TITLE

State-of-the-Art Permanent Magnet Synchronous Motor Control Methods in Automotive Traction Applications Considering Thermal Influences

NAME AND AFFILIATION OF THE AUTHORS

Dr.-Ing. Wilhelm Peters, M.Sc. Oliver Wallscheid, Prof. Dr.-Ing. Joachim Böcker
Paderborn University, Germany
Faculty of Electrical Engineering, Computer Science and Mathematics
Power Electronics and Electric Drives (LEA)

SCOPE AND BENEFITS

- In-depth modelling of the electrical and thermal behaviour of highly utilised PMSM in automotive applications
- Special focus on precise discrete-time model
- Addressing automotive-related issues concerning the control design
    - Maximum-efficiency operation strategy
    - Maximum voltage and temperature utilisation
    - Adaptive and robust current controller
    - Inverter modelling and compensation

CONTENTS

The operating characteristics of permanent magnet synchronous motors designed for the application in automotive traction drives are considerably different compared to the ones of industrial drives. The main characteristics are high magnetic saturation, high electrical fundamental frequencies with respect to the converter switching frequency, a wide constant-power operation range and a nonlinear reluctance torque. For the current controller design a suitable discrete-time motor model is required considering the impact of saturation and cross-saturation effects and a small number of sampling instants per electrical fundamental period. Furthermore, the motor model needs to describe the interaction between the discrete-time controller operation and the nonlinear magnetic characteristics of the motor. Based on that model deviation, a field-oriented current controller with a suitable decoupling of the current components can be designed. Two controller design variants will be presented: a current controller with constant parameters that is robust to varying plant time constants due to saturation effects, and the design of an adaptive controller which parameters are updated using a simplified saturation characteristic model. It will be shown by measurement results that the adaptive controller has a better reference response and disturbance reaction in operation points with low magnetic saturation.

To ensure a high efficiency, an operation point selection that provides appropriate current reference values with respect to the demanded torque is required. This torque control has to be realised in an open-loop manner, since power and torque measurements are not available in automotive applications. Here, a state-of-the-art ME (Maximum Efficiency) operation strategy will be compared to classical MTPC (Maximum Torque per Current) approaches. The impact of the loss characteristics of a given motor, the restrictions due to current and voltage limits and the relevance of different operation points with respect to a specific driving cycle will be discussed. Additionally, a superimposed voltage controller taking varying DC-voltages and parameter uncertainties into account will be presented. This additional controller is required to ensure maximum voltage utilisation beyond base speed while guaranteeing the viability of the current control loop by providing a voltage reserve.

Highly dynamic and stochastically load profiles in automotive applications are making it almost impossible to estimate the temperature characteristics regarding critical motor components, e.g. the stator winding or the permanent magnets, during the drive design phase. Measuring these temperatures is costly and thermal sensors are potential error sources leading to enormous repair efforts in the failure case. Against this background, real-time capable methods to observe critical motor temperatures have to be considered within the motor control software. A suitable temperature estimation will be the basis for a derating controller that is required to prevent device failures due to thermal stress while utilising a given motor to a maximum thermal extent. In addition, certain electrical motor model parameters are temperature sensitive and adapting these parameters within the control software leads to an increased control performance and accuracy.

SCHEDULE

09:30 - 11:00 Part 1:

1. Introduction (15 minutes)
   a. Drive train characteristics of conventional vehicles in contrast to EV and HEV
   b. Longitudinal vehicle dynamics model and drive cycle analyses
   c. Control requirements in automotive traction applications
2. Permanent Magnet Synchronous Motor (PMSM) model (20 minutes)
   a. Continuous-time model
   b. Saturation and cross-saturation effects
   c. Discrete-time model
   d. Parameter identification
3. Control scheme overview (10 minutes)
   a. Boundary conditions for EV & HEV applications
   b. Comparison of different control approaches
   c. State-of-the-art control structure in automobile industry
4. Current control loop design (20 minutes)
   a. Pole placement method
   b. Robust design to address varying parameters
   c. Gain-scheduling design to address varying parameters
5. Operation point selection / operation strategy (20 minutes)
   a. Comparison of two operation strategies: Maximum Torque per Current vs. Maximum Efficiency
   b. Restrictions due to voltage and current limits

    c. Discussion of measurements of two exemplary EV/HEV drives

11:00 - 11:30 Coffee break
11.30 - 13:00 Part 2:

6. Voltage controller (15 minutes)
    a. Voltage limit with 2-Level-IGBT inverter voltage controller loop scheme and main challenges
    b. Plant parameter identification and controller design
7. Thermal influences regarding motor control (10 minutes)
    a. Torque accuracy
    b. Current control disturbances
    c. Safety issues
8. Lumped parameter thermal networks (30 minutes)
    a. Basics
    b. Analytical derivation
    c. Experimental thermal model identification techniques
9. Temperature determination using electrical motor models (20 minutes)
    a. Flux observer based permanent magnet temperature estimation
    b. Signal injection based stator winding temperature estimation
    c. Limitations and challenges
10. Summary and Q&A (20 minutes)

WHO SHOULD ATTEND

The tutorial attendees should be familiar with basics of electric motor modelling and control theory. The tutorial speakers expect a strong demand on the proposed topic since the world-wide trend to electric and hybrid-electric vehicles (EV/HEV) is more and more consolidating. As the electrical drive system is one of the most important parts in EV/HEV related control methods are relevant to a brought potential audience, e.g.:

- Master and Ph.D. students as well as junior research scientists from the described field
- Industrial engineers from the automotive sector or related sectors
- Senior research scientists from other fields interested in the topic and its challenging aspects

Technical Level: Beginners and advanced persons

ABOUT THE INSTRUCTORS

Dr.-Ing. Wilhem Peters

Wilhelm Peters is a postdoctoral fellow and team leader at the Department of Power Electronics and Electrical Drives at Paderborn University. He received his diploma and doctor’s degrees (with honours) in electrical engineering from the Paderborn University in 2008 and 2015, respectively. His current research work is on control methods for electrical drives in automotive traction applications focusing on discrete-time motor model considering magnetic saturation and loss-optimal operation.

M.Sc. Oliver Wallscheid

Oliver Wallscheid is a research assistant and Ph.D.-student at the Department of Power Electronics and Electrical Drives at Paderborn University. He received his bachelor and master degrees (with honours) in industrial engineering from Paderborn University in 2010 and 2012, respectively. In his current Ph.D.-project he is investigating real-time capable methods to observe critical motor component temperatures in automotive traction drive applications.

Prof. Dr.-Ing. Joachim Böcker

Joachim Böcker is full professor and head of the Department of Power Electronics and Electrical Drives at the Paderborn University, Germany. He studied electrical engineering at Berlin University of Technology, Germany, where he received the Dipl.-Ing. as well as Dr.-Ing. degrees in 1982 and 1988, respectively. He was with AEG and DaimlerChrysler research as head of the control engineering team of the electrical drive systems laboratory from 1988 to 2001. In 2001, he started his own business in the area of control engineering, electrical drives and power electronics. In 2003, he was appointed to the current professorship. An important research focus of the past years were control and thermal modelling of automotive electrical drives.