3D Magnetostatic Moment Method dedicated to arc interruption process modeling

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***Abstract*—The behaviour of arcs in circuit breaker is affected by several interactions. To simulate this, a three-dimensional modeling system has already been developed. It takes into account the plasma fluid dynamics, the radiation, the plastic vaporization, the current flow within the electrodes and the plasma, and the magnetic field generated by currents. In order to take into account the influence of ferromagnetic regions the simulation model has to be extended.**

The Magnetic Moment Method (MoM) is an integral method where only active regions (i.e., ferromagnetic regions in our context) are meshed. Thus it is particularly well adapted for breaking modeling with few ferromagnetic regions in comparison to the whole air region.

In this paper, a non-linear MoM model is discussed and finally an arc interruption process modeling with the introduction of ferromagnetic regions is presented.

***Index Terms* — Plasma simulation, circuit breakers, magnetostatics, moment methods, nonlinear equations.**

I. Introduction

When a circuit breaker detects a fault current, it opens the electrical circuit and an arc appears. The ignited arc between the opening contact pieces has to be quickly extinguished. The most effective and hence most widely used possibility for that is to split the arc into series arcs by metallic splitter plates (Fig 1) [1]. Thereby hydrodynamic constraints and magnetic forces on the arc must be under control to ensure an optimal arc displacement.

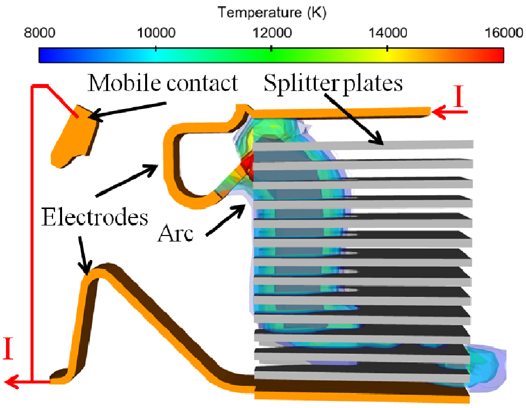

Fig. 1. Arc represented by several iso-values of temperature. The arc appears between the contact pieces, slides between the electrodes and finally it is cooled in splitter plates.

In the case of a breaking process at low current, ferromagnetic regions allow to substantially increase the Lorentz forces on the plasma.

This paper presents the introduction of the ferromagnetic effects thanks to the Magnetostatic Moment Method (MoM) in the Schneider Electric's arc system modeling [2].

II. 3D Magnetostatic Moment Method (MoM)

A. *Standard equation*

For a magnetostatic problem composed by some ferromagnetic regions and coils supplied by currents, the magnetic field can be expressed as the sum of the external field and the reduced magnetic field which derives from the magnetic scalar potential. The magnetic field can be read [3]:

$$\mathbf{H}(\mathbf{r}') = \mathbf{H}_{ext}(\mathbf{r}') - \nabla_{\mathbf{r}'}\left(\int_V \nabla_{\mathbf{r}} G(\mathbf{r},\mathbf{r}')\cdot \mathbf{M}(\mathbf{r})\mathrm{d}^3\mathrm{r}\right) \quad (1)$$

where $\mathbf{H}_{ext}$ is the external field due to the current, $\mathbf{M}$ the magnetization, G is the Green Function for a Laplace's equation, **r** the integration variable and **r'** the position of the computation.

This formulation strongly ensures Maxwell-Ampere and Maxwell-Thomson equations. Therefore to determine the magnetic field **H**, the magnetic law behaviour must also be ensured.

B. *Point-Matching method*

The magnetization is considered uniform in each cell. The equation (1) for p magnetic cells becomes:

$$\mathbf{H} = \mathbf{H}_{ext} + [\mathrm{K}]\mathbf{M} \quad (2)$$

where ($\mathbf{H}$, $\mathbf{H}_{ext}$, $\mathbf{M}$) are 3p vector and [K] is $(3p)^2$ matrix.

The matrix [K] is a matrix of view factors between the cells computed by reduction of singularities [4].

The point matching method consists in checking the magnetic law behaviour at each cell centroid. Thereby the residual 3p vector can be expressed as below:

$$\mathbf{R}(\mathbf{M}) = \mathbf{m}(\mathbf{H}) - \mathbf{M} \quad (3)$$

and the non linear system equation for a Newton Raphson process can be read:

$$\left(\left[\left.\frac{\partial \mathbf{m}(\mathbf{H})}{\partial \mathbf{H}^T}\right|_{\mathbf{H}^{n-1}}\right][\mathrm{K}] - [\mathrm{I}]\right)\Delta\mathbf{M}^n = -\mathbf{R}\left(\mathbf{M}^{n-1}\right) \quad (4)$$

where the first matrix is a diagonal bloc matrix linked with the derivative of magnetic law, $\Delta\mathbf{M}$ is the increment of the magnetization, **R** the residual vector and n the iteration number.

The flowchart of the nonlinear resolution is represented in Fig. 2. In order to reduce the CPU time, the tangent matrix is not updated at each iteration. In other words, a fixed point (with the previous tangent matrix) and a Newton-Raphson method are alternatively used. The presented approach has been validated on several test cases to prove its effectiveness.

