Dr.-Ing. O. Craciun, Comsol Conference 2015

Multiphysics Analysis and Optimization of Mechatronic Devices
Applications for Switching Devices

COMSOL CONFERENCE 2015 GRENOBLE

Power and productivity for a better world™

ABB

A global leader in power and automation technologies
Leading market positions in main businesses

- 145,000 employees in about 100 countries
- Formed in 1988 merger of Swiss and Swedish engineering companies
- Predecessors founded in 1883 and 1891
- Publicly owned company with head office in Switzerland

How ABB is organized
Five global divisions

Power Products

$10.9 billion
36,000 employees

Power Systems

$8.1 billion
20,000 employees

Discrete Automation and Motion

$8.8 billion
29,000 employees

Low Voltage Products

$7.7 billion
31,000 employees

Process Automation

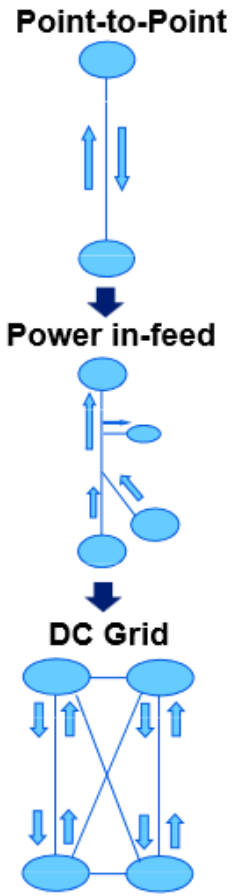
$8.3 billion
28,000 employees

ABB's portfolio covers:

- Electricals, automation, controls and instrumentation for power generation and industrial processes
- Power transmission
- Distribution solutions
- Low-voltage products
- Motors and drives
- Intelligent building systems
- Robots and robot systems
- Services to improve customers productivity and reliability

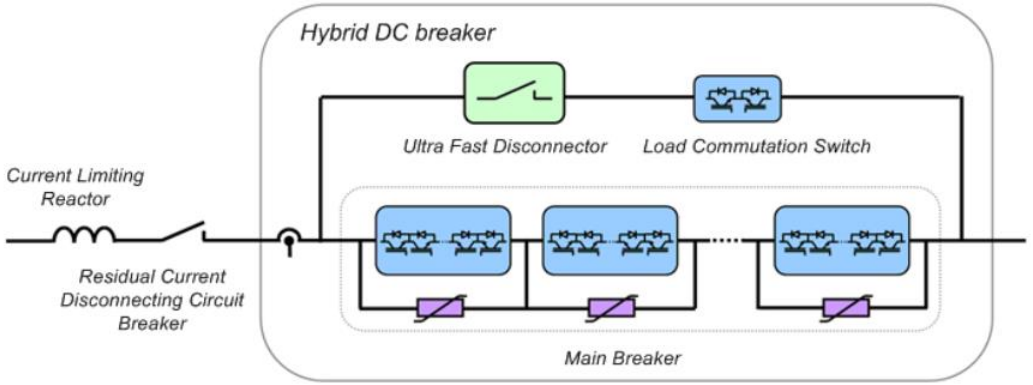
High Voltage Direct Current Breakers

Electromagnetic Actuators Simulation and Optimization
HVDC Breakers and Multiple Terminal Configurations



