CERN

2-D Quench Simulation Framework

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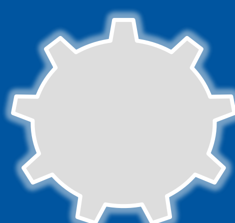
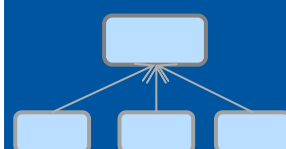
Outline

Introduction

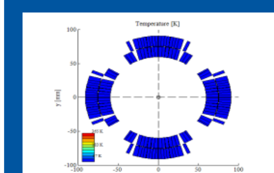
Requirements



Architecture



Results

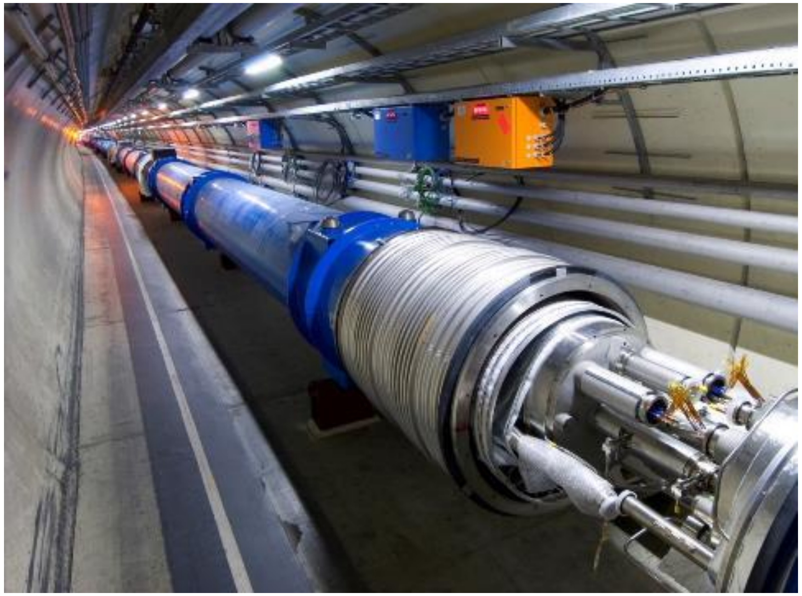


Summary

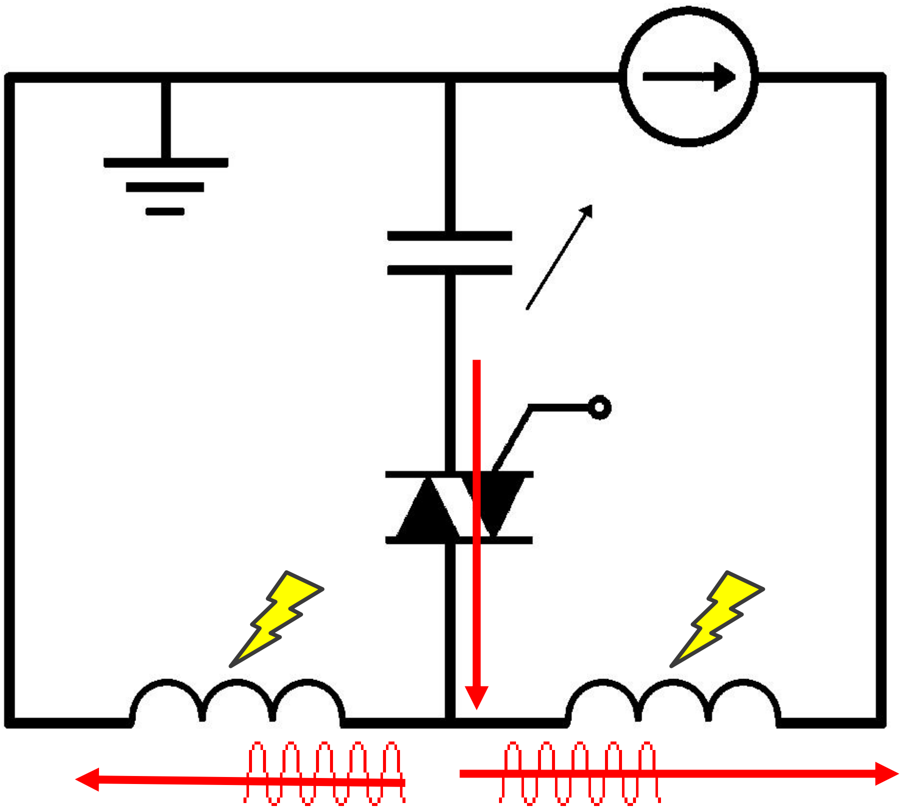
Motivation

Simulation of electro-thermal transient in S.C. circuits is needed in order to

- design electrical circuits with S.C. magnets,
- assess the performance of existing ones,
- study new protection methods.



