Sizing group of the extinguishing electric arc in DC hybrid breaker, one stage

NICULESCU TITU[1], MARCU MARIUS[2], PANA LEON[3], POPESCU FLORIN[4]
Faculty of Mechanical and Electrical Engineering
University of Petrosani
Str. Universitatii nr. 20, 332006, Petrosani, jud. Hunedoara
ROMANIA
niculescu_titu@yahoo.com, mariusmarcu66@yahoo.com, leon_pana@yahoo.com,
floringabriel82@yahoo.com, http://www.upet.ro

Abstract: The paper presents a method of extinguishing the electric arc that occurs between the contacts of direct current breakers. The method consists of using an LC type extinguishing group to be optimally sized. From this point of view is presented a theoretical approach to the phenomena that occurs immediately after disconnecting the load and the specific diagrams are drawn. Using these, the elements extinguishing group we can choose.

Key-Words: hybrid breaker, electric arc, numerical simulation, current zero, diagram, differential equation.

1 Introduction

In the DC circuits that are not natural current zero, a big problem occurs when we want to disconnect the load owing to the electric arc which occurs inside the breaker and can quickly destroy its contacts. In these cases, the switching requires additional circuits that are connected in parallel, across the main switch. The basic idea is to produce a counter current injection which opposes the current arc and results a current zero through the main breaker.

The basic electric circuit of switching DC systems is shown in Fig.1:

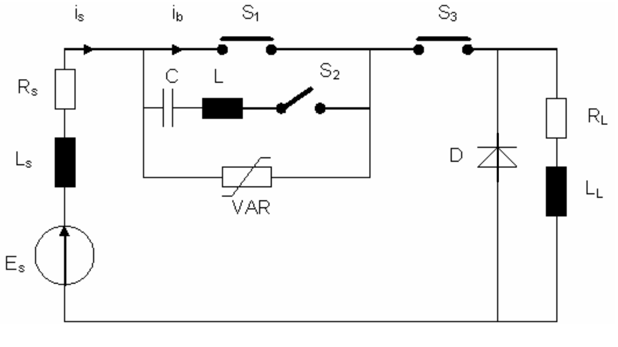

Fig.1 Electric circuit of switching DC systems

The DC power E_s which has the intern parameters L_s and R_s in series with main breaker S_1, electric separator S_3 and load with R_L and L_L parameters, is connected. A switching circuit is connected in parallel across S_1, which consists in the capacitor C, the coil L and the auxiliary switch S_2 (usually is a semiconductor). The VAR varistor limits the overvoltage applied the main breaker, and the freewheeling diode D will take the current when its slope is negative.

To extinguish the arc in the main breaker S_1, the auxiliary switch S_2 is closed immediately after disconnection. Energy stored in the capacitor C, preloaded from the source E_s, is released and that generates a current that opposes the current through the breaker, resulting a zero current through its contacts. The capacitor C and the inductor L form an oscillating circuit which will produce a second current zero if the arc is not extinguished at the first current zero. After arc extinguishing, the capacitor C is loaded again from the source E_s and is ready for a new circuit switching.

2 Analysis of circuit switching

If we consider the continuous equivalent voltage across of the extinguishing circuit U_{lc}, and it equivalent resistance R, the voltage differential equation is given by (1):

$$LC\frac{d^2u_c(t)}{dt^2}+RC\frac{du_c(t)}{dt}+u_c(t)=U_{1c} \quad (1)$$

where the capacitive current is: $i_c(t)=C\frac{du_c(t)}{dt}$ (2)

Based on equations (1) and (2), the numerical simulation scheme in MATLAB-SIMULINK medium of arc current through the main breaker S_1 was released (Fig.2):

