Virtual Design of Electrified Powertrain Systems
Calibrating PMSM Torque Control Lookup Tables Using Model-Based Calibration

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PMSM Calibration

Productive

Automated

Scalable
Effect of Inverter Bus Voltage Drop on Torque Control

- Inverter bus voltage
- Actual torque
- Commanded torque
- Motor speed
Flux-Based Calibration Tables

- Flux levels are adjusted based on variation of inverter bus voltage
- Key enabler: flux-based $i_d$ and $i_q$ tables

Simulink Implementation of Flux-Based Calibration Tables
Flux-Based Calibration Tables – Simulation Results

- Inverter bus voltage
- Actual torque
- Commanded torque
- Motor speed
Flux-Based Calibration Tables

How to calibrate these?
Different Ways to Calibrate Flux-Based Tables

Manual & Rule-Based Calibration

Model-Based Calibration
What is Model-Based Calibration (MBC)?

- Workflow for calibrating parameters for plant models and control systems

- Includes steps for
  - Design of Experiments (DoE)
  - Model fitting and optimization
  - Design parameter tradeoff studies
  - Calibration generation for lookup tables
Model-Based Calibration Workflow ➔ MBC Toolbox

Data Collection ➔ Data Modeling ➔ Calibration ➔ Implementation
Data Collection (PMSM Characterization)

Data Collection (PMSM Characterization)

Test plan

Logged data
Model-Based Calibration Workflow

Data Collection → Data Modeling → Calibration → Implementation
Why Data Modeling?

Statistical models that map input variables to output responses
- Polynomials
- Radial Basis Functions
- Gaussian Process Models

Rationale
- Smooth raw data
- Interpolate between data points
- Reduce number of data points
- Enable fast optimization
Data Modeling

Operating point

Input

Response

Trq  rpm

i_d

map

i_q  flux
Model-Based Calibration Workflow

Data Collection → Data Modeling → Calibration → Implementation
Calibration

Given the fitted model, where is the best (id, iq) operating points that can achieve pre-set optimization objective while satisfying certain physical constraints.

Optimization objective: maximize efficiency (Torque per Amp)

Constraints: current <= current_max
          flux <= flux_allowed
Model-Based Calibration Workflow

- Data Collection
- Data Modeling
- Calibration

Implementation
Calibration Results – Fill Calibration Tables

- $i_d$ table
- $i_q$ table
Takeaways

Model-based calibration workflow
- PMSM control calibration → optimization problem
- Automated calibration process
- Robust to different PMSM designs

<table>
<thead>
<tr>
<th>Manual</th>
<th>Model-Based Calibration</th>
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<tbody>
<tr>
<td>Rule-based searching method</td>
<td>Optimization</td>
</tr>
<tr>
<td>Requires lots of scripting</td>
<td>Automated</td>
</tr>
<tr>
<td>Error prone</td>
<td>Robust</td>
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PMSM Calibration Consulting Service

- **Service components**
  - Hands on calibration support
    - Workflow discussion
    - Coaching of MBC calibration method
  - Calibration workflow tool
    - GUI that implements the entire MBC workflow
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