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A NEW CONCEPT FOR DC CIRCUIT BREAKER – BALLISTIC BREAKER

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This paper presents a new concept of DC circuit breaker for HVDC (High Voltage Direct Current) networks. The circuit breaker operates on the principle of sequential insertion of resistances with variable values in several stages, until the interruption can be performed at a very low current. The Ballistic Breaker performs a smooth break without an electric arc and can be used both in AC and DC grids.

Keywords: Ballistic Breaker, Electromechanical circuit breaker, Commutating circuit breaker

1. Introduction

The interruption of direct current circuits is achieved with much more difficult than the interruption of alternative current circuits. This is due to the fact that the DC current cannot pass through zero. The attempts to surpass the difficulties related to direct current interruptions led to the appearance of some special types of DC breakers. The most important types are: oscillating circuit breakers, solid-state breakers and hybrid breakers.

The best-known breaker used in HVDC systems is the MRTB breaker (Metallic Return Transfer Breaker). Fig. 1 represents the electric diagram of an MRTB made by AREVA. The breaker is able to create an artificial current zero, that is favorable to the arc interruption. In order to do this, a LC oscillating circuit is connected in parallel to the AC breaker. The second branch is a surge arrestor using a metal oxide varistor (MOV).

Solid-state breakers usually use the principle of voltage division by means of listing several IGBT (Insulated Gate Bipolar Transistor) cells. Through this listing, transitory voltages do not endanger the components. The disadvantage of these breakers is that they display important power loss in off position. Hybrid breakers combine IGBT cells with ultra-fast mechanical breakers, which are able to take on the conduction in off position thus reducing the amount of power loss.

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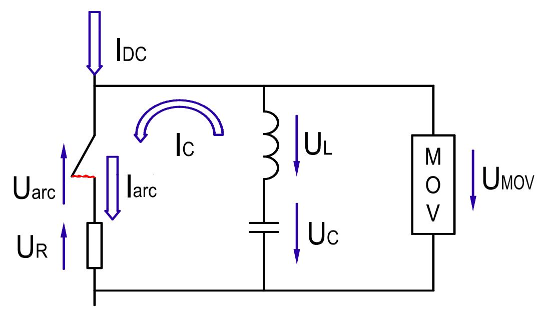

Fig. 1. MRTB – AREVA [1]

Fig. 2 presents the diagram of a hybrid breaker made by ABB. The interruption time is reduced to approximately 3 ms.

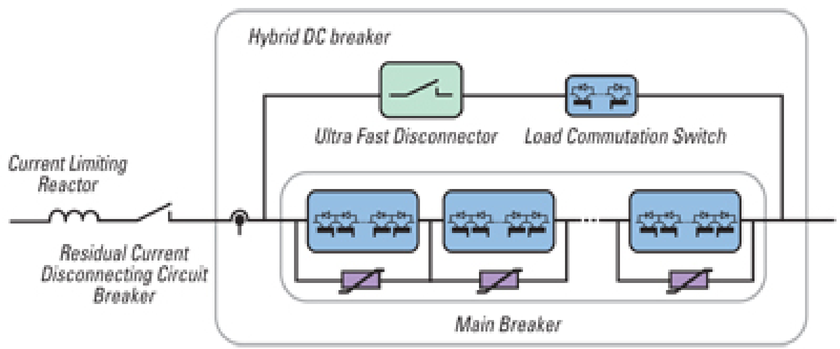

Fig. 2. DC circuit breaker – ABB [2]

2. The foundation of Ballistic Breaker concept

The first idea in the foundation of this concept is taken from [3].

Practically, Nikola Tesla solves the problem of switching low current into direct current through eliminating the unfolding space of the arc, which is supressed by simply rotating the mobile system by 45°.

Another idea has been taken out of [4] and it belongs to inventor Lian Kenneth. Fig. 3 presents the current evolution from this patent.

