



CABLES, T-LINES AND BUS BARS MODELLING

Applications for cables, lines and bus bars models

- Applications:

- » Power networks
- » Thermal analysis
- » Magnetic analysis
- » Electric analysis

- For:

- » Substation, Lightning studies, Transient calculations...
- » Heating based on skin effect, Thermal networks, Thermal conditions in submarine cables...
- » Radiated field, Magnetic field, Skin and proximity effects ...
- » Breakdown electric field, Current sharing, Over-voltages...

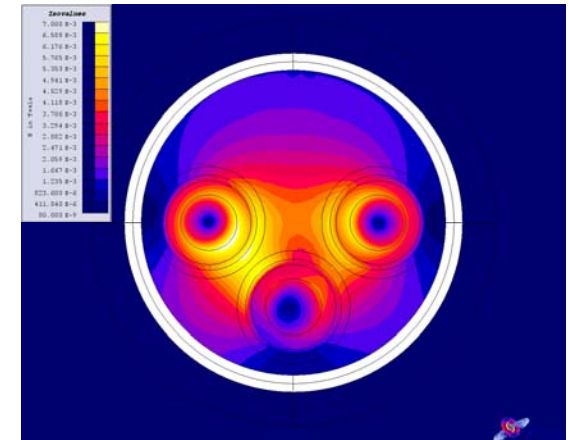


CEDRAT Software solutions

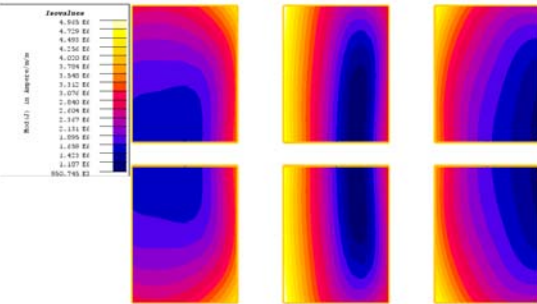
- **Flux[®]** : 2D and 3D steady, harmonic and transient states for thermal, electromagnetic analysis
- **PSCAD**: Cables and Overhead Transmission lines modelling in power network simulation
- **InCa3D**: 3D nonmagnetic structures
- **Portunus**: Thermal network modelling

Benefits of using Flux: Design and Optimization

- Main constraints for the optimization of any type of cables
 - » Eddy currents
 - » Induced voltages
 - » Parameter estimation
 - » Power losses
 - » Temperature rise due to non linear loads

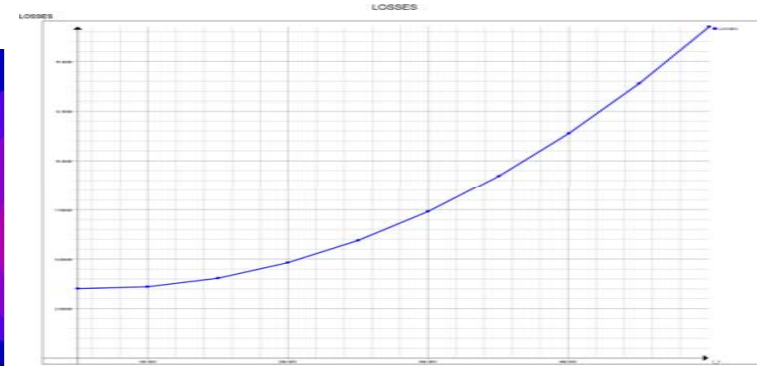
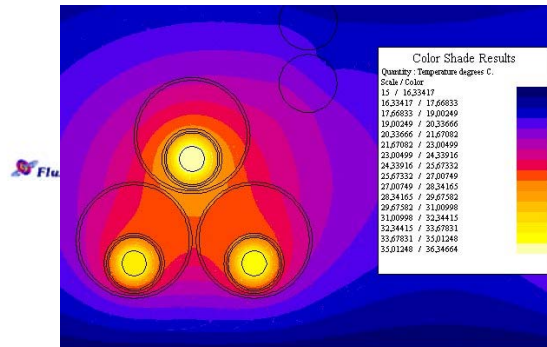


