STUDY OF THE DC VOLTAGE CIRCUIT BREAKERS COMMUTATION WITH EMTPWORKS SOFTWARE SIMULATIONS

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Abstract **– DC voltage circuit breakers, initially intended for protecting and disconnecting the rectifiers (AC/DC converters), have a wide usinge in high voltage systems. This paper presents the results of turn-off LC circuit simulation with EMTPWorks software, which is connected in parallel with the main contacts of a circuit breaker. The semiconductor devices, thyristors, used in the module were adopted because of the low switching frequency and the high capacity to withstand overcurrents, much higher than the rated value, close to the short circuit current. This paper shows in which way the direct current commutation problem is related to HVDC systems, with voltages of 100kV and current values higher than 10kA. In order to solve DC switching problems three methods of creating a zero point of short circuit current focusing on inverse current injection method are presented. The results of the simulation show that the value of the reverse current injected is 30% of the short circuit current value. As further work, the authors intend to determine the maximum value of the reverse current injected relative to the short-circuit current value and to analyze the situation in which the value of the injected reverse current is equals the value of the short circuit current.**

Keywords: *commutation, DC voltage, circuit breakers, HVDC.*

1. INTRODUCTION

Modern electrical energy transport systems require control device, high performance automatic breakers, which should fulfil certain demands such as:

- to have possibility of conducting the current in conduction state without excessive loss;
- to allow fast transition from conduction state into blocking state, in case of a flow without causing any damage;
- to have a high level security when circuit breaker are connected.

Electromechanical classic breakers have a minimal contact resistance into a closed circuit and a very high contact resistance into an open circuit; this is to achieve the mechanical and galvanic separation of contacts. The electric4 arc leads to great usage of contacts, reduces the equipment's life expectancy and high maintenance costs at the same time.

In high voltage DC networks there is a problem of switching into direct current, because disconnecting the short current is needed. The problem related to switching of DC voltage circuit-breakers refers to electric equipments (EE) switching and direct current manifests different against alternative current. Besides, EE functionality occurring adjustment to included transition demands. In general, the problem of electrical commutation refers both to "connect" but especially to "disconnect" electrical appliances.

Voltages, powers, and currents flowing in the high voltage DC transmission systems (HVDC), being very high values require the use of static devices, thyristor category, known for their ability to withstand high overload currents and very high value of reverse voltages.

2. ELECTRICAL EQUIPMENT DEMANDS DUE COMMUTATION

Commutation in connection, but mostly when disconnecting is usually accompanied by ignition, combustion and switching off the electric arc. Intervention leads to arcing disconnect request, in particular thermal contact at AE and components of the boards of extinction, but the request dielectric due switching overvoltage, witch occur immediately after extinction.

Designing DC circuit-breakers must account for the issues arising from the arc disconnection appearance, especially in short-circuit such as [1]:

- time evolution of arc voltage for a given current form, should determine the maximum power extracted from the arc;
- operating at short circuit current is necessary to reduce your own time t_a, using ultra-fast shutters;
- providing a convenient of waveform limited current.

It is desirable to reduce the Joule integral in order to achieve the reduction of the peak current and breaking time t_d. A reduced amount of breaking time implies high values for $L \cdot (di/dt)$ at $t = t_d$. A quite low value of limited current and a relatively long time t_d may be achieved by an appropriate form of the arc voltage. It should increase rapidly in the first moments, and then should maintain values which shouldn't exceed the supply voltage.

3. METHODS USED IN THE DC SWITCHING

For solving problems related to current commutation the point is to try to create a zero point for the short circuit current. There are certain methods for solving this problem.

The inverse voltage generation method reduces the current at zero by creating a larger arc voltage compared to the supply voltage, as in low voltage circuit breakers. Applying this method to high voltage direct current systems seems rather difficult because of the high arc voltage and the high values of the energy to be dissipated. Part of the energy is dissipated in most applications through a resistor and/or capacitor and the other part through the arc.

The divergent current oscillation method creates a zero point by amplitude amplification of a high frequency current oscillation. This method uses the benefits of the negative slope characteristics of the electrical arc, which causes an oscillating current in the circuit formed by the ascending arc, the capacitor C and the inductance L. A small increase of the arc voltage, determines an increase of the current through the capacitor, resulting in a corresponding decrease of the arc current, which induces a further increase of arc voltage due to the negative characteristic of arc. Stability analysis shows that if the time constant of T_a spring is less than a critical value T_c and if the dynamic resistance of the electric arc is negative, then the oscillating current will increase in amplitude [2]. The AC circuit breakers (with oil, air, vacuum or SF_6) can be used for switching in this case, but must be modified to minimize the effect of parallel capacitor.

