This Webinar is sponsored through

IEEE-PELS Technical Committee 1- TC1

Control and Modeling of Power Electronics

https://www.ieee-pels.org/technical-activities/tc-1

Model Predictive Control for Power Electronics Applications

Prof. Marco Rivera

Marco.Rivera@nottingham.ac.uk

Outline

- Power Electronics, Machines and Control Group
- Introduction to Predictive Control in Power Converters and Electrical Drives
- Examples of Predictive Control in Power Converters and Electrical Drives
- Technical Issues for the Implementation of Predictive Control
- Trends and Challenges of Predictive Control
- Conclusions
- Q&A/Discussion

University of Nottingham
UK | CHINA | MALAYSIA

IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

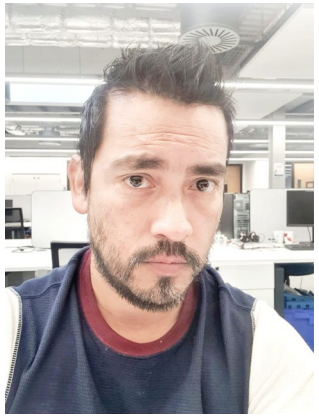
IEEE
Advancing Technology for Humanity

TALCA UNIVERSIDAD CHILE

lceep
Laboratorio de Conversión de Energías y Electrónica de Potencia

Power Electronics, Machines and Control Research Group

Power Electronics and Machine Centre PEMC Research Group



Prof. Marco Rivera

- Transport electrification and energy conversion
- One of the largest integrated PEMD group worldwide
- National/European leader
- >£45M active research grants with >60% of research income linked to industry

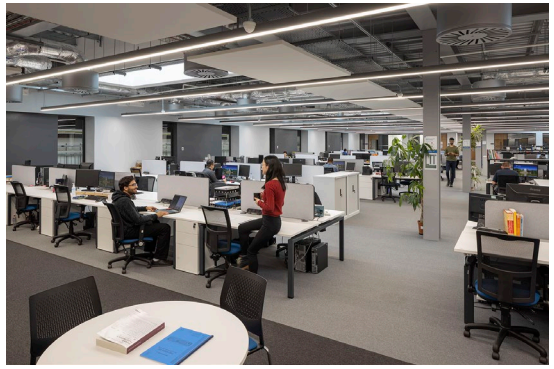
Power Electronics, Machines and Control Research Group

Research Themes

- Electrical machines
- Power electronic systems
- Electric motor drives and systems
- Power electronic integration and reliability

Underlying Scientific Research

- Power device packaging and cooling
- Microgrid control
- Cooling methodologies and thermal integration
- New modelling methods
- Electromagnetic modelling
- Modulation theory
- Physics of failure – power converters and electrical machines
- Advanced control strategies for power converters and drives



More than 200 Researchers/Academics

- ≈ 26 Academic staff [Faculty]
- ≈ 70 Contract research fellows
- ≈ 110 PhD students
- ≈ 12 Visiting scholars/researchers

Current Research Grants ≈ US$45M

Application Areas - Electrification

- Future electricity networks
- Renewable energy
- Microgrids and grid connected converters
- Industrial applications
- Automotive and marine
- All/more electric aircraft

New PEMC Group Facilities - opened March 2021

- 5500m^2 laboratories with 5MVA power supply
- Voltage supplies to 11kV
- Power systems – DC and AC
- Electrical machine testing up to 20MW
- Environmental chambers

https://www.nottingham.ac.uk/research/groups/pemc/home.aspx

Power Electronics, Machines and Control Research Group: Building Layout

Power Electronics Laboratory

Power electronics, devices and converters. Facility for construction, characterisation, analysis and lifetime testing.

- 115m2 environmental testing facility
- Clean room facilities
- X-ray and microcopy space
- Magnetic testing facility
- 38m2 EMC shielded room

Power Electronic Converters and Motor Drives Laboratory

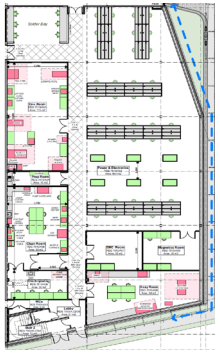
General Machine and Converter testing: work on standard sized electrical machines, motor drives and power converters

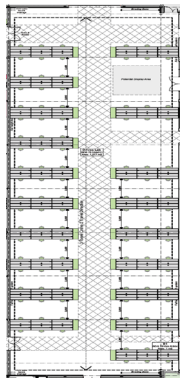
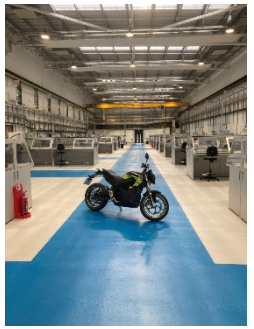
- 80 standard research benches with integrated guarding
- 3-phase 400V @ 64A per bench plus single phase sockets
- 50kW liquid cooling loop

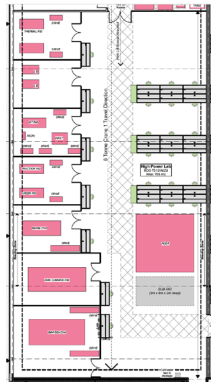
Wolfson High Power Laboratory

For high power, high voltage and large power electronic converter and motor drive system testing

- 5MW total site mains supply
  - 1.1/3.3kW @ 3000A HVAC
  - 400V @ 4000A LVAC
  - 6kV HVDC
- Thermal test cell – 40m2
- High speed testing – 18m2 sunken test rig space



