21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

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Advances in DC neutral breaker performances for bipolar HVDC schemes

M BACKMAN, L LILJESTRAND, F RAFATNIA, S NYBERG
ABB AB
SWEDEN

SUMMARY

DC neutral breakers are commonly used to reconfigure bipolar HVDC transmission systems. If failure occurs in one pole of a bipole transmission, the converters of that pole will block and stop the pole current. The unbalance current will then use the ground as return path. There are usually time restrictions on how long this can be accepted and it is therefore desirable to commutate the current from the ground to the metallic return path that is not used during the failure.

For those cases a Metallic Return Transfer Switch (MRTS) is used to commutate the current from the ground to the metallic return (overhead line or cable) reducing the time duration with current flowing in the ground path. This means that the current in the system is not interrupted in the MRTS application, but instead the current is forced or commutated from the ground path to the metallic return path by the MRTS. The high inductance between the two paths makes the commutation difficult and a sufficiently high counter voltage, in the range of 100 kV, has to be set up by the MRTS to ensure fast commutation.

An MRTS consists of an LC-circuit in parallel to a conventional AC breaker. The capacitor is either pre-charged and together with a closing device discharges a high frequency current into the AC breaker to create a current zero crossing where it will interrupt the current (active injection). The other method is to use the arc voltage characteristics from the AC breaker to trigger a resonance in the LC-circuit without pre-charging of the capacitor or additional closing devices (passive injection). It is easier to increase performance with the active method by changing the charging voltage and capacitance. However the passive method is preferred with lower complexity and higher reliability since the capacitor will not be stressed continuously, no charging device is needed and the closing device can be omitted.

Based on the trend with higher current ratings of HVDC systems, the MRTS performance also needs to be increased. In year 2000 passive MRTS's could interrupt 2500 A, in 2007 an upgrade was made to 5000 A and now performance has been validated to more than 6500 A. This paper will describe how this performance increase has been achieved by careful design of the LC-circuit to minimize the

magnus.backman@se.abb.com

inductance in the loop and how it was validated in high power lab testing using a short circuit generator running at 16,7 Hz with a sequence made to simulate a direct current during the switching event. Tests have been performed for different number of poles in series and different LC-circuits to investigate the performance.

Furthermore, to facilitate even higher nominal current capability in closed position, tests have been made with a one pole breaker in parallel to the MRTS to share the current in normal operation. This enables nominal current capability above 8 kA and interruption tests have been made with this configuration showing first commutation step from the parallel breaker to the MRTS and in a second step the MRTS operation within the same test sequence. The tests show that the first commutation to the MRTS is fast and transfer can be done within 2 ms for currents up to 4 kA.

KEYWORDS

HVDC, breaker, resonance, metallic return

1. INTRODUCTION

DC neutral breakers are used to commutate direct current (DC) from one path to another in an HVDC system. The DC neutral breakers normally includes four types: Metallic Return Transfer Switch (MRTS), Ground Return Transfer Switch (GRTS), Neutral Bus Switch (NBS) and Neutral Bus Grounding Switch (NBGS). MRTS and GRTS are usually located at sending station and NBS and NBGS are located at each station. The MRTS commutates the current from the ground return path to a metallic return path (overhead line or a cable) to avoid longer time duration with current in ground path. GRTS has a similar function as the MRTS but in reversed direction to commutate the current back to the ground path. If there is a ground fault within the converter station, some current will inject from the healthy pole to the faulty pole, NBS is designed to commutate this current to electrode line and isolate the fault at the same time. Finally the NBGS is a project specified device which can be a back-up solution if NBS fails to commutate fault current.
Interrupting DC is different compared to interrupting AC since in an AC application the current is interrupted at the natural occurring current zero crossings. In DC, current can be interrupted by creating a local current zero crossing within the breaker itself or creating an arc voltage higher than the system voltage. Creating a high arc voltage is only feasible in low voltage applications and therefore a local current zero crossing needs to be created for HVDC applications.
This paper focuses on performance increase of the MRTS that commutates current from the ground return path to the metallic return.

