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Capacitive Current Interruption With Air-Break High Voltage Disconnectors

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Abstract—Capacitive current interruption with air-break disconnectors in a high-voltage network is an interactive event between the circuit and arc with a variety of interruptions and reignitions. In this contribution, first, a theoretical analysis related to this interaction is presented. The effect of capacitances at the source side (C_s) and load side (C_l) is investigated. Three distinct frequencies are identified as contributing to the voltage and current events in the circuit. Besides the power frequency quantities, a medium frequency transient arises related to the excursion of voltage across capacitances to the applied voltage, and a high-frequency transient arises due to charge redistribution between load- and source-side capacitance at reignition. Second, experimental results from an interruption measurement are studied in detail. Typical waveshapes of voltages across the capacitances, disconnector, and currents through the disconnector show that the transients during interrupted are in agreement with the theoretical analysis. Reignition voltage of the air gap and energy input to the arc on reignition are also studied. It is concluded that besides a higher interruption current and a higher power supply level, a lower C_s/C_l ratio leads to more severe interruption and longer arc duration. Finally, the actual status of IEC recommendations on testing, that has taken into account this arc-circuit interaction, is summarized.

Index Terms—Arc, capacitive current, disconnector, disconnect switches, high voltage, interruption, measurements, reignition, standards, substation, testing.

NOMENCLATURE

R_s, L_s	Inductance and resistance at the source.
C_s, C_l	Capacitance at the source and load side.
i_d	Current through the disconnector.
u_s	Voltage of the power supply of the network.
U_s	Value of u_s at $t = 0$.
E_m	Amplitude of u_s .

ω_p	Angular power frequency of u_s .
ϕ	Initial phase angle of u_s .
u_{cp}	Voltage across the capacitances at power frequency.
u_{cs}, u_{cl}	Voltage across C_s and C_l .
u_d	Voltage across disconnector.
u_r	Reignition voltage of the air gap.
HF, MF, PF	High, medium, power frequency.
U_E	Equalization voltage at HF oscillation.
R_H, L_H	Equivalent resistance, inductance of HF loop.
ω_{OH}, ω_{OM}	Resonance frequency at HF and MF.
β_H, β_M	Initial phase angle of HF and MF oscillation.
E_{arc}	Energy dissipation.
i_H, i_M	Current through disconnector at HF and MF.
u_{CM}	Voltage across C_s and C_l at MF.
U_r	Reignition voltage at $t = 0$.
U_{cs}, U_{cl}	Voltage across C_s and C_l at $t = 0$.
C_H	Capacitance of C_s, C_l in series.
δ_H, δ_M	Damping constant at HF, MF.
u'_{cl}	Calculated transient voltage across C_l .

I. INTRODUCTION

IN a power substation, disconnectors (in North America, disconnectors are called disconnect switches) are commonly used mechanical devices. The definition of a disconnector is: “A mechanical switching device which provides, in open position, an isolating distance in accordance with specific requirements” by the International Electrotechnical Vocabulary (IEV) 441-14-05. That means disconnectors only have a safety function. However, in practice due to parasitic capacitances such as from unloaded bus bars, lines etc. in the networks, there is always a capacitive current that disconnectors need to interrupt. Moreover, although not designed for interrupting current, disconnectors do have a certain current interrupting capability thanks to one or more moving contacts during switching operations. According to the IEC 62271-102 [1], this small capacitive current, which is called “negligible current”, does not exceed 0.5 A for rated voltage 420 kV and below. In the past, the current

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interrupting capability of the air-break disconnectors has been therefore taken as 0.5 A or less. Nowadays, with the fast development of power networks in the world, user's requirement for small capacitive current interruption using air-break disconnectors frequently exceeds the above stated 0.5 A.

Literature related to capacitive current interruption using air-break disconnectors is sparse, for instance [2]–[15]. A good overview is provided by [12]. The principal work in the past is that from F. E. Andrews in the 1940s. Some results from literature such as [3], [8] were collected for IEC and IEEE recommendations [11]. However, the literatures provide only a limited insight into the mechanism of the capacitive current interruption by an air-break disconnector. In this contribution we will therefore present a more detailed approach to this electrical phenomenon during arcing that, by the associated voltage and current transients, may endanger nearby network components such as (instrument) transformers.

