Institute for Drive Systems and Power Electronics

SEMIKRON DANFOSS

Leibniz Universität Hannover

Self-Sensing Control of Permanent Magnet Synchronous Machines: Enabling Widespread use in Commercial Applications

Semikron Danfoss Innovation Award 2025

N. Himker, V. Willich, G. Lindemann and A. Mertens

03.04.2025

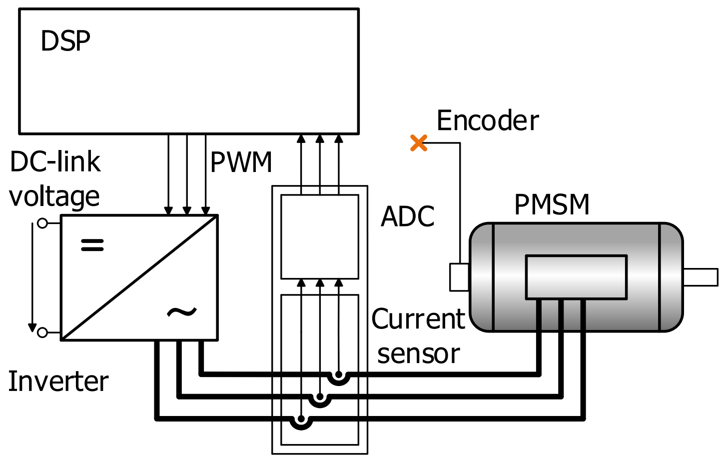
„Enablers“ and „Blockers“ of Self-Sensing Control(SSC)

Enablers

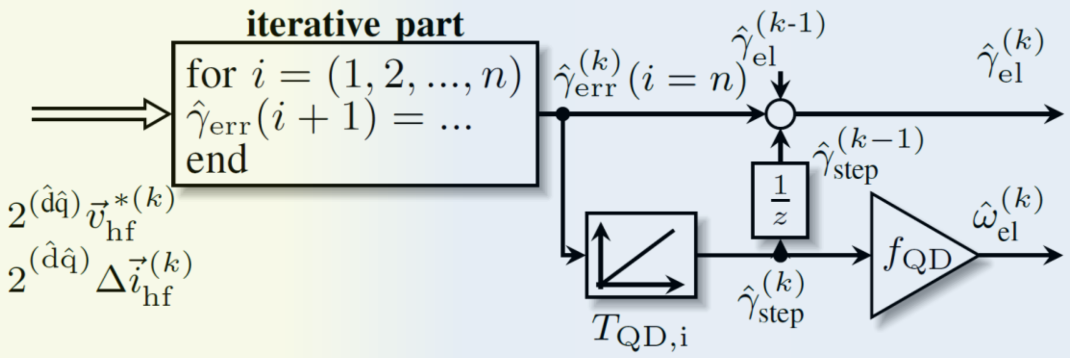
- ↓ Installation space
- ↓ Costs
- ↑ Reliability
- ↑ Redundancy

Blockers

- Accuracy of the position estimation
- Response during transients
- Computational burden
- Complex commissioning

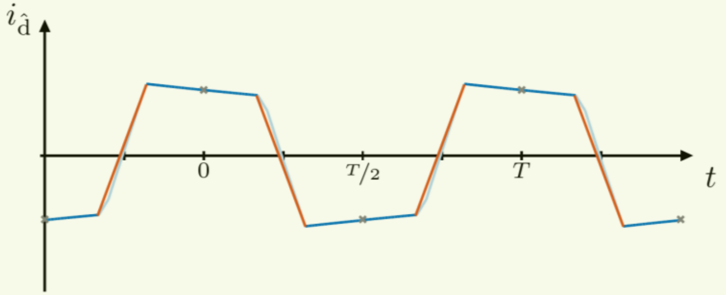


Estimation Structure



Regular Current Sampling [1,2]

- Easy to implement signal processing
- Low computational burden



Slim numerical optimisation [1-3]

- Definition of a simple residual ($^{(\hat{d}\hat{q})}\vec{r}_{\text{FIE-RS}}$)
- Analytical tuning capabilities
- Inherent evaluation of cross-coupling effect (via $L'_{\text{dq,0}}$)