2. MRTS IN AN HVDC CIRCUIT

In figure 1 the different DC neutral breakers are highlighted. If failure occurs in one pole of the bipole, the converters of that pole will block and stop the pole current. The unbalance current will then use the ground as return path during monopolar operation. To avoid having current in the ground for a longer time it is desirable to commutate the current from the ground path to the metallic return. By opening the MRTS the current is commutated from the ground path, see figure 1 (left), to the metallic return path (right). The very high inductance between the two paths makes the commutation difficult and a voltage in the range of 100 kV or more is needed in order to commutate the current to the metallic return path sufficiently fast. This is achieved by connecting a surge arrester across the MRTS that defines the voltage after current interruption to roughly 100 kV and at the same time absorbs the magnetic energy in the system.

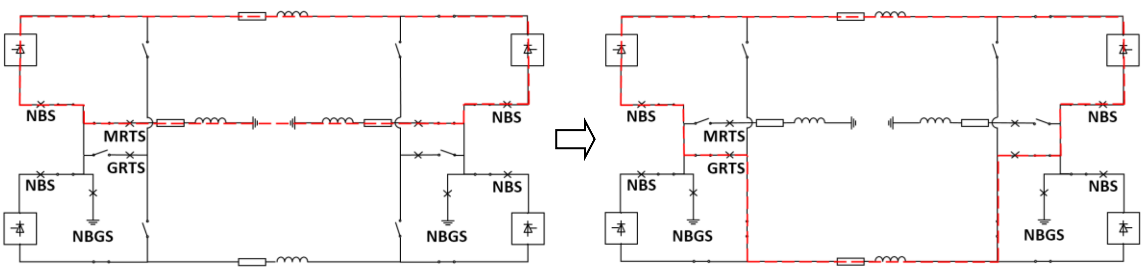

Figure 1. DC neutral breakers in a bipolar HVDC system. Left figure shows the ground path current, right figure shows the metallic return path current.

Breakers for interrupting DC requires a current zero crossing to interrupt. For a high voltage DC breaker an oscillating current is created and superimposed on the direct current through the interrupter. The oscillating current is created by a resonance circuit in parallel with the interrupter and can be either passive (using the arc voltage of the interrupter) or active (using a pre-charged capacitor together with a closing switch) to trigger the resonance, see figure 2. The interrupter is a conventional

SF_6 AC puffer breaker rated 245 kV. The puffer technology ensures good pressure build up and stable performance during arcing, independently of current magnitude. In this paper focus is on the passive resonance circuit since it requires less components and gives a more robust solution.

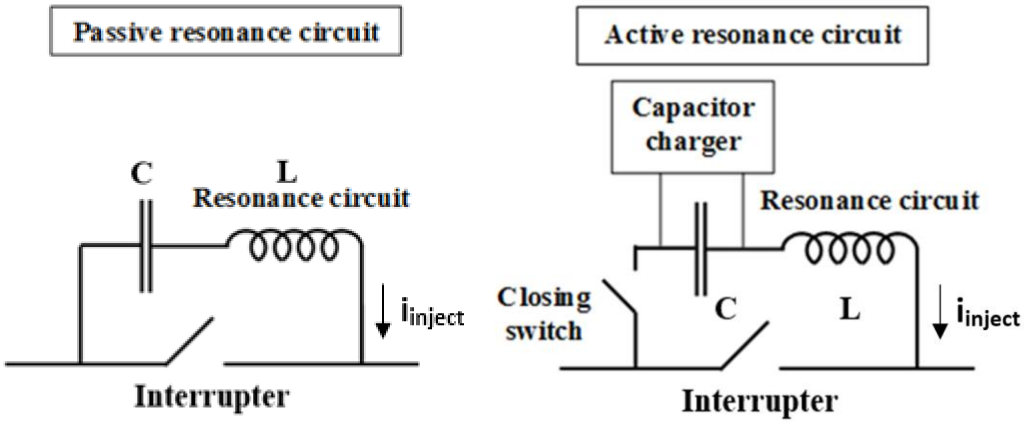

Figure 2. Passive and active resonance circuit.

