Universität Rostock — Traditio et Innovatio

EUROPÄISCHE UNION
Europäischer Sozialfonds

Design and Analysis of Discrete Current Regulators for VSIs

Europäische Fonds EFRE, ESF und ELER in Mecklenburg-Vorpommern 2014-2020

Netz Stabil

This paper was made within the framework of the research project *Netz-Stabil* and financed by the European Social Fund (ESF/14-BM-A55-0015/16). This paper is part of the qualification program *Promotion of Young Scientists in Excellent Research Associations - Excellence Research Programme of the State of Mecklenburg-Western Pomerania*.

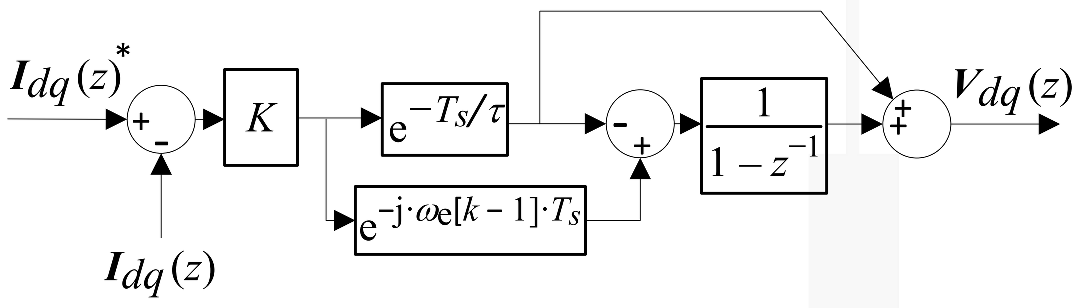
Michael Schütt, Hans-Günter Eckel

Introduction

- This paper compares the quasi-continuous dq-decoupling techniques to various discrete modeling approaches for *Voltage Oriented Control* (VOC)
- To analyze the different techniques, this paper provides both *Frequency Response Functions* (FRFs) for *Command Tracking* (CT) and *Dynamic Stiffnes* (DS), and time domain tests
- Two *Voltage Source Inverter* (VSI) topologies have been used:
  1. Small-Scale Laboratory HVDC-MMC 2. Industrial Converter of a 3 MW Wind Turbine Generator

