Reluctances network modeling under EMTP

Application to transformers simulation

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EMTP

Outline

- Context - Issues
- RNM & EMTP
- Transformers modeling
- Results
- Conclusion

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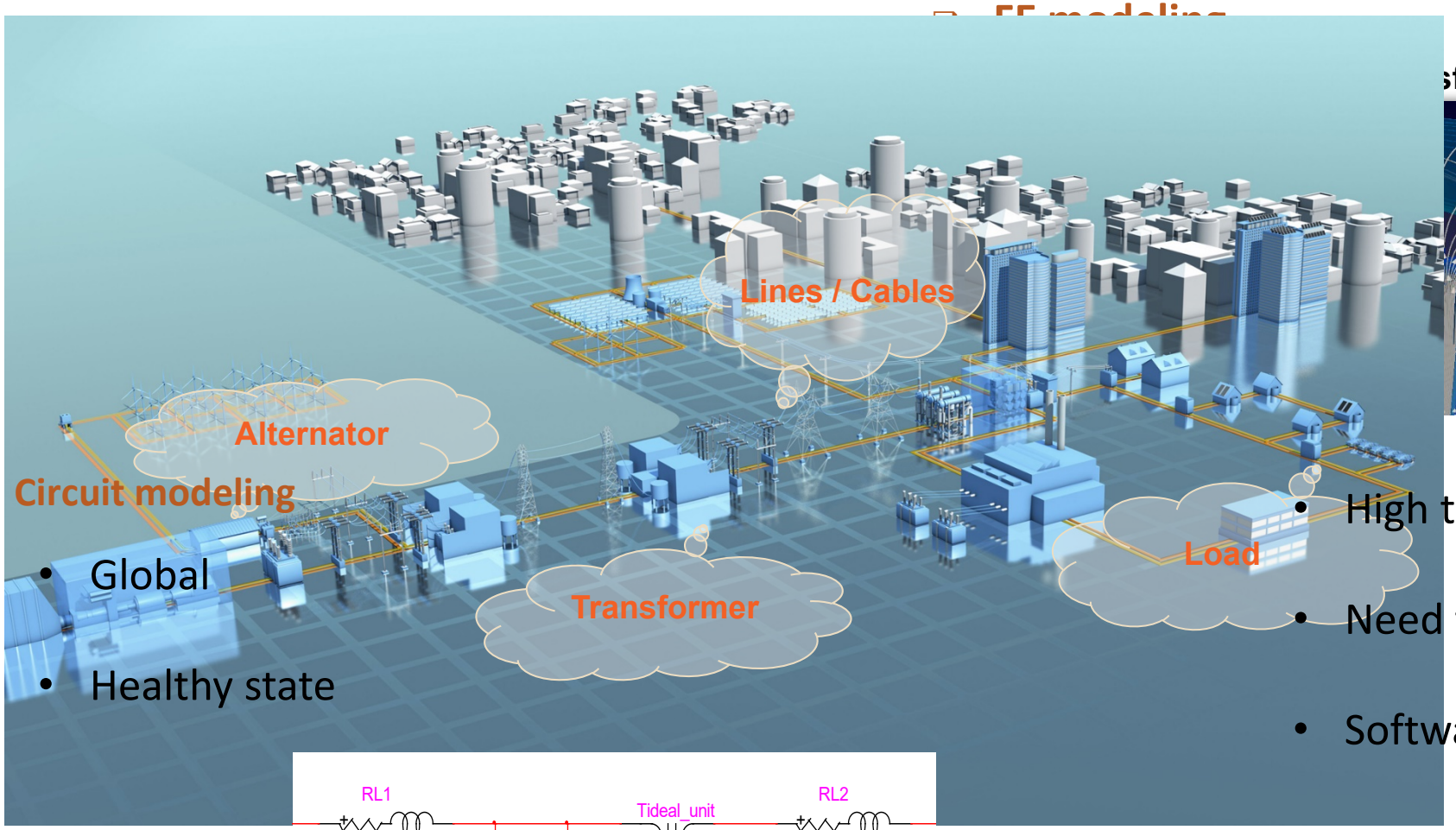
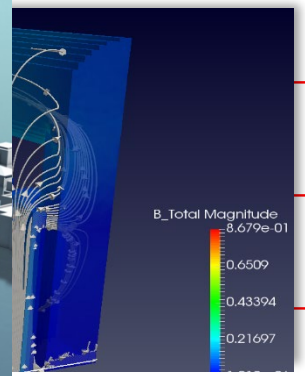
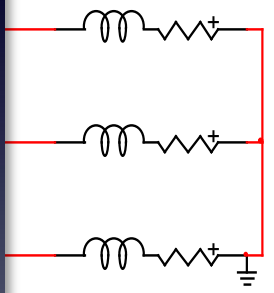
Context



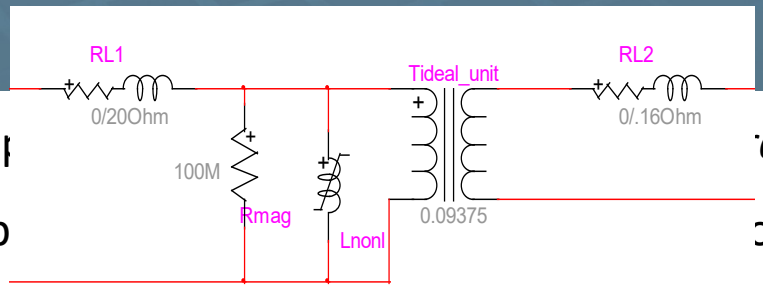




sformer

Load / Network

- **Circuit modeling**
  - Global
  - Healthy state
  - High time consuming
  - Need for electrical coupling
  - Software compatibility



- Improve the op… *…ansformers, lines…*
- Control their b… …ons: *starting, disturbances, faults*
- Explain the damage propagation: *interaction between electrical grid and its equipment*.

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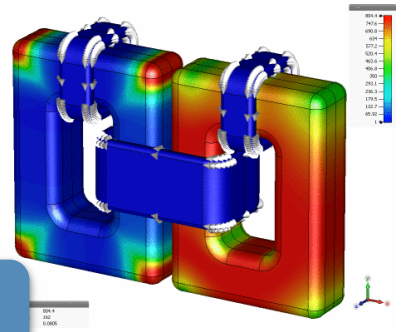


Objective: New Generic Modeling Method under EMTP

complexity

≈ 10^5 ~ 10^6 unknowns

FE computation (Code_carmel)

≈ 10^3 ~ 10^4 unknowns

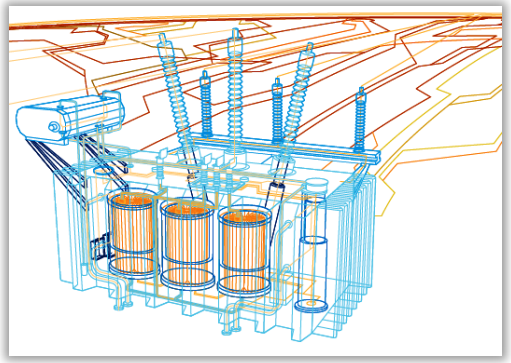
Circuits (EMTP) : Reluctance network

- Precise modeling
- Access to the geometry

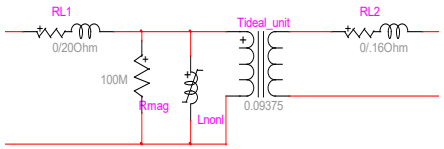
≈ 10^1 ~ 10^2 unknowns

Circuits (EMTP)

- Fast modeling
- System modeling



Interpolation Extrapolation



Rule of 3

time

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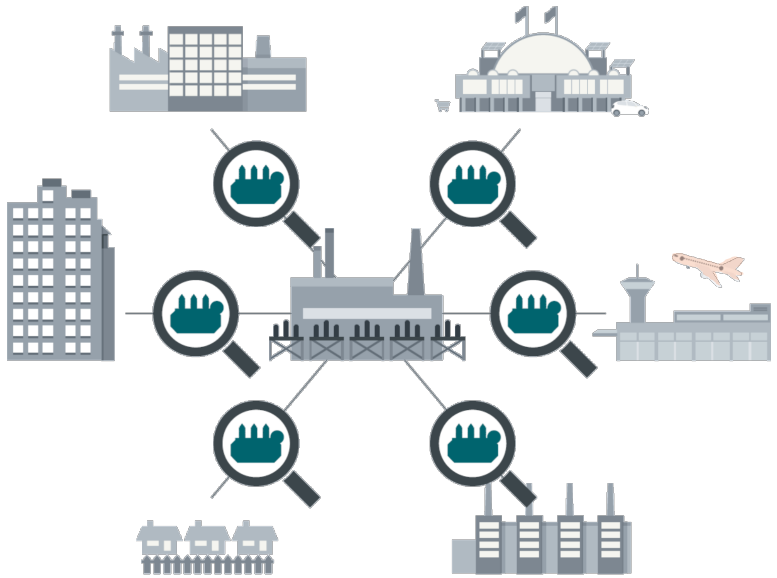
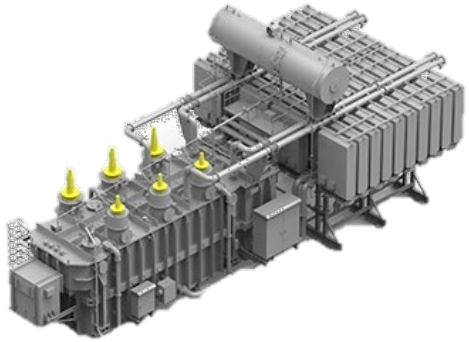
Hidden champions of the power grid

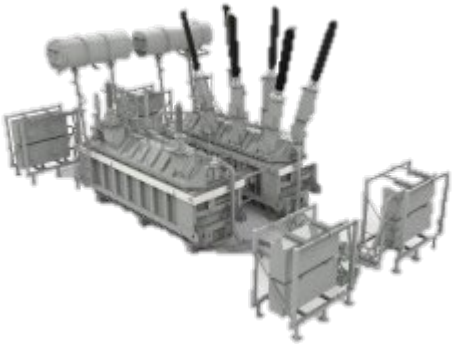


Power Transformers



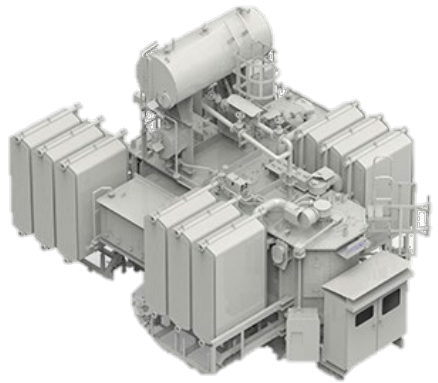
HVDC Transformers

Phase-shifting Transformers



Distribution Transformers

Substation Transformers



Reactors

Objective: study their reaction for different disturbances

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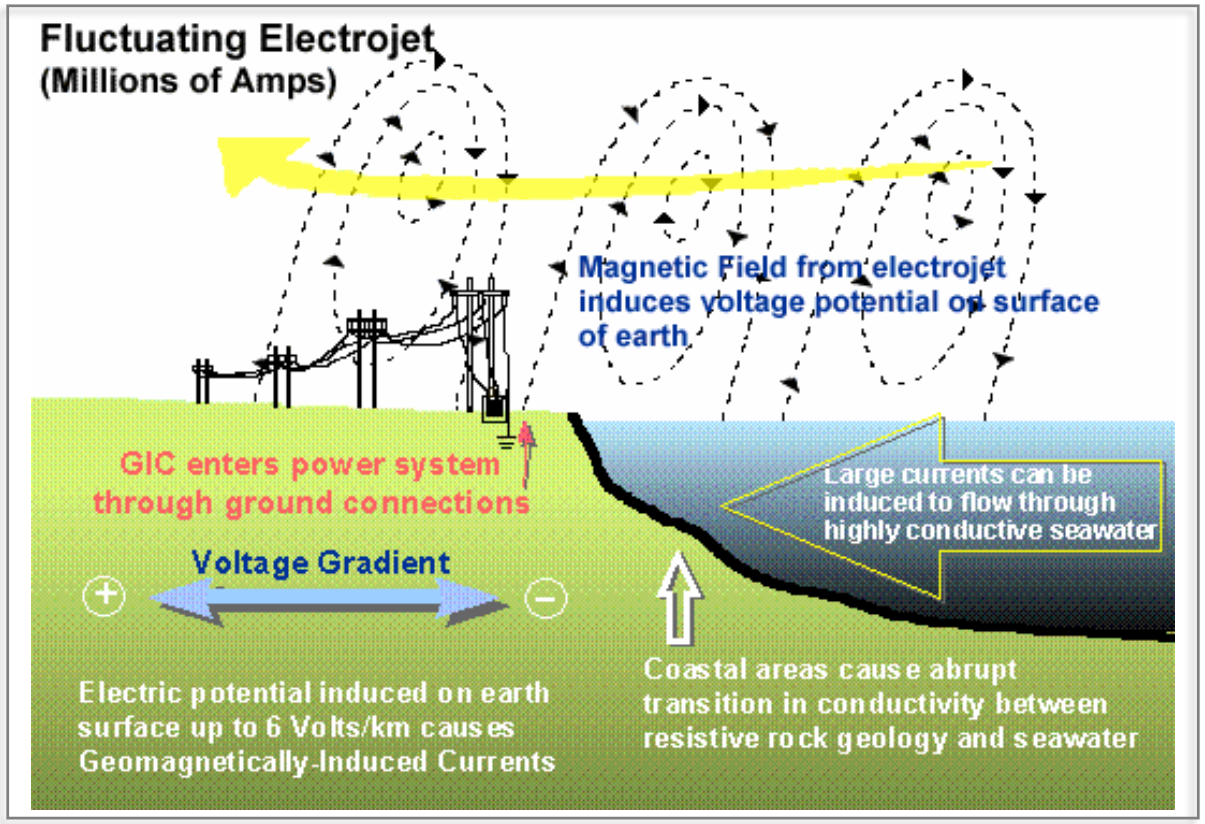
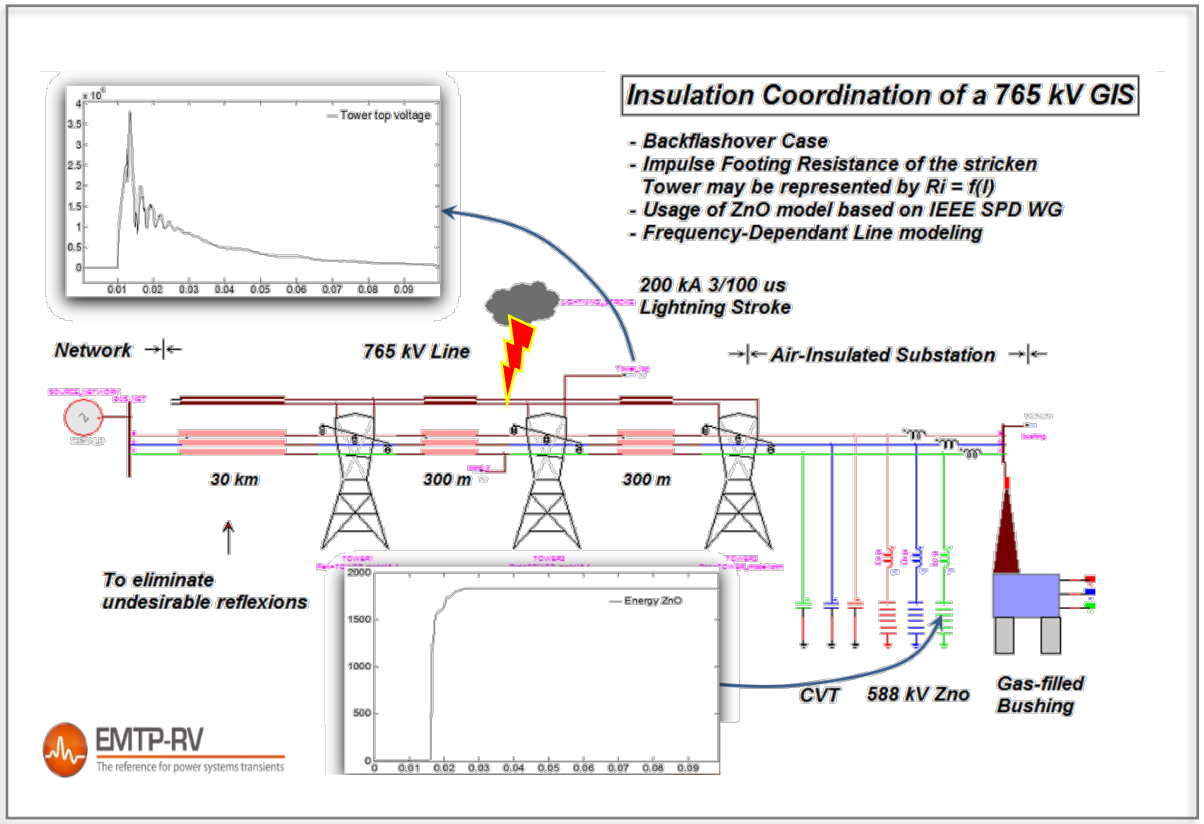
Context

