

## SWITCHING ELECTRIC CIRCUITS WITH DC HYBRID BREAKER

TITU NICULESCU<sup>1</sup>

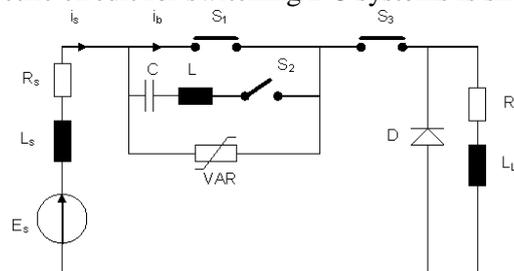
**Abstract:** The paper presents a method of extinguishing the electric arc that occurs between the contacts of direct current breakers. The method consists of using an LC type extinguishing group to be optimally sized. From this point of view is presented a theoretical approach to the phenomena that occurs immediately after disconnecting the load and the specific diagrams are drawn. Using these, the elements extinguishing group we can choose. At the second part of the paper there is presented an analyses of the circuit switching process by decomposing the process in particular time sequences. For every time interval there was conceived a numerical simulation model in MATLAB-Simulink medium which integrates the characteristic differential equation and plots the capacitor voltage variation diagram and the circuit dumping current diagram.

**Keywords:** Arc current, DC systems, voltage variation, MATLAB, Simulink.

### 1. INTRODUCTION

In the DC circuits that contain power breakers, a big problem is the disconnecting the loads, because an electric arc that can destroy its contacts occurs [4], [9]. In these situations we can use an additional circuits that are connected in parallel over the main breaker. These circuits generate a counter current injection which opposes the current breaker and results a current zero through the main breaker and the electric arc will be extinguished [7].

The basic electric circuit for switching DC systems is shown in figure 1:



**Fig. 1.** Electric circuit for switching DC systems

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<sup>1</sup> Ph.D., Associate Prof. Eng., University of Petroșani

The circuit from Figure 1 contains a DC power  $E_s$  which has the intern parameters  $R_s$  and  $L_s$ , in series with a main breaker  $S_1$ .  $S_3$  is an electric separator and at initial moment, a load with  $R_L$  and  $L_L$  parameters is connected. In parallel with  $S_1$  a switching circuit is connected [2], [8]. This consists in the capacitor  $C$ , the inductivity  $L$  and the auxiliary switch  $S_2$  (usually is a semiconductor).

For limiting the over voltages, the VAR varistor is applied across the main breaker, and the freewheeling diode  $D$  will take the current when its slope is negative[3].

The auxiliary switch  $S_2$  is closed immediately after disconnection to extinguish the arc in the main breaker  $S_1$ . Energy stored in the capacitor  $C$ , is released and that generates a current that opposes the current through the breaker, resulting a zero current through its contacts. If the arc is not extinguished at the first current zero, the capacitor  $C$  and the inductor  $L$  form an oscillating circuit which will produce a second 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

We consider the continuous equivalent voltage across of the extinguishing circuit  $U_{lc}$ . In this case the equivalent resistance  $R$ , the voltage differential equation is given by (1), [5], [6]:

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

where the capacitive current is:

$$i_c(t) = C \frac{du_c(t)}{dt} \quad (2)$$

Equation (1) can be written in the equivalent form:

$$\frac{d^2 u_c(t)}{dt^2} = \frac{1}{LC} \left[ U_{lc} - u_c(t) - RC \frac{du_c(t)}{dt} \right] \quad (3)$$

Based on equations (2) and (3), the numerical simulation scheme in MATLAB-Simulink medium of arc current through the main breaker  $S_1$  was released (Figure 2):

