"NON-SUSTAINED DISRUPTIVE DISCHARGES (NSDD)" – A NEW INVESTIGATION METHOD LEADING TO INCREASED UNDERSTANDING OF THIS PHENOMENON

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Abstract- NSDD are an intrinsic feature of vacuum circuit breakers and their distinctive properties are due to the excellent ability of a vacuum gap to interrupt high frequency currents. Until recent years they could not be detected during short circuit testing [1] due to their frequency band being beyond that of phenomena associated with standard 50 Hz testing. However, once discovered their occurrence has been interpreted as a sign of excessive distress of a vacuum interrupter [2].

This paper discusses work carried out to improve the understanding of this phenomenon so that an informed judgement of the real effects of this may be made.

The first part describes a simple test methodology, which has been developed to enable systematic investigations of NSDD without requiring expensive testing at high power test laboratories.

The second part describes and discusses voltage and time dependencies of NSDD on a large variety of circuit breaker and interrupter related properties.

As a result it can be stated, that the NSDD observed are caused by particles released due to mechanical vibrations during the opening operation of the circuit breaker, and that their probability increases significantly with increasing system voltage. However, there is **NO** direct connection between NSDD and the short circuit performance of a vacuum interrupter. The NSDD behaviour is instead strongly dependent on material, surface finish and cleanliness conditions of the individual interrupter components as well as on the manufacturing method of the vacuum interrupter itself.

1 INTRODUCTION

Non-**S**ustained **D**isruptive **D**ischarges (NSDD) are defined by Greenwood as "disruptive discharges between the contacts during the power frequency recovery voltage period resulting in a high frequency current flow, which is related to stray capacitance local to the interrupter" [1]. They are an intrinsic feature of vacuum circuit breakers and their distinctive properties are due to the excellent ability of a vacuum gap to interrupt high frequency currents.

Figure 1 represents a typical oscillogram of a 38kVrms three phase short circuit interruption test showing momentary collapses of the recovery voltage in the bottom phase (U3) due to two NSDDs (time from interruption 374 ms and 418 ms) which in turn cause voltage offsets in the other two phases (U1 and U2).

Although the duration of the discharge is very short of the order of a few µs, and depending on the circuit does not normally lead to re-establishment of a single 50Hz loop of the current just interrupted [3], the potential consequences of these NSDD are not clear, and this has led to many controversial discussions by experts [4], [5].

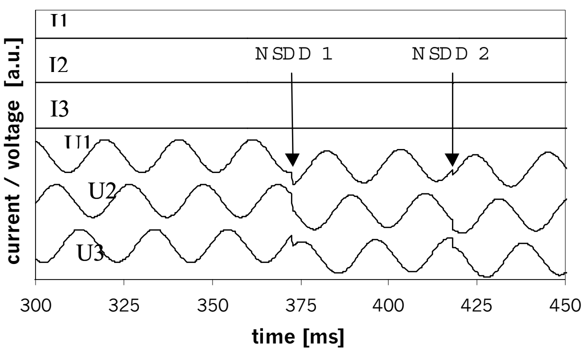

Figure 1: Typical Non-Sustained Disruptive Discharges in a three-phase circuit

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This paper discusses work carried out to improve the general understanding of this phenomenon.

The first part of the research was aimed at establishing a simple test procedure to enable systematic investigations of NSDD without requiring expensive test accesses at high power test laboratories.

The second part used the test methodology developed to study voltage and time dependencies of NSDD on a large variety of circuit breaker and interrupter related properties and by that to identify relevant and non-relevant parameters for the appearance of this phenomenon.

2 EXPERIMENTAL SETUP

2.1 The Electrical Circuit

In the frame of this work a simple test circuit has been developed to allow a systematic in house investigation of the NSDD phenomena without requiring expensive test accesses at high power test laboratories.

The outcome was an optimised RLC test-circuit as shown in Figure 2. It consists of a commercial three phase circuit breaker fitted with vacuum interrupters, a single-phase high voltage power supply (0 to 50 kVrms, 2 kW) and the necessary measuring equipment. The main electrical parameters are shown in table 1.