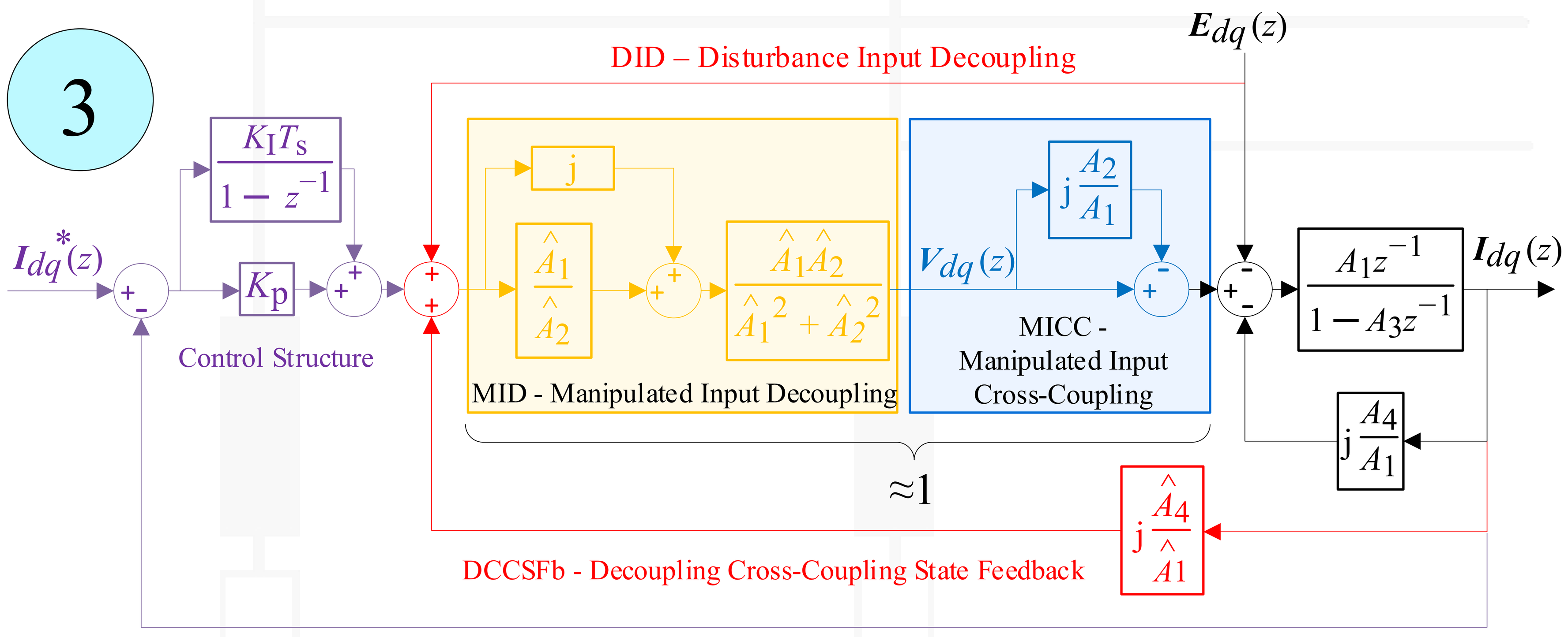
Compared dq-Decoupling Techniques

1



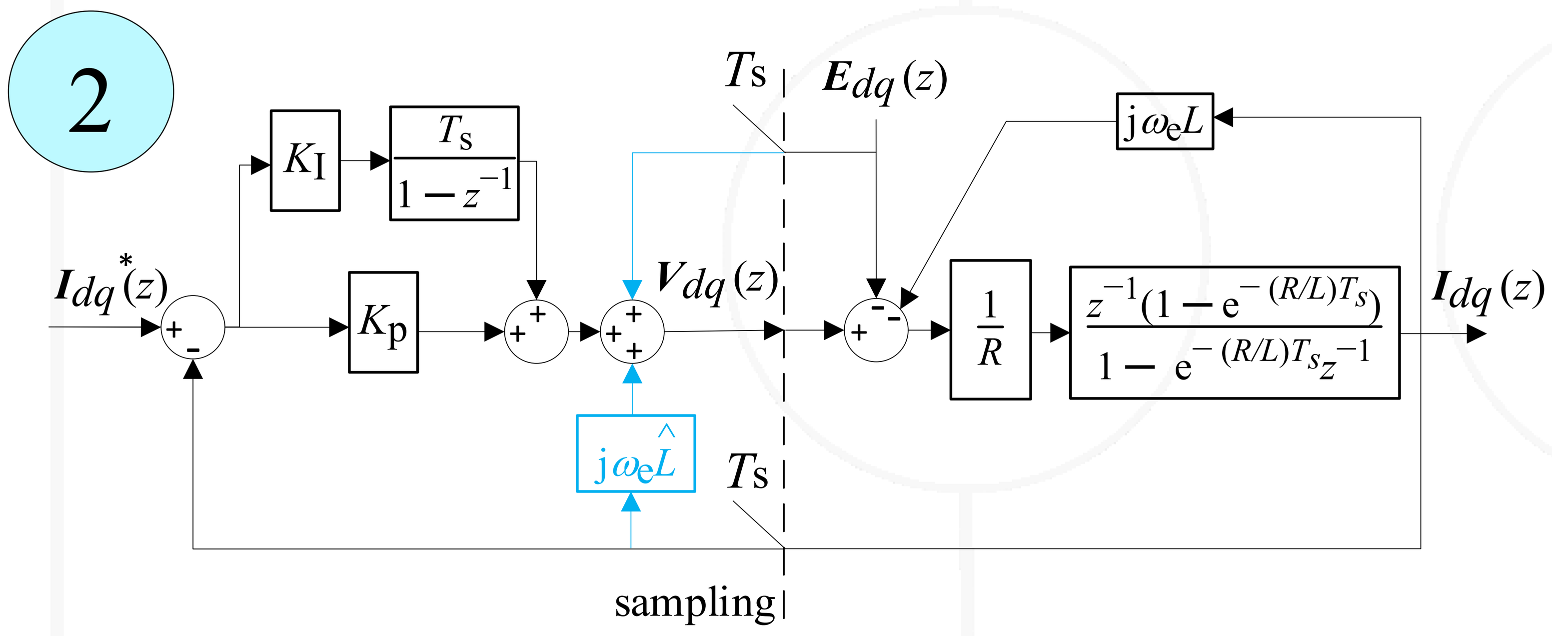
Discrete complex vector synchronous frame PI current regulator obtained via direct modeling (Briz, et.al, 2000).

