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Detailed dynamic thermal-hydraulic network model Application to liquid- immersed power transformers



ABSTRACT

This is the second part of a paper which presents the concept of temperature calculation in oil-immersed power transformers based on a detailed Thermal-Hydraulic Network Model (THNM). The THNM is deeply rooted in physics, incorporating detailed construction, material properties, and cooling equipment characteristics. Software tools based on a steady-state version of detailed THNM are becoming prevalent as design tools. However, a detailed dynamic THNM has not yet reached

that level of technology readiness. Its practical application lies in operational decision-making, grid planning, and investment planning, as well as monitoring, where the detailed dynamic THNM can be used to simulate transformer thermal behavior during grid operation under variable loading conditions.

KEYWORDS:

Thermal-hydraulic network model, transformer loading, transient thermal analysis, digital twin

Detailed results can be observed in both the detailed static THNM, used for LIPT design, and the detailed dynamic THNM at the frozen moment in time

6. Illustration of software details

This chapter shows selected input data and output features to illustrate the level of detail captured by HoST Calculus software [3].

6.1 Input data illustration

The inputs are detailed construction and specifications of the insulating liquid and the cooling equipment used.

The liquid and equipment are selected from the list of commercially available options. Their relevant characteristics are loaded from existing databases.

An example of how the wire parameters are entered is presented in Fig. 8, and the selection of barriers for zig-zag oil

flow between conductors is illustrated in Fig. 9.

6.2 Output dynamic charts

Fig. 10 presents the list of data that can be displayed in dynamic charts. An example of such a chart, showing winding hot-spot and top oil temperatures and other output data, is shown in Fig. 11.

Fig. 12 presents how the calculation of potential overload is initiated for a grid-operating LIPT. Once initiated, the calculation runs in a separate parallel thread.

6.3 Detailed calculation results

Detailed results can be observed in both the detailed static THNM, used for LIPT design, and the detailed dynamic THNM

at the frozen moment in time. The set of values is identical for both options. Fig. 13 presents the global distribution of liquid flow and temperature in LIPT with three windings. It contains three inner branches for the windings, an inner branch for the core, an inner branch for the liquid bypass, and an outer branch for the outer cooling. Fig. 14 presents the distribution of all calculated values inside one of the windings.

The main challenge with dynamic THNM is that it requires extensive information on transformer construction, material properties, and cooling system characteristics - data that is often sensitive or not readily available