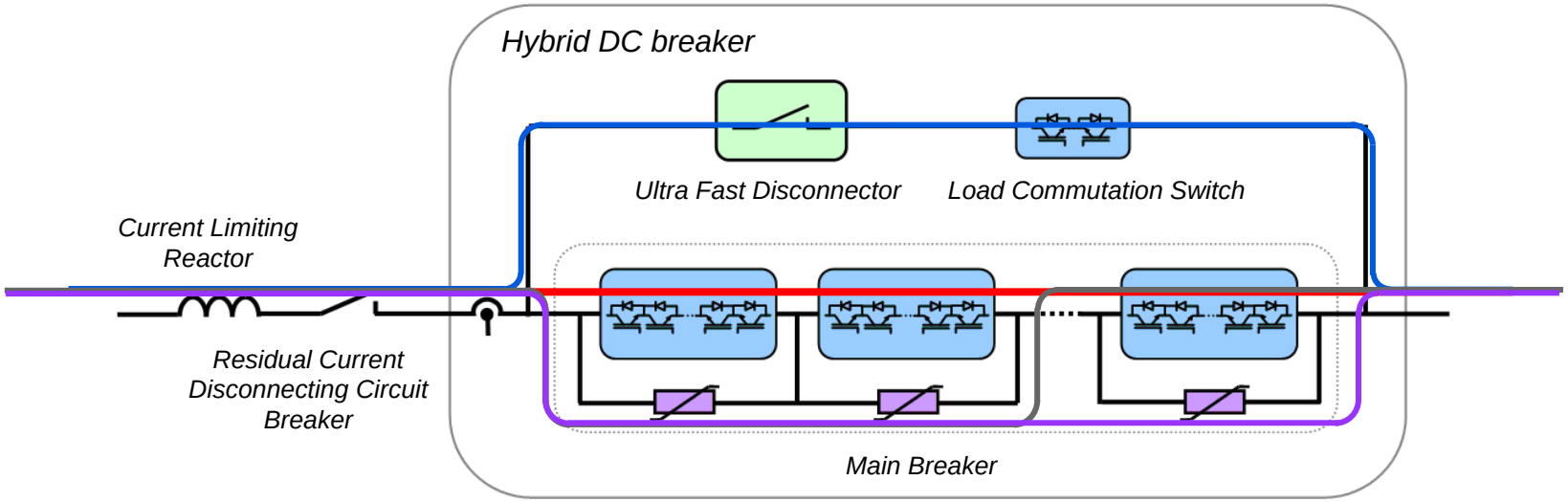
- Grids generally improve availability and security of supply
- HVDC grids reduce overall transmission losses since there are fewer AC/DC conversion units than for multiple point-to-point systems
- HVDC grids enable reliable and efficient integration of remotely located renewable resources. Geographical diversity, in turn, improves balancing of intermittent Power in-feed demand and supply.
- HVDC grids enhance economic utilization of resources by allowing new generation sites to interconnect to remote load centers and energy trading hubs.
- HVDC grids maintain energy supply during disturbances (quick isolation of faults using breakers)

Electromagnetic Actuators Simulation and Optimization
HVDC Breakers and Multiple Terminal Configurations



- **Fast**: Breaking times of less than **2ms**
- Powerful: Current breaking capability of 16kA
- Efficient: Transfer losses are less than 0.01%
- Modular: Easily adapted to actual voltage & current ratings
- Reliable: Protective current limitation, functional check while in service
- Proven: Power electronic design similar to converter technology

Electromagnetic Actuators Simulation and Optimization
HVDC Breakers and Multiple Terminal Configurations



- Normal operation: Current flows in low-loss bypass
- Proactive control: Load Commutation Switch opens and commutates current into Main Breaker; the Ultra Fast Disconnector opens with very low voltage and current stress
- Fault clearance: Residual Current Disconnecting Circuit Breaker and Main Breaker open and commutate fault current into corresponding arrester banks