3



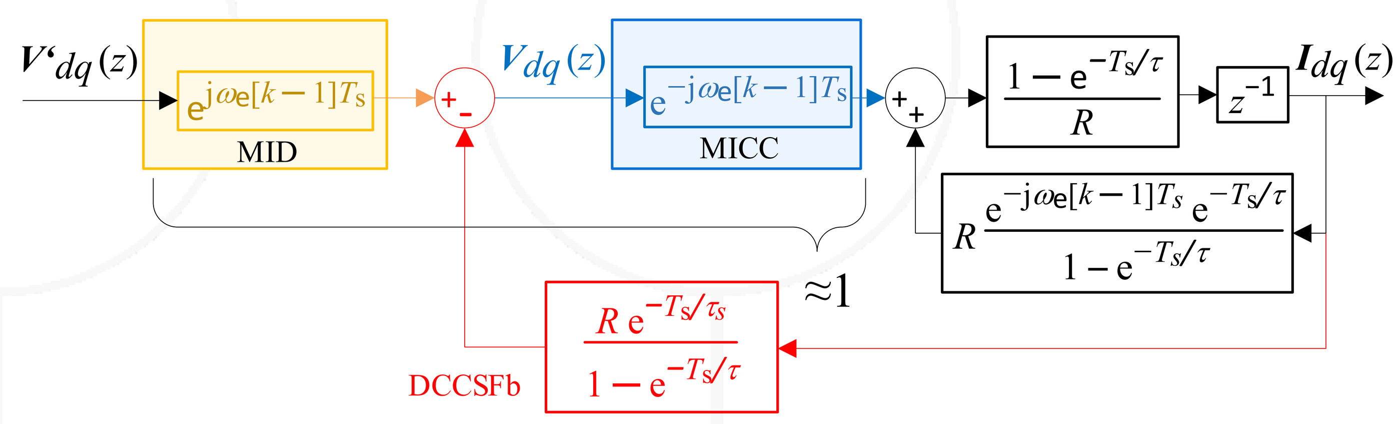
Proposed discrete-time complex vector synchronous frame PI current regulator with discrete DCCSFb and DID (red), MICC (blue), and MID (yellow).

2



Discrete-Time PI controller with DID and continuous DCCSFb approach in blue.

4



Discrete State Block Diagram of the *RL*-plant of a VSI with MICC (blue) and MID (yellow) and full DSFb (red).