Specifically, a study both on theory and experiment is presented in detail. In principle, the capacitive current interruption capability of a disconnector may be affected by various factors such as air humidity, wind speed, earthing type of the system and phase spacing. In this paper, however, only effects of electrical parameters, such as capacitances, inductances, etc. are evaluated. First, a theoretical analysis for steady and transient state phenomena through high-, medium-, and power frequency is given. Second, based on measured data, factors affecting the arc characteristics, reignition voltages and other features such as energy input into the arc on reignition and transient recovery voltage are analyzed and the results are discussed in detail. Finally, conclusions and suggestions for standardization are given.

II. THEORETICAL ANALYSIS OF CAPACITIVE CURRENT INTERRUPTION

Capacitive current interruption with a disconnector consists of a succession of interactive events between circuit and arc with a repetitive sequence of interruptions and reignitions. The reignition is characterized in terms of oscillation frequency, transients of current and voltage, etc. An arc is characterized in terms of arc duration, arc reach (perpendicular distance of outermost arc position to a line connecting the contacts), arc type (repetitive or continuous), energy input into arc from circuit during the reignition, and so forth.

The basic equivalent circuit for capacitive current interruption is shown in Fig. 1. The disconnector is marked with D ; The short-circuit inductance L_s is based on the short-time current for which the disconnector is rated; R_s , C_s and C_l stand for the resistance, capacitance at the source- and load side, respectively; i_d is the current through the disconnector to be interrupted; u_s is the voltage of the power supply of the network.

Before the interruption starts, the disconnector is closed. The entire circuit of Fig. 1 is energized: $u_s = E_m \sin(\omega_p t + \phi)$ with ω_p the angular power frequency, E_m the amplitude, ϕ the initial phase angle. The current i_d and the voltage across the (parallel) capacitances, denoted as u_{cp} are

$$\begin{cases} u_{cp} = E_m \sin(\omega_p t + \phi) \\ i_d = C_l \omega_p E_m \cos(\omega_p t + \phi) \end{cases} \quad (1)$$

Fig. 1. Basic circuit diagram for capacitive current interruption with a disconnector.

It is assumed that the impedances R_s and $\omega_p L_s$ are much smaller than $1/(\omega_p C_{s,l})$, meaning that the voltage u_{cp} is very close to u_s .

When the disconnector opens, the interruption process begins. The basic circuit in Fig. 1 is separated into two parts abruptly. The left part of the circuit, consisting of R_s , L_s , C_s , remains energized with u_s . The voltage across C_s , denoted as u_{cs} , remains very close to the source u_s . The right part of the circuit only contains C_l which has no discharge path and the voltage u_{cl} across C_l is dc due to the trapped charge. The Transient Recovery Voltage (TRV), i.e., the difference between u_{cs} and u_{cl} [16], and the dielectric withstand capability of the air gap between the two contacts of the disconnector are denoted as u_d and u_r , respectively. After the contacts of the disconnector separate, the TRV starts to rise and the dielectric strength starts to recover simultaneously. Once u_d exceeds the dielectric strength of the gap u_r , the arc re-ignites. At a sufficiently low current, the arc lasts no longer than a half power frequency cycle and extinguishes when the arc current passes through zero. When the arc extinguishes temporary at $i_d = 0$, the circuit is separated into two parts again until the next reignition occurs. The interruption process may therefore be described as a periodic arc extinction and reignition. Finally, this sequence comes to an end and the arc extinguishes completely when the distance between the disconnector contacts becomes sufficiently large to prevent any further reignitions.

At each reignition, the voltages u_{cs} , u_{cl} , u_d and current i_d have oscillations at distinct frequencies. A high-frequency (HF) component arises after reignition when the voltages across load- and source side capacitance are equalizing. After this HF process, the voltages u_{cl} , u_{cs} change and a voltage drop arises across L_s which causes a medium frequency (MF) oscillation in the circuit. As the HF and MF oscillations are damped out, the power frequency (PF) remains. These three components are analyzed in detail below.

