Development of Thermal Models for Grid Transformers with Tertiary Windings Connected to BESS

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Contents

1. Background

- Tertiary windings of super grid transformers in transmission networks provide a cost-effective and efficient connection solution for Battery Energy Storage Systems (BESS).
- It's important to understand the impact of BESS connection on the transformer's thermal performance requiring development of an effective three winding thermal model.

Pivot Power's 50MW BESS in Oxford, UK, 1st tertiary connection to grid
Available at: https://www.edf-re.uk/news-and-views/pivot-power-wartsila-and-habitat-energy-activate-50mw-transmission-connected-battery-in-cowley-oxfordshire/

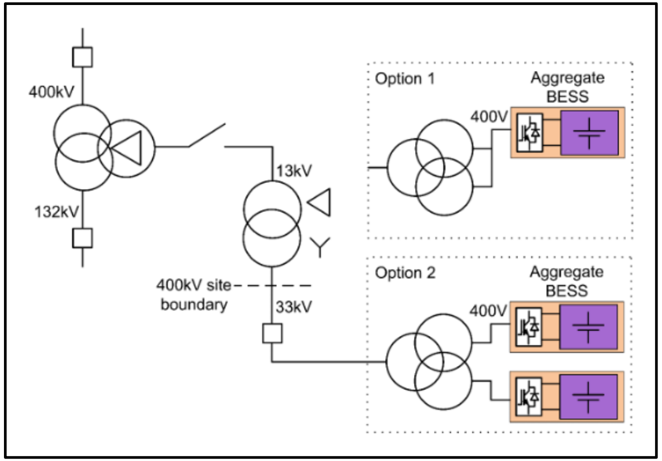
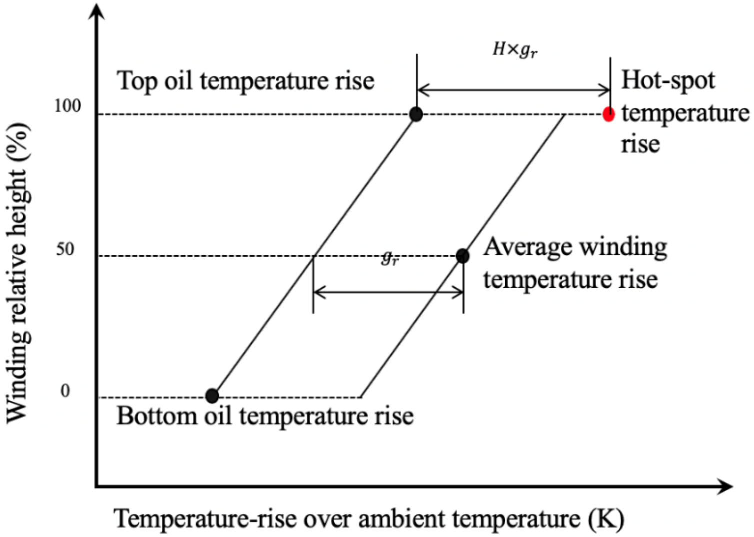


Diagram of Tertiary connection to BESS

2. Modified IEC thermal model

The Diagram and equation of IEC thermal model



IEC 60076-7, Transformer thermal diagram

$$\theta_h(t) = \theta_a + \Delta\theta_{oi} + \left\{ \Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R} \right]^x - \Delta\theta_{oi} \right\} \times f_1(t) + \Delta\theta_{hi} + \left\{ H g_r K^y - \Delta\theta_{hi} \right\} \times f_2(t)$$

$$f_1(t) = \left(1 - e^{(-t)/(k_{11} \times \tau_0)}\right) \qquad f_2(t) = k_{21} \times \left(1 - e^{(-t)/(k_{22} \times \tau_w)}\right) - (k_{21} - 1) \times \left(1 - e^{(-t)/(\tau_0 / k_{22})}\right)$$