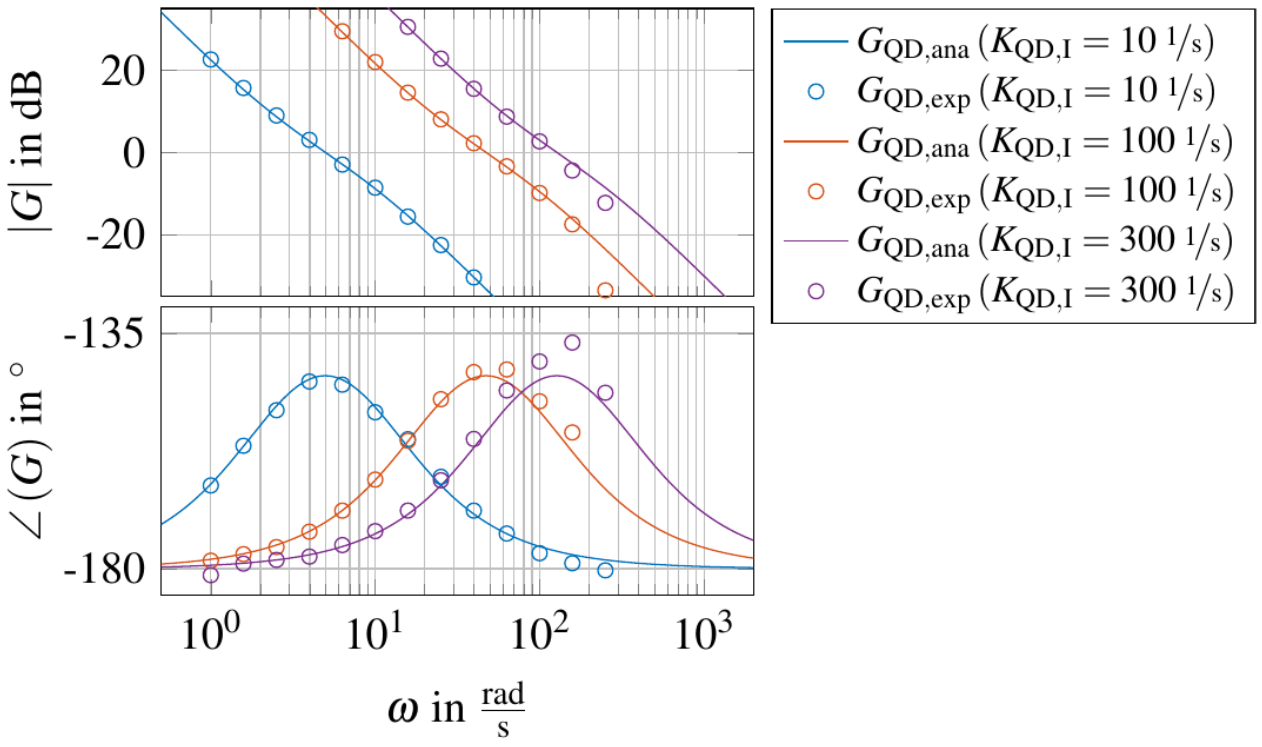
$$^{(\hat{d}\hat{q})}\vec{r}_{\text{FIE-RS}} = T_{\text{PWM}}\,^{(\hat{d}\hat{q})}\vec{v}_{\text{hf}}^{*} - 2^{(\hat{d}\hat{q})}\mathbf{L}'_{(\hat{d}\hat{q})}\,^{(\hat{d}\hat{q})}\Delta\vec{i}_{\text{hf}}$$

$$^{(\hat{d}\hat{q})}\mathbf{L}'_{(\hat{d}\hat{q})} = \begin{pmatrix} L'_{\text{d,0}} & L'_{\text{dq,0}} \\ L'_{\text{dq,0}} & L'_{\text{q,0}} \end{pmatrix}$$

Characteristics of the numerical optimisation

- Lean Numerical optimisation based on Gauss-Newton
- Bandwidth of speed control as a degree of freedom
- Analytical parameterisation capabilities based on the maximum acceleration

Bode plot of the open-loop speed control
(analytical solution vs. experiments)