A. High Frequency (HF) Component

At the instant of reignition, the voltage u_{cs} and u_{cl} will equalize through a high frequency oscillation. The equalization voltage U_E is calculated from charge conservation in both capacitances [12]

$$U_E = \frac{U_{cs}C_s + U_{cl}C_l}{C_s + C_l} \quad (2)$$

where U_{cs} , U_{cl} are the initial voltages across C_s , C_l , respectively.

Fig. 2. High frequency equivalent circuit diagram.

In the HF circuit model shown in Fig. 2, the power supply is ignored since it is decoupled by the high impedance of inductance L_s for the HF oscillation. R_H, L_H represents the high-frequency resistive losses and inductance of the circuit formed by the capacitors, the disconnector and the arc. In Fig. 2, u_{cl} and i_H denote the voltage across C_l and the current in the high frequency loop circuit, respectively.

The HF phenomenon lasts only a short duration (typically less than a few tens of microseconds), during which it can lead to a high transient current through the circuit and transient voltages across both capacitances.

The reignition voltage across the air gap at the reigniting time $t = 0$ is defined as

$$U_r = U_{cs} - U_{cl} \quad (3)$$

Assuming the total resistive losses

$$R_H < 2\sqrt{(L_H/C_H)}, (1/C_H) = (1/C_s) + (1/C_l),$$

we get

$$\begin{cases} u_{cl} = U_E - \frac{U_r}{1+C_l/C_s} \frac{\omega_{0H}}{\omega_H} e^{-\delta_H t} \sin(\omega_H t + \beta_H) \\ i_H = \frac{U_r}{L_H \omega_H} e^{-\delta_H t} \sin(\omega_H t) \end{cases} \quad (4)$$

Similarly, the voltage u_{cs} across the source side capacitance at HF can be calculated

$$u_{cs} = U_E + \frac{U_r}{1+C_s/C_l} \frac{\omega_{0H}}{\omega_H} e^{-\delta_H t} \sin(\omega_H t + \beta_H) \quad (5)$$

where

$$\begin{aligned} \delta_H &= \frac{R_H}{2L_H}, \quad \omega_{0H} = \frac{1}{\sqrt{L_H C_H}}, \\ \omega_H^2 &= \omega_{0H}^2 - \delta_H^2, \quad \beta_H = \arctan \frac{\omega_H}{\delta_H}. \end{aligned}$$

The parameter δ_H is the damping coefficient at HF.

The HF oscillation frequency ω_H depends mainly on the stray inductance and the series connected value of both capacitances. This high frequency can be up to several MHz. The oscillation across the capacitances eventually ceases and settles at a quasi steady state value U_E .

According to (4) and (5), the maximum transient voltage across C_s, C_l (which occurs at negligible HF damping) is $|(U_r)/(1+C_s/C_l)| + |U_E|$ and $|(U_r)/(1+C_l/C_s)| + |U_E|$, respectively. The maximum transient current is about $(U_r/\sqrt{L_H/C_H})$ which depends on the reignition voltage U_r and the electrical parameters of the HF loop.

It is evident that the smaller capacitance has the higher maximum voltage and this increase while u_r increases. Further, u_r increases with increasing contact distance, which means that HF voltages across the capacitances will become largest just before the arc extincts completely. The maximum transient voltage that can occur for HF is $3E_m$, if $U_r = 2E_m$ and either $C_s \ll C_l$ or $C_s \gg C_l$. The current i_H through the disconnector in the HF loop increases with u_r and C_s, C_l . Thus u_r and C_s/C_l (or C_l/C_s) are the key parameters that affect the voltage and current behavior in the HF component of reignition.