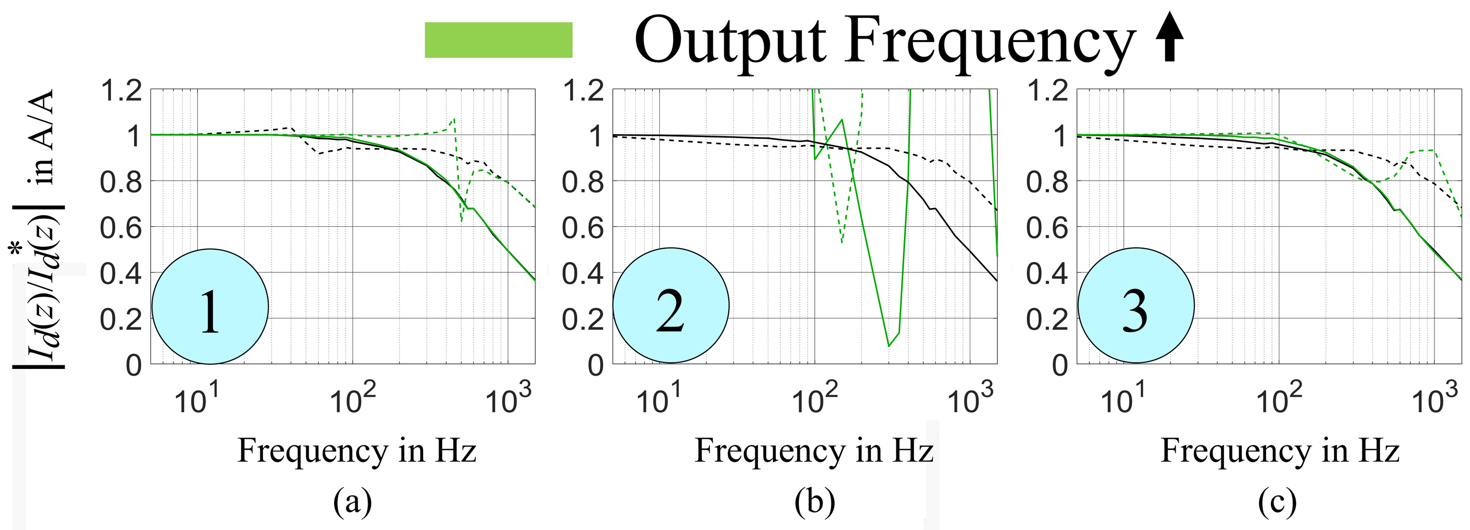
- Four different dq-decoupling techniques are presented and compared during dynamic events:
  1. Discrete CCVC 2. Quasi-Continuous DCCSFb 3. Discrete DCCSFb w/ MID 4. Full DSFb

Institute of Electrical Power Engineering | Power Electronics and Electrical Drives
University of Rostock, Albert-Einstein-Str. 2, 18059 Rostock, Germany

Universität Rostock

Traditio et Innovatio

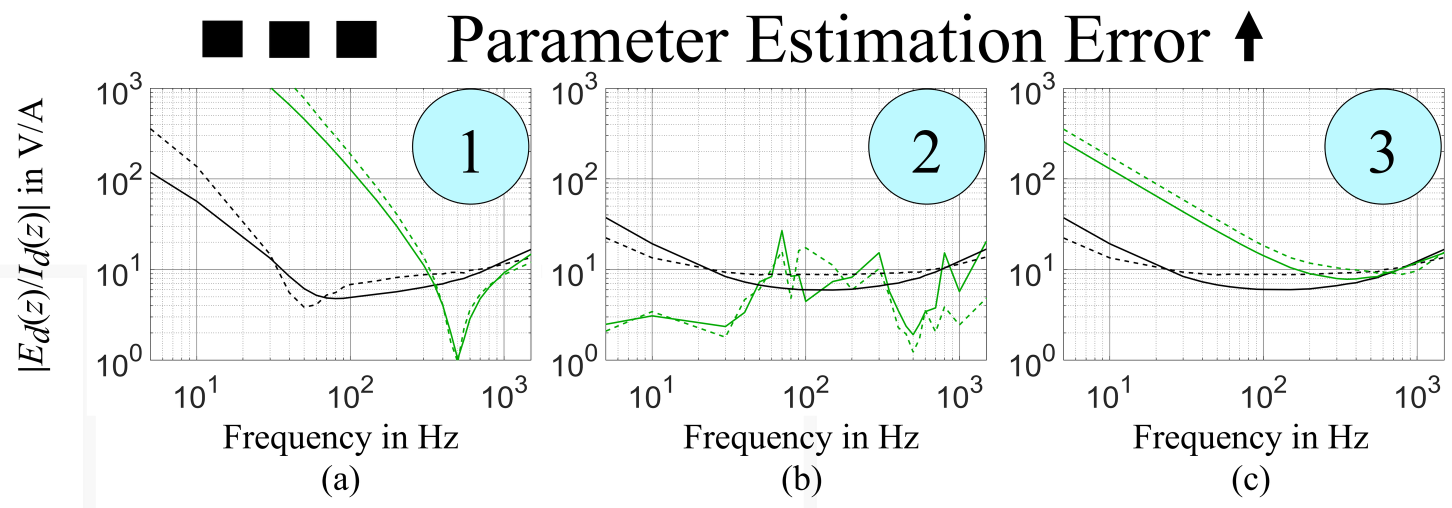
Dynamic Analysis of the Control Techniques