➡ Analytical parameterisation [3]

Inherent Consideration of the Cross-Coupling Effect

Driving through points of identical self inductances

- Difference of the self inductances

$$\Delta L' = \left.\frac{L'_\mathrm{d} - L'_\mathrm{q}}{2}\right|_{i_\mathrm{q}=5\mathrm{A}} = 0\ \mathrm{p.u.}$$

- Mean value of the self inductances

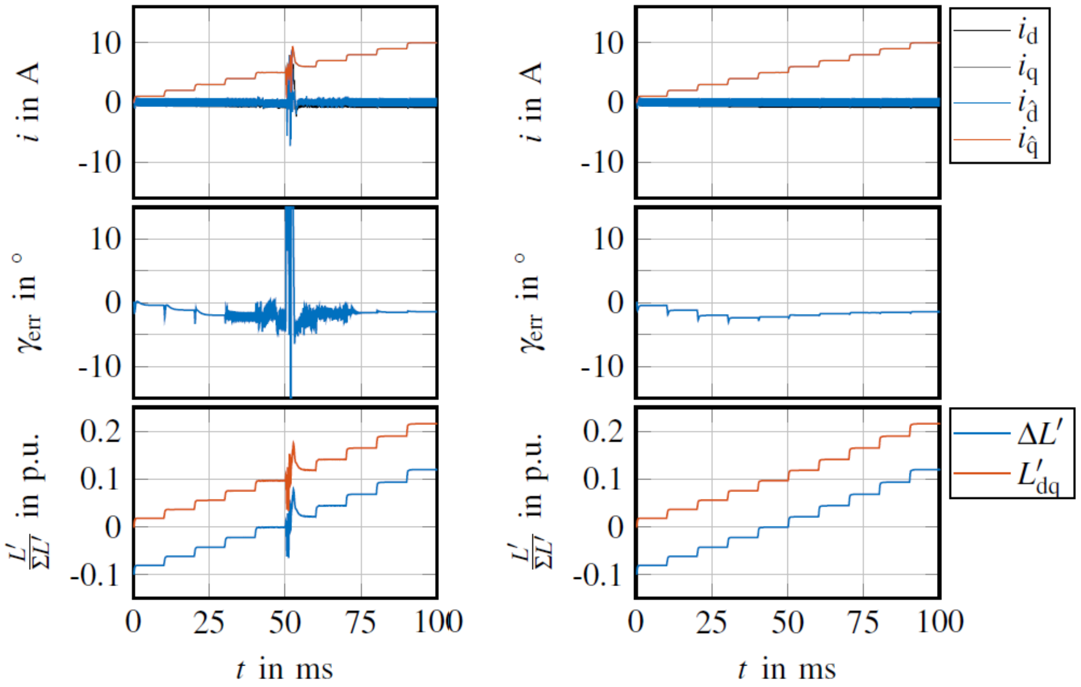
$$\Sigma L' = \left.\frac{L'_\mathrm{d} + L'_\mathrm{q}}{2}\right|_{i_\mathrm{q}=5\mathrm{A}} = 1\ \mathrm{p.u.}$$