The inverse current injection method creates a zero point by the superposition of an inverse high frequency current over the direct current, by discharging of a capacitor, previously charged. Conventional AC circuit-breakers can be used in this case, but the auxiliary circuit configuration tends to be more complicated than other methods.

To overcome this problem a current injection method should be reverse.

4. EMTPWorks SOFTWARE

The design of the high voltage transmission systems requires the use of real-time simulators, capable to simulate the operation of electrical networks. Real-time simulators were usually the only tools available for testing in order to improve the performance of the system.

EMTPWorks is the new graphical user interface (GUI) with which can design components of the electrical networks. It contains a library of advanced electrical components including: RLC devices, control devices, encapsulated function for different control system (PWM, PID, HVDC, etc.) specific measurement functions of periodic signals (VRMS, P, Q, etc.), different phasor functions, lines and data cables or multi-phase models of voltage-dependent non-linear resistance, the loop reactor, various models with spring breakers etc.

ScopView [5] is a data acquisition and signal processing software tailored for viewing and analyzing the results from EMTPWorks. This can also be used simultaneously to load, view and process data from applications such as EMTP-RV, and MATLAB files Comtrade. Graphical tools including zoom, average and RMS interactive displacement of graphs, etc. ScopeView also possesses advanced mathematical analysis capabilities and post-processing and saves them in a database.

5. MODULATOR WITH THYRISORS

Based on these considerations, disconnecting short-circuit current is accomplished by using a reverse injection modulator with hybrid commutation. The modulator is connected in parallel with the main contacts of the breaker. The modulator depicted in figure 1 contains the main contact of the breaker Sw_1, the thyristors T_1-T_4, the turn-off capacitors C_1-C_4, the turn-off coils L_1-L_4, magnetically coupled and the reverse current diodes D_1-D_4.

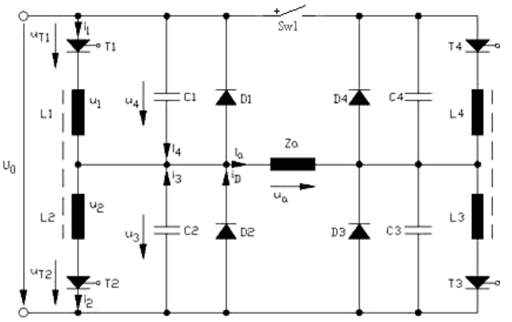

Fig.1. Modulator with LC turn-off groups

In order to determine the analytic expressions for the components of the modulator we have to consider the differential equations system which characterizes the operation of the turn-off circuit:

$$i_1 - i_2 + i_3 + i_4 - i_a = 0 \quad (1)$$

$$u_1 = U_0 - u_2 = u_4 = L_s \cdot \frac{di_1}{dt} + M_s \cdot \frac{di_2}{dt} \quad (2)$$

$$u_2 = u_3 = L_s \cdot \frac{di_2}{dt} + M_s \cdot \frac{di_1}{dt} \quad (3)$$

$$u_3 + u_4 = U_0 \quad (4)$$

where U_0 -is the DC bus voltage;
L_s - is the inductor self-inductance in the turn-off circuit;
M_s is mutual inductance in the turn-off circuit; the other sizes are defined in [3].

Because the time interval t_1, in which the current on thyristor T1 drops to zero is less than a half of a cycle we may assume that $u_1(t)=U_0$. This voltage is equal with turn-off coil voltage and the voltage applied on thyristor T_1 at $t=t_1$, hereupon thyristor T_1 is blocked, is:

$$u_{T1}(t_1) = -U_0 \qquad (5)$$

To determine the voltage on thyristor T_1 to an intermediate coupling factor (k_1) the voltage upon the capacitor C_2 and the current through the thyristor T_1 at the moment t_1, are:

$$u_3(t_1) = 0,5U_0 \cdot (1+\cos(\omega_3 t_1)) \qquad (6)$$

$$i_2(t_1) = \frac{i_a}{k_1} \qquad (7)$$

At this point the system of equations which describes the operation of the circuit becomes:

$$-i_2 + i_3 + i_4 - i_a = 0 \qquad (8)$$

$$u_3 = L_s \frac{di_2}{dt} \qquad (9)$$

The conditions of the turn-off groups are estabilished based on intermediary factor on equations:

$$i_2(t_1) = i_a \qquad (10)$$

$$u_3(t_1) = U_0 \qquad (11)$$

When the voltage u_3 is negative, the reverse current diodes D_2, D_4 start to conduct. This means that at the moment $t=t_2$ in the inductor L_2 the stored energy must be minimum, so during the conduction interval of the thyristor T_2 is also minimum because the increased value of the current in the thyristor T_2, automatically increases the conduction time interval of the diode D_2 during the commutation process.

If the thyristors T_1 and T_3 control the inductance terminals L_1-L_3 we face a potential difference of approximately $U_0/2$. The capacitor C_1 is quickly discharged and the load capacitor C_2 voltage is U_0. At the end of the first half cycle, capacitor C_2 discharges through L_2 and T_2, and a voltage drop occurs on the second magnetically coupled turn-off coil, which determines the reverse polarization of the thyristor T_1. In this case we can say that switching is easily a forced one.

6. SIMULATION RESULTS

With EMTPWorks software [4] we have simulated a thyristors modulator, whose electrical diagram is presented in figure 1. The circuit is supplied from a 20Vcc voltage source and absorb a 1A current. Circuit components values are: capacitors C_1-C_4=10μF, inductors L_1-L_4=1mH and impedance Z_a=20Ω.

We have focused our analysis on two cases:

Case I

Thyristors T_1 and T_3 are in conduction when the load current is cancelled, diodes D_1 and D_3 will have a reversed polarization due to reverse power they acquire. At the instant t=0, the capacitors C_2, C_4 will be discharged through the thyristors T_2, T_4.

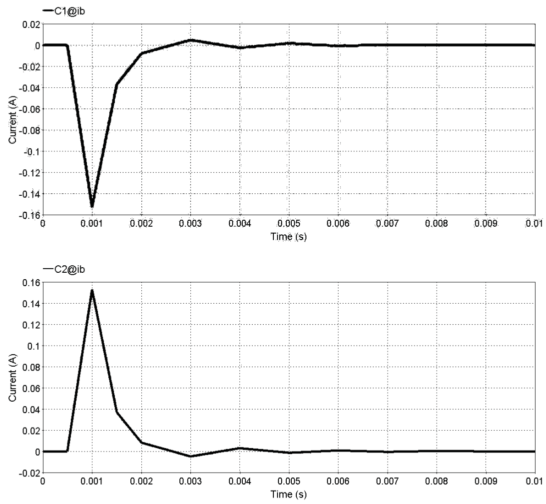

Fig. 2. Current waveforms through the turn-off capacitors C_1 and C_2; case I.

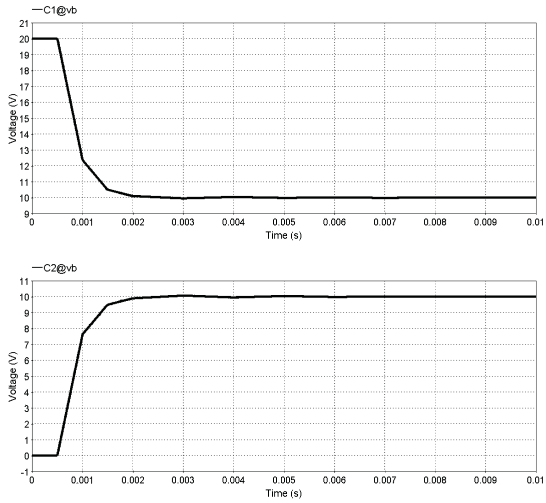

Fig. 3. Voltage waveforms at the turn-off capacitors terminals C_1 and C_2; case I.