3-phase cable: Electromagnetic field



Bus bars: Current density

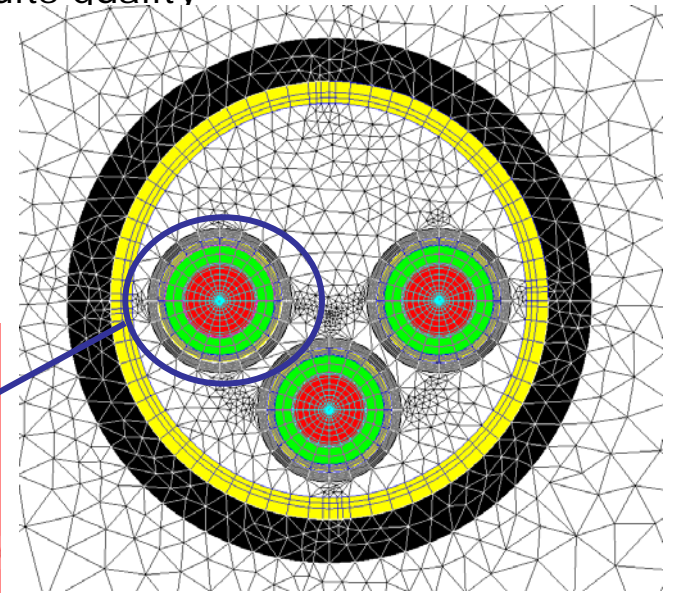
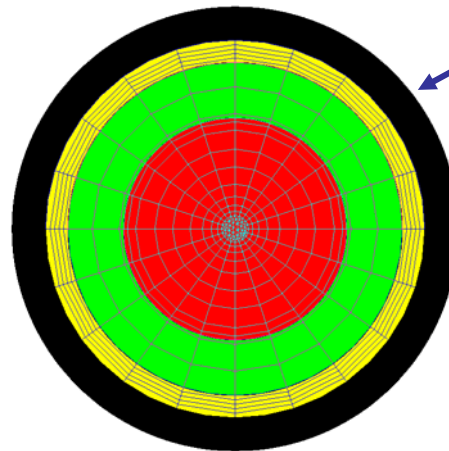
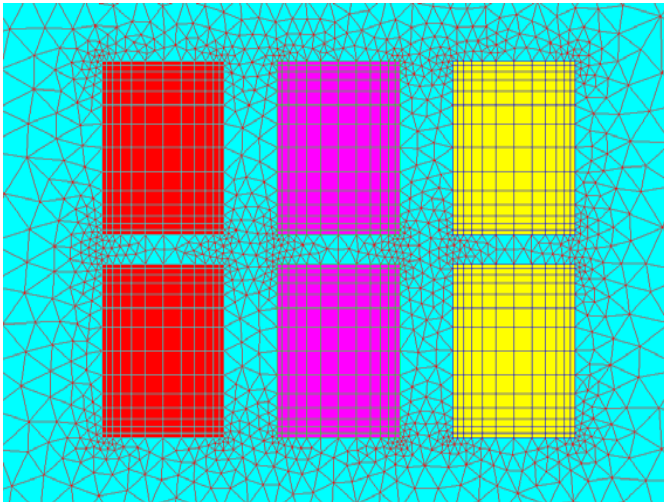
3-phase cable: Temperature map



Power losses curve versus current

Benefits of using Flux

- Mixed mesh generator:
 - » Possibility to mix tetrahedrons and mapped mesh in the same model
 - » Mapped mesh allow to
 - ✓ Adapt the mesh to the skin effect
 - ✓ Reduce the mesh size while increasing results quality
 - ✓ Reduce calculation time



