



Plasma Simulation in STAR-CCM+ -- towards a modern software tool

1 Introduction

Electrical arcs and other forms of industrial plasmas have a large number of technical applications, including circuit breakers, arc welding, and plasma torches. In spite of this, there are no useful numerical simulation tools for arcs available on the market. Researchers are forced to couple different codes, leading to simulations that are neither fast nor very robust.

Siemens PLM software has entered this market with their software STAR-CCM+. It contains a state-of-the-art CFD solver with an integrated FE-based solver for the magnetic fields. Moreover, it is able to cope with moving geometries and data interpolation between the two solvers in a single software environment. The Computational Physics Group at the IET Institute for Energy Technology at HSR University of Applied Sciences Rapperswil, has started a collaboration with Siemens PLM software to develop STAR-CCM+ into an optimal tool for arc simulations in industrial research.

The basic functionality for plasma simulations is already available in STAR-CCM+; our collaboration is intended towards adding additional physical models and extending the user interface for an easy and complete set up of arc simulations within one tool. We are currently working on:

- Simple setup of moving contacts applicable to both solvers
- Implementation of arc root models through surface sources including a voltage drop in the electromagnetic solver
- Implementation of flexible boundary conditions for radiation models and smart averaging of the absorption spectrum
- Software testing with respect to academically as well as industrially relevant cases

The goal of the collaboration is to realize relevant modeling concepts for plasma simulations into STAR-CCM+. Hence, an integrated and modern plasma simulation framework with powerful CAD import, automatic mesher, and parallel solvers, will soon become available for the plasma simulation community.

As an early adopter of this approach, we are keen to work with end users to challenge the new tool with a variety of arc simulations. We will be happy to check if your simulation requirements are met by STAR-CCM+, and how to recreate your specific models in STAR-CCM+.

In the remainder we present simulation results of a model circuit breaker using STAR-CCM+. Although a very simple simulation setup was used, we are eagerly moving towards more complex and demanding settings that will be presented soon.

2 Example of a low-voltage circuit breaker simulation

We outline the geometry setup, the circuit model, the physics settings, and present results of voltage and current curves.

2.1 Geometry

The model circuit breaker (cf. Figure 1) consists of two electrodes, a steel cylinder, and a plastic enclosure. The simulation domain size is approximately 28 x 34 x 10 mm in x-y-z directions. The upper electrode moves upwards with a speed of 5 m/s while the lower electrode is fixed.

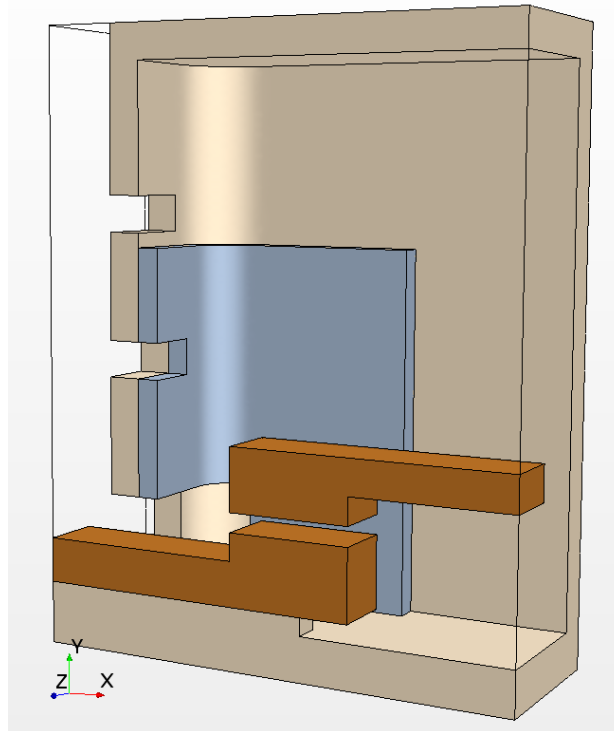


Figure 1: Geometry of model circuit breaker.

2.2 Electric circuit model

A test circuit consisting of an AC voltage source and a resistor is attached to the circuit breaker model (cf. Figure 2). The terminals A and B are connected to the upper and lower electrode, respectively. The time-dependent arc resistance $R_{arc}(t)$ is evaluated at every timestep as the arc voltage divided by the arc current:

$$R_{arc}(t) = \frac{U_{arc}(t)}{I_{arc}(t)}$$

Due to its simplicity, the electric circuit has been implemented by analytical formulas directly as boundary conditions (see below). More complex circuits can be implemented in STAR-CCM+ using its circuit model.