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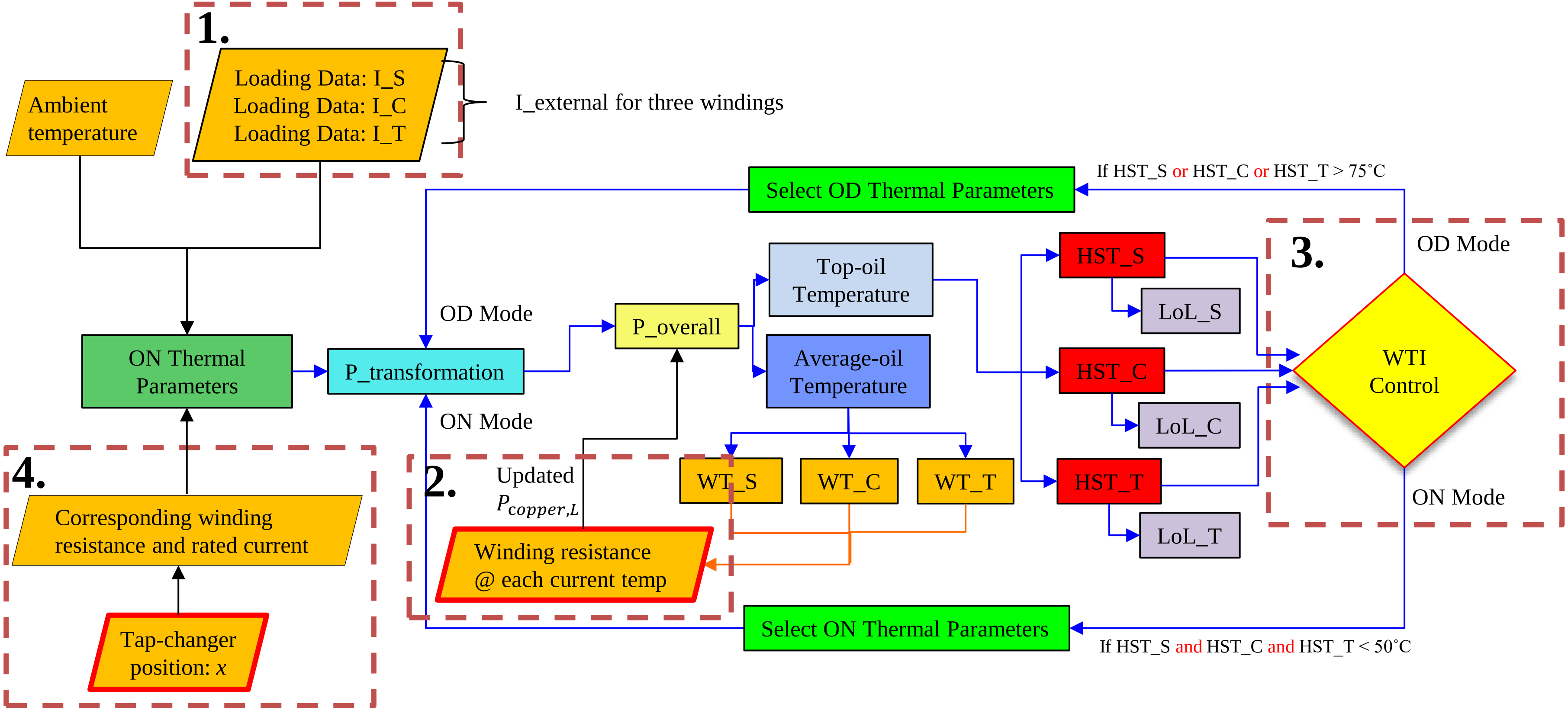
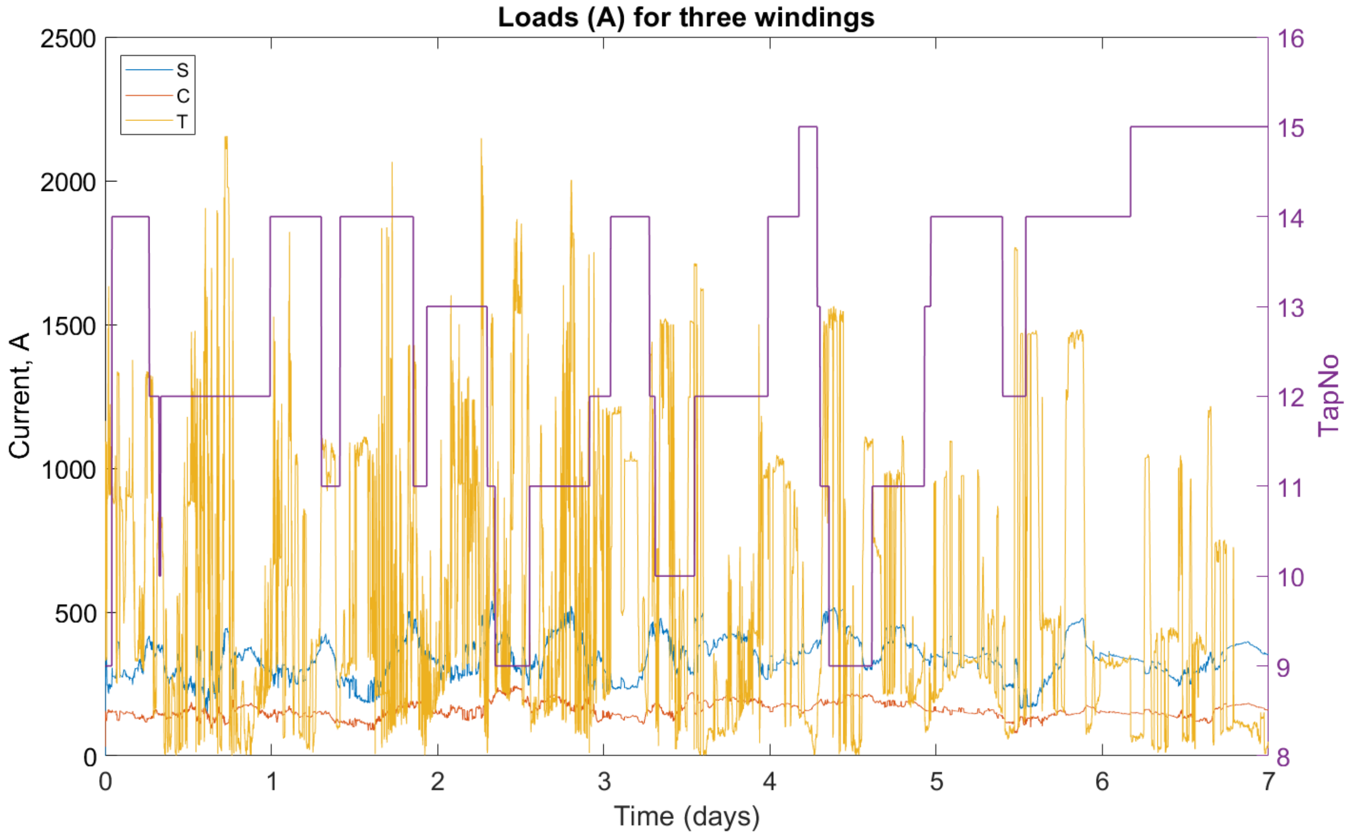
Modified model with four figures



[CIGRE-UK A2|D1]