- Cross-coupling inductance

$$\left.L'_\mathrm{dq}\right|_{i_\mathrm{q}=5\mathrm{A}} = 0.1\ \mathrm{p.u.}$$

A: Without mutual inductance as a source of information

B: With mutual inductance as a source of information

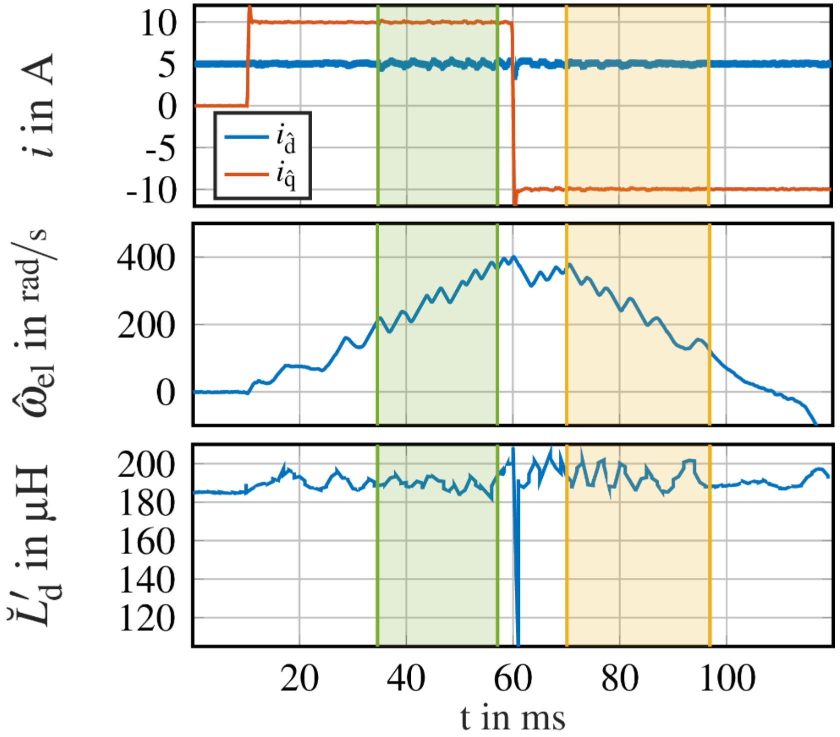


Enabling of SSC for highly saturated machines in the low speed area [4]

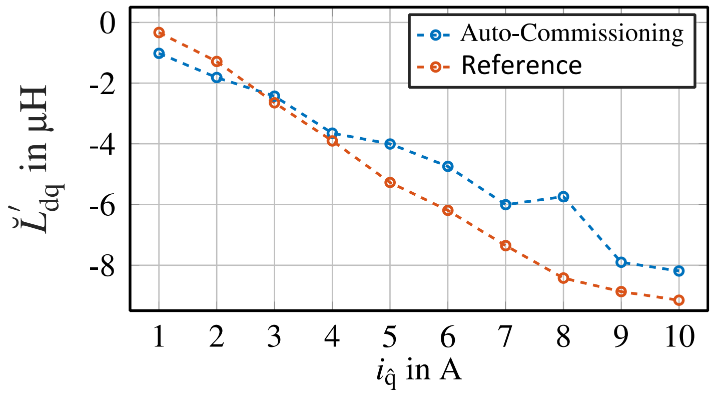
Automatic Commissioning of the SSC

- No need for a position sensor or separate testbench
- Identification of key-parameters in free-wheeling
  - Parameters of the QD calculation
  - Identification of the saturation-dependent inductance matrix

