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# EXPERIMENTAL AND SIMULATION STUDIES ON THE VOLTAGE DROP OF ARC IN LOW-VOLTAGE CIRCUIT BREAKER

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**Abstract.** In low voltage circuit breaker (LVCB) apparatus, a current limitation is performed by increasing the arc voltage. This increase is mainly realized in the splitters plates of the arc chamber by additional drop voltages due to anode and cathode sheaths regions. The consideration of the voltage drops near-electrodes regions is so one of the most important mechanism to improve the description of the arc behavior in LVCB. In this paper, the arc voltage evolution has been studied by experimental and simulation by considering a simple geometry constituted by two rails runner with one or two splitters plates. One magneto hydrodynamic model in three dimensions (3D) was developed to simulate the arc motion and the arc splitting process. In order to compare with the model results, experimental tests have been carried out.

**Keywords:** Low-voltage circuit breaker, voltage drop, splitters, experiment, simulation.

## 1. INTRODUCTION

The principle of LVCB consists to create a current limitation by increasing the arc voltage. The increase of the voltage is carried out by various mechanisms: increase of the losses, arc elongation and multiplication of the voltage drops in the splitters. To quantify and better describe these mechanisms, studies are conducted through models and experiments [1][2][3][4]. The most theoretical approach studied and applied in LVCB is the one proposed by Lindmayer [2]. This method allows considering an additional drop voltage through the resistivity in the layers. Another approach consists to describe the sheath with a non-equilibrium approach [5]. Nevertheless this method is difficult to implement for a real configuration with several splitters plates. Some authors [6][7][8][9][10] studied numerically the splitting process. Considering a nonlinear permeability of ferromagnetic material's they focus their studies on the influence of eddy currents [9] and on the influence of metal vapors coming from iron splitter plate erosion[10]. In those studies, the cathode voltage was treated by U-J curves and the anode arc root description was determined with the LTE-diffusion model of Lowke and Tanaka[11]. Another group has studied the arc phenomena in LVCB by an imaging system applied to a flexible test apparatus [12][13][14][15]. The studies were devoted to the influence of vent aperture size on re-ignition and arcing phenomena. They also proposed a modified method to consider the voltage due to the sheath regions. The ability to predict the arc extinction was analyzed and compared[16] with the Lindmayer approach[2]. The most complete study was proposed by Iturregi et al.[17]. They designed a 3D model in

LVCB to analyze the arc behavior. Nevertheless incoherencies appear in the comparison between one and two splitters plate: the additional drop voltage due to a second splitter is not present in the total voltage evolution versus time. The method is not clearly described as the authors used directly the @Ansys module which includes the Lindmayer approach. In this paper, the process of arc splitting is analyzed by theoretical and experimental works. Experimental tests have been realized using one and two splitters: high speed camera and electrical measurements. For the model we have implemented the Lindmayer approach and used the same geometries of Iturregi et al.[17].

## 2. NUMERICAL METHOD

### 2.1. Hypotheses

The following assumptions have been used: (1) The air medium plasma is assumed to be in Local Thermodynamic Equilibrium (LTE). (2) The plasma is a Newtonian fluid and the flow is laminar. (3) Vapors from the walls and electrodes are not taken into account. (4) Radiation is treated using the net emission coefficient method.

### 2.2. Equations

Based on the Fluent software, we have implemented a fluid model to simulate electrical arc behavior in a LVCB. It can be characterized by the macroscopic fluid quantities: velocity, pressure, enthalpy. All these quantities are obtained from the Navier-Stokes equations with Lorentz forces and Joule effects and completed with Maxwell equations to consider electromagnetism effects. The magnetic field is obtained from the

67 current path in the runners and plasma through the  
 68 vector potential resolution and a BiotSavart formula-  
 69 tion is used at the boundaries. In order to represent  
 70 the additional voltage drop for the runners and split-  
 71 ters, an effective electrical conductivity is defined [2]  
 72 based on experimental works[6][8]. The voltage evo-  
 73 lution versus the current density is plotted in the  
 74 Figure 1. These characteristics (a-b-c-d) suggested  
 75 by Lindmayer et al [2] in air medium with copper  
 76 runners enable some tuning of the model to adjust the  
 77 voltage, they represent the current ability to jump on  
 78 the splitter plate.