7 day loading data for single SGT connected to BESS



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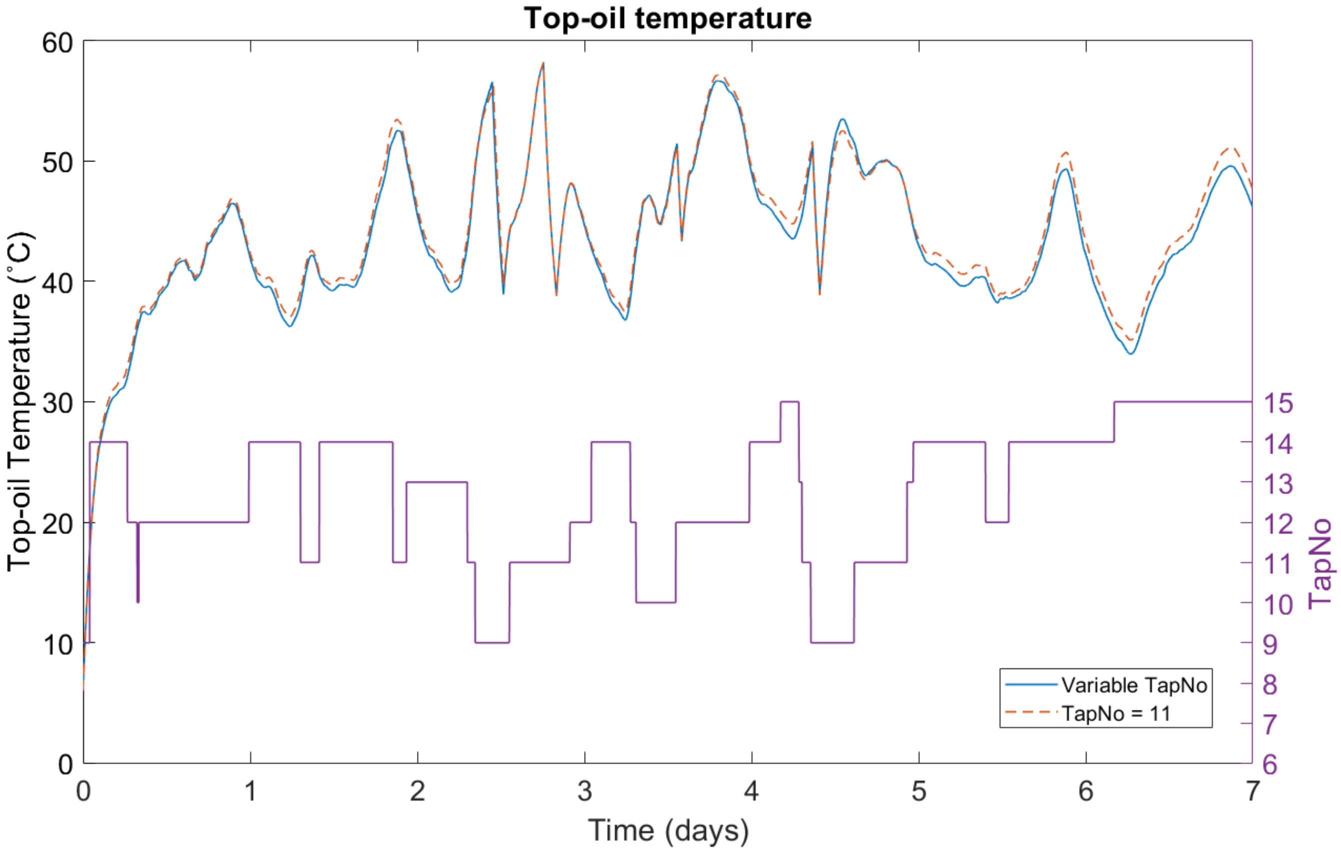
Top-oil temperature



