IEEE POWER
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Distinguished Lecturer Seminar

Model Predictive Control in Power Electronics:

A Critical Review and Recent Industrial Products

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Model Predictive Control in Power Electronics
Outline

Introduction

- Control and modulation
  – *The classic approach in power electronics*
- Vision for power conversion control
  – *And the case for model predictive control*

Control concepts

- Finite control set model predictive control (FCS-MPC)
  – *Direct model predictive control*
- Model predictive pulse pattern control (MP^{3}C)
  – *Fast control of optimized pulse patterns (OPPs)*
- Model predictive control of load commutated inverters (LCI)
  – *Coordinated control with constraints*

Assessment and conclusions

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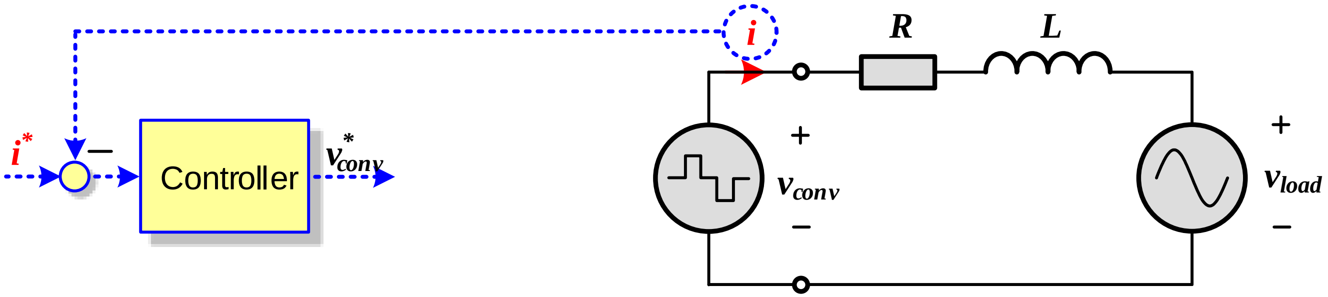
Assessment and conclusions

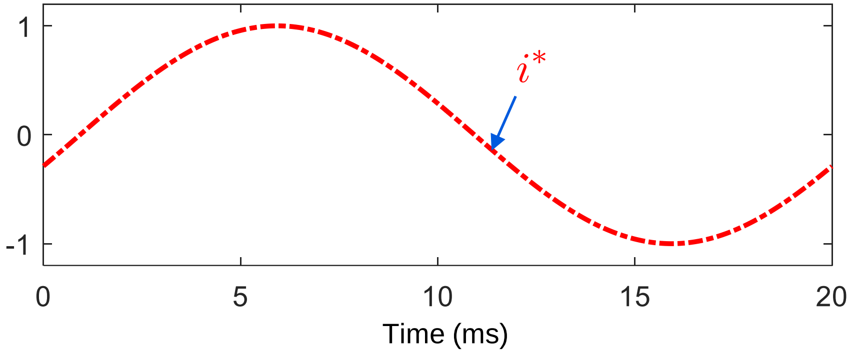
Introduction to Control and Modulation
A Simple Control Problem

Single-phase converter with active *RL* load

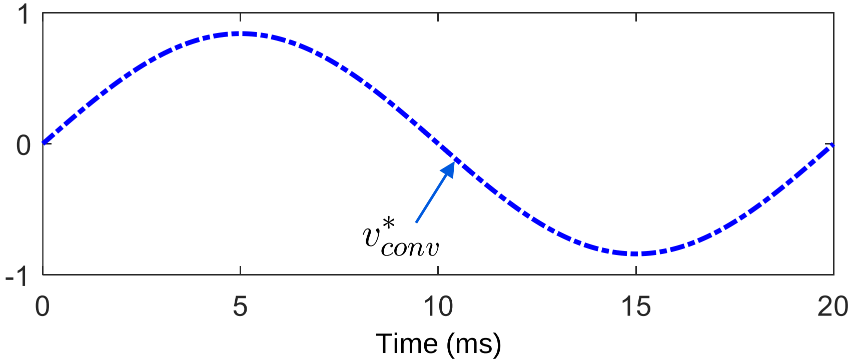


Control objective:

Regulate the load current i along its reference i^*



by manipulating the reference converter voltage v^*_{conv}



Control problem: manipulate the plant input such that the output **follows its reference**, the plant is **stabilized** and an acceptable **performance** is achieved (despite **disturbances**)

Introduction to Control and Modulation
A Simple Control Problem

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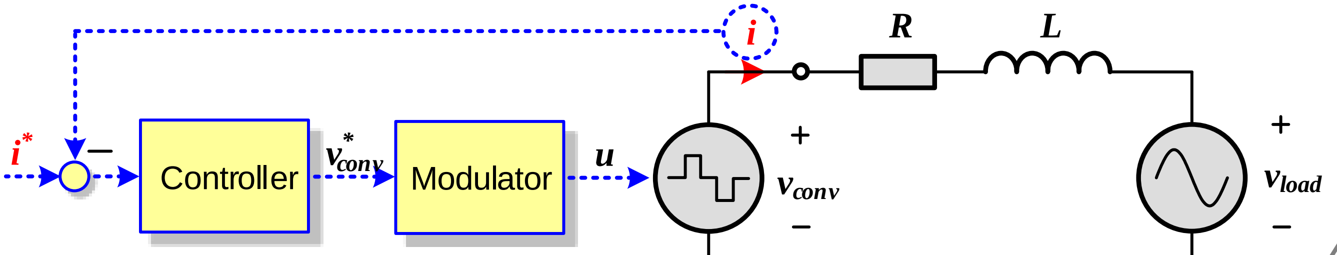

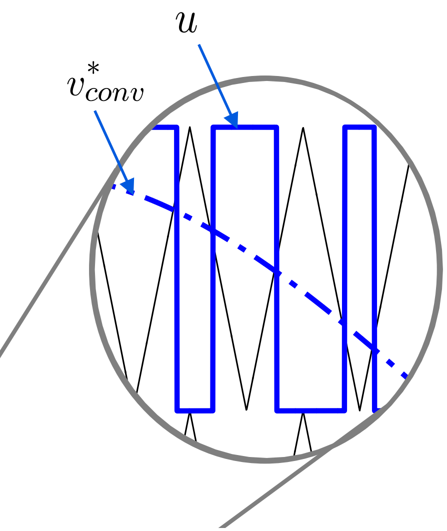

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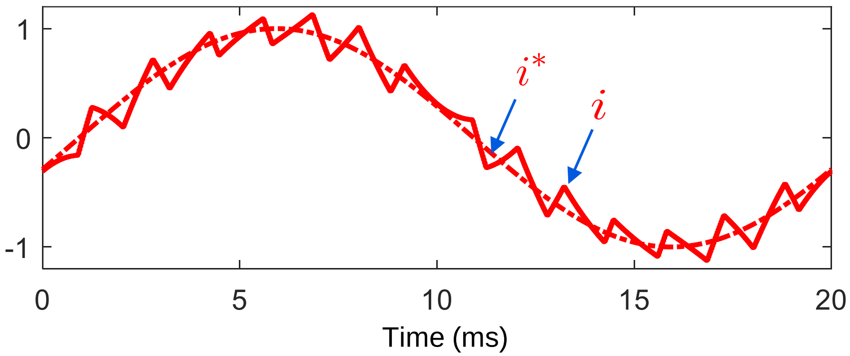
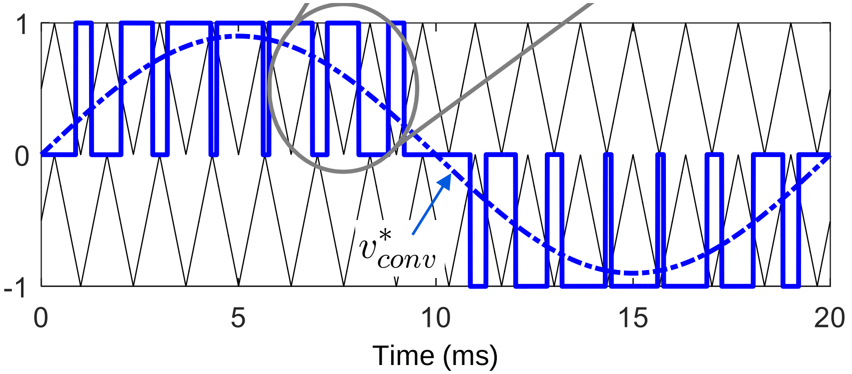


by manipulating the switch position $u \in \mathbb{Z}$

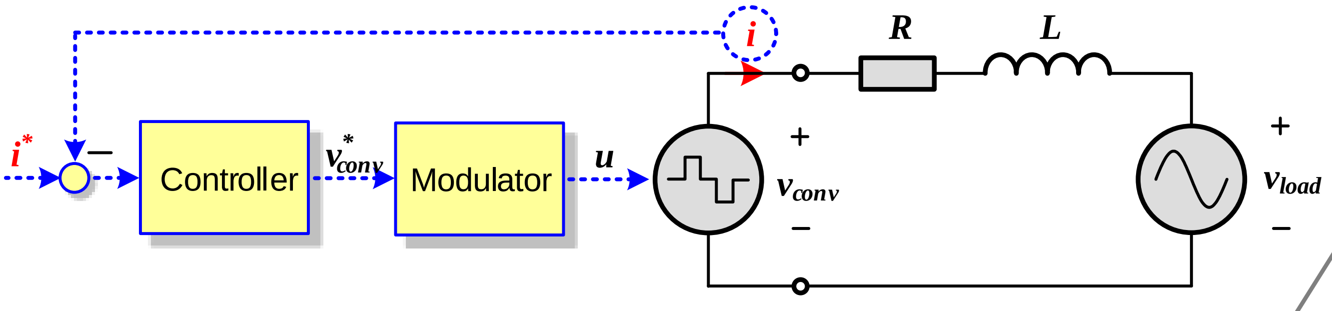


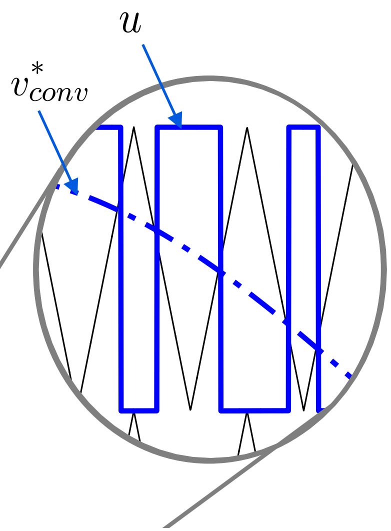
… using carrier-based pulse width modulation

A **pulse width modulator** translates the real-valued input reference v^*_{conv} into **switching commands** *u*

Introduction to Control and Modulation
A Simple Control Problem

Single-phase converter with active *RL* load





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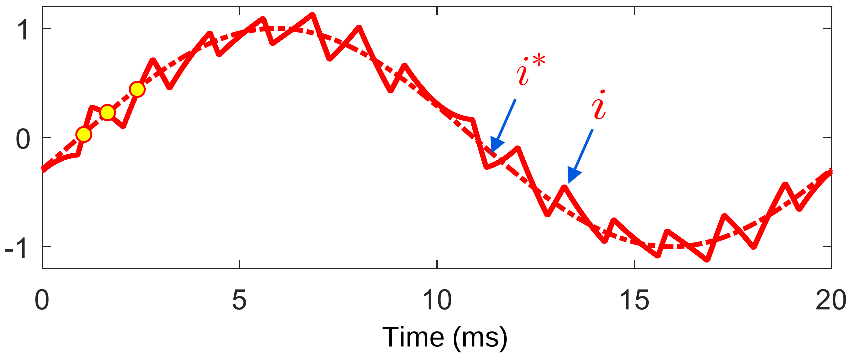

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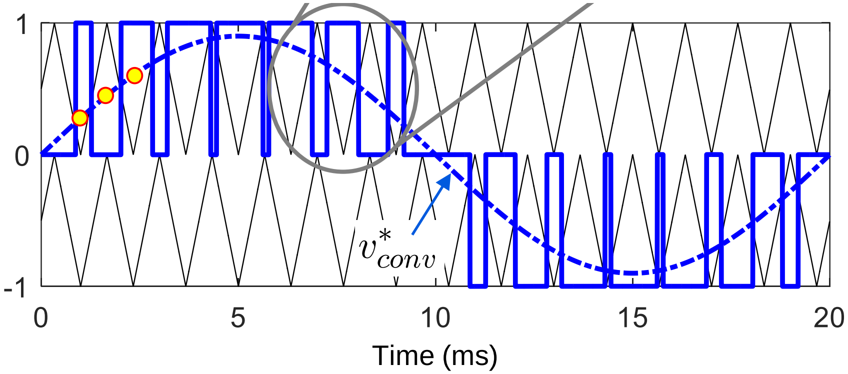


… using carrier-based pulse width modulation

Carrier-based PWM and appropriate sampling **hides the switching behavior**

This directly extends to three-phase systems and general loads (such as electrical machines and the grid)

Introduction to Control and Modulation

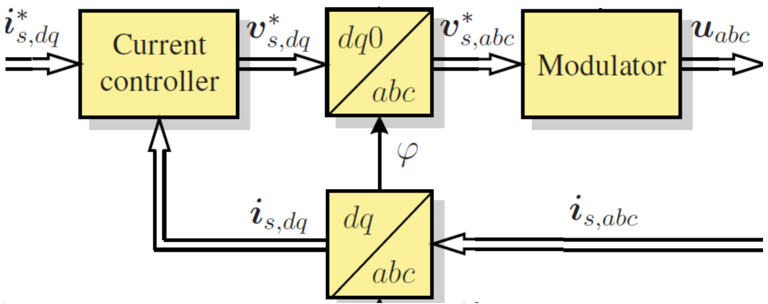
Inner (Current) Control – The Commonly Used Approach

- Split the inner control problem into a **current controller** and a **modulator**

=> Hides the switching characteristic from the controller (assuming zero current ripple at the sampling instants)

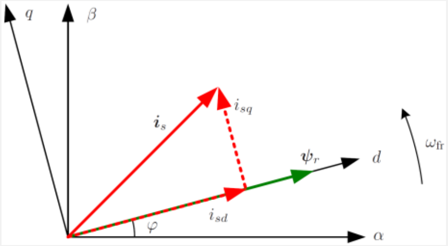
- Work in a **rotating** coordinate system

=> Turns ac quantities into dc quantities (at steady-state operation)



Current controller:

- Field-oriented or voltage-oriented control (FOC / VOC):
  - **PI control**
  - Deadbeat control



Modulator:

- Classic modulation
  - **Carrier-based PWM**
  - Space vector modulation (SVM)
  - Discontinuous PWM
- “Programmed” modulation
  - Optimized pulse pattern (OPP)
  - Selective harmonic elimination (SHE)

Current controller and modulator combined:

- Direct torque control (DTC) or direct power control (DPC)

