PECULIARITIES OF NON-SUSTAINED DISRUPTIVE DISCHAGES AT INTERRUPTION OF CABLE/LINE CHARGING CURRENT

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ABSTRACT

It has been found out that NSDD probability increases at cable/line charging current interruption compared with no-load test. This fact has been explained by formation of contact welds at closing of the preliminary charged cable/line. These welds being torn apart at the following contact partition may serve as a source of macro-particles or surface irregularities resulting in increased probability of NSDD.

1. INTRODUCTION

Non-sustained disruptive discharge (NSDD) represents a phenomenon appeared within a fraction of seconds after current interruption. NSDD is generally attributed with interruption of short circuit currents by vacuum circuit breakers (VCB). After appearance of NSDD high-frequency (HF) current determined by the stray parameters of circuit adjacent to the breaker flows through its contacts. This current is interrupted shortly afterward so that power frequency current does not sustain this breakdown. So, at the millisecond time scale NSDD cannot be traced out from the current record. At the same time load voltage experiences sudden fall providing appearance of the DC content which gradually decays afterward. However, resulting overvoltages are generally far from dangerous. So, from the customer standpoint NSDD does not represent a phenomenon to be cared for. Eventually due to this reason NSDD is treated differently by different standards: they are not recognised by American, Russian and Chinese national standards but are reflected in new IEC622100 edition, which does not allow having more than 3 NSDD at short circuit performance test.

Mechanism of NSDD appearance is not entirely revealed. Two prevailing theories include breakdown initiated by macro-particles [1] and breakdown caused by sudden fluctuation of field emission [2,3].

Whatever the reason is the following experimental facts shall be taken into account when NSDD at short circuit interruption is considered:

- NSDD probability strongly depends on the recovery voltage [1,4];
- NSDD probability depends on the mechanical characteristics of the breaker [4,5];
- NSDD time delay is distributed statistically and can reach fractions of second [1,4,5];
- NSDD probability demonstrates weak dependency on the value of interrupting current. (In [4] NSDD has been observed at currents of order of several milliamps);
- At no load interruptions conditioning effect is observed [4].

Recently additional requirement associated with NSDD has been introduced by IEC for cable/line charging current interruption. In accordance with this requirement not more than 1 out of 9 interrupting tests can be followed by NSDD. As for this application NSDD may result in generation of dangerous overvoltages investigation of this phenomenon becomes important irrespective to the current standardization approach.

The aim of the present study was to investigate peculiarities of NSDD behaviour at interruption of cable/line charging current.

2. EXPERIMENTAL SET-UP

During cable/line charging current interrupting test VCB shall interrupt capacitive current 4-31.5A after closing of the preliminary charged cable/line. At closing high frequency current (up to 2kHz) having amplitude ~600A flows through closing VCB contacts. We assumed that this current might provide destructive effect on the contact surface due to possible contact welding. Consequently this current should be modelled properly. At the same time breaking current is so small that it can barely provide essential effect. Therefore in the experimental set described below we did not model this current.

2.1 Test circuit

Fig. 1 illustrates a layout of test circuit.

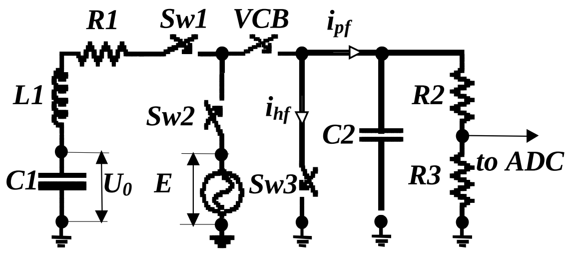

Fig. 1. Test circuit

The circuit consists of:

- Power frequency circuit (E-Sw2-C2), similar to the one described in [4], provided recovery voltage;
- High frequency circuit (C1-L1-R1-Sw1-Sw3) provided HF current at closing.

Main electrical parameters of these circuits are shown in the table below

High-frequency circuit		*Power-frequency circuit*	
U_0, initial	*39kV*	*E, rms*	*16kV*
C1	*1.6μF*	*power frequency*	*50Hz*
L1	*5mH*	*C2*	*1nF*
R1	*4Ohm*	*R2*	*270MOhm*
Natural frequency	*2kHz*	*R3*	*0.1MOhm*
i_{hf}	*600A*	*i_{pf}, rms*	*7mA*
damping factor	*0.9*	*(R2+R3)C2 time*	*270 ms*

2.2 Test duties

Test duty "CO"

At test duty "CO" Sw2 and test VCB are at first open. Sw1, Sw3 are closed. C1 is charged to 39kV. When test VCB closes C1 is discharged through VCB main contacts (moment 1 in Fig.2). Afterward Sw1, Sw3 open to isolate HF circuit from the power frequency one. Sw2 closes, C2 starts charging (moment 2 in Fig.2). When E reaches its peak test VCB departs its contacts (moment 3 in Fig.2). AC voltage with 100% DC shift is applied to open contacts of the test VCB. DC component decays afterward with time constant ~270ms.