---: $\tau_{\text{est}} = 3\,\tau\,(L_{\text{est}} = 1.5L,\, R_{\text{est}} = 0.5R),\ \omega_e = 2\pi 500$ rad/s —: $\tau_{\text{est}} = \tau,\ \omega_e = 2\pi 500$ rad/s

---: $\tau_{\text{est}} = 3\,\tau\,(L_{\text{est}} = 1.5L,\, R_{\text{est}} = 0.5R),\ \omega_e = 2\pi 50$ rad/s —: $\tau_{\text{est}} = \tau,\ \omega_e = 2\pi 50$ rad/s

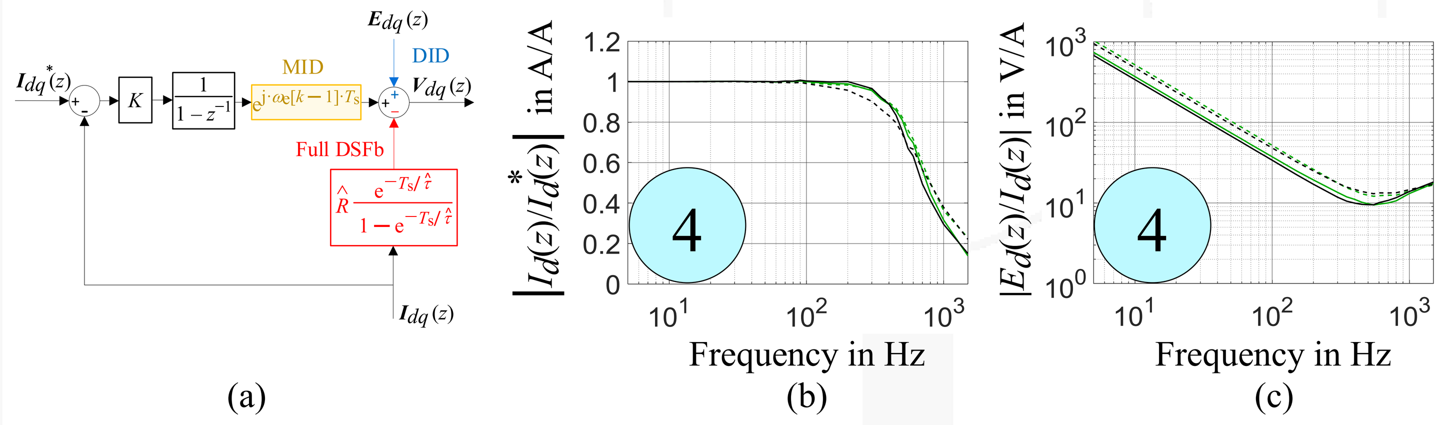
CT FRFs for 2 kHz switching frequency, 500 Hz bandwidth - (a) discrete CVC, (b) w/ continuous DCCSFb, (c) w/ discrete DCCSFb and MID.



---: $\tau_{\text{est}} = 3\,\tau\,(L_{\text{est}} = 1.5L,\, R_{\text{est}} = 0.5R),\ \omega_e = 2\pi 500$ rad/s —: $\tau_{\text{est}} = \tau,\ \omega_e = 2\pi 500$ rad/s

---: $\tau_{\text{est}} = 3\,\tau\,(L_{\text{est}} = 1.5L,\, R_{\text{est}} = 0.5R),\ \omega_e = 2\pi 50$ rad/s —: $\tau_{\text{est}} = \tau,\ \omega_e = 2\pi 50$ rad/s