Current interruption

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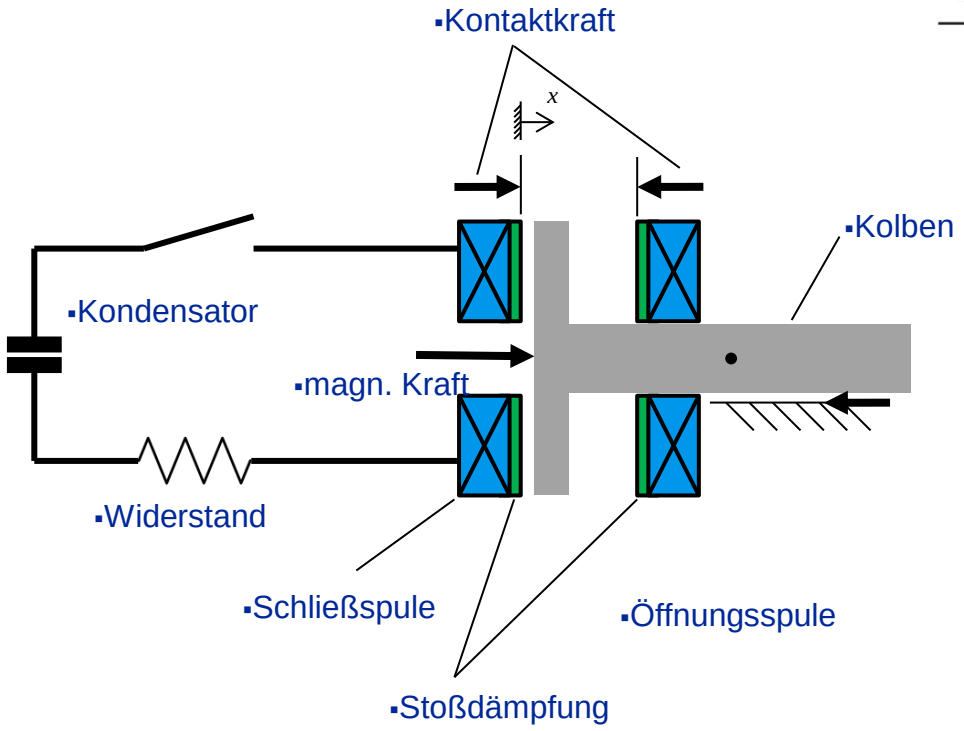
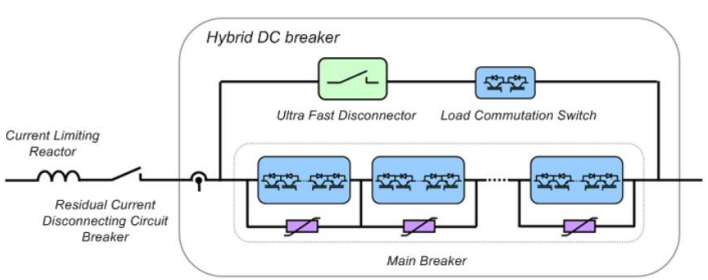
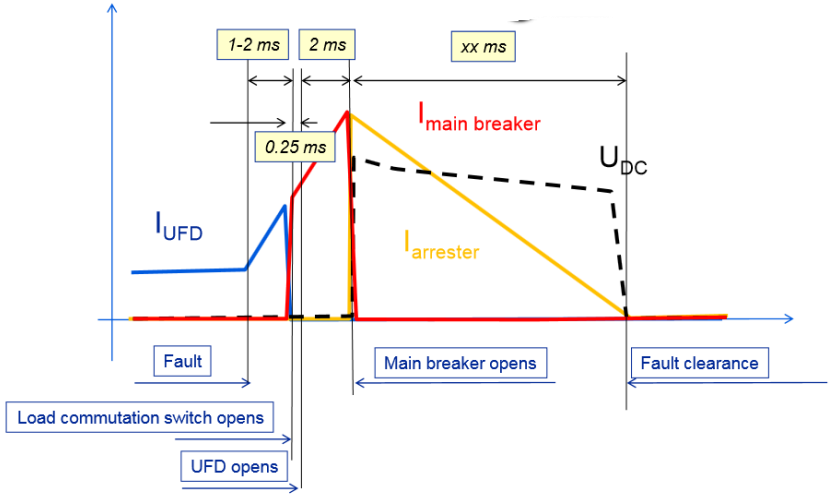
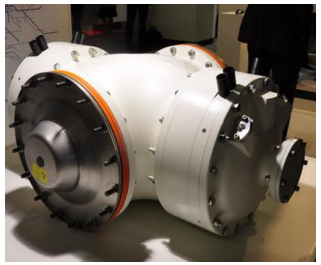
HVDC Breakers and Multiple Terminal Configurations