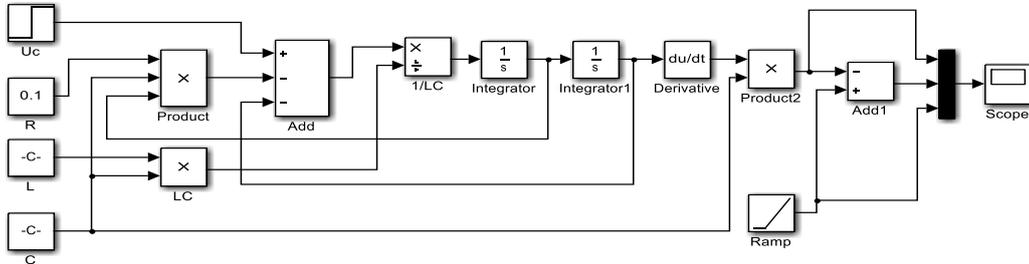
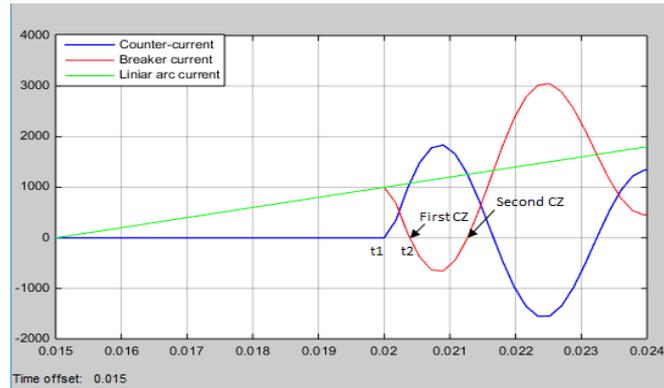


Fig. 2. Simulink model of arc current

The above scheme (Figure 2) generates currents diagram from Figure 3. As is shown in figure 3, the current value  $i_{t1}$  is reached at time  $t_1$  (reported at the time of load disconnection). At this moment voltage capacitor C is  $U_{C1}$  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 voltage decreases to  $U_{C2}$  value.

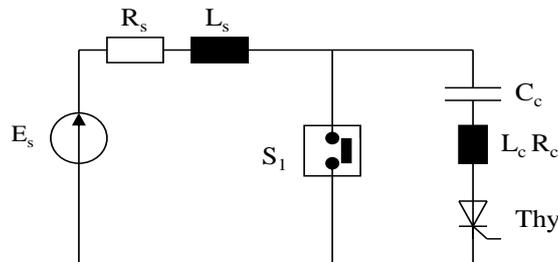


**Fig. 3.** Currents diagram through the main breaker

Forcing zero current through the main breaker leads to arc extinguishing. The Simulink models presented were made for the following values of electric parameters:  $U_c=2000[V]$ ;  $R=0.1\Omega$ ;  $C=500\mu F$ ;  $L=500\mu H$ .

### 3. ANALYSES OF SWITCHING PROCESS

For the study of switching process there is used the circuit from figure 4.



**Fig. 4.** Switching circuit scheme

The current interrupting process can be split in intervals, where every interval is described by a differential equation. These differential equations can be integrated using the MATLAB-Simulink medium, which allows plotting the variation curves for the current and capacitor voltage [1].

There are considered the following time periods:

- $t_1$  – time after that  $S_2$  closed and dumping process begins;
- $t_2$  – time after that occurs the first current zero through the main breaker  $S_1$ ;
- $t_3$  – time after that the source current was zero and C capacitor is fully charged at maximum.

### 3.1. Time interval [0 – t<sub>1</sub>]

Throughout this time interval, the E<sub>s</sub> source current passes the loop in figure 5 and is described by the differential equation (4):

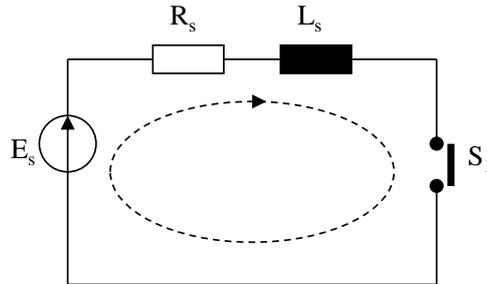


Fig.5. Current flowing for [0-t<sub>1</sub>] interval

$$L_s \frac{di_s}{dt} + R_s i_s = E_s \quad (4)$$

If the initial conditions for this interval are taken into account, the circuit current expression is:

$$i_s(t) = \frac{E_s}{R_s} (1 - e^{-\frac{t}{T}}) \quad (5)$$

where  $T = L_s/R_s$  is circuit time constant.

Its variation is an exponential function.

### 3.2. Time interval [t<sub>1</sub> – t<sub>2</sub>]

At the t<sub>1</sub> moment the oscillation in extinguishing circuit begins, and counter current through the main breaker occurs.

