A Transient Current Vector Potential to Consider the Rotor Excitation of Synchronous Machines Under Short Circuit Condition

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Abstract

This work presents a method to approximately take account of the rotor excitation field of a synchronous machine under maximum aperiodic short-circuit condition using an impressed current vector potential in a three-dimensional (3-D) transient finite element analysis. The method is applied to compute end region phenomena like end-winding forces or eddy current losses in conducting machine parts where the effects of the rotor excitation field cannot be neglected. A complex 3-D geometry model, the numerical method and the computation results like end-winding forces are presented. The transient analysis of the electromagnetic field has been performed using the ***T***, *Φ*-*Φ* formulation solved with an in-house software.

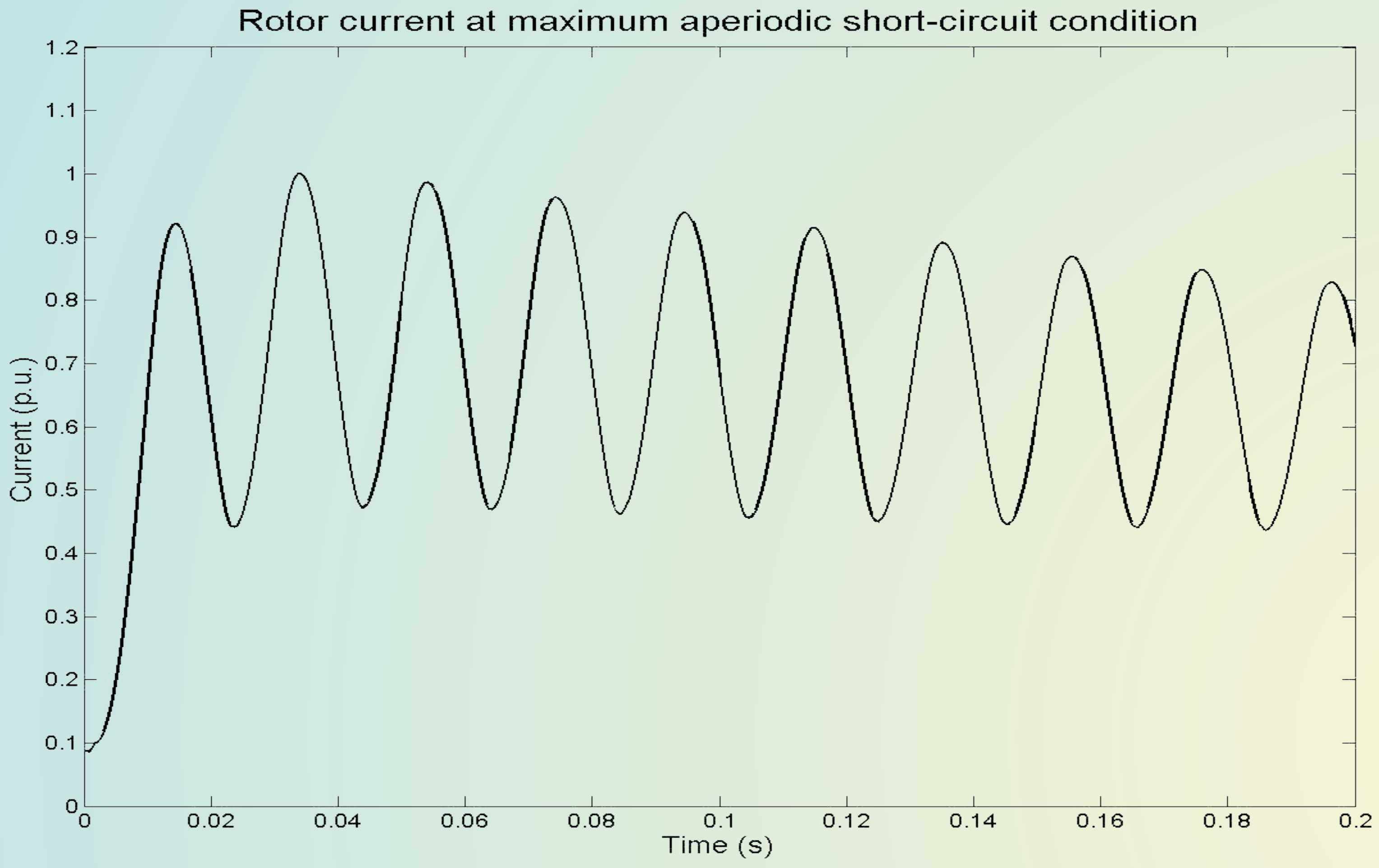
Rotor excitation field

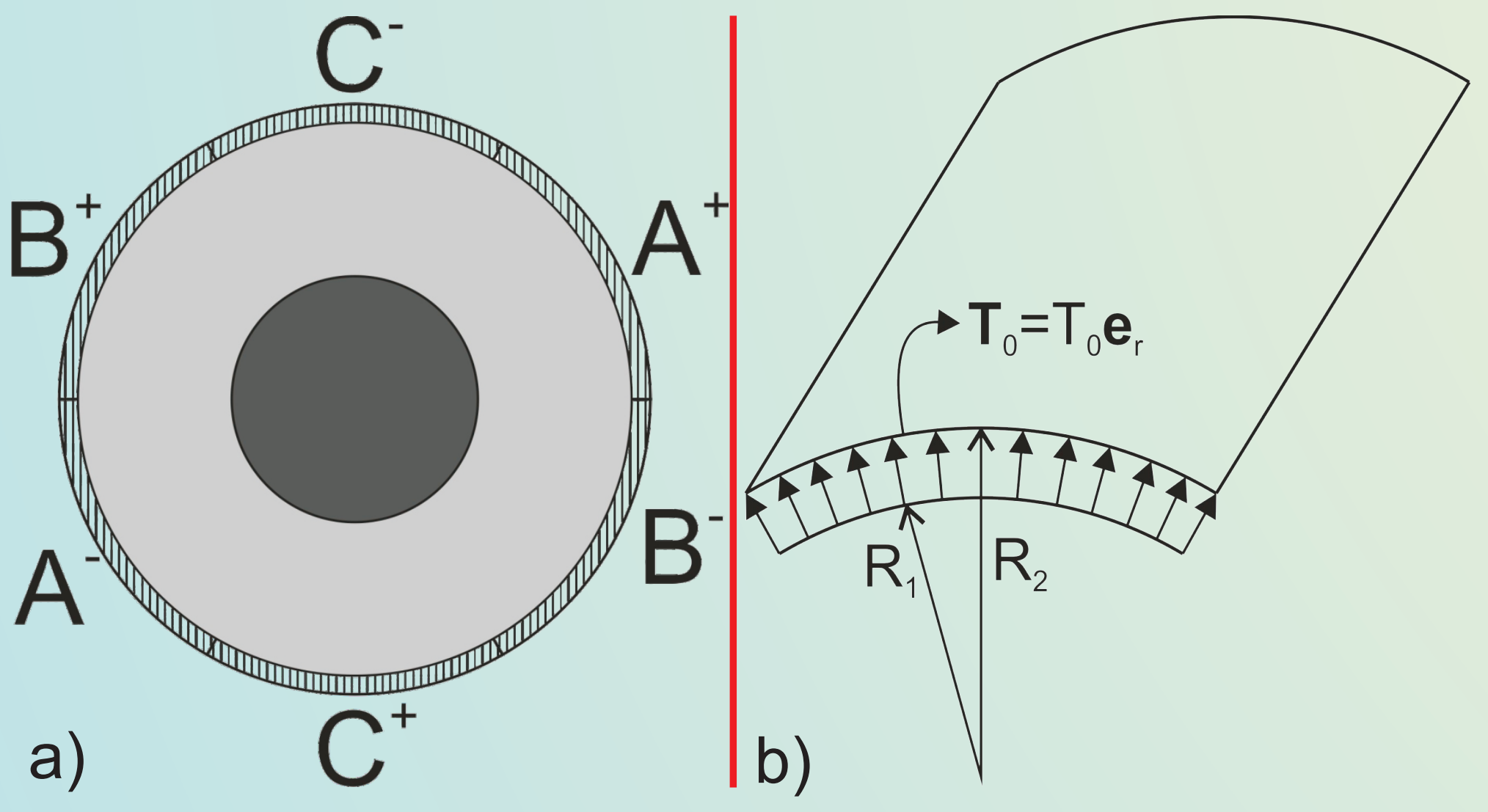
The rotor current can be written as

$$i_r = i_{R0} + i_{R0} \cdot \frac{x_d - x_d'}{x_d} \left[e^{-\frac{t}{T_d'}} - (1-k) e^{-\frac{t}{T_d''}} - k e^{-\frac{t}{T_a}} \cos\phi \right]$$

and transformed into a 3-phase AC current excitation

$$\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \begin{bmatrix} \cos\phi & -\sin\phi \\ \cos(\phi - 2\pi/3) & -\sin(\phi - 2\pi/3) \\ \cos(\phi + 2\pi/3) & -\sin(\phi + 2\pi/3) \end{bmatrix} \begin{bmatrix} i_r \\ 0 \end{bmatrix}$$





a) Thin layer defined in azimuthal direction to consider the impressed current vector potential $\mathbf{T}_0$

b) Schematic presentation of the prescribed $\mathbf{T}_0$ along one pole in the air-gap