Natural disturbances



Geomagnetically Induced Currents (GIC)



Lightning

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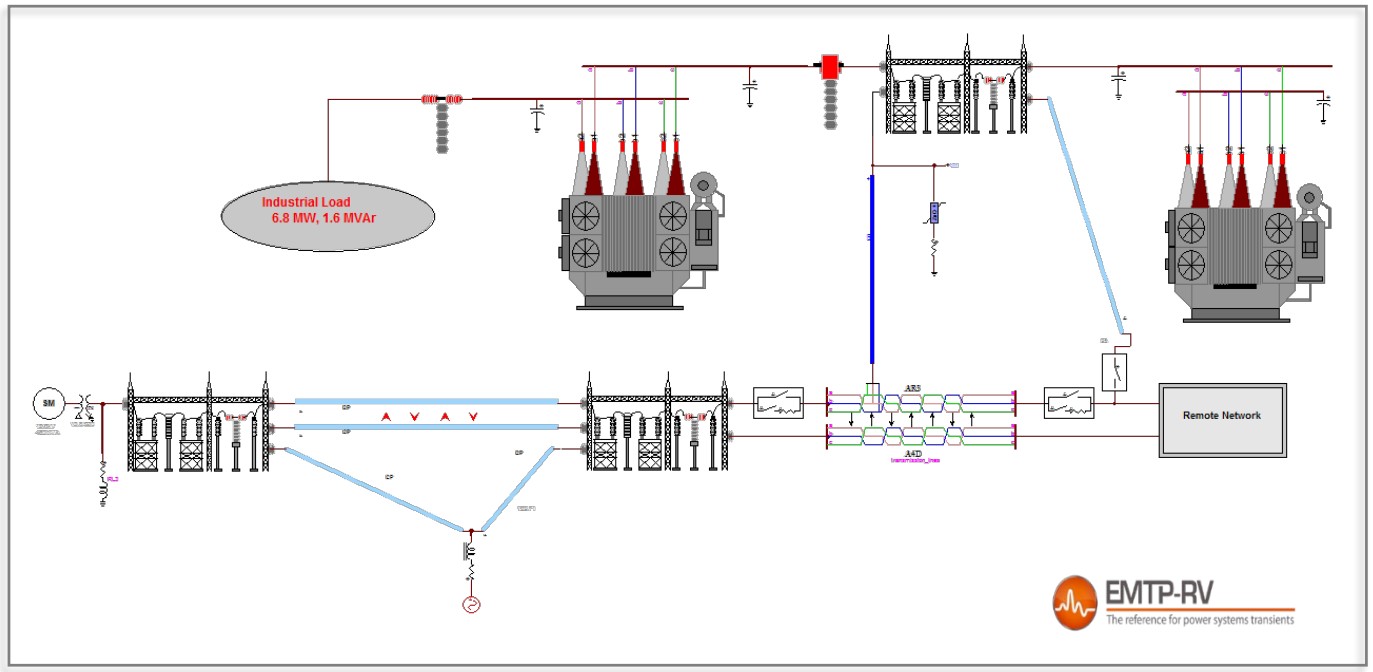
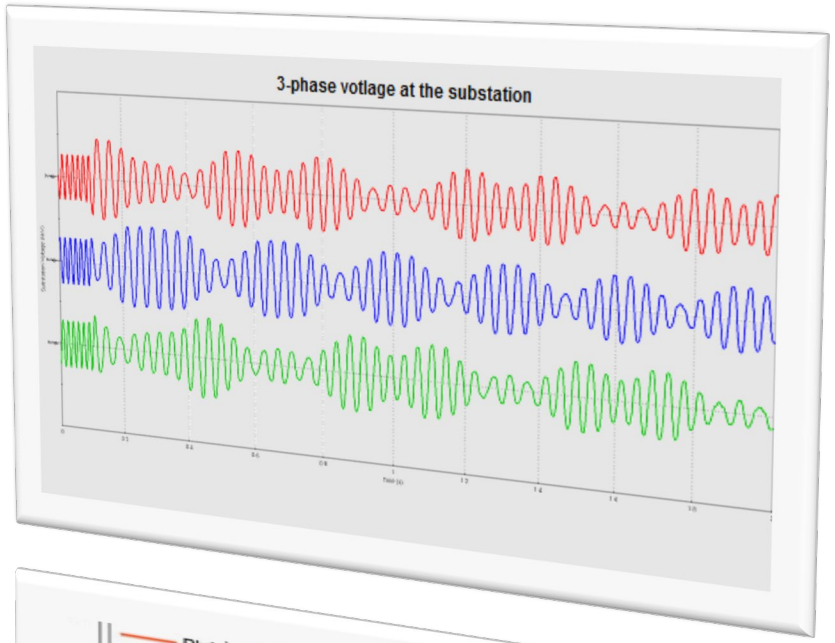
Context

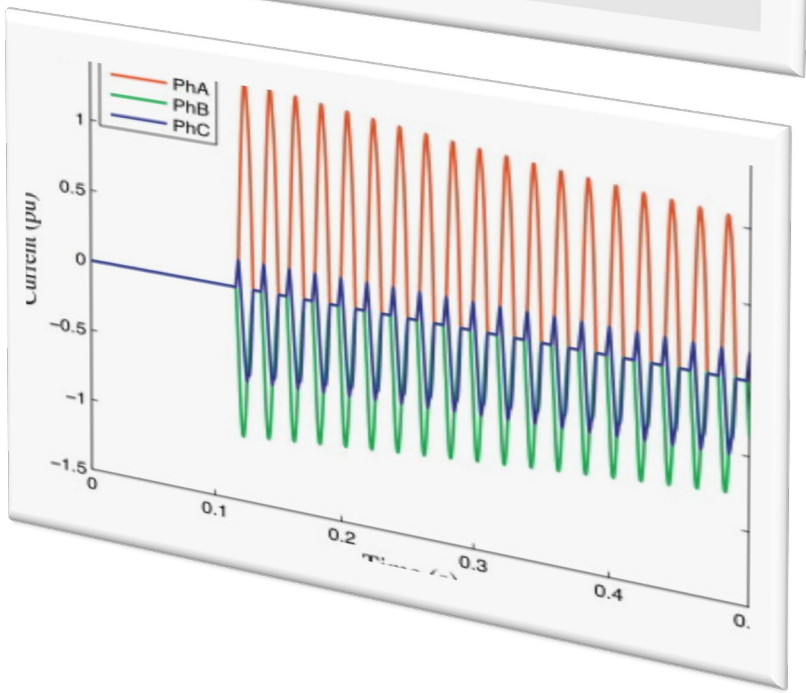
System disturbances



Ferroresonance



Inrush currents



Outline

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The reluctance network method & EMTP

	Ohm's law	Kirchhof's Law (for nodes)	Kirchhof's Law (for loops)
Electrical Circuit	$emf = R\,I \Leftrightarrow \vec{J} = \sigma\,\vec{E}$ Behavior law	$\sum_j I_j = 0 \Leftrightarrow \oiint \vec{J}\cdot\overrightarrow{ds} = 0$ Charge conservation	$\sum_k emf_k = 0 \Leftrightarrow \oint \vec{E}\cdot\overrightarrow{dl} = emf$ Faraday's law
Analogy			
Magnetic Circuit	$mmf = \mathcal{R}\,\varphi \Leftrightarrow \vec{B} = \mu\,\vec{H}$ Behavior law	$\sum_j \varphi_j = 0 \Leftrightarrow \oiint \vec{B}\cdot\overrightarrow{ds} = 0$ Flux conservation	$\sum_k mmf_k = 0 \Leftrightarrow \oint \vec{H}\cdot\overrightarrow{dl} = mmf$ Ampere's law

- The analogy : electrical circuit ↔ magnetic circuit
- RNM : use an equivalent magnetic circuit

→ Circuit software can be adopted to make reluctance network analysis

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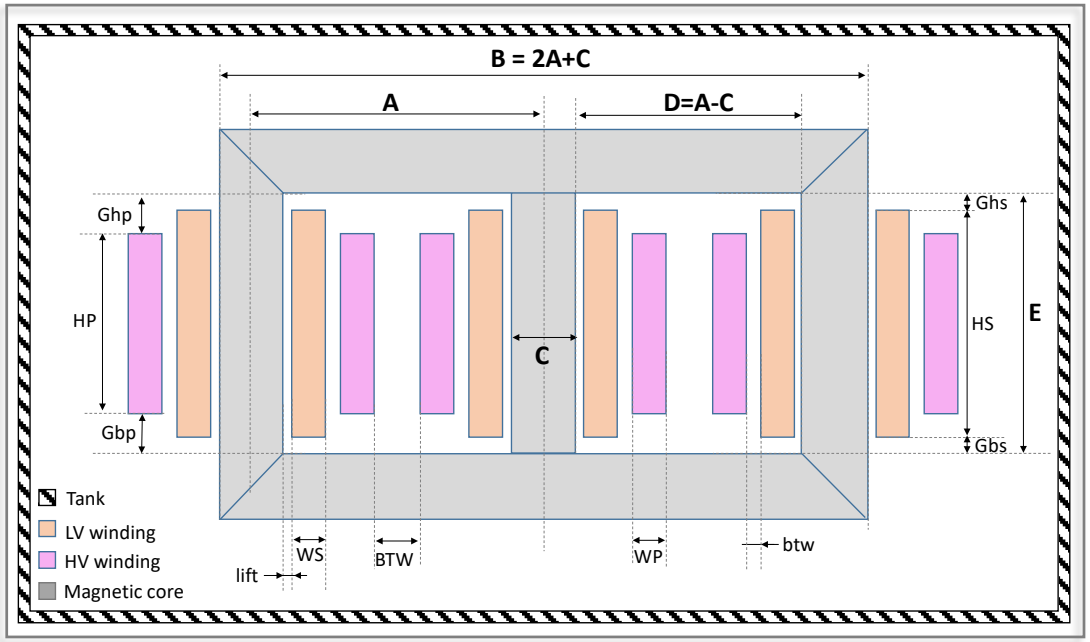
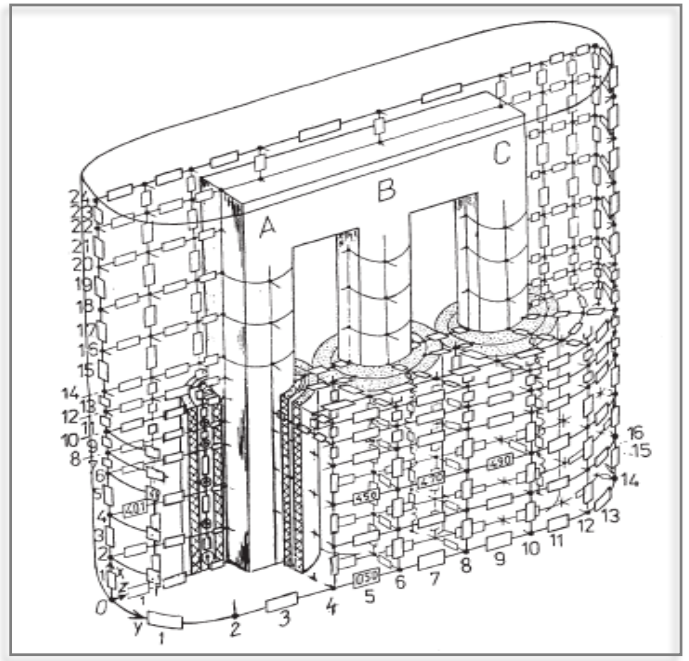
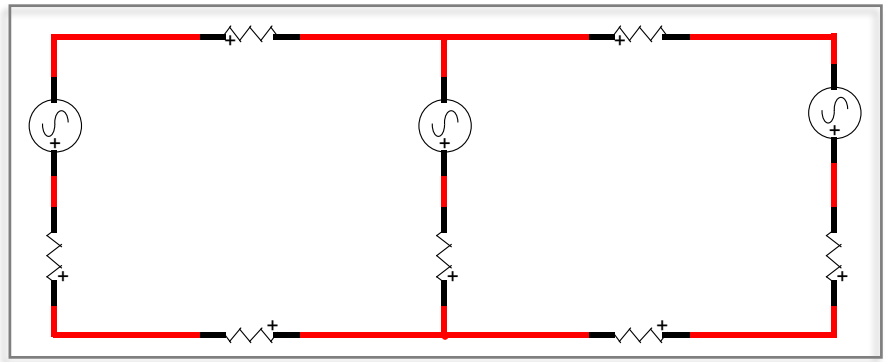
Three-phase transformer : cross-section



[J .Turowski]





- Satisfy a specific system (Case-by-case modeling)
- Weak coupling with electrical circuit
- Need for human intervention

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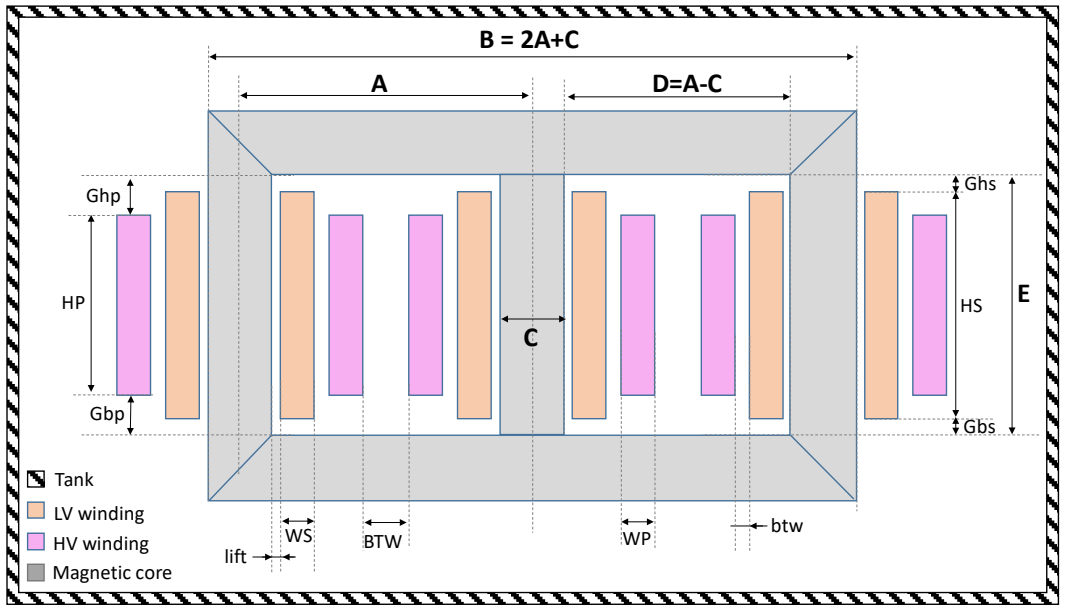
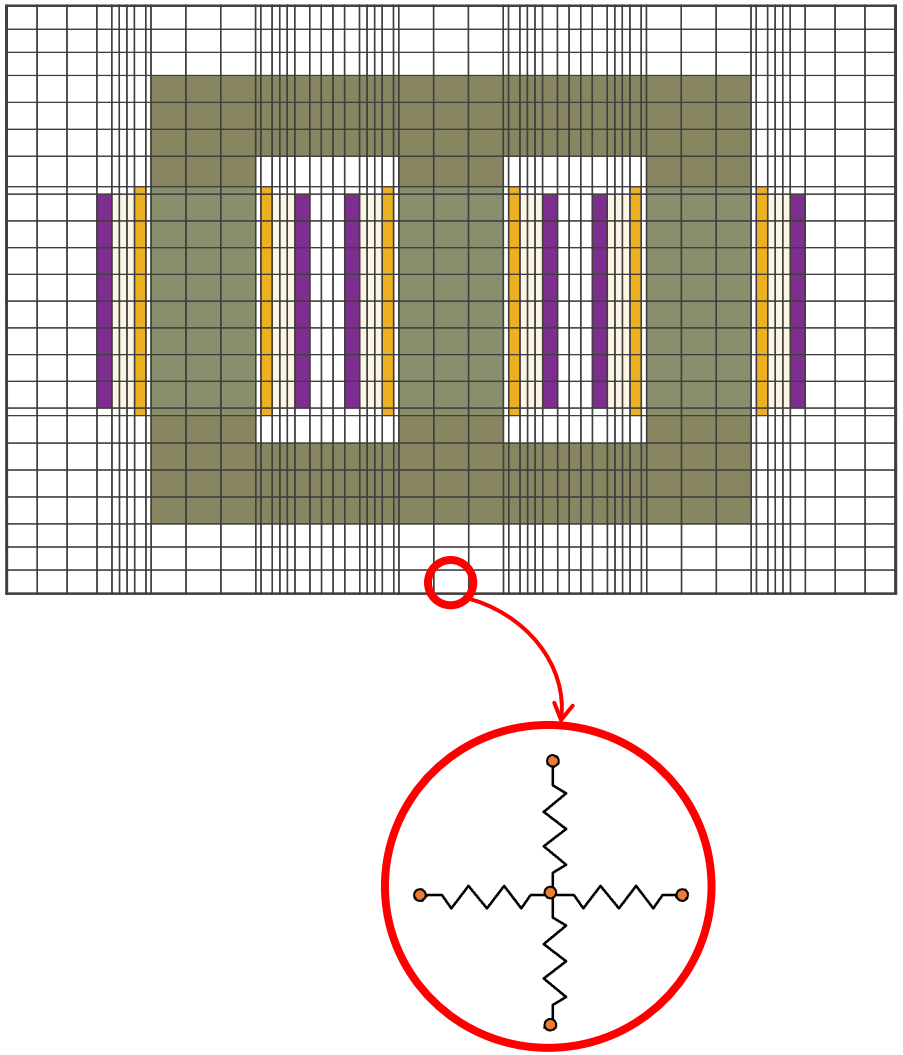
Transformer design