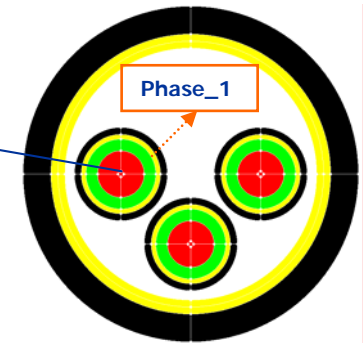
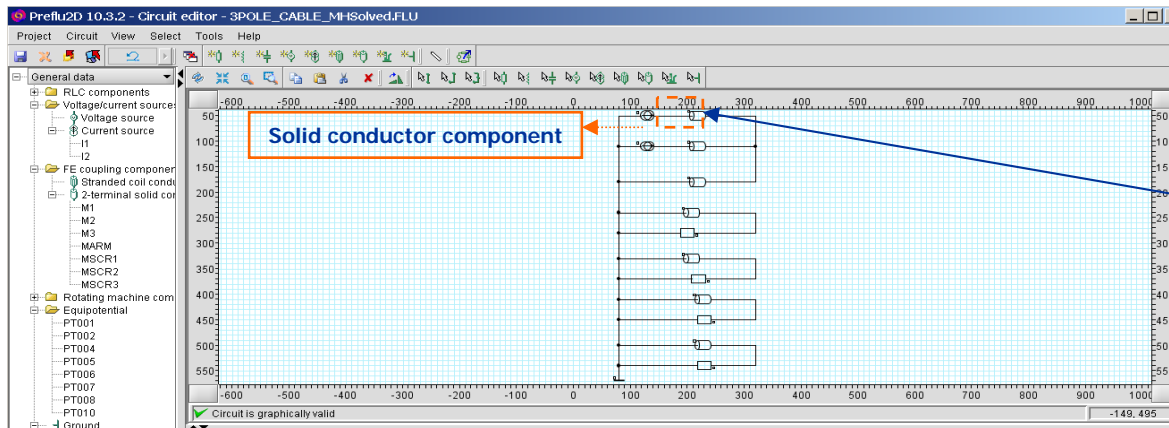
Benefits of using Flux

- Easy modeling and geometric tolerance:
 - » Propagation of geometry with keeping mesh and region properties
 - » Possibility of modeling very small internal details
 - » CAD import: STEP,IGES,DXF and mesh import Pro-E, Patran, Nastran ...

- Allowing the multi parametric studies:
 - » Solving the FEM model thanks to the geometric and physical parameters
 - ✓ For instance, parameterize the frequency in order to analyze the eddy currents or the electromagnetic field for bus bars
 - ✓ Parameterize the current through the conductors for 3-phase cables

Benefits of using Flux

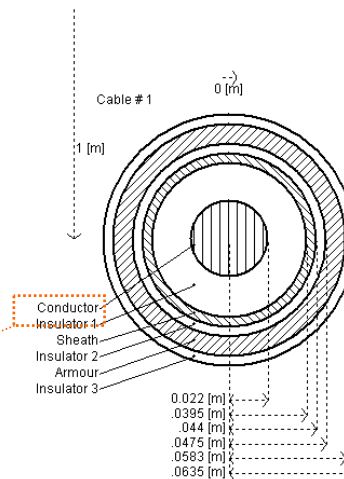
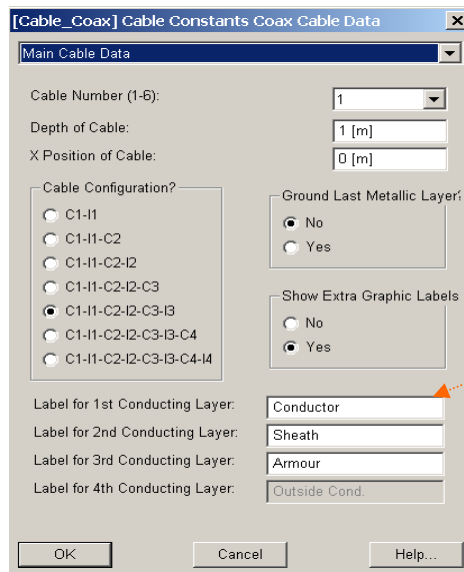
- Electric circuit coupling integrated in Flux:
 - » Allows to represent bars, armour sheets, conductors with solid conductor component:



- » Within a solid conductor, coupling between the electric and the magnetic A.C. fields to take into account eddy currents in the conductor
- » Circuit equations are solved in the same loop as the electromagnetic ones
- » Pyflux language can be used to design the circuit

Benefits of using PSCAD: Power networks modelling

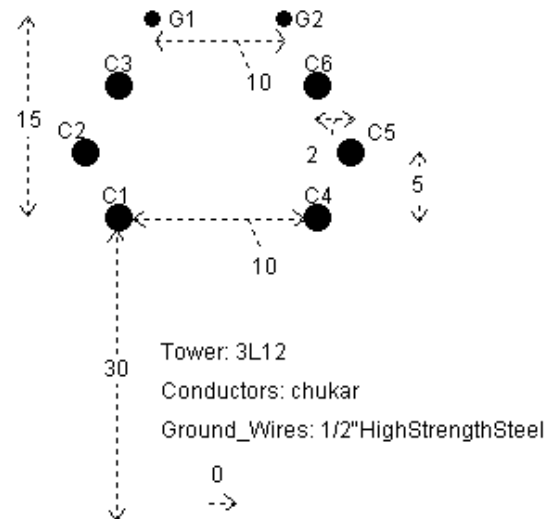
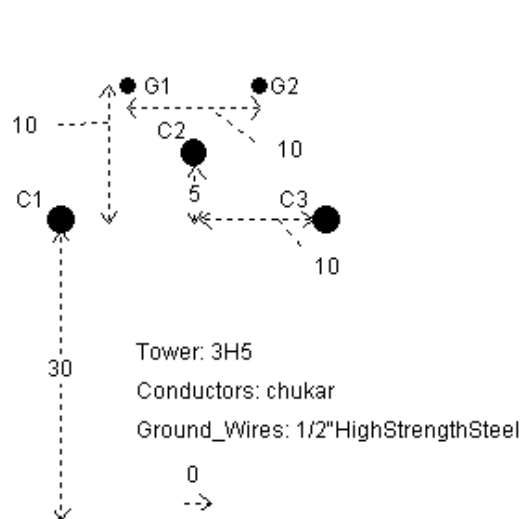
- Expanded choices to design the geometry configuration including material characteristics
 - » Co-axial cable models:
 - ✓ Defined with a centre solid conductor (can have up to three concentric conductors about the centre)
 - ✓ Each conductor is separated by an insulator.
 - ✓ The cable cross-section is used to define the geometric positions and the conductor/insulator properties of the cable system.
 - ✓ Earth ground path to adjust of ground resistivity and permeability



Benefits of using PSCAD :

» Transmission line tower component:

- ✓ Various configurations: 3,6 or more conductors
- ✓ Horizontal or Vertical arrangements
- ✓ With or without ground wires