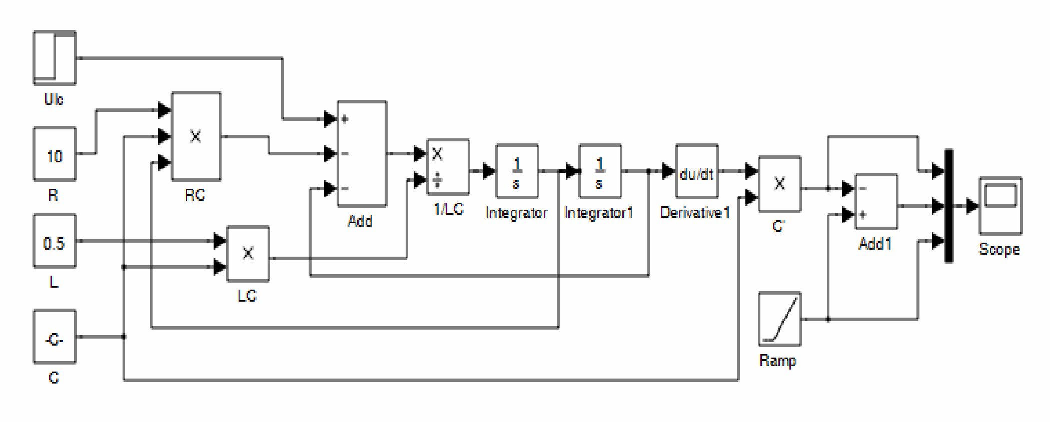

Fig.2 Numerical simulation of arc current

The simulation scheme from Fig.2 generates the MATLAB currents diagram (Fig.3). As is shown in this figure, at time t_1 (reported at the time of load disconnection) the current value i_{t1} is reached, when the voltage capacitor C is U_{C0} value. At this time t_1 a counter current injection in opposite to i_s occurs through the main breaker and the breaker current begins to decrease. At time t_2 it becomes zero and the capacitor drop voltage decreases to U_{C2} value.

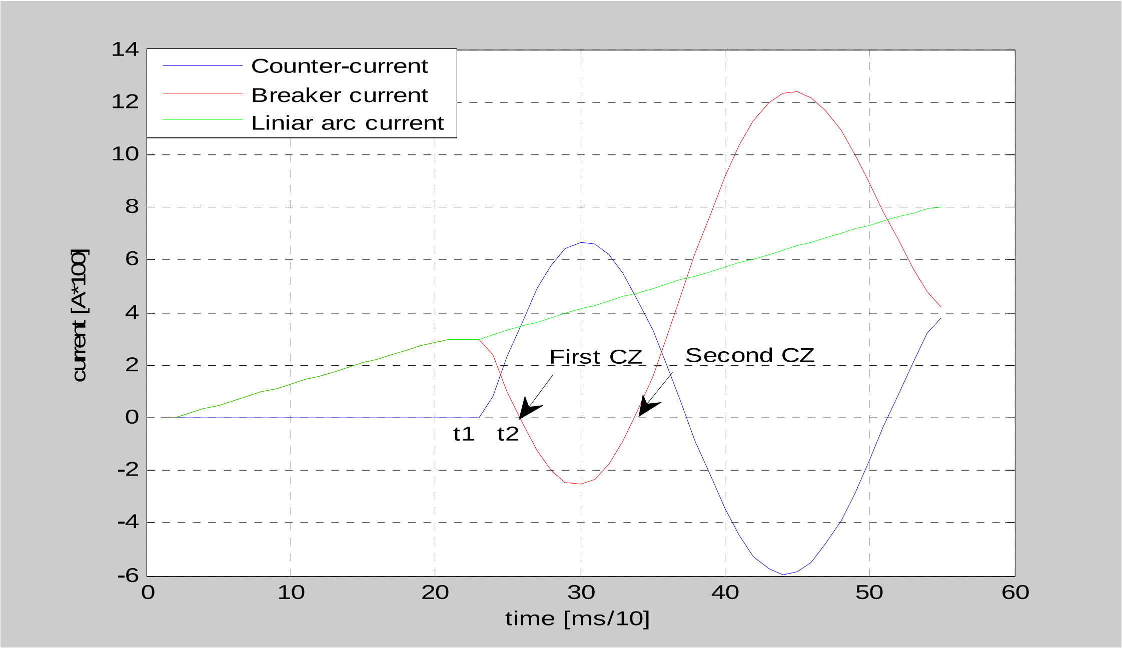

Fig.3 Currents diagram through the main breaker

Forcing zero current through the main breaker lids to arc extinguishing.