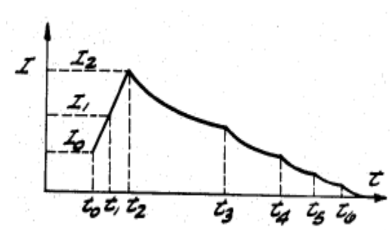

Fig. 3. Current evolution of Lian Kenneth patent [4]

The basic idea is to obtain a sequential interruption, which would allow a smooth passage of the current towards zero. These two ideas have been taken over and improved by using advanced unconventional materials. The result is a Ballistic Breaker based on new interruption principles. These principles are:

- Sequential insertion of some resistances, which can be performed both through linear and rotative movement. These sequences gradually divide the tension so that it can be interrupted.
- The resistive elements used have the same shape, but are manufactured out of materials of different resisivity. Thus, a gradual diminution of the current is obtained.
- When passing from one resistance to another, the electric arc is eliminated by grading the resistivity at the commutation edges.
- The activation of Ballistic Breaker can be obtained by using: elastic devices, step-by-step engines, gas pressure energy.

3. Sequence optimizing

Generally, 18 sequences are used for obtaining the interruption. Table 1 presents the parameter values associated to each sequence.

Table 1

Values of parameters for Ballistic Breaker [5]

commutation	time, ms	R (ohms)	Δ time at R, ms	amps	(inductive energy, joules)
#1	2.667	50.0	0.657	10000.0	5000000
#2	3.324	69.4	0.473	7200.0	2592000
#3	3.797	96.5	0.341	5184.0	1343693
#4	4.138	134.0	0.245	3732.5	696570
#5	4.383	186.1	0.177	2687.4	361102
#6	4.560	258.4	0.127	1934.9	187195
#7	4.687	358.9	0.092	1393.1	97042
#8	4.778	498.5	0.066	1003.1	50307
#9	4.844	692.3	0.029	722.2	26079
#10	4.873	961.6	0.034	520.0	13519
#11	4.907	1335.5	0.011	374.4	7008
#12	4.918	1854.9	0.018	269.6	3633
#13	4.936	2576.2	0.013	194.1	1883
#14	4.948	3578.1	0.009	139.7	976
#15	4.958	4969.5	0.009	100.6	506
#16	4.967	6902.1	0.005	72.4	262
#17	4.972	9586.3	0.003	52.2	136
#18	4.975	13314.3	0.002	37.6	71
final circuit open	4.978	> 1E8		27.0	37

There can be observed that specific values of resistance, time, intensity and energy correspond to each interruption sequence. Table 2 presents values of resistivity for 14 commutation sequences.

Table 2

Values of resistivity for Ballistic Breaker [5]

	1	2	3	4	5	6
ρ [Ω·m]	1,5 . 10^{-8}	1,5 . 10^{-6}	1,3 . 10^{-6}	1 . 10^{-4}	1 . 10^{-3}	1 . 10^{-2}

7	8	9	10	11	12	13	14
1 . 10^{-1}	1 . 10^{0}	1 . 10^{1}	1 . 10^{2}	1 . 10^{3}	1 . 10^{4}	1 . 10^{5}	1 . 10^{6}

Unconventional materials are used to obtain these values. Conductive elastomers represent more than half of the values in the table.

4. The description of linear and rotative patterns in the case of Ballistic Breaker

4.1. The linear pattern

Fig. 4 presents the linear pattern of Ballistic Breaker.