Motivation



Current Change

Magnetic Field Change

Coupling-Losses (Heat)

Temperature Rise

QUENCH

Coupling
Loss
Induced
Quench

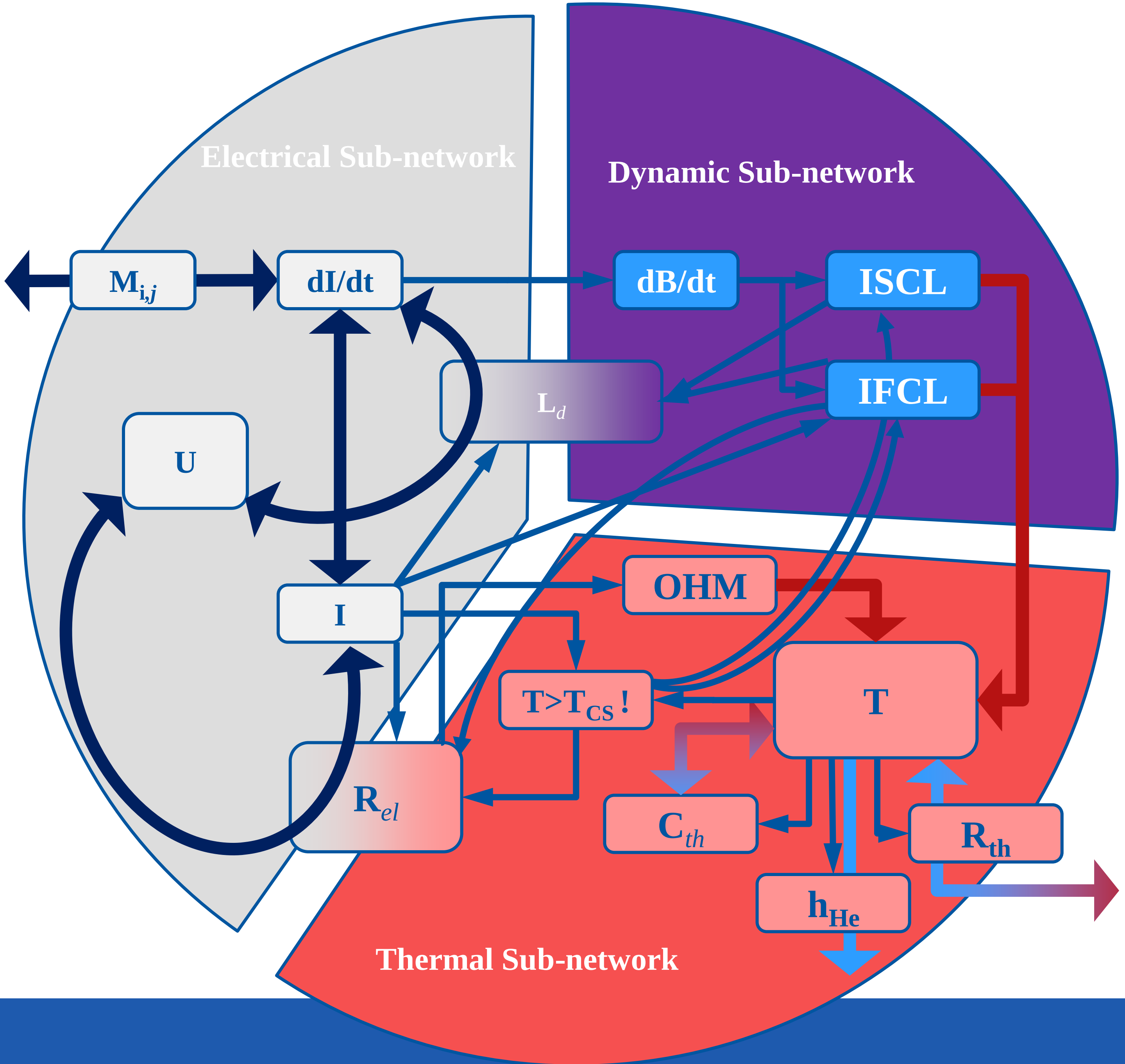
EU Patent EP13174323.9, June 2013.

E. Ravaioli et al., MT23, 2013.

E. Ravaioli et al., EUCAS11, 2013.

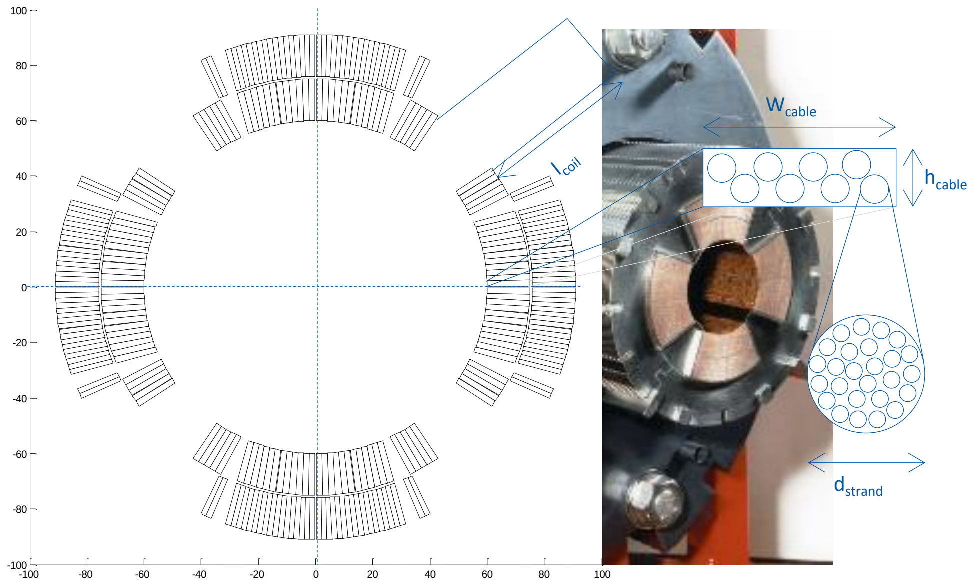
E. Ravaioli et al., CHATS-AS, 2013.