B. Medium Frequency (MF) Component

Upon reignition, also a medium frequency oscillation starts. The MF component which lasts about a few milliseconds also causes a transient voltage and current. At this stage the voltage across the arc is neglected. R_H, L_H in Fig. 2 are neglected as well, because their equivalent impedances are much smaller than the capacitance's impedance at MF. Therefore C_s and C_l with an identical initial voltage U_E are in parallel and the equivalent circuit of Fig. 1 can be applied. Because of the charge redistribution during the HF part, the voltages across C_s and C_l have changed and cause a voltage drop across L_s and R_s .

The time of reignition is again taken as $t = 0$. On the time scale of the MF oscillation, u_s can be treated as a constant ($U_s = E_m \sin \phi$). Similarly as for the HF analysis, we find for u_{CM} (the voltage across C_s and C_l at MF), and for i_M (the current through the disconnector at MF)

$$\begin{cases} u_{CM} = U_s - \frac{U_r}{1+C_s/C_l} \frac{\omega_{0M}}{\omega_M} e^{-\delta_M t} \sin(\omega_M t + \beta_M) \\ i_M = \frac{1}{(1+C_s/C_l)^2} \frac{U_r}{L_s \omega_M} e^{-\delta_M t} \sin(\omega_M t) \end{cases} \quad (6)$$

where

$$\begin{aligned} \delta_M &= \frac{R_s}{2L_s}, \quad \omega_{0M} = \sqrt{\frac{1}{L_s(C_s + C_l)}}, \\ \omega_M^2 &= \omega_{0M}^2 - \delta_M^2, \quad \beta_M = \arctan \frac{\omega_M}{\delta_M}. \end{aligned}$$

The oscillation at medium frequency ω_M mainly depends on both capacitances and inductance L_s . Generally speaking this oscillation frequency is in the order of several kHz.

Similarly, as for the high frequency transient, the voltages in MF across both capacitances with initial voltages U_E are damped due to the equivalent resistance in the loop and finally reach the value U_s . The maximum transient voltage is about $|U_s| + |(U_r)/(1+C_s/C_l)|$ and increases with increasing $U_r, C_l/C_s$ and U_s . Similar to the HF analysis, the maximum theoretical transient voltage is $3E_m$. The current through the disconnector at MF depends on U_r , capacitance ratio and L_s . The maximum current also increases with increasing U_r .

C. Three Components Synthesis

After the HF and MF components have damped out, only the PF component remains. Since the time constants involved differ considerably, the HF component has disappeared on the timescale for MF and MF has disappeared on the timescale for PF. For instance, the initial voltage at MF is the steady state voltage at HF and the initial voltage at PF is the steady state voltage at MF. In order to find the complete behavior, the three

components are combined. The voltage u_{cl} across the load side capacitance and the current i_d flowing through the disconnector at reignition can be written as

$$u_{cl} = -\frac{U_r}{1 + C_l/C_s} \frac{\omega_{0H}}{\omega_H} e^{-\delta_H t} \sin(\omega_H t + \beta_H) - \frac{U_r}{1 + C_s/C_l} \frac{\omega_{0M}}{\omega_M} e^{-\delta_M t} \sin(\omega_M t + \beta_M) + E_m \sin(\omega_P t + \phi) \quad (7)$$

$$i_d = \frac{U_r}{L_H \omega_H} e^{-\delta_H t} \sin(\omega_H t) + \frac{1}{(1 + C_s/C_l)^2} \frac{U_r}{L_s \omega_M} e^{-\delta_M t} \sin(\omega_M t) + C_l \omega_P E_m \cos(\omega_P t + \phi). \quad (8)$$

Equations (7) and (8) are the combination of the three frequency components in the voltage across the load side capacitance and the current through the disconnector on reignition respectively. The voltage across the source side capacitance can be calculated in a similar manner.

Equations (7) and (8) show that the voltage and current in the loop, on reignition, depend on the air gap reignition voltage, power supply level and the network electrical parameters. In order to further understand the capacitive current interruption with an air-break disconnector, Section III focuses on this phenomenon experimentally.

