Numerical modelling of high-pressure arc discharges: matching LTE arc core with the electrodes

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Numerical simulations of electric arcs burning in high-pressure gases are commonly performed by means of a model in which the arc plasma is assumed to be in local thermodynamic equilibrium (LTE). In this work, this model is supplemented with a self-consistent description of the interaction of the LTE arc bulk with the electrodes. This is done with the use of the equation of balance of energy in the non-equilibrium near-electrode layers that separate the LTE bulk from the electrodes. As an example, the developed model has been applied to a short free-burning arc in atmospheric-pressure argon in a wide range of arc currents, from 20 to 200 A. The simulation results have been compared with those from a model that does not rely on assumptions of thermal or ionization equilibrium in the bulk plasma, as well as with the experiment, and a good agreement was found.

Numerical modelling of high-pressure electric arcs is of high interest due to many industrial applications. The essential elements of the numerical models are interfaces separating the bulk plasma from the electrodes, which are supposed to provide a reasonably accurate description of the physics governing the plasma-electrode interaction.

The choice of the model of plasma-electrode interaction depends on the description of the bulk plasma being used. As far as the plasma-cathode interaction is concerned, self-consistent models exist for a fully non-equilibrium (NLTE) description and a two-temperature (2T) description, which takes into account different electron and heavy-particle temperatures but assumes ionization equilibrium. On the other hand, most works dedicated to simulation of high-pressure arc discharges employ the assumption of LTE. LTE models are significantly simpler than the NLTE and 2T models; their numerical realization is simpler, may rely on ready-to-use specialized software such as Equilibrium DC Discharge (sub)module of the Plasma module of commercial software COMSOL Multiphysics, and requires less computation resources. It is therefore highly desirable to develop a self-consistent method of matching solutions in the LTE bulk plasma and in the electrodes.

A self-consistent matching of an LTE bulk plasma with a cathode, proposed in this work, is based on the balance of energy in the near-cathode non-equilibrium plasma layer, which comprises a quasi-neutral ionization layer and a space-charge sheath [1]. The matching of an LTE bulk plasma with an anode is based on the balance of energy in the near-anode layer and on a pre-computed value of the so-called anode heating voltage.

The system of MHD equations is solved in the LTE bulk plasma. The heat conduction and current continuity equations are solved in the electrodes. Solutions in the different domains are matched through boundary conditions. The commercial software COMSOL Multiphysics is employed.

As an example, simulation results are reported for the conditions of experiment [2]: a free-burning 1 cm-long atmospheric-pressure argon arc with a rode tungsten cathode and a plane copper anode, the arc current varying from 20 to 200 A. The effect of the cathode shape on the arc temperature has been investigated as well.

The computed distributions of plasma parameters are compared with those obtained by means of the NLTE approach [3]. The current-voltage characteristic of the arc is compared with the experiment [2]. In both cases, a good agreement has been found.

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