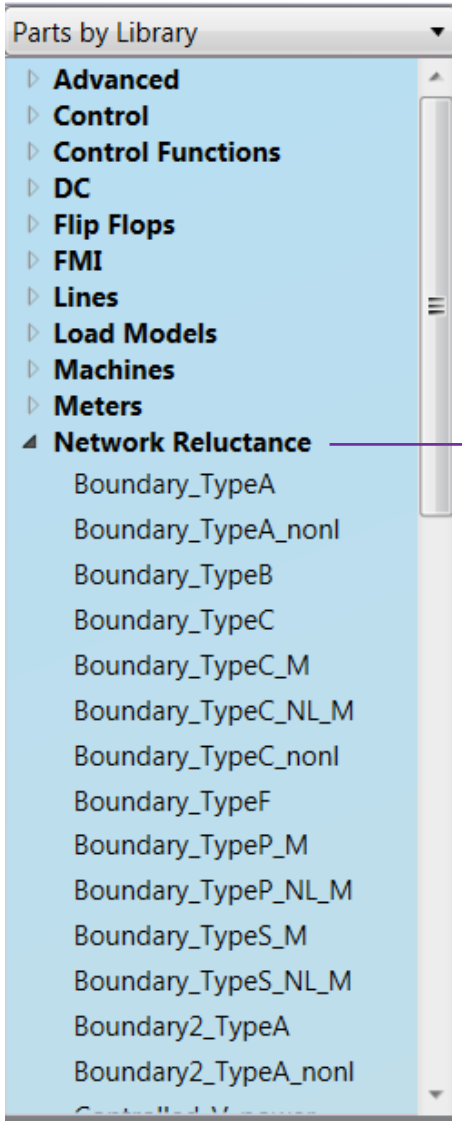


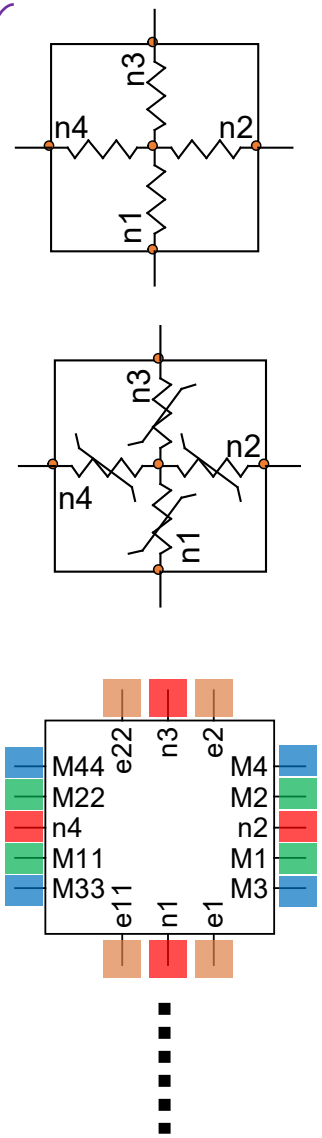
Geometry mesh



→ **Each element** is substituted with an **elementary circuit** (cell)

→ A **new EMTP library** for all possible configurations





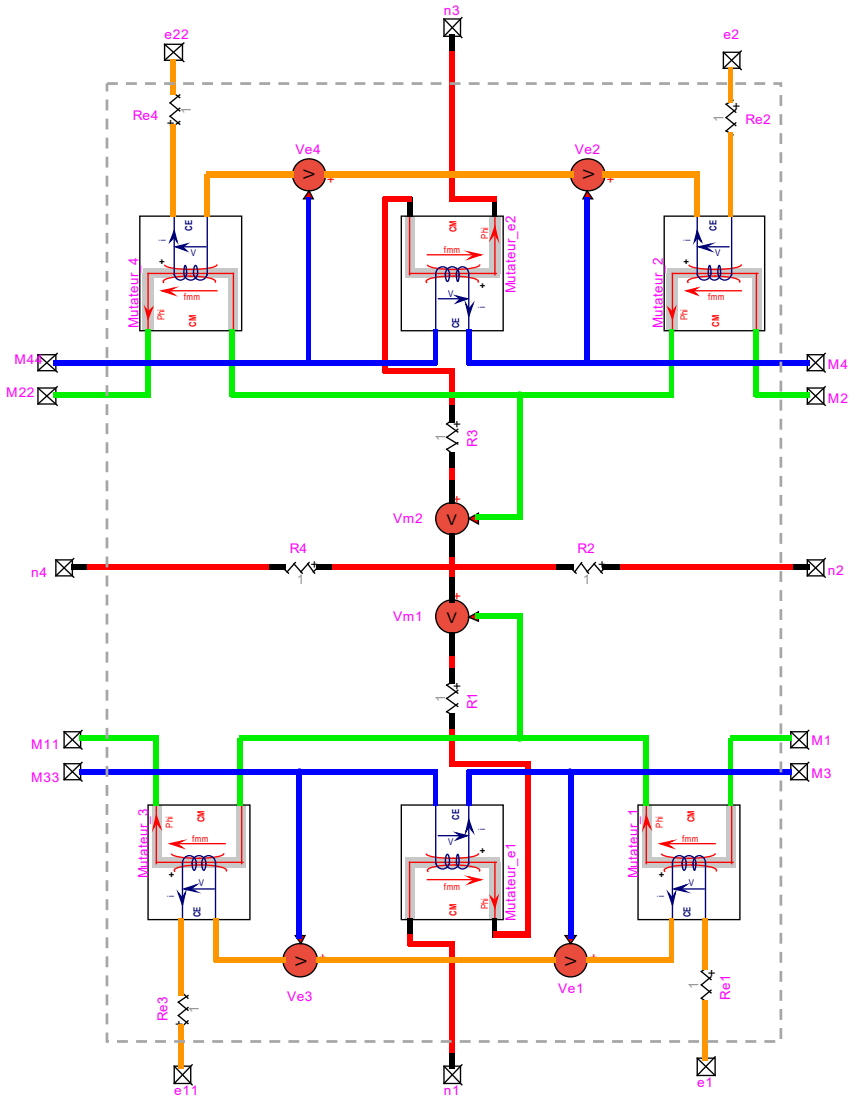
Electromagnetic coupling

$$emf = -\frac{\partial \varphi}{\partial t}$$

$$mmf = i(t)$$

An all-in-one cell that contain:

- *Magnetic circuit*
- *Electrical circuit*
- *Electric to magnetic*
- *Magnetic to electric*



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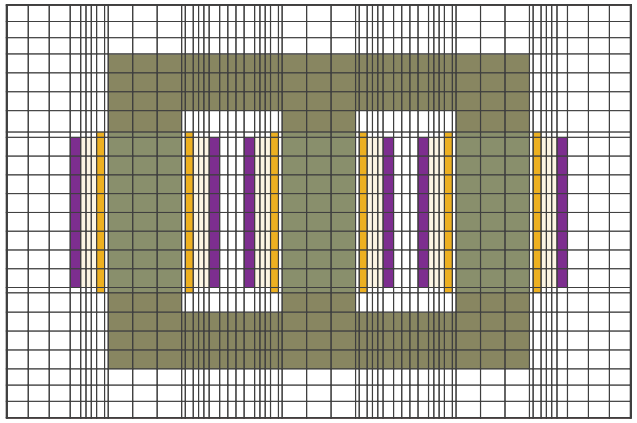


Physical parameters ?

Linearity ?

Coupling ?

Device type finder

for each mesh element, we identify which device to use from EMTP Library

Add devices

Build the RN model in EMTP

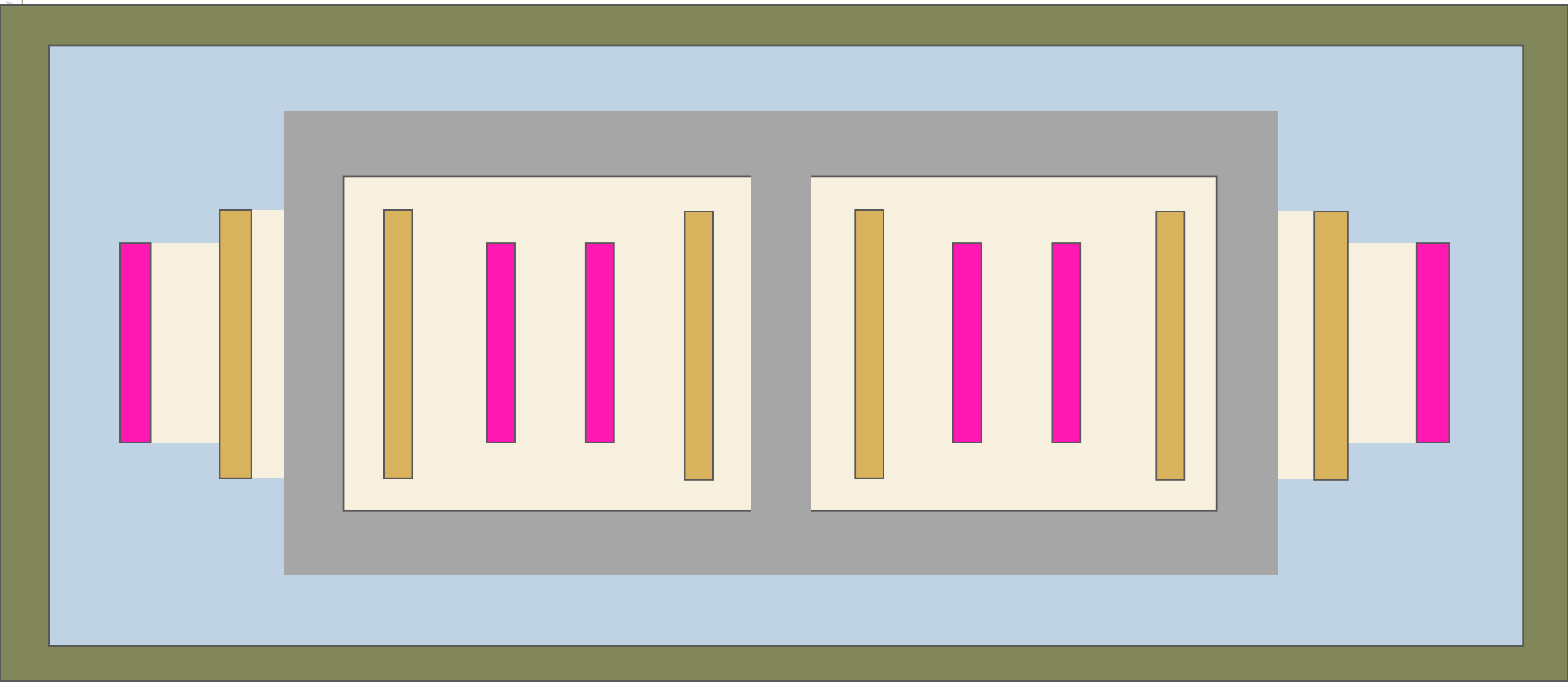
Connect devices

Establish connections between devices

Update circuit components parameters

Set the devices parameters

➔ 920 elements (*46 x 20*) !



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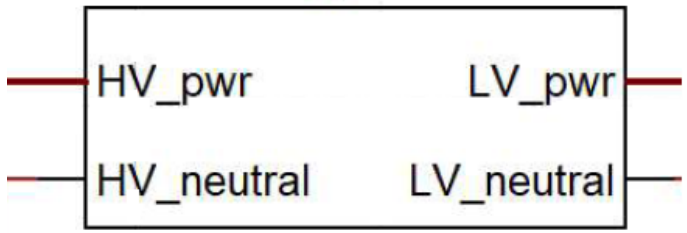
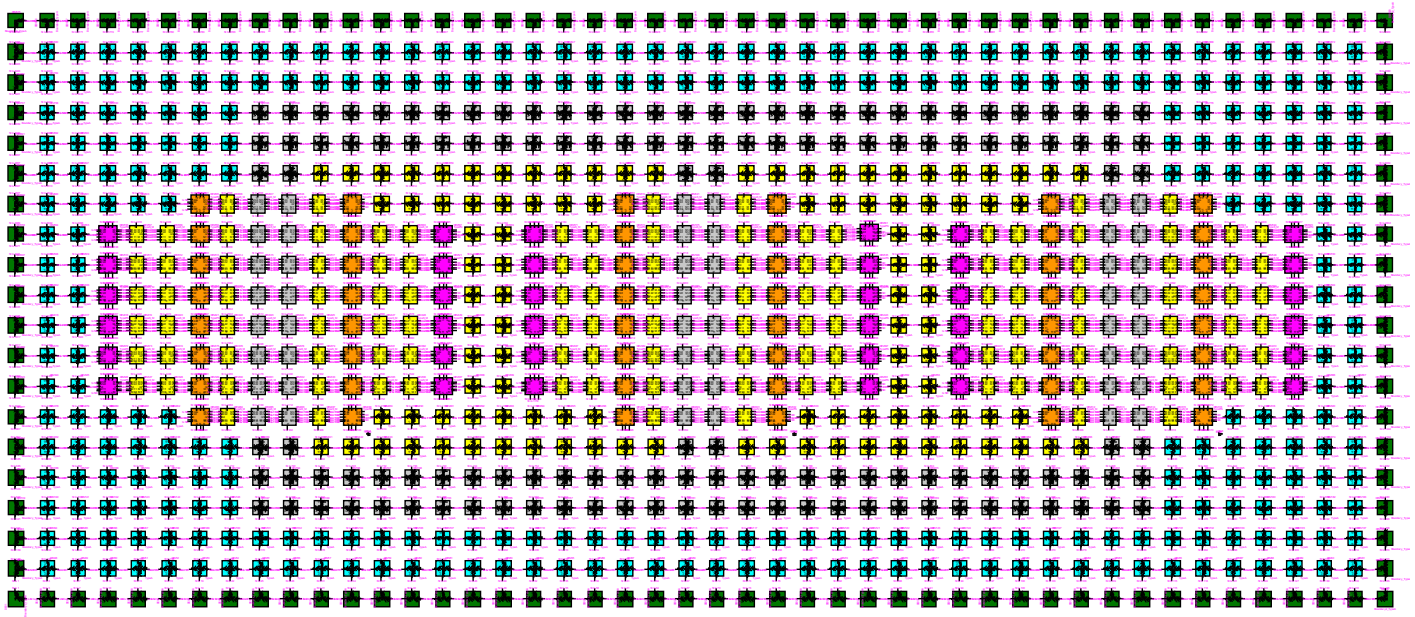
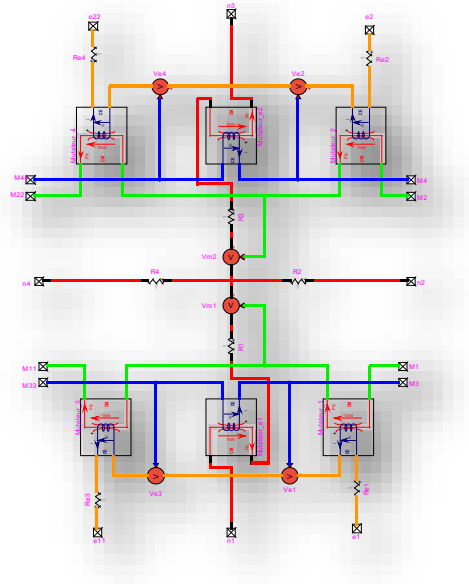
1st Layer : global



