has been repeated on the same set of samples until they weld to each other. The arcing time and mass loss are measured after each test. Figure 3 shows a typical arc voltage and current waveforms. The voltage waveform shows a sharp fall from the dielectric breakdown voltage at 20 kV to arc voltage, which is in the order of tens of volts. The first 50μs of the voltage fall is neglected due to interference with electromagnetic noises caused by air breakdown. Because of limitation on oscilloscope bandwidth, the arc voltage is measured for the first millisecond of arc burning while expecting to decay slightly to 13 V, which is the minimum voltage drop across the plasma sheath in front of the contacts [12, 14]. Figure 3 (b) shows the 50 Hz half-cycle of sinusoidal current with an amplitude of 22 kA. The waveform is divided into two parts. The pre-strike arc burns for 2.2 ms, while the current rises to ~9 kA. The rest of the current passes through the contacts when they are in touch.

For the sake of accuracy in the obtained results, each test has been repeated for three different samples. The contacts were cleaned after each test, and the mass loss was measured with an accuracy of 0.00001 gr.

3 Results

A summary of results including number of tests at two test voltages of 10 and 20 kV with constant fault current of 22 kA is shown in Table 1. The results show an increase in mass loss with pre-strike arcing time by repeating the test at each specific sample. The highest arcing time is measured for samples 02 and 03 for the third time of repeating the test (3^{rd}-Table 1), which is about four milliseconds and resulted in welding of the contacts. The pre-strike arcing current rises to ~20 kA before the contacts' touch.

At the test voltage of 10 kV, the results show the mass loss is higher for the second time of repeating the test than the third time. Even for the test voltage of 20 kV, there is a slight difference between the mass loss for the second and third times of repeating the tests. This is an indication of arc ignition at different spot of the contact's surface.

Visual inspection of the pin's eroded area at different test conditions is taken to clarify the difference in mass loss changes. Figure 4 shows the pin's eroded surface for the first and the second samples of each test voltage. The arc ignites at a random spot on the contact's surface by air breakdown. At the test voltage of 10 kV, arc hits the same spot in case of sample one, while for sample two at the second time of repeating the test, two spots close to each other are observed in the side view of the contacts, and eroded surface is larger compared to sample one at the second time of repeating the test. Therefore, hitting at the same spot for arc ignition causes higher mass loss, which could be a reason for electric field enhancement at sharp points or more conductive area due to aggregated molten copper compared to the rest of the contact's surface.

For the test voltage of 20 kV, the contact is eroded for more than 50 % of the first test's surface area. The mass loss at this test condition is more than ten times higher than the test voltage of 10 kA. For the second time of repeating the test, the erosion almost covered the whole contact's surface. After the third time, the contact's surface is totally burnt for sample one, and some deformation on the contact's shape is observed on the side view of the pin. The third time of repeating the test for sample two at test voltage of 20 kV and short-circuit current of 22 kA, causes the contacts to weld and fail to re-open.

Table 1. The arcing time and mass loss for each test and repeated for three times for test voltage of 10 kV and 20 kV with constant fault current of 22 kA.

Breakdown Voltage: 10 kV		**Number of tests**		
		1st	**2nd**	**3rd**
Sample 01	**Arcing time (ms)**	1.13	1.37	1.37
	Mass loss (mg)	6.62	35.19	32.08
Sample 02	**Arcing time (ms)**	1.15	1.32	1.37
	Mass loss (mg)	7.32	13.99	24.08
Sample 03	**Arcing time (ms)**	0.98	1.41	1.47
	Mass loss (mg)	3.96	53.28	28.64

Breakdown Voltage: 20 kV		**Number of tests**		
		1st	**2nd**	**3rd**
Sample 01	**Arcing time (ms)**	2.5	3.35	2.855
	Mass loss (mg)	67.44	203.68	104.59
Sample 02	**Arcing time (ms)**	2.18	2.73	4.45
	Mass loss (mg)	69.71	86.8	334.47
Sample 03	**Arcing time (ms)**	2.62	2.62	3.58
	Mass loss (mg)	65.46	128	336.01