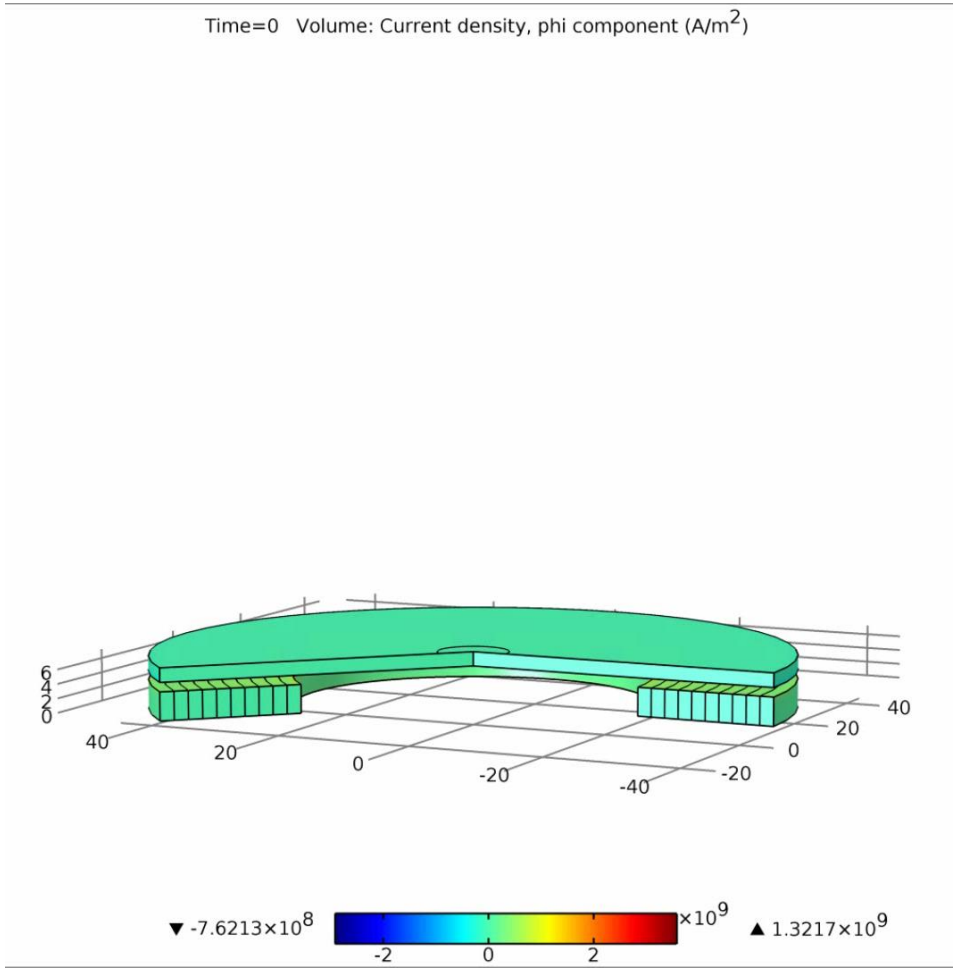






Electromagnetic Actuators Simulation and Optimization
HVDC Breakers and Multiple Terminal Configurations