3 Sizing group of the extinguishing electric arc

During the process of extinguishing the arc, L and C form an oscillating circuit. From equality of capacitor electric energy with the coil magnetic energy, it follows that the maximum injection counter current is given by:

$$I_{C\max} = U_{C0}\sqrt{\frac{C}{L}} \tag{3}$$

At initial moment, S_1 closed and S_2 opened is considered. Voltage across the capacitor is U_{C0} and the current growth can be approximated as linear. Approximative expression of slope current is:

$$\left(\frac{di_c}{dt}\right)_{\max} = -\frac{U_{C0}}{L} \tag{4}$$

so $i_c(t)$ has a linear variation according to Fig.3:

$$i_c(t) = -t\frac{U_{C0}}{L} \tag{5}$$

The capacitor drop voltage can be writing:

$$u_c(t) = \frac{1}{C}\int_0^t i_c(\tau)d\tau + U_{C0} = -\frac{t^2}{2LC}U_{C0} + U_{C0} \tag{6}$$

At time t_2 the main breaker current becomes zero and we note it t_z. The capacitor current and the voltage capacitor at this time are:

$$i_c(t_z) = i_z = -t_z\frac{U_{C0}}{L} \tag{7}$$

$$u_c(t_z) = -\frac{t_z^2}{2LC}U_{C0} + U_{C0} \tag{8}$$

If the notation is made: $L_T = L_s + L$ and we consider that at t_z moment the drop voltage on resistance R_s is zero, we can write the voltage equation:

$$E_s + u_c(t_z) = L_T\frac{di_c}{dt} + u_c(t) \tag{9}$$

Solution of differential equation (9) is:

$$i_c(t) = \left(\frac{E_s + u_c(t_z)}{\omega_0 L_T}\right)\sin(\omega_0(t-t_z)) + i_z\cos(\omega_0(t-t_z)) \tag{10}$$

where: $\omega_0 = \frac{1}{\sqrt{LC}}$

There is made the notation:

$$tg\eta = \frac{\sin\eta}{\cos\eta} = \frac{i_z\omega_0 L_T}{E_s + u_c(t_z)} = \frac{i_z}{\omega_0 C(E_s + u_c(t_z))} \tag{11}$$

If in relation (10) is replaced the i_z value, after simple trigonometric transformation, we obtain:

$$i_c(t) = \left(\frac{E_s + u_c(t_z)}{\omega_0 L_T\cos\eta}\right)\sin(\omega_0(t-t_z)+\eta) =$$

$$= \left(\frac{\omega_0 C(E_s + u_c(t_z))}{\cos\eta}\right)\sin(\omega_0(t-t_z)+\eta) \tag{12}$$

Capacitor voltage is obtained by integrating the current expression:

$$u_c(t) = \frac{1}{C}\int_{t_z}^t i_c(\tau)d\tau + K \tag{13}$$

Integration constant K is determined from the condition: $t = t_z$, which leads to: $k = -E_s$.

Expression of capacitor voltage has the form:

$$u_c(t) = \left(\frac{E_s + u_c(t_z)}{\cos\eta}\right)\cos(\omega_0(t-t_z)+\eta) - E_s \tag{14}$$

Maximum of capacitor current is obtained after a time $t = t_{i\max}$. From relation (12), the condition for maximum current is:

$$\sin(\omega_0(t_{i\max} - t_z)+\eta) = 1 \tag{15}$$

leading to a maximum current:

$$i_{c\max} = \left(\frac{E_s + u_c(t_z)}{\omega_0 L_T\cos\eta}\right) = \left(\frac{\omega_0 C(E_s + u_c(t_z))}{\cos\eta}\right) \tag{16}$$

Starting from relation (16) was drown the $i_{C\max} = f(C)$, for three values of resonance frequency: 500Hz, 1000Hz și 1500Hz and two values of voltage E_s: 500V and 1000V. There were obtained the diagrams from Fig.4a and Fig.4b.

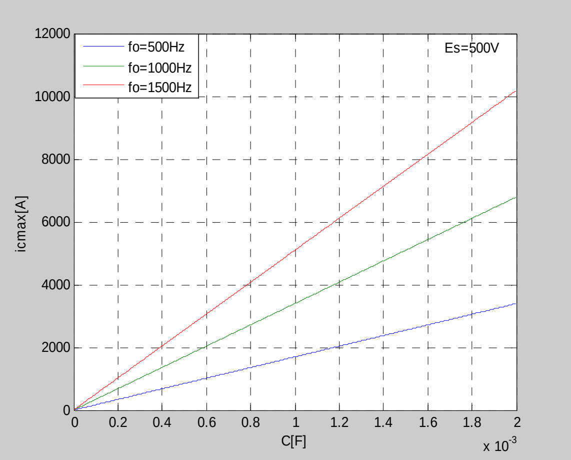

Fig.4a. Variation of peak capacitive current, depending on extinguishing capacity circuit for E_S=500[V]