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Assessment and conclusions

Vision for Power Conversion Control
Objectives

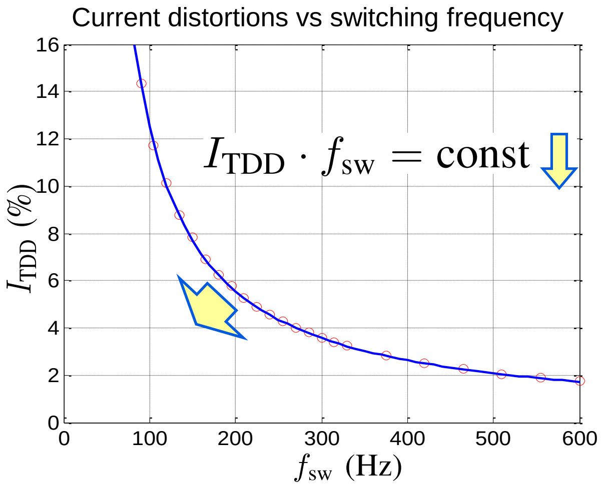
Develop **control** methods that **fully utilize** the hardware **capability** of the power electronic system

- Minimize harmonic **distortions**

  => **Load**-friendly operation

- Minimize **switching effort** (switching frequency / losses)

  => **Converter**-friendly operation



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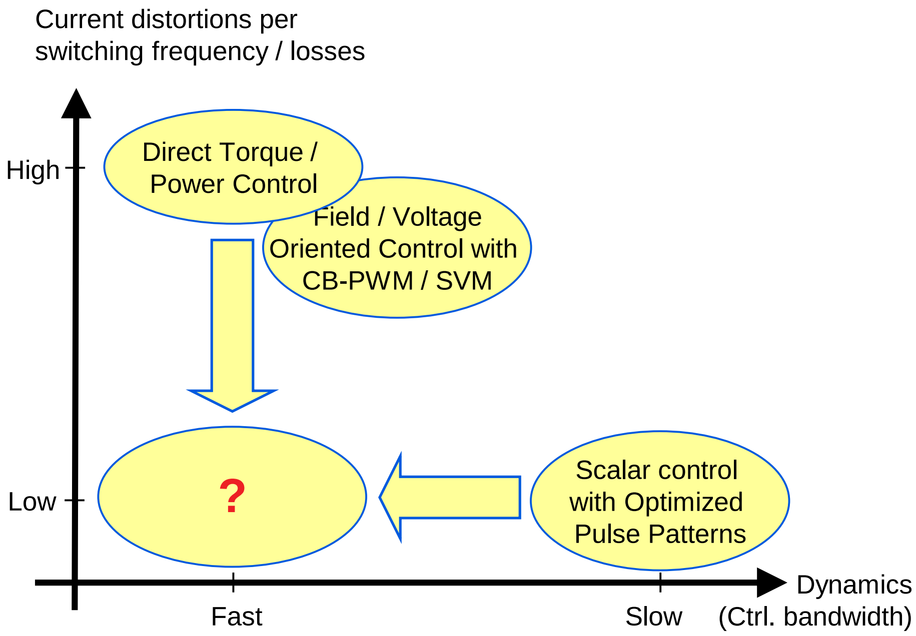
- Maximize the **dynamic performance**

  => Fast power steps and **disturbance rejection**

- Ensure operation within safe operating limits

  => High **availability**



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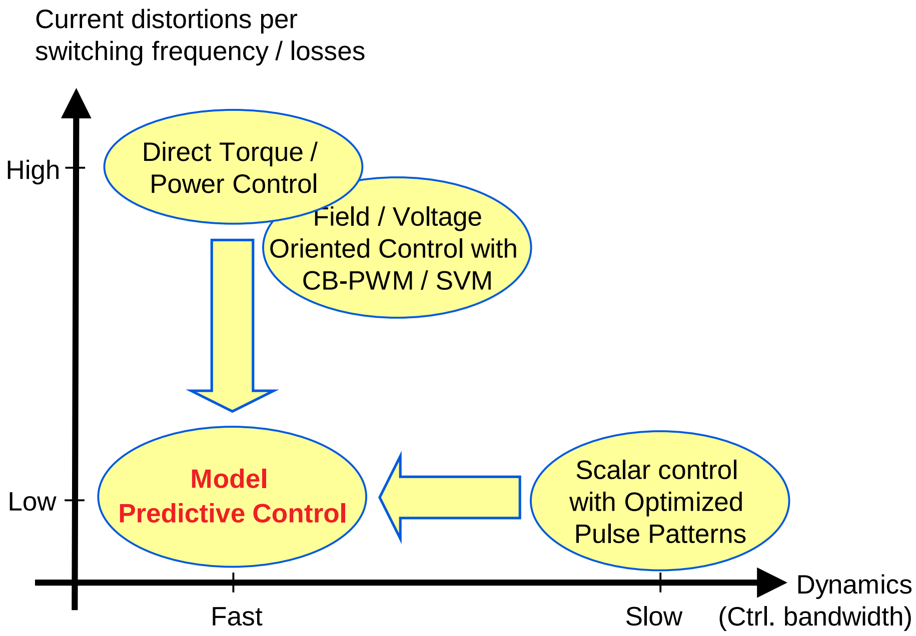


Vision for Power Conversion Control

Model Predictive Control

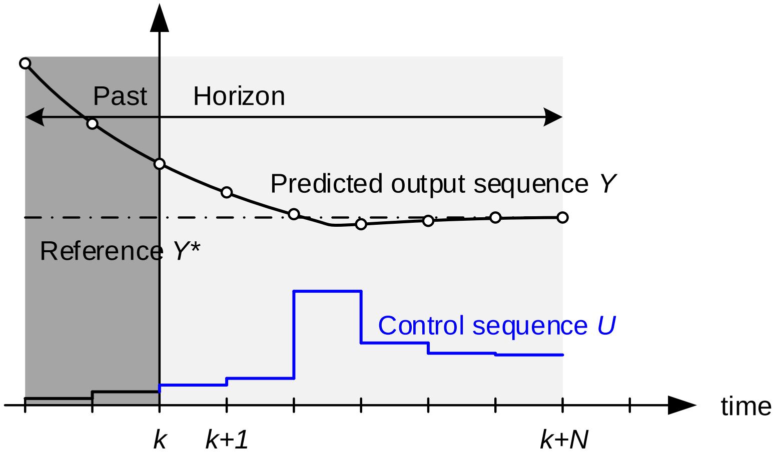
Concept: Use a mathematical model of the system to predict its future evolution over a horizon (taking into account constraints) and choose the "best" control input by solving a numerical optimization problem. At the next step, obtain new measurements and re-plan over a shifted horizon.

Key Features:

- **Internal model:** describes the dynamic system behaviour
  => basis for predictions, makes the controller 'smart'

$$\boldsymbol{x}(k+1) = f\big(\boldsymbol{x}(k), \boldsymbol{u}(k)\big)$$

$$\boldsymbol{y}(k) = g\big(\boldsymbol{x}(k)\big)$$



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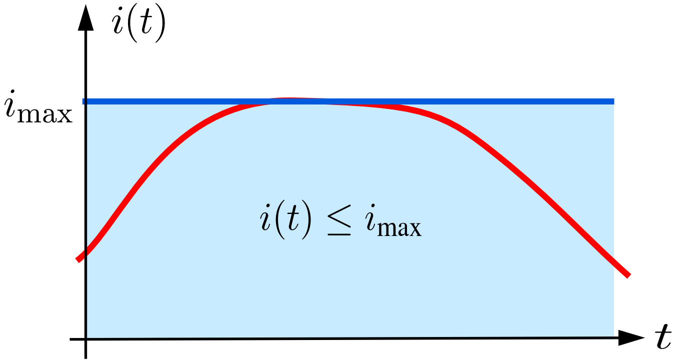

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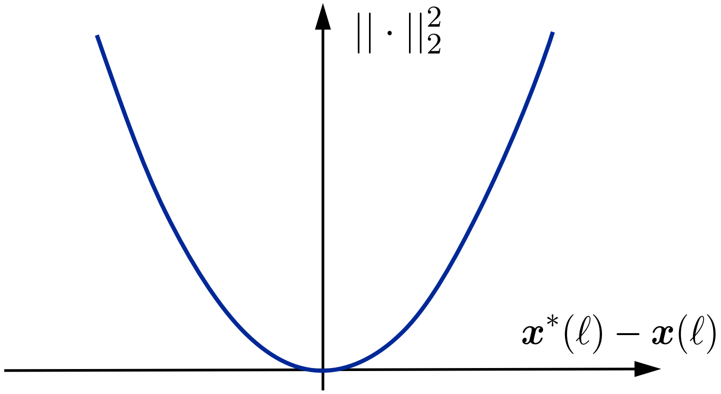
  - => *controller design and tuning*



$$J=\sum_{\ell=k}^{k+N-1}||\boldsymbol{i}^*(\ell+1)-\boldsymbol{i}(\ell+1)||_2^2+\lambda_u||\boldsymbol{\Delta u}(\ell)||_2^2$$

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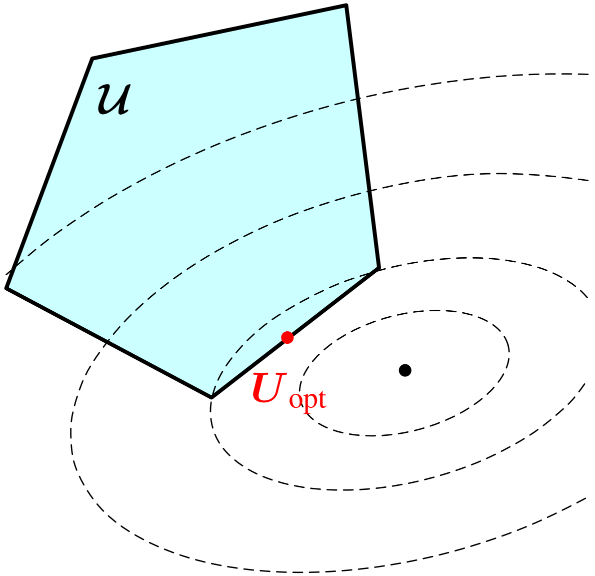
  => *yields the optimal control input*



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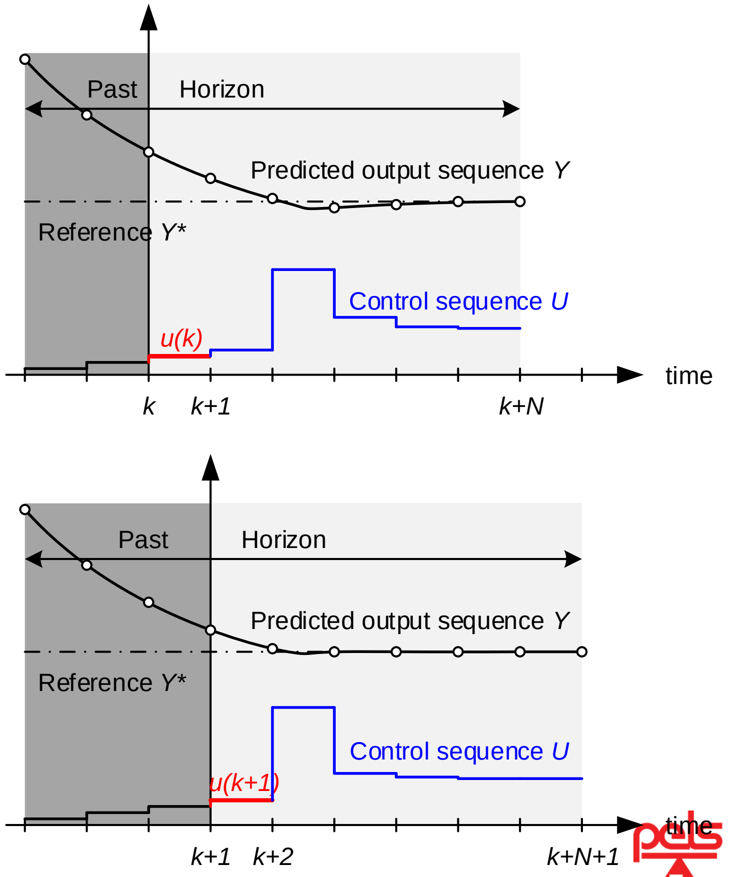
- **Receding horizon:** applies only the first control action of a long plan and repeats this procedure at the next time step

  => *feedback and robustness*



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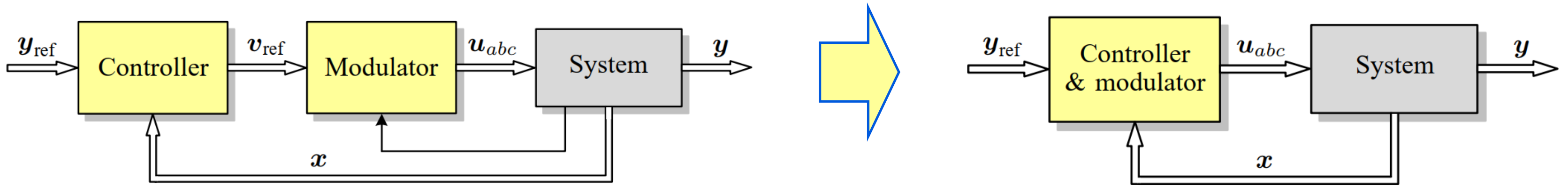
Vision for Power Conversion Control
Challenges and Solution Approaches

To make the model predictive control concept **applicable** to power electronics, it must be **tailored** to the problem at hand:

- **Sampling intervals** are very short => Little time to solve the optimization problem
- System inputs are the converter **switch positions** => Integer manipulated variables
- Optimal **switching patterns** can be pre-computed => Use them in the controller design

Combine control and modulation in one computational stage with model predictive control:

- Avoid the **delay** of the modulator stage
- Consider the **switching** characteristic in the controller



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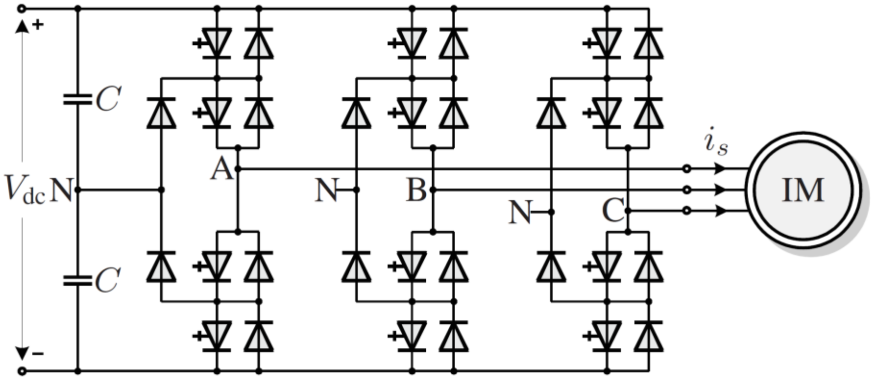
Assessment and conclusions