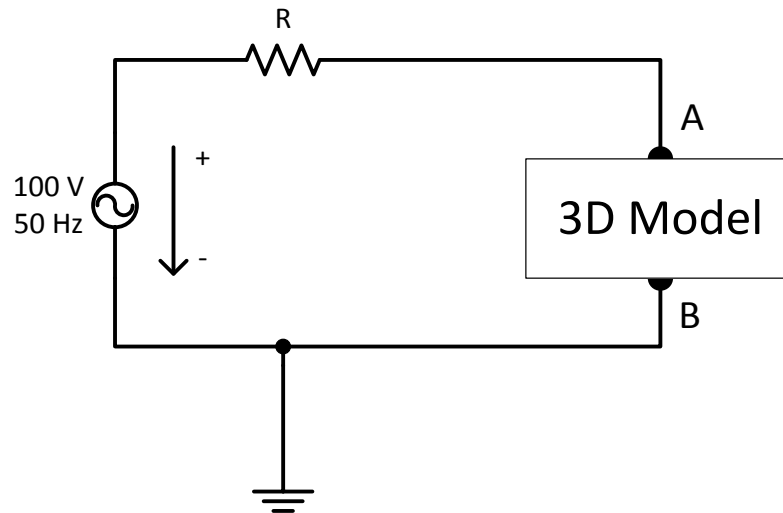


Figure 2: Electric test circuit.

2.3 Meshing and Data Mapping

As many other gas flow solvers, STAR-CCM+ is traditionally based on the finite volume method (FVM) for its gas flow solvers. A finite element method (FEM) solver for the magnetic vector potential has recently been added. While the FVM solvers support polyhedral and tetrahedral grids, the FE magnetic potential solver only supports more traditional cell shapes, tets, hexas, etc. Moreover, the gas flow requires higher resolution in the air domain than the magnetic vector potential.

Therefore, the domain is discretized using two grids (cf. Figure 3): a finer polyhedral mesh with prism layers for the solvers in FV formulation (gas flow and electric potential), and a coarser tetrahedral mesh for the FE magnetic potential solver, both using the same geometry and meshing environment. The blue surface indicate symmetry conditions, and the orange surface represents pressure outlet conditions. The body contours are shown in red.

Data mapping between the meshes is available by data mappers inside STAR-CCM+: selecting the quantities to be mapped as well as the source and target regions is supported in the user interface. Table below summarizes the data mapping settings.

Quantity	Mapped from ...	Mapped to ...
Electric Current Density	FV grid	FE grid
Magnetic Flux Density	FE grid	FV grid

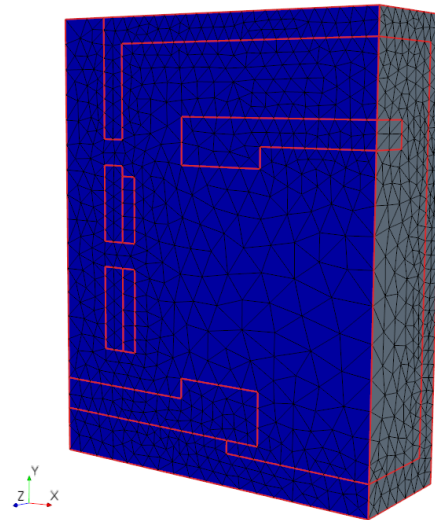
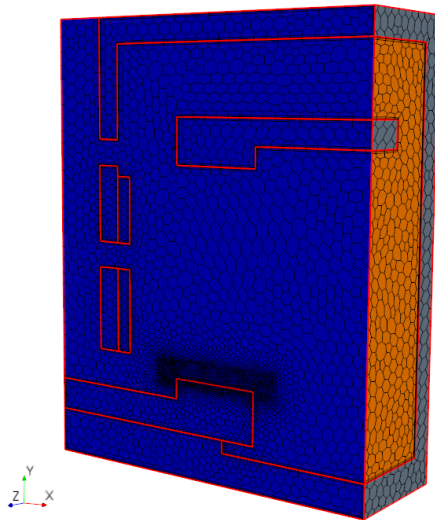


Figure 3: Polyhedral and tetrahedral grid. Solid geometry is outlined in red.

2.4 Physics settings

2.4.1 Gas model

For simplicity, the gas is modelled as an ideal gas and radiative heat losses are computed by a net emission coefficient. STAR-CCM+ allows for real gas data that are functions of pressure and temperature, i.e. $\phi(p, T)$. A multi-band discrete ordinate method (DOM) is available for radiation modelling. These functionalities have already been tested and will be used in subsequent simulations. Turbulence has been neglected although a common set of turbulence models is also available.