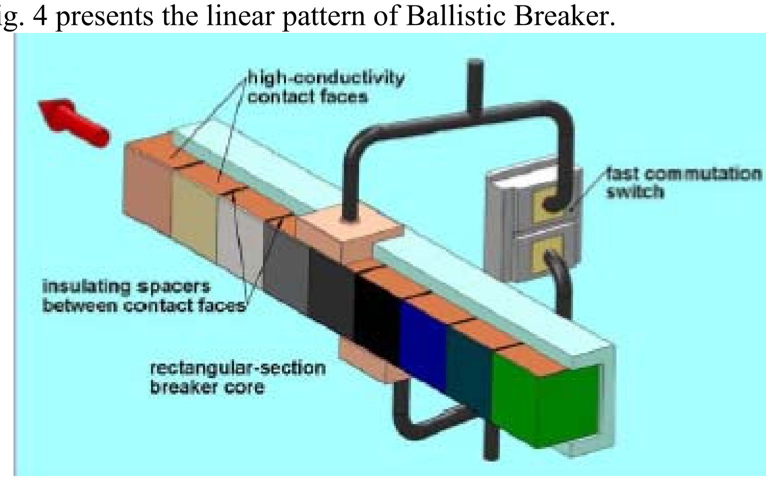

Fig. 4. The linear pattern of Ballistic Breaker [6]

There can be observed a series of resistances obtained from materials of different resistivity. The succesion of resistances slides between two cursors. The commutation is performed in the direction pointed by the arrow, starting with small resistances and finishing with big resistances. This series of resistances can be launched (whence the term „Ballistic") from the starting position through different methods. After launching, the resistances cross the current line one by one, lowering the value of the current from one sequence to another until it reaches zero.

4.2. The Rotative Pattern

Fig. 5 presents the rotative pattern of Ballistic Breaker.

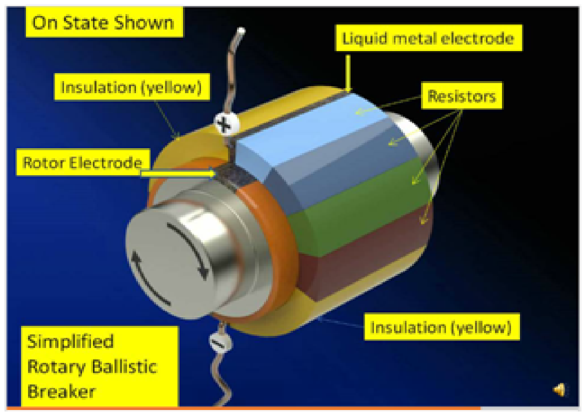

Fig. 5. The rotative pattern of Ballistic Breaker [6]

With this pattern, the resistive elements are placed on a stator. The passage from one sequence to another is performed through rotating the rotor assembly.

5. Simulations

The first PSPICE simulation pattern is present in [5]. This pattern is presented in Fig. 6.

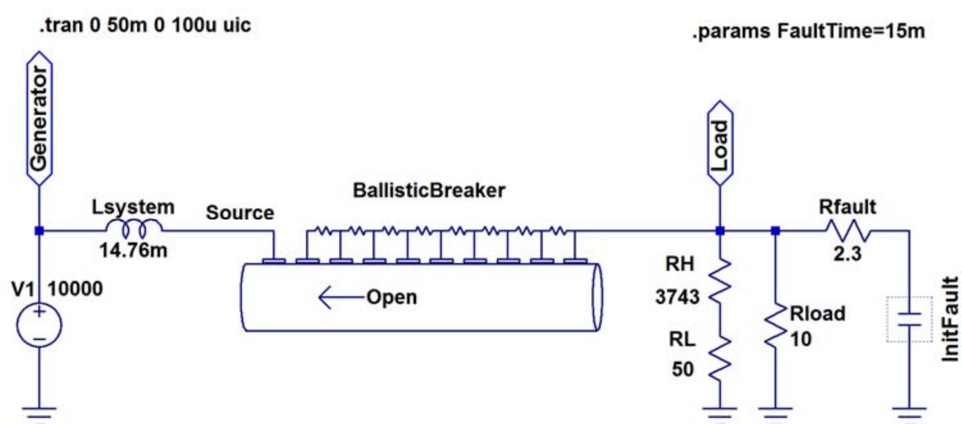

Fig. 6. PSPICE model [5]

The pattern is based on an ideal source of voltage that is the actual breaker with the time and simulation parameters of the short-circuit. Fig. 6.a. presents the result of the simulation based on this pattern.