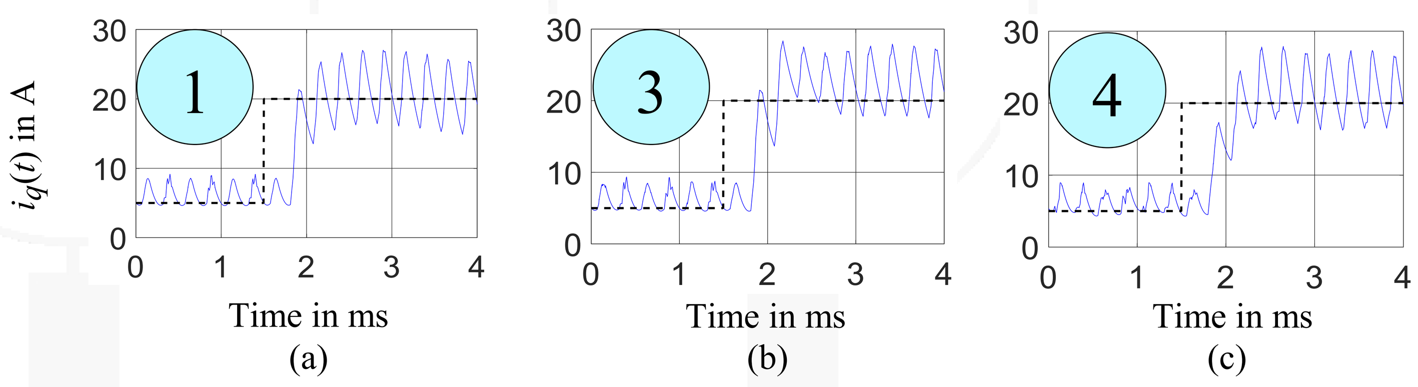
DS FRFs for 2 kHz switching frequency, 500 Hz bandwidth - (a) discrete CVC, (b) w/ continuous DCCSFb, (c) w/ discrete DCCSFb and MID.



---: $\tau_{\text{est}} = 3\,\tau\,(L_{\text{est}} = 1.5L,\, R_{\text{est}} = 0.5R),\ \omega_e = 2\pi 500$ rad/s —: $\tau_{\text{est}} = \tau,\ \omega_e = 2\pi 500$ rad/s

---: $\tau_{\text{est}} = 3\,\tau\,(L_{\text{est}} = 1.5L,\, R_{\text{est}} = 0.5R),\ \omega_e = 2\pi 50$ rad/s —: $\tau_{\text{est}} = \tau,\ \omega_e = 2\pi 50$ rad/s

Control technique with full DSFb; (a) control structure, (b) CT, (c) DS @ 2 kHz switching frequency, 500 Hz bandwidth.