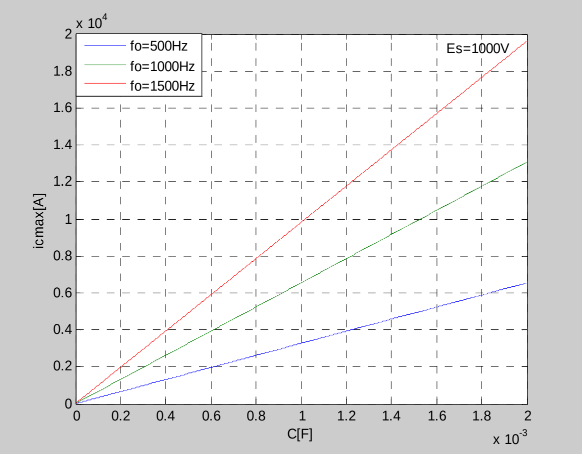

Fig.4b. Variation of peak capacitive current, depending on extinguishing capacity circuit for E_S=1000[V]

If we take into account the relationship between resonance frequency, capacity and inductivity, the relation (16) becomes:

$$i_{c\max} = \frac{\omega_0 (E_s + u_c(t_z))}{\omega_0 L_T \cos\eta} \qquad (17)$$

where $\eta = \eta(L_T)$, and has the value given by relation (11). In Fig.5 dependence diagrams are drawn i_{cmax}= f(L_T) for the same values of their frequency and voltage Es. In Fig.5a is plotted the variation of peak capacitive current, depending on extinguishing inductivity circuit for source value E_s = 500[V], and in Fig.5b is plotted the variation of peak capacitive current, depending on extinguishing circuit for a source value E_s = 1000[V]

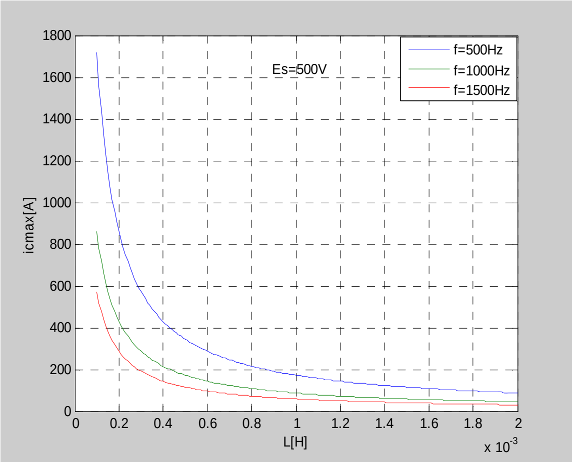

Fig.5a. Variation of peak capacitive current, depending on extinguishing inductivity circuit for E_s=500[V]

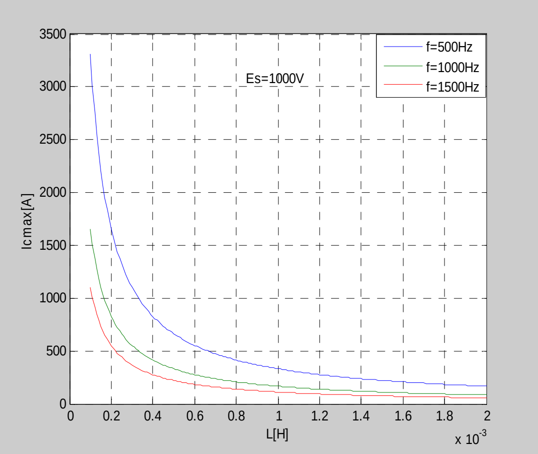

Fig.5b. Variation of peak capacitive current, depending on extinguishing inductivity circuit for E_s=1000[V]

The two diagrams from Fig.5a and Fig.5b, are plotted for three values of frequencies, 500[Hz], 1000[Hz] and 1500[Hz].

The moment when capacitive current is maximum, is directly derived from the relation (15):

$$t_{i\max} = t_z + \frac{1}{\omega_0}\left(\frac{\pi}{2} - arctg\left(\frac{i_z}{\omega_0 C(E_s + u_c(t_z))}\right)\right) \qquad (18)$$

If t_z = 2ms, in Fig.6, time dependence is given after the capacity current is maximum, for the source voltage E_s = 500V. Value pairs (L,C) to achieve the switching for the three frequency, results from diagram Fig. 7.