2nd Layer : design & mesh



3rd Layer : cell



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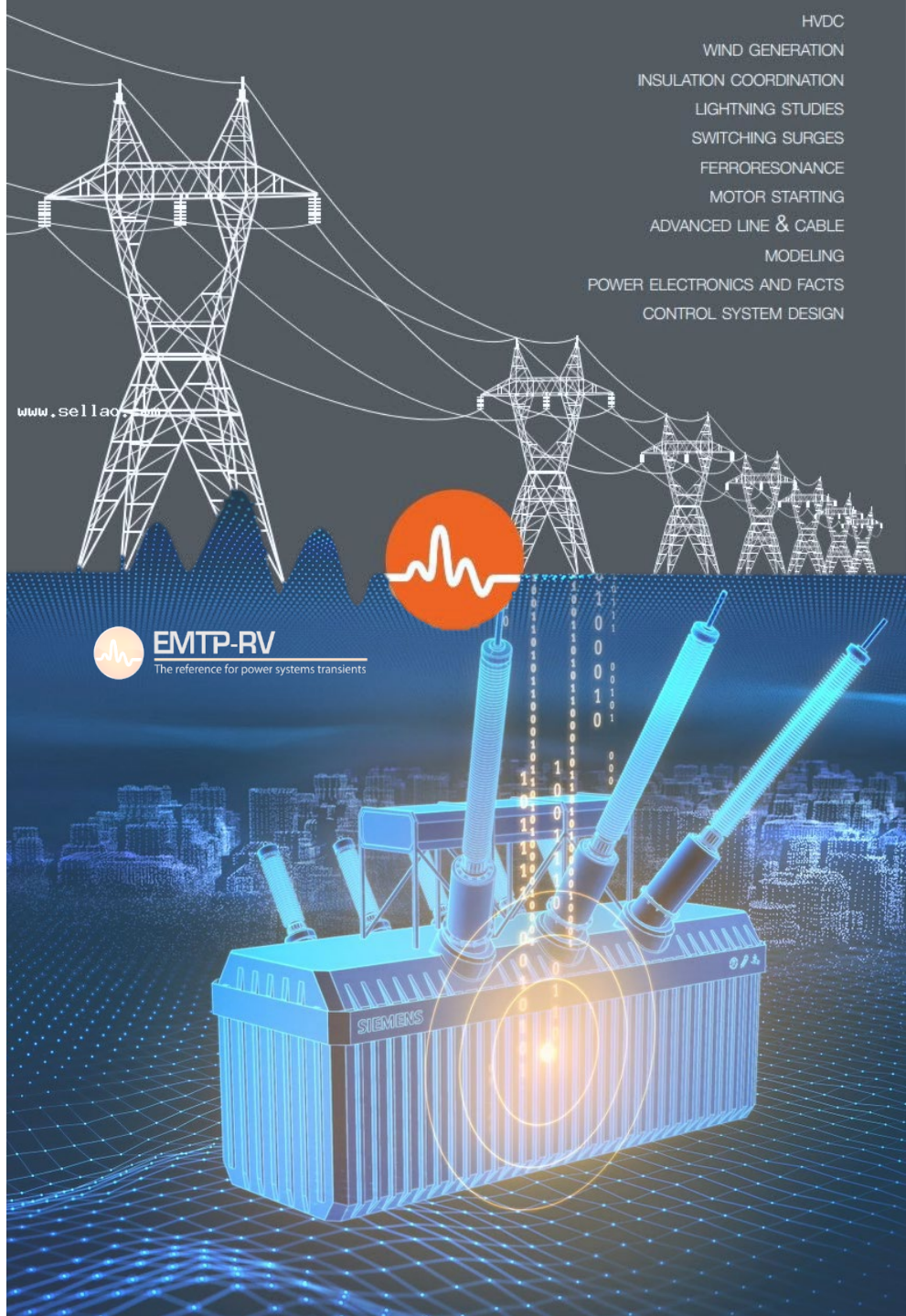

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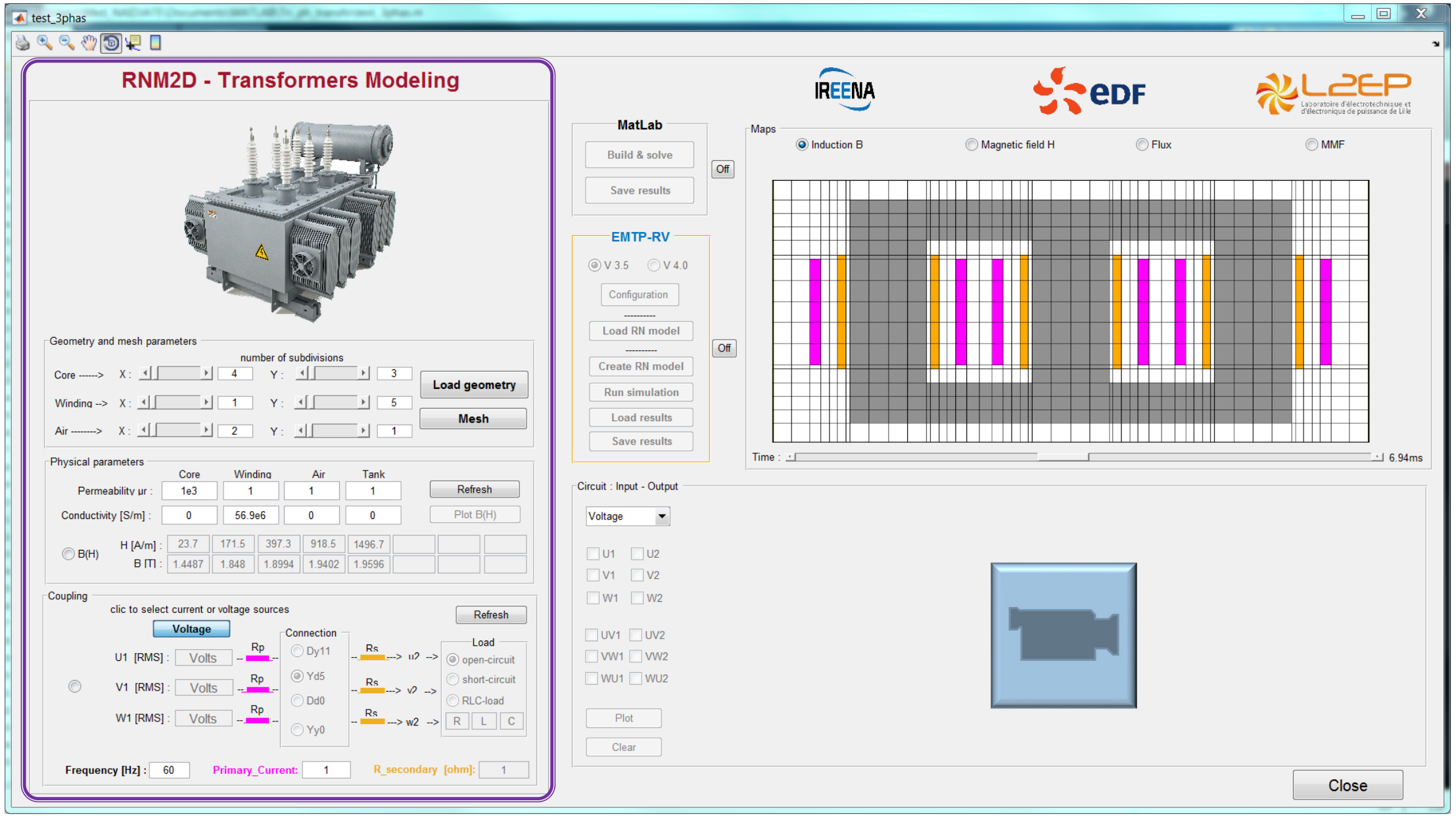

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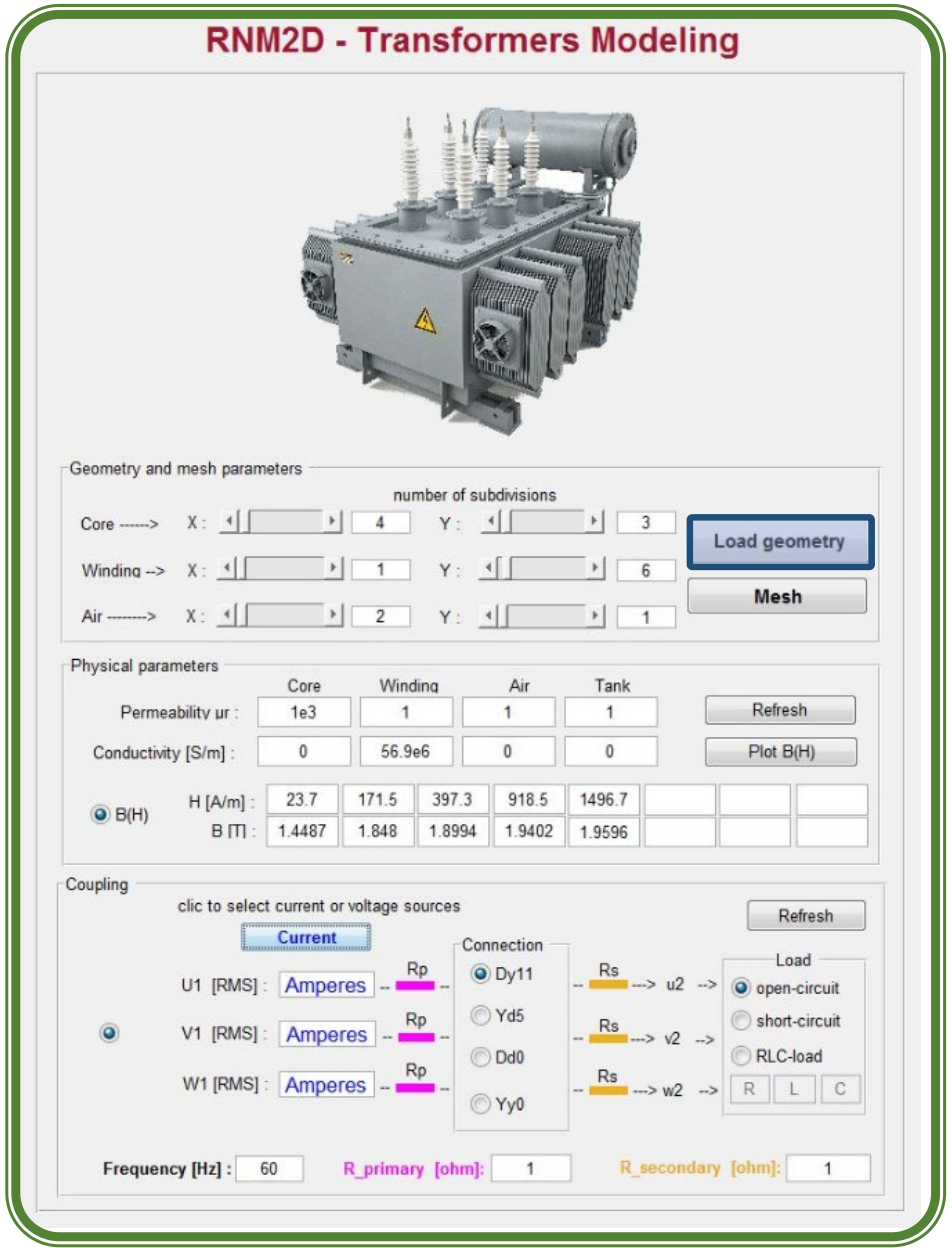
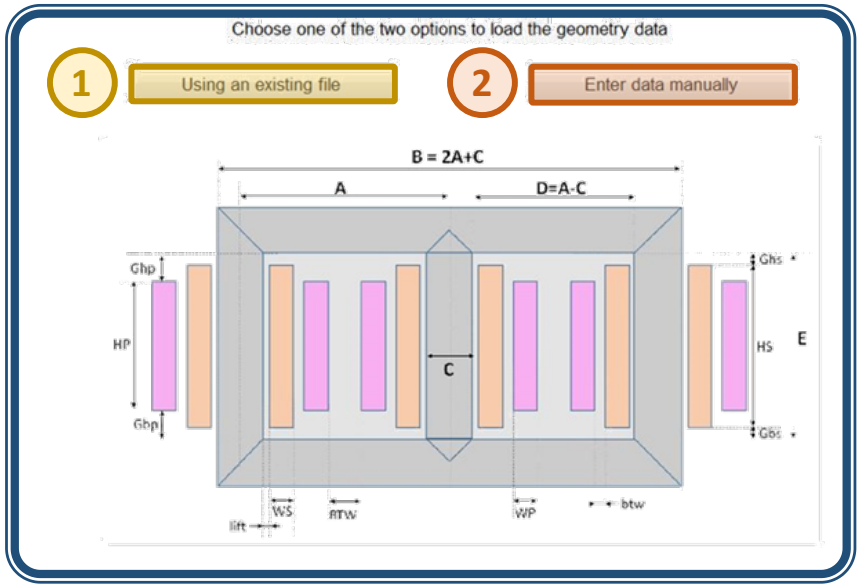
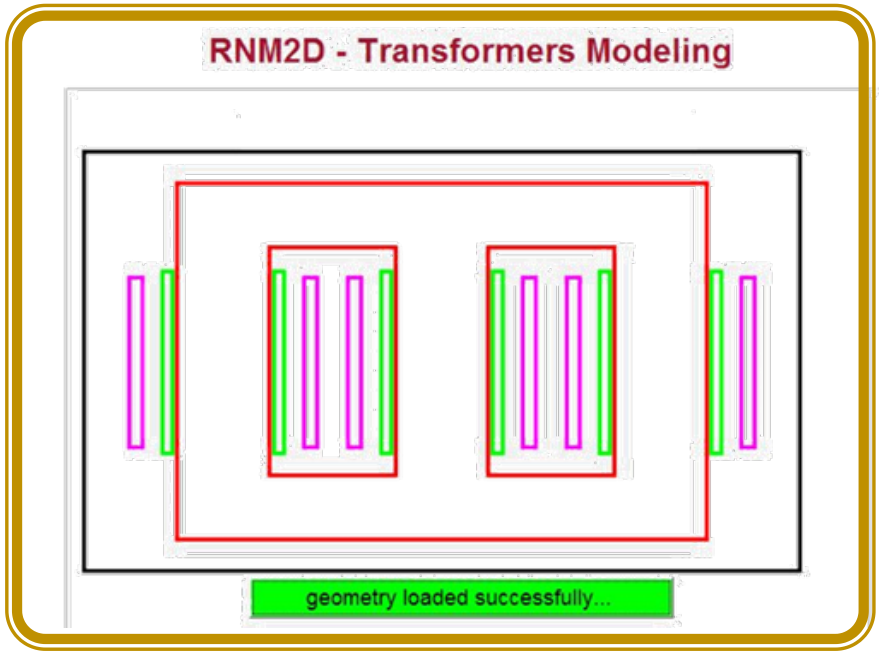




*.m, *.mat, etc.