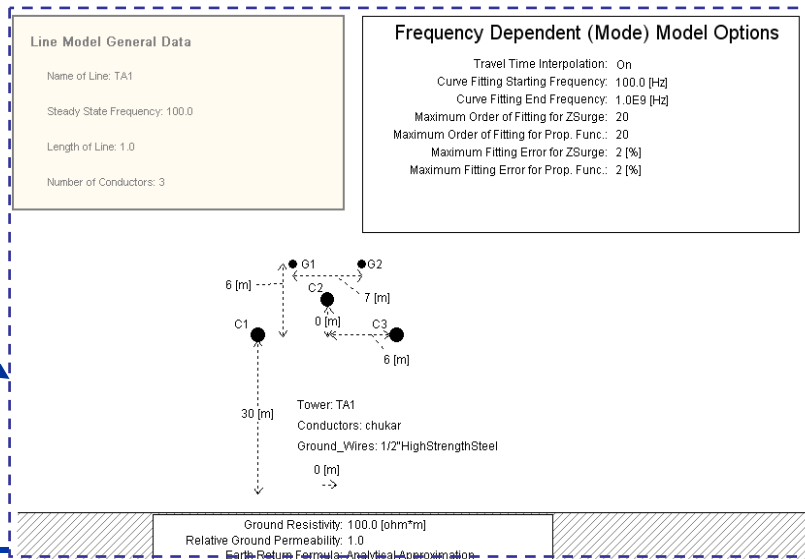
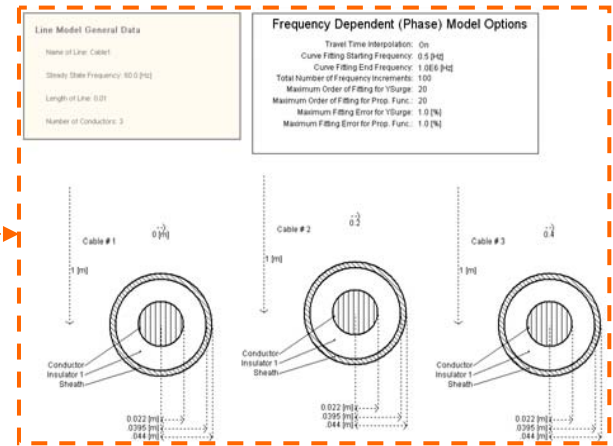
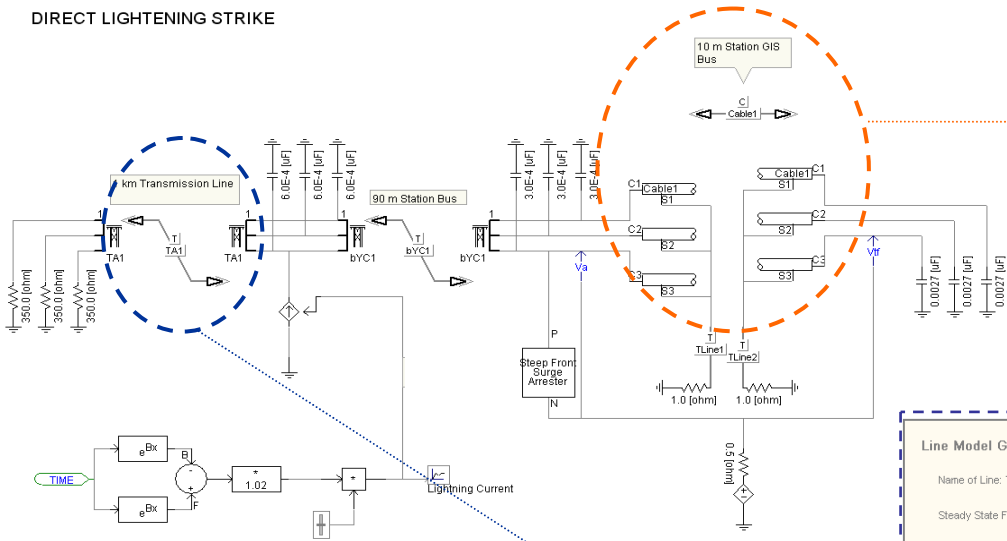
Benefits of using PSCAD :

- Influence of the cables and lines on the complete power system simulation model
 - » Advanced models to take into account the wave transmission on the cable or transmission line
 - ✓ Bergeron model:
 - Very simple, constant frequency model based on travelling waves
 - Represents the L and C elements of a PI Section with lumped resistance
 - Represents the fundamental frequency only
 - Suitable for studies where the fundamental frequency load flow is most important
 - ✓ Frequency dependent (phase) model:
 - Uses curve fitting to duplicate the frequency response
 - It is the most advanced time domain model available as it represents the full frequency dependence of all line parameters.
 - Useful for studies wherever the transient or harmonic behaviour of the line or cable is important.
 - » PSCAD libraries also contains more simple models to represent cables and T-lines such as Pi-sections and simple passive components