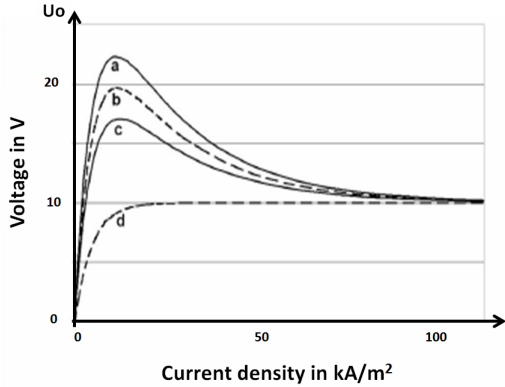


Figure 1. Evolution of voltage drop versus current density [3]

### 2.3. Boundary conditions

80 "Classical" boundary conditions are used [1]. The  
 81 magnetic field is calculated from the vector potentials  
 82 but the BiotSavart formulation is used to close the  
 83 system resolution.

### 2.4. Geometries

85 The geometries for the simulation are presented in  
 86 the Figure 2. The dimensions of the chambers are  
 87 40x2.5x11 mm (xyz) and the rails are 40x2.5x1.5  
 88 mm (xyz). It should be noted that the dimension  
 89 of the splitters plate are not the same: for one splitter:  
 90 20x2.5x2 mm (xyz) and for two splitters: 20x2.5x1  
 91 mm (xyz). D1=8mm represents the distance between  
 92 the two runners; D2 = 3 mm is the distance between  
 93 runners and splitters, for the third geometry D3 =  
 94 2 mm. These dimensions are far from real LVCB  
 95 but chosen to correspond with Iturregi et al. [17]. A  
 96 uniform grid is used in the geometry leading to 1.12  
 97 million cells.

## 3. SIMULATION RESULTS

99 We present the main results obtained with the 3D  
 100 model applying the Lindmayer approach. The arc  
 101 splitting behavior is shown through the current den-  
 102 sities in Figure 4 for one and two splitter plates. Figure  
 103 3 presents the voltage evolution for the two cases. The  
 104 calculation time step is 10 μs and the input current  
 105 is 50 A DC. The curve "c" of Figure 1 was chosen to

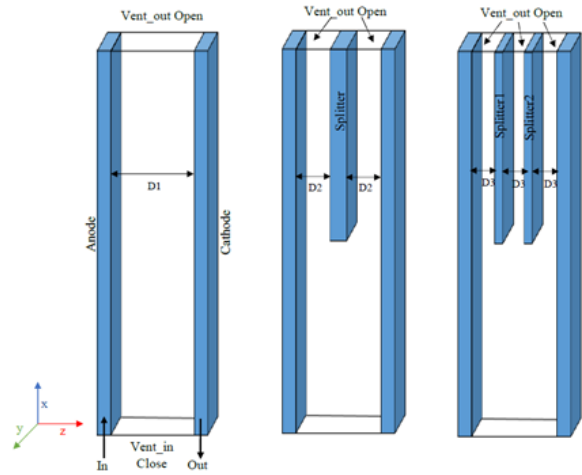


Figure 2. Geometries used for the simulation (From left to right: 0 splitter, 1 splitter and 2 splitters)

simulate the sheath contribution. There is no symme- 106  
 try plane in our simulation. In order to reduce the 107  
 calculation time, the arc is ignited 1.5mm front of 108  
 the splitters plates. 109

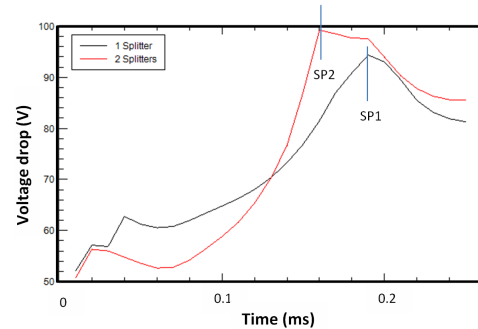


Figure 3. Voltage drop in the simulation with 1 and 2 splitters

In case of one splitter: At  $t = 50 \mu s$  the arc starts 110  
 to bend and moves toward the splitters. Due to 111  
 the arc elongation the voltage increases progressively 112  
 from 61V at  $t=50 \mu s$  to its maximum value 94 V at 113  
 $t=0.19ms$ . Then the voltage decreases. At  $t=0.19ms$  114  
 the drop voltage is due to the effects of the arc elon- 115  
 gation and to the additional voltage sheathes. After 116  
 time  $t=0.19ms$ , the current flows progressively into 117  
 the splitter leading to a diminution of the current 118  
 path and of the total voltage. The current path goes 119  
 into the splitter totally at  $t = 0.21 ms$ . At  $t = 0.25$  120  
 $ms$  there is only one path of current and the volt- 121  
 age drop decreases to 81 V. The contribution of the 122  
 splitter sheath on the total voltage is around 30 V in 123  
 the following case. In case of two splitters, the pre- 124  
 sented times are not the same; indeed the arc motion, 125  
 the splitting process time and behavior are different. 126  
 At  $t = 0.14 ms$ , the arc column bends around the 127  
 splitter plates, the arc voltage increases up to 76.6 V. 128  
 Compared to one splitter case, we can observe that 129  
 at  $t=0.15ms$  the arc begins to jump on the splitters. 130