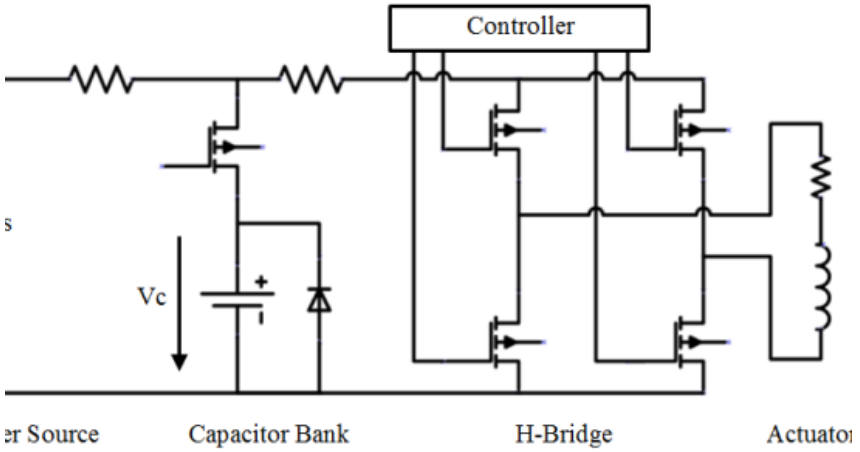


Medium Voltage Reclosers

Electromagnetic Actuators Simulation and Optimization
GridShield Recloser

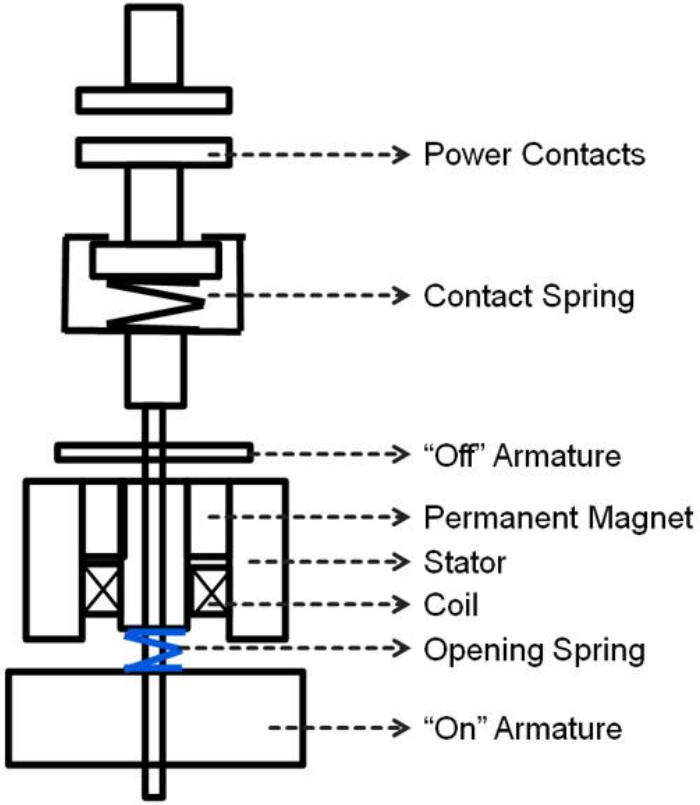
- The ABB 3-phase GridShield® recloser is a well know medium voltage protection device in which single coil actuators are used main component driving the opening and closing the device
- It has the ability to perform as a recloser, sectionalizer or automated load break switch.
- The proven design is rated for 10,000 full load operations

Electromagnetic Actuators Simulation and Optimization
GridShield Recloser

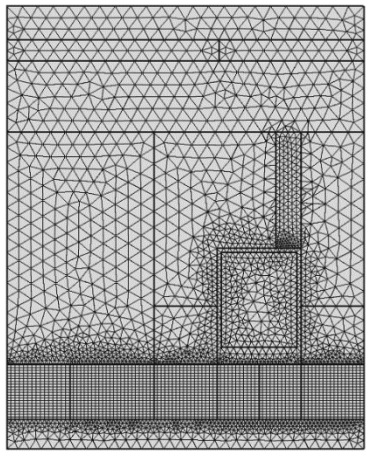


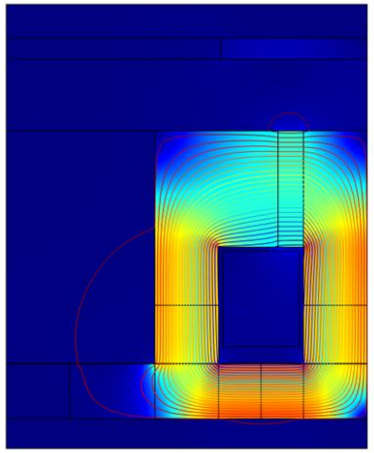
- The Electromagnetic actuators of ABB 3-phase GridShield® recloser are powered by suitable Electronic Control Units enabling safe Closing Opening Closing cycles all over the temperature ranges

Electromagnetic Actuators Simulation and Optimization
Operating Principle



Electromagnetic Actuators Simulation and Optimization
2D Static Simulations





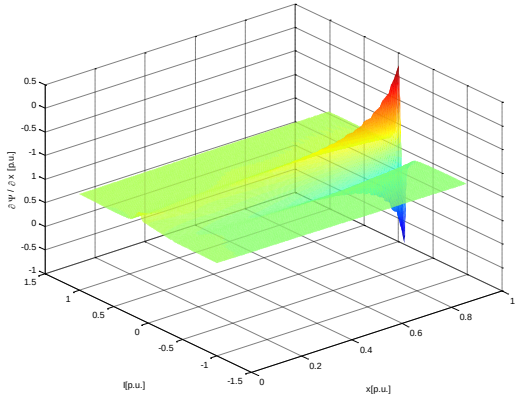
- The 2D Static Actuator modeling involves the usage of the magnetic fields interface.
- The multi-turn coil domain feature is being used for the actuator’s coil modeling.
- The holding force in close and open position is being computed (based on the Maxwell Surface Stress Tensor).

