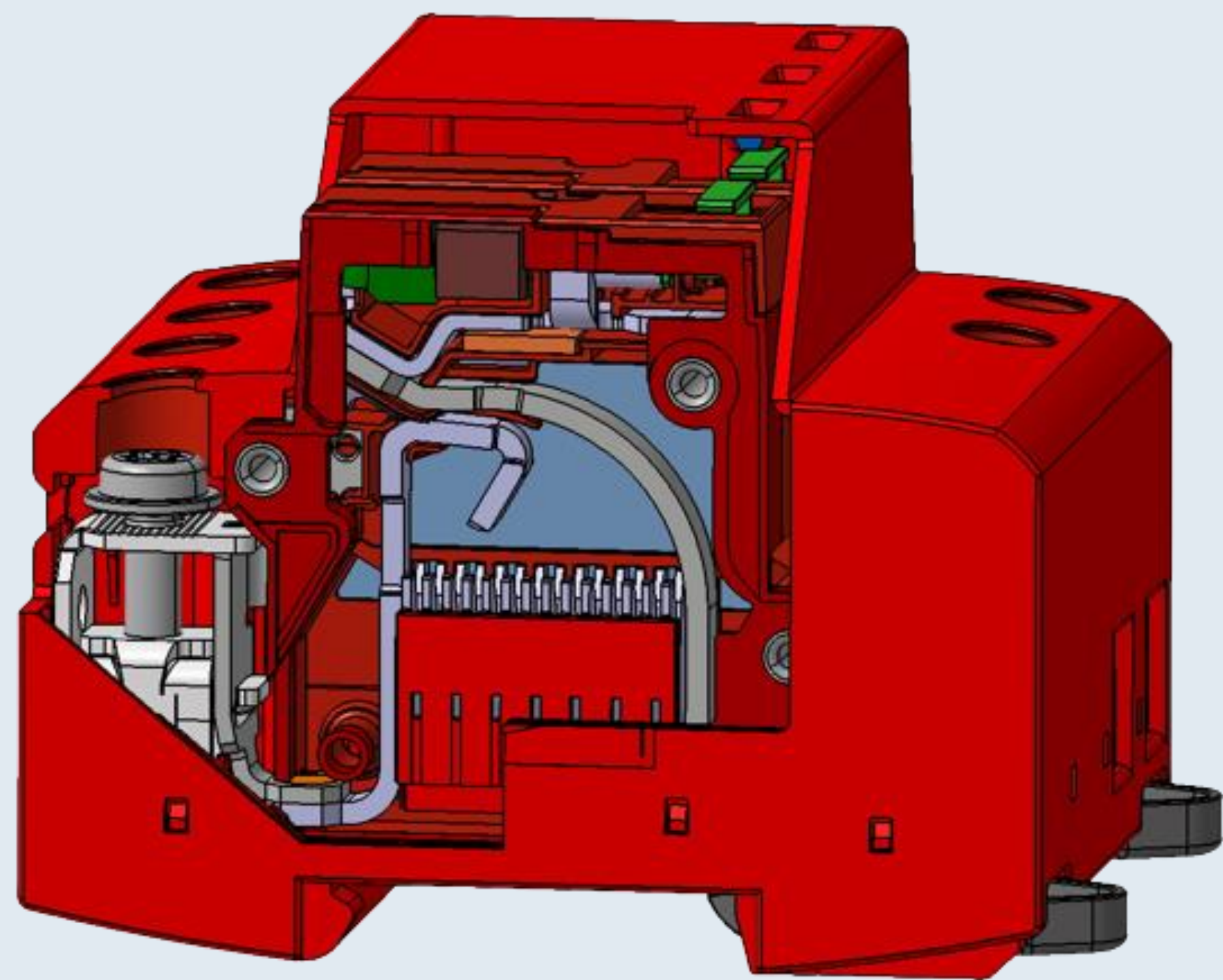# Simulation of the Arc Motion in Low-Voltage Surge Protection Devices

The arc development in low-voltage surge devices is accompanied by interrelated electromagnetics, fluid flow, and heat transfer and can be characterized as a multiphysics problem.

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Introduction

Surge protection devices (SPD) are widely used in electrical grids to suppress over voltages during transient conditions caused by voltage surges and to prevent damages of industrial or household devices [1, 2]. The working principle is based on the initiation of an arc with a burning voltage lower than the rated supply voltage. The arc has to be led to its extinction clearing the subsequent over current and avoiding that it is further supplied by the power grid. Magneto-hydrodynamic models of the arc evolution can support the product development. The large computation cost is still a problem in 3D models. It can be significantly reduced if the arc chamber is slim and does not exhibit substantial irregularities in the third dimension. Models of low-voltage switching devices with parallel or diverging runners can be set up using 2D planar chamber geometries.

Mass continuity
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

Momentum
$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho (\boldsymbol{u} \cdot \nabla) \boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \boldsymbol{K}] + \boldsymbol{F}$$

Energy

3D
$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p \boldsymbol{u} \cdot \nabla T + \nabla \cdot \boldsymbol{q} = Q$$

2D
$$d_z \rho c_p \frac{\partial T}{\partial t} + d_z \rho c_p \boldsymbol{u} \cdot \nabla T + \nabla \cdot \boldsymbol{q} = d_z Q$$

Current continuity
$$\nabla \cdot \boldsymbol{j} = 0$$

Ohm's law
$$\boldsymbol{j} = \sigma \boldsymbol{E} + \boldsymbol{j}_e, \boldsymbol{E} = -\nabla V$$

Maxwell equations
$$\nabla \times \frac{1}{\mu_0 \mu_r} \boldsymbol{B} = \boldsymbol{j}$$
$$\boldsymbol{B} = \nabla \times \boldsymbol{A}$$

FIGURE 1. Governing equations of the MHD model of arc motion in the SPD's chamber.