Satisfying the condition $curl(\mathbf{T}_0) = \mathbf{J}$ it follows that,

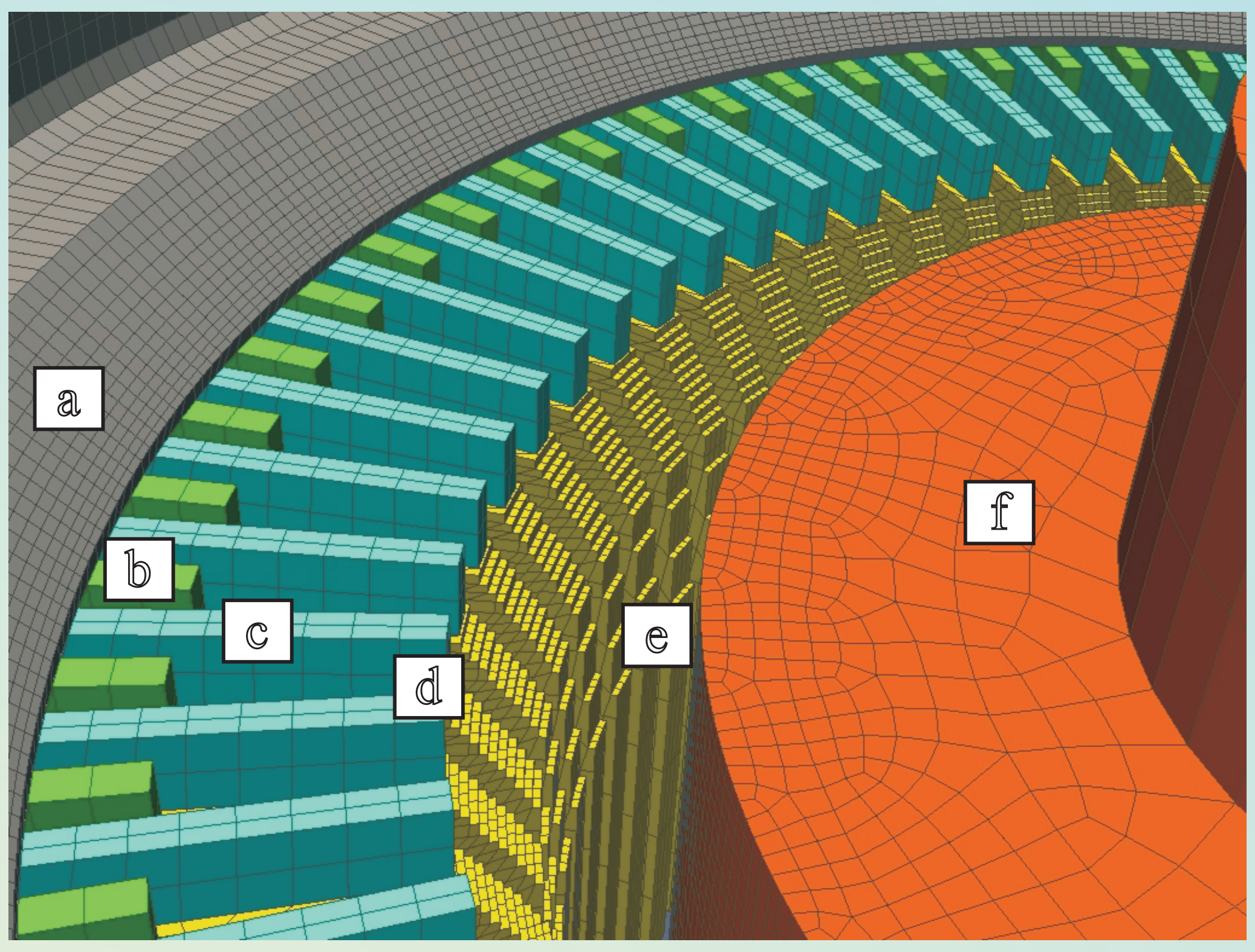
$$curl\mathbf{T}_0 = \frac{\partial T_{0r}}{\partial z}\mathbf{e}_\phi - \frac{1}{r}\frac{\partial T_{0r}}{\partial \phi}\mathbf{e}_z = \mathbf{J},$$ where T_{0r} denotes the radial component.