E. Ravaioli et al., SuST, 2014.



Electrical Sub-network
Dynamic Sub-network
Thermal Sub-network
$M_{i,j}$
dI/dt
dB/dt
ISCL
IFCL
L_d
U
I
OHM
T
$T>T_{CS}$!
R_{el}
C_{th}
R_{th}
h_{He}

S.C. Magnets Modelling - Approach

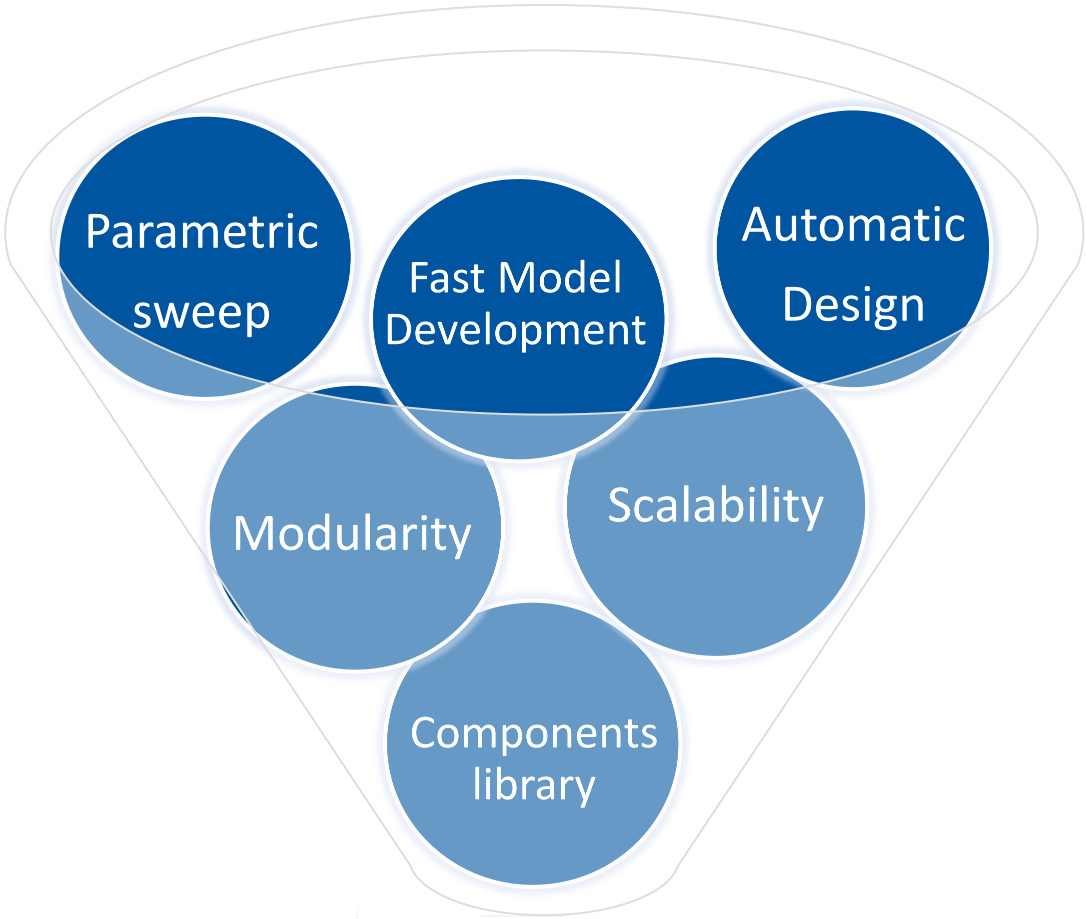


The model calculates inter-filament and inter-strand coupling loss.

Challenges

- Different levels of detail
  - entire circuit→ magnet→ cable→ strand→ filament
- Different physical domains
  - electrical, thermal, dynamic effects
- High flexibility needed
  - different magnet configurations, protection schemes
- Quick simulations
  - model development in 1-2 days, simulation runs < 1 hour

Framework Requirements



Framework Architecture

GUI/Excel

MATLAB (Application)

Simulink (Solver, library)

Components library

Thermal Mass (NbTi/Nb3Sn, Cu, G10, Kapton)

Hot Spot Calculation (NbTi/Nb3Sn)

Conductive Heat Transfer (Kapton, G10)

Helium Cooling

Quench Resistor (NbTi/Nb3Sn, Cu)