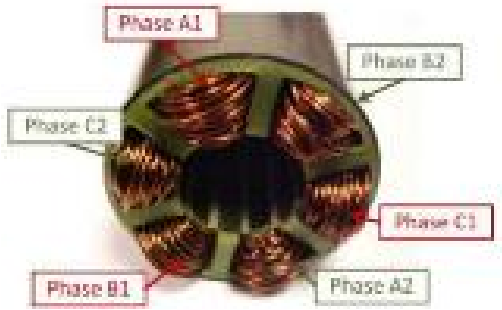





https://www.nottingham.ac.uk/research/groups/pemc/home.aspx

Electrical Machine Demonstrators

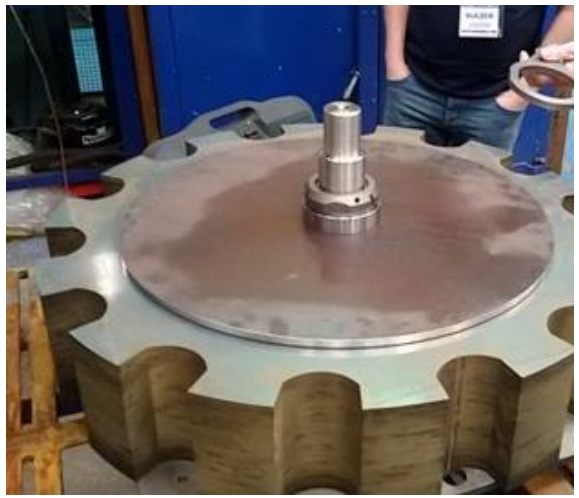
150 kW, 32krpm PM generator – 16kW/kg



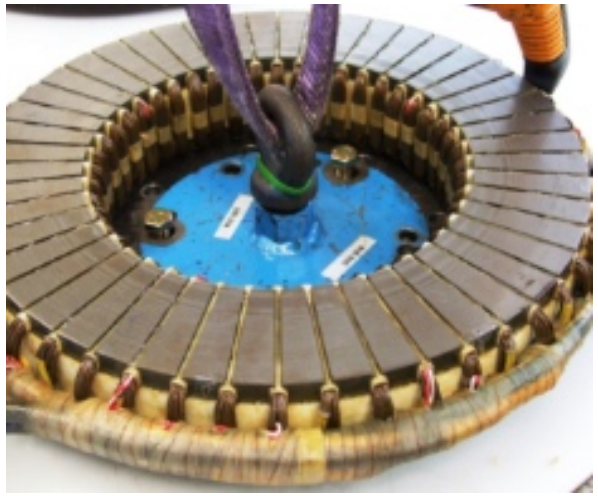
Fault-tolerant multi-phase machine

7kNm machine for aircraft taxiing – 43 Nm/kg and 184 kNm/m3

PM assist – SynRel machine for EV applications



SRM for energy storage

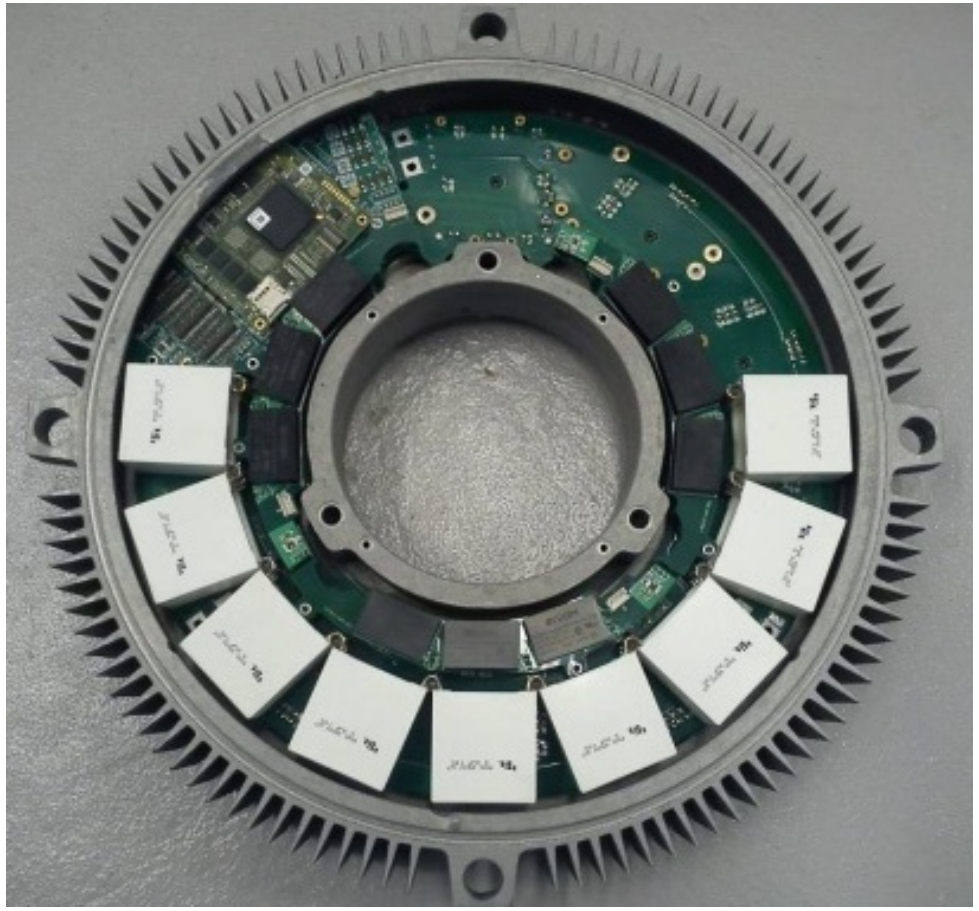


Integrated dual-airgap axial machine

24V, 5kW, 120 krpm PM machine turbo compunding

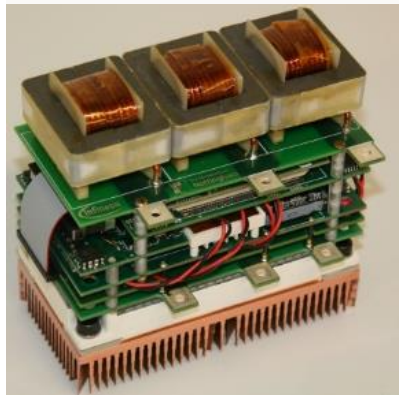
https://www.nottingham.ac.uk/research/groups/pemc/home.aspx

Power Electronics Converters

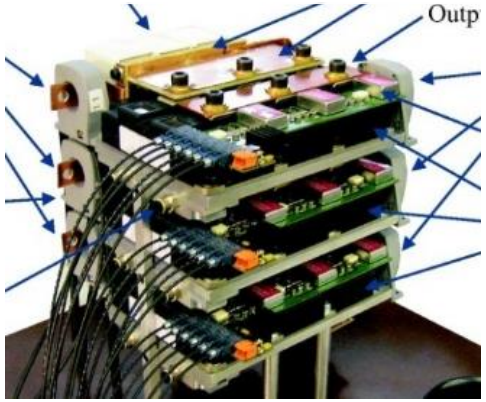


30kW matrix integrated into machine endplate

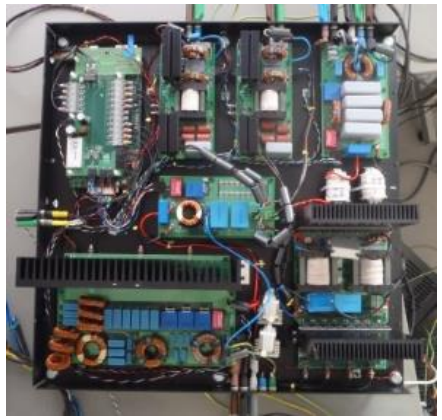
20kW/litre SiC JFET matrix converter



150kW Si/SiC matrix converter



3.3kW, 500kW modular AC-AC converter



Aerospace SiC Mosfet DC-DC converter

450kW dual-bridge CSR

Fault-tolerant multi-phase 4MVA e-drive

https://www.nottingham.ac.uk/research/groups/pemc/home.aspx

University of Nottingham
UK | CHINA | MALAYSIA

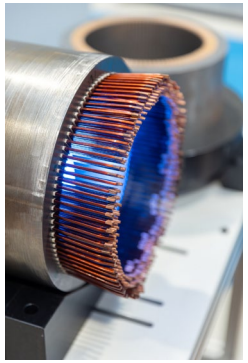
pels
IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