Figure 8. Wire data

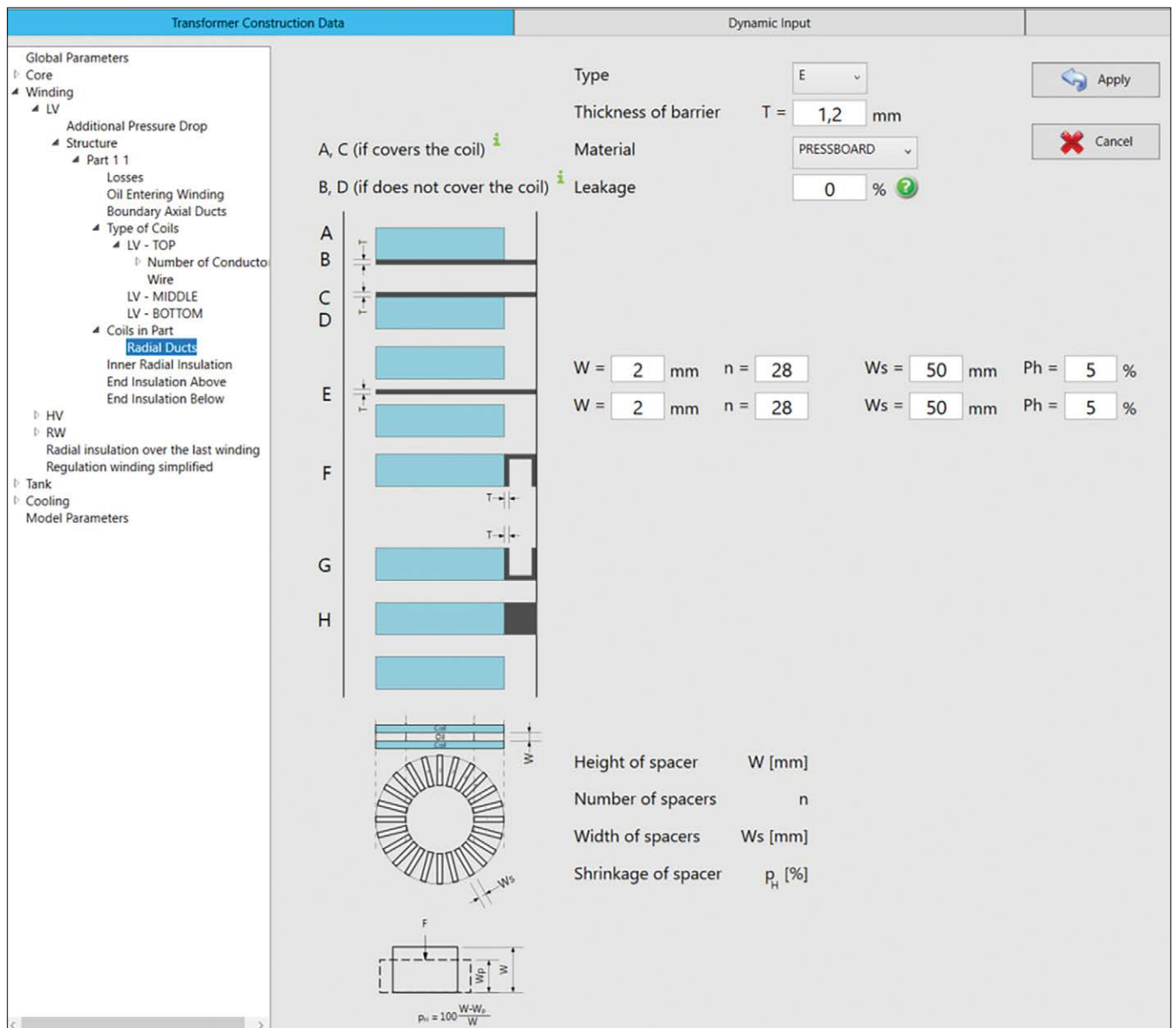


Figure 9. Barriers for zig-zag oil flow between conductors

The application of the dynamic version represents the future of temperature calculation during transient thermal processes