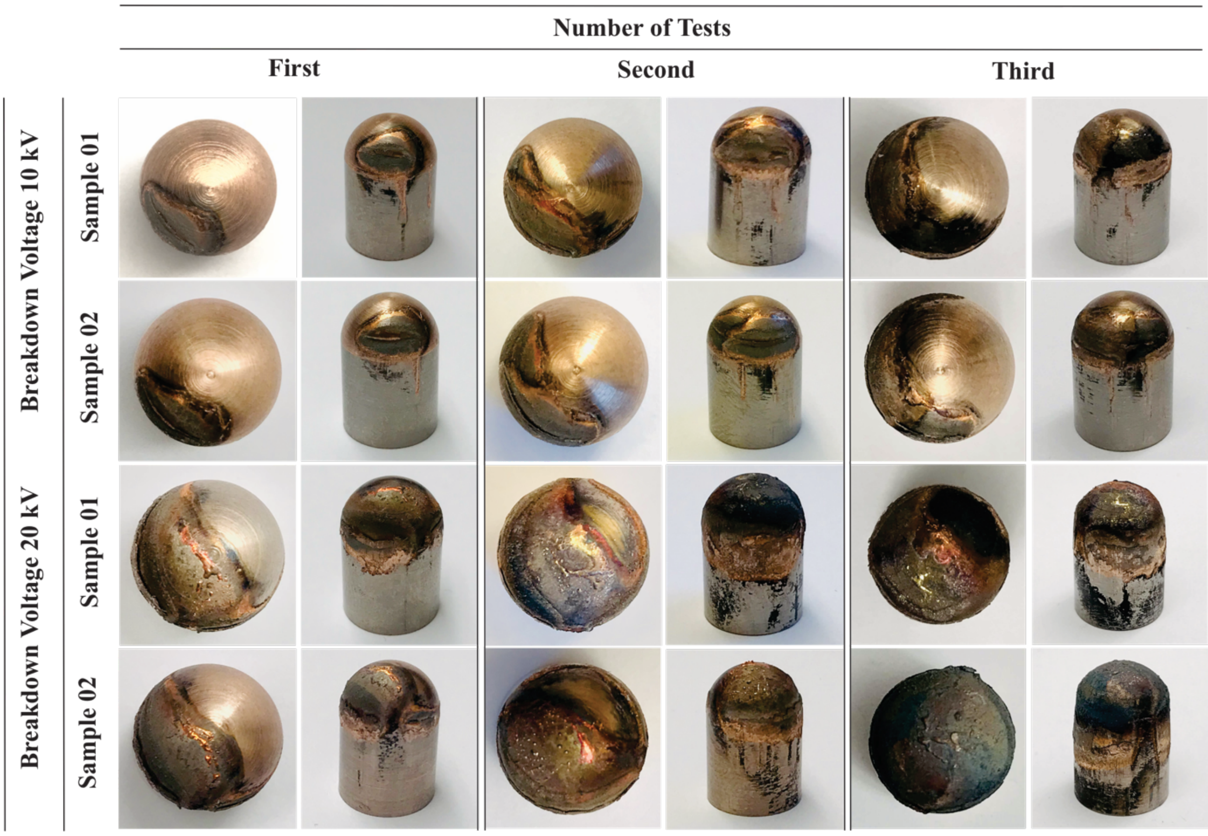

Fig 4. Eroded contacts' surface after each three times repeating the test at test voltage of 10 kV and 20 kV when a short circuit current of 22 kA passed through the contacts.

4 Discussion

Making operation of MV-LBS under fault condition is the main failure reason of the switch. The switching behavior at different pre-strike arcing times with the same short circuit current has shown the interaction between the arc and the contacts could have a deteriorating impact on switch service life by heating up the contacts surfaces to melting and evaporation points and occasionally welding them to each other in the closed position, as has occurred after three times of repeating the test at the voltage of 20 kV and fault current of 22 kA. At test voltage of 10 kV, although the contacts could withstand a couple of times more than the eroded contacts at 20 kV, we should take into account that gradual erosion of the contacts could lead to shortening the length of the contacts that would cause failure in current interruption.

Mass loss measurement is a proper method to get an approach on the contacts' erosion and prediction of the switch failure, though it needs a dedicated assessment of the results. At test voltage of 10 kV, the second time of repeating the test shows higher mass loss compared to the third time. It can be seen in figure 4 for the contacts surface erosion at 10 kV that the arc did not ignite at same spot by dielectric breakdown. For contacts with smaller front area, the arc could initiate from the same spot each time, enhancing the erosion and shortening the switch service life. Therefore, the size of the contacts plays a crucial role in enduring longer under fault conditions.

Regardless of the eroded area impact on pre-strike arcing time, the mass loss for different arcing time is plotted in figure 5. The results show an increase in pre-strike arcing time causes higher mass loss and erosion of the electrical contacts. Higher arcing time does not necessarily lead to higher energy dissipation between the contacts since the increase in arc current in the order of kiloampers follows by a slight decrease in arc voltage. However, higher arcing time means more time for heat conduction between the arc and the contacts to melt and evaporate the metal surfaces. In the closed position, the melted metals cool down and could weld the contacts to each other.

The obtained results indicate that the rate of contact erosion caused by making operation is increasing with increasing arcing time which is mainly because of partly absorption of dissipated arc energy by contacts' surfaces. Therefore, if the contacts are in full-touch in the closed position, the erosion only depends on the pre-strike arc time and energy, not the amount of short-circuit current. Therefore, the influential factors and involved parameters in the switch operation should be designed to decrease the impact of pre-strike arc to improve the switch service life.

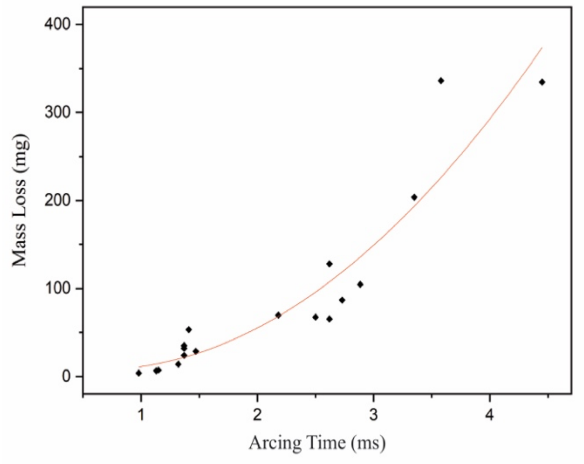

Fig 5. Mass loss as a function of arcing time when the short circuit current is kept constant (22 kA)

5 Conclusion

The electrical arcing contacts erosion/welding in an MV-LBS during making operation was investigated to understand the impact of the pre-strike arc before the contacts touch on switch failure. Experiments were conducted for test voltages of 10 kV and 20 kV, while the 50 Hz half-cycle sinusoidal short circuit current with peak of 22 kA was kept constand.

The results showed switch failure to re-open after three times repeating the test on the same set of contacts at test voltage of 20 kV. Further, an increase in mass loss with arcing time at the same current proved the impact of pre-strike arc on the contacts erosion/welding.

This work should be continued by further studies on optimizing the switch design and finding the interrelation between different parameters involved in switch operation like the speed of closing and the contacts material to minimize the impact of pre-strike arc on the contacts welding.

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