The amplitude of the current density J_0 is defined as,

$$\int_{R_1}^{R_2}\int_0^{2\pi} J_0 \cos^2(\phi) \cdot r\, d\phi\, dr = \Theta_0 \longrightarrow J_0 = \frac{2\Theta_0}{\pi\left(R_2^2 - R_1^2\right)}$$

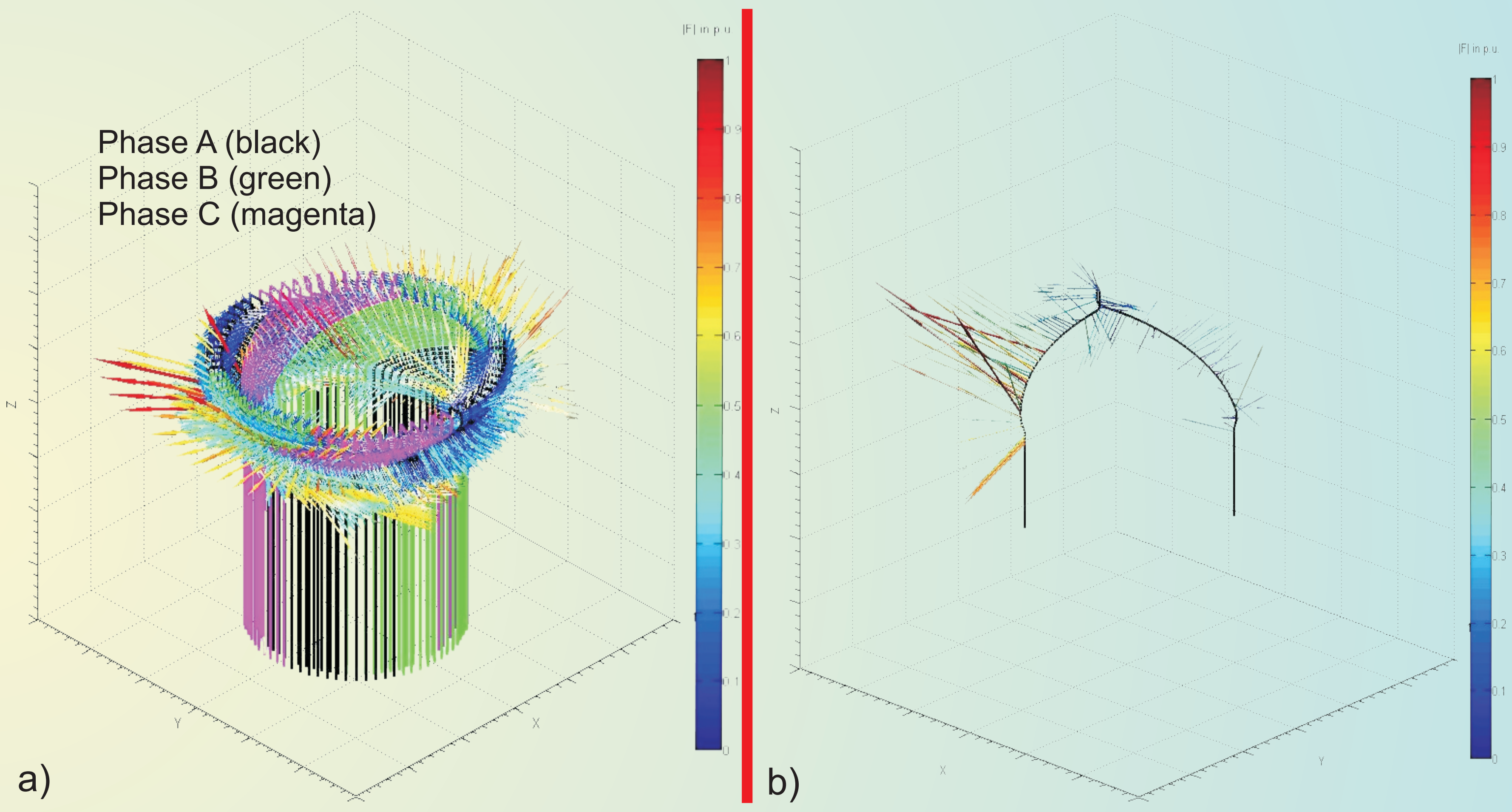
with the magneto-motive force (mmf), $\Theta_0 = \frac{2}{\pi}\frac{N\xi_w}{p} i_r$

3D-Finite Element Model



3-D FE model of the synchronous machine at the end-region without end-winding system.
(a) clamping plate
(b) short clamping fingers
(c) long clamping fingers
(d) stator
(e) rotor
(f) shaft

Stator end winding forces at short circuit condition



a) Forces in p.u. acting on the end winding system at 10ms
b) Forces in p.u. acting on one branch of Phase A at 10ms

The forces have been calculated using the Lorentz-equation:

$$\mathbf{F}_L = I \int (d\mathbf{l} \times \mathbf{B})$$

Conclusion

A new method to consider the rotor excitation current of a synchronous generator under short circuit condition has been presented. The active rotor part as well as the rotor end-winding excitation field, are considered with an impressed current vector potential function in a transient simulation. Applied to a detailed model of a synchronous machine, the end-winding forces have been calculated.

Acknowledgment

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