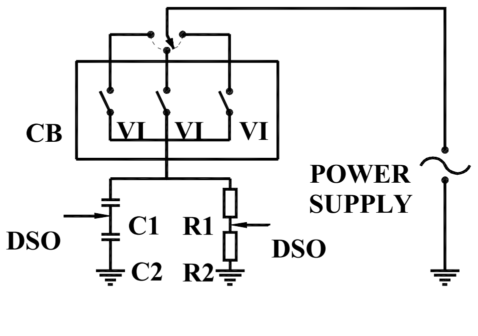

Figure 2: Electrical circuit used for NSDD investigation

The different types of vacuum interrupters and circuit breakers used in this investigation, both commercial and testing devices, will be referred to as VI1, 2, etc. and CB1 and 2, respectively. All voltage levels are given as rms values. The operation of the test circuit is described in paragraph 2.2.

Table 1: Electrical parameters of the test circuit

C1	Capacitance 1	50 pF
C2	Capacitance 2	500 nF
R1	Resistance 1	1 GΩ
R2	Resistance 2	500 Ω
Z	Impedance	63 MΩ
RC	RC - Time	50 ms

2.2 Operation of Test Circuit

When the circuit breaker is in closed condition, a 50 Hz current flows depending on the applied voltage and is limited by an impedance of 63 MΩ defined by C1, C2 and R1, R2 (e.g. 0.7 mA at 45 kV). These capacitors and resistors have also been used as capacitive and resistive dividers, which, when connected to a digital storage oscilloscope (DSO), allowed the measurement of the voltage on the load side of the circuit breaker.

After the opening (O) of the circuit breaker the vacuum interrupter interrupts the current and the applied voltage appears across the vacuum gap. The voltage on the load side of the CB will decay from its level at the instance of contact separation to zero depending on the RC-time (t = 50 ms) defined by C1, C2 and R1, R2.

If NSDDs occur, they will lead to fast and clearly measurable offsets in the load side voltage waveform, which allow the determination of the number, time and polarity of the NSDD.

2.3 Test Procedure

The following paragraph describes the test sequence, which has been used for the investigations described in this paper.

For each test a circuit breaker has been equipped with three vacuum interrupters of the same type. Then one phase of the CB was connected to the test circuit as shown in Figure 2.

The actual test sequence, if not marked otherwise, consisted of 30 close-open operations (CO) with an interval of about 10 s, which have been repeatedly performed at different voltage levels (e.g. 45 kV, 38 kV, 32 kV, 27 kV, 24 kV, 20 kV). After every opening the power frequency voltage was recorded for a period of 5 s and checked for the appearance of NSDD. Every individual NSDD was recorded together with information about polarity and time of occurrence measured from the moment of contact separation. The test was subsequently repeated for the interrupters in the two remaining phases. This resulted in a sample size of at least three interrupters for every investigated parameter, which was considered to be the absolute minimum needed.

3 EXPERIMENTAL RESULTS

The study showed that it was possible to generate and detect NSDD as a consequence of breaking currents in the order of milli-amperes. This is an important result and indicates to us that the NSDD phenomena is not indicative of the limit of interruption ability of a vacuum interrupter, but instead is a basic phenomenon related to interruption in vacuum at all current levels.

Using the experimental arrangement described above time and voltage dependencies of NSDD on a large variety of circuit breaker and interrupter related properties have been studied. The main results are presented in this chapter.

3.1 Time Dependence of NSDD

The time between contact separation and the appearance of an NSDD has been evaluated for more than 1000 events each for two different types of circuit breakers at a voltage of 45 kV.

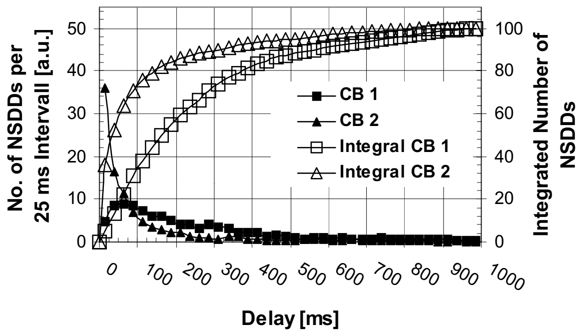

Figure 3: Time dependence of NSDD for two different circuit breaker types

Figure 3 shows the number of NSDD occurring within 25 ms intervals and integrated between 0 and 1000 ms from contact opening for both circuit breaker types and randomly selected interrupter types. The total number of NSDD observed for each circuit breaker type has been normalised to 100 a.u. (arbitrary units) to allow a meaningful comparison.