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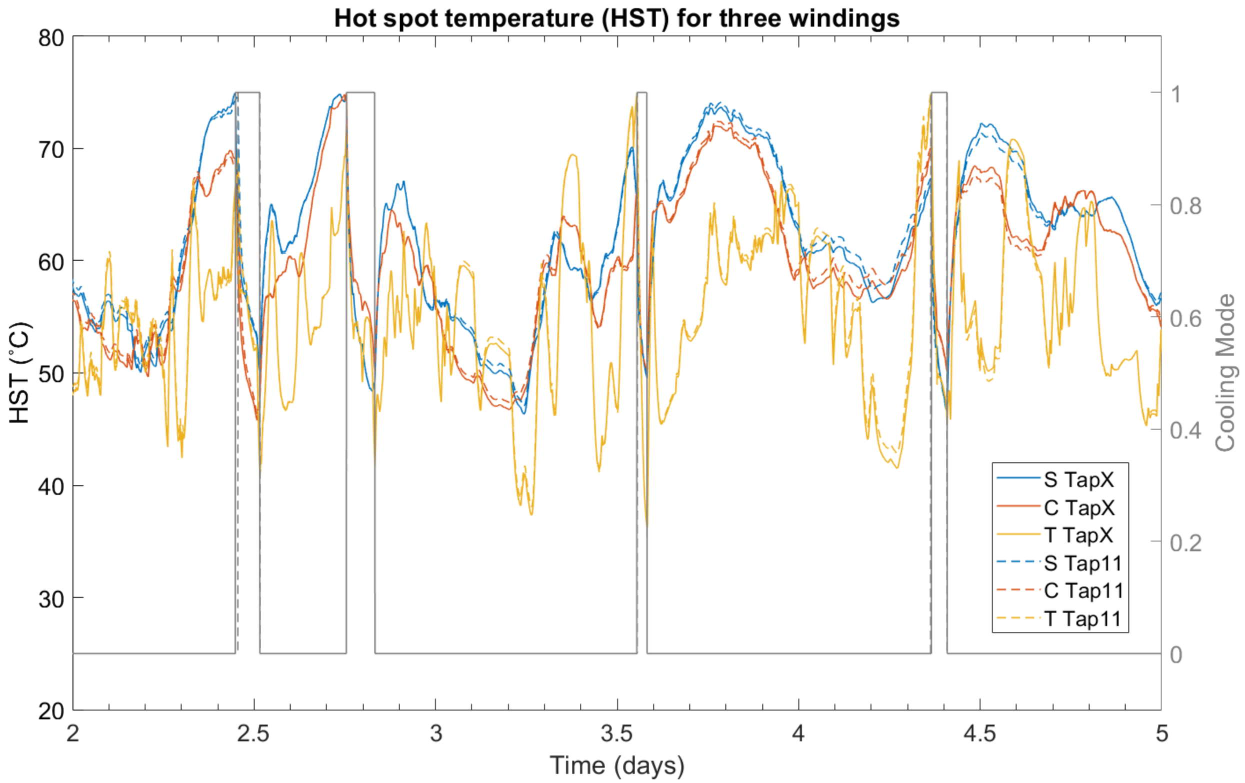
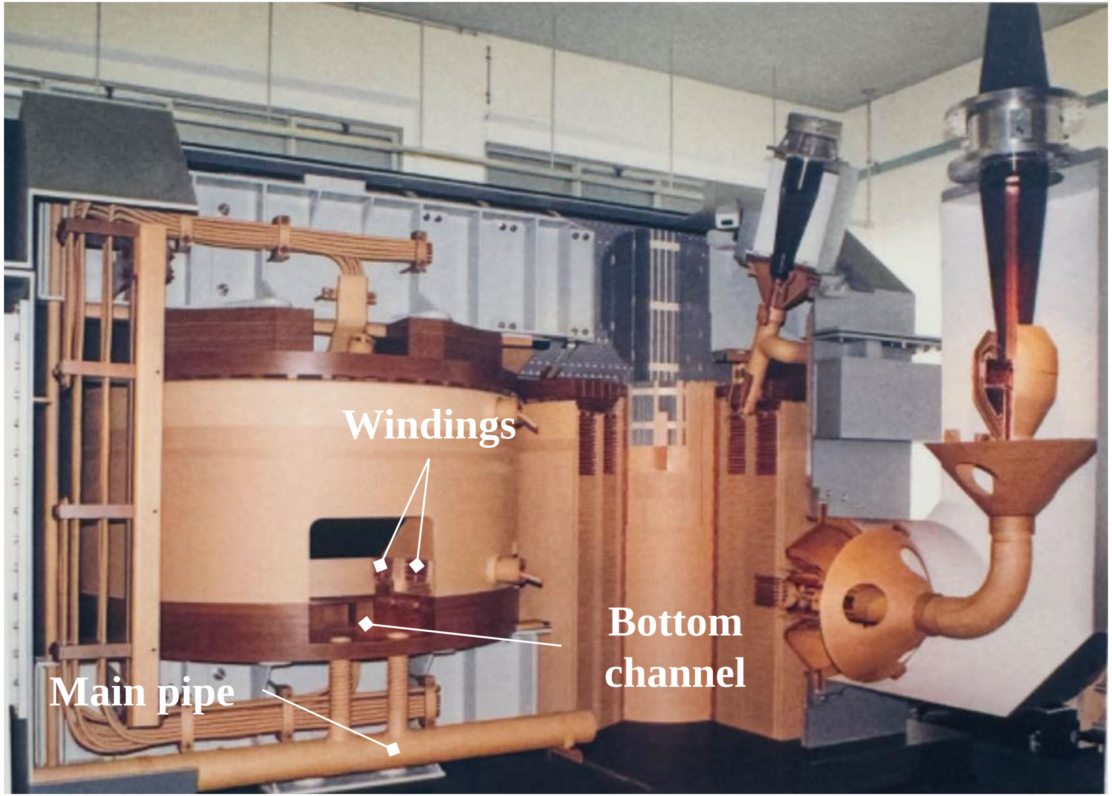
Hot spot temperature and Cooling mode for three windings



3. Multi-component CFD model

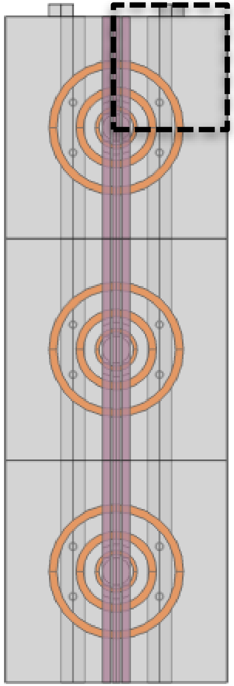
A super-grid transformer module (one phase)