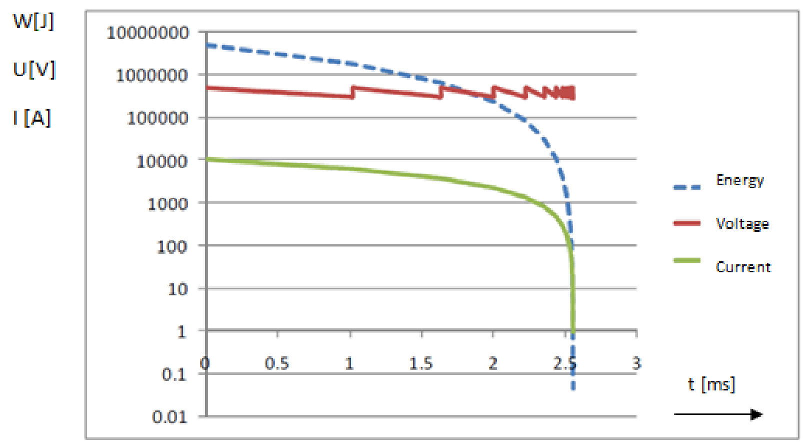

Fig. 6.a. Parameters evolution [6]

The result of the simulation points to three main parameters: current, voltage and energy. The current has a decreasing character, starting from 10000 A and reaching 0 in a 2,6 ms time. The energy has a similar character, starting from approximately $5 \cdot 10^6$ J and gradually decreasing towards zero.

The second simulation pattern is used by the scientists of MSU (Mississippi State University). This pattern is shown in Fig. 7.

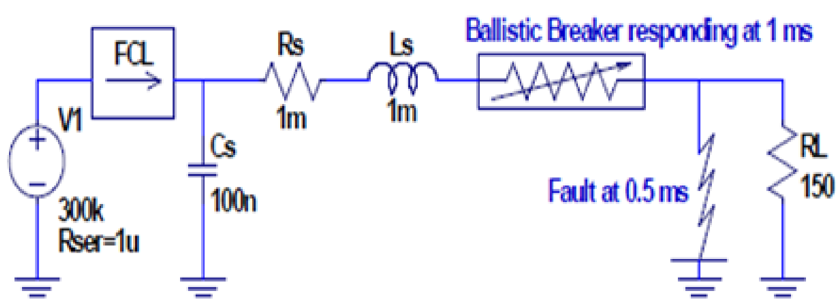

Fig. 7. PSPICE model from MSU [8]

The pattern contains a FCL (Fault Current Limiter) circuit in the form of a block scheme. The actual breaker is symbolized as an adaptable resistance and has a response time of 1 ms.

The results of the simulation using the PSPICE pattern contain two variants: the continuous variant and the discrete variant. The continuous variant is presented in Figs. 7.a. and 7.b.

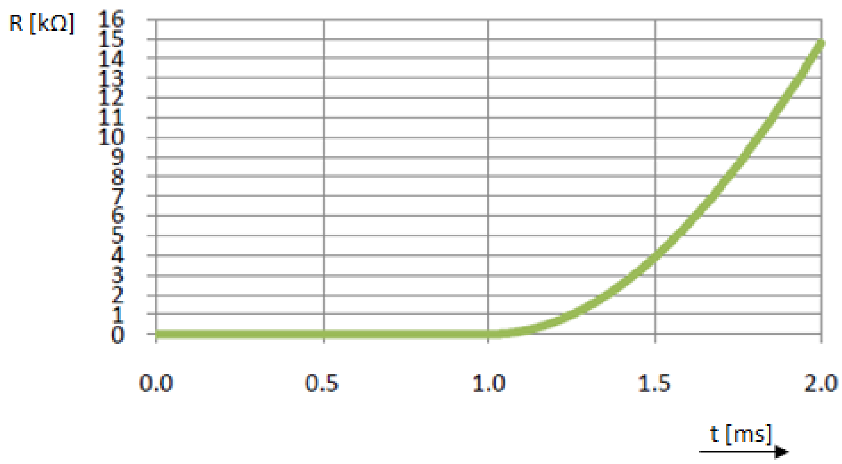

Fig. 7.a. Resistance evolution [7]

