Master thesis

Surrogate models for electric drives

Offline optimized pulse patterns (OPPs) are a specific kind of a pulse with modulation (PWM) technique. Using them in an electric drive, which contains the electric machine, the inverter and the control algorithm, results in a lot of benefits. They can reduce the current ripple of the machine, the drive losses and the corresponding cooling effort. To calculate these OPPs offline in a simulation environment, the model must consider the inverter, machine and control algorithm, and, therefore, a coupled simulation that includes a circuit simulation addressing the inverter, a finite element analysis model of the machine and the control algorithm. However, this co-simulation approach comes with various challenges, mainly enorumous computational effort leading to exhaustive computing times as well as a significant uncertainty regarding the utilized loss estimation (model-to-reality gap) [1]. Therefore, a new approach is to determine the OPPs based on data-driven models which result from real-world drive measurements. Since experimental tests are costly and eventually time-consuming, a neural ordinary differential equation (NODE)-based surrogate approach utilizing limited real-world data should be developed which allows an accurate prediction of the drive's dynamic behavior and comes with an acceptable numerical complexity level in the forward path.

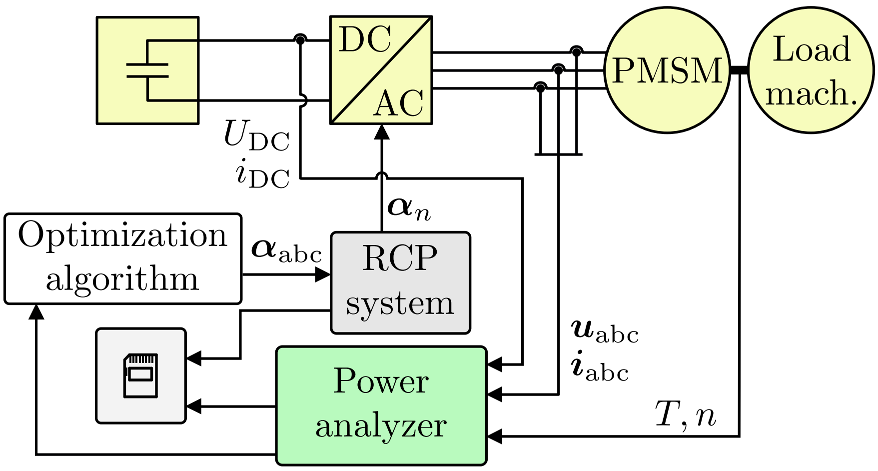

Figure 1: Simplified structure of determining online pulse pattern optimization at the test bench.

Key research questions:

- What are possible topologies of the surrogate model?
- How large is the computational effort of this model (during training and inference)?
- What is the accuracy of the predicted drive states (losses, torque,...)?

Necessary requirements:

- Finished course work on electrical machine and machine learning fundamentals
- First experiences in modelling of dynamical systems
- Solid programming skills 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 surrogate models of electric drives and related fields is the first step. Also, getting familiar with the structure and applications of OPPs is part of this WP. Relevant work will be stored in a literature review software (e.g., JabRef) and summarized in the thesis.

WP 2: Model development **[6 weeks]**
In the literature surrogate models are published which estimates steady-state parameters of the machine e.g., motor geometries [2]. Also published are surrogate models, which covers the transient process of electrical machines [3]. Based on the problem statement addressed in this master thesis, both, the steady-state operation and the transient process must be considered. Therefore, new models should be developed, which combine these two different requirements. A potential starting point for this investigation can be NODE models.

WP 3: Hyperparameters **[6 weeks]**
The selected surrogate model from the previous WP has a set of hyperparameters that need to be tuned. The hyperparameter optimization (HPO) can be automated using available open-source toolboxes and should also focus on the complexity vs. accuracy trade-off by identifying the Pareto front between these two objectives. Depending on the computational load of this WP, the HPO can be parallelized on a high-performance computing (HPC) cluster.

WP 4: Evaluation **[2 weeks]**
In this WP different machine learning models should be evaluated regarding their accuracy and their computational effort. The aim of this WP is to find a model type, which can be optimized in the next step.