Coupling to the electrodynamic model is established by the electric conductivity (cf. Figure 4) being a function of pressure and temperature, i.e. $\sigma = \sigma(p, T)$, and the Lorentz force ($\vec{F}_L = \vec{j} \times \vec{B}$) as a momentum source for the gas flow. Electrode material data correspond to copper. The plastic enclosure is modelled as insulating material. The steel cylinder has a relative magnetic permeability of $\mu_r = 10^4$; its electric conductivity is set to $\sigma = 0 \text{ S/m}$, for instance due to an insulating material coating the cylinder surface.

The timestep length is initially set to $\Delta t = 0.5 \mu\text{s}$ and is set adaptively based on a CFL condition. The maximum timestep length is $5 \mu\text{s}$ because the domain is remeshed every $50 \mu\text{s}$.

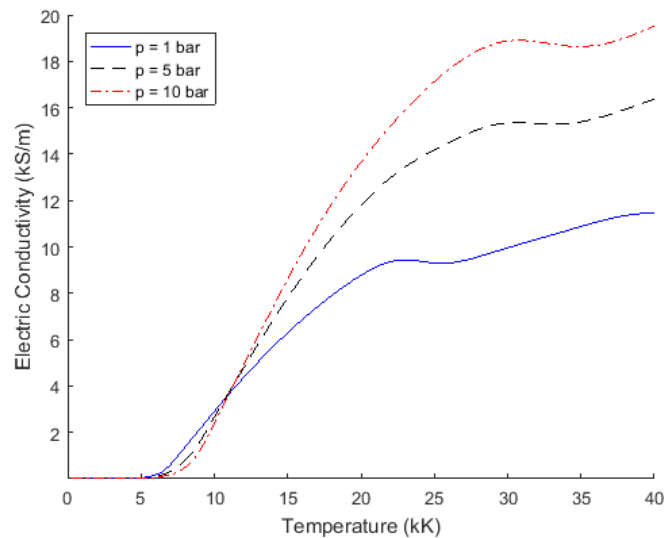


Figure 4: Electric conductivity of air.

2.4.2 Boundary and initial conditions

Symmetry conditions are used on the xy -plane for all quantities. A pressure outlet condition is specified in both x -directions. The gas is initially at rest and 300 K uniformly.

The electric circuit yields a voltage $U(t) = U_0(t) - R \cdot I(t)$ at the upper electrode where $U_0(t) = 100 \cos(2\pi ft)$ and $f = 50 \text{ Hz}$. The resistance is set to $R = 0.5 \Omega$, and the current $I(t)$ is evaluated at terminal B.

Arc ignition is modelled as a cylinder with 1 mm radius and conductivity $\sigma = 100 \text{ S/m}$ located centrally between the electrodes. Initial electrode distance is 1 mm.

2.5 Results

Figure 5 shows the voltage and current oscillograms of the arc (measured between the terminals A and B), and the applied voltage to the electric circuit (i.e. the voltage source). Arc resistance is shown in Figure 6. A [video](#) is available on our YouTube channel.

The initial arc resistance is 7 Ohm, arc voltage 87 V, and current 25 A. Ohmic heating then yields to full gas breakdown in a few microseconds and the electrode gap is filled with hot and conductive plasma; a minimum arc voltage of 5 V is observed. Subsequently, the arc contracts and is pushed in ($-x$)-direction; a local maximum of 15 V is observed. After 100 μs , the arc is located near the electrode edge and burns in fully across the electrode; the arc voltage has dropped to 10 V. Subsequently, the arc voltage raises as it becomes elongated due to electrode motion and Lorentz force. At 340 μs , the arc voltage has dropped to 32 V since a major fraction of air between the lower exhaust holes is occupied with plasma. At 400 μs , the arc voltage increases to 40 V since the arc has almost left the electrode contact surface and is

elongated further. Then arc voltage is increasing due to elongation by electrode motion, and the arc burns near the steel cylinder surface. The arc is extinguished after 1.7 ms.