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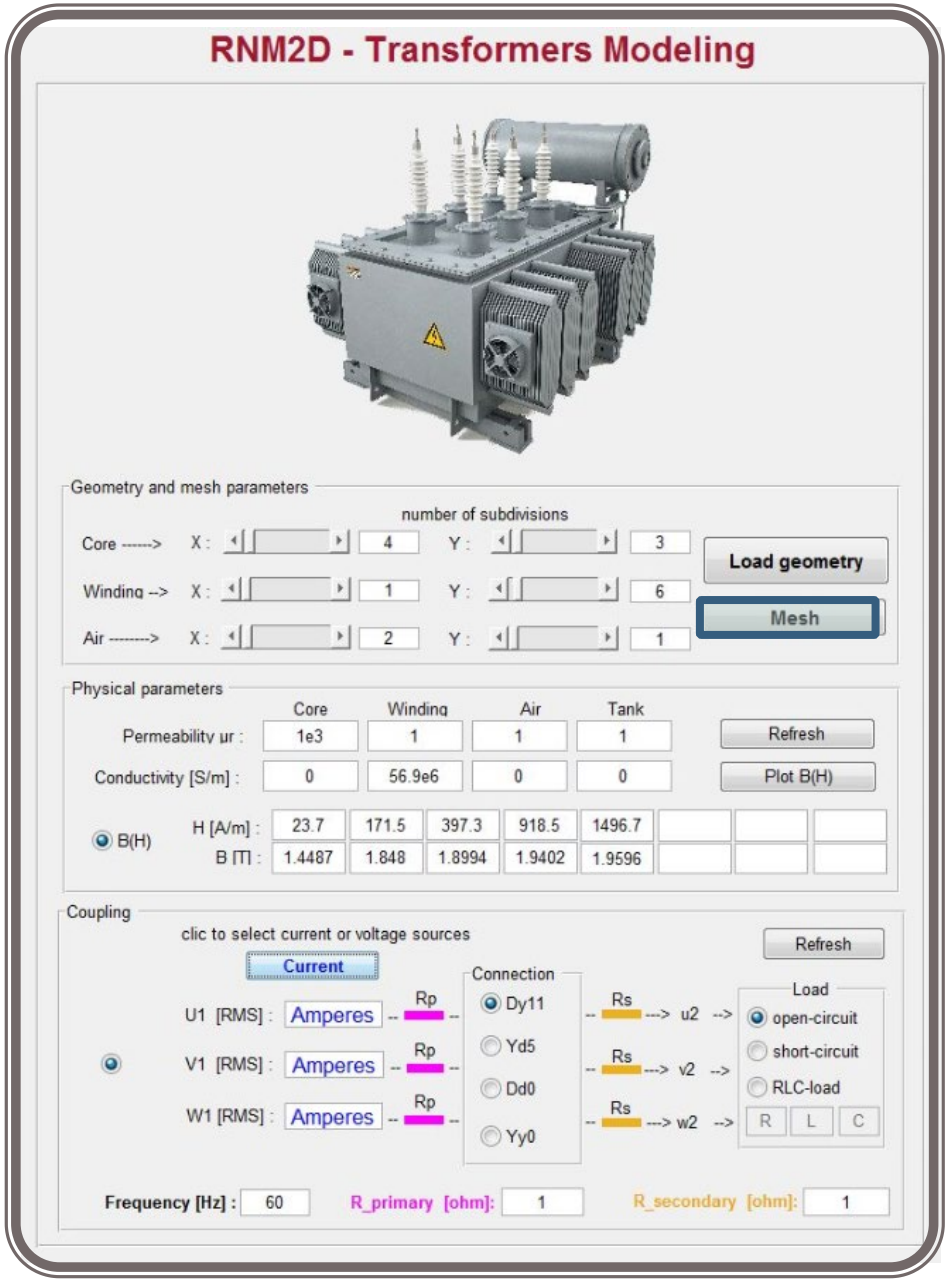

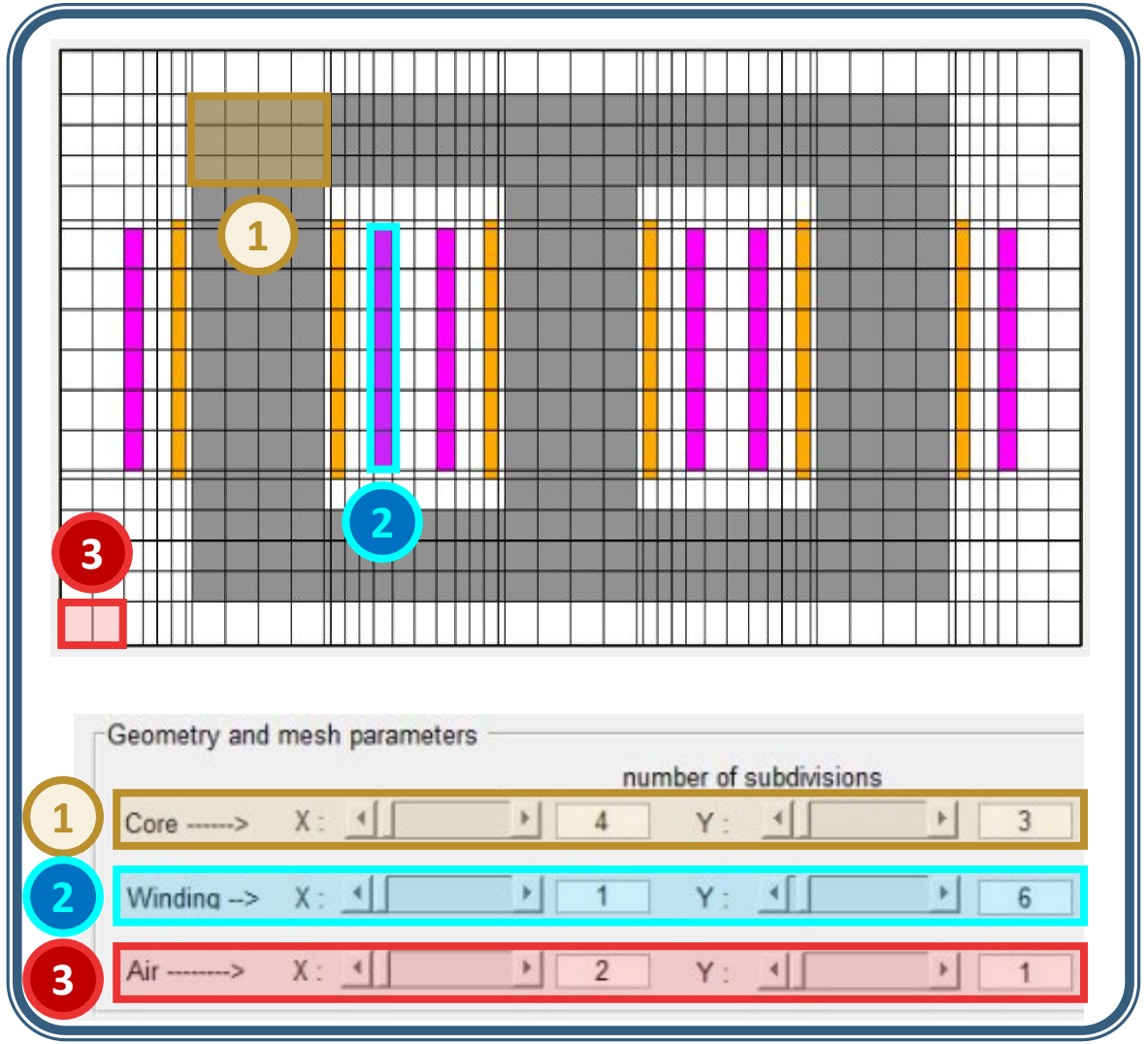

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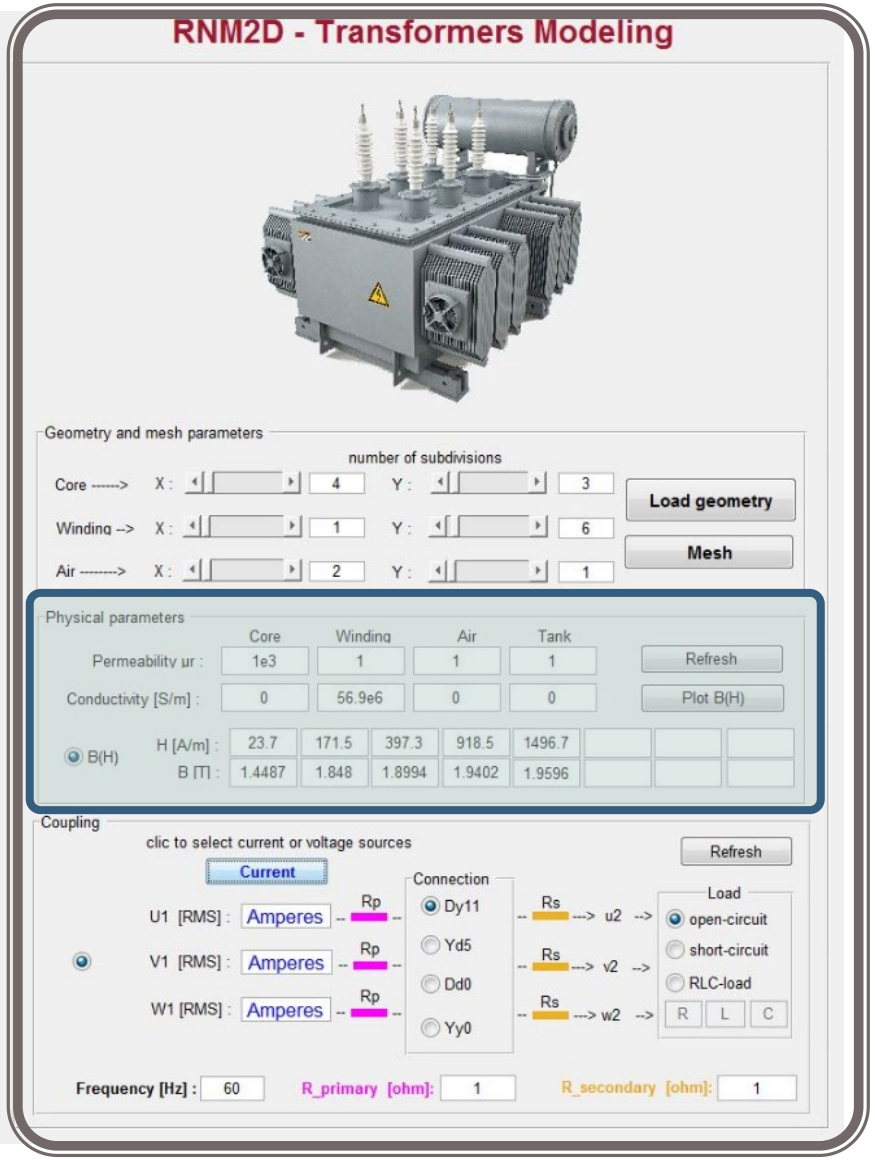

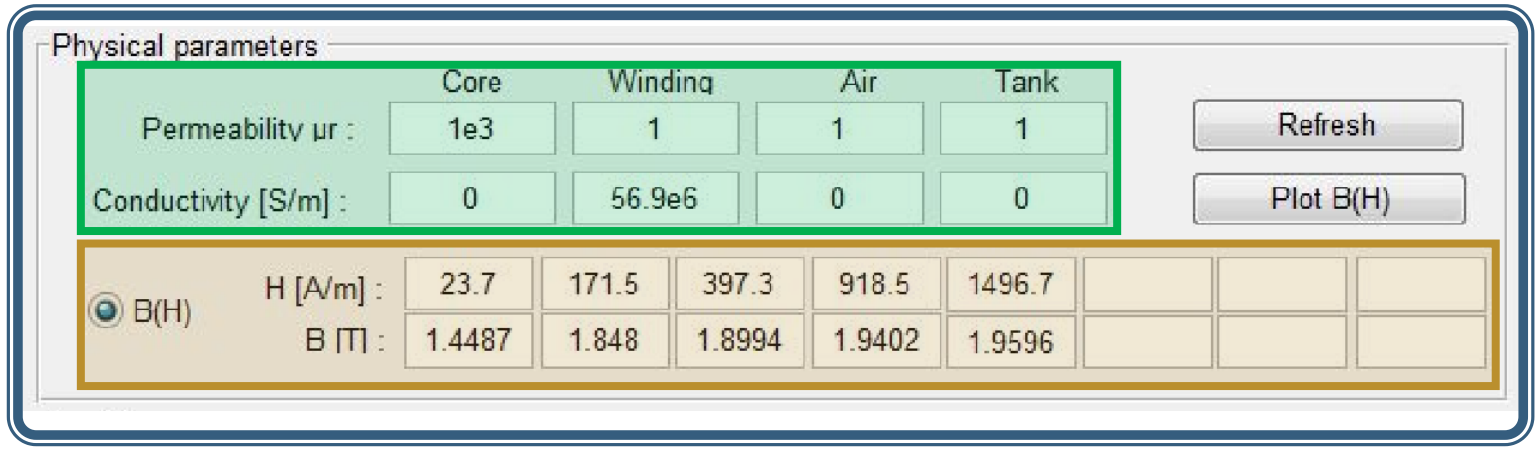

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RNM2D - Transformers Modeling

Geometry and mesh parameters

number of subdivisions

Core ------>	X :	4	Y :	3	Load geometry	
Winding -->	X :	1	Y :	6	Mesh	
Air ------->	X :	2	Y :	1		

Physical parameters

	Core	Winding	Air	Tank		
Permeability ur :	1e3	1	1	1	Refresh	
Conductivity [S/m] :	0	56.9e6	0	0	Plot B(H)	
B(H) H [A/m] :	23.7	171.5	397.3	918.5	1496.7	
B [T] :	1.4487	1.848	1.8994	1.9402	1.9596	

Coupling

clic to select current or voltage sources

Current

Refresh

U1 [RMS] : Amperes -- Rp --

V1 [RMS] : Amperes -- Rp --

W1 [RMS] : Amperes -- Rp --

Connection: Dy11, Yd5, Dd0, Yy0

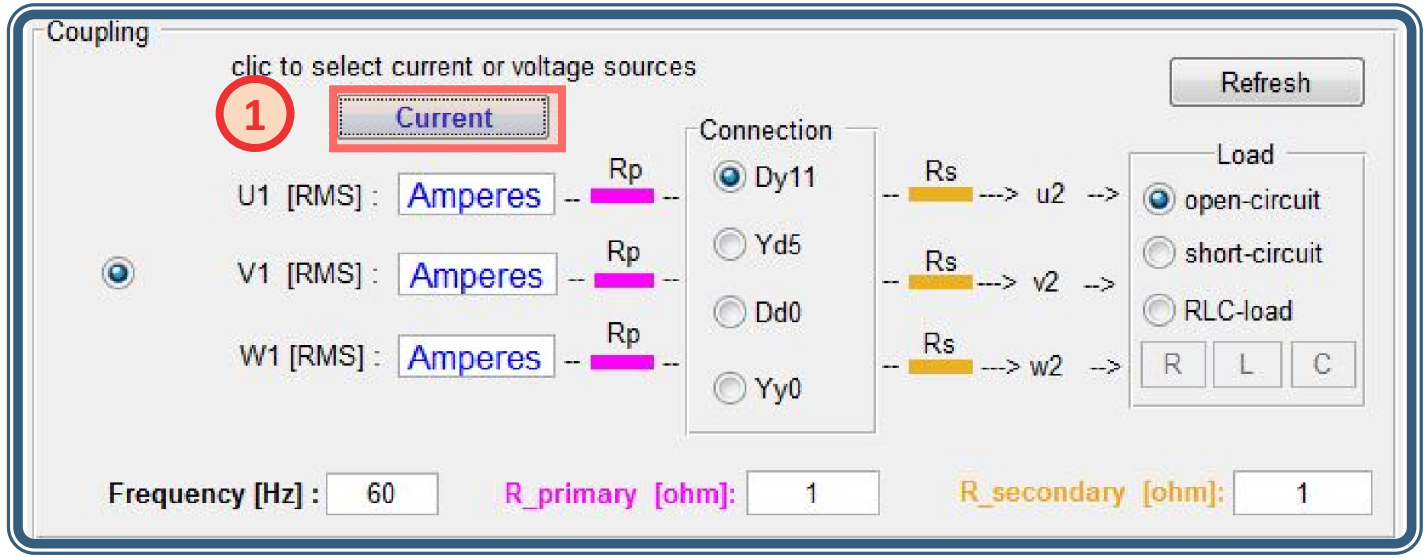
Rs ---> u2 -->

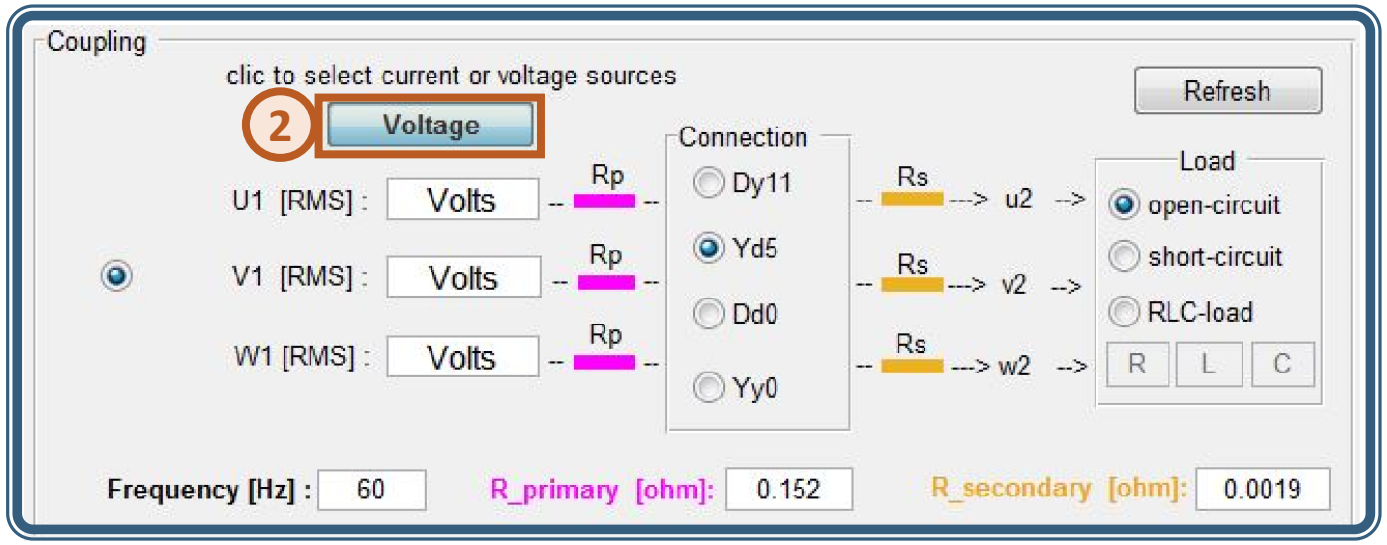
Rs ---> v2 -->

Rs ---> w2 -->

Load: open-circuit, short-circuit, RLC-load (R L C)