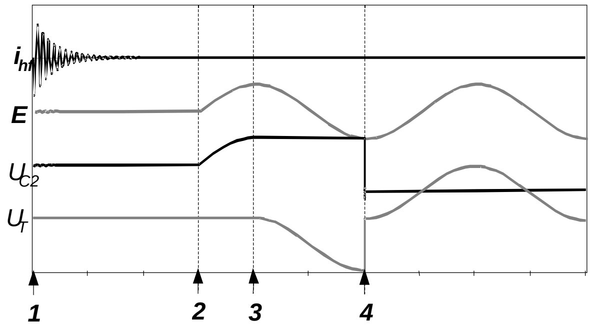

Fig. 2 . Test circuit operation

In case of appearance, NSDD is identified by abrupt change of C2 voltage (moment 4 in Fig.2). NSDD time delay is calculated as a time interval between partition of the main contacts of test VCB and NSDD appearance.

Source voltage has been applied for 4s after VCB opening.

Test duty "O"

At test duty "O" preliminary closing of test VCB has been excluded. The rest of the test procedure has been the same as for test duty "CO".

2.3 Test Sequence

Test sequence for each VCB included 100 "O" test duties followed by 50 "CO" test duties.

2.4 Test VCB

4 types of VCB differed by applied vacuum interrupters and actuators were subjected to the mentioned test sequence.

3. EXPERIMENTAL RESULTS

Fig. 3 demonstrates cumulative distribution of NSDD time delays for all VCB subjected to test sequence.

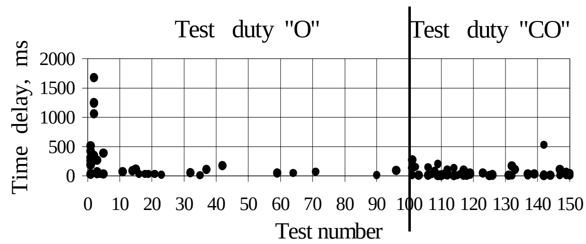

Fig. 3. Distribution of NSDD time delay

Fig. 4 shows cumulative frequency of NSDD appearance for all VCB for every 10 successive tests.

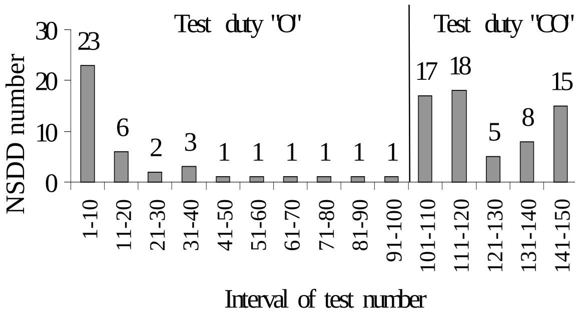

Fig. 4. Cumulative frequency of NSDD appearance

NSDD probability related to complete “O” and “CO” test duties for each tested VCB is shown in Fig. 5. Note that this data takes into account only first NSDD, ignoring subsequent breakdowns.

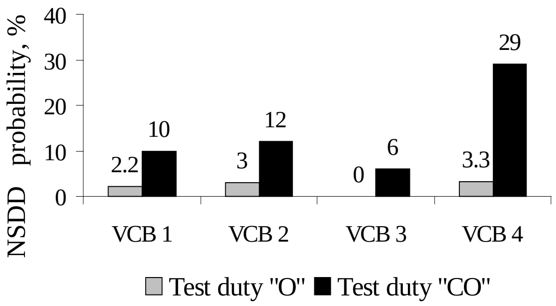

Fig. 5. NSDD probability for different VCB

4. DISCUSSION

The difference in NSDD appearance for test duties “O” and “CO” is clearly seen from the abovementioned experimental results for all test VCB. At test duty “O” NSDD conditioning has been observed that also coincides with the results presented in [4]. At test duty “CO” NSDD probability increases, no conditioning effect is observed. It looks as new mechanism of NSDD initiation appears.

Let’s regard processes appearing at “CO” test duties in details (Fig.6).

When VCB contacts are closing voltage of the preliminary charged capacitor C1 (39kV in the present tests) is applied to contact gap. Assuming dielectric strength of the gap to be equal ~40kV/mm one can expect pre-breakdown to appear at contact distance of ~1mm. With the closing speed equal to 1m/s this will result in HF current flowing through the closing contacts within ~1ms. Let’s remind that natural frequency of this current is 2kHz, therefore about two cycles of these current will flow through the gap before contact closing (Fig.6).

