Bachelor thesis

Automated lumped-parameter thermal network (LPTN) modeling of electrical machines

Temperature modeling of electrical machines is important both for the design as well as for the operation phase to prevent thermal damage while utilizing the machine's full potential [1]. The temperature distribution in the machine is influenced by various factors such as the machine's geometry, the material properties, the cooling system, and the load profile. The temperature distribution can be modeled using a lumped-parameter thermal network (LPTN) which consists of thermal resistances and capacitance as well as power loss inputs [2]. Compared to finite element analysis or computational fluid dynamics models, LPTNs are typically numerically much more lightweight and allow fast inference. The goal of this thesis is to develop an automated approach to generate LPTN models for electrical machines based on available physics-based knowledge with the intended output of an open-source software package.

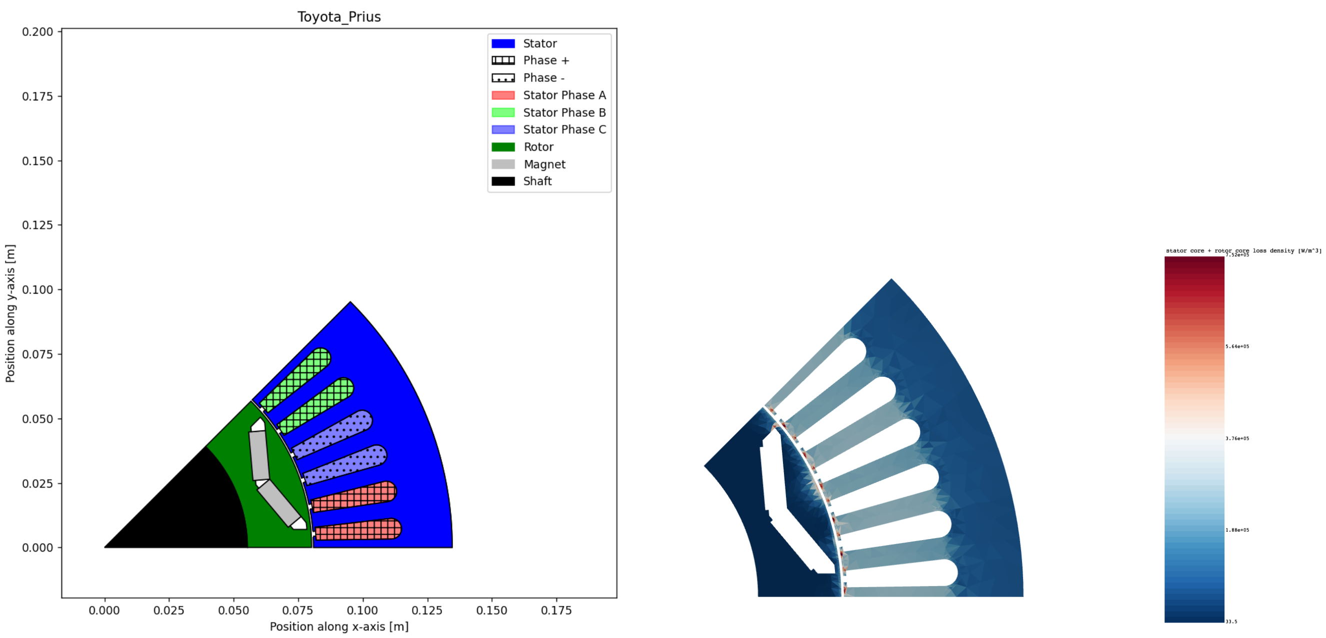

Figure 1: Finite element analysis (FEA) with loss distribution [3].

Key research questions:

- Can one automate the LPTN generation process of arbitrary machine geometries?
- Is it possible to integrate a distributed loss input into the LPTN model?
- How to consider the coupled electro-thermal effects in the temperature model?

Necessary requirements:

- Finished course work on electrical machine fundamentals
- Interest in modeling and simulation of differential equations
- Interest or experience in scientific programming languages (e.g., Julia, JAX, PyTorch)

WP 1: Literature research **[3 weeks]**
Scanning the scientific literature for relevant publications and patents related to LPTN modeling for electrical machines is the first step. Moreover, relevant (open-source) software work in the area of thermal and electromagnetic modeling should be considereed (e.g., PYLEECAN). This includes the identification of relevant keywords as part of the search strategy. Relevant work will be stored in a literature review software (e.g., JabRef) and summarized in the thesis.