Boundary conditions	Momentum	Enthalpy	Scalar Potential	Vector Potential
Cathode	$v=0$ m/s	Heat Transfer	Continuity	BiotSavart
Anode	$v=0$ m/s	Heat Transfer	Continuity	BiotSavart
In	/	$dT/dn=0$	$I=50$ A	/
Out	$v=0$ m/s	$dT/dn=0$	0 V	/
Vent In	$v=0$ m/s	300 K	$dV/Dn=0$	BiotSavart
Vent Out	$P=1$ atm	Convection	$dV/Dn=0$	BiotSavart
Walls	$v=0$ m/s	300 K	$dV/Dn=0$	/
Splitters	$v=0$ m/s	Heat Transfer	Continuity	BiotSavart

Table 1. Boundary conditions used in the simulation model.

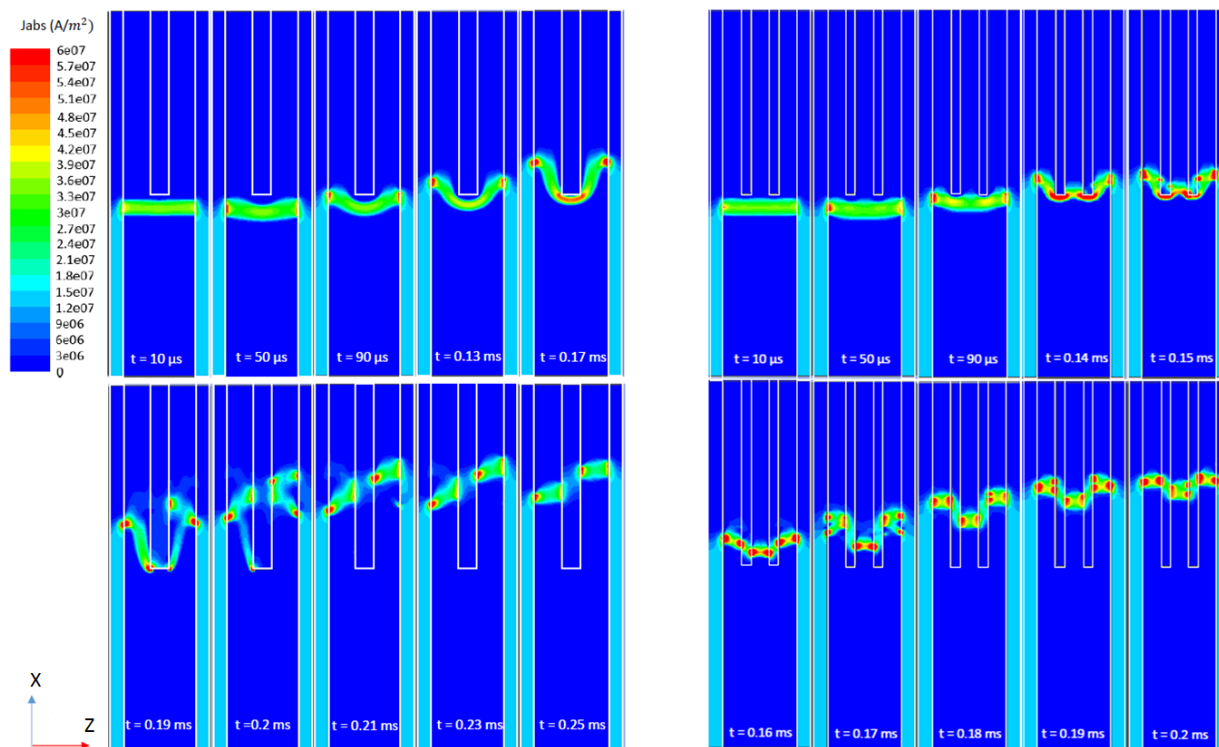


Figure 4. Simulated current densities using curve c for one (left) and two (right) splitters.