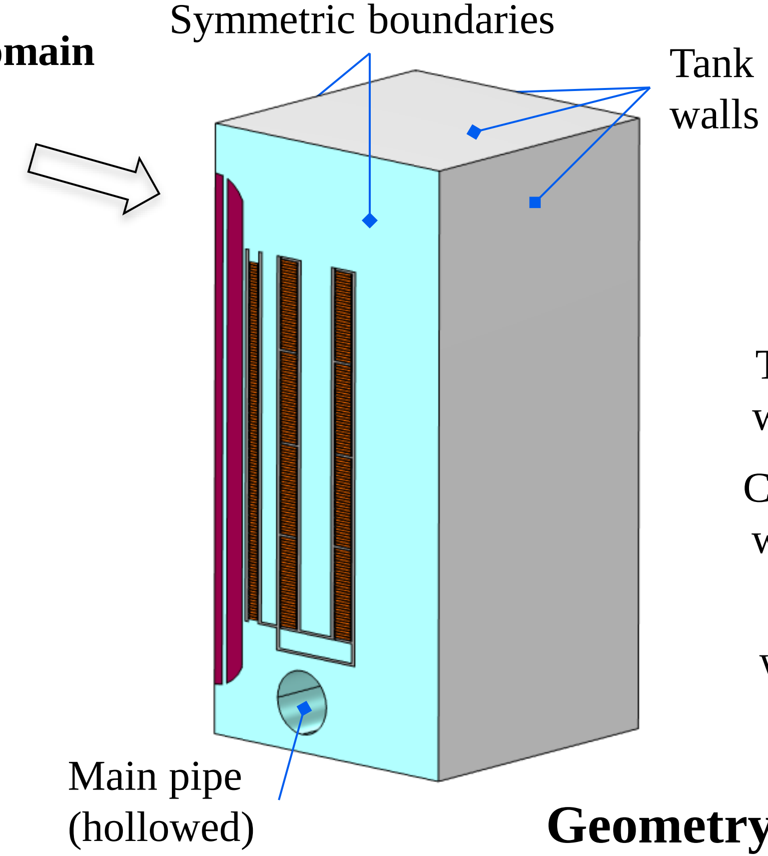


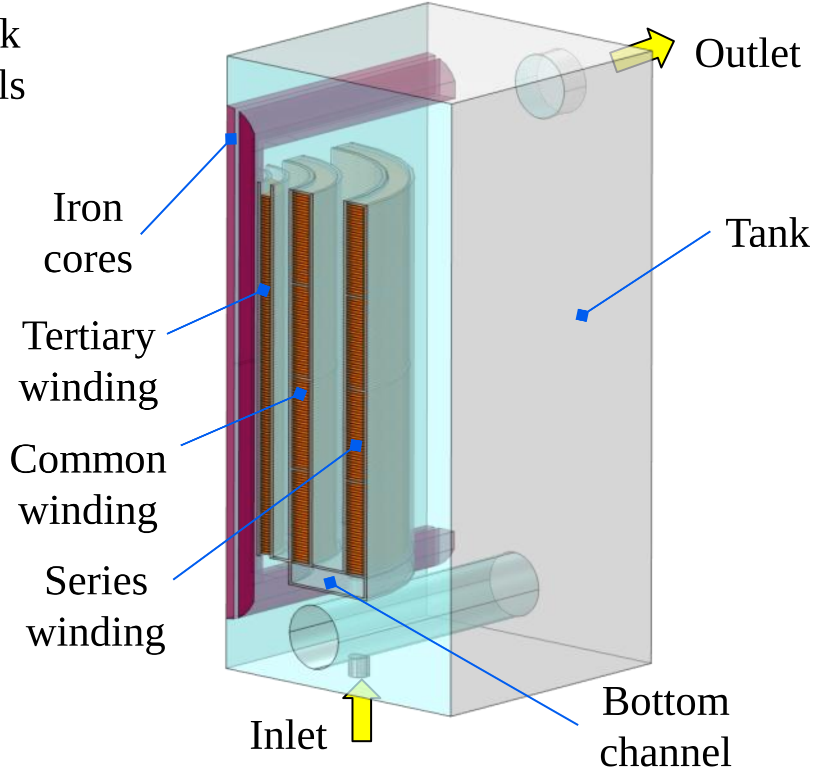
Weidmann Electrical Technology, Transformerboard III, H. AG, Rapperswil, Switzerland, 2022

CAD model of SGT (one phase in quarter)