Inter-filament Coupling Loss in X/Y direction

Inter-strand Coupling loss

Dynamic effects (Inductance depends on current)

Superconducting Magnet

CLIQ

Diode

Energy Extraction

Quench Heater

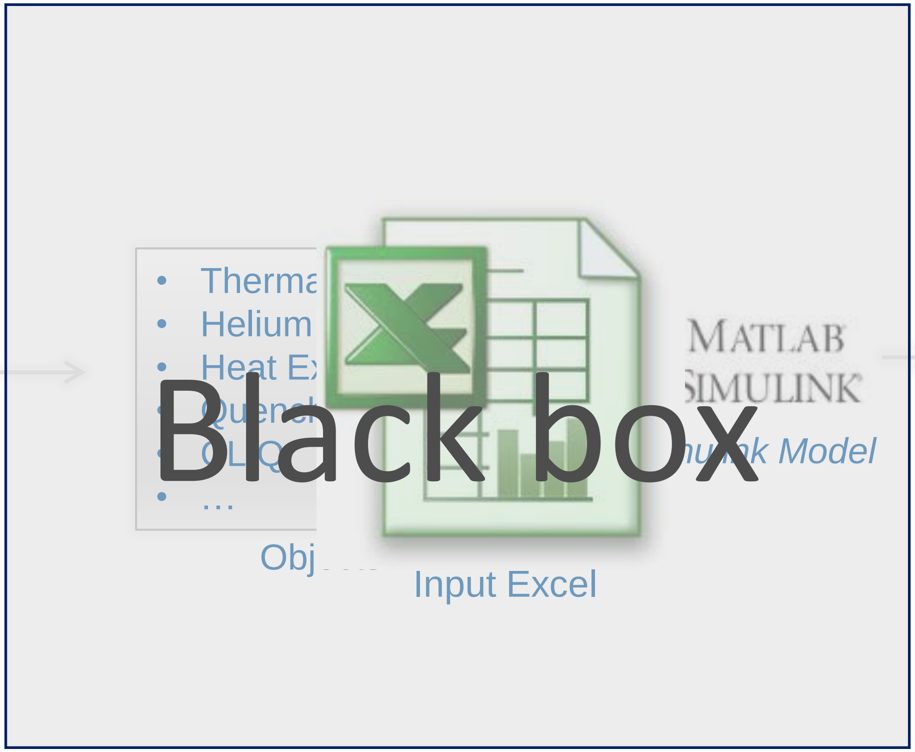
Quench Protection

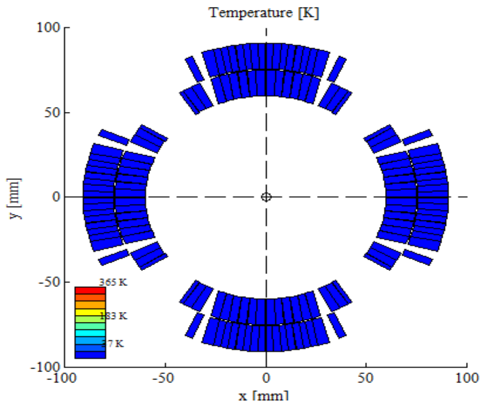