To trigger the resonance a sharp voltage step in the arc voltage is needed. The current response will be according to equation 1 where Uarc is the voltage step, L and C the inductance and capacitance in the resonance circuit. It is then evident that a high voltage step (more interrupter units in series increases likelihood of a large voltage step) together with high capacitance and low inductance will give the highest current oscillation to start the resonance. In a next step the current oscillation will continue to grow based on the negative characteristics of the arc voltage versus current (du/di) representing a negative resistance. Finally the resonance current becomes larger than the current to be interrupted giving a current zero crossing where the breaker can interrupt the current in the interrupter branch and the arc is extinguished.

$$i_{inject}(t) = U_{arc}\sqrt{\frac{C}{L}}\sin\left(\omega \cdot t\right) \qquad \omega = \frac{1}{\sqrt{LC}} \tag{1}$$

Once the current is interrupted locally, the current will commutate from the interrupter path to the LC-circuit instead and start to charge the capacitor. The rate of rise of the recovery voltage (du/dt) is given by equation 2 and since the capacitance is quite large (tens of µF) this will result in a moderate rate of rise that is easily handled by the interrupter.

$$\frac{dU_{TRV}}{dt} = \frac{I_{dc}}{C} \tag{2}$$

When the capacitor voltage exceeds the protective level of the parallel connected surge arrester, current is commutated to the surge arrester as a next step and current finally starts to commutate from the ground path to the metallic return path, driven by the voltage (about 100 kV) from the surge arrester.

3. TEST CIRCUIT

In order to test the performance of the MRTS a 16,7 Hz circuit has been designed and built to simulate a DC with a fairly constant current during the interruption process. A 3-phase short circuit generator is providing the current to the test object and at first only two phases are closed with a closing instant providing maximum asymmetrical current and then the third phase is closed shortly after the peak current is reached. This gives a discontinuity in the current, maintaining the current magnitude for some additional milliseconds. Figure 3 shows the principle test layout; from left is the short circuit generator, generator breaker (GB), making switch (MS), impedance (Z), D/Y connected transformer, current measurements (Ix), capacitor banks (Cx), stray inductance (Lstray), test breaker (TB), auxiliary breaker (Aux 2), voltage measurements (Ux) and surge arrester (ZnO).

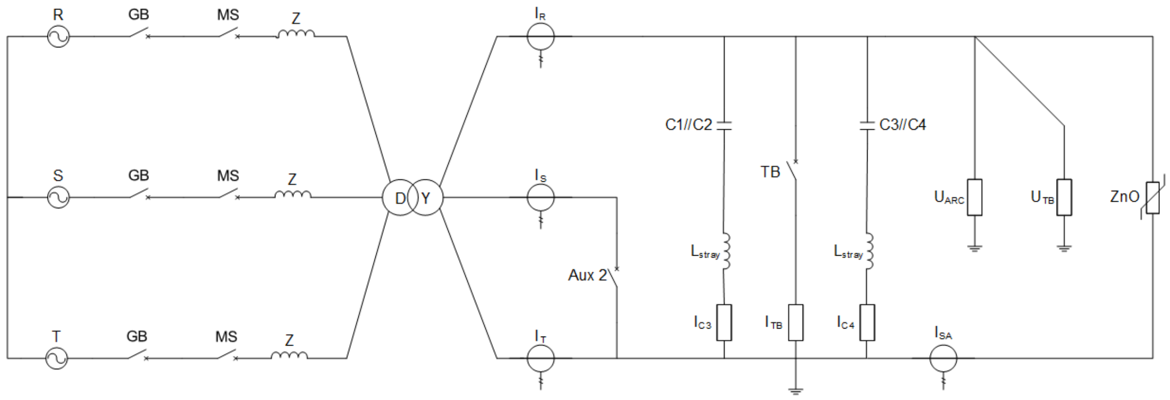

Figure 3. Test circuit for MRTS tests

Figure 4 shows the current provided from the circuit when the auxiliary breaker, Aux 2, closes 32,5 ms after closing of the first two phases. In this example current is kept above 4000 A for almost 10 ms.