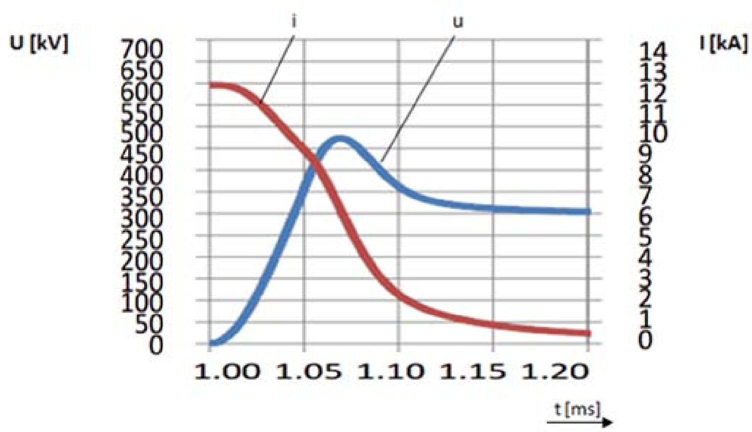

Fig. 7.b. Continuous parameters evolution [7]

Let us observe not only the evolution of the voltage and current, but also of the resistance inserted in the circuit. In the case of continuous insertion, the resistance increases smoothly, without variations.

The discrete variant is shown in Figs. 7.c. and 7.d.

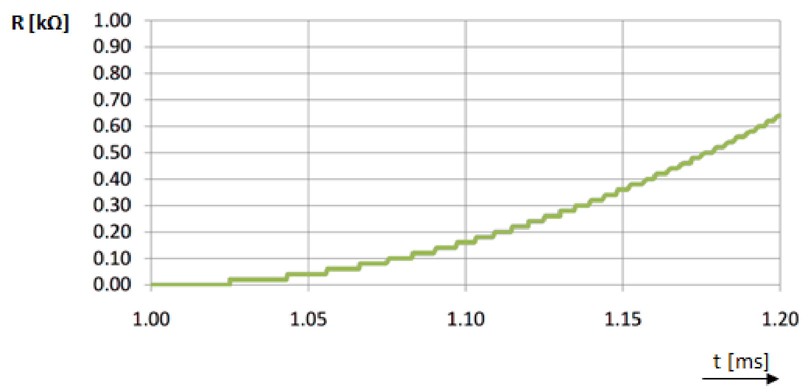

Fig. 7.c. Discrete resistance insertion [7]

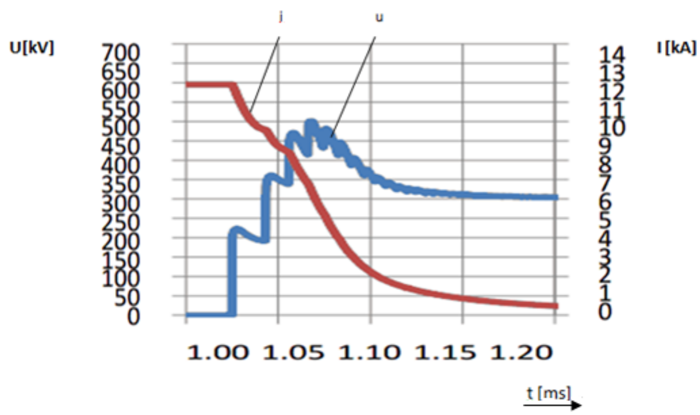

Fig. 7.d. Discrete parameters evolution [7]

The evolution in voltage is performed in stages and at the insertion of the resistance, the steps $L \cdot \frac{di}{dt}$ corresponding to each sequence can be observed.

The third simulation pattern is practically based on the same PSPICE pattern as in the patent, but it contains complete simulation sequences. The result of this simulation is presented in Fig. 7.e.