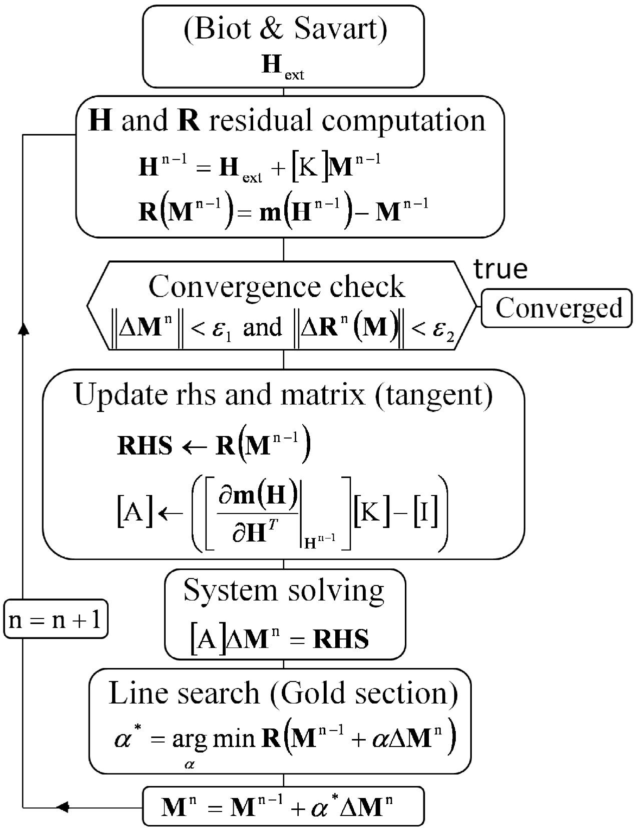

Fig. 2. Non linear flowchart resolution where A is the solving matrix, RHS the right hand side vector, ε_1 and ε_2 are tolerance parameters.

III. Circuit Breaker Application

The core of the arc system modelling is based on the commercial software Fluent and user defined functions used to take into account all others phenomena (real gas, radiation, plastic vaporization, arc root, electromagnetism) [6].

During a breaking process, the current density of the arc leads to:

- ohmic heating (Joule losses > energy source) and
- magnetic forces (Lorentz forces > momentum source)

which cause gas flow and energy transport within and out the plasma (Diagram represented in Fig 3.)

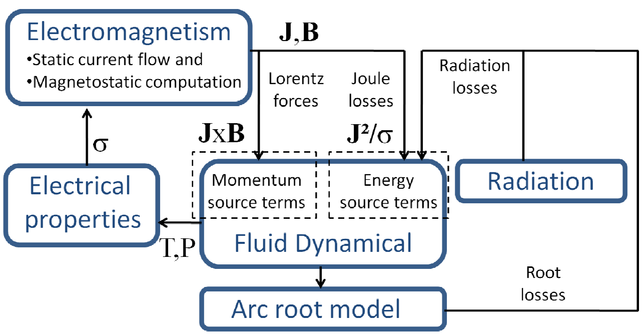

Fig. 3. Diagram of the resolution procedure for the arc interruption process modeling (T temperature, P pressure, σ electrical conductivity).

In a circuit breaker model two ferromagnetic "cheeks" are introduced close to the breaking chamber. During the breaking process simulation, the magnetization in cheeks and their influence on the magnetic field seen by the arc can be observed (Fig 4).

The comparison of the global electrical data (I current and U_{arc} arc voltage) for several configurations allows finding the best design for an optimal arc interruption breaking process.

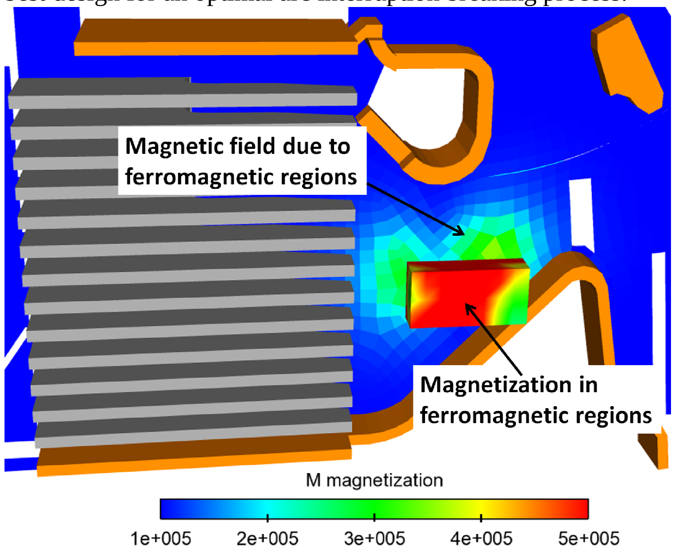

Fig. 4. Magnetization representation in ferromagnetic regions and magnetic field due to ferromagnetic regions represented on a middle plane of the circuit breaker.

IV. Conclusion

The MoM method is suitable and well adapted for the breaking modelling. Compared to other approaches [7], it avoids the meshing of the whole air region and the use of two different meshes.

The use of the compression method is in progress. A further reduction in the computation time is expected.

The introduction of MoM in the arc system modelling allows considering ferromagnetic regions position and shape optimization. An improvement in the design of circuit breakers is expected.

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