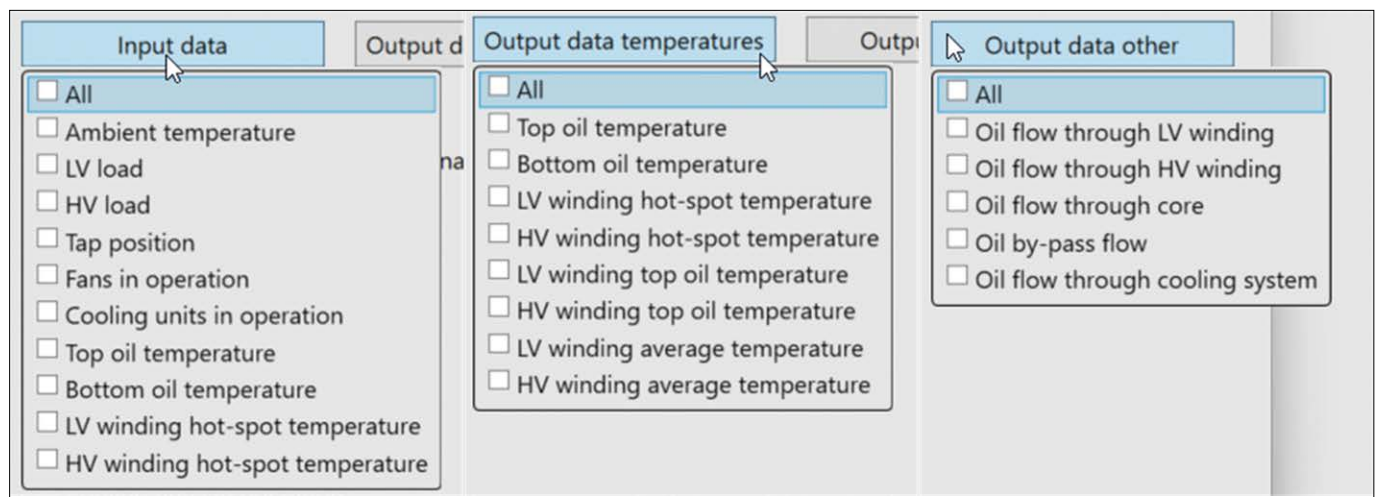


Figure 10. List of data that can be shown in dynamic charts

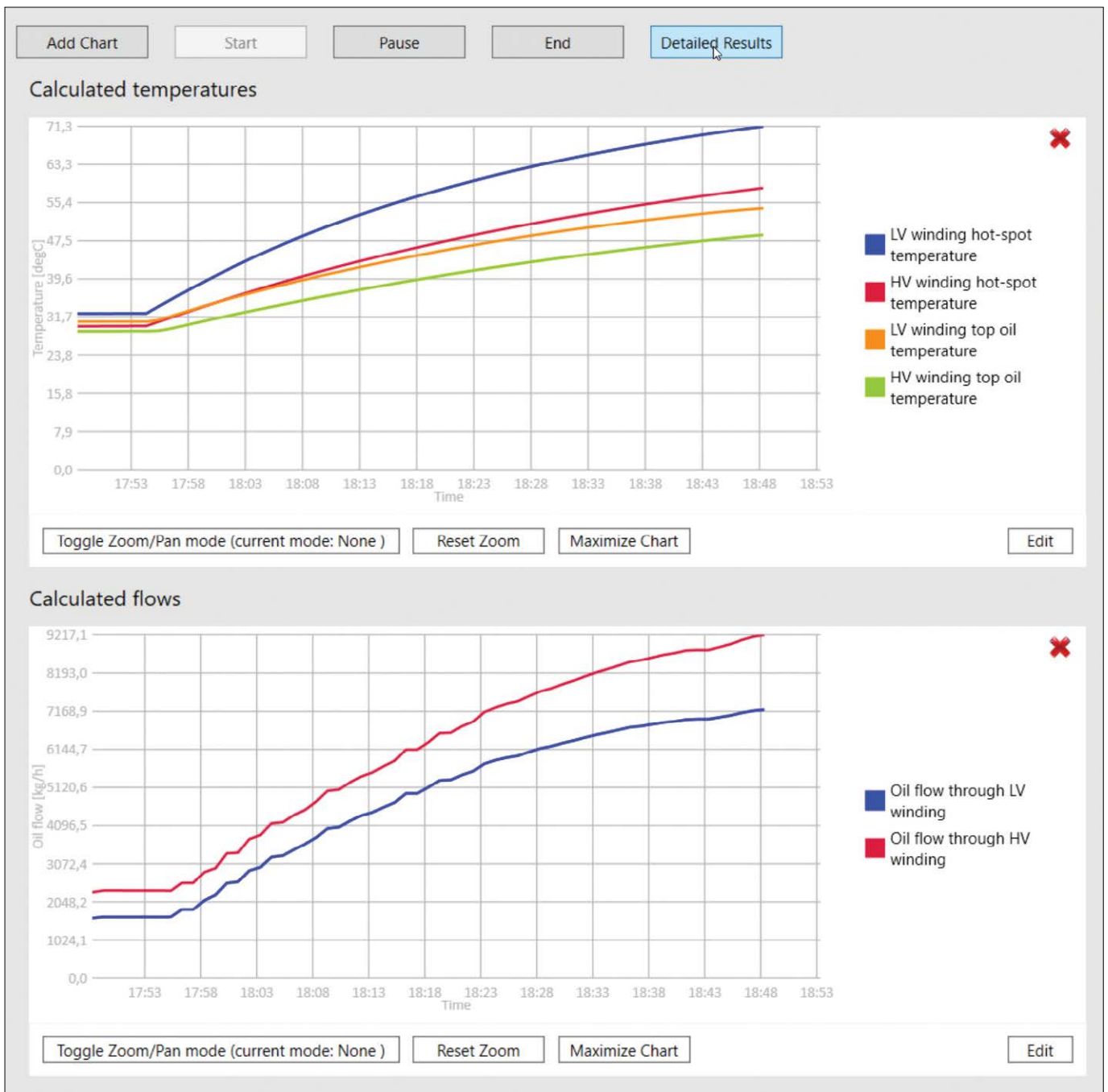


Figure 11. Example of a dynamic chart

OVERLOAD DATA

Overload duration min

Load values for each winding (p.u.)

LV	HV
<input type="text" value="1.2"/>	<input type="text" value="1.2"/>

Figure 12. Starting calculation for potential overload

7. Conclusion

The paper presents key points of a dynamic thermal digital twin for LIPTs. It is implemented as a detailed dynamic THNM, being deeply rooted in physics and detailed construction transformer data. While software tools based on the steady-state version of the detailed THNM have recently become prevalent as design tools, the application of the dynamic version represents the future of temperature calculation during transient thermal processes. The paper describes the principles for building a detailed dynamic THNM, discusses its practical applications, presents results from its

application, and illustrates the input data, output charts, and the presentation of the results.

The main challenge with dynamic THNM is that it requires extensive information on transformer construction, material properties, and cooling system characteristics - data that is often sensitive or not readily available. The computational time required for dynamic THNM is significantly longer compared to that of simplified models. Currently, the simulation runs at approximately one-third the duration of the actual transient thermal process, with potential for faster performance through further optimization.

A key advantage of dynamic THNM is that it does not rely on measurement data for parameterization. By incorporating detailed representations of hydraulic and thermal phenomena within LIPT, the model can accurately respond to changes in grid operating conditions. These characteristics qualify the model as a thermal digital twin of the LIPT, capable of delivering high-accuracy temperature predictions. Preliminary testing on the transformers validates the model's accuracy and alignment with expected performance.