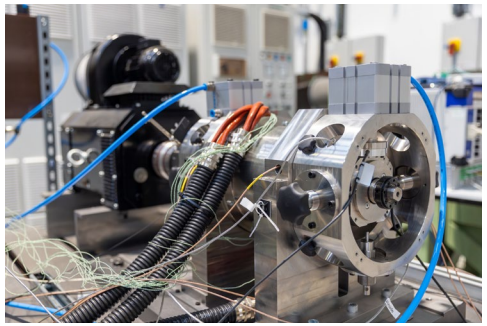
IEEE
Advancing Technology for Humanity

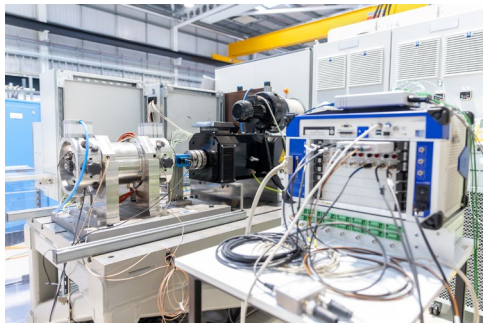
TALCA UNIVERSIDAD CHILE

lceep
Laboratorio de Conversión de Energías y Electrónica de Potencia

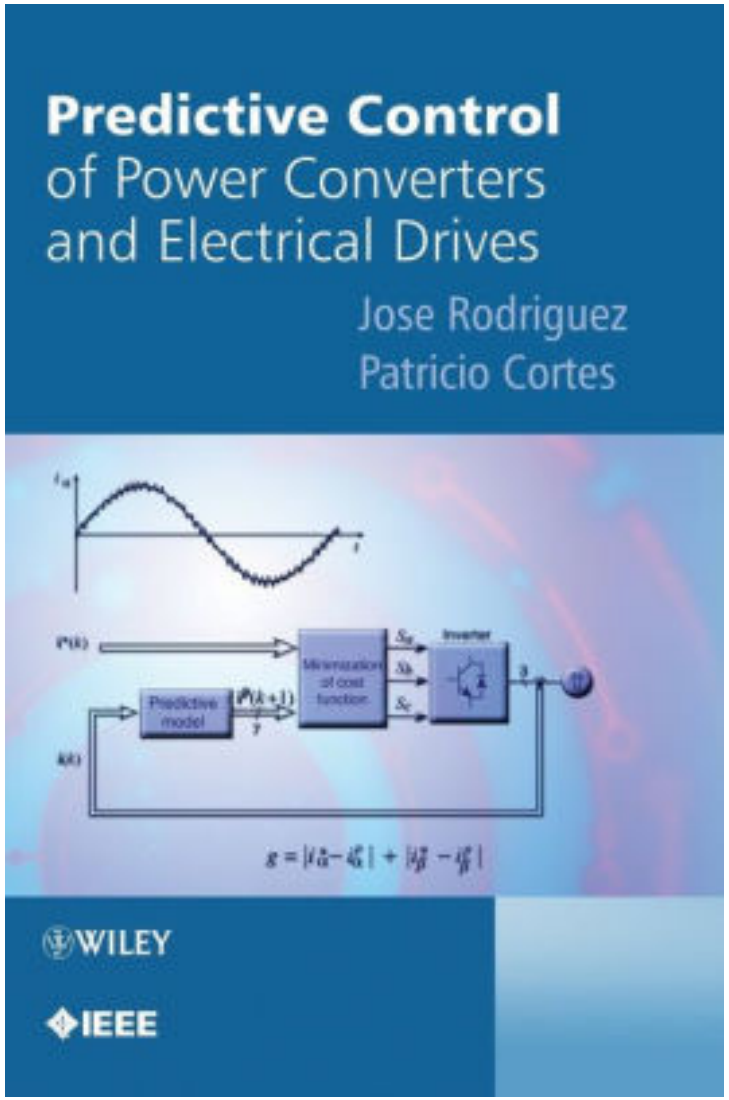
Power Electronics, Machines and Control Research Group







Introduction



Predictive Control of Power Converters and Electrical Drives | Wiley Online Books

IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 64, NO. 2, FEBRUARY 2017 935

Model Predictive Control for Power Converters and Drives: Advances and Trends

Sergio Vazquez, *Senior Member, IEEE*, Jose Rodriguez, *Fellow, IEEE*, Marco Rivera, *Member, IEEE*, Leopoldo G. Franquelo, *Fellow, IEEE*, and Margarita Norambuena, *Member, IEEE*

***Abstract*—Model predictive control (MPC) is a very attractive solution for controlling power electronic converters. The aim of this paper is to present and discuss the latest developments in MPC for power converters and drives, describing the current state of this control strategy and analyzing the new trends and challenges it presents when applied to power electronic systems. The paper revisits the operating principle of MPC and identifies three key elements in the MPC strategies, namely the prediction model, the cost function, and the optimization algorithm. This paper summarizes the most recent research concerning these elements, providing details about the different solutions proposed by the academic and industrial communities.**

apply in multivariable systems, and presents a fast dynamic response. Further, it allows for nonlinearities and constraints to be incorporated into the control law in a straightforward manner, and it can incorporate nested control loops in only one loop [4], [5].

In particular, power electronic applications require control responses in the order of tens to hundreds of microseconds to work properly. However, it is well known that MPC has a larger computational burden than other control strategies. For this reason, most of the works focused on this issue at the initial research stages of MPC for power electronic systems [6].

Model Predictive Control for Power Converters and Drives: Advances and Trends | IEEE Journals & Magazine | IEEE Xplore

A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives

Emrah Zerdali, *Senior Member, IEEE,* Marco Rivera, *Senior Member, IEEE,* and Patrick Wheeler, *Fellow, IEEE*

A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives

- Basic Principles of Model Predictive Control

A PREDICTIVE CONTROLLER FOR THE STATOR CURRENT VECTOR
OF AC MACHINES FED FROM A SWITCHED VOLTAGE SOURCE

Joachim Holtz and Siegfried Stadtfeld
Laboratory for Electrical Machines and Drives, University of Wuppertal
Postfach 10 01 27, 5600 Wuppertal 1, West-Germany

Abstract

The paper describes a novel approach to the PWM problem based on an on-line optimization of the switching sequence. In this concept, the standard pulsewidth modulator is completely eliminated. Input quantities to a switching controller are the stator current vector components as supplied by a field oriented control system. These are used to control the current vector trajectory in the complex plane such that a minimum spatial error with respect to the reference vector is maintained. In this way, the computation of the stator voltage reference signals usually required in PWM systems is avoided. A predictive algorithm is implemented in the switching controller to obtain minimum current harmonics at minimum switching frequency. The optimization is effective under all operating conditions including transients and zero stator frequency operation.