Modelling domain

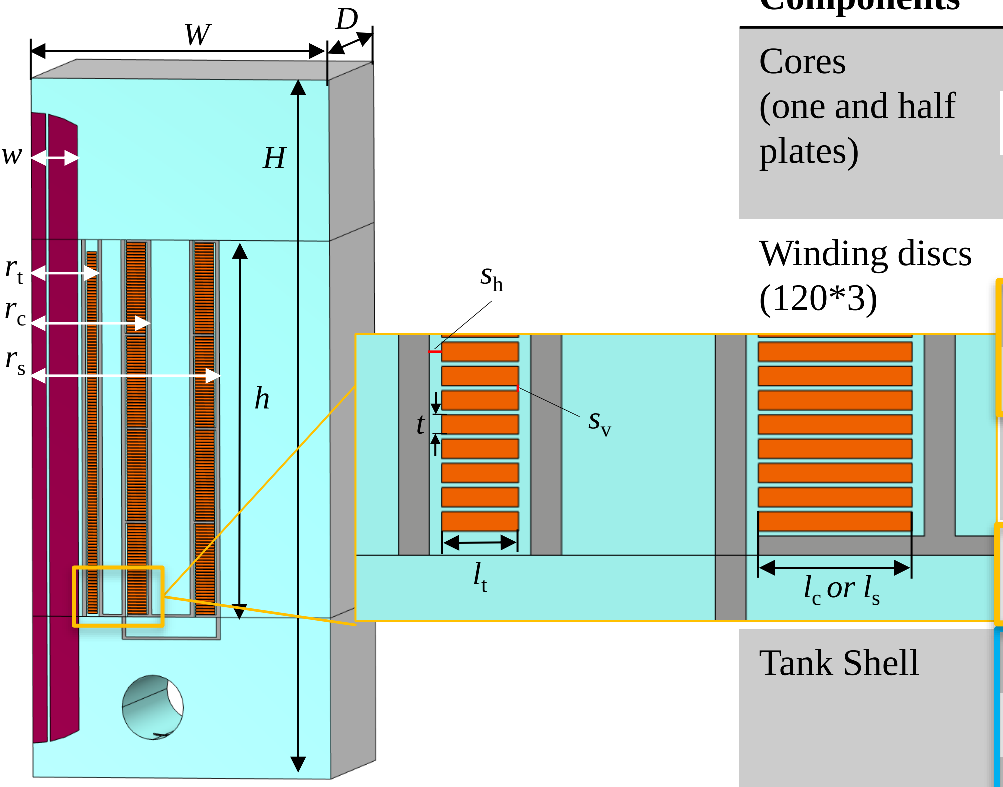






Geometry in quarter

Components and dimensions of SGT



Components	Dimensions	Values
Cores (one and half plates)	Height:	3.092 m
	Width, *w* (radius)	0.23 m
	Depth, *d* (half)	1.468 m
Winding discs (120*3)	Total height, *h* (ter/com/ser)	1.815/1.872/1.872
	Thickness, *t*	12 mm
	Length, *l* (ter/com/ser)	50/100/100 mm
	Outer radius, r_t, r_c, r_s (ter/com/ser)	0.328/0.584/0.948 m
	Spacings of ducts, s_v, s_h (Vertical/horizontal)	3/8 mm
Tank Shell	Height, *H*	3.472 m
	Width, *W* (half)	1.468 m
	Depth, *D* (half)	1.468 m

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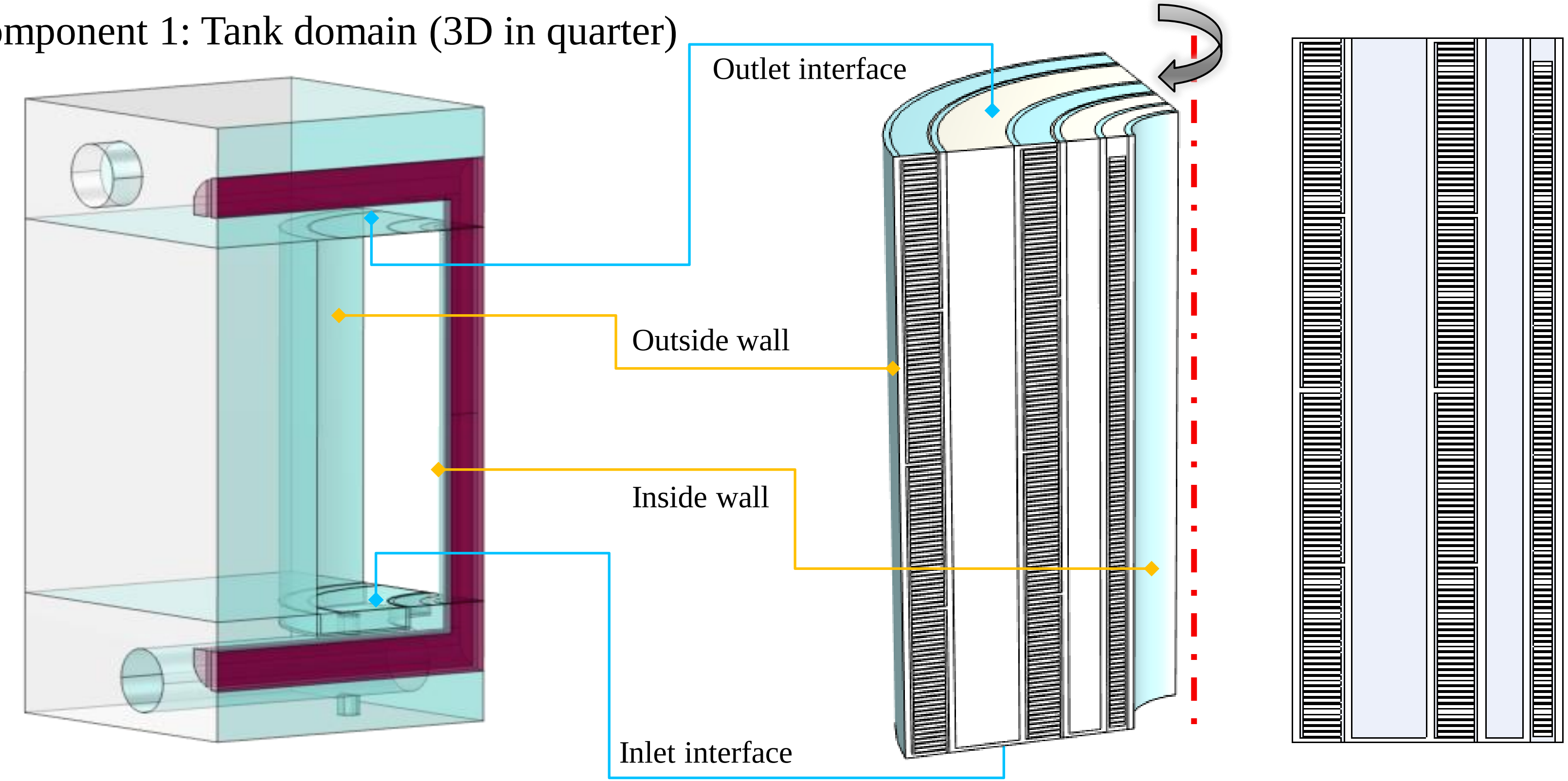
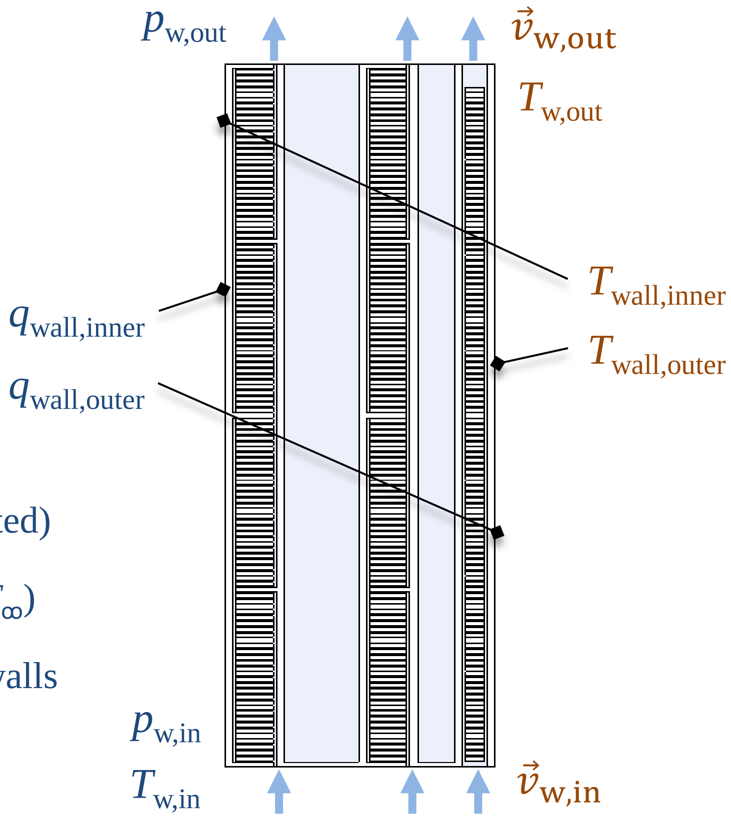
Two separate components

