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Field-Circuit Coupling Applied to Inductive Fault Current Limiters

Domenico Lahaye and Dalibor Cvoric

Applied Mathematics and Power Processing Units

TU Delft, Delft, The Netherlands

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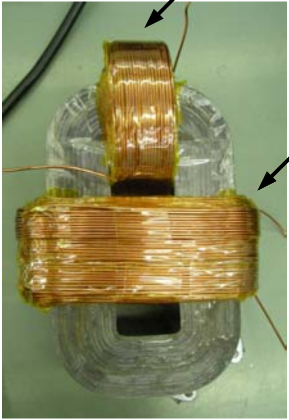
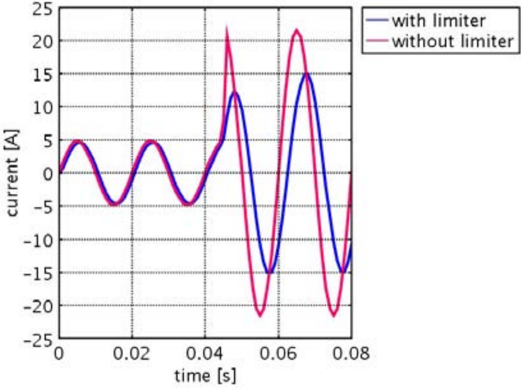
Inductive Fault Current Limiter (Wolfus e.a. 2007)

DC winding



AC winding

Current through AC winding - Line current



transparant before fault

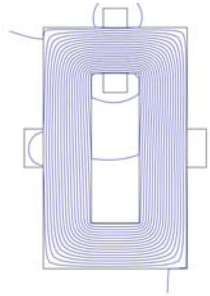
limiting after fault

Questions

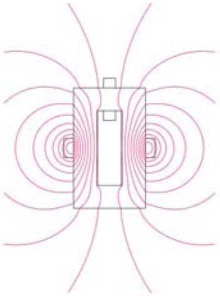
- How does is work?
- How can it be modeled?
  Magnetic field - Electrical circuit coupled model
- How can it be optimized?
  Test case for multilevel (space-mapping) optimization technique

Magnetic Flux Contributions

DC Flux



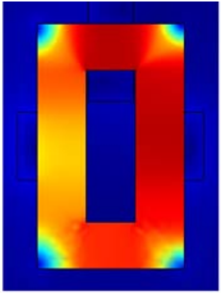
AC Flux



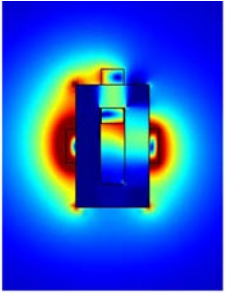
Superimpose in the presence of saturation

Total Magnetic Flux and Field

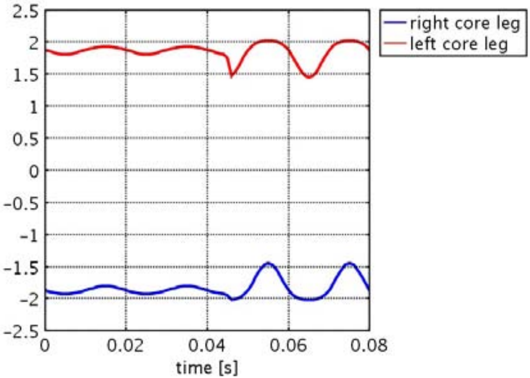
Magnetic Flux



Magnetic Field



Magnetic Flux in the Core Legs



asymmetric

saturation

FCL Working Principle

$$\left.\begin{array}{c}\text{DC flux}\\ \text{AC flux}\\ \text{core asymmetry}\\ \text{core saturation}\end{array}\right\} \Rightarrow \text{current limiting}$$

FCL Working Principle

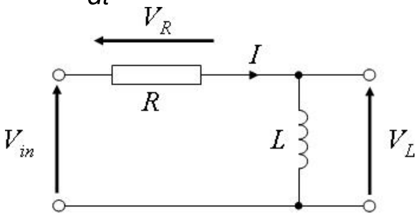
DC flux AC flux core asymmetry core saturation	}	$\Rightarrow$ current limiting

How to formalize/quantify?