Current Lead

Power Converter

Other

MATLAB Application



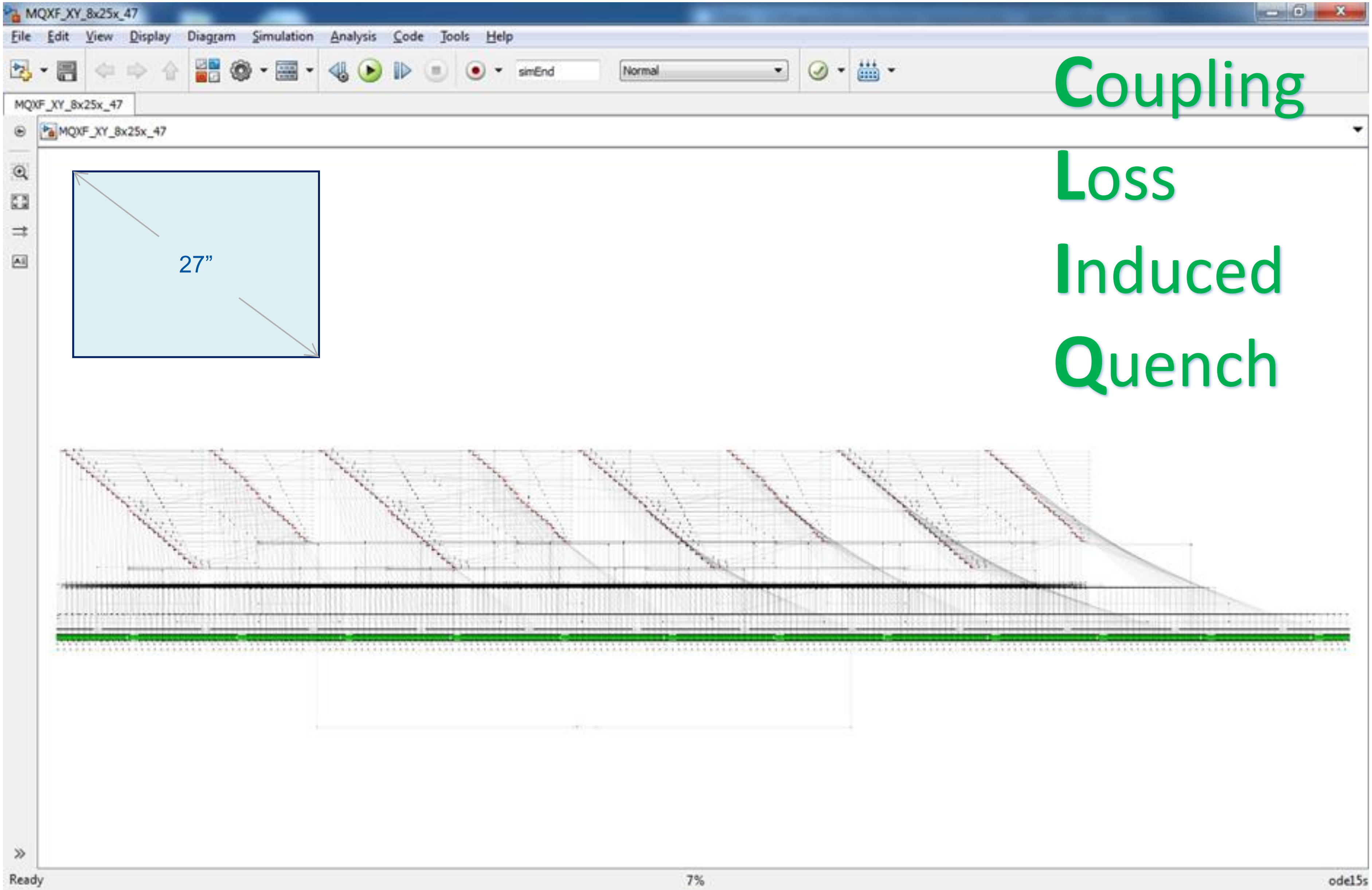


Results Analysis

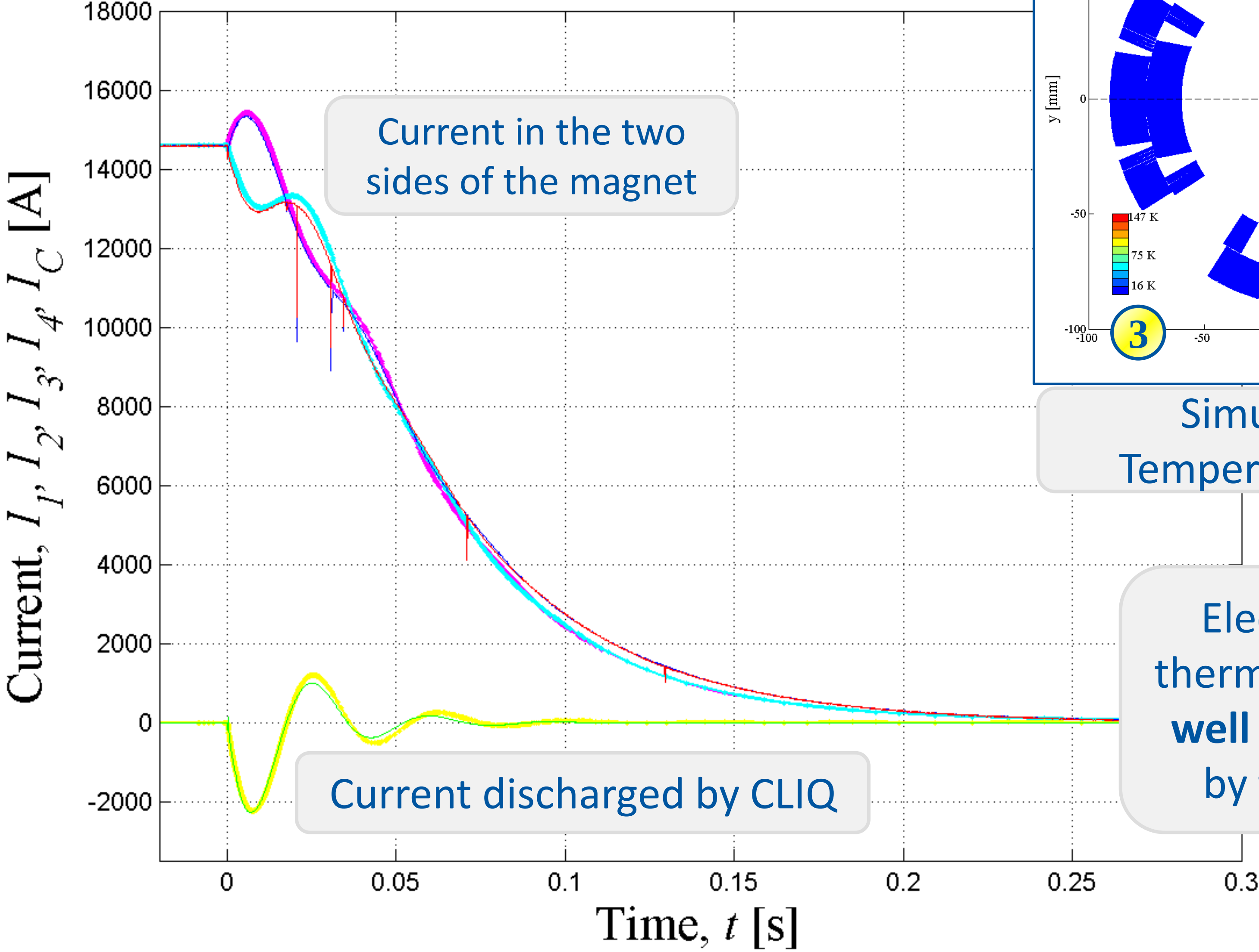
Main Application Modules

- Parametric Sweep
- Parallel Computing
- Report Generation
- Simulation Control
- Executable Modules