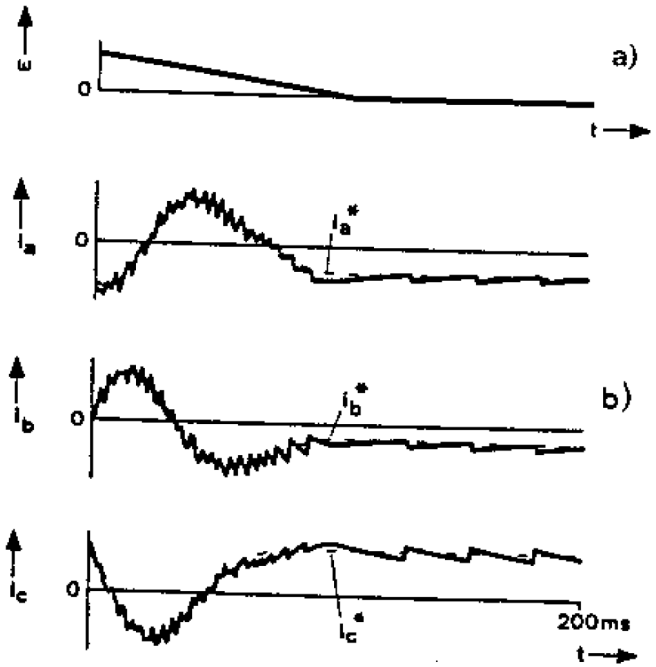


Fig. 13. Braking and operation at zero stator frequency
a) speed
b) stator currents

Holtz J, Stadtfeld S (1983) A predictive controller for the stator current vector of AC machines fed from a switched voltage source. In: Proceedings of the international power electronics conference, Japan. IEEE, pp 1665–1675

University of Nottingham
UK | CHINA | MALAYSIA

pels
IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

IEEE
Advancing Technology for Humanity

TALCA UNIVERSIDAD CHILE

lceep
Laboratorio de Conversión de Energías y Electrónica de Potencia

- Basic Principles of Model Predictive Control

- Basic Principles of Model Predictive Control

New Modulation Strategy for a Matrix Converter with a Very Small Mains Filter

Stefan Müller Ulrich Ammann Stephan Rees

University of Stuttgart, Institute of Power Electronics and Control Engineering
Pfaffenwaldring 47, 70550 Stuttgart, Germany
phone: +49 (0) 711 / 6 85 - 73 87, fax: +49 (0) 711 / 685 - 73 78
e-mail: ammann@ilr.uni-stuttgart.de, www: http://www.uni-stuttgart.de/ilr

New modulation strategy for a matrix converter with a very small mains filter | IEEE Conference Publication | IEEE Xplore

Predictive control of three-phase inverter

J. Rodríguez, J. Pontt, C. Silva, M. Salgado, S. Rees,
U. Ammann, P. Lezana, R. Huerta and P. Cortés

A new method for current control based on a predictive strategy is presented. This uses a discrete-time model of the load to predict the future value of the current for each of the possible voltage vectors generated by the inverter. The vector which minimises the current error at the next sampling time is selected. Experimental results that confirm the feasibility of the method are given.

Predictive control of three-phase inverter – Electronics Letters 2004

- Basic Principles of Model Predictive Control

New Modulation Strategy for a Matrix Converter with a Very Small Mains Filter

Stefan Müller Ulrich Ammann Stephan Rees

University of Stuttgart, Institute of Power Electronics and Control Engineering
Pfaffenwaldring 47, 70550 Stuttgart, Germany
phone: +49 (0) 711 / 6 85 - 73 87, fax: +49 (0) 711 / 685 - 73 78
e-mail: ammann@ilr.uni-stuttgart.de, www: http://www.uni-stuttgart.de/ilr

New modulation strategy for a matrix converter with a very small mains filter | IEEE Conference Publication | IEEE Xplore

Predictive control of three-phase inverter

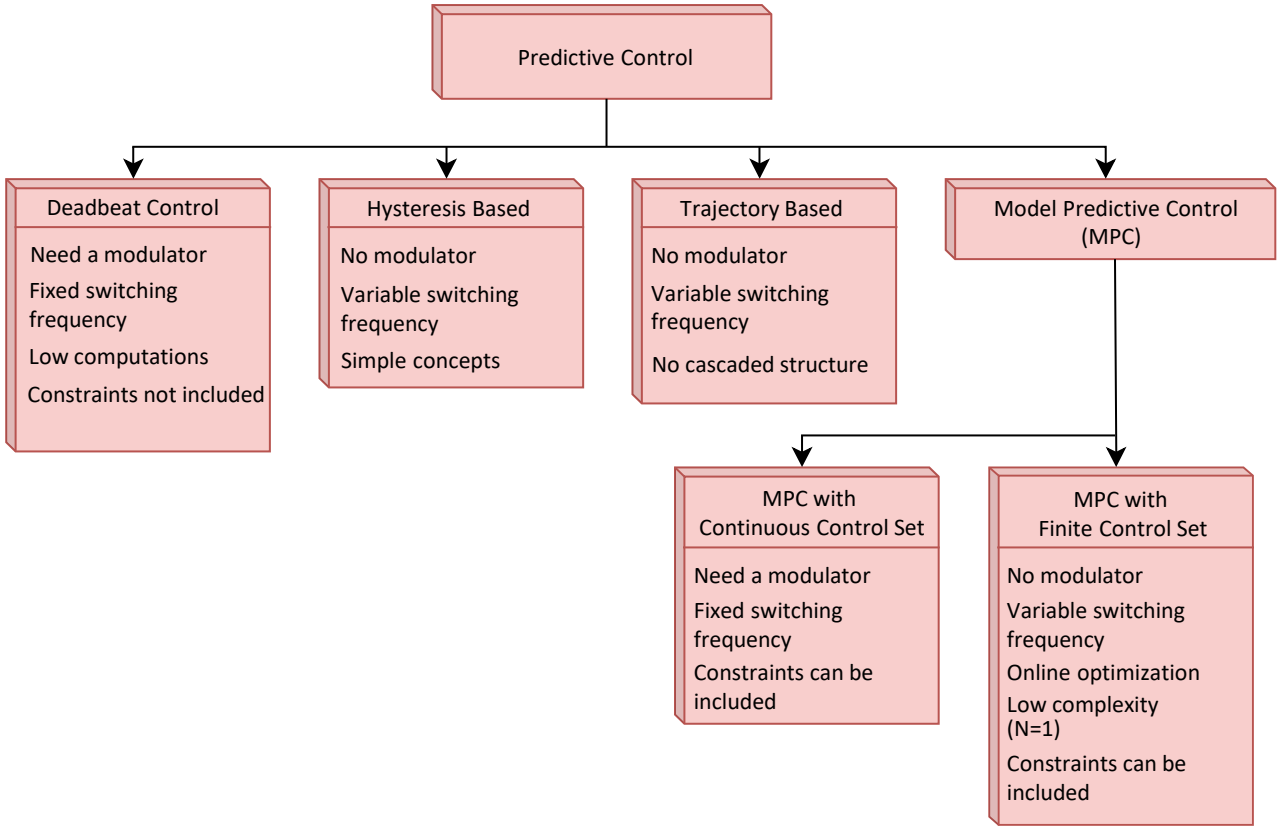
J. Rodríguez, J. Pontt, C. Silva, M. Salgado, S. Rees,
U. Ammann, P. Lezana, R. Huerta and P. Cortés