III. EXPERIMENTAL RESULTS INVESTIGATION

A series of tests is performed on capacitive current interruption with an air-break high-voltage disconnector in a test-circuit. Those measurements are carried out at 90 kV to 173 kV supply voltage in the KEMA High Power Laboratory, the Netherlands. The basic simplified test circuit is shown in Fig. 1. The current to be interrupted varies over a range from 0.23 A to 2.1 A, and the source- and load side capacitance are taken in the range of $C_s = 1.5$ nF–100 nF, $C_l = 4.3$ nF–40 nF respectively. Various combinations of current and of C_s and C_l are selected. The value of L_s is fixed at 480 mH. A center-break type disconnector with rated voltage of 300 kV is subjected to the test. The bandwidth of the voltage divider and the current transformers allows to measure signals up to 1 MHz and 100 kHz, respectively. Noise with frequencies above the bandwidths is filtered from the recorded signals.

During the experiments, general interruption characteristics such as arc duration, gap length, the blade angle at arc extinction, and overvoltage across C_l are recorded. The instantaneous current i_d , the voltages u_{cs} and u_{cl} are recorded as well. Further, high-speed video recording of the arc is made. The initial analysis of the measured data has been done in [12] and [13] and revealed as follows.

- Arc duration increases with magnitude of current interrupted (at constant C_s), and also increases with decreasing value of C_s/C_l .
- The minimum blade angle of the disconnector required for the arc extinction is about 50 degrees. The disconnector can be close to fully open for the smallest values of C_s/C_l before the current was finally interrupted.

Fig. 3. Typical wave shapes of (a) voltage u_{cs} , u_{cl} and (b) their expansions.

- The overvoltage across the load side capacitor reached a maximum value of 2.33 p.u. when $C_s/C_l \ll 1$.
- The thermal effect which affects the arc behavior becomes significant for currents larger than 1 A.

Most of these conclusions can be explained by the theoretical model mentioned in Section II, showing that with smaller C_s/C_l , the transients in current and voltage are larger especially at MF.

In the following section, a more detailed analysis of the measured data is given. First, the various typical wave shapes are shown of the relevant transient phenomena during arcing. Second, the interruption process is analyzed, taking into account the reignition voltage and the energy input to the arc during the reignitions.

A. Voltage and Current Wave Shapes From Measurements

During the tests two high voltage dividers are used to measure voltage across C_s and C_l . Typical waveforms of u_{cs} , u_{cl} , i_d , u_d are shown in Figs. 3–5. The circuit parameters for this measurement are: $U_s = 173$ kV rms, $C_s = 1.5$ nF, $C_l = 40$ nF. The waveforms of Figs. 3–5 confirm that the capacitive current interruption with an open-air disconnector consists of multiple arc reignitions and arc extinctions. The arc extinguishes (temporarily) regularly at the arc current zero at each half cycle. This means that the reignition of the arc mainly depends on TRV and capability of the air gap to withstand it.

During the interruption, the maximum overvoltage of u_{cl} is 2.33 p.u. [see Fig. 3(a)]. The maximum MF transient current of about 60 A [see Fig. 5(a)] is observed (the measuring system does not allow observation of the HF current component). Within the chosen test parameters the overvoltage became largest just before complete arc extinction, which is in agreement with the theoretical analysis in Section II [see Fig. 3(a)].

Fig. 4. Typical wave shapes of (a) voltage u_d and (b) its expansion.

Fig. 5. Typical wave shapes of (a) current i_d and (b) its expansion.

The voltage u_d across the disconnector is not measured directly, but is determined as the difference between voltages u_{cs} and u_{cl} . The absolute error in the dividers is with a few percent too high for determining the arc voltage by subtracting these voltages directly. Therefore a correction is made by adjusting the measured voltages such that they become equal with closed

disconnecter. The typical u_d waveform of Fig. 4 clearly shows the arc duration and Transient Recovery Voltage (TRV) rising at each half power frequency cycle.

An interesting feature is that values of u_d , i_d (Figs. 4 and 5) on each moment of reignition do not rise continuously with the increasing contacts distance, but a few “steps” are observed. This phenomenon indicates that reignition voltage not only is determined by the distance between two contacts of the disconnector but also depends on other influences, the most important of which is a reduction of breakdown voltage due to the heating of the air by the arc.