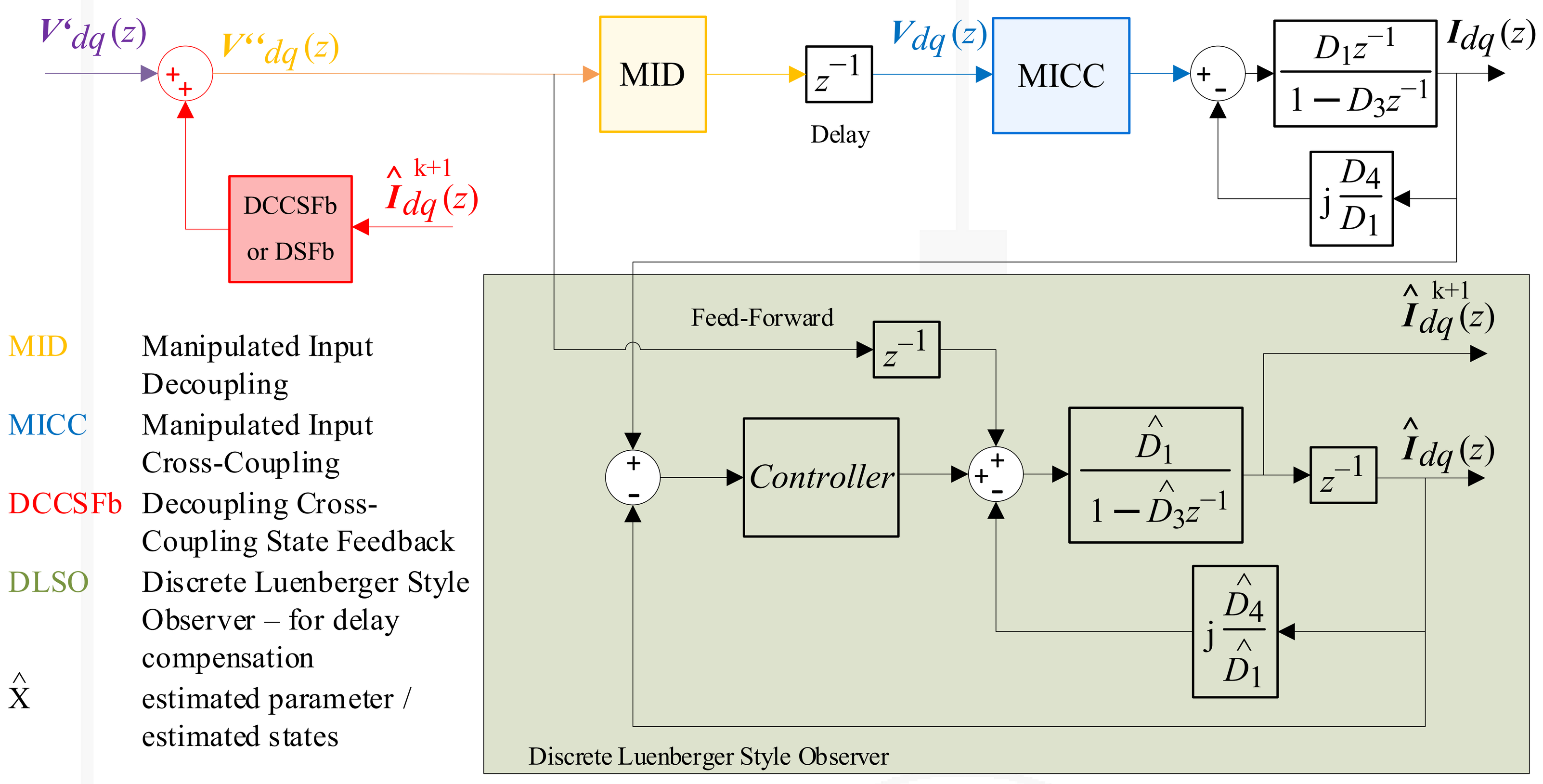


---: $v_{\text{qref}}(t)$ —: $i_q(t)$

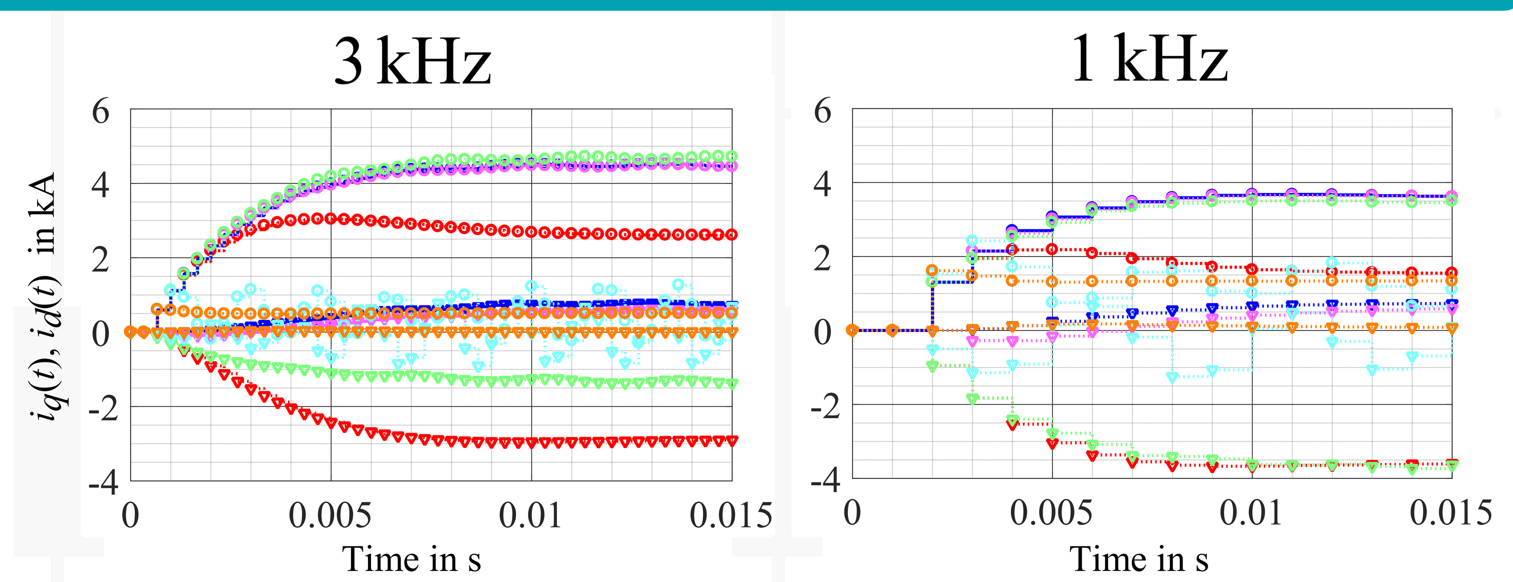
Response in q-axis current during a simultaneous step command on q- and d-axis current of the studied control topologies @ $\omega_e = 2\pi 500$ rad/s, $f_{\text{sw}} = 2$ kHz and $\tau_{\text{est}} = 3\,\tau$ ($L_{\text{est}} = 1.5L$, $R_{\text{est}} = 0.5R$); (a) CVC, (b) discrete DCCSFb w/ MID, (c) discrete full DSFb w/ MID.

- Discrete approaches show superior command tracking and disturbance rejection properties
- The discrete techniques show different behavior regarding robustness
- The advantages of discrete approaches are more pronounced at lower switching frequencies

Delay Compensation and Analysis of Different Decoupling Techniques (State-Feedback-based)



Discrete plant model with one period input delay with delay compensation using a Discrete Luenberger Style Observer (DLSO).



---: w/o MID & DCCSFb ---: w/ discrete MID & full DSFb (exp.) w/o delay comp.

---: continuous DCCSFb (ωL) ---: w/ discrete MID & DCCSFb (trig.) w/o delay comp.

---: w/ discrete MID & full DSFb (exp.) & delay comp. (DLSO – see Fig.14)

---: w/ discrete MID & DCCSFb (trig.) & delay comp. (DLSO – see Fig.14)