Coupling Loss Induced Quench

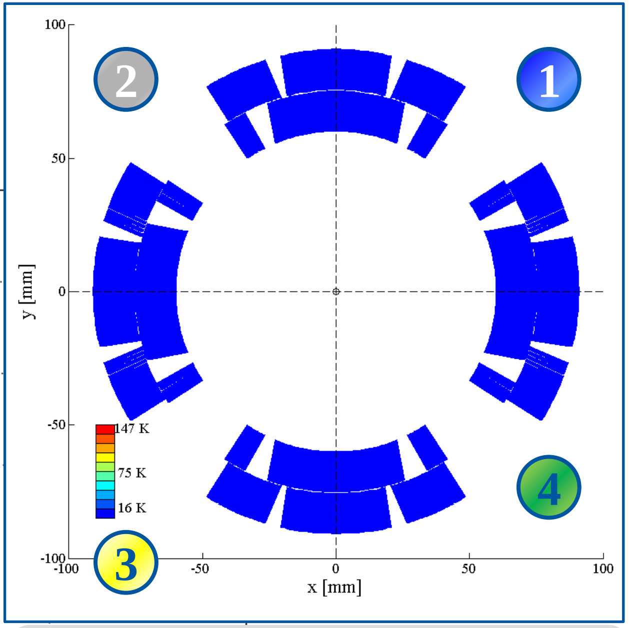


HQ02b Test Results – Currents



Current in the two sides of the magnet

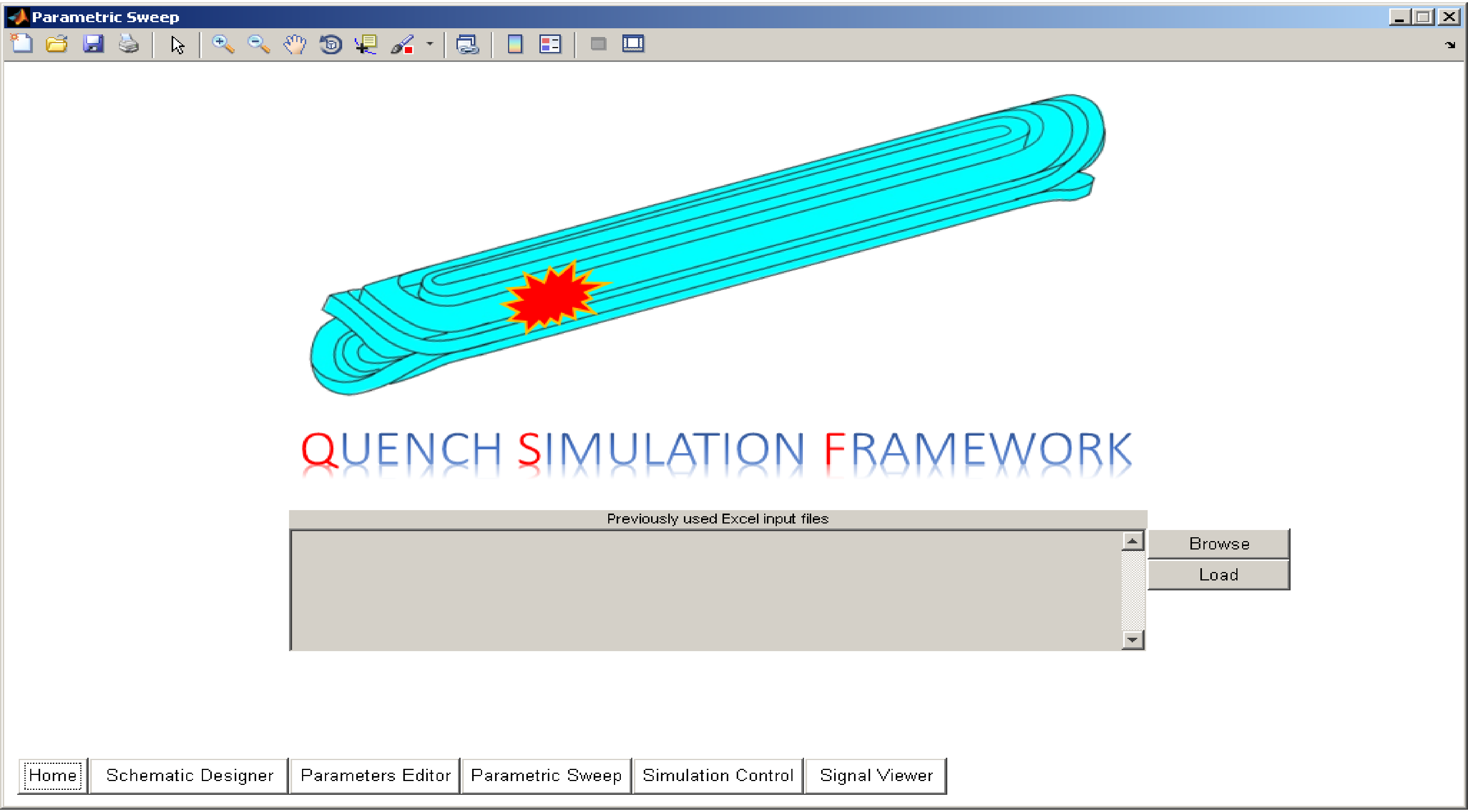
Current discharged by CLIQ



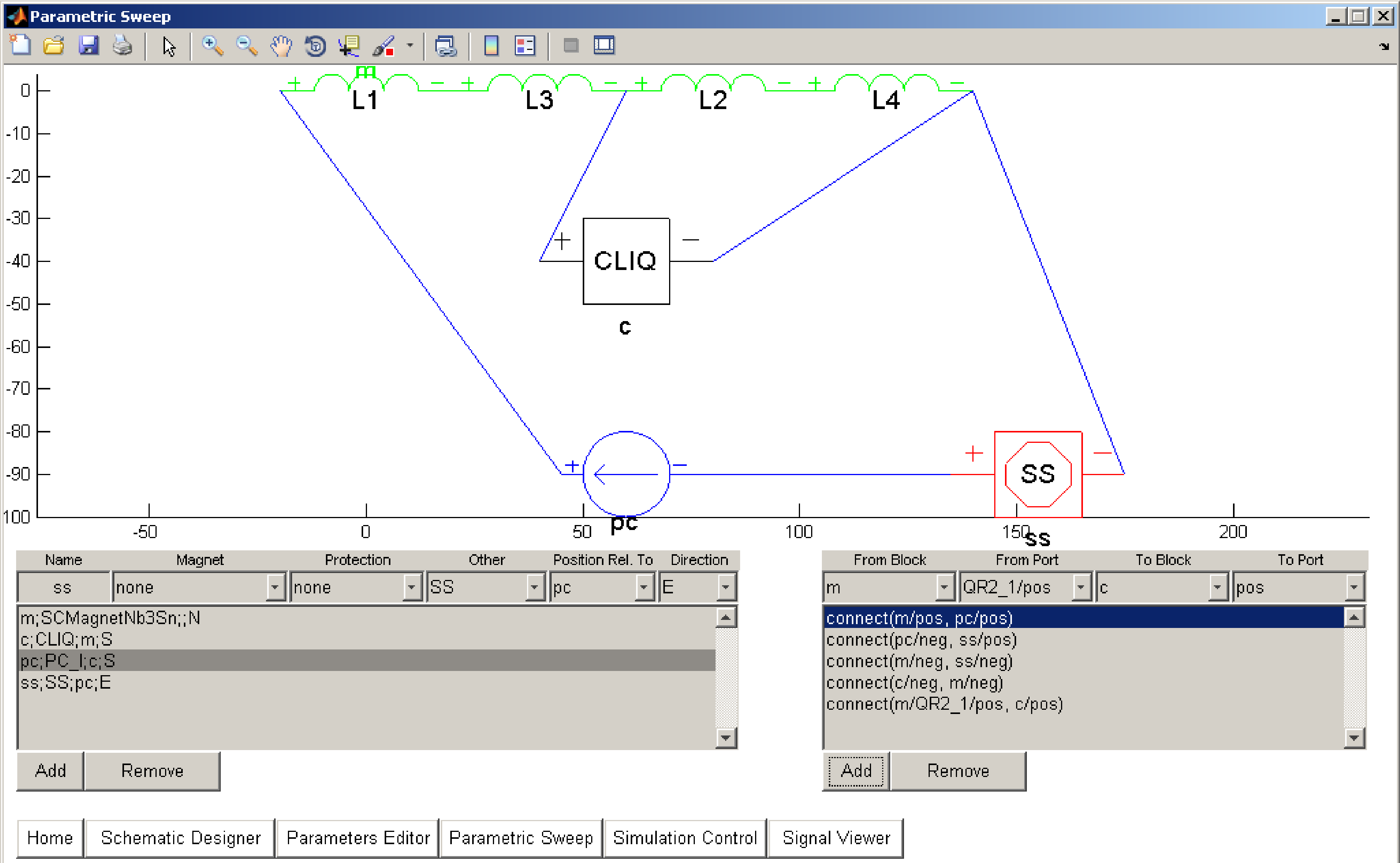
Simulated 2D Temperature Profile

Electrical and thermal transients **well reproduced** by the model

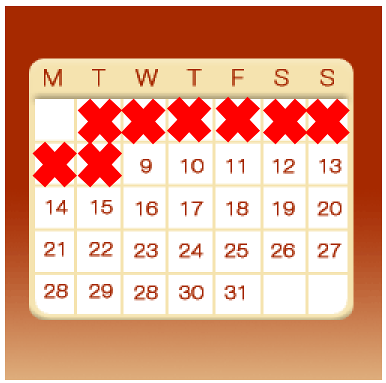
Graphical User Interface



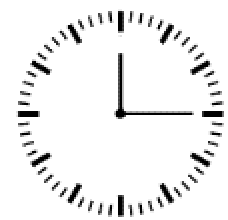