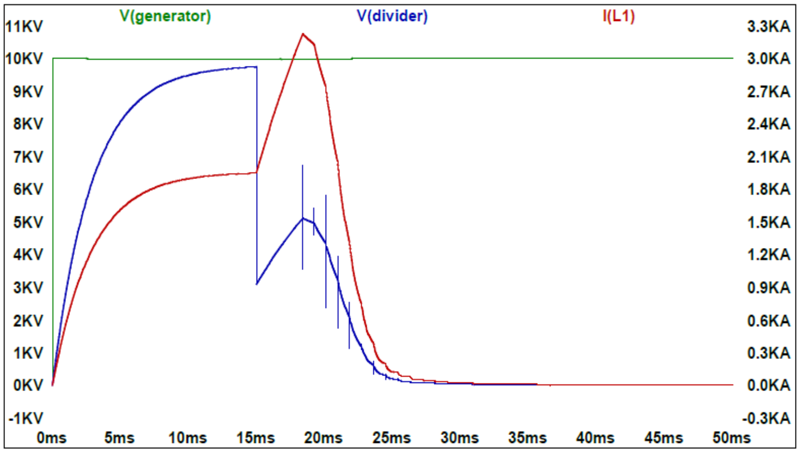

Fig. 7.e. Ballistic Breaker - full parameters evolution [7]

The graphic shows maximum values of transitory voltage which appear with each commutation. The same graphic presents the evolution of current.

6. MATLAB simulation

The MATLAB/Simulink simulation was achieved by the author. It was carried out by means of an original simulation model presented in fig. 8:

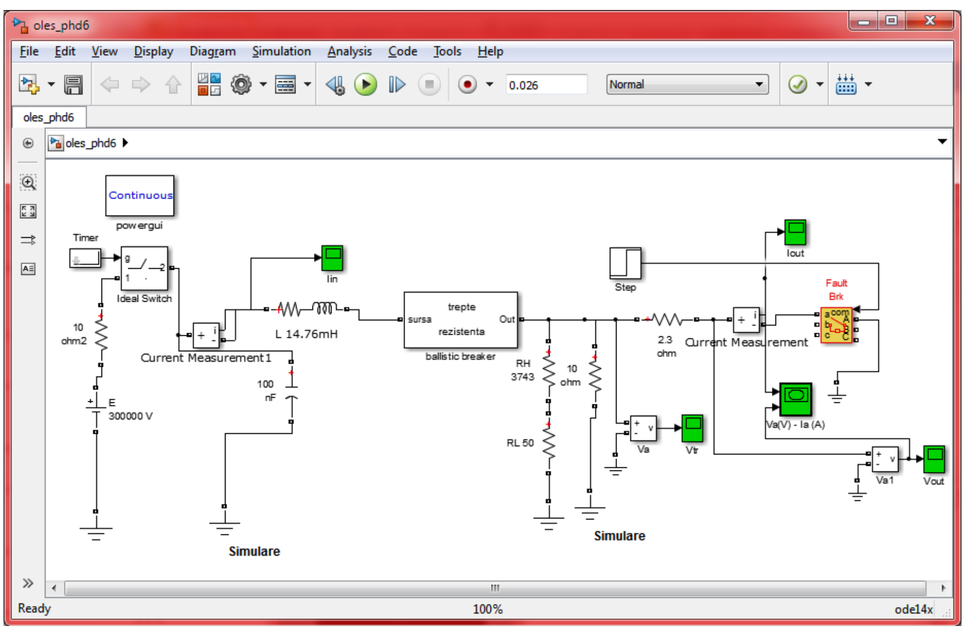

Fig. 8. MATLAB simulation model for Ballistic Breaker circuit

A MATLAB program was prepared, which is complying the steps of the resistor and of the time. The MATLAB simulation is necessary for keeping a close look on the details of the interruption processes for the networks in which the Ballistic Breaker is used.