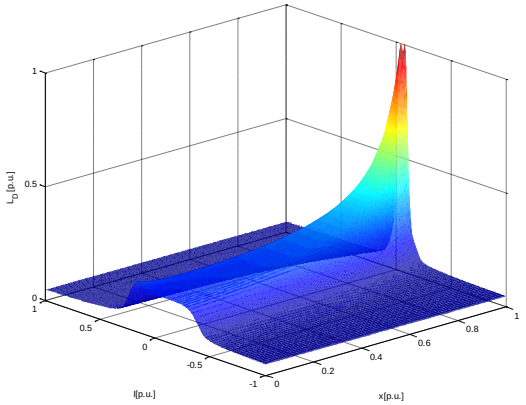
Electromagnetic Actuators Simulation and Optimization
Lumped Parameters Approach

$$U(t) = U_R(t) + U_E = R \cdot i(t) + \frac{d\psi}{dt}$$

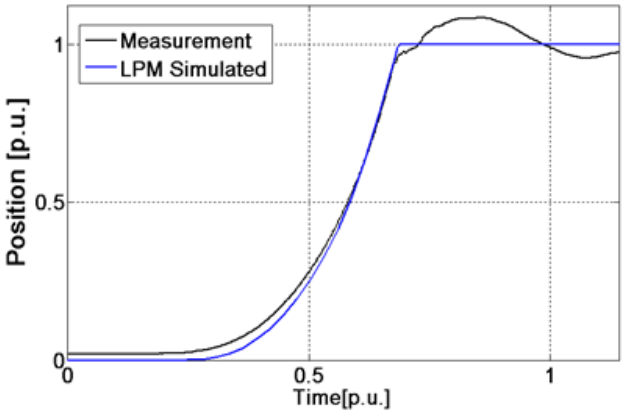
$$U(t) = R \cdot i(t) + \frac{\partial \psi(i,x)}{\partial x} \cdot \mathrm{v}(t) + \frac{\partial \psi(i,x)}{\partial i} \cdot \frac{di}{dt}$$

$$\begin{cases} U_1(t) = R_1 \cdot i_1(t) + M_1 \cdot \mathrm{v}(t) + L_{D2} \cdot \dfrac{di_1}{dt} + \dfrac{\partial \psi_1(i_1, i_2, x)}{\partial i_2} \cdot \dfrac{di_2}{dt} \\ U_2(t) = R_2 \cdot i(t) + M_2 \cdot \mathrm{v}(t) + L_{D1} \cdot \dfrac{di_2}{dt} + \dfrac{\partial \psi_2(i_1, i_2, x)}{\partial i_1} \cdot \dfrac{di_1}{dt} \end{cases}$$

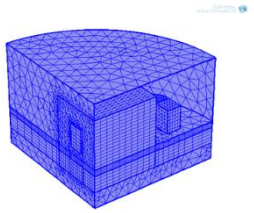




- Mid-Complexity simulation approach enabling fast parameters optimization
- It involved the export of look-up tables from the FEA models (2D or 3D Magnetostatic simulations).



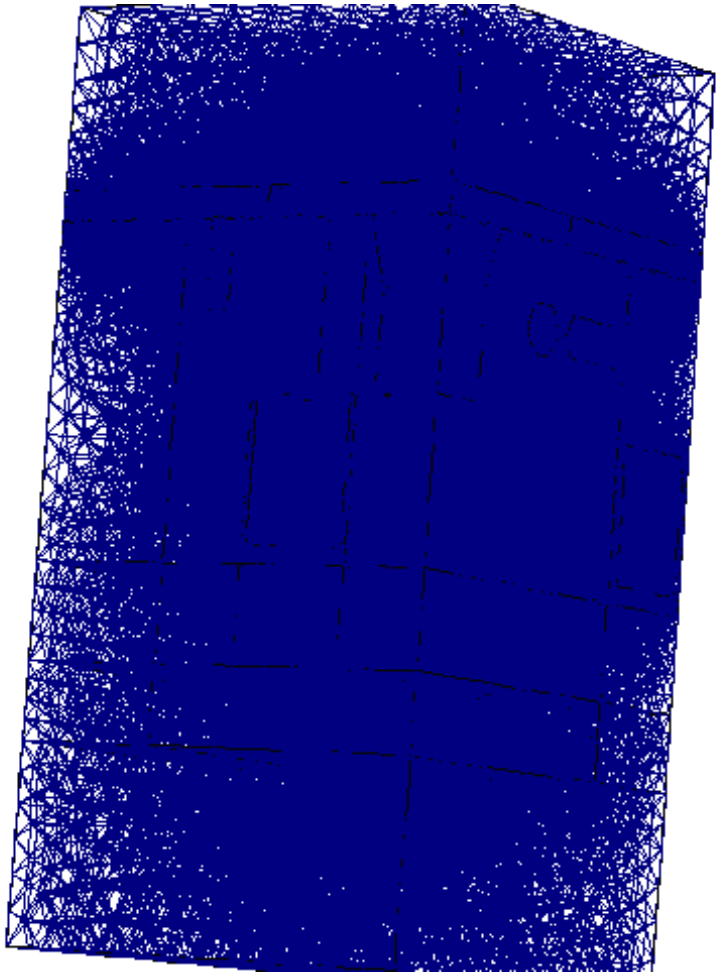
Electromagnetic Actuators Simulation and Optimization
3D Dymanic Simulations