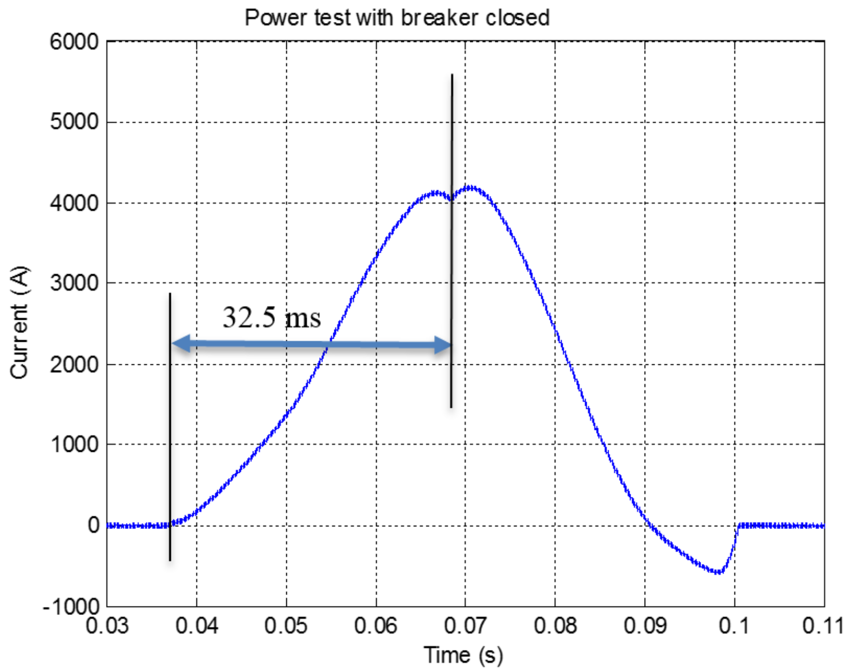

Figure 4. 16,7 Hz current with full asymmetry and third phase closes after 32,5 ms.

According to equation 1 it is beneficial to increase the capacitance and reduce the inductance in the resonance circuit to get larger current oscillations. Increasing capacitance add cost but minimizing inductance can be made without adding significant cost. However, the interrupter poles (245 kV AC breaker poles, type HPL 245 B1) and the capacitor banks' physical size makes it difficult to keep the stray inductance low. One way to reduce the inductance is to split the capacitor bank in two parts and place the interrupter poles between the two capacitor banks. Figure 5 shows a split of the capacitor banks together with three interrupter poles in series and figure 6 shows a picture from the test setup in the high power lab.

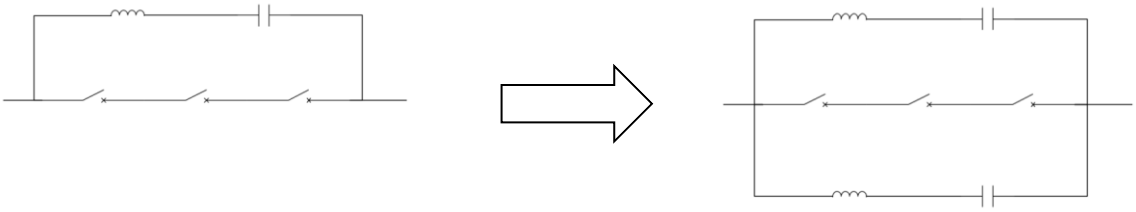

Figure 5. Split of capacitor bank to minimize stray inductance.

Figure 6. Test setup of MRTS with capacitor banks in front of and behind the three breaker poles connected in series.

4. TEST RESULTS

A number of high power tests have been performed to evaluate the interruption performance. Figures 7-9 shows an example of successful interruption of 6,86 kA with three interrupter poles connected in series and the surge impedance, $Z = \sqrt{L/C}$, of the resonance circuit is 0,42 Ohm.

Figure 7 presents the current through the breaker (I_{TB}) and the arc voltage (U_{ARC}) across the breaker. The dashed dotted vertical lines represents the contact separation of the breaker poles and an estimated instant when oscillation starts that lead to current interruption. In this measurement the arc voltage measurement is clipped at 7 kV when current is interrupted. Contact separation is made at 101 ms and arcing time is 16,9 ms. At 112,3 ms arc voltage starts to oscillate and triggers the resonance and 5,6 ms later, current zero is reached.