MATLAB pattern for the interruption simulation in a HVDC network presents parameters similar to those of the previous PSPICE models (network voltage V=300 kV, rated current Io=6 kA, network inductance L=14,76 mH, network resistance R=50Ω). The shortcircuit is simulated by means of a sub-model called "Fault Breaker", which can be found in the MATLAB library.

The model contains all the elements necessary for measuring current and voltage under the form of the "blockset" in MATLAB library/Simulink (Fig. 9).

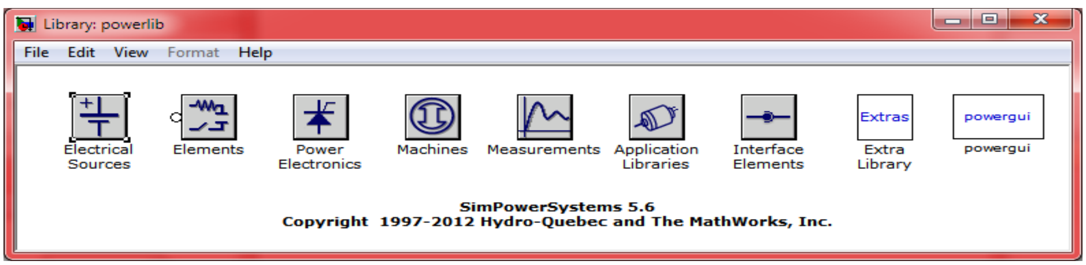

Fig. 9. Elements from MATLAB Library

The resistance of the shortcircuit R_{fault} is 2,3 Ω and the resistance of the R_{load} charge is 10 Ω. The simulation pattern is presented in a monopolar underground shape. The result of the MATLAB simulation is extremely time-consuming and thus a global look over the process is necessary (fig. 10),

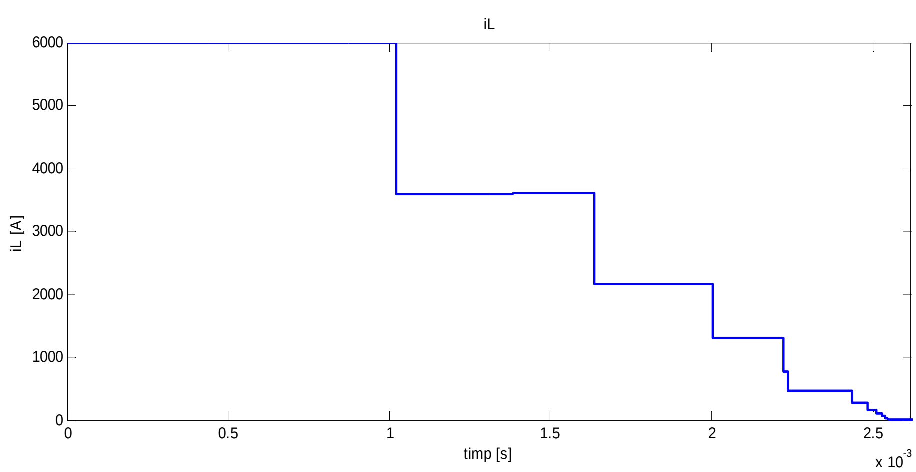

Fig. 10. Graphic of the current steps

This process must be followed by a detailed view of its final part (fig. 11). One can observe that the current value reaches from 6000 A to zero in approximately 2,55 ms, which is close to the result obtained in PSPICE simulations. The simulation result of the Ballistic Breaker MATLAB program presented differs greatly from those made in PSPICE, in that the discretisation is more obvious for the first steps. Fig. 11 represents a detail from fig. 10 for t >2,4 ms.