Frequency [Hz] : 60 R_primary [ohm]: 1 R_secondary [ohm]: 1





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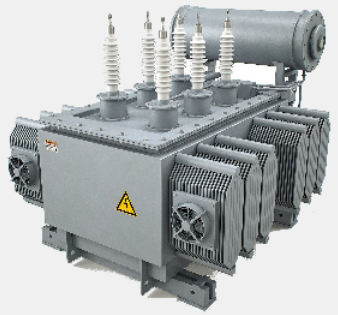
test_3phas

RNM2D - Transformers Modeling



Geometry and mesh parameters

		number of subdivisions				
Core ------>	X :	4	Y :	3	Load geometry	
Winding -->	X :	1	Y :	5	Mesh	
Air ------->	X :	2	Y :	1		

Physical parameters

	Core	Winding	Air	Tank	
Permeability μr :	1e3	1	1	1	Refresh
Conductivity [S/m] :	0	56.9e6	0	0	Plot B(H)

B(H)	H [A/m] :	23.7	171.5	397.3	918.5	1496.7		
	B [T] :	1.4487	1.848	1.8994	1.9402	1.9596		

Coupling

clic to select current or voltage sources — Refresh

Voltage

U1 [RMS] :	Volts	Rp	Rs	---> u2 -->	
V1 [RMS] :	Volts	Rp	Rs	---> v2 -->	
W1 [RMS] :	Volts	Rp	Rs	---> w2 -->	

Connection: Dy11, Yd5, Dd0, Yy0

Load: open-circuit, short-circuit, RLC-load (R, L, C)

Frequency [Hz] : 60 Primary_Current: 1 R_secondary [ohm]: 1

IREENA EDF L2EP

MatLab

Build & solve — Off

Save results

EMTP-RV

V 3.5 V 4.0

Configuration

Load RN model

Create RN model — Off

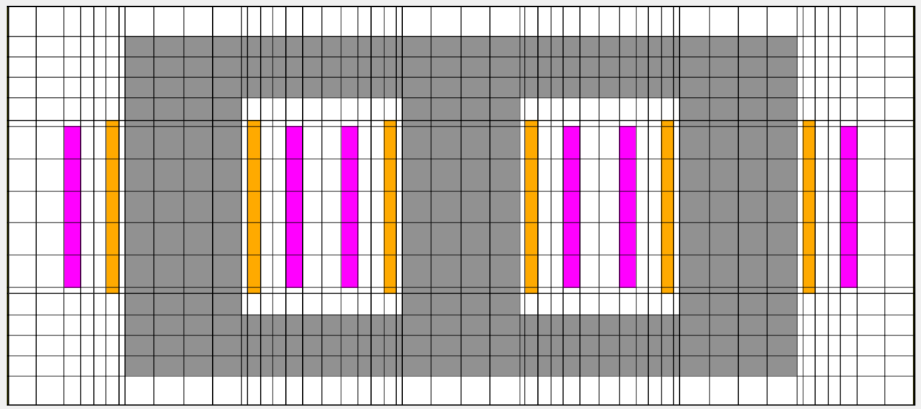
Run simulation

Load results

Save results

Maps

Induction B | Magnetic field H | Flux | MMF



Time : 6.94ms

Circuit : Input - Output

Voltage

U1 U2 V1 V2 W1 W2 UV1 UV2 VW1 VW2 WU1 WU2

Plot

Clear

Close

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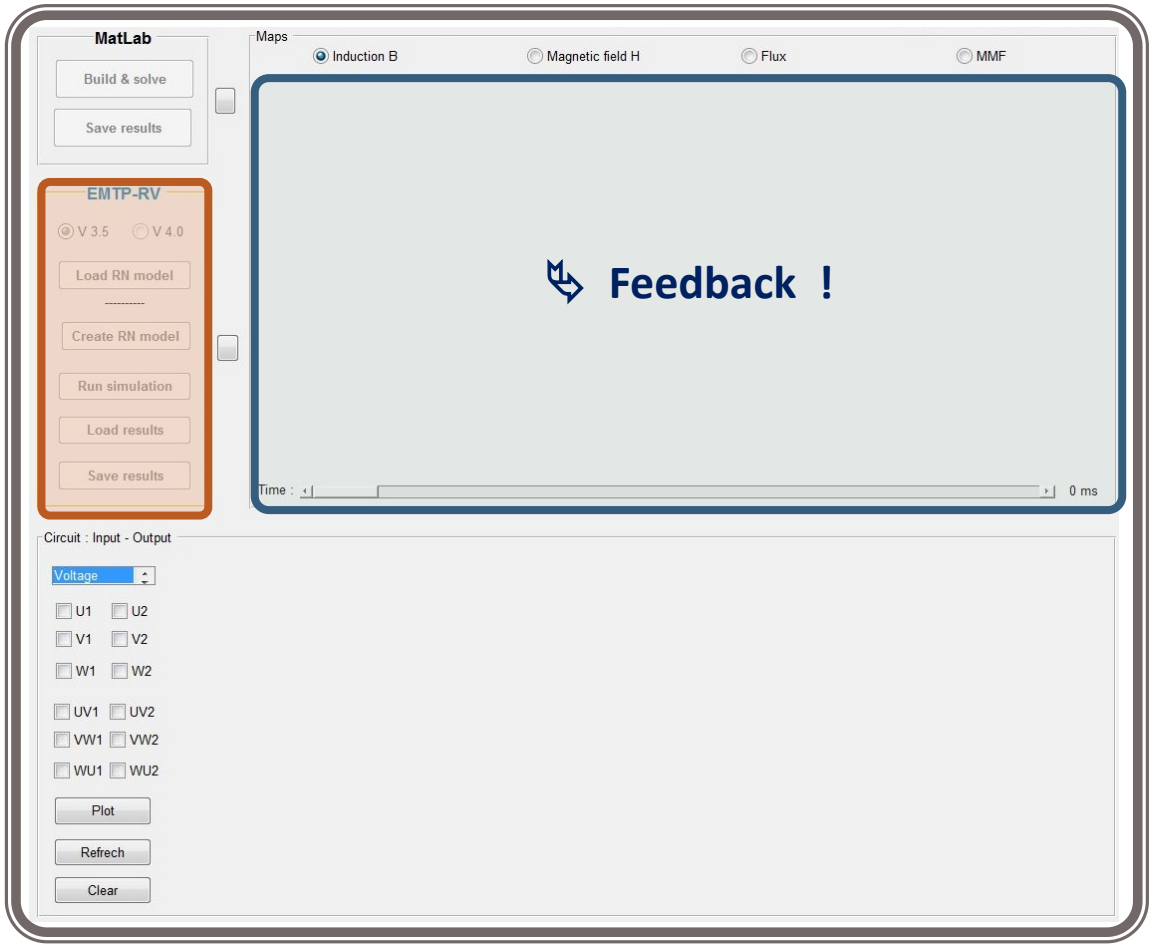
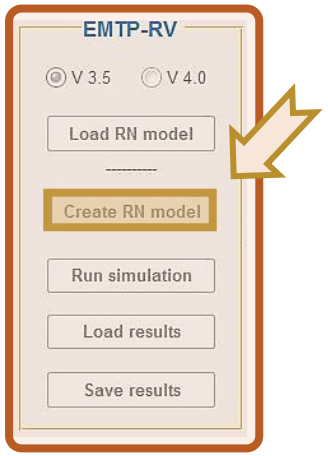
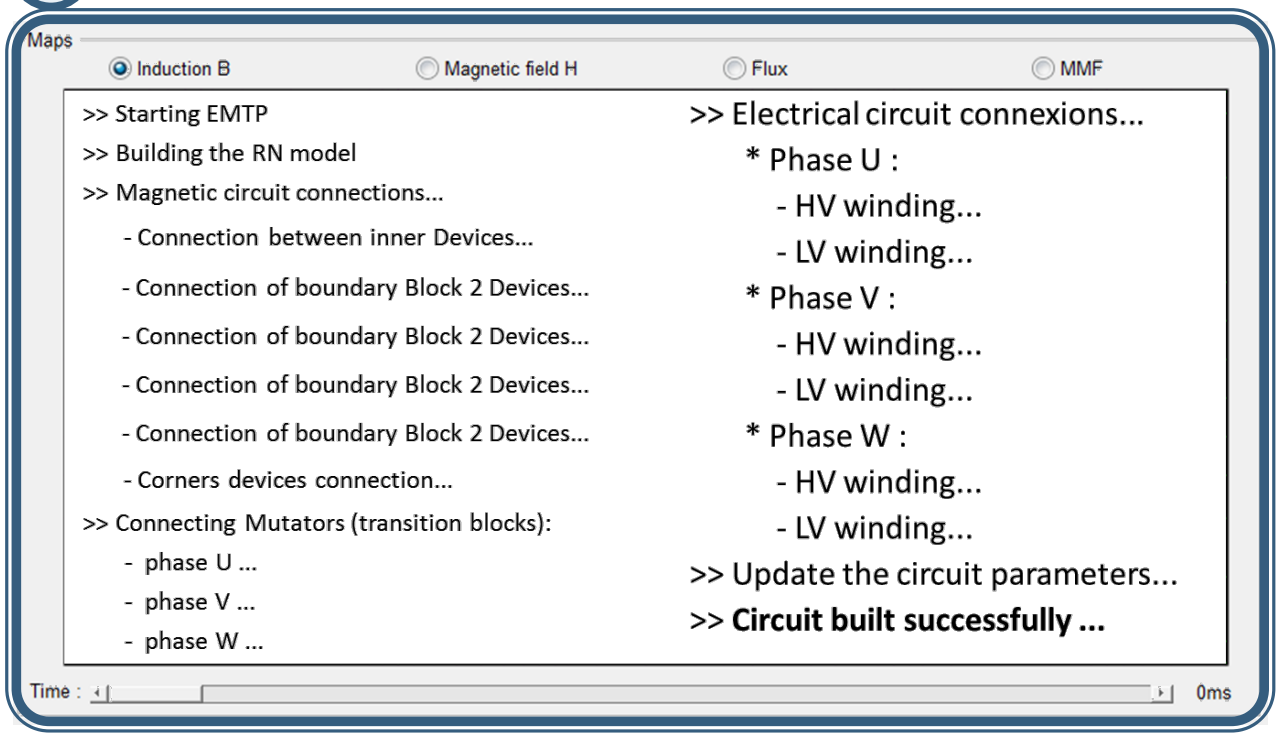


1 Steps:

EMTP-RV
The reference for power systems transients



2 Instantaneously informed of the tasks performed by EMTP



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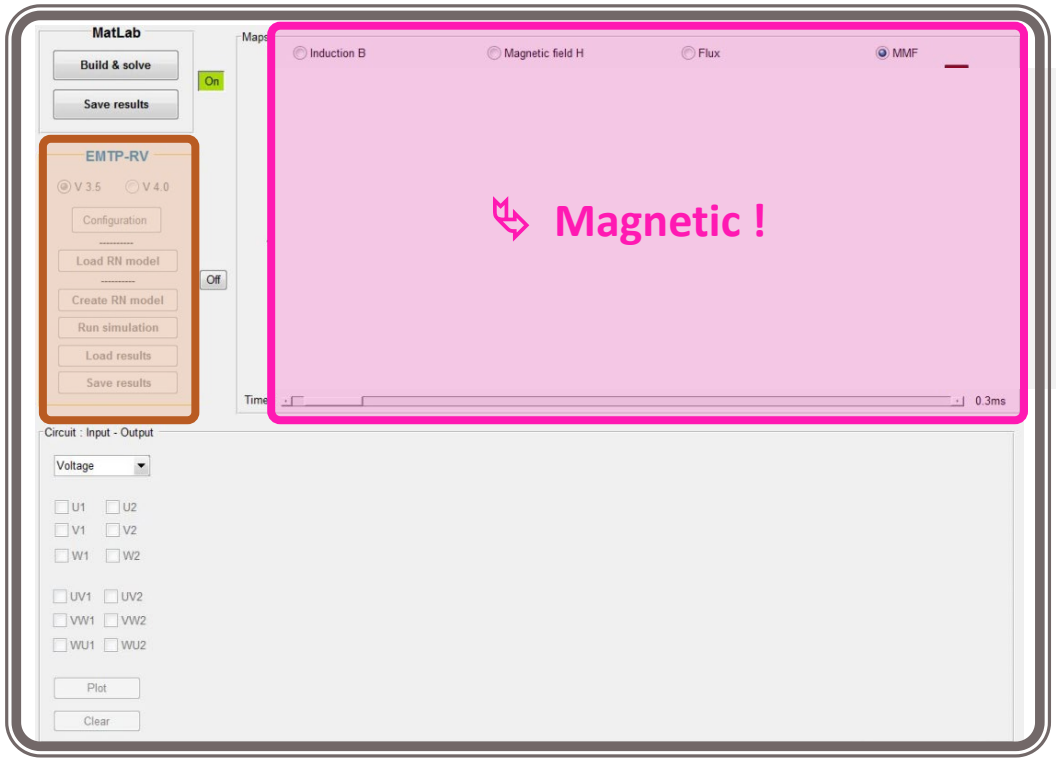
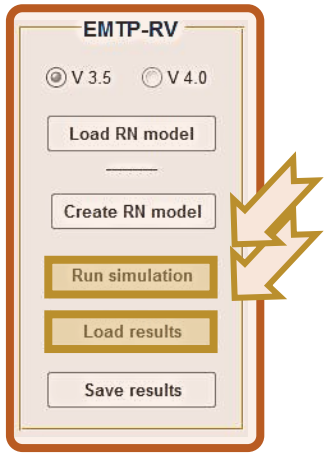
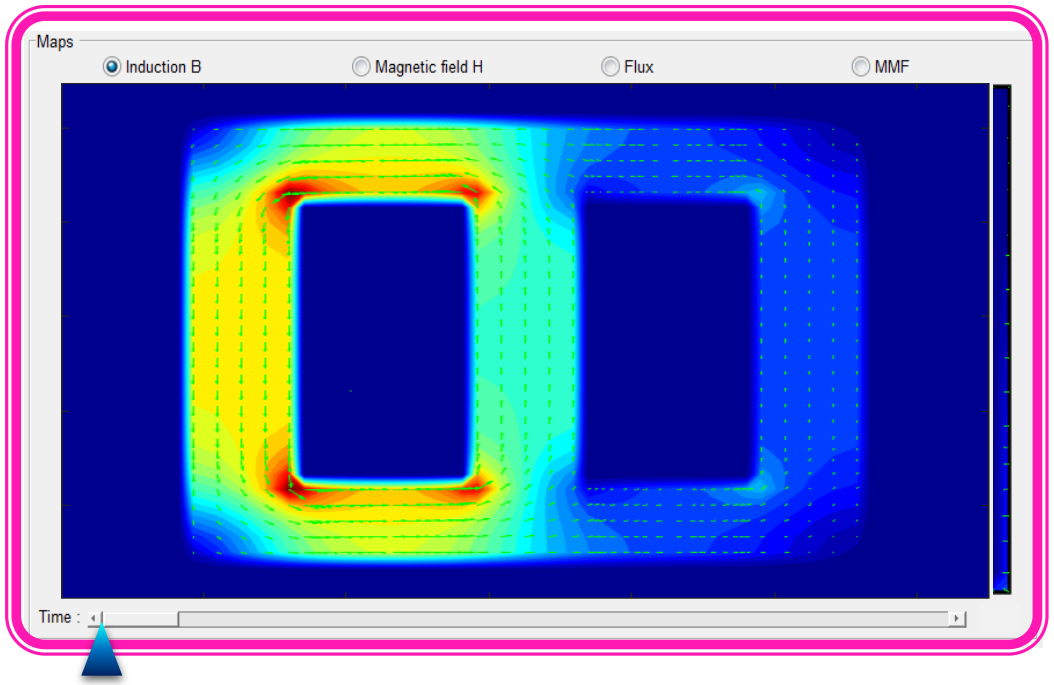




