

Model Predictive Control of Electric Powertrains

Von der Fakultät für Maschinenwesen der Rheinisch-Westfälischen Technischen Hochschule Aachen zur Erlangung des akademischen Grades eines Doktors der Ingenieurwissenschaften genehmigte Dissertation

vorgelegt von

Lukas Weber

Berichter: Universitätsprofessor Dr.-Ing. Heike Lorenz
 Universitätsprofessor Dr.-Ing. Kai Brenner

Tag der mündlichen Prüfung: 12. Juni 2026

Diese Dissertation ist auf den Internetseiten der Universitätsbibliothek online verfügbar.

Unofficial template, not affiliated with or endorsed by RWTH Aachen University. The author, committee and results in this sample are fictional. Delete this line before you submit.

Abstract

Electric vehicles convert battery energy into motion through an inverter and a permanent-magnet synchronous machine whose efficiency depends strongly on the operating point. This dissertation develops a model predictive controller that chooses current references for the machine and the torque split between two drive units so as to minimize losses while tracking the driver's torque demand. A convex loss model makes the optimization solvable within the 100-microsecond control period of the inverter. On a dual-motor test bench driven through a standard urban cycle, the controller reduces drivetrain losses by 7.8% compared with a fixed 50/50 torque split.

Kurzfassung

Diese Dissertation entwickelt eine modellprädiktive Regelung für elektrische Antriebsstränge, die Stromsollwerte und die Momentenaufteilung zwischen zwei Antriebseinheiten so wählt, dass die Verluste minimiert werden. Ein konvexes Verlustmodell erlaubt die Lösung innerhalb der Regelperiode des Umrichters. Am Prüfstand sinken die Verluste im Stadtzyklus um 7,8 %.

Acknowledgements

I thank my supervisor for her guidance and the opportunity to work at the institute, my colleagues for their help at the test bench, and my family for their support.

Contents

Abstract	i
Kurzfassung	ii
Acknowledgements	iii
1 Introduction	1
2 Background	2
3 Loss-Minimizing Predictive Control	3
4 Test-Bench Results	4
5 Conclusion	5
A Loss Model Identification	6

List of Figures

3.1	The predictive controller computes current references for both drive units.	3
-----	---	---

List of Tables

4.1	Drivetrain losses over an urban driving cycle.	4
-----	--	---

Chapter 1

Introduction

An electric drivetrain is efficient on average but not uniformly: a machine running at low torque and high speed may waste several times the energy it wastes near its best operating point. Vehicles with two drive units can exploit this by splitting the demanded torque between them, and the machine controller can choose the current references that minimize losses for a given torque. Doing both optimally, at the rate an inverter requires, is the subject of this dissertation.

Chapter 2

Background

In the rotor reference frame, the torque of a permanent-magnet synchronous machine with p pole pairs is

$$T = \frac{3}{2} p (\psi_{\text{PM}} i_q + (L_d - L_q) i_d i_q), \quad (2.1)$$

so the same torque can be produced by many current pairs (i_d, i_q) with different copper and iron losses. Model predictive control chooses inputs by optimizing a model's predictions over a receding horizon [1].

Chapter 3

Loss-Minimizing Predictive Control

We approximate the combined inverter and machine losses by a convex quadratic in the currents of both units, fitted to bench measurements. The controller solves a small quadratic program at every control period, tracking the demanded total torque while minimizing predicted losses under current and voltage limits.



Figure 3.1: The predictive controller computes current references for both drive units.

Chapter 4

Test-Bench Results

Table 4.1 reports drivetrain losses over a standard urban driving cycle.

Table 4.1: Drivetrain losses over an urban driving cycle.

Strategy	Losses (kJ)	Relative
Fixed 50/50 split, MTPA currents	412	1.000
Rule-based split, MTPA currents	395	0.959
Predictive control (this work)	380	0.922

The predictive controller saves most where the demanded torque is low, when shutting down one unit and running the other near its efficient region beats sharing the load.

Chapter 5

Conclusion

Loss-minimizing control of a dual-motor drivetrain is feasible at inverter rates when the loss model is convex. Including the battery's own losses and thermal limits in the model is the next step.

Appendix A

Loss Model Identification

The loss model was fitted to 1,240 steady-state operating points measured on the test bench, with a mean absolute error of 2.1% of the measured losses.

Bibliography

- [1] James B. Rawlings, David Q. Mayne, and Moritz M. Diehl. *Model Predictive Control: Theory, Computation, and Design*. Nob Hill Publishing, second edition, 2017.