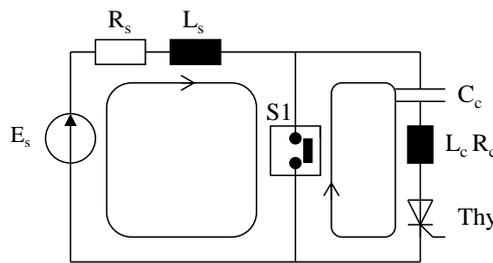


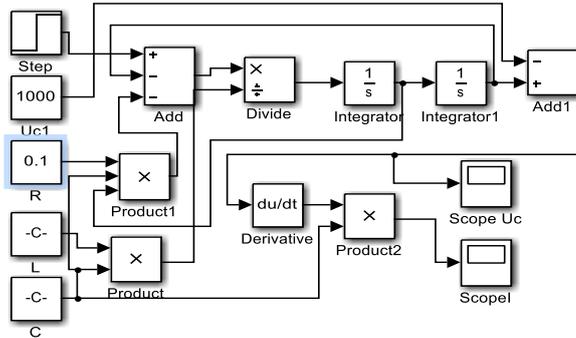
Fig. 6. Current flowing for [t<sub>1</sub>-t<sub>2</sub>] interval

The capacitor voltage which belongs to the extinguishing circuit is described by the second order differential equation:

$$LC \frac{d^2 u_c}{dt^2} + RC \frac{du_c}{dt} + u_c = U_{c1} \quad (6)$$

where U<sub>c1</sub> is the voltage at which the C<sub>c</sub> capacitor is charged at t<sub>1</sub> moment.

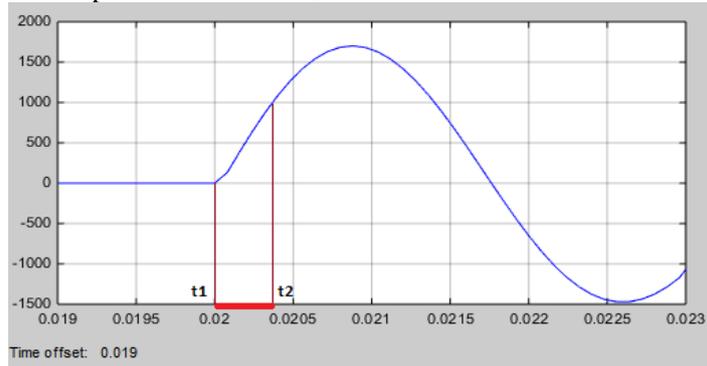
Differential equation (6) is integrated using MATLAB-Simulink medium. The numerical simulation scheme which plots the capacitor voltage variation and the current through the extinguishing circuit is presented in figure 7:



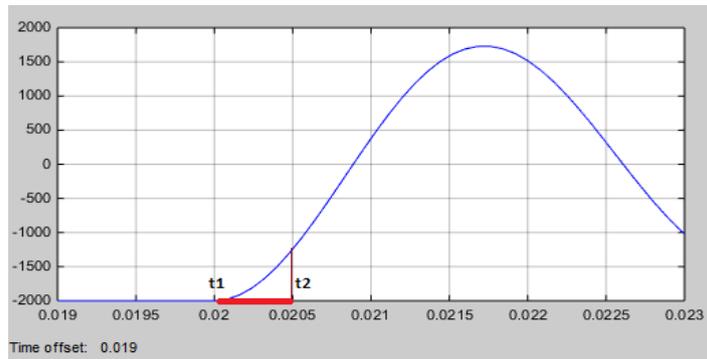
**Fig.7.** Simulink model for oscillating voltage and capacitor current for  $[t_1-t_2]$  interval

This model generates the following diagrams (Figure 8 and Figure 9):

At moment  $t_2$ , the current through the main breaker  $S_1$  became zero and the voltage across the capacitor reached  $U_{c2}$ .