Benefits of using PSCAD: Example

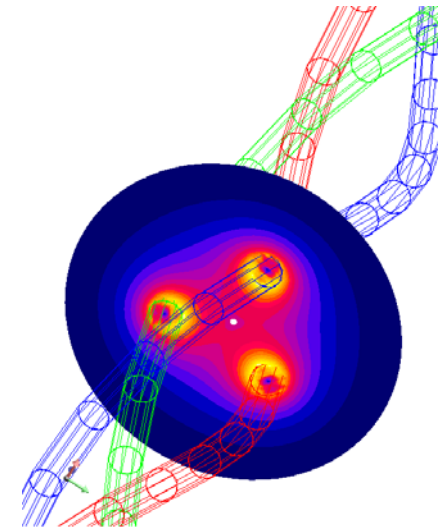
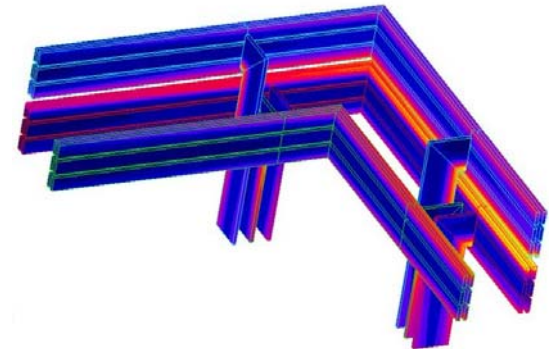
Lightning Strike

DIRECT LIGHTENING STRIKE



InCa3D – Efficient Analysis of Conductors and Bus bars

- EM analysis of 3D nonmagnetic structures
 - » Dedicated solution for power connections
 - ✓ Power busbars, busways
 - ✓ Cables
- Main constraints:
 - » Complex 3D systems
 - » Large dimensions
 - » Frequency and proximity effects
- Results:
 - » Current distribution
 - » Power losses
 - » Magnetic field emitted
 - » Impedance matrix – export to circuit simulator
 - » Link to thermal tool IcePak



Why is InCa3D well adapted for cabling modeling?

1) **PEEC method** for the extraction of stray elements

- » Model the 3D structure by an equivalent electrical circuit
 - ✓ Partial resistances, self inductances, mutual couplings
 - ✓ Integrated solving of circuit equations for complete EM analysis

- » No need to mesh the surrounding air
 - ✓ Fast and easy mesh of the system
 - ✓ Calculation time dramatically optimized
 - ✓ Possibilities to simulate large-scale systems

Why is InCa3D well adapted for cabling modeling?

2) **Simplified definition** of the system

- » Tube oriented geometry description
- » Automatic mesh according to solving frequency
 - ✓ Accounts for skin and proximity effects

3) Natural **parametric** facilities :

- » To easily manage the PEEC model from a list of geometric and physical parameters

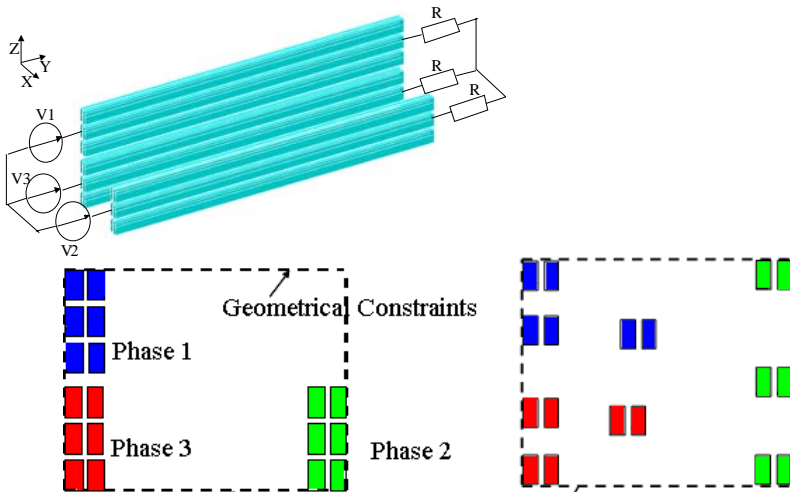
4) Completely **scriptable** modeling process