Methodology

The arc development is accompanied by interrelated electromagnetics, fluid flow, and heat transfer and can be characterized as a multiphysics problem. The CFD Module, the AC/DC Module and the Heat Transfer Module along with user defined features are used which are related to radiative heat transfer and the event definition of the arc ignition. The arc is ignited in air at atmospheric pressure and the arc plasma is usually considered to be in the state of local thermodynamic equilibrium. A magneto-hydrodynamic (MHD) model is developed based on the time-dependent partial differential equations (Figure 1) for conservation of mass, momentum and energy along with the equations of current continuity, Maxwell equations, Ohm's law and the equation of state.

Results

The distribution of the plasma temperature is shown in Figure 2 as obtained from the 2D planar model and in the plane of symmetry of the 3D model. Four instants are chosen to represent the ignition, the distribution at maximum current, and those at 50% and 25% of the maximum during current decay. The evolution of the arc in both models is very similar. The arc motion occurs in the same way in both models. The computational domain is finer spatially resolved in the 2D model. This allows us to obtain finer details of the arc attachment on the electrodes and towards the gas outflow. The results correlate with the measurements obtained from optical emission spectroscopy. The 2D model is computationally very efficient and its use can be favoured for preliminary developments.
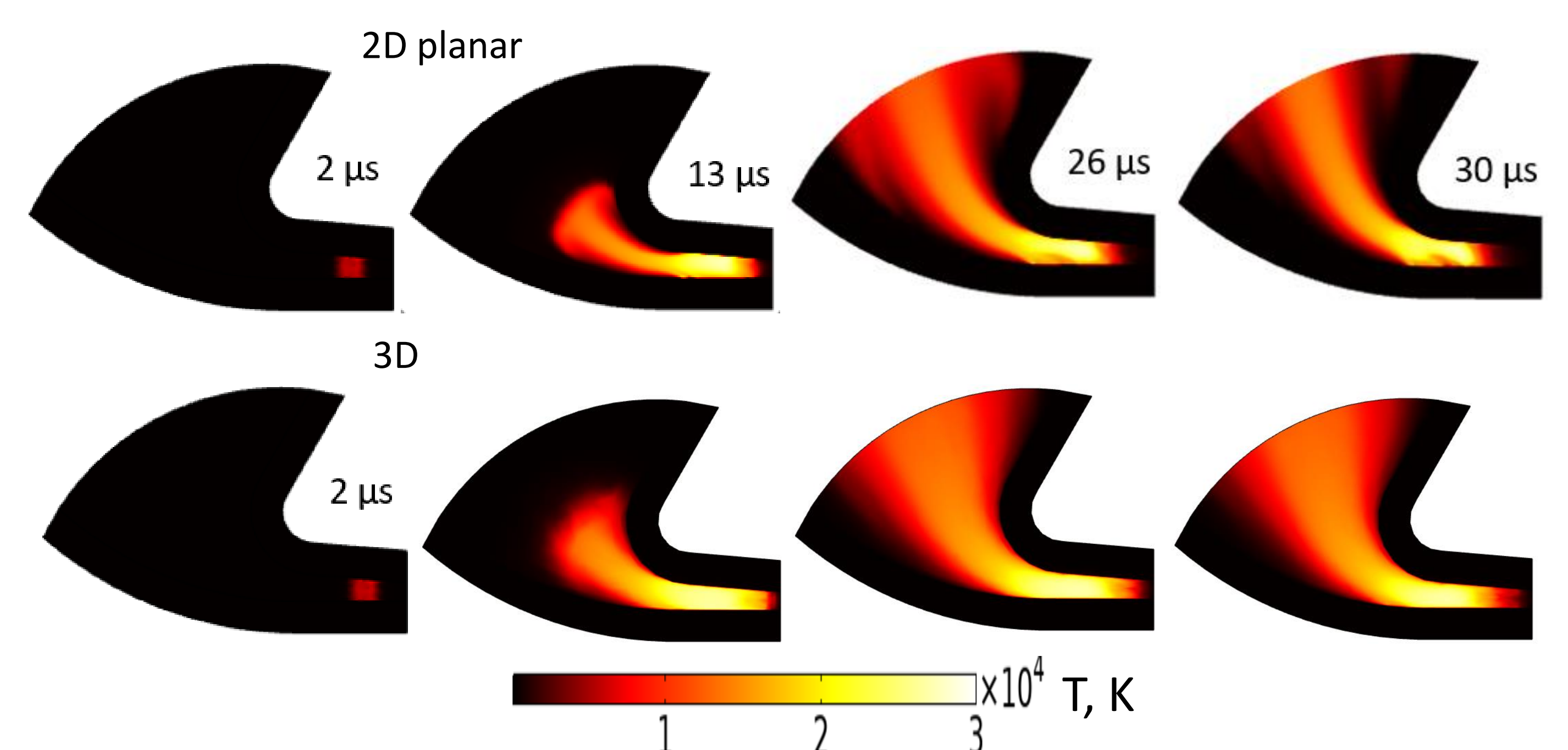

FIGURE 2. Snap shots of the arc evolution obtained in the 2D and the 3D models.

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