Finite Control Set Model Predictive Control
Case Study and Control Problem

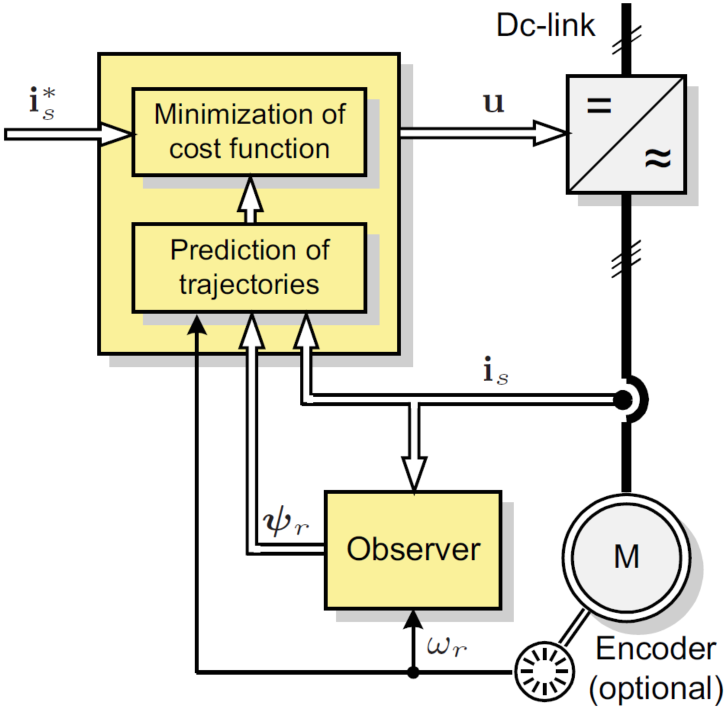
Case Study

- Medium-voltage drive
- Three-level NPC inverter with 5.2kV dc-link voltage
- Induction machine with 3.3 kV, 2 MVA and 50 Hz



Control Problem

- Regulate the stator current $\mathbf{i}_s$ along its reference $\mathbf{i}_s^*$ by manipulating the three-phase switch position $\mathbf{u}$
- Minimize the switching frequency



Finite Control Set Model Predictive Control
Control Problem Formulation

Cost function:

$$J = \sum_{\ell=k}^{k+N-1} \underbrace{||\, \boldsymbol{i}^*(\ell+1) - \boldsymbol{i}\,(\ell+1)||_2^2}_{\text{Tracking error (deviation from reference)}} + \underbrace{\lambda_u ||\boldsymbol{\Delta u}(\ell)||_2^2}_{\text{Penalty on switching effort}}$$

$$\boldsymbol{\Delta u}(\ell) = \boldsymbol{u}(\ell) - \boldsymbol{u}(\ell-1)$$

System model:

$$\boldsymbol{x}(\ell+1) = \boldsymbol{A}\boldsymbol{x}(\ell) + \boldsymbol{B}\boldsymbol{u}(\ell)$$

with $\boldsymbol{x} = [\boldsymbol{i}^T \ \boldsymbol{\psi}^T \ \ldots \ ]^T$

$\boldsymbol{u} \in \mathbb{Z}^3$

Input constraints:

$$\boldsymbol{u}(\ell) \in \{-1, 0, 1\}^3$$

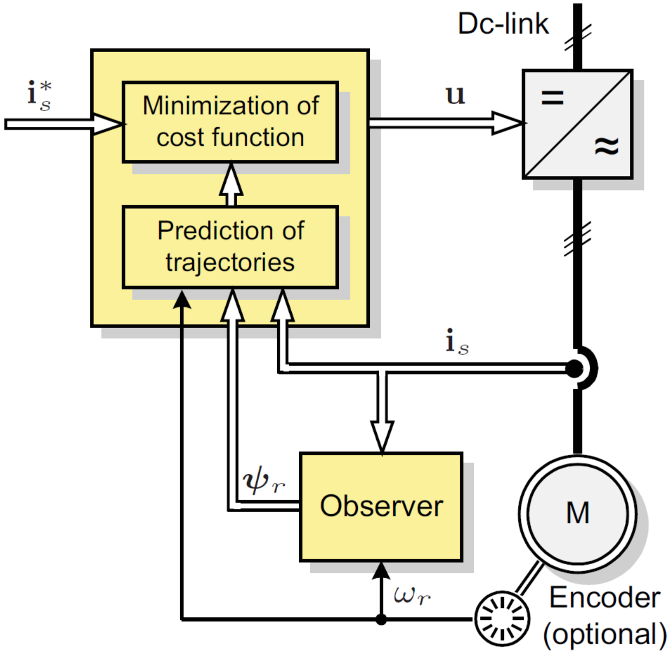
$$||\boldsymbol{\Delta u}(\ell)||_\infty \leq 1$$

Minimize the cost function

subject to the evolution of the system model and the input constraints

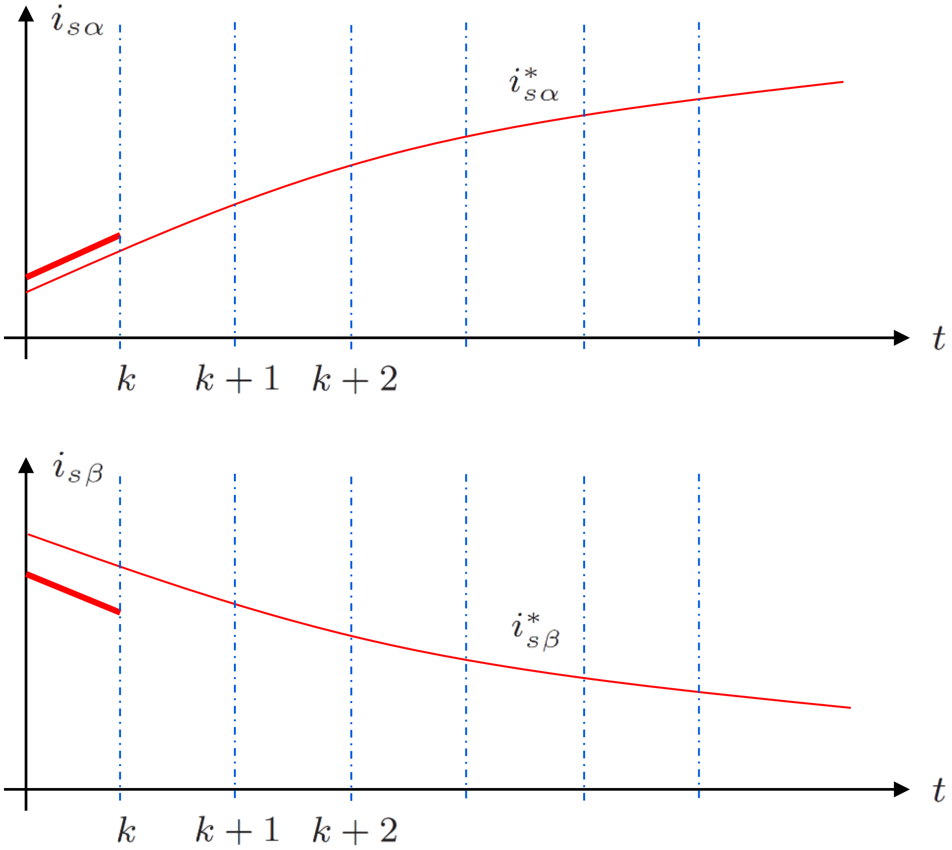
Finite Control Set Model Predictive Control
Enumeration

Control scheme



The controller directly manipulates the switch position ***u*** (without a modulator)

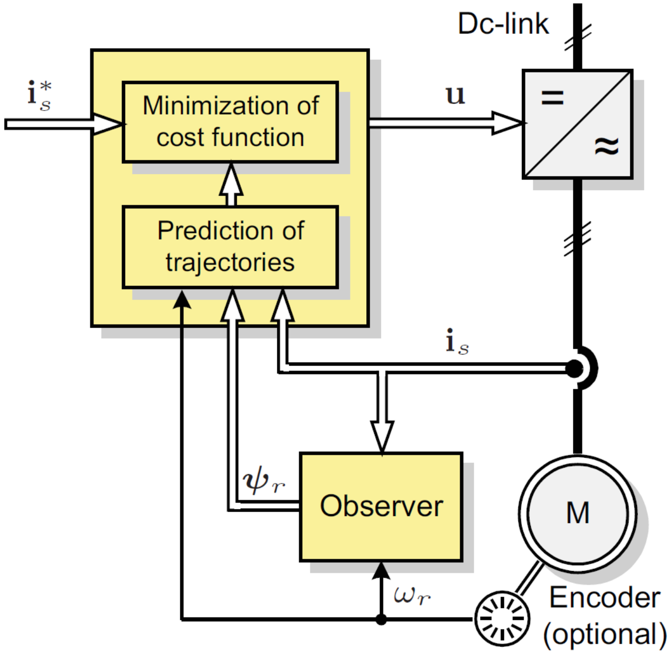
Tracking of current references



Finite Control Set Model Predictive Control

Enumeration with $N = 1$

Control scheme



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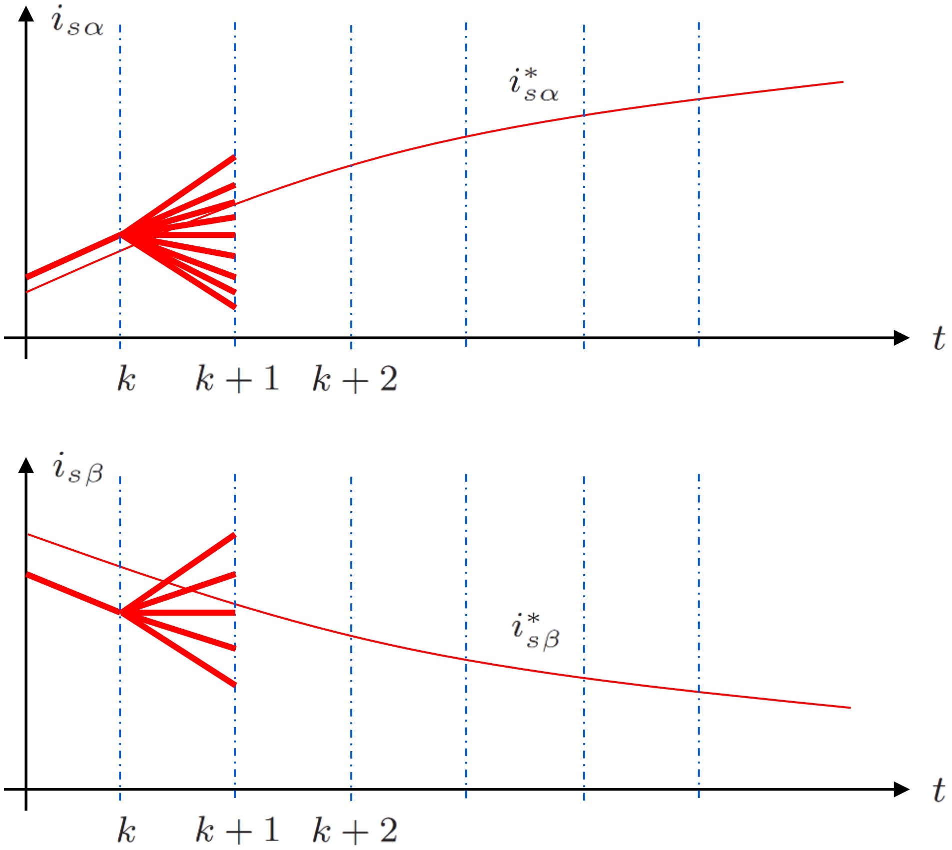
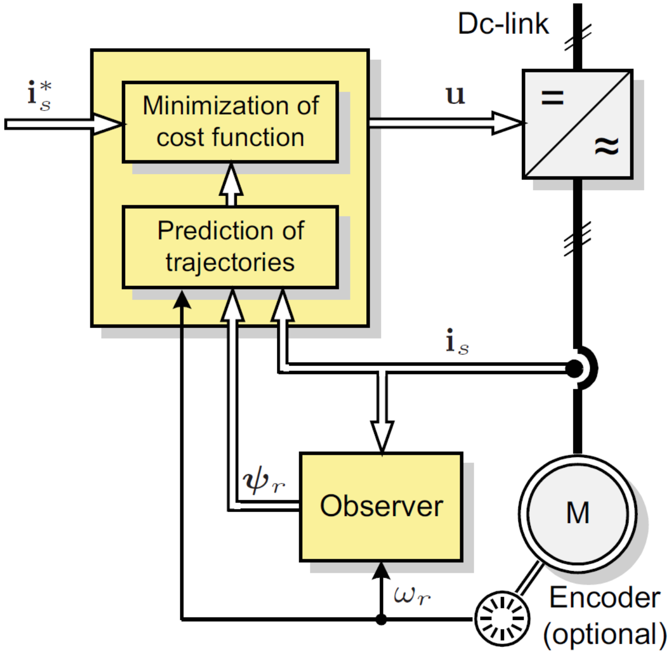


27 combinations

Finite Control Set Model Predictive Control

Enumeration with *N* = 2

Control scheme



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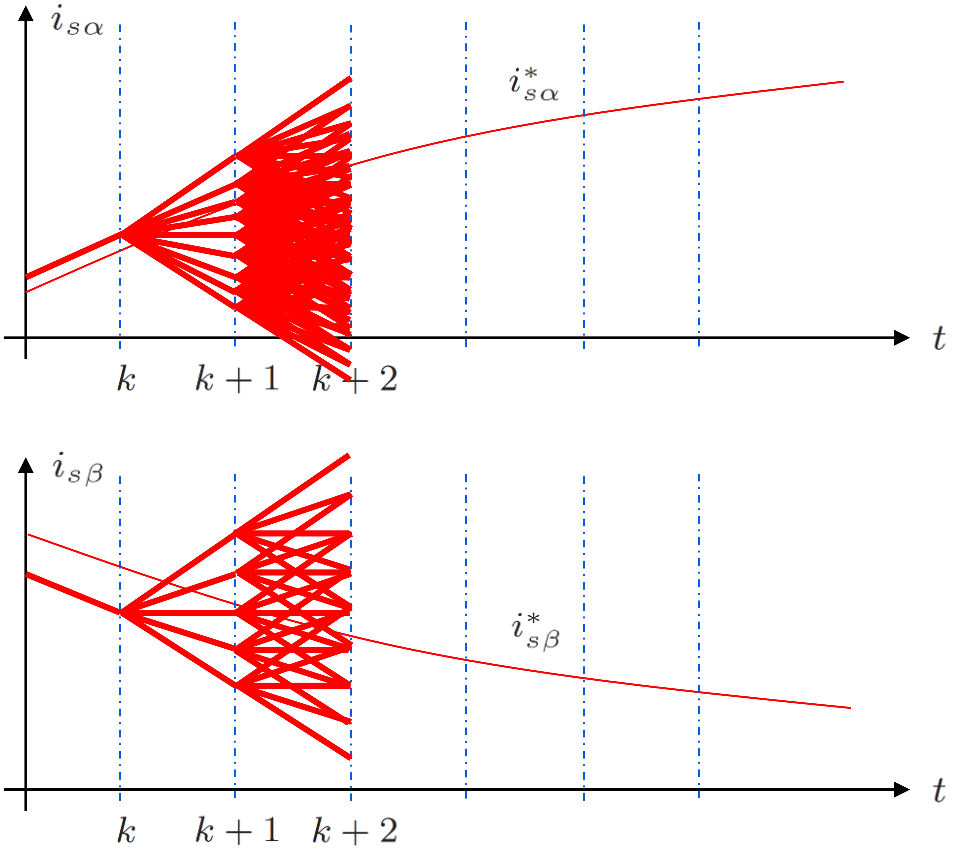
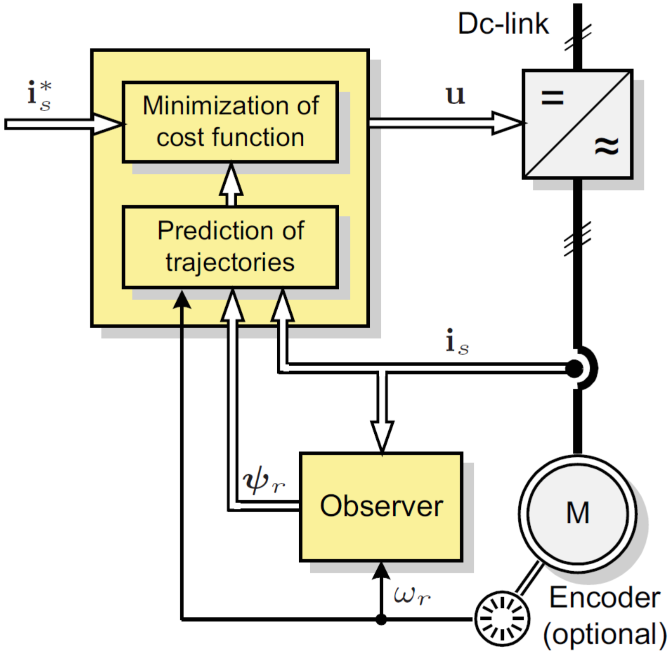