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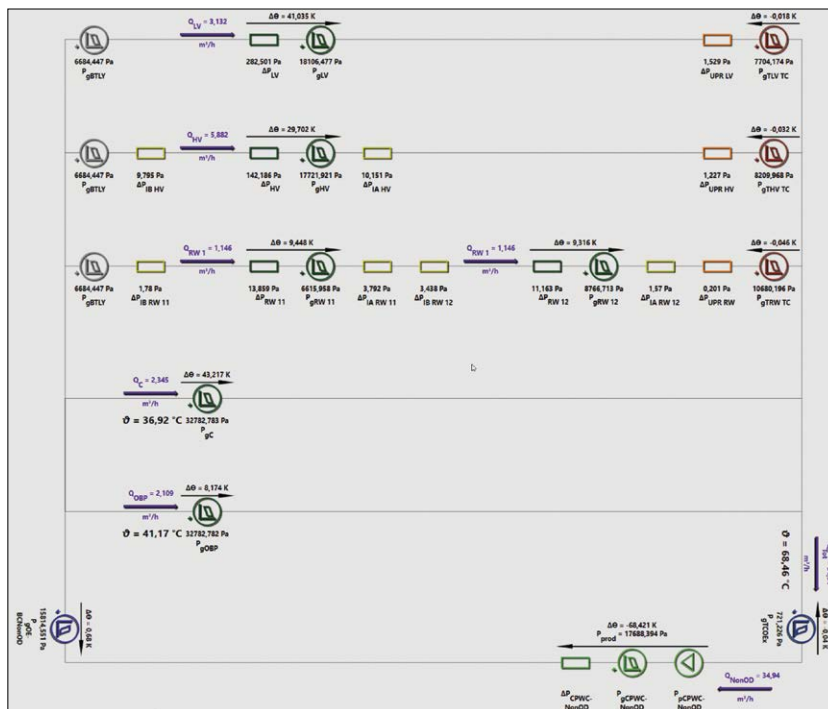


Figure 13. Global distribution of liquid flow and temperature in LIPT with three windings

A key advantage of dynamic THNM is that it does not rely on measurement data for parameterization

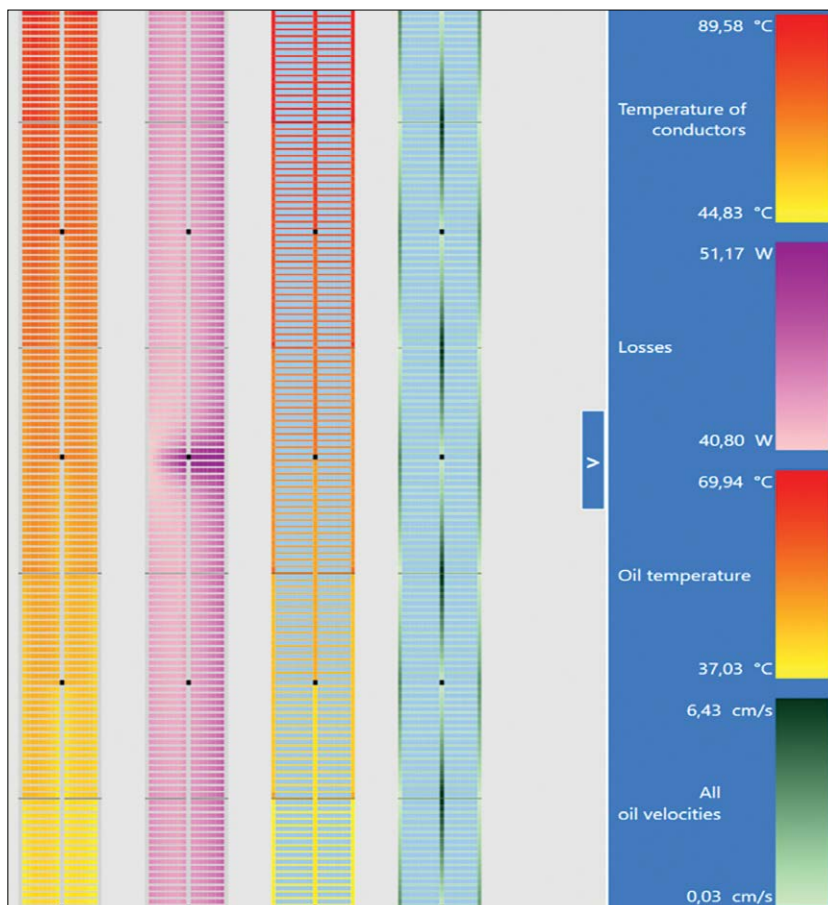


Figure 14. Distribution of calculated data for one winding (losses are presented as value of total losses in each conductor)

By incorporating detailed representations of hydraulic and thermal phenomena within LIPT, the model can accurately respond to changes in grid operating conditions

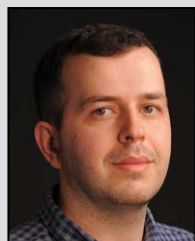
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