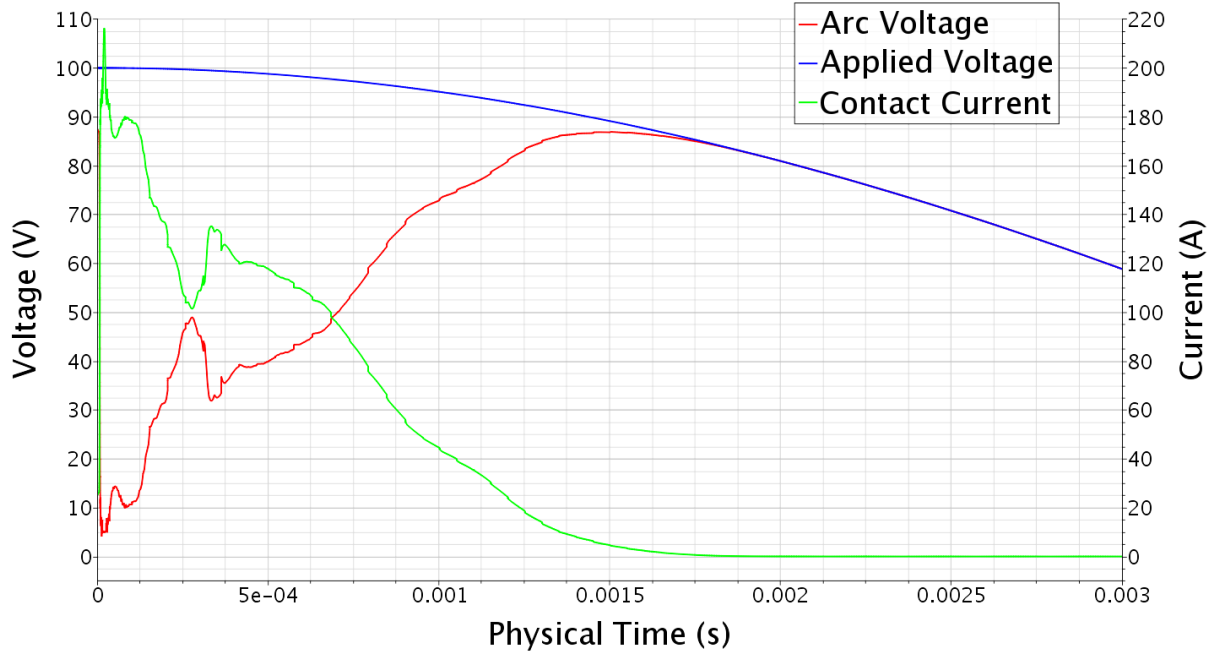


Figure 5: Voltage and current oscillograms.

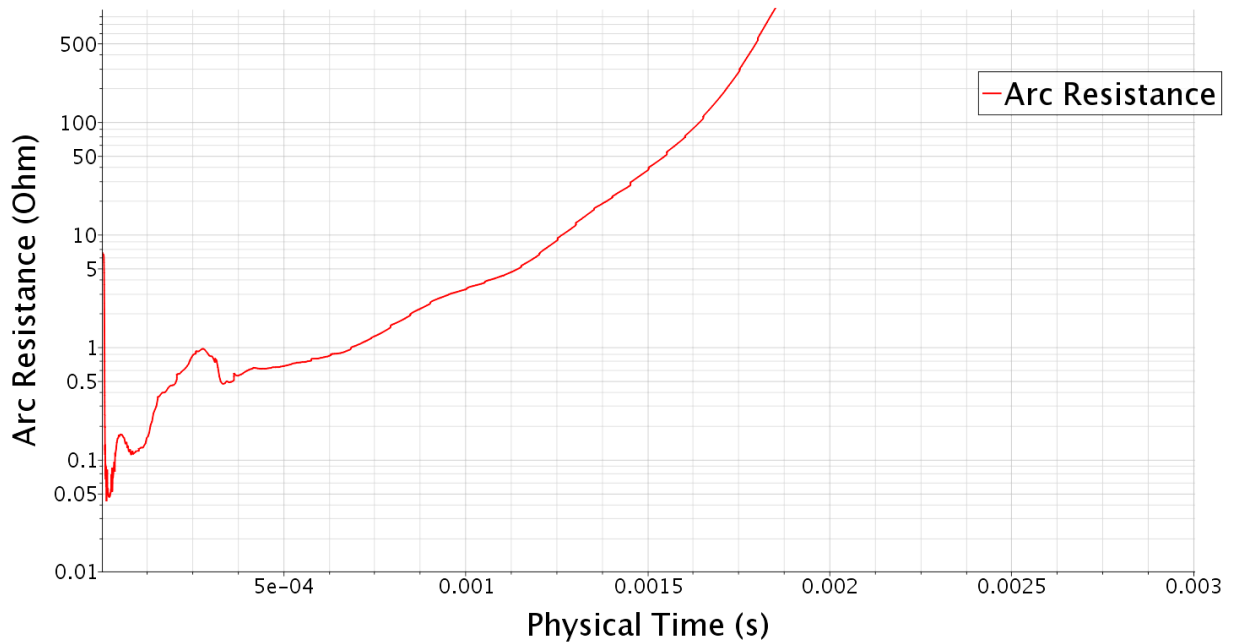


Figure 6: Measured arc resistance.



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Acknowledgement

We thank Dr. Paul Hilscher from Siemens PLM software for his extensive support and providing plasma material data.

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