B. Reignition Voltage

By analyzing the disconnector voltage u_d , the reignition voltage (u_r) development can be obtained. In order to present the reignition voltage waveshapes, one group of measured data is selected. The results for the measurements performed at a power supply level of 173 kV are given in Fig. 6. The following observations are made:

- Reignition voltage level can be as high as 500 kV (2.05 p.u.) at $C_s/C_l = 3.1$. It does not increase continuously but with a few “steps” at both positive and negative polarities.
- The current i_d and the ratio of C_s/C_l significantly influence the reignition voltage and arc duration. The reignition voltage increases with decreasing i_d and increasing C_s/C_l . The reason is that with larger i_d , and smaller C_s/C_l , there is a higher energy input into the arc on reignition. The arc path needs more time to recover its dielectric strength.
- The positive and negative reignition voltages are not symmetrical. For example, at 2.1 A in Fig. 6(a) the negative voltage is larger than the positive reignition voltage, especially close to the final arc extinction point; at $C_s/C_l = 0.08$ in Fig. 6(b), the positive reignition voltage is larger than the negative reignition voltage as well.
- As mentioned before, a reignition occurs each half power frequency period. However, because of the polarity dependence which causes an asymmetrical overvoltage across C_s and C_l , a few groups of measured data show only one reignition within each full power frequency cycle. Further, the experimental results show that this phenomenon only happens at $C_s/C_l < 0.1$.

C. Energy Input into the Arc on Reignition

The energy input into the arc on reignition is an important influential factor for the arc duration, and the next reignition voltage value. Once a reignition occurs, the arc connects two capacitances electrically. There is a current i_d through the arc and a voltage u_d across the arc. The energy input into the arc is calculated by integration in each half cycle the product of the current i_d and voltage u_d starting from the moment of reignition t_1 until the (temporary) arc extinction t_2 : $E_{arc} = \int_{t_1}^{t_2} u_d i_d dt$. From the typical energy waveshapes shown in Figs. 7 and 8, the following conclusions are given:

- The energy input into the arc on reignition is typically a few hundred Joule and up to a few thousands Joule at lower ratio of C_s/C_l . It becomes larger gradually (with occasional “steps”) when the contacts of disconnector are

Fig. 6. Effects of current and capacitor ratio C_s/C_l on reignition voltage (a) i_d with $C_s = 1.5$ nF, (b) C_s/C_l with $i_d = 2.1$ A.

moving away. It reaches the largest value, just before complete arc extinction.

- The energy level at each half cycle rises very fast once the reignition starts, where the higher frequencies components dominate. Then it remains almost constant during the power frequency period (also see Fig. 7) [14].
- C_s, C_l, i_d have significant influence on the arc energy and on the reignition probability. It can be observed that the energy input into the arc is higher with higher interruption current and lower C_s .

D. Comparison With Theoretical Analyses

The bandwidth and sampling rate of the measuring system in the test are too low to show the entire HF component. Only the medium frequency component therefore can be compared with theory in detail in this contribution.

First, a specific measurement with one group of parameters is discussed. In order to compare with measured results, the parameters selected are as close as possible to those in the real test: $U_r = 410$ kV (see Fig. 4), $C_s = 1.5$ nF, $C_l = 40$ nF, $L_s = 480$ mH, $R_s = 3$ k Ω , $R_H = 25$ Ω , $L_H = 15$ μ H, $E_m = 173 \times \sqrt{2}$ kV, $\phi = 90^\circ$.

The simulated waveshape for the voltage across the load side capacitance on the reignition is shown in Fig. 9. It shows clearly that u_{cl} has three components HF, MF, and PF and there are oscillations at HF and MF. The HF component lasts a few microseconds and the MF component lasts a few milliseconds. The MF component, which lasts about 4 ms according to the model in Fig. 9, has the same duration as in the measurement (see Figs. 3–5). The medium frequency which is 1 kHz by theory

Fig. 7. Energy input into the arc on reignition versus time with parameters current and capacitor ratio C_s/C_l . (a) C_s/C_l ($i_d = 2.1$ A). (b) i_d ($C_s = 1.5$ nF).