- Model 1 *(mod1)*
  - Definitions
    - Boundary System 1 *(sys1)*
    - View 1
    - View 5
  - Geometry 1
    - Import 10 *(imp10)*
    - Form Union *(fin)*
  - Materials
    - Air *(mat2)*
    - Copper *(mat3)*
    - Soft Iron (with losses) *(mat4)*
  - Magnetic Fields *(mf)*
    - Ampère's Law 1
    - Magnetic Insulation 1
    - Initial Values 1
    - Ampère's Law 2
    - Multi-Turn Coil Domain 1
      - Automatic Current Calculation 1
        - Electric Insulation 1
        - Input 1
        - Output 1
      - Gauge Fixing for A-Field 1
    - Force Calculation 1
    - Ampère's Law 3

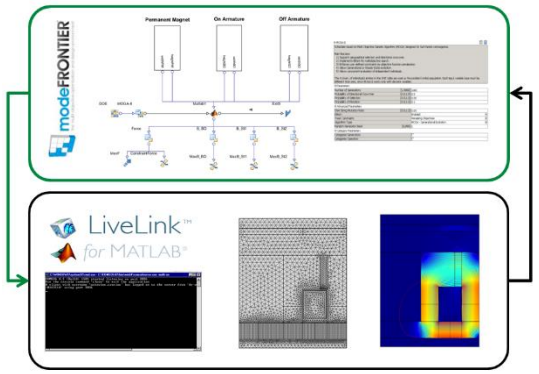
- Model 1 *(mod1)*
  - Definitions
  - Geometry 1
  - Materials
  - Magnetic Fields *(mf)*
  - Electrical Circuit *(cir)*
    - Ground Node 1
    - Capacitor 1
    - External I Vs. U 1
    - External I Vs. U 2
    - External I Vs. U 3
    - External I Vs. U 4
  - Global ODEs and DAEs *(ge)*
    - Global Equations 1
  - Moving Mesh *(ale)*
    - Fixed Mesh 1
    - Prescribed Mesh Displacement 1
    - Prescribed Deformation 1
    - Free Deformation 1
    - Prescribed Mesh Displacement 3
    - Prescribed Mesh Displacement 2
  - Mesh 1
    - Size
    - Free Tetrahedral 1a

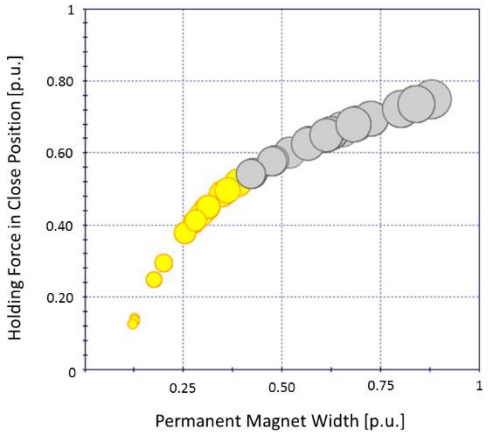
Electromagnetic Actuators Simulation and Optimization
3D Dymanic Simulations

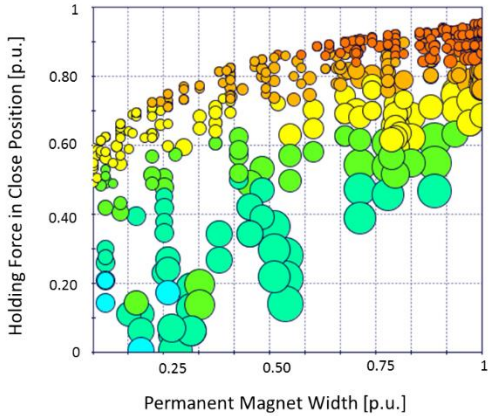


Multi-Physics Optimization and Cosimulation based on Comsol Multiphysics

Electromagnetic Actuators Simulation and Optimization
Multi-Objective Optimization Approach