Component 1: Tank domain (3D in quarter)



Component 2: Winding domain (2D axisymmetric)

Step 1: Initialization (2D model computation)



Outputs:

- Inlet and Outlet velocities
- Outlet temperatures
- Wall temperatures

Inputs:

- Inlet and Outlet pressures (estimated)
- Inlet temperatures (initialized to T_∞)
- Heat transfer rate on inner/outer walls (initialized to zero)

Step 2: coupling method

Extruding data — **Coordination transforming** — **Intruding data**

2D model ⇨

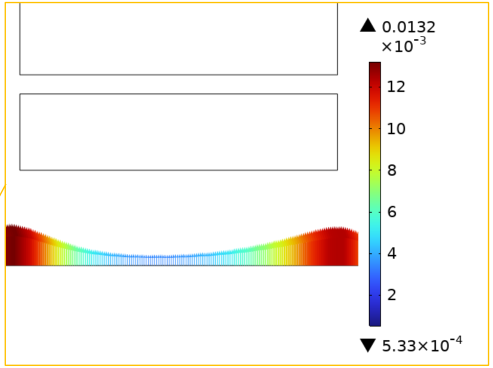
$$\vec{v} = \begin{bmatrix} u_R \\ u_Z \end{bmatrix} = \begin{bmatrix} u_R(R,Z) \\ u_Z(R,Z) \end{bmatrix}$$

⇨

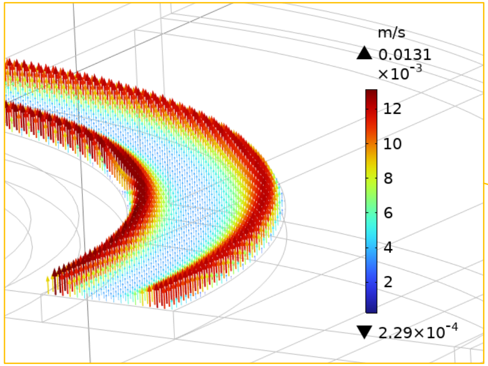
$$\vec{v} = \begin{bmatrix} u_X \\ u_Y \\ u_Z \end{bmatrix} = \begin{bmatrix} u_R\left(\sqrt{X^2+Y^2}, Z\right) \times \frac{X}{\sqrt{X^2+Y^2}} \\ u_R\left(\sqrt{X^2+Y^2}, Z\right) \times \frac{Y}{\sqrt{X^2+Y^2}} \\ u_Z\left(\sqrt{X^2+Y^2}, Z\right) \end{bmatrix}$$

⇨ 3D model

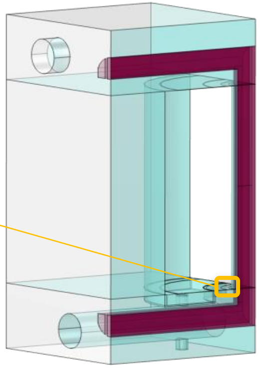
Comp 2



Velocity field at Tertiary inlet in Ω_1(R,Z)



Velocity field at Tertiary inlet in Ω_2(X,Y,Z)