27^2 = 729 combinations

Finite Control Set Model Predictive Control
Enumeration with $N = 3$

Control scheme



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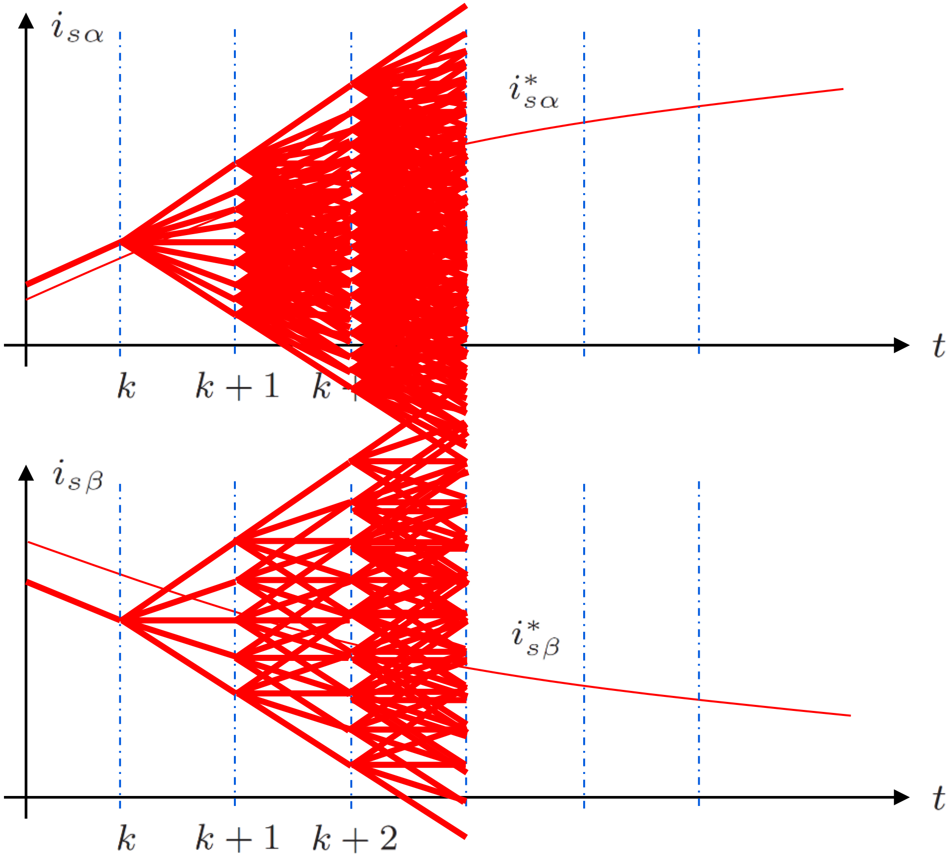


27^3 = 19’700 combinations

Finite Control Set Model Predictive Control
Sphere Decoder

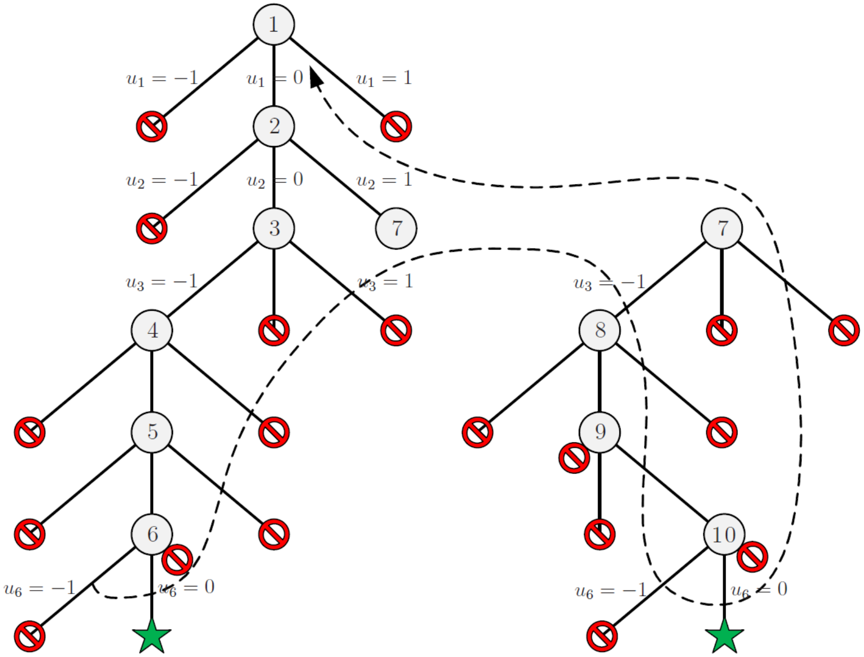
Branch and bound algorithm

- Branching over the set of single-phase switch positions $\mathcal{U} = \{-1, 0, 1\}$ that meet the switching constraint $||\Delta \boldsymbol{u}(\ell)||_\infty \leq 1$
- Bounding: consider solutions only within the sphere of radius $\rho(k)$:

  $$||\boldsymbol{V}\boldsymbol{U}(k) - \boldsymbol{V}\boldsymbol{U}_{\text{unc}}(k)||_2 \leq \rho(k)$$

  If the radius is exceeded => certificate has been found that the branch is suboptimal
- The sphere is tightened whenever a better solution is found

Example: search tree for horizon *N*=2



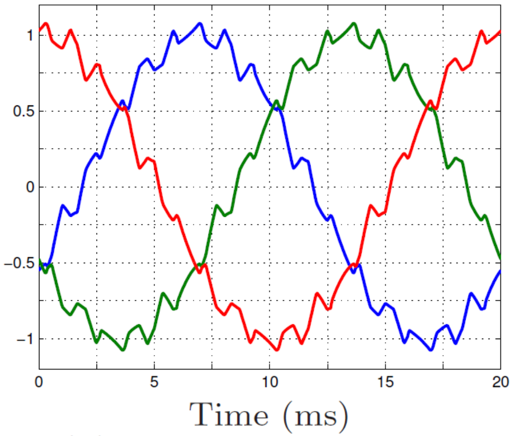
Modified **sphere decoder** solves the integer optimization problem quickly

T. Geyer and D. Quevedo: “Performance of multistep finite control set model predictive control for power electronics", IEEE Trans. on Power Electronics, Mar. 2015

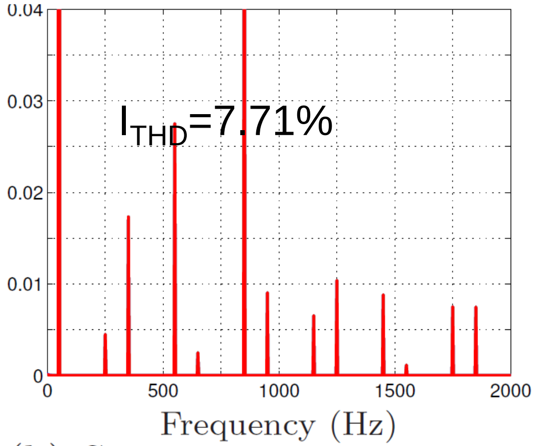
Finite Control Set Model Predictive Control

Steady-State Performance at w=1pu, T=1pu and f_{sw}=250Hz

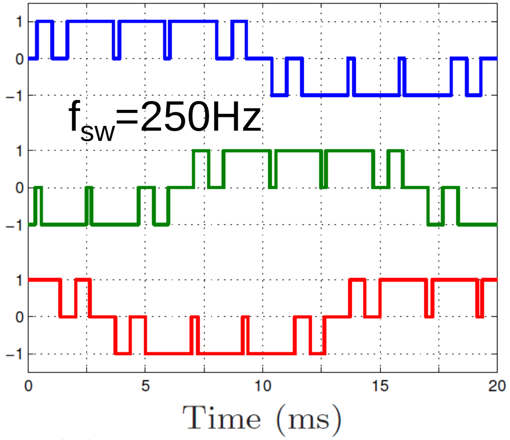
Space vector modulation



(a) Stator currents $\mathbf{i}_s$

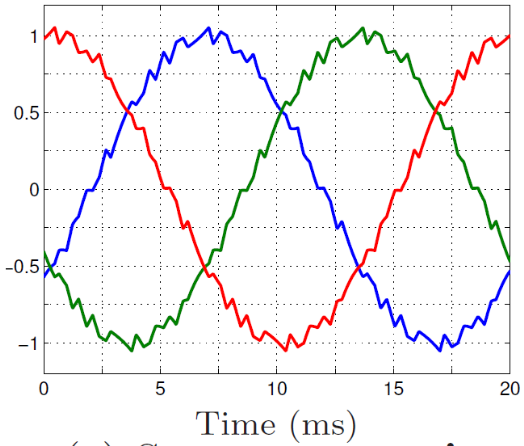


(b) Stator current spectrum



(c) Switch positions u

Optimized pulse pattern



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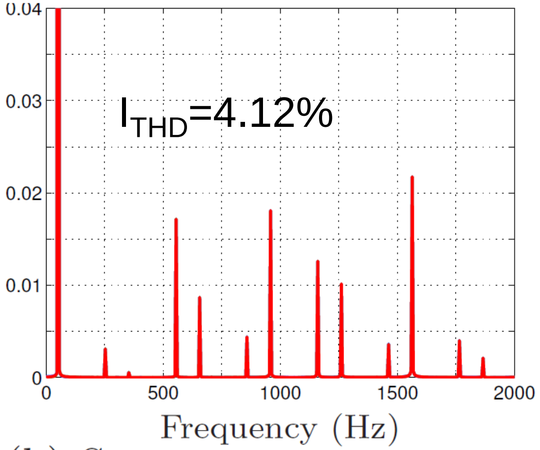

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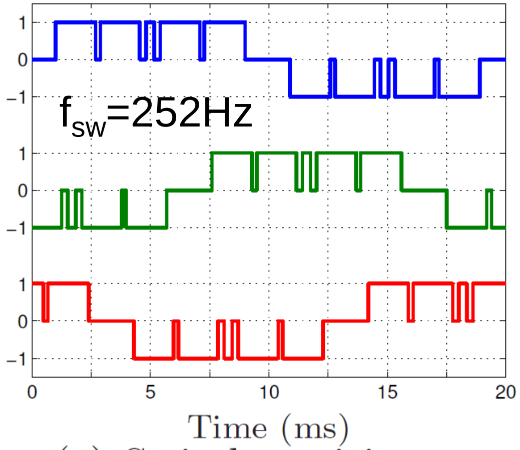
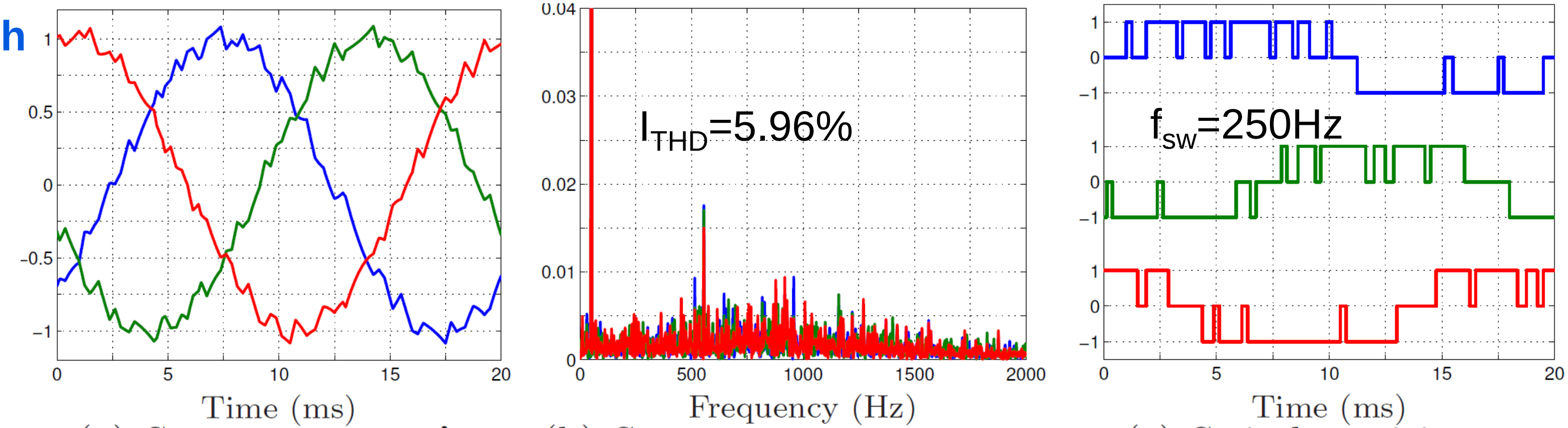


(c) Switch positions u

Finite Control Set Model Predictive Control

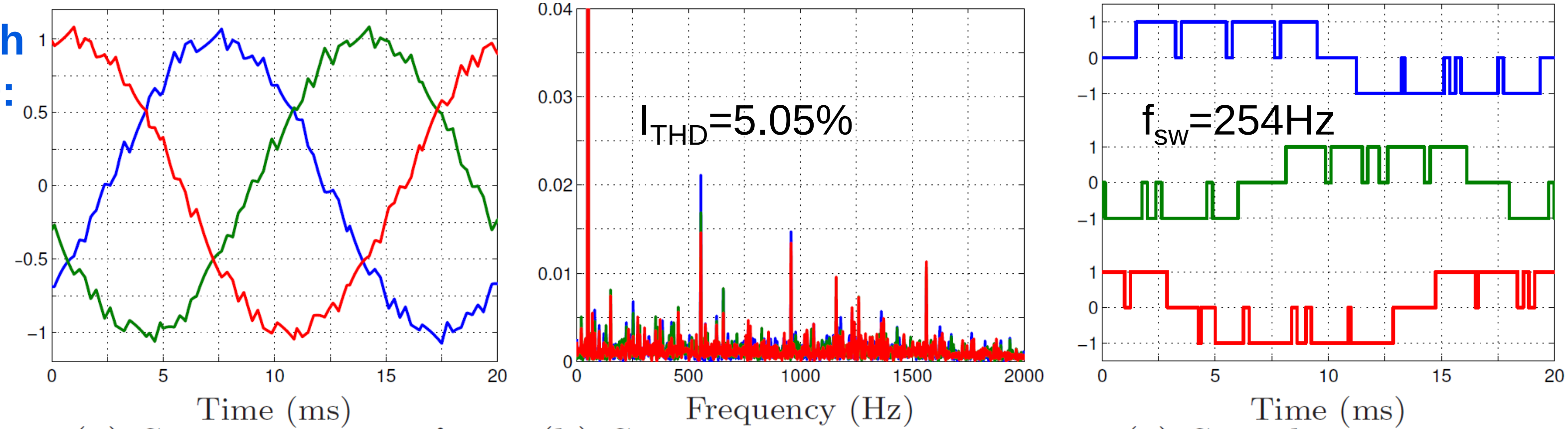
Steady-State Performance at w=1pu, T=1pu and f_{sw}=250Hz