A new method for current control based on a predictive strategy is presented. This uses a discrete-time model of the load to predict the future value of the current for each of the possible voltage vectors generated by the inverter. The vector which minimises the current error at the next sampling time is selected. Experimental results that confirm the feasibility of the method are given.

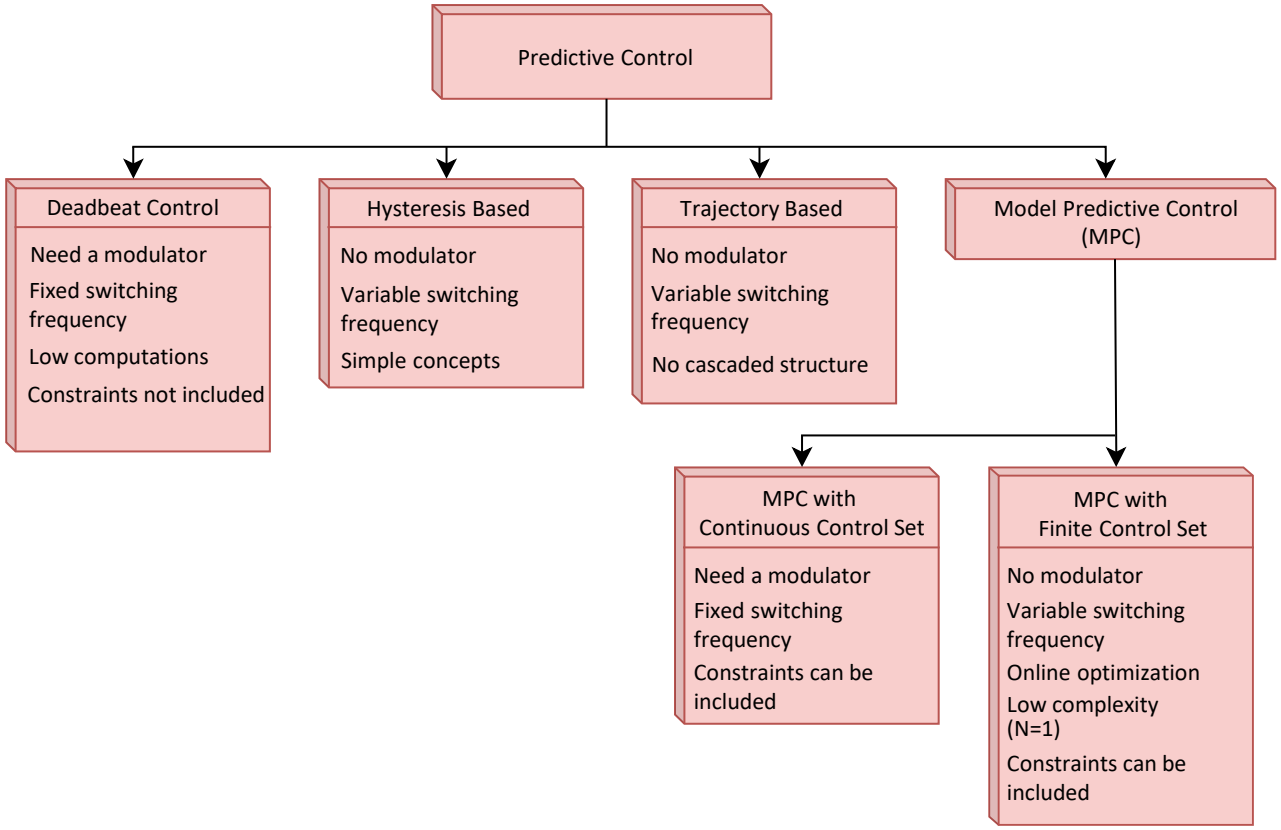
Predictive control of three-phase inverter – Electronics Letters 2004

MPC uses a **model of the system** to predict the behavior of the controlled variables and then select the actuation sequence **that minimizes a certain cost function**. The cost function represents **the desired behavior of the system**.