Current in RL Circuit

- line current - current through AC winding: $I(t)$

$$V_{in} = V_R + V_L = RI + \frac{d(L\,I)}{dt}$$



Current in RL Circuit

- line current - current through AC winding: $I(t)$

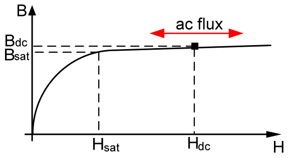
$$RI + \frac{d(L\,I)}{dt} = V_{in}$$

- model fault by allowing a drop in resistive voltage counteracted by surge in induced voltage

- induced voltage controlled through impedance: $L(t)$

$L(t) \sim \mu_r(t)$ and $\frac{d\mu_r}{dt} \neq 0$ implies $\frac{dL}{dt} \neq 0$

Impedance (L) and Core Permeability (μ_r)



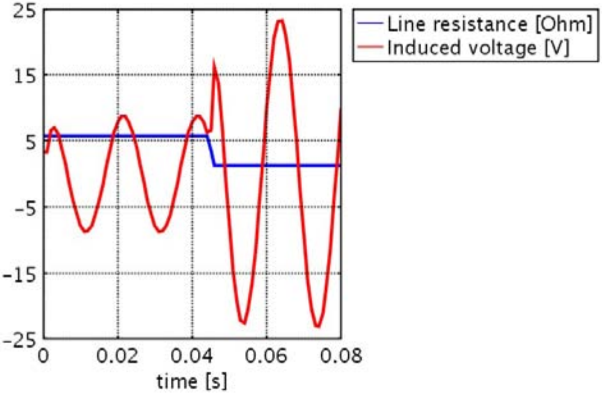
desaturation

$\rightarrow$ increase of permeability μ_r

$\rightarrow$ increase of impedance L

$\rightarrow$ increase of induced voltage

Resistance Drop and Induced Voltage



Induced Voltage Computation

- S_{cr}: core cross-section S_{cl}: coil cross-section
  N_t: number of turns ℓ_z: length in z-direction
- induced voltage

$$
\begin{aligned}
V_{ind} &= -N_t \frac{d}{dt} \int_{S_{cr}} \mathbf{B} \cdot d\mathbf{S} \qquad \text{[Ampère - Lenz Law]} \\
&= \frac{N_t\, \ell_z}{S_{cl}} \int_{S_{cl}} E_z dS \qquad \text{[homogenization]}
\end{aligned}
$$

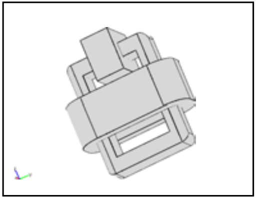
- can be generalized to 3D models

Magnetic Field- Electrical Circuit Coupling

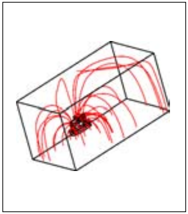
- Magnetic Field
  PDE for (component of) the magnetic vector potential in the structure of the FCL
- Electric circuit
  ODE for the current through the AC coil - Line current
- Coupling through the magnetically induced voltage
  integration coupling variable

3D Results

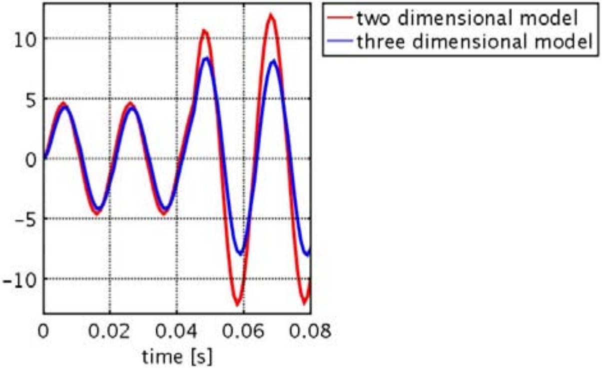
Geometry



Magnetic Field



3D Results



End-Effects important - Need to be taken into account

Conclusions

- we presented a field-circuit coupled of an inductuive fault current limiter
- two-dimensional model allows to illustrate and quantity the current limiting principle
- three-dimensional model is required for a more realisitic modeling

Further Information

- Wolfus e.a., *Fault Current Limiters (FCL) with the Cores Saturated by Superconducting Coils*, (WO 2007/029224 A1), March 2007.
- author: ta.twi.tudelft.nl/nw/users/domenico/

Vielen Dank!