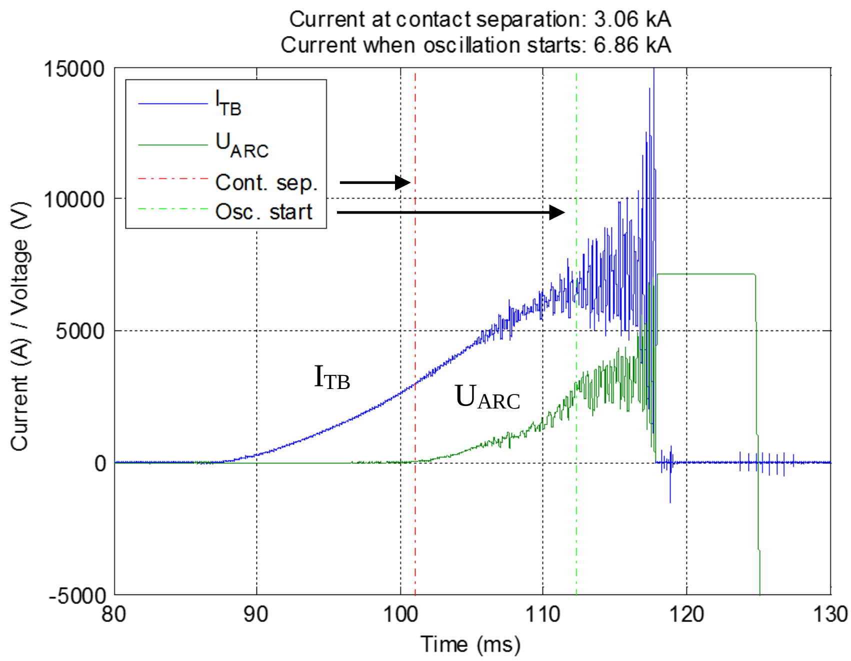

Figure 7. Interruption of 6,86 kA current. 3 poles in series and Z=0,42 Ohm.

The supply current (I_R) to the breaker is shown in Figure 8 and here it is more visible that the current during the last 5,6 ms of arcing time is always above 6,86 kA (red dashed-dotted line). Note also that the supply current continues to flow when the interrupter has interrupted, initially charging the capacitor and then the surge arrester starts to conduct.

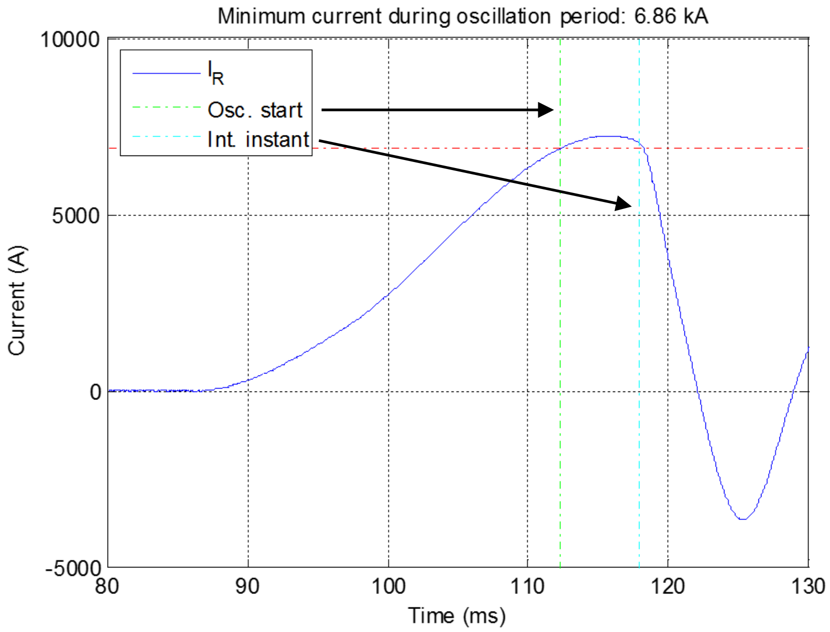

Figure 8. Supply current I_R during the interruption sequence.

Finally figure 9 shows the recovery voltage across the breaker and it is easily seen how the voltage increases linearly during the charging of the capacitor and then at 111 kV the surge arrester starts to limit the voltage. It is this voltage that is used to commutate the current from the ground path to the metallic return. This voltage can be increased by changing the surge arrester protective level if higher driving voltage is needed to force the current faster from the ground path to the metallic return. A higher recovery voltage is not posing any problem for the series connected 245 kV breaker poles to handle.