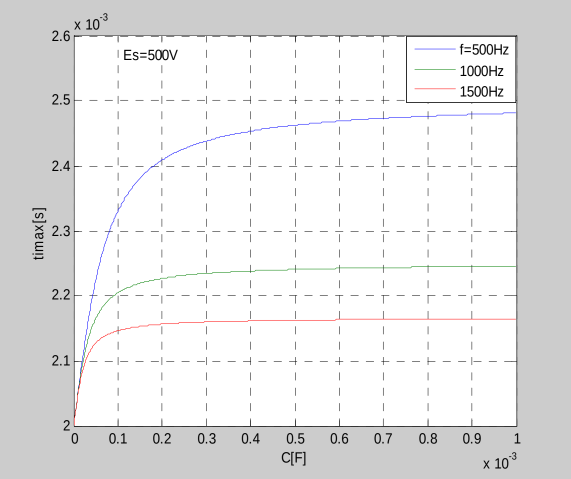

Fig.6 Time diagram for i_{cmax}

The diagrams from Fig.6 and Fig.7 are plotted for the same values of frequencies.

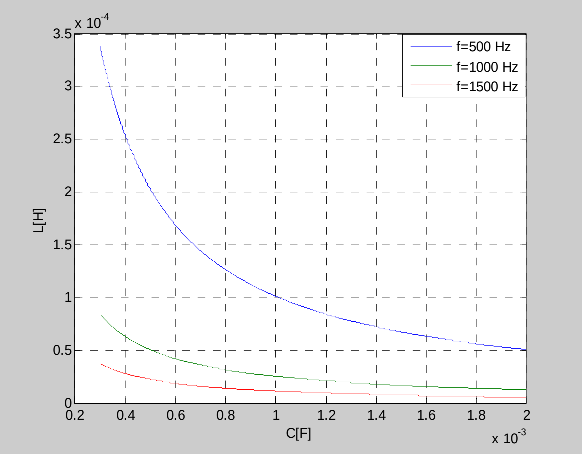

Fig.7 Values needed for commutation

With the aid of these graphs, a choice of initial voltage level and corresponding capacitor value for a DC system could be made. If is not exist inductance or resistance in the upstream line on the source side, the minimum voltage across the capacitor will be at the end of commutation equal with initial voltage, plus the supply voltage. In practice, lines are considered to be inductive, and could increase the residual voltage due the electromagnetic energy exchange between the coil and the capacitor.

4 Conclusion

The current commutation process happens after the electrodes of the main breaker S_1 opened to an enough distance to allow any next overvoltage. If the auxiliary switch S_2 was chosen unidirectional (solid state switch – thyristor), the counter-current from a resonant LC circuit could provide two current-zeros, so exist two opportunities for circuit interruption.

Another way of interrupting the load current, involves the using of a bidirectional switch. In this case, after the source current was commutated, the current oscillation continued for several time periods according to the circuit damping, until the final capacitor voltage becomes equal with the supply voltage. During oscillation, energy is transferred between source and LC circuit. The use of a vacuum breaker is an excellent method to interrupt the load current.

Depending on the commutation value chosen, an appropriate switch might be found from the available power semiconductors. Solid-states switches were commonly vulnerable to increasing slope currents. The switch had to be able to withstand surge counter-currents when switching on and surge voltages when switching off. Basically, power semiconductors allowed high current to be switched by lowering its frequency. When the frequencies of LC circuit are high, a good method for interrupting the load current, consists of using the vacuum breakers.

References:

[1] Ali Atmaji, *Direct Current Hybrid Breakers*, Data Library Technical University Eindhoven, 2000.

[2] C.M. Franck, *HVDC Circuit Breakers: A Review Identifying Future Research Needs* (IEEE) Trans. on Power Delivery, vol. 26, pp. 998-1007, April 2011.

[3] E. Koldby, M. Hyttinen, *Challenges on the Road to an Offshore HVDC Grid* Nordic Wind Power Conference, Bornholm, Sept. 2009.

[4] Marin Ghinea, Virgiliu Firteanu, *MATLAB calcul numeric- grafica – aplicatii*, Editura Teora, Bucuresti 2000.

[5] M. Rahimo, A. Kopta, U. Schlapbach, J.Vobecky, R. Schnell, S. Klaka,*The Bi-mode Insulated Gate Transistor (BiGT) A potential technology for higher power applications* Proc. ISPSD09, June 2009.

[6] Simona Halunga-Fratu, Octavian Fratu, *Simularea sistemelor de transmisie analogice si digitale folosind mediul MATLAB/SIMULINK*, Editura MatrixRom, Bucuresti 2004.

[7] Tiberiu Tudorache *Medii de calcul in ingineria electrica MATLAB*, , Editura MatrixRom, Bucuresti 2006.