Schematic Editor – Netlist



Summary – time savings



Standard Approach



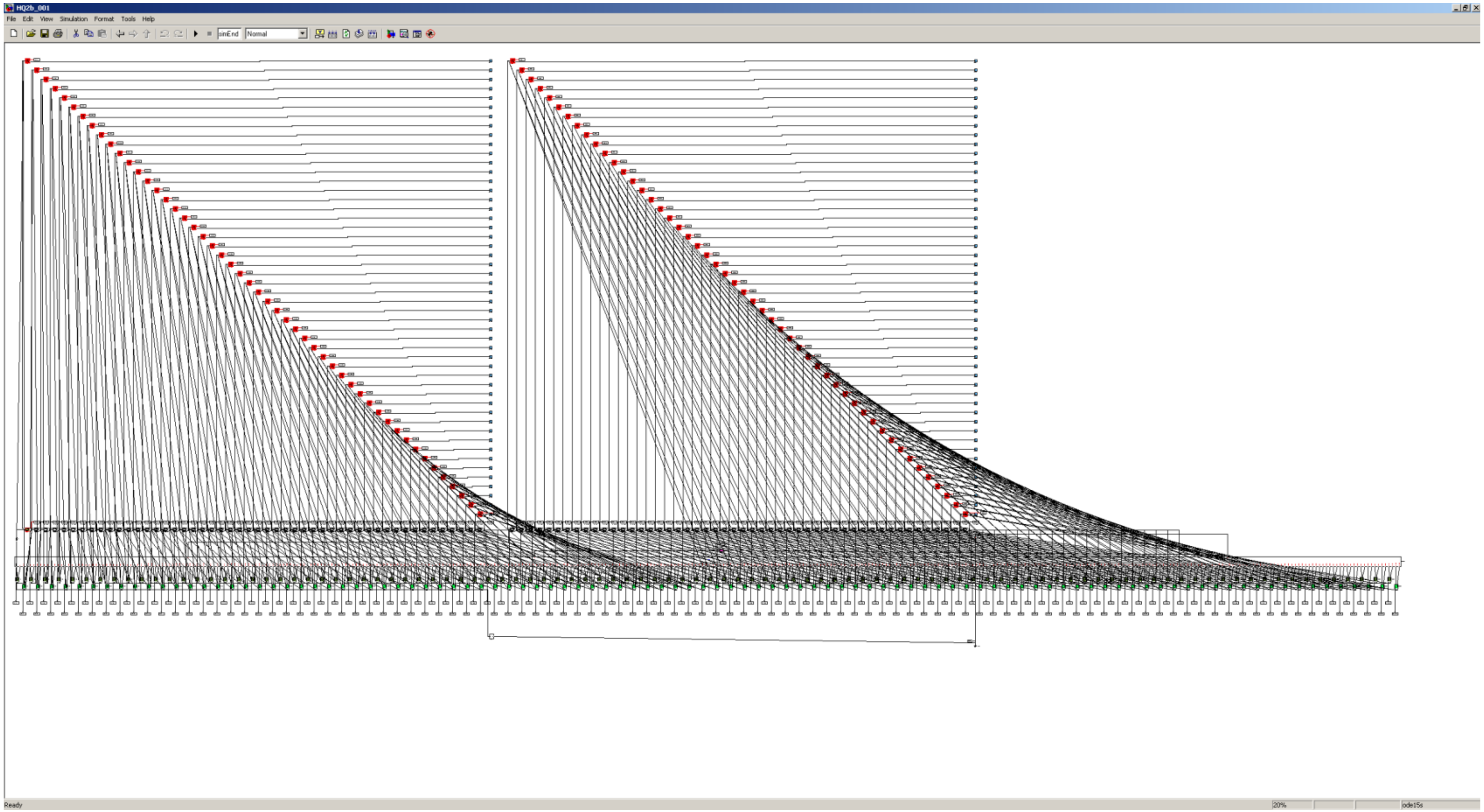
Quench Simulation Framework

Summary

- Model results **successfully** validated against PSpice simulation results and/or against tests
- **Same** physics contained in the "hand-made" PSpice models is now contained in **highly-efficient**, easily created Simulink models
- **No experience** with Simulink needed to run simulations
- QSF makes it easy to simulate **various** magnet types and new quench protection schemes
- OOP and Design Patterns enabled to develop **clean** and **maintainable** code

Future Work

- Parameters Optimization
- Quench Initiation (2D+1 geometry**)**
- Solenoid Geometry
- Components optimization
- Improve Magnetic Field Calculation (remove ROXIE/Soleno dependency)
- Validation with results from new magnets



Thank you for attention!

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