Fig. 8. Expansion at $t = 900 - 1260$ ms from Fig. 7(a) with $C_s/C_l = 100/40$.

is 963 Hz in the measurement. Therefore, for the medium frequency phenomena measurement and theory are in agreement.

Second, the measured and calculated overvoltages across load side capacitance are compared in detail below. Table I shows that the calculated results are slightly larger than those obtained from measurement, probably because of differences in damping. The predicted maximum overvoltage of 3 p.u. is higher than the value of 2.33 p.u. observed in the measurements.

The data analyzed from measurement show that the transients during interruption are qualitatively in agreement with the theoretical analysis.

IV. IMPLICATIONS FOR STANDARDIZATION

As already pointed out in Sections II and III, the macroscopic arc behavior is strongly dependent on the circuit as quantified as

Fig. 9. Waveshape for overvoltage across load side capacitance and its HF expansion.

TABLE I
COMPARED OVERVOLTAGE BETWEEN MEASUREMENT
RESULTS AND CALCULATION

u_s (kV)	C_s/C_l	u_{cl} (p.u.)	u'_{cl} (p.u.)
90.0	60/19.3	1.39	1.52
171.5	6/19.3	2.09	2.32
173.0	1.5/40	2.33	2.57
173.0	6/40	2.25	2.40

Note: u_{cl} (p.u.), u'_{cl} (p.u.) is overvoltage across load side capacitance from measurement and calculation respectively

Fig. 10. Disconnector arc duration as a function of C_s/C_l for arc current 1.0 and 2.2 A.

C_s/C_l . This is also illustrated in Figs. 10 and 11 showing the arc duration and observed overvoltages as a function of C_s/C_l for two values of the current.

This observation implies that for testing of the disconnector switching capability, the circuit plays a major role (this also applies to the testing of auxiliary interrupting devices such as so-called whips). Since no test-circuit has been defined yet, one of the tasks of the IEC maintenance team, elaborating an amendment to the IEC standard 62271-102 [1] was to define a circuit. It was decided that 20 CO (close-open) tests have to be performed with $C_s/C_l = 0.1$, adopting a test-circuit as in Fig. 1. Alternative, but yet adequate supply circuits supplying much less than the short-time current are discussed. It was decided to give the document the status of a technical report and allow time for collecting experience. The technical report will be issued in 2009 [17].

Fig. 11. Measured overvoltages (p.u.) across load as a function of C_s/C_l .

V. CONCLUSION

In this paper, in order to investigate small capacitive current interruption phenomena with a high-voltage air-break disconnector, a relative simple circuit is selected for study from theoretical and experimental point of view.

Both approaches show that the capacitive current interruption with an air-break disconnector is an event with multiple reignitions containing high frequency (a few MHz), medium frequency (a few kHz) and power frequency components in current and voltage. These reignitions can cause significant overvoltages (a value up to 2.33 p.u. was experimentally observed whereas 3 p.u. was predicted as a theoretical maximum), higher transient currents and prolong arc duration. This makes the interruption more severe and might cause damage to nearby equipment.

Specifically, the energy input to the arc, the overvoltage, the (transient) current depend on the interrupted current i_d , C_s , C_l (especially the ratio C_s/C_l) and source voltage u_s . At lower values of C_s/C_l (with ratio less than one), higher current i_d , higher voltage power supply u_s , the arc duration and overvoltage across the load tend to increase. The results show that by a suitable choice of C_s/C_l , arc duration and transient voltage and current may be reduced. Making C_s/C_l as large as possible is one option. Larger C_s/C_l leads to a lower energy input into the arc and makes the air gap to recover its dielectric strength faster. It is therefore easier to interrupt with shorter arcs and with lower overvoltages.

Also, the energy input into the arc, the overvoltages and the transient current in the circuit always reach the largest value just before the arc extincts completely. Reducing the arcing time (making the arc extinct with lower reignition voltage at the end) therefore is a key problem to be solved for this issue.

The final purpose of this project is to develop air break disconnectors that have increased current interruption capability.

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