FCS-MPC with horizon *N*=1:



(a) Stator currents $\mathbf{i}_s$ (b) Stator current spectrum (c) Switch positions u

FCS-MPC with horizon *N*=10:



(a) Stator currents $\mathbf{i}_s$ (b) Stator current spectrum (c) Switch positions u

Long horizons concentrate the **spectral content** (particularly in the common-mode harmonics)

Finite Control Set Model Predictive Control

Animation

Drive System:

- 3-level NPC inverter with dc-link voltage V_{dc} = 5.2kV
- 3.3kV induction machine rated at 2MVA

Operating point:

- Nominal speed w=1pu with rated torque T=1pu

Controller parameters:

- Prediction horizon $\boldsymbol{N} \mathbf{= 40}$
- Penalty on switching λ_u = 0.075
- Sampling interval T_s = 25us

Performance metrics:

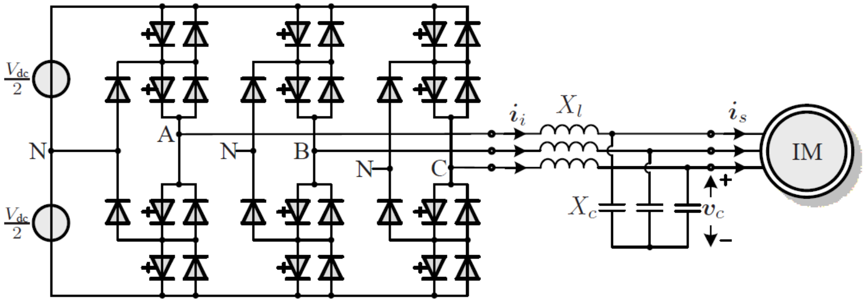
- Switching frequency f_{sw} = 202Hz
- Current distortions iTHD = 5.27%

PredCtrl_N40_w1_3L_steadyState.mp4

Finite Control Set Model Predictive Control

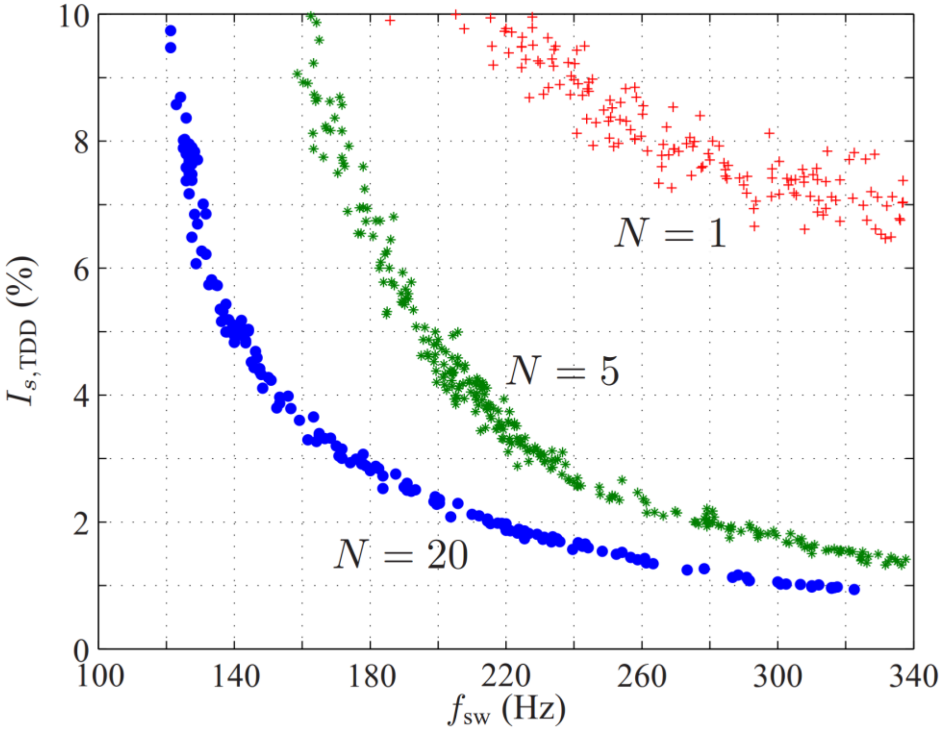
Drive System with *LC* Filter

System parameters



- MV induction **machine**: 3.3kV, 2MVA, 50Hz, X_σ = 0.25pu
- ***LC* Filter**: X_l = 0.117pu, X_c = 0.336pu, f_{res} = 304Hz
- Sampling **interval**: T_s = 125μs

Current TDD vs switching frequency

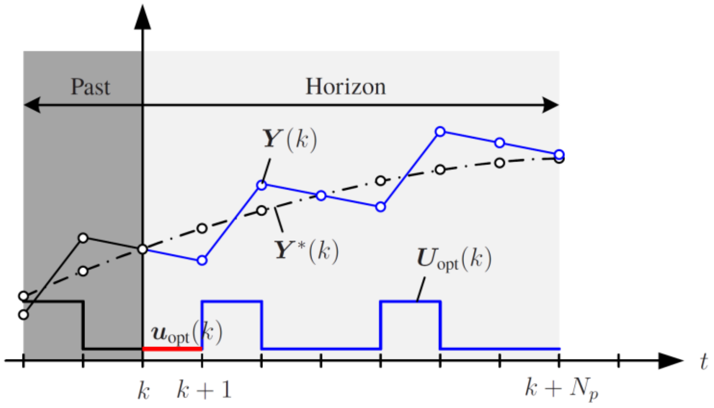


Long prediction horizons enable operation at switching frequencies f_{sw} **below** 50% of the **resonance frequency** f_{res}

Finite Control Set Model Predictive Control
An Assessment

Benefits:

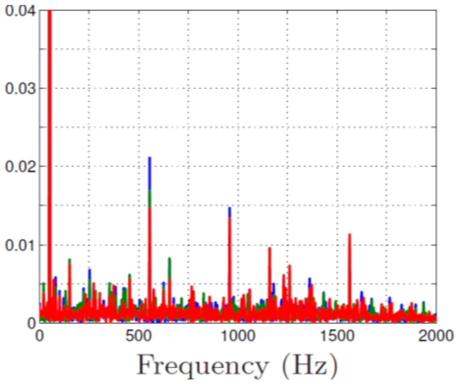
- Conceptually **simple**
- Applicable to almost **any control** problem
- Achieves very **fast** dynamic response
- Adapts well to “**complicated systems**”, such as *LC* filters, saliency in machines, etc



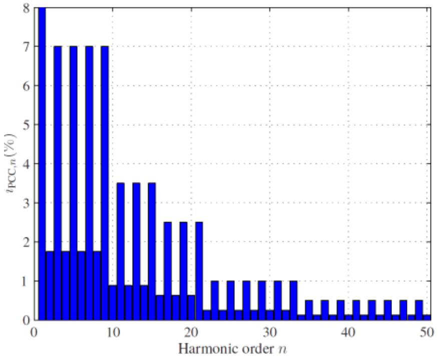
Limitations:

- Sphere decoding is restricted to **linear** systems with **integer** inputs
- A high **sampling frequency** is required
- A non-deterministic **harmonic spectrum** results with **even-order** harmonics
  => Not suitable for grid-side converters?

Harmonic current spectrum



Limits on harmonic currents (IEEE 519)



Model Predictive Control in Power Electronics
Outline

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- Control and modulation
  - *The classic approach in power electronics*
- Vision for power conversion control
  - *And the case for model predictive control*

Control concepts

- Finite control set model predictive control (FCS-MPC)
  - *Direct model predictive control*
- Model predictive pulse pattern control (MP^{3}C)
  - *Fast control of optimized pulse patterns (OPPs)*
- Model predictive control of load commutated inverters (LCI)
  - *Coordinated control with constraints*

Assessment and conclusions

Optimized Pulse Patterns
Optimization Problem and Example

Computation of **optimal** pulse patterns

Given:
- The desired voltage amplitude
  => modulation index m
- The desired switching frequency
  => number of switching angles d

Compute the optimal switching angles α_i that minimize the current distortions (for an inductive load)

$$\underset{\alpha_i}{\text{minimize}} \sum_{n=5,7,\ldots} \left(\frac{1}{n^2} \sum_{i=1}^{d} \Delta u_i \cos(n\alpha_i) \right)^2$$

$$\text{subject to } \frac{4}{\pi} \sum_{i=1}^{d} \Delta u_i \cos(\alpha_i) = m$$

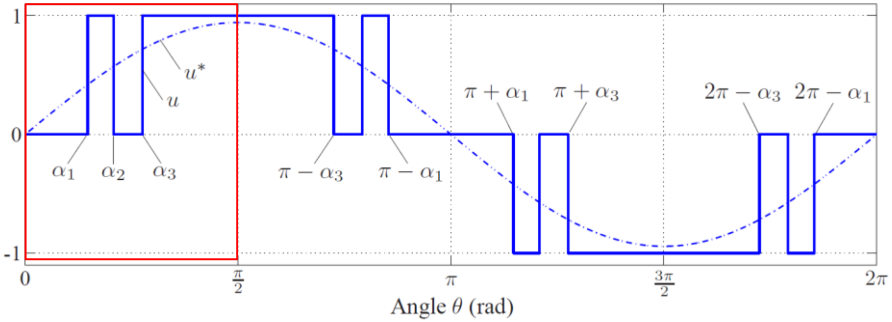
$$0 \leq \alpha_1 \leq \alpha_2 \leq \ldots \leq \alpha_d \leq \frac{\pi}{2}$$

=> Nonlinear optimization problem

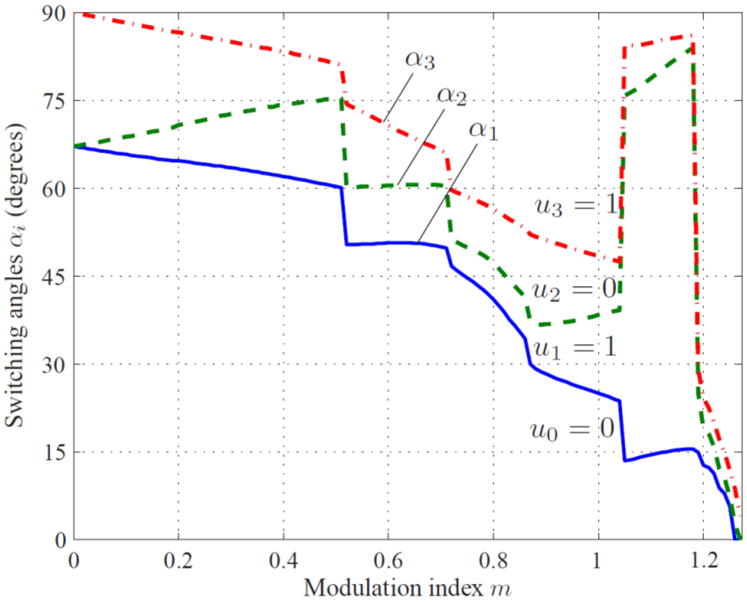
G. S. Buja: “Optimum output waveforms in PWM inverters,” IEEE Trans. Ind. Appl., Nov./Dec. 1980

Example for 3-level converter

Switching pattern (with *d*=3, quarter- and half-wave sym.):



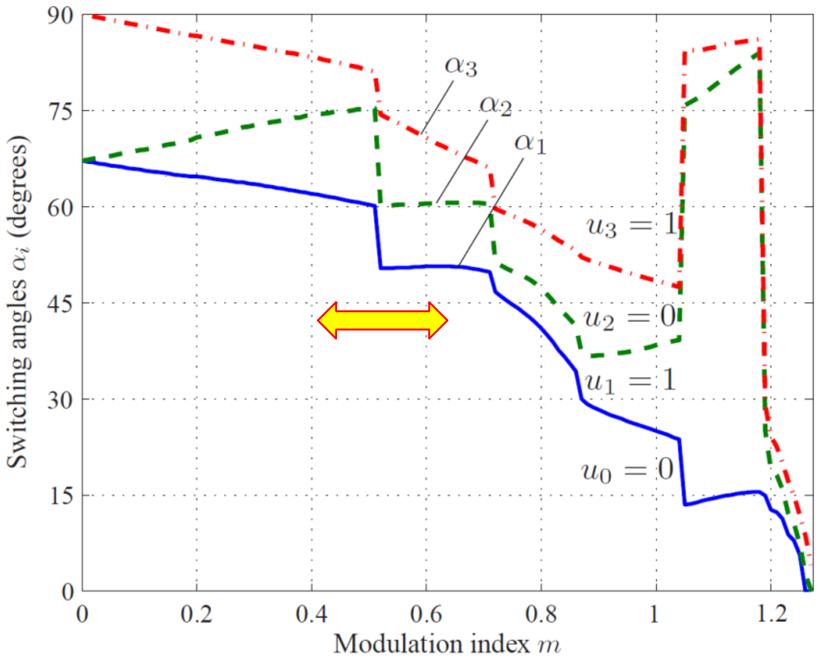
Set of witching angles:



Optimized Pulse Patterns
Difficulties Arising for Linear Controllers

Linear controllers sample the converter current at **regular** sampling instants and manipulate the **modulation index** *m*

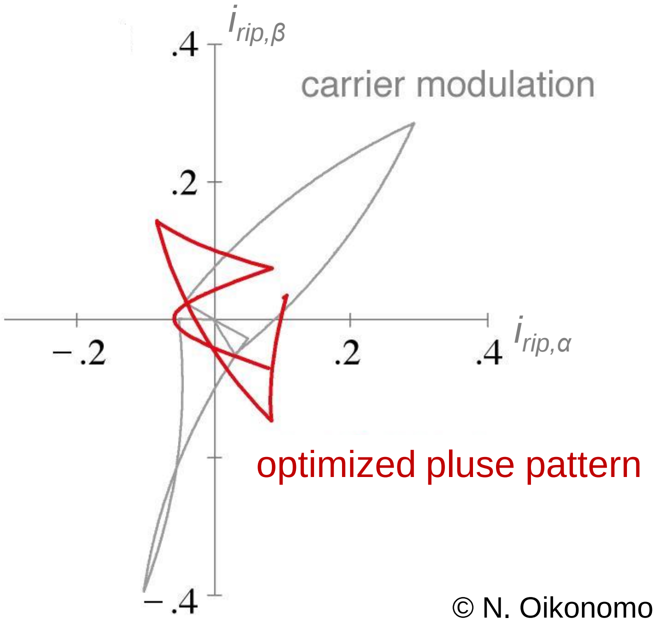
The switching angles are discontinuous in *m*