Exemplary identification for $\breve{L}'_{\mathrm{d}}$



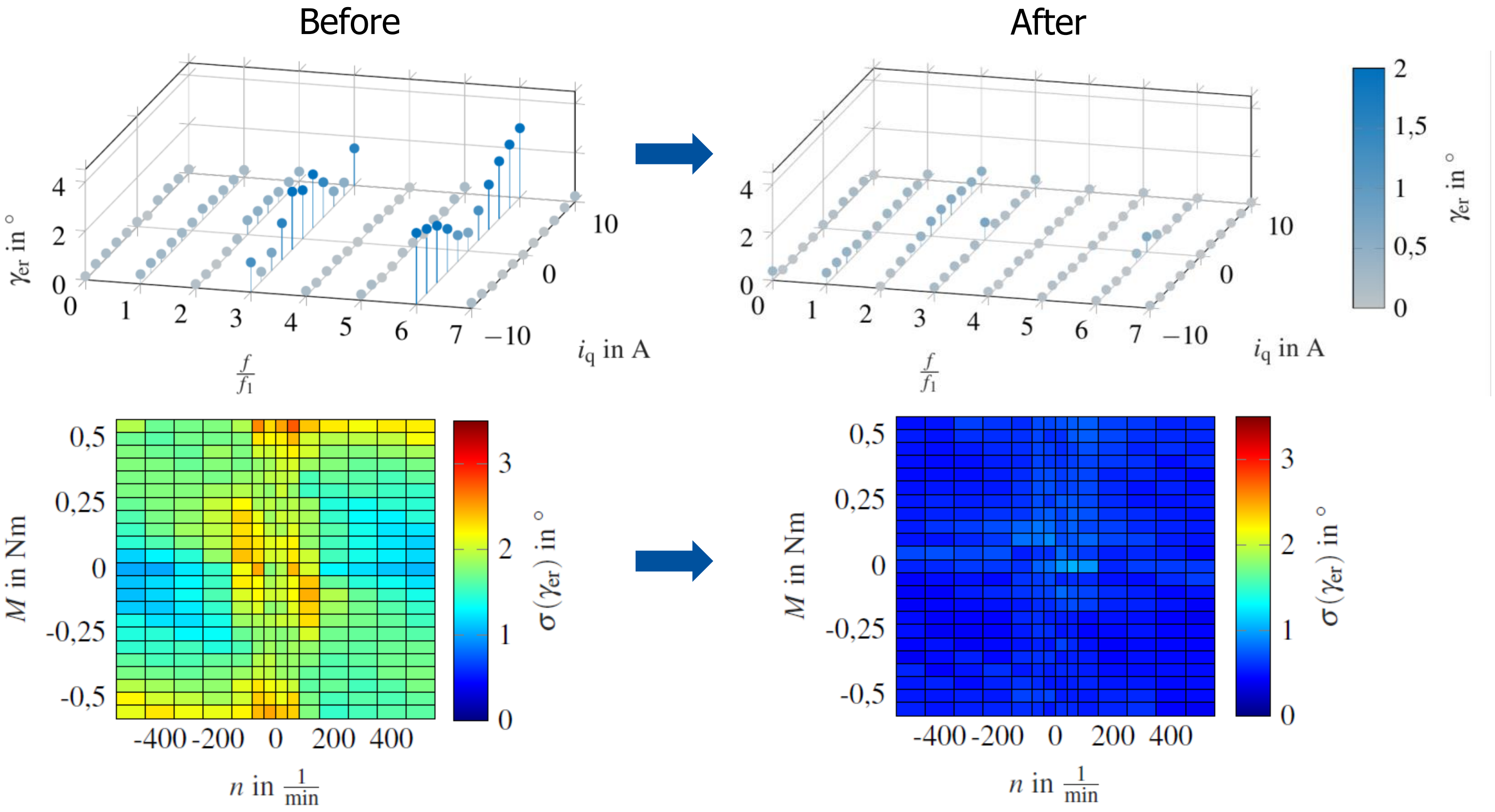
Identification result for $\breve{L}'_{\mathrm{dq}}$



➡ Easier commissioning of SSC [5]

Reduction of Estimation Errors

- Frequency components (f_1 := stator frequency)
  - Constant speed
  - Varying q-current