- Basic Principles of Model Predictive Control: Control Strategies

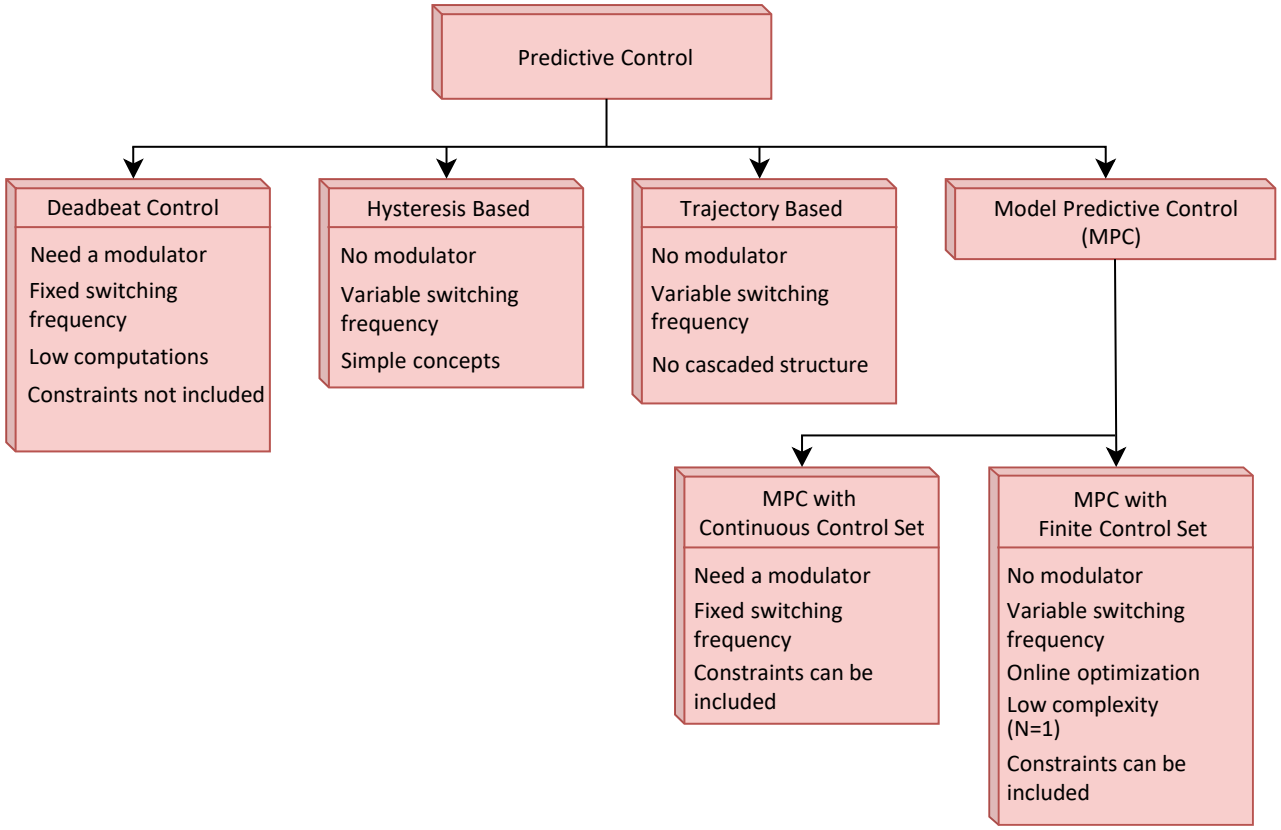


- Basic Principles of Model Predictive Control: Control Strategies



The main characteristic of predictive control is the use of the model of the system for prediction of the future behavior of the controlled variables.

- Basic Principles of Model Predictive Control: Control Strategies



The main characteristic of predictive control is the use of the model of the system for prediction of the future behavior of the controlled variables.

This information is used by the controller in order to obtain the optimal actuation, according to a predefined optimization criterion.

- Basic Principles of Model Predictive Control: Advantages

- Concepts are very intuitive and easy to understand.
- It can be applied to a great variety of systems.
- The multivariable case can be easily considered.
- Delay times can be compensated.
- Easy inclusion of nonlinearities in the model.
- Simple treatment of constraints.
- The resulting controller is easy to implement.
- This methodology is open to include modifications and extensions depending on specific applications.

- Basic Principles of Model Predictive Control: Disadvantages

- Large amount of calculations.
- The quality of the model has a direct influence on the quality of the resulting controller.
- In the classical MPC strategy is observed a variable switching frequency.
- When there are several objectives weighting factors are needed.

University of Nottingham
UK | CHINA | MALAYSIA

pels
IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

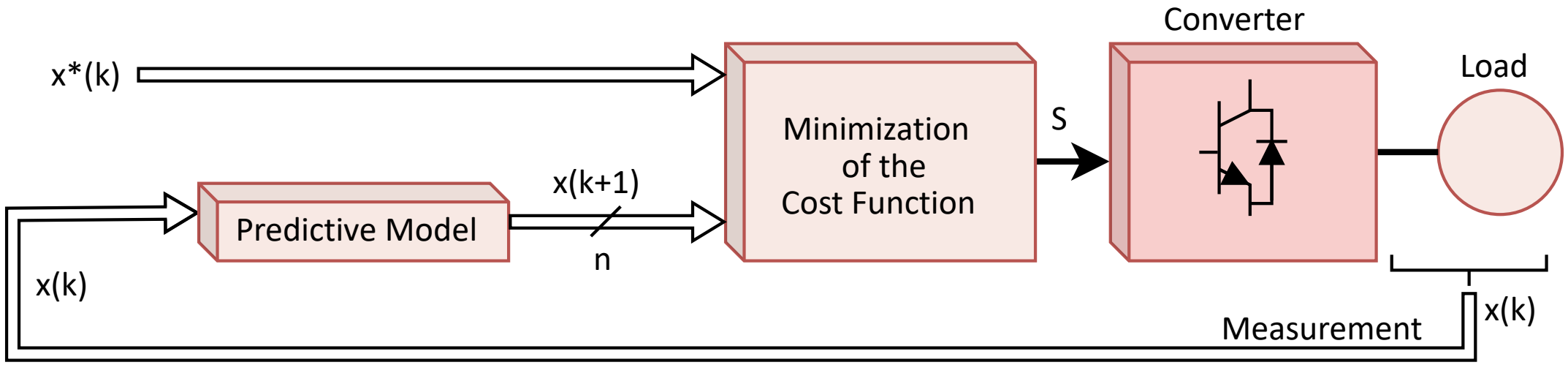
IEEE
Advancing Technology for Humanity

TALCA UNIVERSIDAD CHILE

lceep
Laboratorio de Conversión de Energías y Electrónica de Potencia

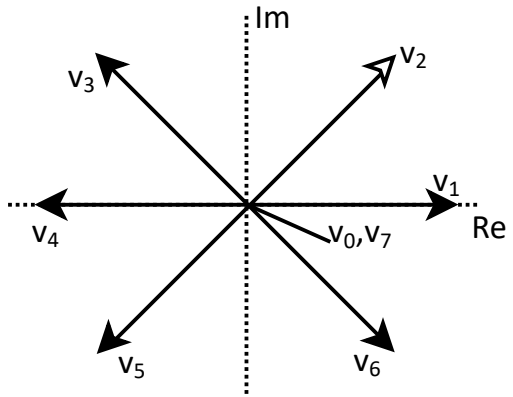
Predictive Control for Power Converters and Electrical Drives

- Controller Design: General MPC Scheme for Power Converters



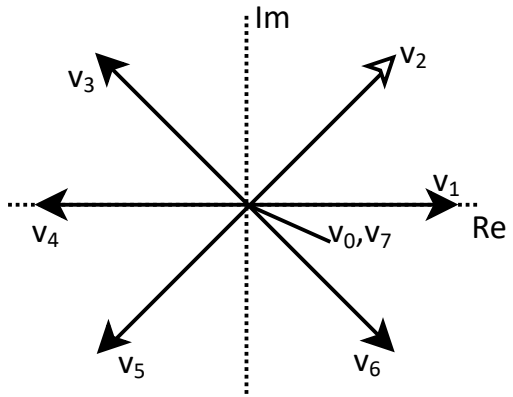
- Controller Design: How Does it Work?

- The converter is modelled as a system with finite states



- Controller Design: How Does it Work?