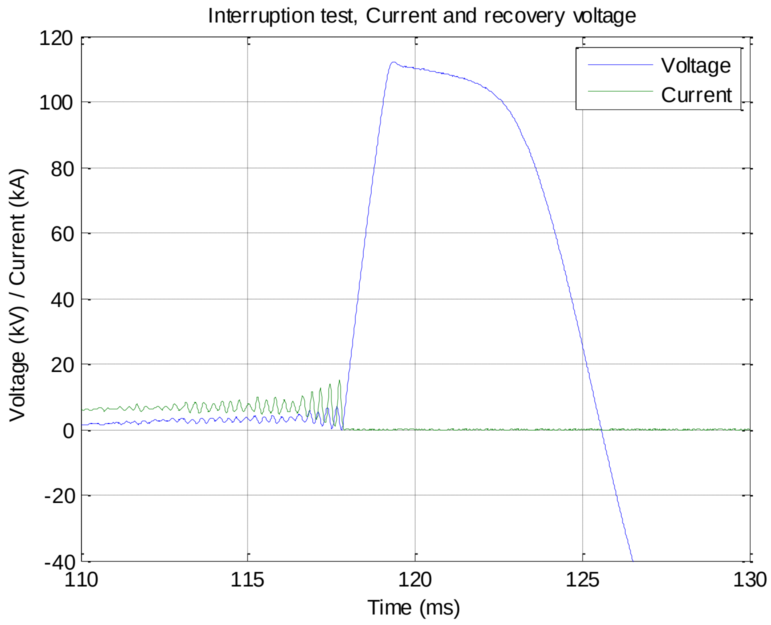

Figure 9. Recovery voltage after current interruption.

Another example of an interruption that is not considered successful is shown in Figure 10. Again three interrupter poles are used but the surge impedance has been increased from 0,42 to 0,47 Ohm. In this test, oscillations start to increase and decrease a few times until it eventually creates an oscillation that gives a current zero crossing. The arcing time is then quite long, 25,6 ms, and the supply current has already started to decline making it easier to interrupt the current. Therefore this test is considered not successful.

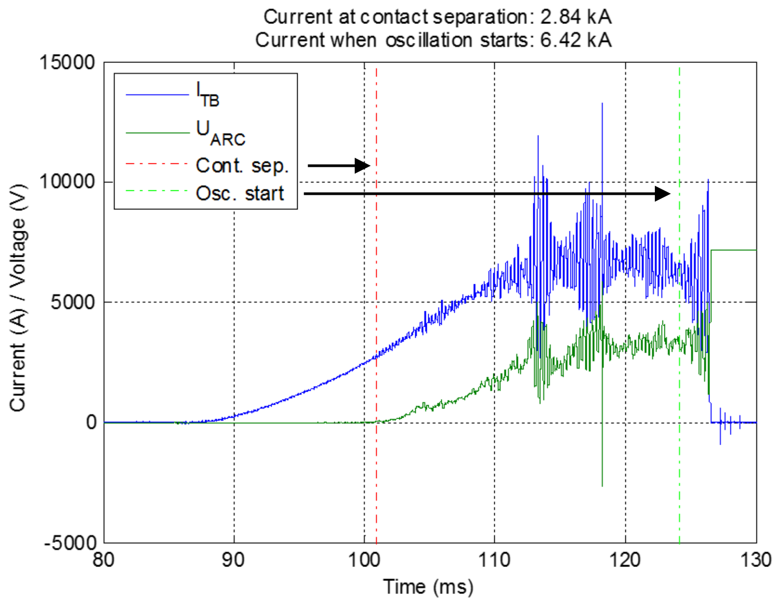

Figure 10. Interruption of 5,57 kA. 3 poles in series and Z=0,47 Ohm.