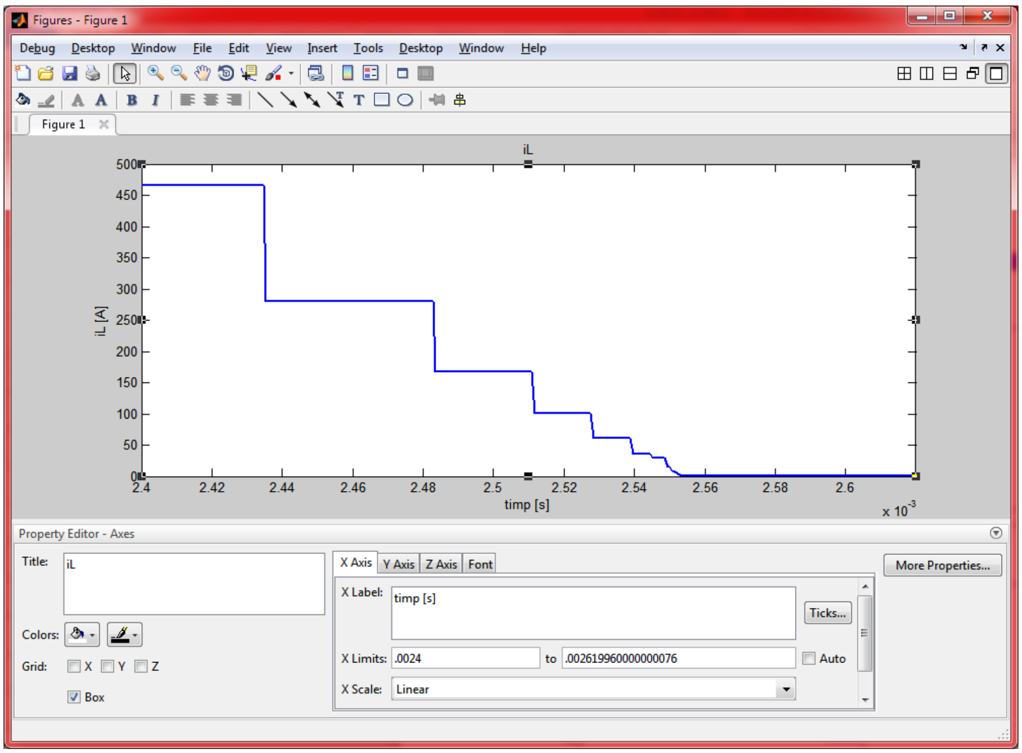

Fig. 11. Detail of the final part of the graphic

The main advantage of the MATLAB simulation is that of offering a clear presentation of the interruption process. Practically, each sequence of the interruption process is associated with a stage of current.

In the case of PSPICE simulations, the results are presented in the form of curves which theoretically present the evolution of the phenomena.

Another major advantage of the MATLAB simulation pattern is that it can reflect the real parameters of the networks in which the simulated Ballistic Breaker interrupters work.

The PSPICE simulation has certain limitations, especially regarding the rated voltages of the simulated circuits.

Thus, the MATLAB simulation is much closer to the real phenomena, but the correlation with the parameters of each prototype must be achieved.

For verifying the obtained parameters, a simulation in the MATLAB program has been performed. This has respected the classical HVDC system parameters and the calculation relations found in the patent [5].

7. Conclusions

The MATLAB simulation represents a necessary step towards the understanding of the phenomena with the future purpose of achieving Ballistic Breaker prototypes.

We consider that the Ballistic Breaker represents a solution for the future achievement of the interruption in HVDC systems. Ballistic Breaker represents a radical change of concept compared with all the existing interruption solutions.

Ballistic Breaker performs a smooth interruption, without an electric arc, both in continuous and alternative current. The uses of this concept may be extremely varied, at any level of voltage. The reduced power loss while functioning represents a great advantage for this concept.

A disadvantage would be the high cost for achieving the prototype, due to the unconventional technical solutions. The estimated price of Ballistic Breaker is of approximately 12 ÷ 15 $ /kW, that is half of the price of classical systems. The Ballistic Breaker represents a competitor for the hybrid models by ABB, ALSTOM or the TWENTIES European Project, in the context of the development of the HVDC systems related to the offshore eolian parks.

Acknowledgments

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R E F E R E N C E S

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