131 From this time, two arc roots appear on the splitters  
 132 plates, the current density through the splitter plates  
 133 increases and the current path out of the splitters  
 134 plates gradually fades. Compared with the case of  
 135 one splitter, the arc voltage evolution is faster. At  
 136 time  $t=0.25$ ms the difference on the total arc voltage  
 137 between the two cases is only 4 V. The comparison is  
 138 difficult to make as the current paths and arc lengths  
 139 are not the same. According to the results with one  
 140 splitter an additional voltage  $V=30$  V between the  
 141 two cases should exist. Nevertheless the arc positions  
 142 are different, the medium temperature is different and  
 143 the arc behavior not the same as shown by the voltage  
 144 evolutions Figure 3.

#### 145 4. EXPERIMENTAL RESULTS

146 The dimensions of the experimental setup are the  
 147 following: 126x15x20 mm (x,y,z) for the chamber,  
 148 126x15x1 mm (x,y,z) for the runners and 50x15x1

149 mm for the splitter plate. There is a wire located in  
 150 front of the splitter to ignite the electrical arc. The  
 151 experimental setup is composed by a generator which  
 152 can product a prospective peak current up to 13 kA  
 153 with a maximum charging voltage of 600 V in AC,  
 154 a high-speed camera (Photron SA5), a differential  
 155 voltage probe and a Rogowski coil for the electrical  
 156 measurements. Figure 5 presents the current evolu-  
 157 tion and the total voltages versus time for one and  
 158 two splitters. The first peak of voltage at  $t = 0.25$   
 159 ms characterizes the arc ignition. After that, the arc  
 160 moves toward to the upper side of the chamber. Dur-  
 161 ing the arc motion the voltage is nearly constant 60  
 162 V until  $t = 2$  ms. At this time the arc arrives in front  
 163 of the splitter plate. In the case with one splitter, arc  
 164 voltage increases by squeezing against the splitter, by  
 165 touching the lower edge of the splitter until arc was  
 166 totally on the splitter from  $t = 2$  ms to  $t = 3$  ms. The  
 167 voltage drop contribution dues to the splitter can be

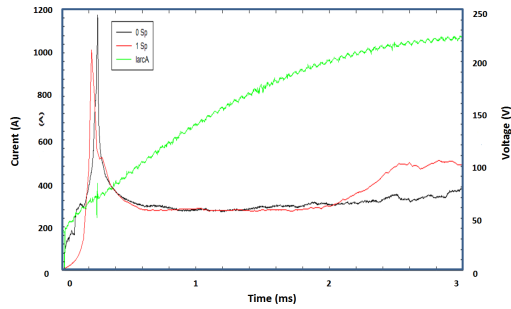


Figure 5. Experimental voltage drop and total current Cases with one and without splitter in the chamber

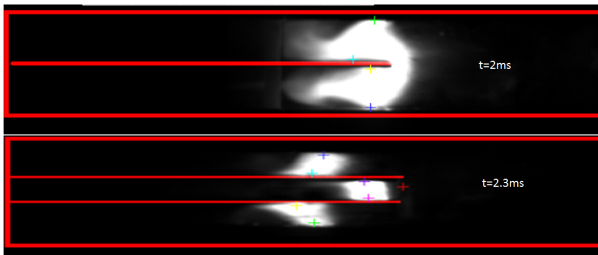


Figure 6. Example of arc behavior in front of one and two splitters plates obtained by fast camera

168 calculated by the difference between the case without  
 169 splitter. The value is nearly 25 V. This sheath con-  
 170 tribution is in the same order of magnitude than the  
 171 theoretical case, nevertheless we have seen between  
 172 the two theoretical cases (one and two splitters) that  
 173 the comparison is difficult due to the tortuous current  
 174 paths or arc behavior in the plasma.

175 Finally we present Figure 6 two images obtained by  
 176 the high speed camera to illustrate the arc behavior  
 177 observed experimentally. In the upper picture the  
 178 arc is bent in front of the splitter as in the down  
 179 picture the arc is segmented by the presence of the  
 180 two splitters plates.

## 181 5. CONCLUSION

182 A 3D model was developed and the effective electri-  
 183 cal model of conductivity suggested by Lindmayer [2]  
 184 introduced in the developments to characterize the  
 185 additional voltage due to the splitter plate sheathes.  
 186 The feasibility is demonstrated in cases of one and  
 187 two splitters plates. Interesting results are obtained  
 188 on the voltage evolutions. In the same time investiga-  
 189 tions are made to characterize the arc behavior in an  
 190 experimental setup by high speed camera and electri-  
 191 cal measurements. The theoretical and experimental  
 192 configurations are at this time different nevertheless  
 193 the same order of magnitude was observed with an ad-  
 194 ditional drop voltage around 20-30V for each splitter  
 195 plate. The next step of our study will consist to use  
 196 the same geometry for the model and the experience  
 197 and to perform one parametric study on the number  
 198 of splitters plates.

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