This shows the importance of keeping the surge impedance as low as possible by either increasing capacitance or reducing the leakage inductance. By splitting the capacitor bank in two halves as indicated in Figure 5 is one way to reduce the leakage inductance effectively. Measurements for one configuration show that if a capacitor bank with a capacitance of C is divided into two halves, 0,5C on each side, with a leakage inductance of L and 0,88L in each branch is electrically equivalent to C and 0,67L, see figure 11. This is of course dependent on how the physical design of the capacitor bank is made. If we assume that one large capacitor bank, C, can be designed with a leakage inductance of L, then dividing the capacitor bank in two could reduce the surge impedance to 82% of the original circuit, $Z = \sqrt{0{,}67 L / C} \approx 0{,}82 \cdot \sqrt{L / C}$. This will significantly improve interruption capability.

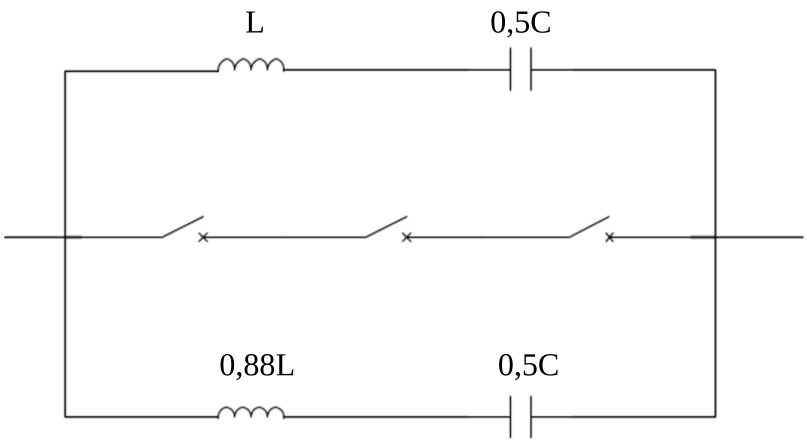

Figure 11. Capacitor bank divided in two smaller units to reduce leakage inductance.

As an example, reducing the surge capacitance to 0,37 Ohm makes it possible to use only two series connected poles and still maintaining good interruption capability. Figure 12 shows an example when 6,0 kA was successfully interrupted (minimum current during the oscillation period was 6,03 kA).

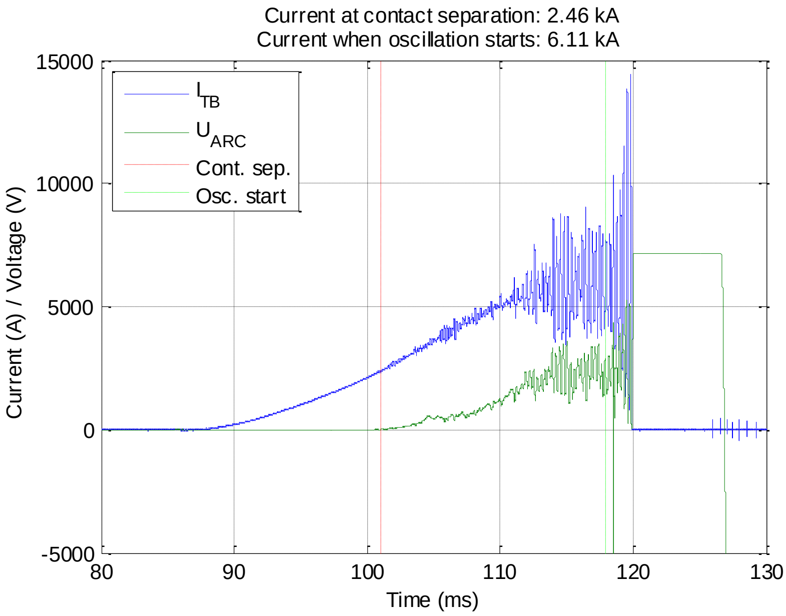

Figure 12. Interruption of 6,03 kA current. 2 poles in series and Z=0,37 Ohm.

In some installations even higher nominal current capability is requested, up to 8000 A. In those cases a parallel breaker can be added to share the nominal current to avoid overheating of the contacts. Figure 13 shows an example when a parallel breaker has been added to share the current between the test breaker (ITB) and the auxiliary parallel breaker (IAB). When opening the parallel breaker, current is commutating so fast (< 2 ms) that it is possible to have contact separation a few milliseconds later in the test breaker and complete the interruption in the same test sequence. In a real installation a longer time delay can be added between the parallel breaker and the test breaker to ensure that the nominal direct current can be ramped down from 8000 A to a current below 6800 A that can be interrupted by the MRTS.