Magnetic fields quantities



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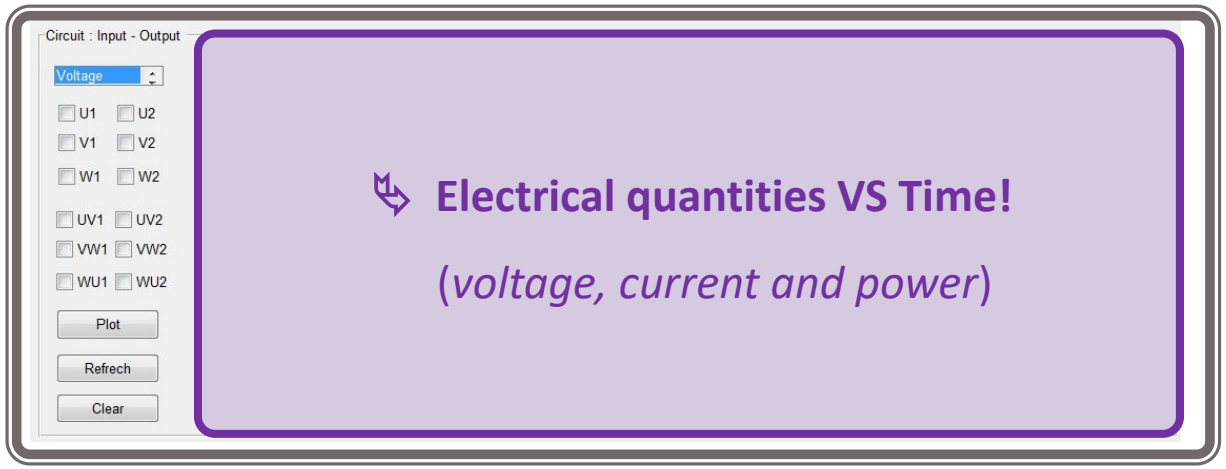
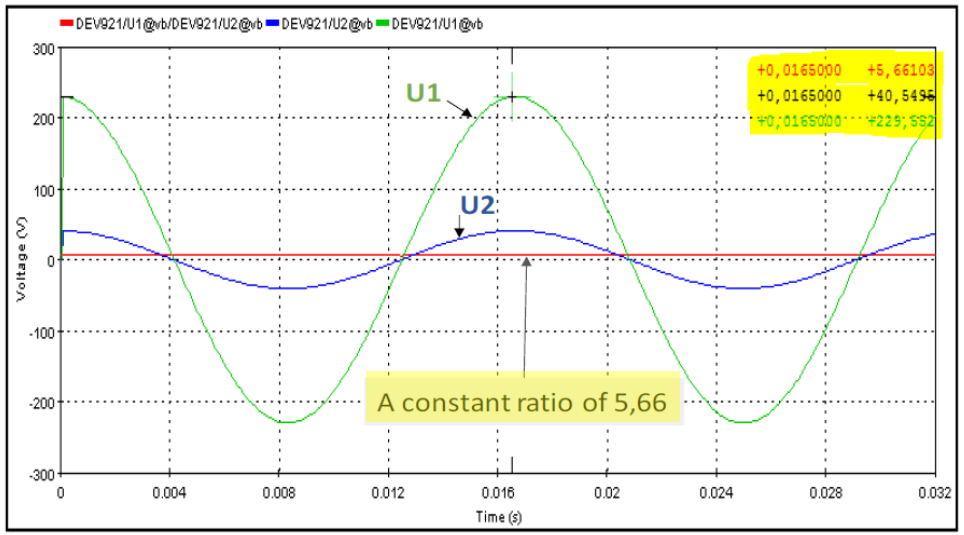


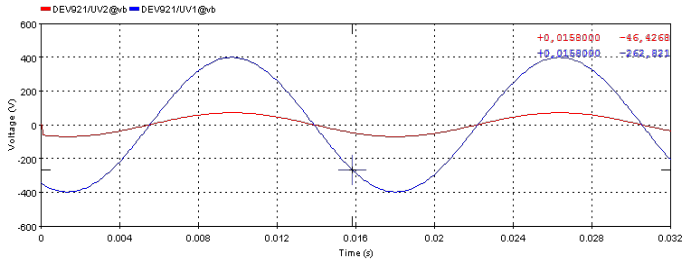
↳ **Electrical quantities VS Time!**

(*voltage, current and power*)

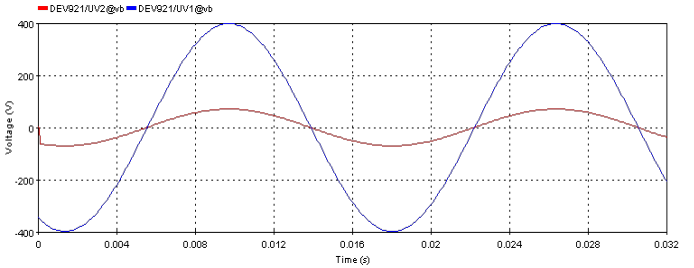


Coupling Behavior

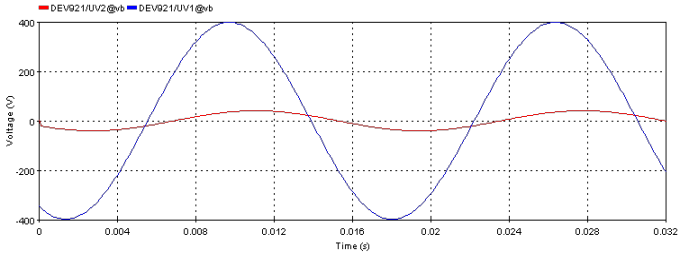
Yy0



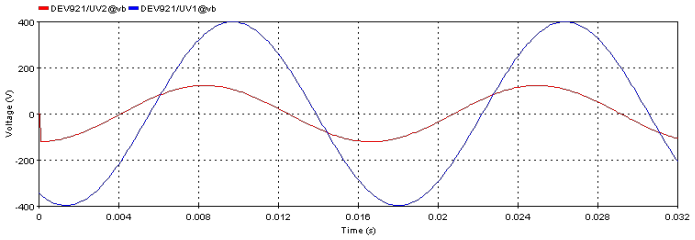
Dd0



Yd11

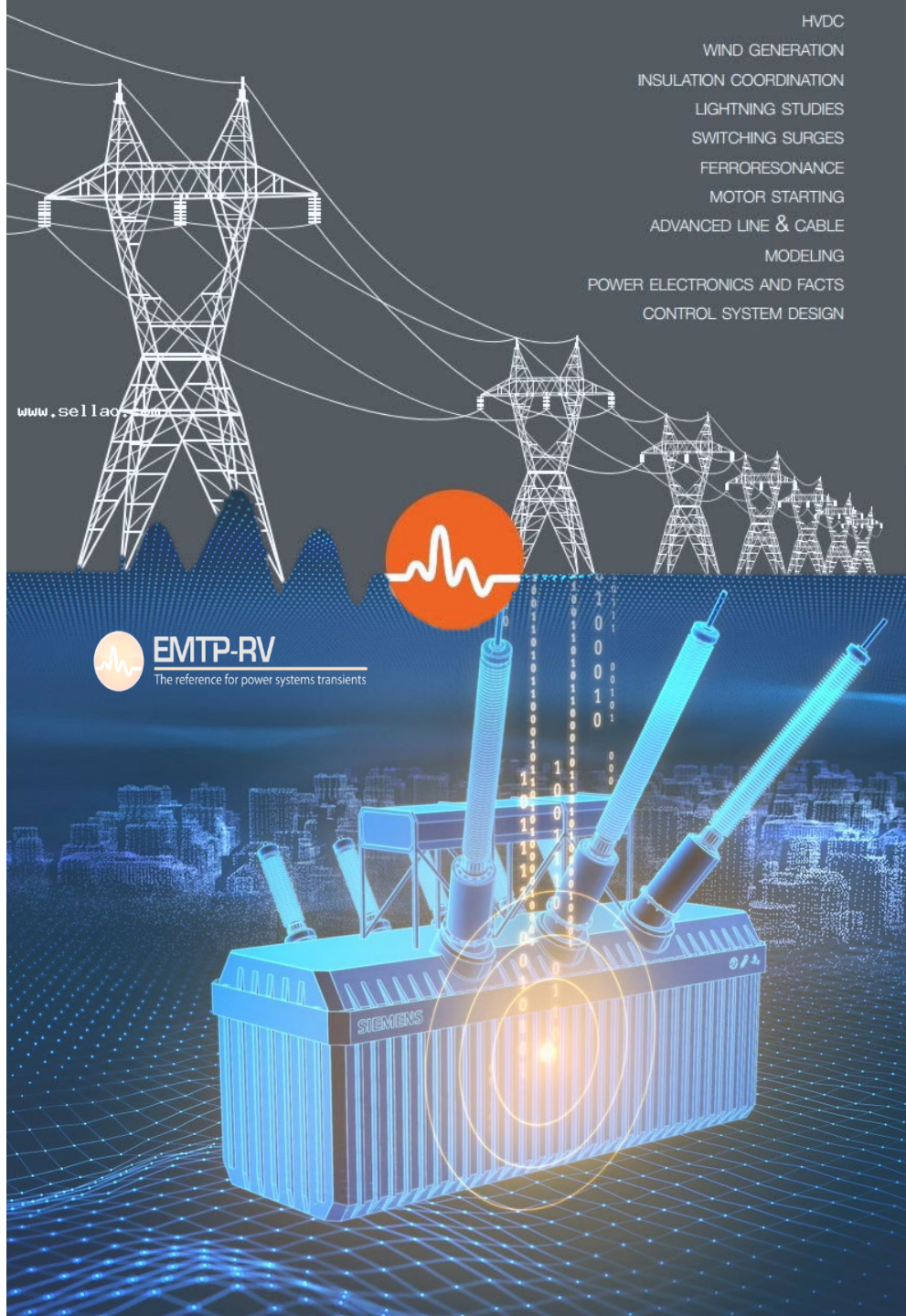


Dy5



Outline

- Context - Issues
- RNM & EMTP
- Transformers modeling
- Results
- Conclusion



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Testing the global electromagnetic behavior

15 MVA

25,6 kV / 4,5 kV

↓ Vmax =4118 volt ↓

↓ Vmax =35000 volt ↓

Voltage

Current

Flux

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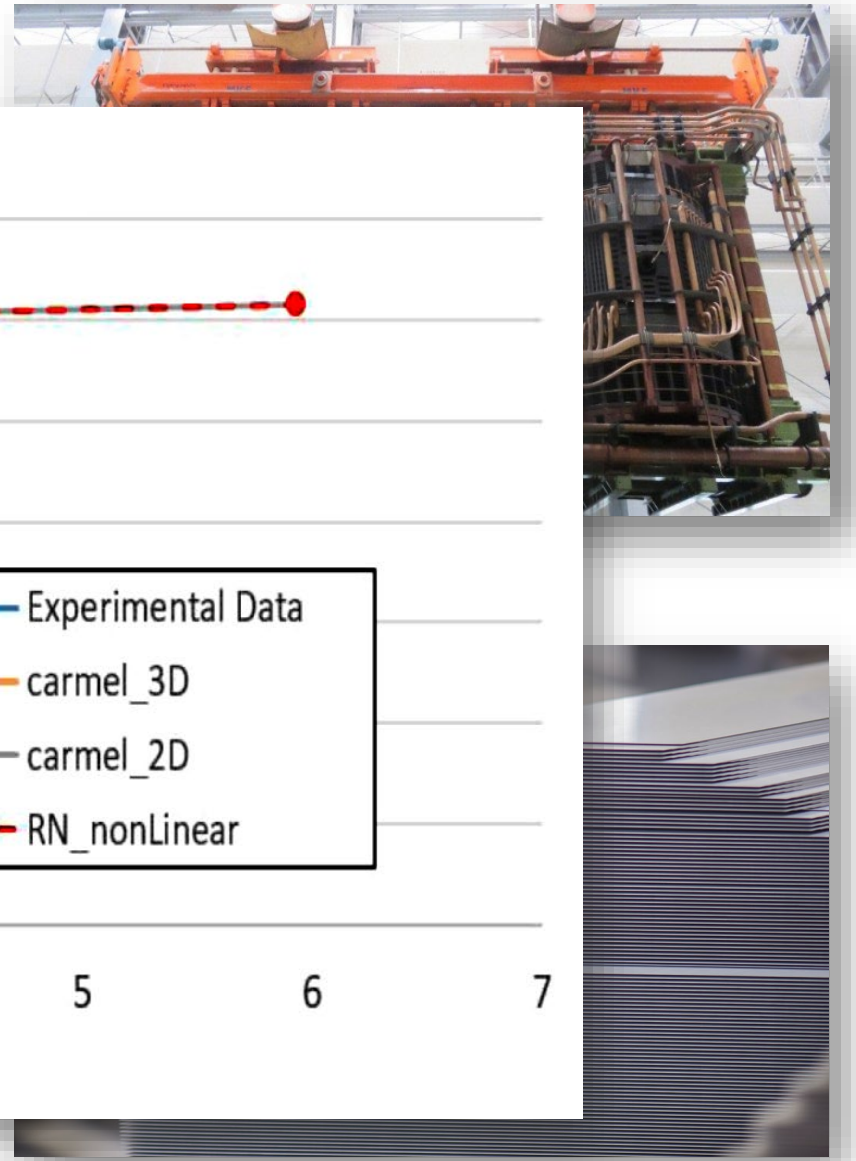
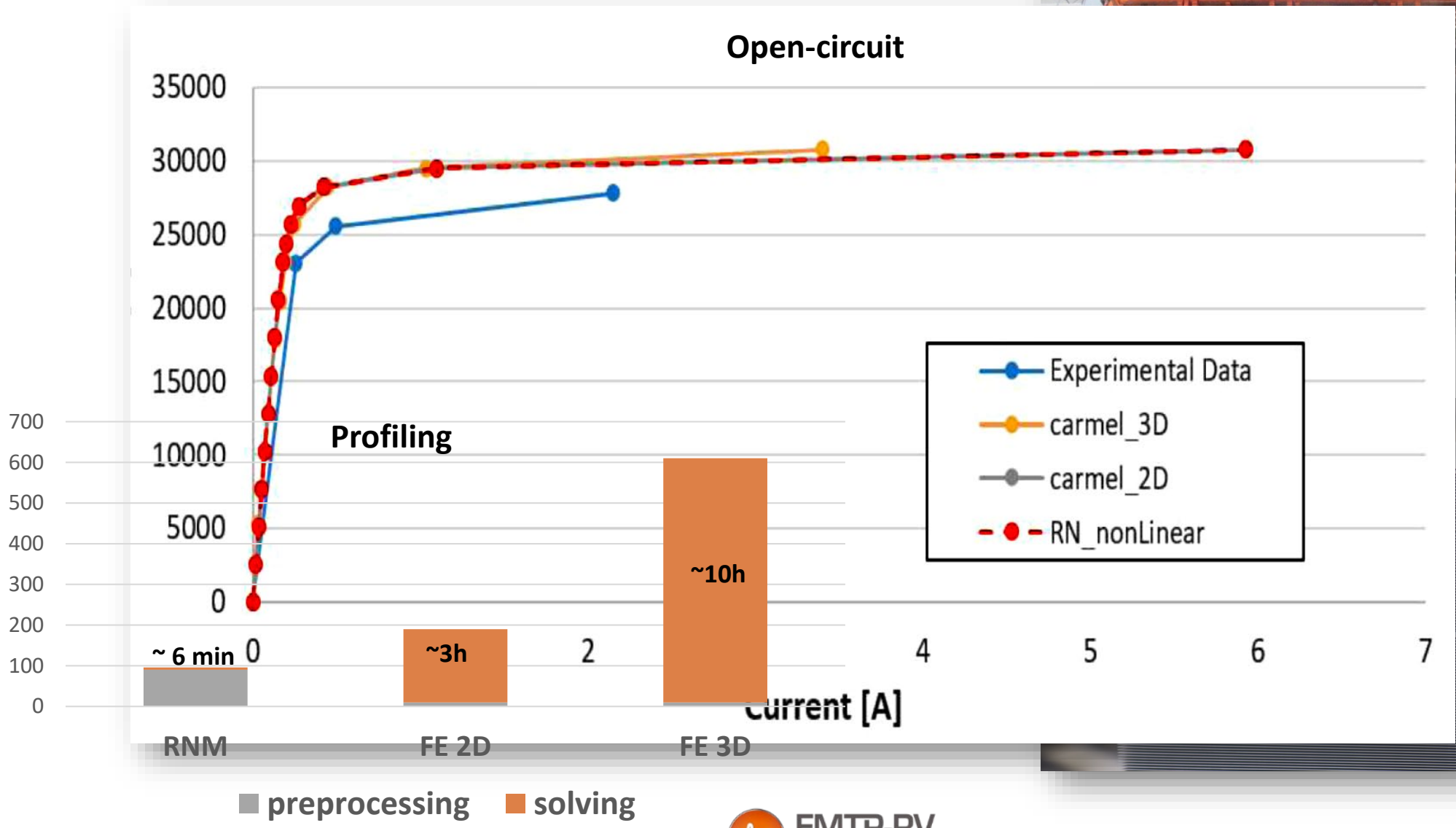
Test 1: Open-Circuit