Comp 1

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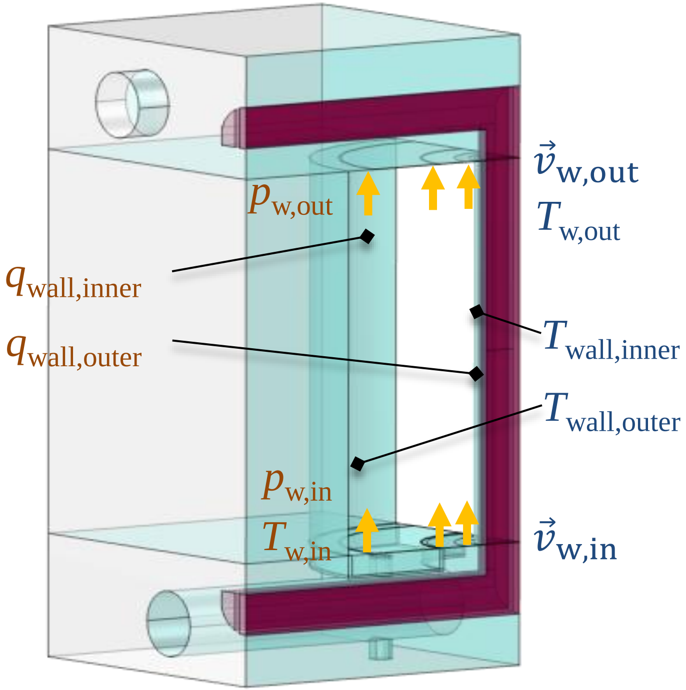
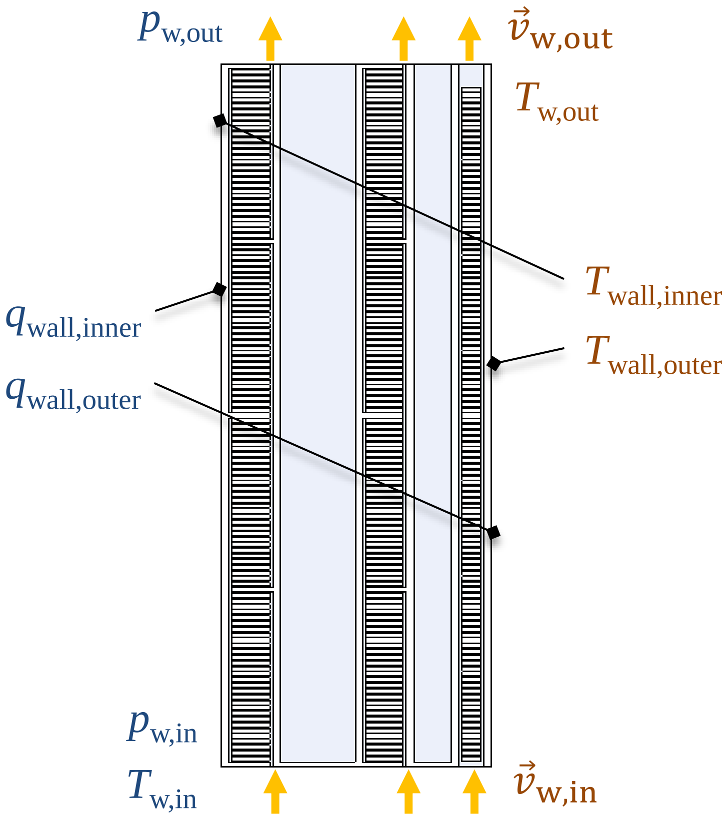
Step 3: Iteration (2D-3D model computation)





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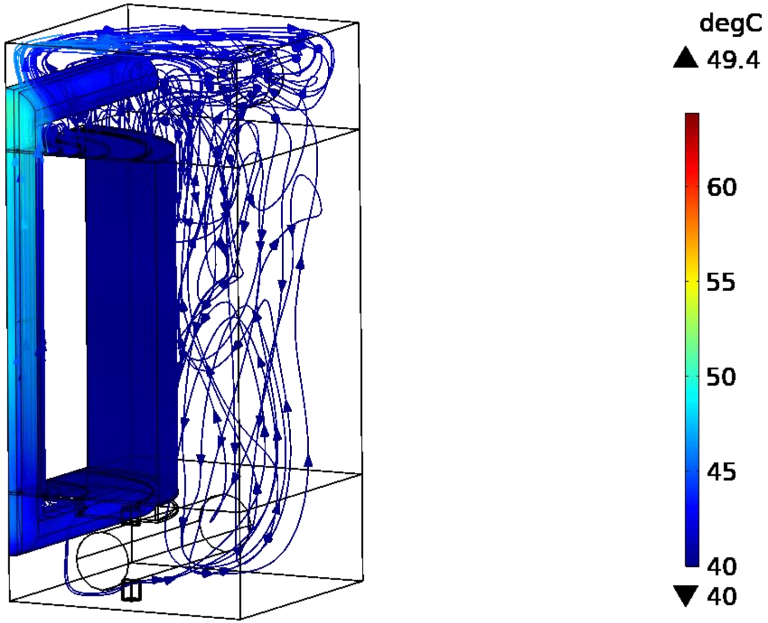
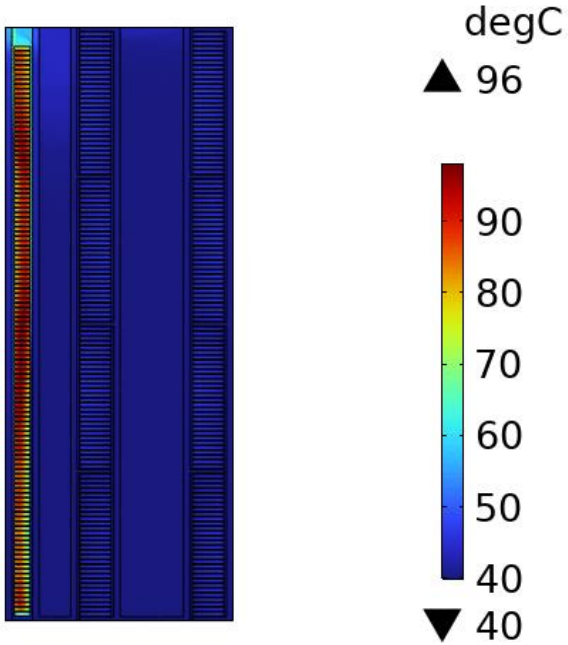
Oil flow temperature (Comp 1) & HST (Comp 2)





Conclusion and Outlook

- The IEC dynamic thermal model (DTM) was modified by incorporating features of dual-cooling mode, tertiary connection, temperature-dependent resistance, and tap-changer numbers.

- A multi-dimensional CFD model has been preliminarily developed to thoroughly analyze the thermofluidic behavior and hotspot temperatures of three windings.

- To complete the CFD model and utilize the numerical simulation results to validate and further refine the modified DTM