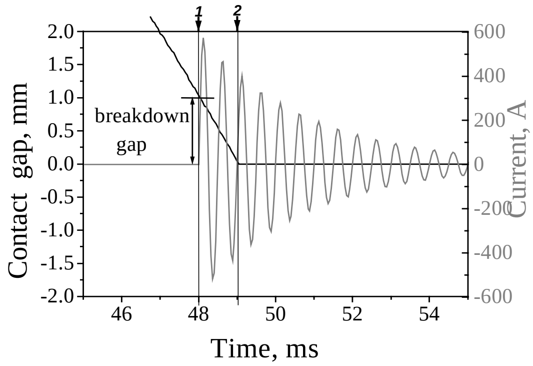

Fig. 6. Current and contact gap when closing

Arc energy determined by this current can be calculated as follows:

$$W_{arc} = \int_0^{T_a} |I_a(t)| \cdot U_{arc} dt \qquad (1),$$

where U_{arc} - arc voltage (~30V); $I_a(t)$ - arc current; T_a -arcing time.

Substituting abovementioned values into equation *(1)* one can get the following estimate for energy input into electrodes:

$$. W_{arc} = 16J$$

In order to evaluate the maximum size of the area which can be welded due to this energy input, one can assume that all energy has been spend to heat and melt sphere with a certain diameter D. Than the following energy balance equation can be written:

$$W_{arc} = \rho \cdot \frac{\pi}{3} \cdot D^3 \cdot c \cdot (T_{melt} - T_0) + J \cdot \rho \cdot \frac{\pi}{3} \cdot D^3 \qquad (2),$$

where ρ - density, c - heat capacity, J - melting heat, T_{melt} - melting temperature for contact material; T_0 - initial temperature.

From this equation one can estimate maximum diameter D_{max} of the melted area substituting into equation *(2)* parameters of the applied contact material (CuCr70/30):

$$D_{max} = 0.9mm$$

Certainly this diameter provides an upper estimate as heat propagation has been ignored.

It seems reasonable to assume that this estimate determines maximum size of particle that can be torn apart at contact opening and that can be responsible for NSDD.

We evaluated the size of the melted area from another standpoint measuring welding force after closing at the same experimental conditions. Test VCB that shown the worst NSDD behaviour has been selected for this extra test. The distribution of weld force is illustrated in Fig.7.

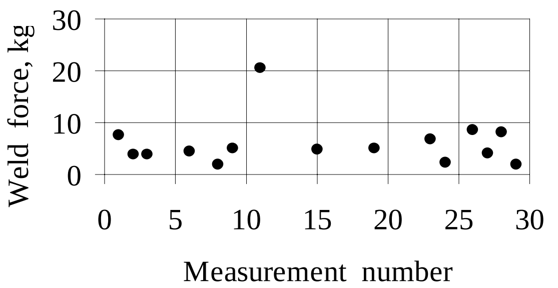

Fig. 7. Weld force distribution

As it follows from Fig.7 maximum registered welding force achieved 220N. If we apply the following equation for evaluation the size of the welded area [6]:

$$F_{weld} = {H \cdot S_{weld}}/{3} \qquad (3),$$

where H - contact material hardness;

S_{weld} - welding spot area,

we can estimate maximum diameter of the welded area to be 0.7mm, which is in reasonable agreement with the estimate derived from the equation of energy balance.

At last we observed in microscope the surface of the contacts subjected to abovementioned tests and found out the crater having 0.7mm in diameter (Fid.8)

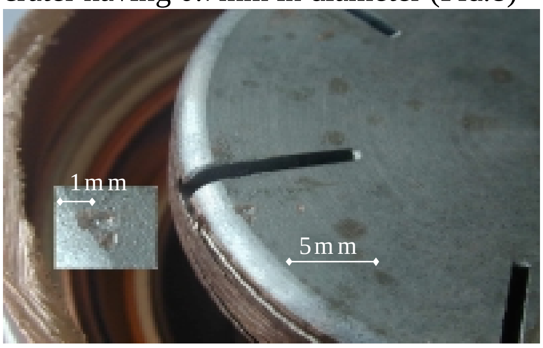

Fig. 8 Biggest crater

Such craters can eventually source appearance of macro particles affecting NSDD performance of VCB. At the same time appearance of such craters result in significant change of surface structure which may affect emission characteristics resulting in its turn in changing NSDD behaviour.

5. CONCLUSIONS

At standard cable/line charging current interruption test prescribed by IEC622100 probability of NSDD increases substantially compared with no-load interruptions. At the same time conditioning effect is not observed. These features can be explained with the formation of contact welds appeared as a result of HF current closing. At contact partition macro-particles having typical diameter of a fraction of mm may appear from these welds at a statistical manner. Eventually these particles might be responsible for the abovementioned peculiarities. At the same time mentioned welds form craters at contact partition providing substantial change of surface microstructure, which may result in changing emission performance of the VCB affecting in its turn NSDD behaviour.

6. ACKNOWLEDGEMENTS

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