WP 2: Model toolchain **[5 weeks]**
Based on a basic geometrical and material representation of an electrical machine, a software-driven modeling toolchain describing space-resolved thermal capacitances and resistances should be developed. The toolchain should be able to import geometries from common CAD software (e.g., FreeCAD) and export the LPTN model in a common data format (e.g., JSON, XML). Ideally, the resulting LPTN model is compatible with existing FEA-based loss models (e.g., PYLEECAN) which deliver important input data for the LPTN model. Also, a scalability in terms of the node granularity would be an interesting feature. The output of this WP will be an initial ODE model of the machine's temperature distribution wrapped in an off the shelf ODE solver.

WP 3: Model coupling **[2 weeks]**
The losses of an electrical machine are temperature-dependent. For example, the DC ohmic losses in the winding increase with temperature while eddy current losses in the iron parts decrease with temperature. Consequently, a considered loss input is only valid for a specific temperature distribution of the machine. Hence, the question arise if the loss model from WP2 can be coupled with the temperature model to consider the temperature dependency of the losses via mutual iterations.

WP 4: Empirical comparison **[2 weeks]**
Within WP1 relevant work should be identified which reports on the thermal behavior of some exemplarily electrical machines. This data can be used to validate the developed LPTN model. The comparison should be done in terms of the temperature distribution considering the external data as ground truth. Systematic deviations should be utilized to double-check the above automated toolchain for modeling or implementation bugs.

WP 5: Documentation **[3 weeks]**
All work packages should be reported in a structured way within the thesis. A LaTeX template should be used for this purpose: `https://github.com/IAS-Uni-Siegen/thesis_latex_template`. Writing instructions can be found within the provided template source files. Based on the previous empirical findings, conclusions should be drawn, and future research directions should be outlined.

Gantt chart

The planned timetable is shown in the Gantt diagram below.

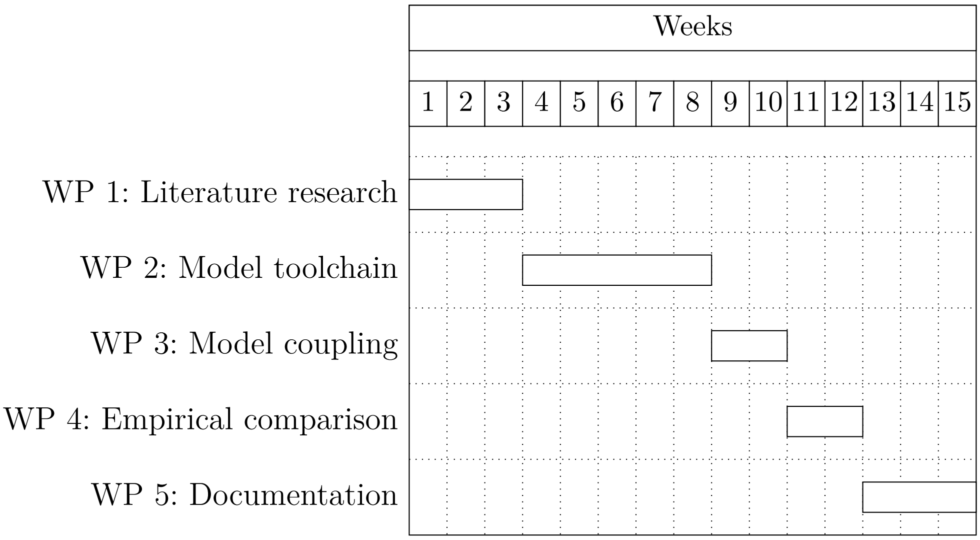

Figure 2: Gantt chart for the thesis.

References

[1] O. Wallscheid, "Thermal monitoring of electric motors: State-of-the-art review and future challenges," *IEEE Open Journal of Industry Applications*, vol. 2, pp. 204–223, 2021.

[2] F. Qi, A. Stippich, M. Guettler, M. Neubert, and R. W. De Doncker, "Methodical considerations for setting up space-resolved lumped-parameter thermal models for electrical machines," in *International Conference on Electrical Machines and Systems (ICEMS)*, 2014, pp. 651–657.

[3] P. Bonneel, J. L. Besnerais, E. Devillers, C. Marinel, and R. Pile, "Design optimization of innovative electrical machines topologies based on pyleecan open-source object-oriented software," in *International Conference on Electrical Machines (ICEM)*, 2020, pp. 2493–2499.