It can clearly be seen, that with CB 1 the highest probability for the appearance of an NSDD lies between 25 ms and 100 ms with a maximum of 9 a.u. between 50 ms and 75 ms. By contrast CB 2 shows a distinct maximum of 36 a.u. for the time interval 0 ms to 25 ms and a very steep drop for the following time intervals. This results in the fact that with CB 2 80 % of all NSDD occurred within 150 ms after contact separation, while it took 375 ms to reach the same level with CB 1. In both cases more than 99 % of all events occurred within one second after contact separation and no NSDD could be detected at times larger than three seconds up to the five second limit of measurement.

We believe that these results indicate that NSDD are particle induced breakdowns, initiated by particles that have been released within the interrupter as a consequence of mechanical vibrations caused by the operating mechanism of the circuit breaker, and that the significantly different time dependence of NSDD seen with both CB can be explained by the fact that they have distinct frequency spectra and time constants in respect to their vibration behaviour.

To corroborate this theory CB 1 was then used to perform sequences of four fast close-open (CO) operations at 45 kV within 1.2 s. The number of NSDD given in arbitrary units (a.u.), which occurred after each opening, based on more than 25 sequences can be seen in Figure 4.

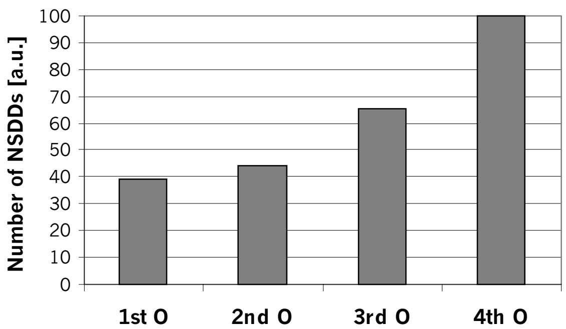

Figure 4: Number of NSDD depending on the number of O within a multiple CO sequence

It is noticeable that the probability for the occurrence of NSDD rises by more than 150 % from the 1st opening to the 4th one, which can be explained by a build-up of vibrations in the course of the operating sequence. We believe that thermal effects can be ignored as the maximum discharge current only amounted to less then 1 mA.

3.2 Voltage Dependence of NSDD

The voltage also has an important influence on the NSDD behaviour. Figure 5 shows the probability of an opening operation with at least one NSDD as a function of the applied voltage for three different types of vacuum interrupters and circuit breaker CB1.

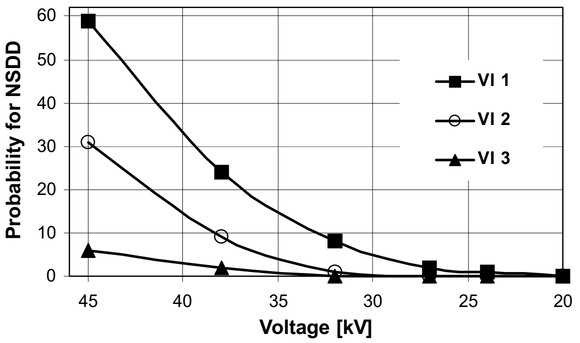

Figure 5: Probability of an opening operation with at least one NSDD as function of the applied voltage

It clearly indicates that the NSDD performance depends strongly on the type and condition of the tested interrupter. VI 1 shows a probability of NSDD more than six times higher than VI 3 over the entire investigated voltage range. The probability drops in all cases by at least 50 % when the test voltage is decreased from 45 kV to 38 kV and in no case could an NSDD be found at voltages below 24 kV which is the design rating for the interrupters tested.

The testing of the interrupters at higher than rated voltages allowed us to study the large numbers of NSDD shown. This behaviour allows a prediction about the NSDD performance at lower voltages after having performed tests at e.g. 45 kV.