Enforce **smooth** switching angles

=> Suboptimal pulse pattern

The current ripple is (in general) never zero



© N. Oikonomou

Use **slow** controllers

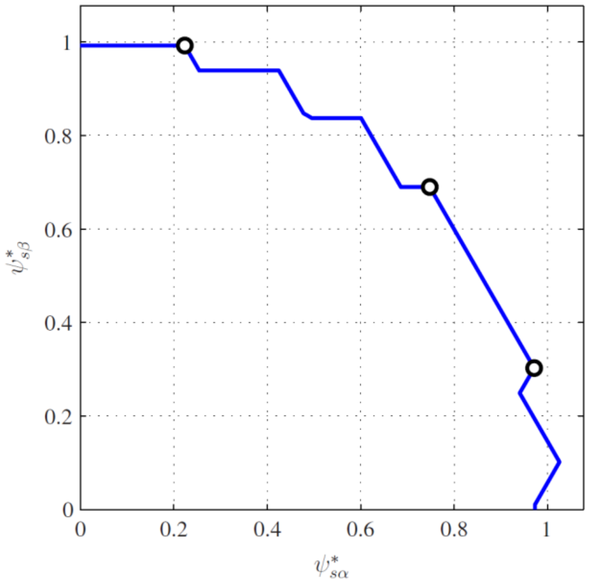
=> Poor disturbance rejection / response in transients

Model Predictive Pulse Pattern Control (MP^{3}C)
Control Principle

Stator flux trajectory

Stator flux: $\boldsymbol{\psi}_s(t) = \boldsymbol{\psi}_s(0) + \frac{v_{\mathrm{dc}}}{2}\int_0^t \boldsymbol{u}_{\mathrm{OPP}}(\tau)\mathrm{d}\tau$

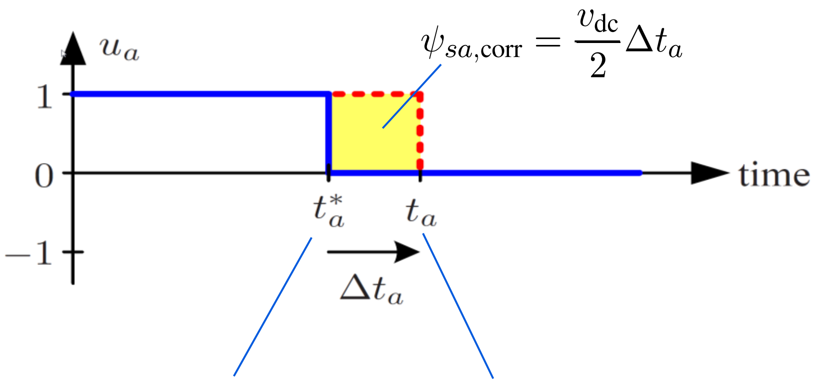
=> Integrate the optimal pulse pattern to derive the optimal stator flux trajectory



Stator flux reference trajectory is **optimal**
(minimizes the current distortions) => **Tracking**

Stator flux correction

- Manipulate the time-instants of the switching transitions to correct the stator flux
- Example: switching transition in phase a



Nominal switching time

Corrected switching time

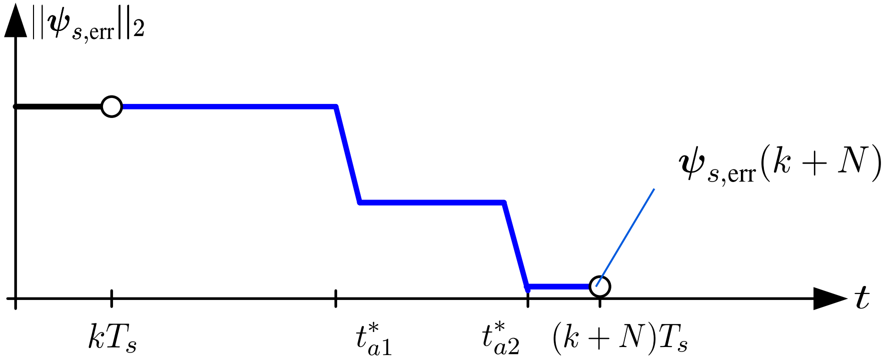
Formulate and solve a
model predictive control problem in real time

J. Holtz and N. Oikonomou: “Synchronous optimal pulse width modulation and stator flux trajectory control for medium-voltage drives,” IEEE Trans. Ind. Appl., Mar./Apr. 2007

T. Geyer, N. Oikonomou, G. Papafotiou and F.D. Kieferndorf: "Model predictive pulse pattern control", IEEE Trans. Ind. Appl., Mar./Apr. 2012.

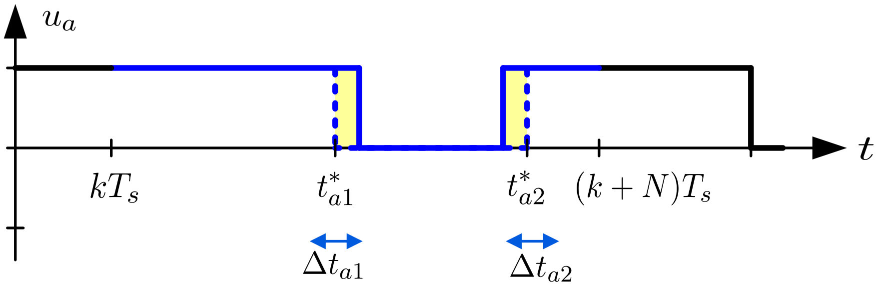
Model Predictive Pulse Pattern Control (MP^{3}C)
Control Problem Formulation

Stator flux error (controlled var.): $\psi_{s,\mathrm{err}} = \psi_s^* - \psi_s$ (in *αβ*)



$$\psi_{s,\mathrm{err}}(k+N) = \psi_{s,\mathrm{err}}(k) - \frac{v_{\mathrm{dc}}}{2} f(\Delta \boldsymbol{t})$$

Switching time modifications (manipulated var.): $\Delta \boldsymbol{t}$



… similarly in phases *b* and *c*

=> Model predictive pulse pattern control (**MP^{3}C**) of the switching time modifications $\Delta \boldsymbol{t} \in \mathbb{R}^n$

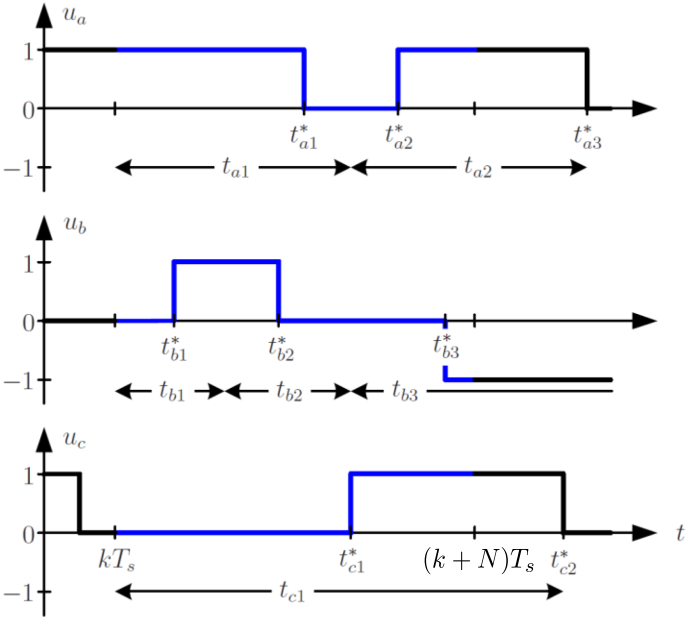
T. Geyer, N. Oikonomou, G. Papafotiou and F.D. Kieferndorf: "Model predictive pulse pattern control", Trans. on Ind. Appl., Mar./Apr. 2012.

Model Predictive Pulse Pattern Control (MP^{3}C)
Optimization Problem

Optimization problem

$$\begin{aligned}\underset{\Delta \boldsymbol{t}}{\text{minimize}}\ & \|\boxed{\boldsymbol{\psi}_{s,\text{err}} - \boldsymbol{\psi}_{s,\text{corr}}}(\Delta \boldsymbol{t})\|_2^2 + \Delta \boldsymbol{t}^T \boldsymbol{Q} \Delta \boldsymbol{t} \\ \text{subject to}\ & kT_s \le t_{a1} \le t_{a2} \le \ldots \le t_{an_a} \le t^*_{a(n_a+1)} \\ & kT_s \le t_{b1} \le t_{b2} \le \ldots \le t_{bn_b} \le t^*_{b(n_b+1)} \\ & kT_s \le t_{c1} \le t_{c2} \le \ldots \le t_{cn_c} \le t^*_{c(n_c+1)}\end{aligned}$$

Example:



Solution approaches

- This is a quadratic program (**QP**) in $\Delta \boldsymbol{t} \in \mathbb{R}^n$

  => Solve with an active set or a gradient method
- Or simplify the QP to a **deadbeat** control problem
  - by setting $\boldsymbol{Q} = 0$ and
  - by choosing the minimal horizon *N* (such that the prediction interval includes at least one switching transition per phase)
- In case of very large flux error: **insert** additional switching transitions

T. Geyer, N. Oikonomou, G. Papafotiou and F.D. Kieferndorf: "Model predictive pulse pattern control", IEEE Trans. Ind. Appl., Mar./Apr. 2012.

Model Predictive Pulse Pattern Control (MP^{3}C)
Medium-Voltage Lab

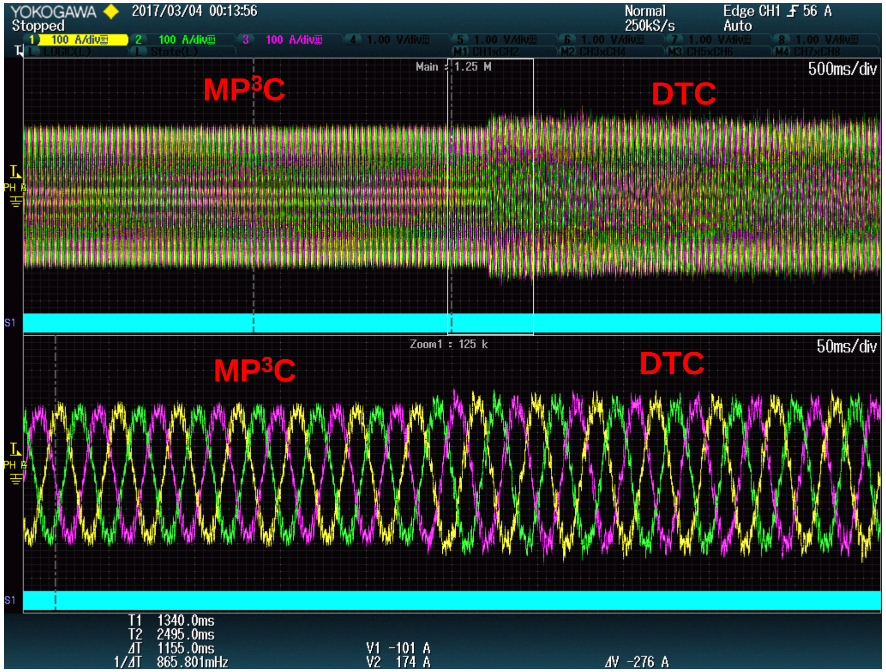
2 MVA induction machine:

3-level neutral point clamped converter:

Model Predictive Pulse Pattern Control (MP^{3}C)
Experimental Results (MV Lab)

Steady-state operation:

55% speed, 60% torque



Results obtained by Vedrana Spudic

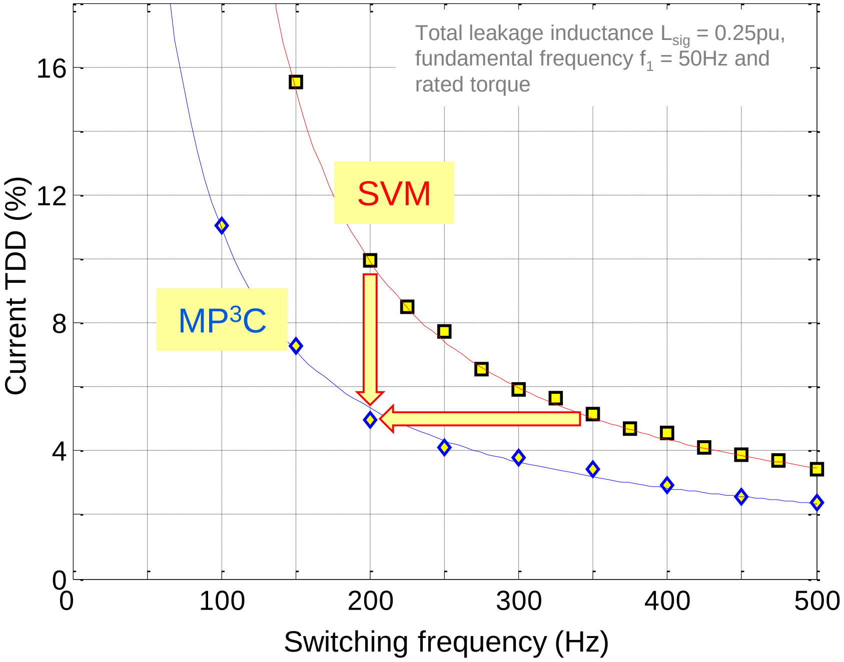
Up to **50% lower** current distortions for the same switching frequency (or vice versa)

=> Machine-friendly operation, lower switching frequencies, higher power

Model Predictive Pulse Pattern Control (MP^{3}C)

Commercial Benefits

Current TDD vs Switching frequency:

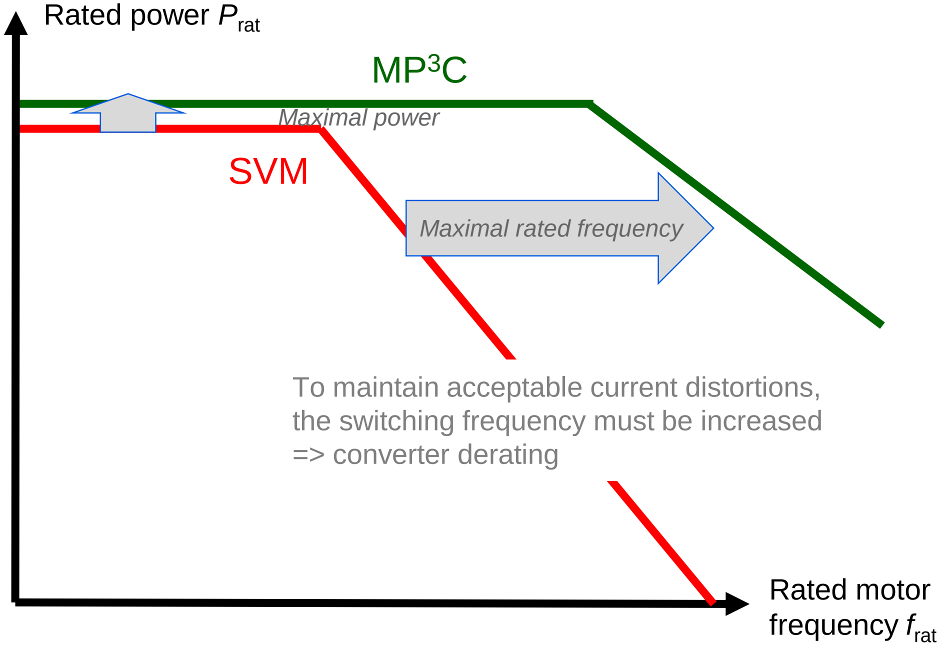


Total leakage inductance L_{sig} = 0.25pu, fundamental frequency f_1 = 50Hz and rated torque

At low pulse numbers:

- Up to 50% lower **current distortions** or
- Up to 40% lower **switching frequency**

Additional Benefit of Low Current TDD:



To maintain acceptable current distortions, the switching frequency must be increased => converter derating

=> Lower switching frequencies for the same harmonic distortions

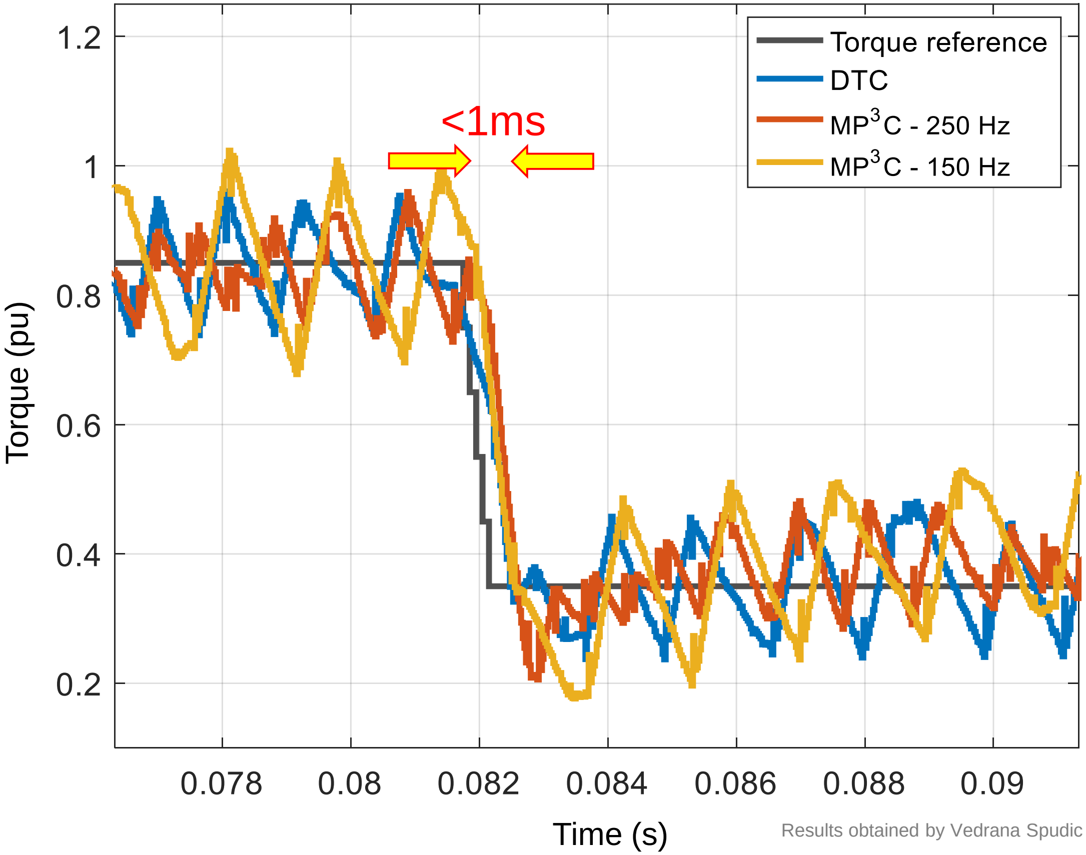
=> Higher fundamental frequencies at rated power

Higher maximal **power** and extended **market** reach => **Cost reduction**

Model Predictive Pulse Pattern Control (MP^{3}C)

Torque Steps (MV Lab)

Three-level converter at f_1 = 20Hz



Results obtained by Vedrana Spudic

Dynamic performance similar to Direct Torque Control (**DTC**)

Model Predictive Pulse Pattern Control (MP^3C)
Press Release (March 2019)

MEDIUM VOLTAGE AC DRIVES

ABB industrial drives

ACS6080, 5 to 36 MW

ACS6080 medium voltage drives offer high dynamic performance, reliability and safety for demanding applications. On top of ABB's new MP^3C control technology, the drive provides easy-to-use interfaces to simplify operation and ABB Ability™ remote condition monitoring.

https://new.abb.com/drives/medium-voltage-ac-drives/acs6080

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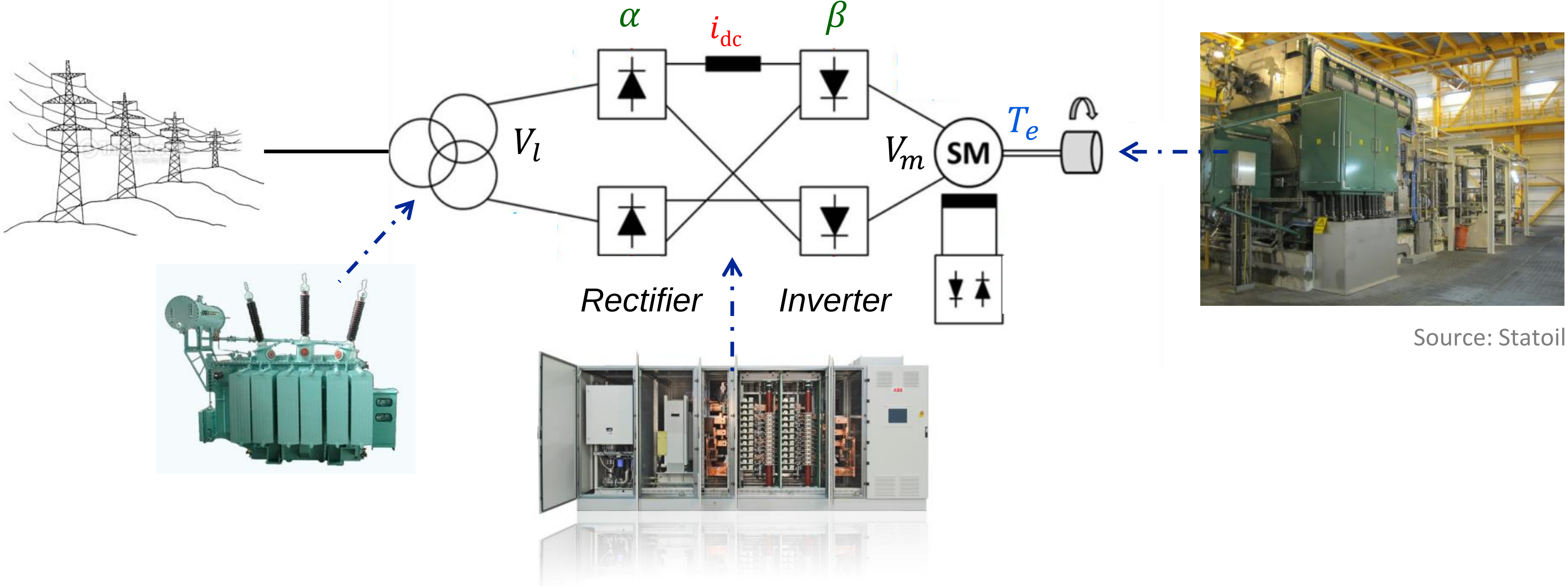
  - *Direct model predictive control*
- Model predictive pulse pattern control (MP^{3}C)
  - *Fast control of optimized pulse patterns (OPPs)*
- ➡ Model predictive control of load commutated inverters (LCI)
  - *Coordinated control with constraints*

Assessment and conclusions

Coordinated Control: Load Commutated Inverter Drive

Problem Definition



Source: Statoil

System:

- Load commutated inverter (LCI) with synchronous machine

Model:

- Dc-link dynamic: $L_{dc}\frac{d}{dt}i_{dc} = V_l\cos(\alpha) - V_m\cos(\beta)$
- Electromagnetic torque: $T_e = -i_{dc}\cos(\beta)$

Control objective:

- Regulate the torque T_e and the dc-link current i_{dc} to their references by manipulating the firing angles α and β while respecting constraints

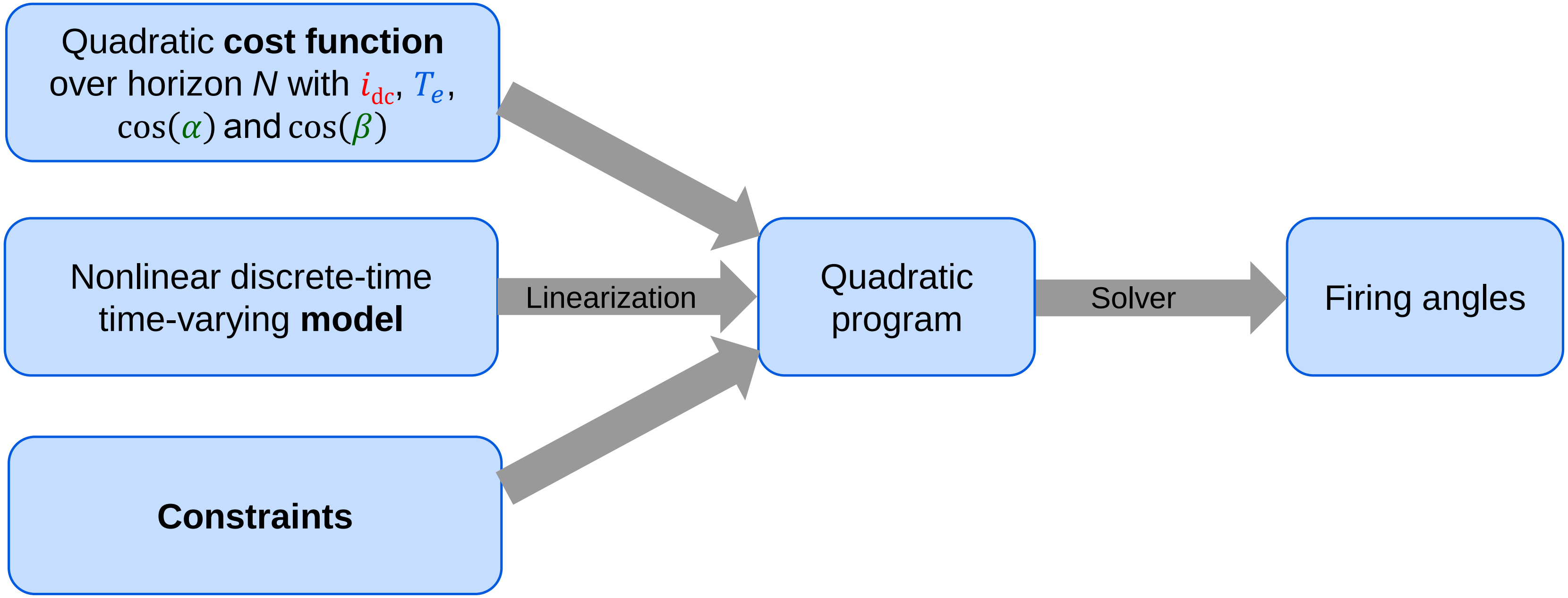
Constraints:

- $0 \le i_{dc} \le i_{dc\,max}$
- $\alpha_{min} \le \alpha \le \alpha_{max} \quad \beta_{min} \le \beta \le \beta_{max}$

T. Besselmann, S. Van de moortel, S. Almer, P. Jörg and J. Ferreau: “Model predictive control in the multi-megawatt range”, Trans. on Ind. Electronics, July 2016

Coordinated Control: Load Commutated Inverter Drive

Model Predictive Control Formulation



Quadratic **cost function** over horizon *N* with i_{dc}, T_e, $\cos(\alpha)$ and $\cos(\beta)$

Nonlinear discrete-time time-varying **model**

Constraints

Linearization

Quadratic program

Solver

Firing angles

Control platform: PEC 3 (dual core PowerPC with 1.2 GHz)

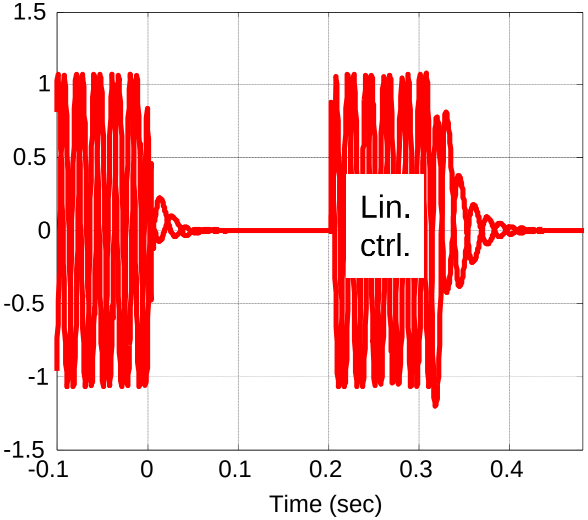
Sampling interval: 1ms

T. Besselmann, S. Van de moortel, S. Almer, P. Jörg and J. Ferreau: “Model predictive control in the multi-megawatt range”, Trans. on Ind. Electronics, July 2016

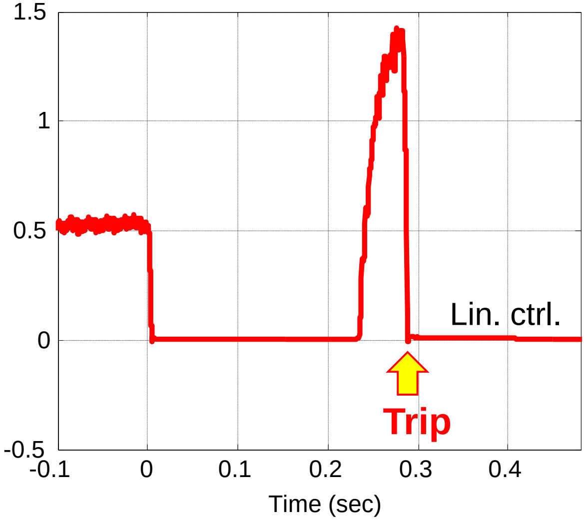
Coordinated Control: Load Commutated Inverter Drive

Experimental Results on LV drive

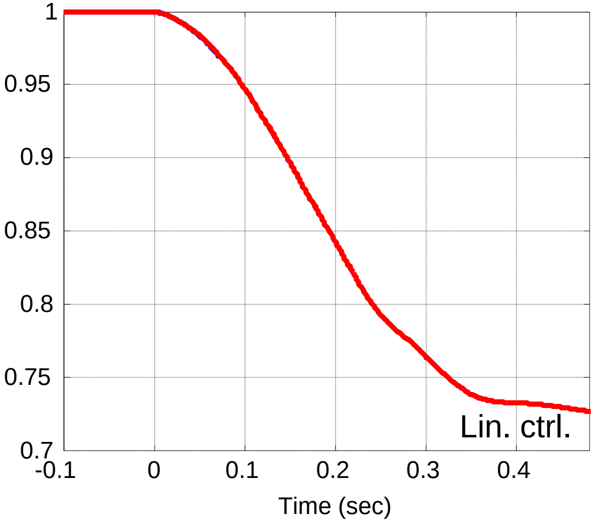
Grid voltage



Dc-link current i_{dc}



Mechanical speed



Results obtained by Thomas Besselmann

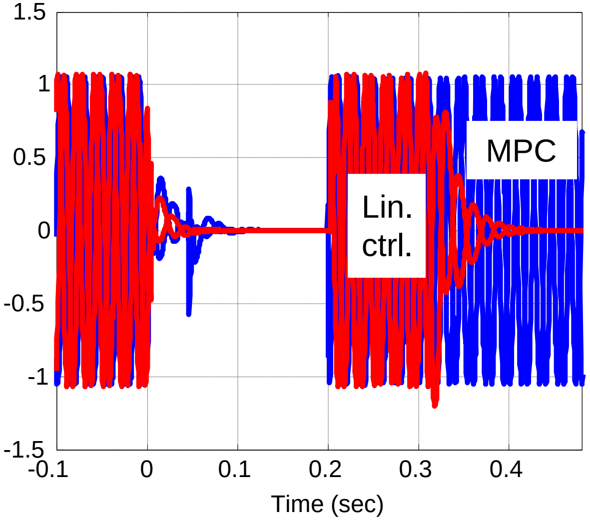
Low-voltage ride through:

- **Linear** controller (separate PI control loops for rectifier and inverter) **trips** when restoring power (i_{dc} too high)

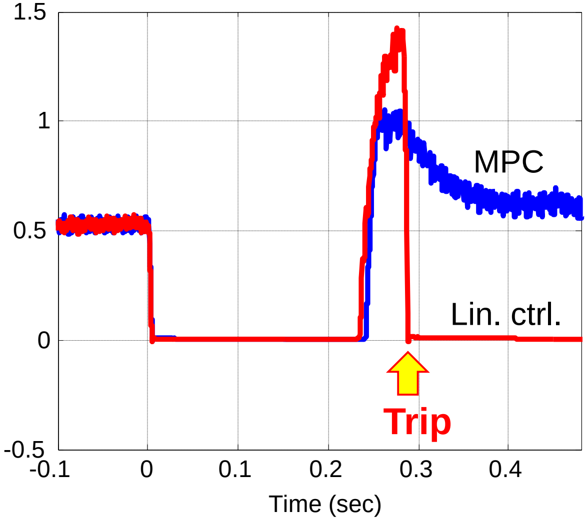
T. Besselmann, S. Van de moortel, S. Almer, P. Jörg and J. Ferreau: “Model predictive control in the multi-megawatt range”, Trans. on Ind. Electronics, July 2016

Coordinated Control: Load Commutated Inverter Drive

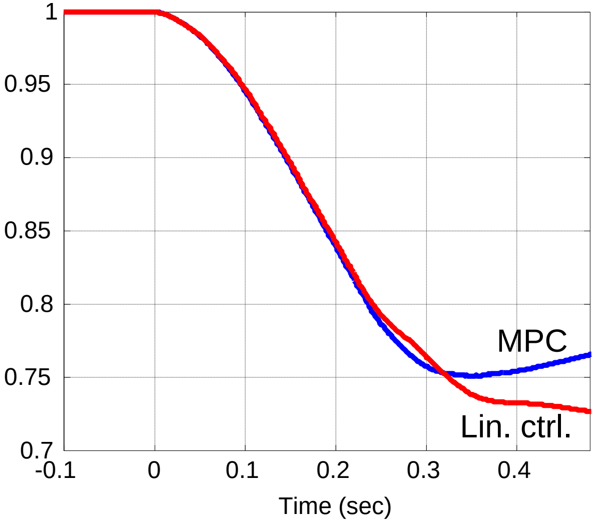
Experimental Results on LV drive



Grid voltage



Dc-link current i_{dc}



Mechanical speed

Results obtained by Thomas Besselmann

Low-voltage ride through:

- **Linear** controller (separate PI control loops for rectifier and inverter) **trips** when restoring power (i_{dc} too high)
- **MPC** rides through and respects the constraints

T. Besselmann, S. Van de moortel, S. Almer, P. Jörg and J. Ferreau: “Model predictive control in the multi-megawatt range”, Trans. on Ind. Electronics, July 2016

Coordinated Control: Load Commutated Inverter Drive
Pilot Installations (since Mid 2015)

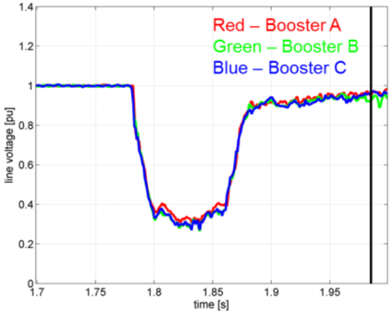
Kollsnes, Norway

- Processes about **40%** of Norway's gas export
- Grid voltage disturbances
- Trips very costly (0.5M$ per hour)
- Six compressor strings with 41.2 MW LCIs
- All are now controlled by MPC

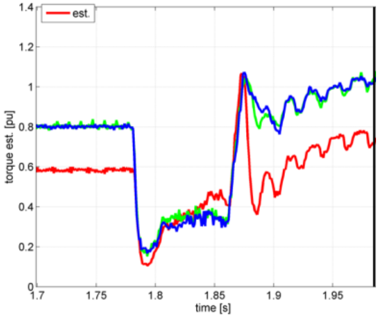
Kårstø, Norway

- Europe's biggest export port for natural gas liquids
- Three 7.5 MW LCIs in booster compressors are controlled by MPC
- Low-voltage ride through

Grid voltage



Torque



Results obtained by Thomas Besselmann

Commercial benefits

- Improved low-voltage **ride through** => higher **availability**
- Lower **reactive power** => Increased **efficiency**

Service note

Drive System Consulting service
Advanced Control Performance Optimization
for MEGADRIVE-LCI

T. Besselmann, S. Van de moortel, S. Almer, P. Jörg and J. Ferreau: "Model predictive control in the multi-megawatt range", Trans. on Ind. Electronics, July 2016

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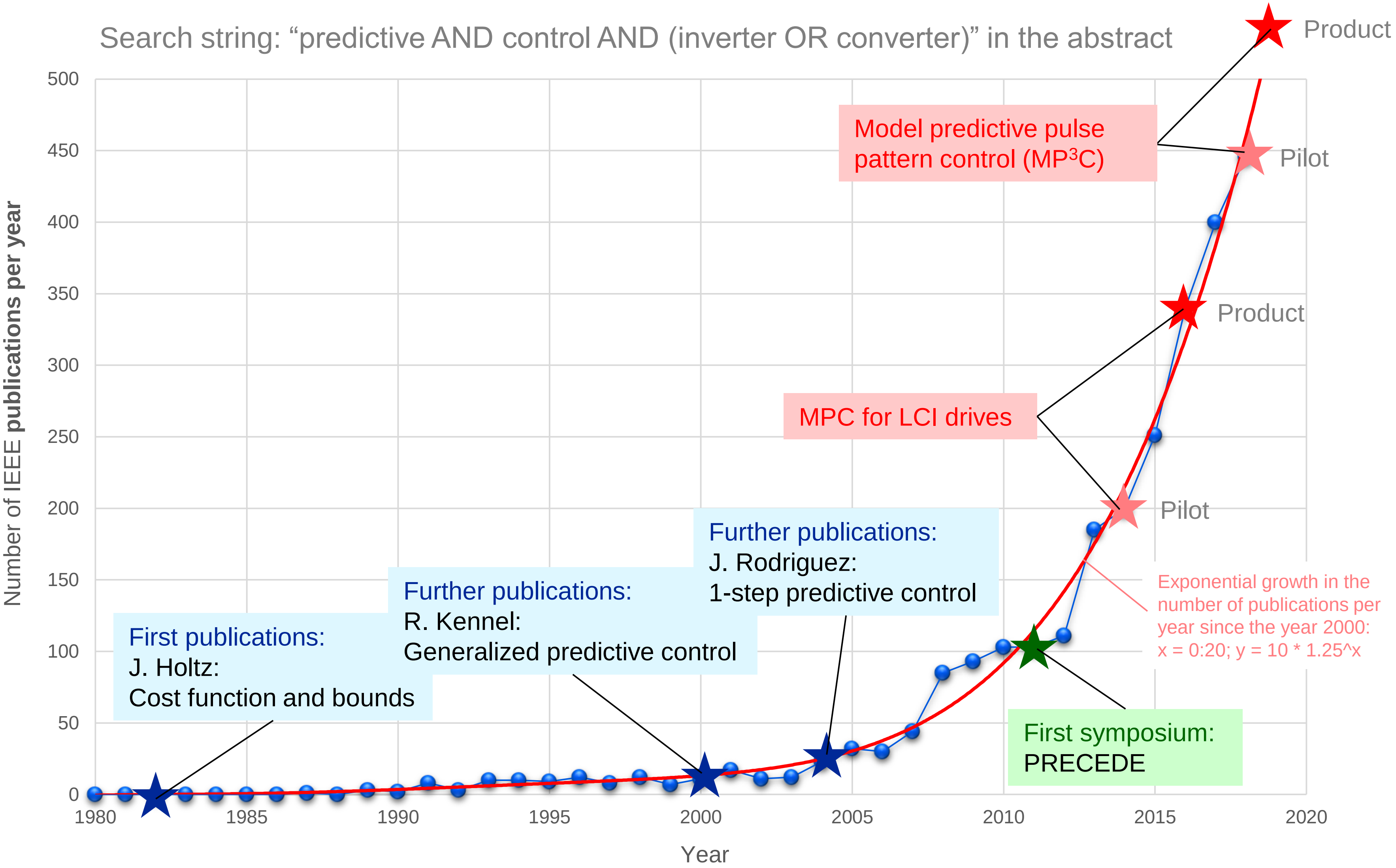
Assessment and conclusions

Model Predictive Control in Power Electronics
Milestones



Search string: “predictive AND control AND (inverter OR converter)” in the abstract

Model predictive pulse pattern control (MP^{3}C)

MPC for LCI drives

Exponential growth in the number of publications per year since the year 2000: x = 0:20; y = 10 * 1.25^x

Further publications:
J. Rodriguez:
1-step predictive control

Further publications:
R. Kennel:
Generalized predictive control

First publications:
J. Holtz:
Cost function and bounds

First symposium:
PRECEDE

The number of annual publications **doubles every three years**

Model Predictive Control in Power Electronics
Conclusions

Commercial benefits of MPC:

- Minimization of the **cost per MVA** of the power electronic system
- Superior performance during **transients** and faults
- Operation within the **safe operating area**
- Reduced effort to **design** and **adapt** the controller

=> Cost savings and boost of competitiveness

Challenges:

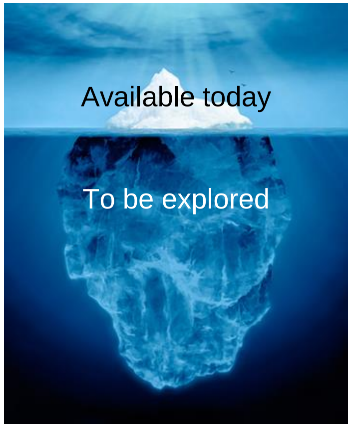
- Built-up of **know-how** and productization is time consuming
- Conceptual **simplicity** is mandatory
- Applicability to the whole **product range** is a must

An assessment:

- **Model predictive control** in power electronics has rapidly expanded with significant interest in the **academic** community
- Control is a potential **differentiator** and **cost saver** for industry, so interest in **industry** is ramping up
- A significant **monetary benefit** is required to ensure adoption by industry – this is often neglected

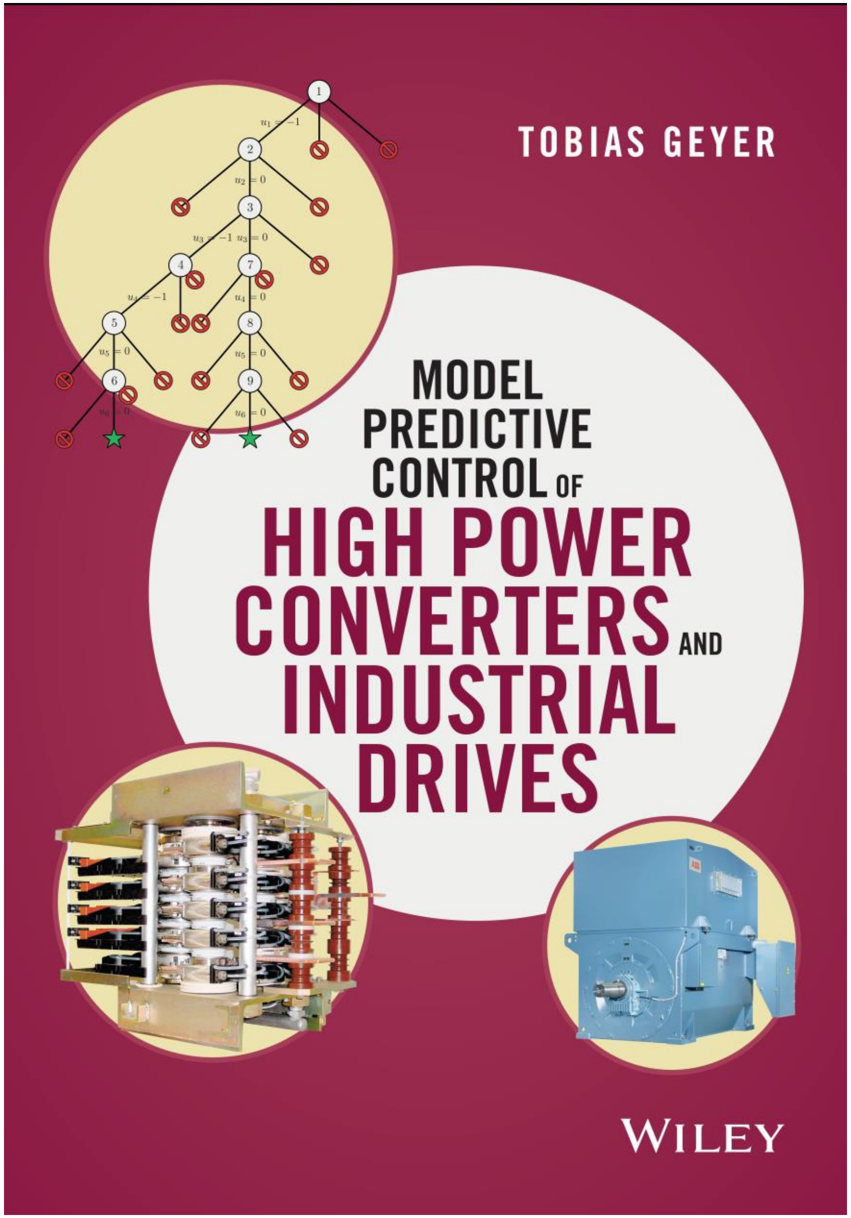
  => Look beyond overly simplistic approaches

- Lack of **computational power** is typically not the limiting factor



Model predictive control for power electronics is still at an **early stage** despite some success stories

MPC of High Power Electronics and Industrial Drives



TOBIAS GEYER

MODEL PREDICTIVE CONTROL OF HIGH POWER CONVERTERS AND INDUSTRIAL DRIVES

WILEY

Five main parts:

- **Introduction:** MPC, machines, semiconductors, topologies, MV inverters, requirements, CB-PWM, OPPs, field oriented control, direct torque control
- **Direct MPC with reference tracking (FCS-MPC):** predictive current control, predictive torque control, integer quadratic programming formulation, sphere decoding, performance evaluation for NPC inverter drive system without and with LC filter
- **Direct MPC with bounds:** model predictive direct torque control, extension methods, performance evaluation for 3L and 5L inverter drive systems, state-feedback control law, deadlocks, branch and bound methods, model predictive direct current control, model predictive direct power control
- **MPC based on PWM:** model predictive pulse pattern control, pulse insertion, performance evaluation for NPC inverter drive system, experimental results for 5L inverter drive system, MPC of an MMC using CB-PWM
- **Summary and conclusions:** performance comparison of direct MPC schemes, assessment, summary and discussion, outlook

576 pages, available on http://eu.wiley.com