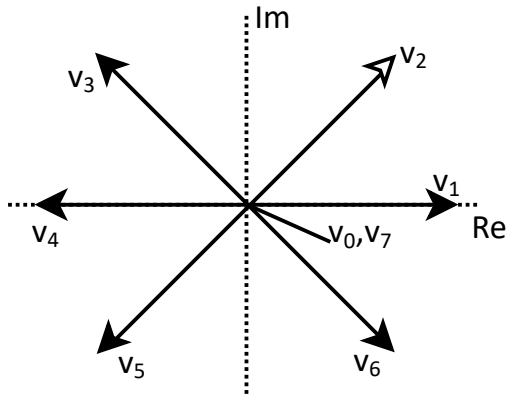
- The converter is modelled as a system with finite states
- A model of the load is used to predict the behaviour for each possible switching state



$$\hat{\mathbf{i}}(k+1) = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}(k) + \frac{T_s}{L}\left(\mathbf{v}(k) - \hat{\mathbf{e}}(k)\right)$$

- Controller Design: How Does it Work?

- The converter is modelled as a system with finite states
- A model of the load is used to predict the behaviour for each possible switching state
- A cost function is defined and represents the desired behaviour of the system

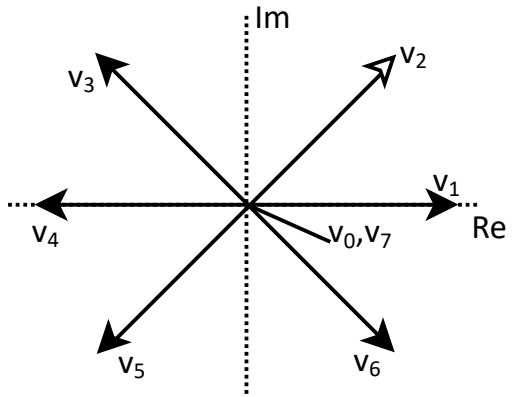


$$\hat{\mathbf{i}}(k+1) = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}(k) + \frac{T_s}{L}\left(\mathbf{v}(k) - \hat{\mathbf{e}}(k)\right)$$

$$g = |i_\alpha^* - i_\alpha^p| + |i_\beta^* - i_\beta^p|$$

- Controller Design: How Does it Work?

- The converter is modelled as a system with finite states
- A model of the load is used to predict the behaviour for each possible switching state
- A cost function is defined and represents the desired behaviour of the system
- The switching state that minimizes the cost function is selected to be applied in the next sampling instant

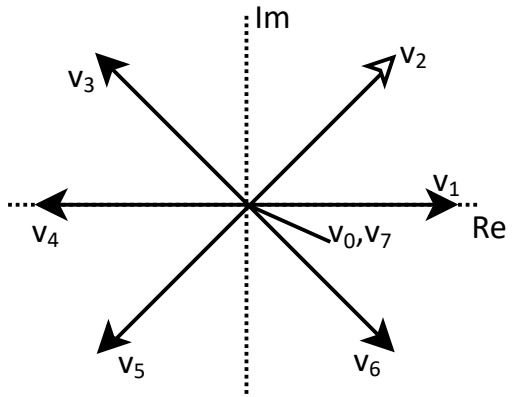


$$\hat{\mathbf{i}}(k+1) = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}(k) + \frac{T_s}{L}\left(\mathbf{v}(k) - \hat{\mathbf{e}}(k)\right)$$

$$g = |i_\alpha^* - i_\alpha^p| + |i_\beta^* - i_\beta^p| \qquad g_{min} = \min\{ g \}$$

- Controller Design: How Does it Work?

- The converter is modelled as a system with finite states
- A model of the load is used to predict the behaviour for each possible switching state
- A cost function is defined and represents the desired behaviour of the system
- The switching state that minimizes the cost function is selected to be applied in the next sampling instant



$$\hat{\mathbf{i}}(k+1) = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}(k) + \frac{T_s}{L}\left(\mathbf{v}(k) - \hat{\mathbf{e}}(k)\right)$$

$$g = |i_\alpha^* - i_\alpha^p| + |i_\beta^* - i_\beta^p| \qquad g_{min} = \min\{ g \}$$

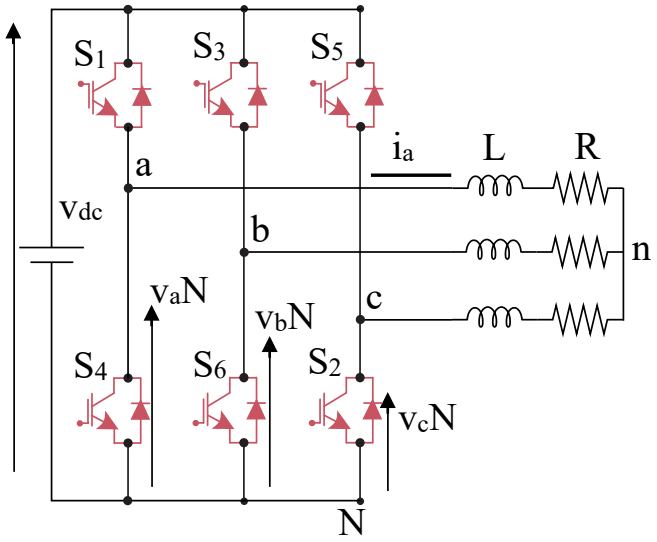
… and that is all!!

