Exploring arcing phenomena in low-voltage contactors: a comprehensive study through numerical modelling and experiment

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Since the experiment cannot allow to describe in detail all the physical phenomena of arcing in low voltage contactors, it is best to implement a numerical model based on the first principles and not relying on a priori assumptions. In this work, numerical modelling of arcing in low-voltage contactors on cold electrodes in atmospheric-pressure argon is investigated by means of the unified 1D modelling. The explosion of the last bridge of the contactors is not described by the model. The modelling starts from an "after explosion" state. The effect of initial conditions, assumed at this state, is studied. Results are compared with results of experiments performed at Schneider Electric. A good agreement is observed between the numerical and experimental results.

The unified arc modelling approach, developed and used by workers from different countries, allows one to describe, in a natural way, the whole process of development of short non-stationary arcs, including the arc ignition and the switching of polarity, until the arc is extinguished. In [1] the first quarter-period after the ignition, from a cold state, of a short AC arc between parallel electrodes in atmospheric-pressure argon was studied. In this work the study is extended to longer times to investigate the changes of polarity with subsequent reignitions of the arc after each change of polarity. The equations and the boundary conditions are written in the spirit of previous work [2].

The explosion of the last bridge, occurring when the electrodes of a contactor begin to open, is not described by the model; the modelling starts from an "after explosion" state. The effect of initial conditions, assumed at this state, is studied. It is found that the computed ignition voltage exceeds experimental ones. Effects that can be responsible for this deviation are investigated: increased value of the secondary electron emission coefficient, increased surface temperature of the electrodes, and/or field electron emission from the cathode surface enhanced by the presence of microprotrusions on the surface.

The setup of an experiment with contractors, carried out at Schneider Electric in Grenoble, consists of the power supply, a resistor and two electrodes: one static and the other mobile. The experimental condition of arcing in low-voltage contactors is with cold electrodes and in atmospheric-pressure air. During the experiment, the arc current, arc voltage, and the displacement of the mobile electrode carrier are recorded. In this experiment, new electrodes were used. The contacts separate until the distance between them is 8 mm.

The numerical modelling of the AC current transfer in a contactor is compared with the experimental result. For that, it is necessary to evaluate the amplitude of the current density to be used in the modelling to perform a comparison. Assuming 5 mm for the attachment diameter and taking 800 A for the amplitude of the applied arc current, one obtains a value of the order of 4×10^{7} $\mathrm{Am^{-2}}$ for the current density amplitude. The electrode material was assumed to be copper, and the plasma-producing gas was argon instead of air; approximations that are deemed reasonable for a quantitative comparison. The modelling results reported here refer to a fixed interelectrode gap of h=100 μm.

The initial temperatures of the gas and the electrodes must be specified as initial conditions. In principle, the initial conditions should describe the post-initial explosion state. Unfortunately, there appears to be no reliable information on this state. Therefore, suitable initial conditions must be identified by trials and errors. Let us first consider results obtained assuming the typical cold initial conditions.

The computed arc voltage and the measured arc voltage are shown in Fig. 1, along with the current density, evaluated as described above in terms of the measured arc current for the experimental date. The arc voltages in the simulation begin at the first CZ and in the case of the experimental the opening of the electrodes occurs approximated at the 16 ms. These two points are not comparable, because the initial conditions of the simulations are not for the conditions of the "after explosion". Nevertheless, at the instant 16 ms the arc voltage of the experimental and the modelling are very close. This means that at the instant 16 ms of the modelling can be the initial conditions that describe the "after explosion" state of the electrodes. After this point one can see that there is a clear qualitative agreement between the modelling and the experiment: there are significant overvoltage peaks after each CZ according to both the modelling and the experiment, and the height of the peaks (the overvoltage value) decrease with time.

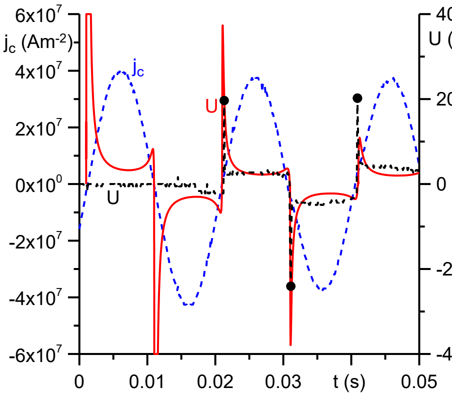

Fig. 1 Solid: computed arc voltage. Dashed: current density and arc voltage from the experimental data.

In Fig. 1, it is shown that, in the experiments, the electrodes open under high current conditions, resulting in an arc voltage of approximately 20 V. Additionally, based on the final state of the electrodes, it can be concluded that the typical temperature remains below the boiling point. That means that for reaching the same conditions in the modelling, it will be necessary to improve the modelling initial conditions. This can be done by increasing the value of the secondary electron emission coefficient, γ, by changing the initial surface temperature of the electrode, and/or by introduction of the field enhancement factor, β. The impact of these three mechanisms can be observed in Fig. 2. Here the current density linearly increases with time from 0 to 10^7 Am^{-2} within 1 ms and is maintained constant after 1 ms, the electrodes separation is 10 mm and the material is tungsten.

The three mechanisms studied in this work have an impact on the initial arc discharge voltage, but they do not bring it down to the values observed in the experiment. There are several parameters to be adjusted in the model: the current value, or current density at the instant of the opening of the electrodes, the effect of the opening of the electrodes, or maybe increased β until 300. This will be addressed in the next works.

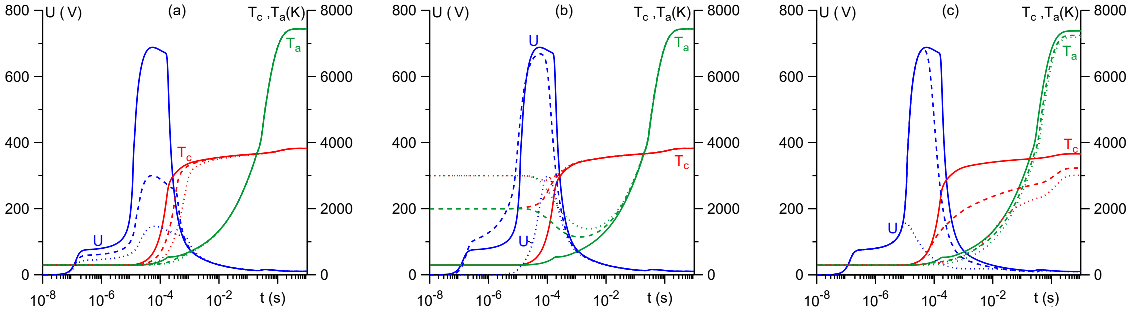

Fig. 2 Evolution of the arc voltage and electrode surface temperatures for different values of: (a) γ. Solid: γ=0.1. Dashed: 0.2. Dotted line: 0.4, (b) T_s. Solid: T_s=300 K. Dashed: 2000 K. Dotted: 3000 K and (c) β. Solid: β=1. Dashed: 50. Dotted: 100.

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