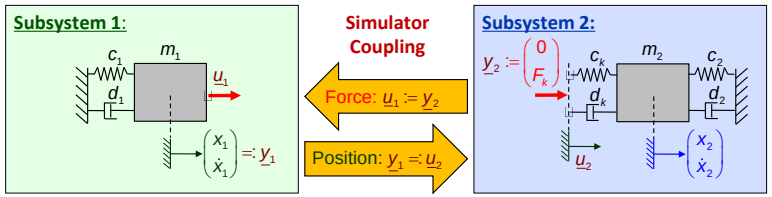


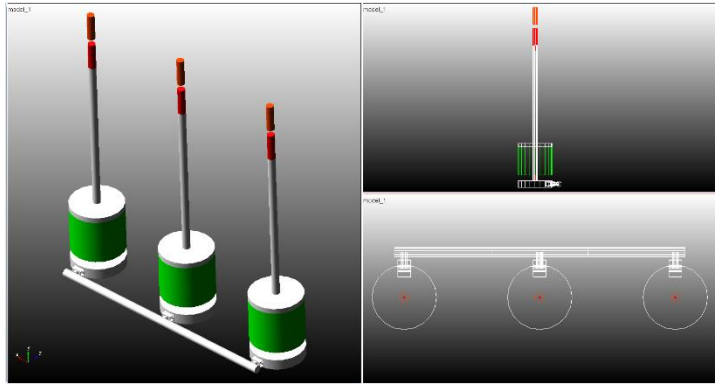


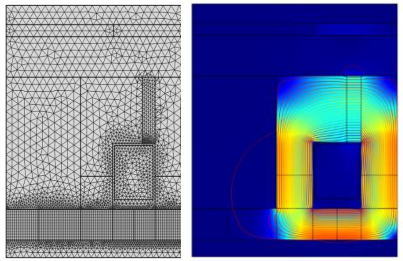


- Example of optimization results using LiveLink for Matlab and modeFrontier MOGAII optimization toolbox
- Permanent Magnet volume optimization
- Geometry optimization as a function of different design parameters

Electromagnetic Actuators Simulation and Optimization
Cosimulation based on Comsol Multiphysics







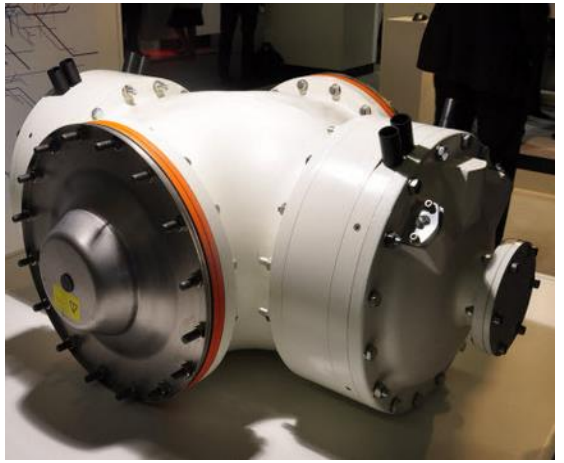
Goal

- Coupling of two or more commercial simulation tools at solver-runtime
- Commercial software:

  Comsol - Adams - Abaqus - ...
- Realize complex and transient multiphysics models of electromechanical products
- Reusable & validated sub-model components on physical domain level

Conclusion and Outlook

Electromagnetic Actuators Simulation and Optimization
Conclusion and Outlook



- Optimization and Multidomain study platform for LV, MV and HV reclosers (2D, 3D, Lumped Parameters Models, Cosimulation, Multiobjective Optimization)
- The influence of different design parameters is analyzed in order to enable the robust design of switching devices.
- Further work will focus on: CFD, Multibody Dynamics, Stress and Fatigue Analysis, Optimization Module, New 5.2 Features!
- Extend the cosimulation platform creating an interface to Matlab
- **Comsol Multiphysics** is really **FUN → We continue together!**

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