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 et al. 2007)

DC winding

AC winding
Current through AC winding - Line current

- transparent before fault
- limiting after fault
Questions

- How does it 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

\[
\begin{align*}
&\text{DC flux} \\
&\text{AC flux} \\
&\text{core asymmetry} \\
&\text{core saturation} \\
\Rightarrow & \text{current limiting}
\end{align*}
\]
FCL Working Principle

DC flux
AC flux
core asymmetry
core saturation

⇒ current limiting

How to formalize/quantify?
1 Introduction

2 Inductive Fault-Current Limiter

3 Field-Circuit Coupling

4 Conclusions
Current in RL Circuit

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

\[
V_{in} = V_R + V_L = RI + \frac{d(LI)}{dt}
\]
Current in RL Circuit

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

\[
RI + \frac{d(LI)}{dt} = V_{in}
\]

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

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

\[
L(t) \sim \mu_r(t) \text{ and } \frac{d\mu_r}{dt} \neq 0 \text{ implies } \frac{dL}{dt} \neq 0
\]
Impedance ($L$) and Core Permeability ($\mu_r$)

- Desaturation
- Increase of permeability $\mu_r$
- Increase of impedance $L$
- Increase of induced voltage
Resistance Drop and Induced Voltage
Induced Voltage Computation

- $S_{cr}$: core cross-section
- $N_t$: number of turns
- $S_{cl}$: coil cross-section
- $\ell_z$: length in $z$-direction

induced voltage

$$ V_{ind} = -N_t \frac{d}{dt} \int_{S_{cr}} B \cdot dS \quad \text{[Ampère - Lenz Law]} $$

$$ = \frac{N_t \ell_z}{S_{cl}} \int_{S_{cl}} E_z dS \quad \text{[homogenization]} $$

- 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 inductive fault current limiter

- two-dimensional model allows to illustrate and quantity the current limiting principle

- three-dimensional model is required for a more realistic modeling
Further Information


author: ta.twi.tudelft.nl/nw/users/domenico/

Vielen Dank!