△: $i_q(t)$; ○: $i_d(t)$; Left: $f_{\text{sw}} = 3$ kHz, $T_s/\tau = 0.13$; Right: $f_{\text{sw}} = 1$ kHz, $T_s/\tau = 0.39$

Open-loop step response of various MID & DCCSFb techniques with parameter estimation error for a 3 MW two-level inverter with $1T_s$ input delay. $\tau_{\text{est}} = 1.5\,\tau$ ($L_{\text{est}} = 1.2L$, $R_{\text{est}} = 0.8\,R$) Step command: $v_{q,\text{ref}}(t) = 0$ V, $v_{d,\text{ref}}(t) = 50$ V, $\omega_e = 2\pi 50$ rad/s, w/ delayed parameters D_1-D_4.

- Discrete approaches provide enhanced decoupling properties compared to quasi-continuous (2)
- Technique (1) – high robustness, but can get oscillatory at high output frequencies
- Technique (3) – overall well-behaved. Medium sensitivity regarding delay and load estimation
- Technique (4) – well-behaved. Low parameter sensitivity regarding load but very sensitive to delay

Conclusion

- At low switching frequencies (depends on ratio of T_s and τ), the advantages of discrete modeling become very apparent, especially at high synchronous speed (method 2 is unstable for some o.p.)
- The examined discrete decoupling techniques differ in robustness attributes

Institute of Electrical Power Engineering | Power Electronics and Electrical Drives
University of Rostock, Albert-Einstein-Str. 2, 18059 Rostock, Germany