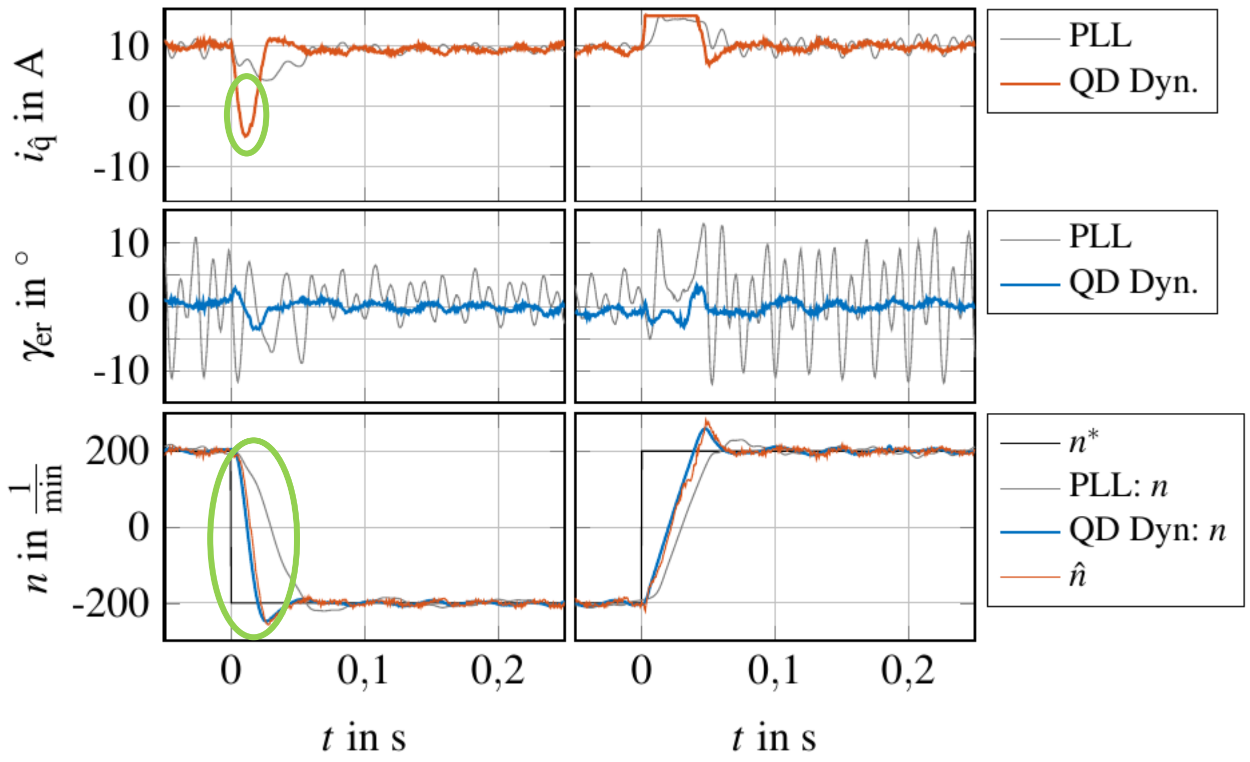
- Standard deviation (with MTPC active)
  - Varying speed (n)
  - Varying torque (M)

Highly accurate position estimation [4,6]

Maximum Dynamic in the Low Speed Area

- Speed-controlled operation [3]
  - Setpoint is reversed
  - Rated torque is applied
- Phase-locked loop (PLL)
  - Results of earlier research
- QD Dynamic
  - Maximum bandwidth of speed control
  - Compensation of a saliency of higher order

Speed control with changing setpoint at rated torque



➡ High control dynamic [4]

Enabling the Widespread use in Commercial Applications

- Introducing an analytically parameterised estimator: The QD calculation
- Broadening the application of SSC to highly saturated machines
- Identifying the key parameters in an automatic commissioning procedure
- Increasing dynamics and accuracy of the SSC

Institute for
Drive Systems and
Power Electronics

Leibniz
Universität
Hannover

Thank You! Any Questions?

Dr.-Ing. Niklas Himker	niklas.himker@iav.de
M.Sc. Viktor Willich	viktor.willich@ial.uni-hannover.de
Dr.-Ing. Georg Lindemann	georg.lindemann@cariad.technology
Prof. Dr.-Ing. Axel Mertens	mertens@ial.uni-hannover.de

Awarded by:

SEMIKRON DANFOSS

Funded by:

DFG Deutsche Forschungsgemeinschaft

Literature

[1] V. Willich and A. Mertens, "Self-Sensing Control of a PMSM Used for an Automotive Application with a Novel Rotor Position Estimator Based on the Back-Electromotive Force," SLED, 2023

[2] V. Willich et.al., "Dynamic Position Estimator for a PMSM using Regular Current Sampling and Numerical Optimisation," ICEMS, 2024

[3] N. Himker, A. Mertens, „Analytical Design of Self-Sensing Control for PMSM Using Quasi-Direct Calculation", OJIA, 2023, DOI: 10.1109/OJIA.2023.3276820

[4] N. Himker, „Anisotropie-basierte geberlose Regelung von permanentmagneterregten Synchronmaschinen", TEWISS, 2024

[5] G. Lindemann, „Selbst parametrierbare positionsgeberlose Regelung für den Grunddrehzahlbereich einer permanentmagneterregten Synchronmaschine", TEWISS, 2024

[6] N. Himker, et.al., „Reduction of the Effect of Machine Saturation on the Quality of Self-Sensing Control", TPEL, 2025, DOI: 10.1109/TPEL.2024.3487314