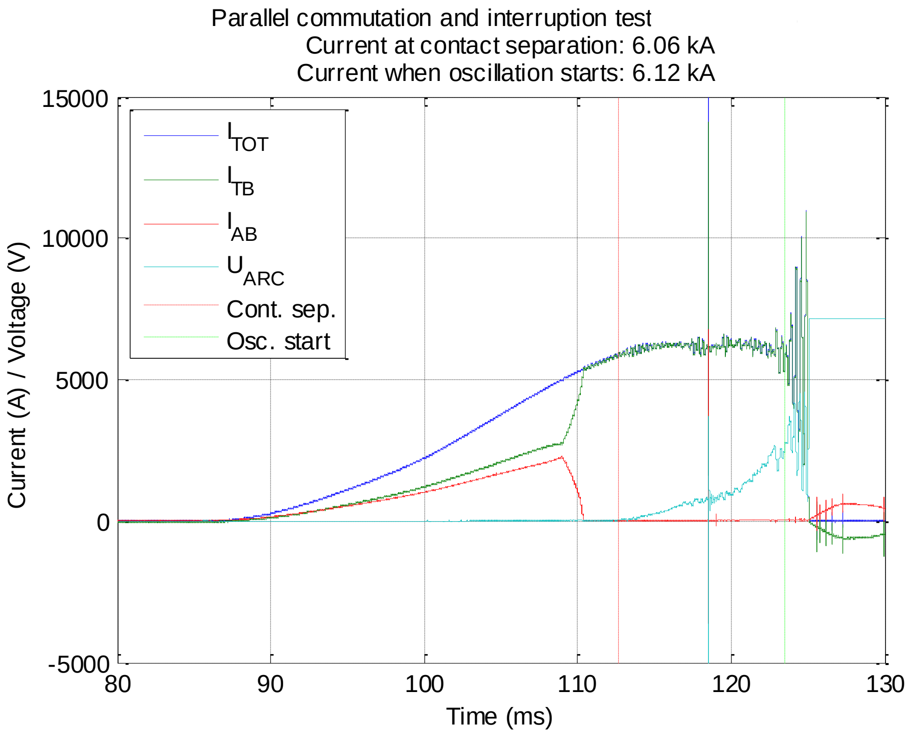

Figure 13. Parallel commutation and interruption test, 5,64 kA interruption current.

5. CONCLUSIONS

HVDC power transmission capacity is steadily increasing and 8 – 10 GW systems are installed or in planning stage, [3] and [4]. To meet these new requirements it is not only sufficient to increase the voltage, also the nominal current capability need to increase. This has led to the necessity to improve performance of DC neutral breakers above 5000 A as presented in this paper.

By careful design, minimizing leakage inductance in the resonance circuit, it has been possible to design a DC neutral breaker using only a passive resonance circuit. The performance has been validated with high power testing and interruption performance now exceeds 6800 A and nominal current capability can be above 8000 A if a parallel breaker is added. The HVDC neutral breaker is therefore able to meet existing and future high demanding HVDC applications. The interruption limit is not yet reached and further improvements can be made to push the interruption capability even higher if needed from a system point of view.

BIBLIOGRAPHY

[1] D. Andersson, A. Henriksson "Passive and Active DC Breakers in the Three Gorges-Changzhou HVDC Project", in Proc. 2001 IEEE ICPS Conf. Available: www. abb.com

[2] Siemens, "5000A DC Siemens commutation breaker successfully tested in China", [Online]. Available: http://www.ptd.siemens.de/141216_Newsletter_5000A_MRTS.pdf

[3] "Completion of the Jiuquan-Shaoshan ±800KV UHVDC project", [Online]. Available: https://hvdcnewschina.blogspot.se/2017/06/completion-of-jiuquan-hunan-800kv-uhvdc_15.html

[4] CEPRI Electric Power Engineering Co. LTD., "SGRI launches world's first ±800kV/6250A UHVDC converter valve," Press Release, [Online]. Available: http://www.cepri.com.cn/release/details_66_738.html