- » Useful to go towards geometry optimization

InCa3D for Cabling Optimization

Layout optimization

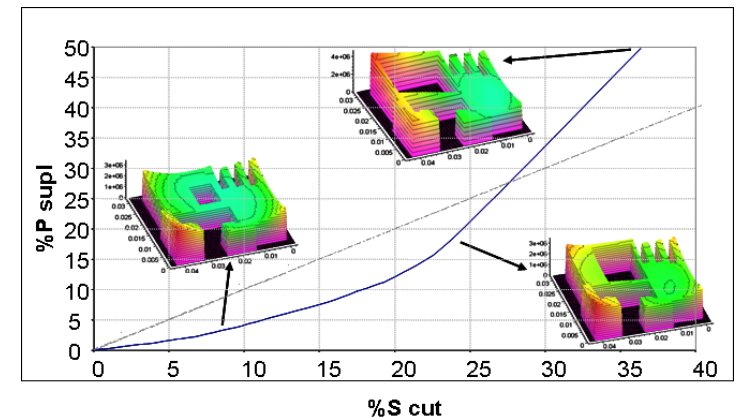
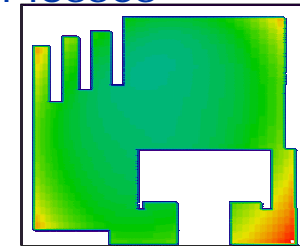
- » To act on the proximity effects
- » Up to 25% efficiency increase



	Losses before optimization (W)	Losses after optimization (W)	Earnings
Phase 1	222	168	24.3 %
Phase 2	158	149	5.7 %
Phase 3	233	170	27 %
Total	613	487	20.5 %

Shape optimization

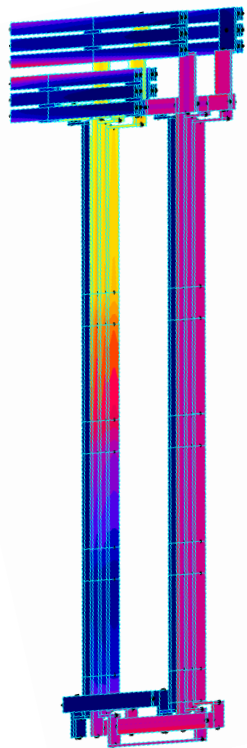
- » To act on the skin effect
- » Up to 15% efficiency increase
- » Compromise between material reduction and additional losses



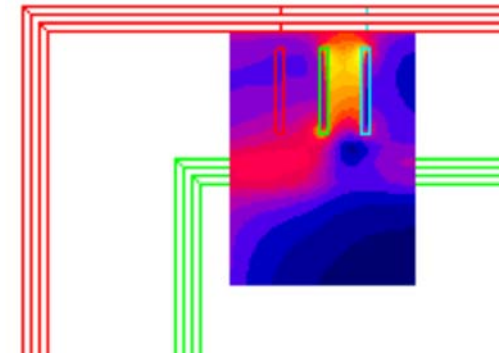
Courtesy of
Schneider Electric

InCa3D – Efficient Cables and Busbar analysis

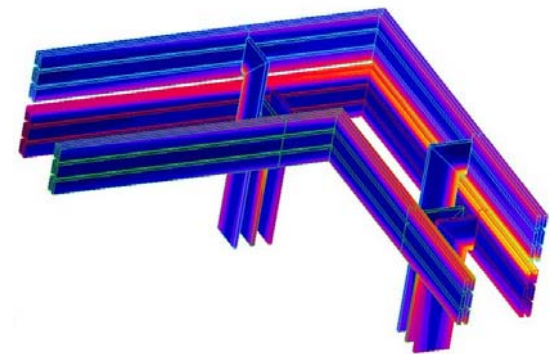
- Study of a 3-phase distribution bus bar