During the course of the investigation conditioning effects were seen. This is illustrated in figure 6, which shows the number of NSDD after each opening depending on the number of subsequent openings at 45 kV for interrupters before and after conditioning.

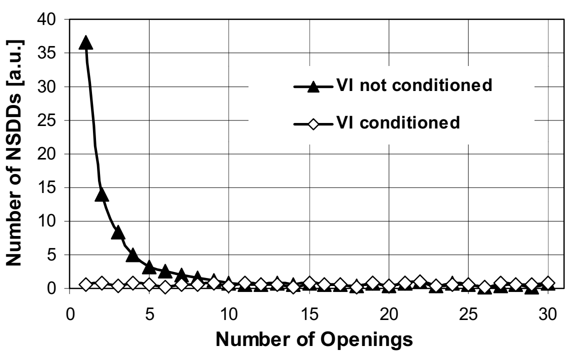

Figure 6: Number of NSDD depending on the number of subsequent openings both before and after conditioning at 45 kV

The filled symbols stand for the 1st 30 operations within a standard NSDD test. It can clearly be seen that the number of NSDD per opening drops from more than 35 after the first operation to an average level of less than one after 10 operations.
The second curve represents the same interrupters during a second series of 30 CO. It shows a relatively constant number of NSDD after every opening. On average the probability of NSDD was reduced by a factor of 10 by this means.

This effect can be explained by postulating that the released particles, which led to NSDD within the first 10 operations, have been destroyed by the NSDD themselves, and that the main source of particles has been depleted. However there appears to be a secondary source of particles with this type of interrupter which is not susceptible to this conditioning effect and leaves a small residual probability of NSDD.

It has to be pointed out, that the conditioning effect described in this paragraph has nothing to do with conventional voltage or current conditioning procedures normally used for vacuum interrupters.

3.3 Other Relevant Parameters

In this paragraph some other relevant parameters for the NSDD behaviour will briefly be described. All results relate to our standard test sequences at 45 kV.

The total number of NSDDs lay between 0 and 173 for different types of interrupters in an unconditioned state, which shows the clear influence of the type of vacuum interrupter.

The contact material and its surface condition play an important role too. Just by changing the type of contact material for the same type of interrupter the probability for NSDDs rose from an average of 4% to an average of 57 %. Also changing the surface condition of the contacts, but maintaining the type of contact material led to a drop in probability of NSDD from 45% to 11 %.

Another important parameter is the manufacturing process of the vacuum interrupter itself. Modifying, for example, the cleaning procedure of the components prior to the seal-off led to a significant decrease in the total number of NSDDs for a specific interrupter type.

3.4 Not Relevant Parameters

In the frame of this work many parameters were investigated, but not all of them had a significant influence on the NSDD behaviour.

After evaluation of several thousands of NSDD events no systematic correlation could be found between the probability for the occurrence of an NSDD and the polarity of the power frequency voltage at the instant of the NSDD.

The results also indicate that the NSDD behaviour does not depend on the performance of an interrupter during power frequency or BIL tests. That means that conventional conditioning procedures such as voltage conditioning not only do not appear to improve the NSDD properties of an interrupter, but also cannot even be used to check interrupters in respect to their NSDD performance.

4 CONCLUSIONS

Within the frame of this work the time and voltage dependencies of NSDD on a number of circuit breaker and interrupter related properties have been studied. This allowed us to identify relevant and non-relevant parameters for the appearance of this phenomenon and gave a much better understanding.

The results indicate that the NSDD detected are caused by particles released inside the vacuum interrupters due to mechanical vibrations during the opening operation of the circuit breaker and that their probability increases significantly with increasing system voltage.

However, the results also indicate that the NSDD do not reflect the voltage conditioning state of a new interrupter and that there is **NO** direct correlation between the occurrence of NSDD and the short circuit performance of a vacuum interrupter.

The NSDD behaviour was shown to be strongly dependent on interrupter design parameters such as material, surface finish and cleanliness conditions of the individual interrupter components as well as on the manufacturing method of the vacuum interrupter itself.

5 ACKNOWLEDGEMENTS

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