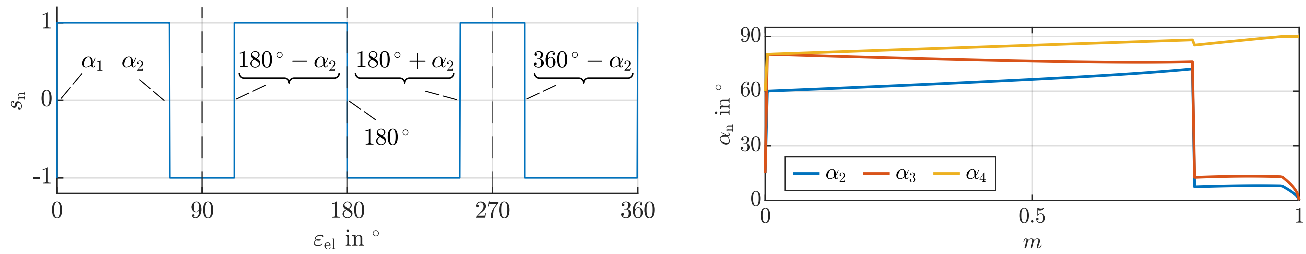
Bachelor thesis

Calculation of optimized pulse patterns for electric drives

Offline optimized pulse patterns (OPPs) are a specific kind of a pulse with modulation (PWM) technique. OPPs are part of the synchronized pulse patterns, which means that the start and end pulse of a pulse pattern are synchronized with the motor's fundamental frequency. Compared to other PWM methods, the switching angles $\boldsymbol{\alpha}$ are fixed for a certain modulation index m and, therefore, the switching angles are calculated based on a drive model during the development process. Mostly a lumped-parameter machine model, i.e., an ordinary differential equation, is used for this task [1], [2]. In the figure below on the left side an exemplary structure of an OPP is shown. On the right side the switching angles $\boldsymbol{\alpha}$ of a different OPP with a discontinuity at $m \approx 0.8$ is visualized.



(a) Exemplary structure of an OPP.

(b) Switching angles $\boldsymbol{\alpha}_\mathrm{n}$ for an exemplary OPP.

Using OPPs 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. These benefits motivates research towards OPPs and the aim of this thesis is to calculate OPPs in a closed-loop optimization algorithm within in end-to-end differentiable software environment.

Key research questions:

- What influence does the OPP have on the machine's behavior (losses, torque ripple,...)?
- What are the conflicting objectives of the OPP design?
- How large is the computational effort of such an optimization?

Necessary requirements:

- Finished course work on electrical machine and power electronic fundamentals
- First experiences or interest in numerical optimization and modeling
- Interest in scientific programming languages (PyTorch, JAX, Julia,...)

WP 1: Literature research **[3 weeks]**
Scanning the scientific literature for relevant publications and patents related to OPPs of electric drives and related fields is the first step. Also, getting familiar with typical constrained optimization problems in the pulse pattern optimization domain 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 **[3 weeks]**
The simulation time cost-efficient lumped-parameter model of the electrical machine should be implemented in end-to-end differentiable scientific programming language. This model must contain prediction of the current, torque and loss responses of the drive, which first-order principle description can be taken from available literature resources.

WP 3: Optimization framework **[4 weeks]**
A closed-loop simulative framework to optimize the pulse patterns must be implemented. Therefore, available optimization algorithms from the above-mentioned programming languages can be used. Moreover, a cost function has to be defined, which represents the different scopes of the optimization and the constraints. Here, also conflicting objectives (e.g., loss minimization vs. torque ripple minimization) must be taken into account.

WP 4: Parallelization **[3 weeks]**
Due to the expected high computational effort, the optimization problem should be optimized regarding the computing time. One possibility is to split the problem into multiple parts and run those in parallel (e.g., for different operating points of the drives).

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.

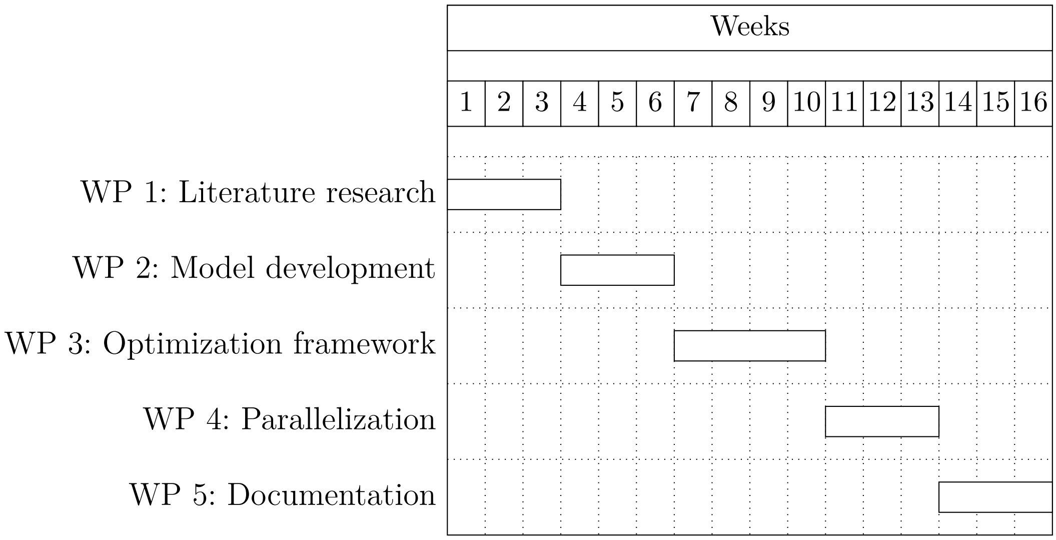


Figure 2: Gantt chart for the thesis.

References

[1] A. Birda, J. Reuss, and C. M. Hackl, "Synchronous Optimal Pulsewidth Modulation for Synchronous Machines With Highly Operating Point Dependent Magnetic Anisotropy," *IEEE Trans. on Ind. Electron.*, vol. 68, no. 5, pp. 3760–3769, 2021.

[2] N. Hartgenbusch, R. W. De Doncker, and A. Thünen, "Optimized Pulse Patterns for Salient Synchronous Machines," in *Int. Conf. on Electr. Mach. and Syst.*, 2020.