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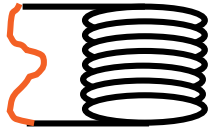
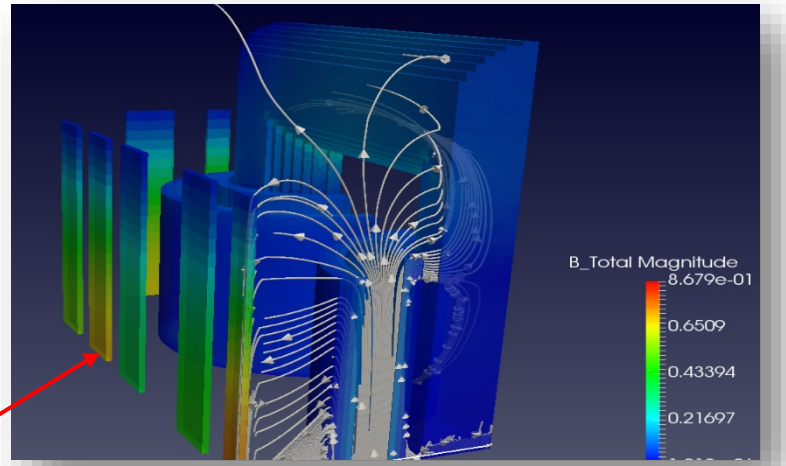
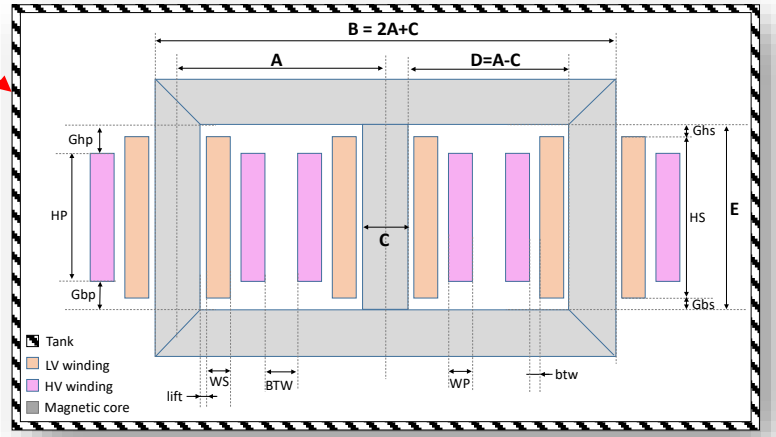
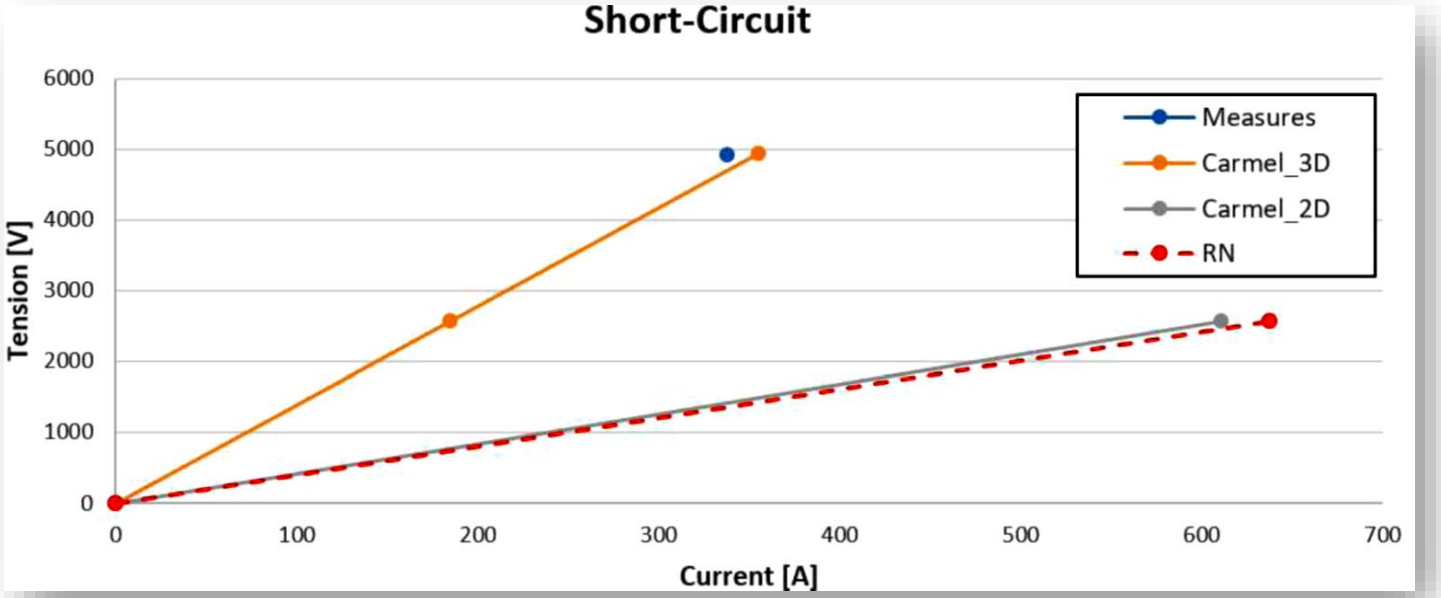
Test 2: Short-Circuiting the secondary winding





Tank





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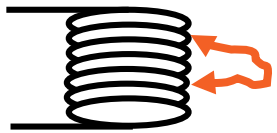
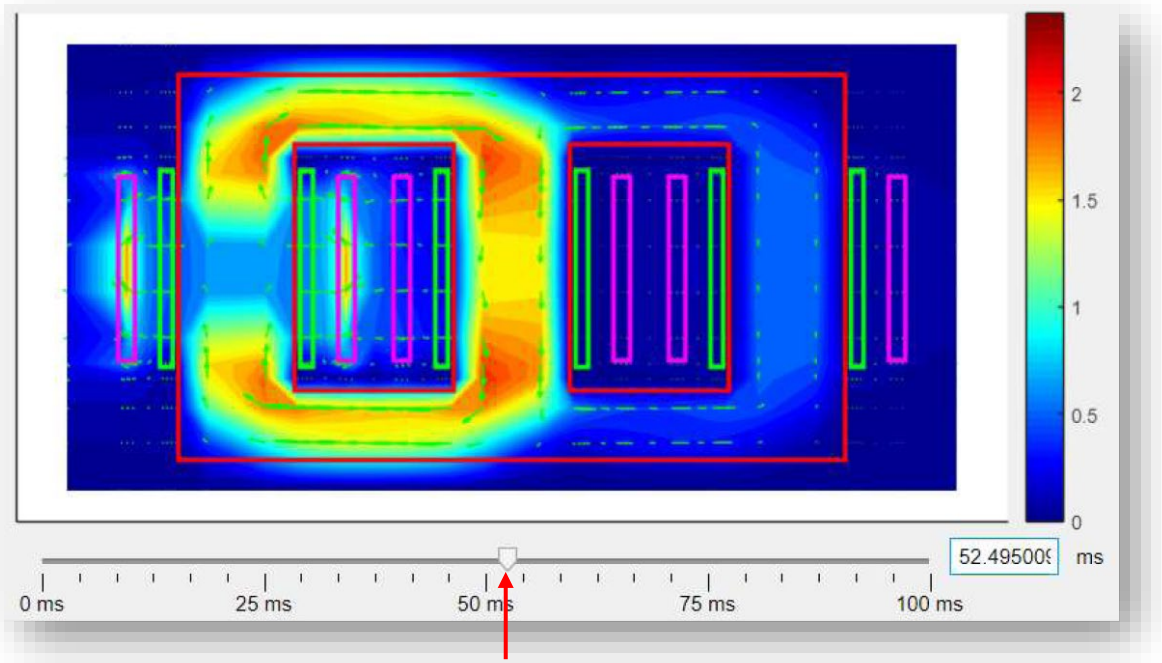
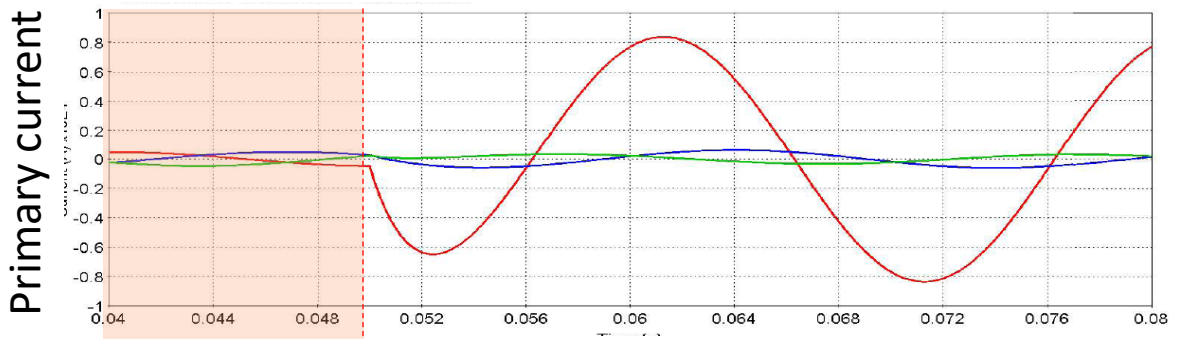
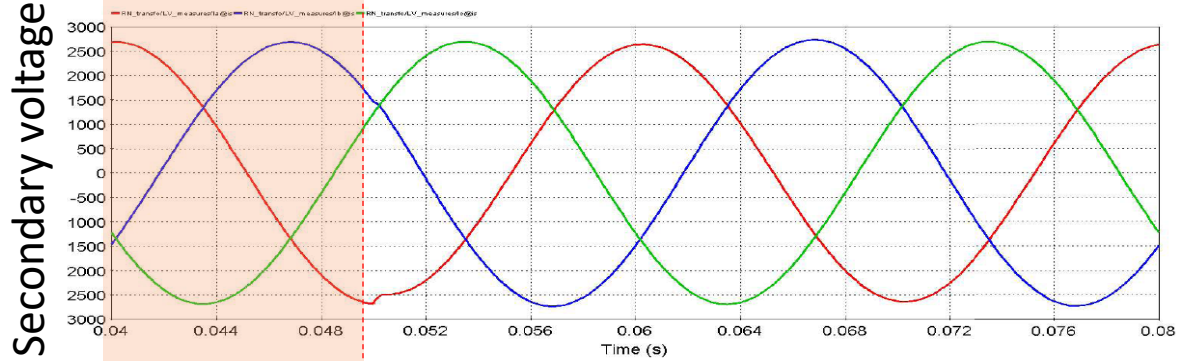
Test 3: Short-circuit between turns

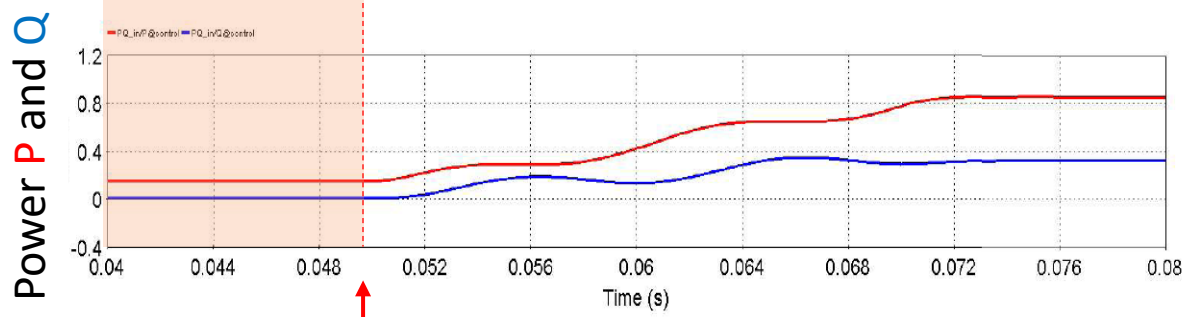




52 ms







52 ms

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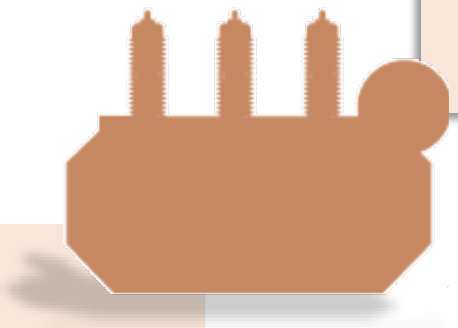
CONCLUSION

New EMTP library

- **Graphical user interface**
  - ➢ MatLab ↔ EMTP
  - ➢ Post-treatment

  Fields color maps, circuit quantities



- **Generic and multi-use method**
  - ➢ Adaptive mesh
  - ➢ Automatic creation of the equivalent RN model
  - ➢ Can be adapted to different transformers topologies:

    single-phase, five columns, shell-type, etc.

Field maps

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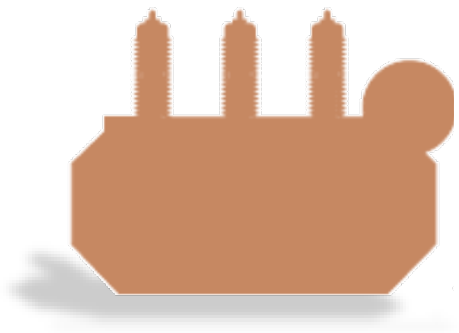
PERSPECTIVES



- Single-phase
- Five column

90%

Extra tests : - Geomagnetically Induced Currents
- Lightning
- Inrush currents …

60%

3D problem

30%

Optimization and sizing

1 %


thank
you