WP 5: Optimization **[5 weeks]**
A simulative framework to optimize the pulse patterns of the electric drive should be developed, including the surrogate model inside a closed-loop framework. Therefore, a cost function should be defined, which represents the scopes of the optimization. This could include the minimum losses, but also the resulting torque ripple of the machine depends on the pulse pattern. Eventually, this task needs to be offloaded to the HPC cluster for computational speed up.

WP 6: 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.

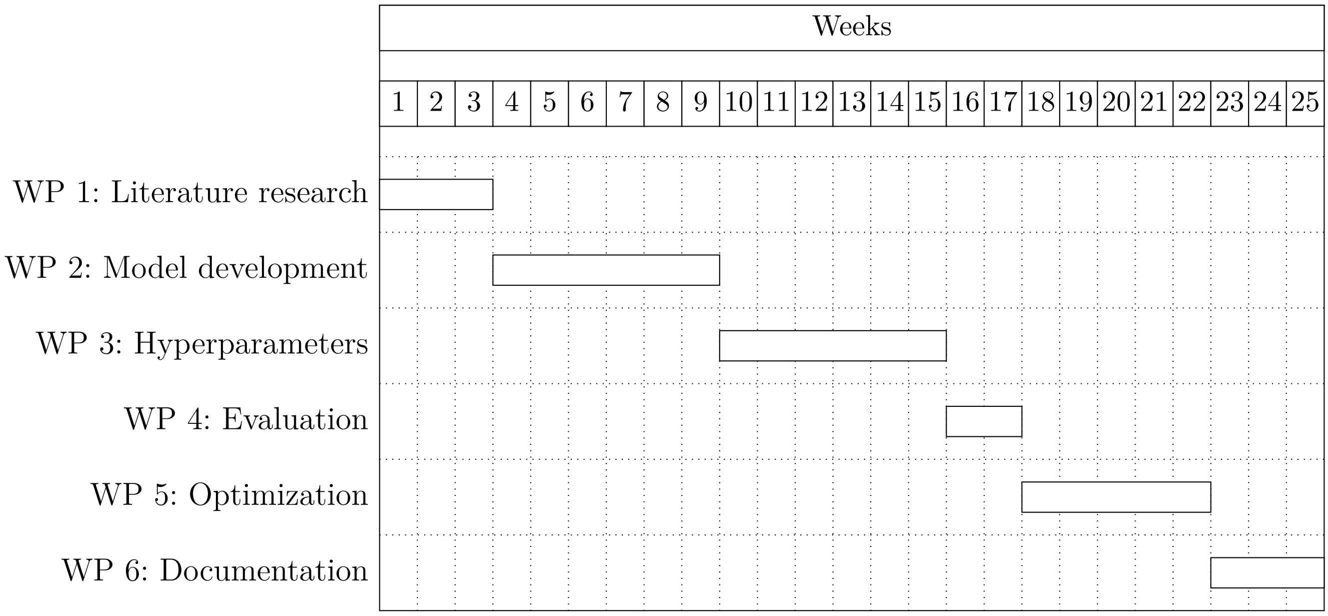

Figure 2: Gantt chart for the thesis.

References

[1] L. Hölsch, A. Brosch, R. Steckel, T. Braun, S. Wendel, J. Böcker, and O. Wallscheid, "Insights and Challenges of Co-Simulation-based Optimal Pulse Pattern Evaluation for Electric Drives," *IEEE Transactions on Energy Conversion*, pp. 1–12, 2024.

[2] J. Gu, W. Hua, W. Yu, Z. Zhang, and H. Zhang, "Surrogate Model-Based Multiobjective Optimization of High-Speed PM Synchronous Machine: Construction and Comparison," *IEEE Trans. on Transportation Electrification*, vol. 9, no. 1, pp. 678–688, 2023.

[3] M. Tahkola, V. Mukherjee, and J. Keränen, "Transient Modeling of Induction Machine Using Artificial Neural Network Surrogate Models," *IEEE Trans. on Magn.*, vol. 58, no. 9, pp. 1–4, 2022.