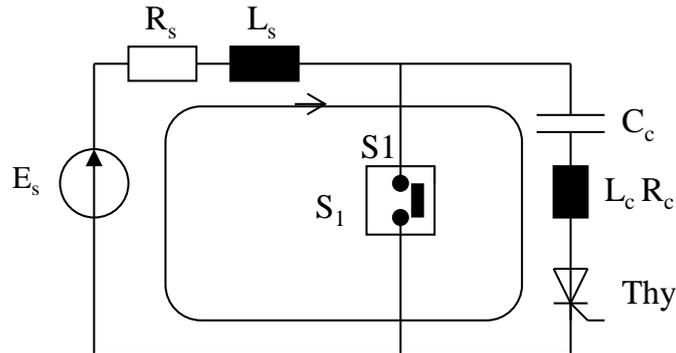
**Fig. 8.** Current variation in  $[t_1-t_2]$  interval



**Fig. 9.** Capacitor voltage variation in  $[t_1-t_2]$  interval

### 3.3. Time interval [t<sub>2</sub> – t<sub>3</sub>]

In this interval, source current becomes equal to the capacitor current. The capacitor voltage at the initial moment is U<sub>c2</sub>, and the current is I<sub>t2</sub>. After the opening of main breaker, current flowing occurs according to scheme in figure 10:

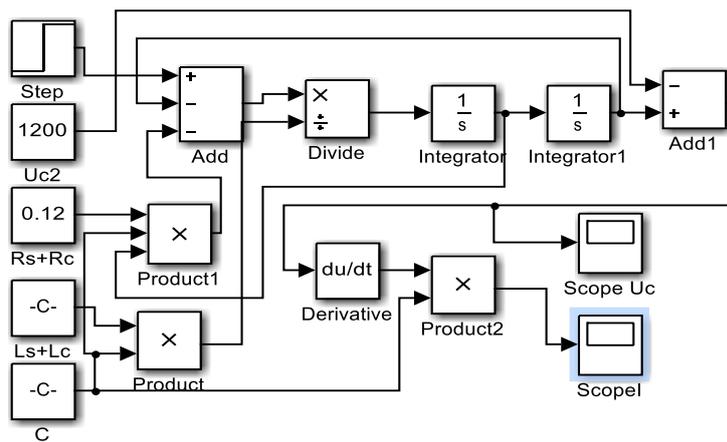


**Fig. 10.** Current flowing for [t<sub>2</sub>-t<sub>3</sub>] interval

The capacitor voltage which belongs to the extinguishing circuit, is described by the second order differential equation:

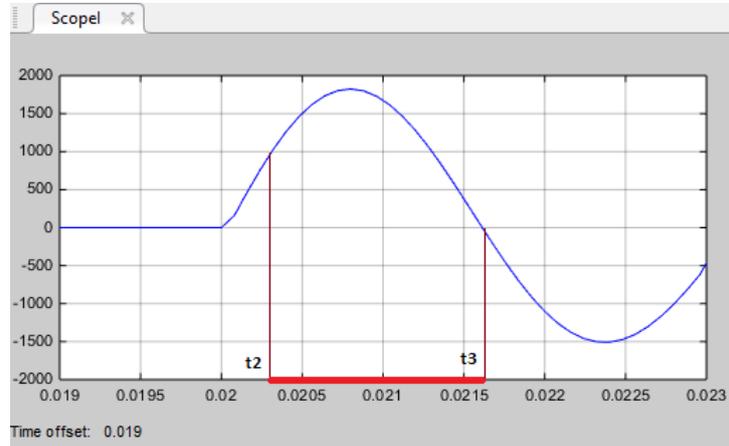
$$C_c(L_s + L_c)\frac{d^2u_c}{dt^2} + C_c(R_s + R_c)\frac{du_c}{dt} + u_c = U_{c2} \quad (7)$$

Differential equation (7) is integrated using MATLAB-Simulink medium. Numerical simulation model which plots the capacitor voltage variation and the current through the extinguishing circuit is presented in figure 11:

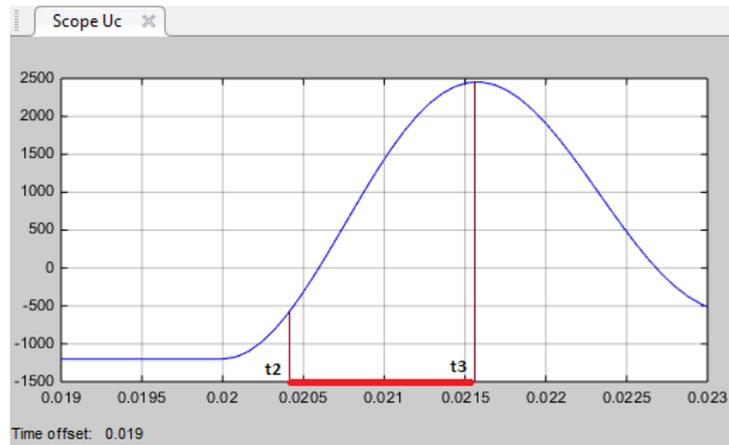


**Fig.11.** Simulink model for oscillating voltage and current through the capacitor for [t<sub>2</sub>-t<sub>3</sub>] interval