Study of consequences of heavy unbalanced conditions



Magnetic field emitted



Current distribution

Courtesy of
Schneider Electric

Portunus : Easy thermal network modeling

Flux
PSCAD
InCa3D
Portunus

Applications

- » Power cables

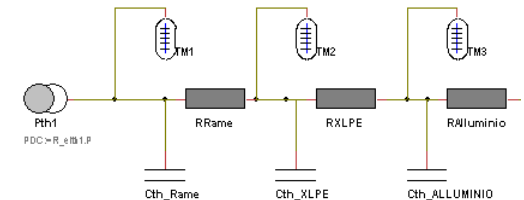
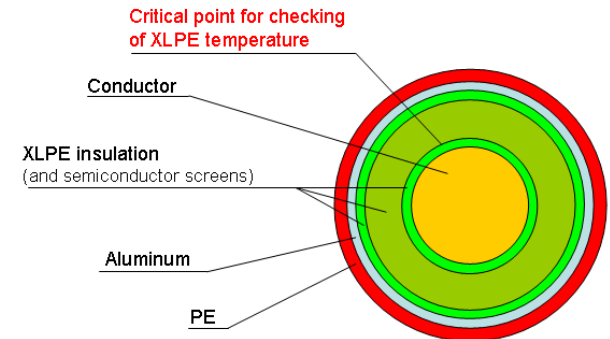
Challenges

- » Multiple layers with different material characteristics
- » Combined electrical and thermal phenomena
- » Quick and easily accessible thermal pre-computation

Results

- » Heating of the different layers in the cable
 - ✓ Temperature at steady state
 - ✓ Transient analysis of temperature rise
- » Coupled electrical and thermal effects

XLPE 2500 Cu Cable Section



Why is Portunus well adapted to thermal modeling of cables ?

Flux
PSCAD
InCa3D
Portunus

1) Thermal network modeling

» Simple modeling of thermal phenomena

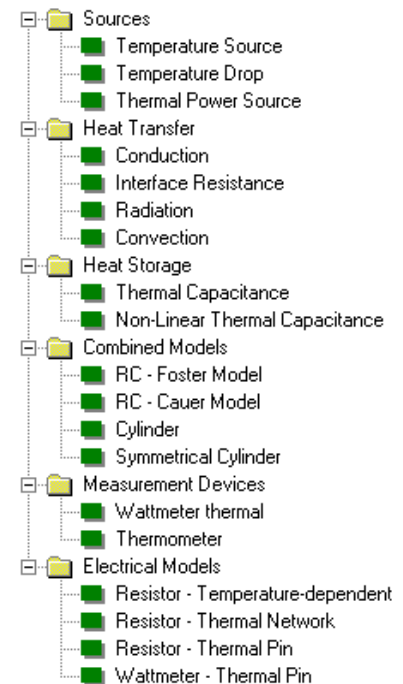
- ✓ No complex geometry and mesh description like in CFD software

» Integrated preprocessor

- ✓ Easy definition of thermal properties
- ✓ Material database

2) Extensive thermal library

- » Accounts for **conduction**, **convection** (natural and forced) and **radiation**
- » **Coupled** electrical – thermal models
- » Well documented library



Why is Portunus well adapted to thermal modeling of cables ?

3) Multi-domain simulation

- » **Interaction** between electrical and thermal components
 - ✓ Temperature dependent resistance
 - ✓ Heat source depending on the current value

4) Efficient, robust and user-friendly system simulator

- » Simple single interface
- » Parametric solving
- » Variable step time to take into account as well electrical and thermal time constants

Thermal modeling becomes accessible to everyone!!