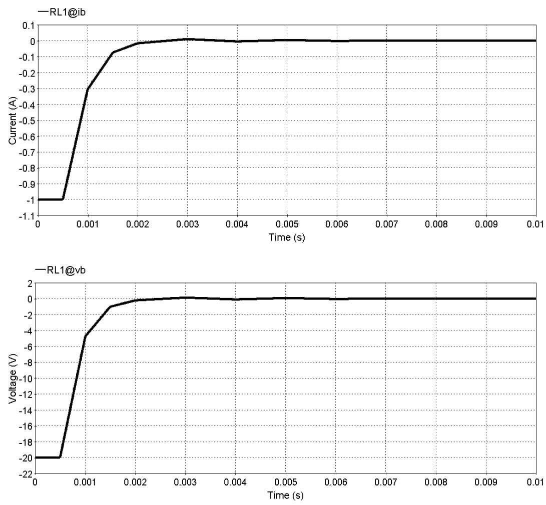

Fig. 4. Current and voltage waveforms through the modulator impedance; case I

The next figures show the current and voltage waveforms at the terminals of the capacitors C_1, C_2, respectively the impedance Z_a.

Case II

Thyristors T_2 and T_4 are in conduction when the load current is cancelled, diodes D_2 and D_4 will be reverse polarizated due to reverse power they acquire. At the instant t=0, capacitors C_1, C_3 will be discharged through the thyristors T_1, T_3.

The next figures show the current and voltage waveforms at the terminals of capacitors C_1, C_2, respectively impedance Z_a.

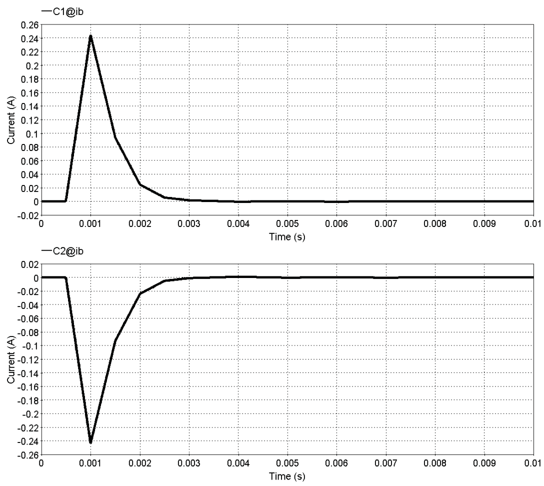

Fig. 5. Current waveforms through the turn-off capacitors C_1 and C_2; case II

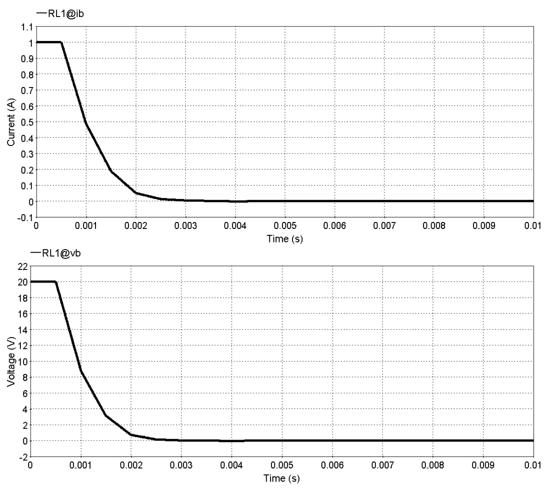

Fig. 6. Current and voltage waveform through the modulator impedance; case II.

By commutating of the two thyristor groups T_1-T_3 and T_2-T_4 over a period of 5ms, one can see that the current waveform is almost sinusoidal.

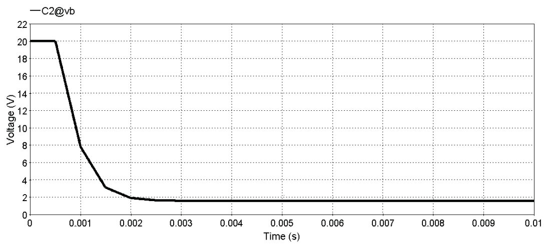

Fig. 7. Voltage waveforms at terminal of the turn-off capacitor C_2; case II

7. CONCLUSIONS

The analysis of the reverse current injection through modulator using thyristors, the circuit simulation with EMTPWorks software, highlights the followings:

- the turn-off groups and the turn-off capacitors in particular, are strongly electric stressed during commutation (figure 5);
- the value of reverse current injected is 30% from the value of the short circuit current;
- in the future the authors intend to determine the maximum value of the reverse injected current relative to the value of the short-circuit current, namely to analyze the situation in which the value of the injected reverse current equals the value of the short circuit current.

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