The Simulink model in Fig.11 generates the following diagrams:



**Fig.12.** Current variation in  $[t_2-t_3]$  interval



**Fig.13.** Capacitor voltage variation in  $[t_2-t_3]$  interval

At time  $t_3$ , the source current will be zero when the capacitor  $C_c$  was fully charged, see figure 13.

The Simulink models presented (Figure 7 and Figure 11) were made for the following values of electric parameters:  $U_c=2000[V]$ ;  $R=0.1\Omega$ ;  $R_s=0.02 \Omega$ ;  $C=500\mu F$ ;  $L=500\mu H$ ;  $L_s \approx 0$ .

#### 4. CONCLUSIONS

The auxiliary switch S2 was chosen unidirectional (solid state switch – thyristor) and the counter-current from a resonant LC circuit could provide two current-zeros. For this reason exist two opportunities for circuit interruption.

Another way of interrupting the load current, involves the using of a bidirectional switch (vacuum breaker). In this case, after the source current was commutated, the current oscillation occurs 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.

Depending on the commutation current value chosen, an appropriate switch might be found from the available power semiconductors. Solid-states switches were commonly vulnerable to increasing slope currents. But the switch had to be able to withstand surge counter-currents when switching on and surge voltages when switching off. The 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]. **Ghinea I., Firțeanu V.**, *MATLAB numerical calculation, graphics*, (in Romanian), Teora Publishing House, Romania, 1994.
- [2]. **Marcu M., Samoilă L., Popescu F.G.**, *Power Active Filter Based on Synchronous Reference System Theory*, 1<sup>st</sup> WSEAS International Conference on Industrial and Manufacturing Technologies (INMAT '13), Vouliagmeni, Athens, Greece, May 14-16, 2013.
- [3]. **Marcu M.D., Popescu F.G., Niculescu T., Pana L., Handra A.D.**, *Simulation of power active filter using instantaneous reactive power theory*. Harmonics and Quality of Power (ICHQP), 2014 IEEE 16th International Conference, pp.581 – 585, Bucharest, Romania, 2014.
- [4]. **Merlin M., Green T., Mitchenson P., Trainer D., Critchley D., Crookes R.**, *A new hybrid multi level Voltage-Source Converter with DC fault blocking capability*, 9<sup>th</sup> IET International Conference on AC and DC Power Transmission 2010 ACDC, oct, 2010, pp. 1-5.
- [5]. **Niculescu T., Niculescu M.**, *The study of fundamental electrical circuits transitory phenomena using MATLAB software*, Simpozion international multidisciplinary UNIVERSITARIA SIMPRO 2010, Electrical Engineering and Energetics System Control, Applied Informatics and Computer Engineering, Editura Universitat, octombrie 2010, pp. 31-34.
- [6]. **Niculescu T.**, *Technology and Engineering Applications of Simulink, Chapter 2: Study of Inductive-Capacitive Series Circuits Using the Simulink Software Package* ISBN 978-953-51-0635-7, Hard cover, Publisher: InTech, Published: May 23, 2012.
- [7]. **Niculescu T., Marcu M., Popescu F.G.**, *Study of switching electric circuits with DC hybrid breaker, one stage*, International Conference on Innovative Research 2016 - ICIR Euroinvent 2016, IOP Conf. Series: Materials Science and Engineering 133, 2016.
- [8]. **Niculescu T., Popescu F. G., Marcu M., Slusariuc I. R.**, *Study of Electrical Switching Processes with NI USB Data Acquisition Systems and MATLAB-SIMULINK*, Environment, International Journal of Circuits, Systems and Signal Processing, Vol.12/2018, ISSN: 1998-4464, pp.629-636, 2018.
- [9]. **Uțu, I., Păsculescu, D.**, *Power Quality Study in Order to Comply with European Norms*. Publicat in Revista Calitatea, Supplement of “Quality - Access to Success” Journal, Vol.18, S1, January 2017, ISSN 1582-2559, pag. 366-371.