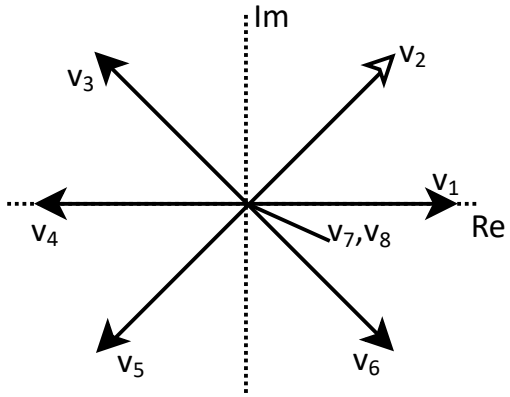
Examples

Predictive Control for Power Converters and Electrical Drives

Model Predictive Control for Three Phase Inverter

- Two Level Voltage Source Inverter: Topology and Switching States



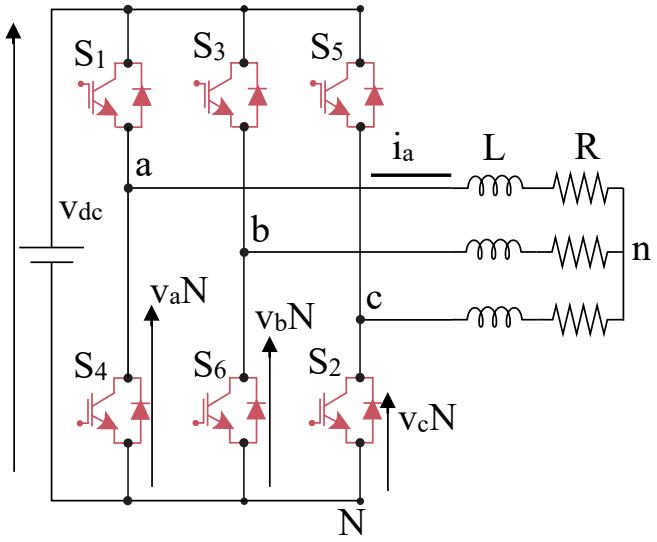


Valid Switching States of the VSI

#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

- 6 commutation devices
- 8 valid switching states

- Two Level Voltage Source Inverter: Converter Model

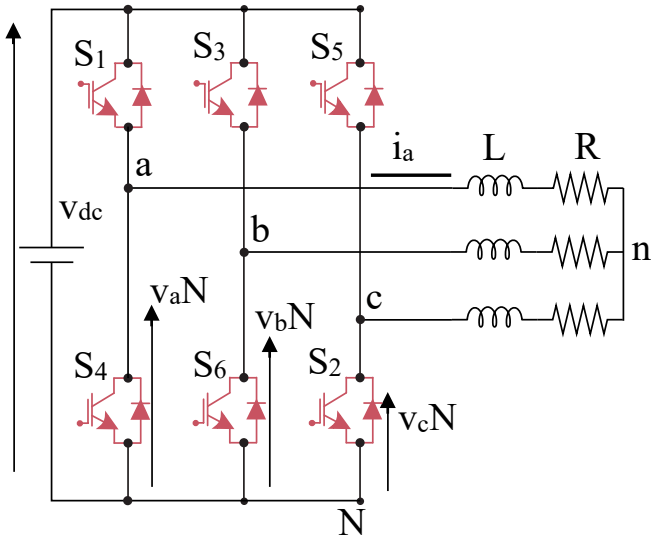


Valid Switching States of the VSI

#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

$$i_{dc} = \begin{bmatrix} S_1 & S_3 & S_5 \end{bmatrix} \mathbf{i} \qquad \mathbf{v} = \begin{bmatrix} S_1 \\ S_3 \\ S_5 \end{bmatrix} v_{dc}$$

- Two Level Voltage Source Inverter: Load Model

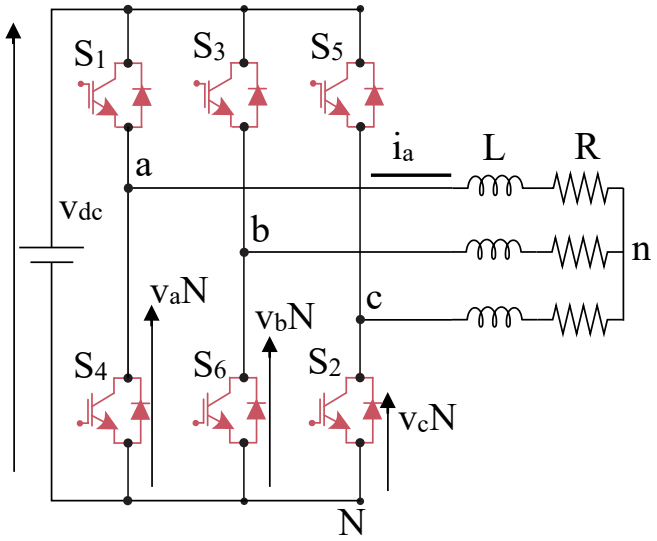


Valid Switching States of the VSI

#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

$$\mathbf{v} = L\frac{d\mathbf{i}}{dt} + R\mathbf{i}$$

- PCC of a Two Level Voltage Source Inverter: Discrete Model



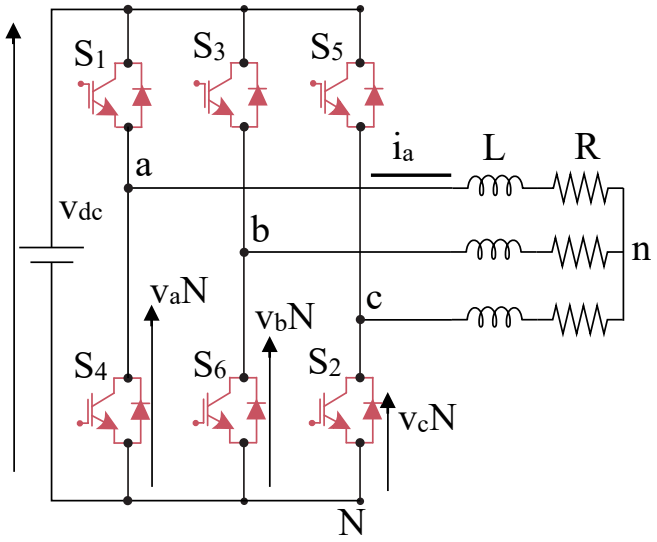
Valid Switching States of the VSI

#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

- Considering Euler approximation

$$\mathbf{i}^{k+1} = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}^k + \frac{T_s}{L}\mathbf{v}^k$$

- PCC of a Two Level Voltage Source Inverter: Discrete Model



Valid Switching States of the VSI

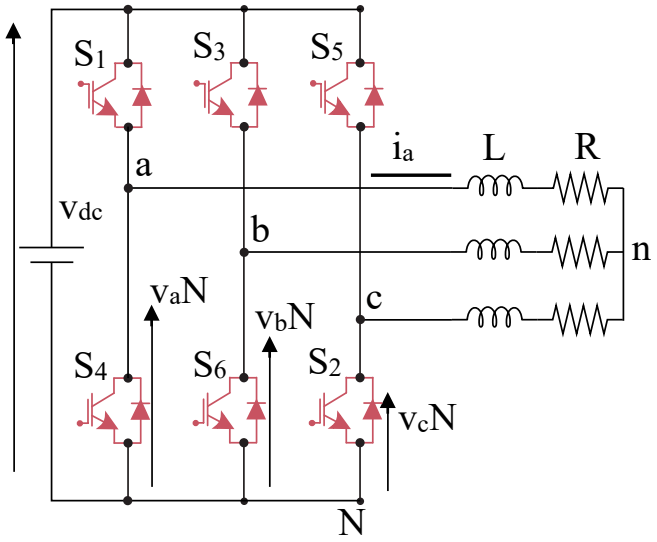
#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

- Considering Euler approximation

$$\mathbf{i}^{k+1} = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}^k + \frac{T_s}{L}\mathbf{v}^k$$

$$\mathbf{v} = \begin{bmatrix} S_1 \\ S_3 \\ S_5 \end{bmatrix} v_{dc}$$

- PCC of a Two Level Voltage Source Inverter: Cost Function



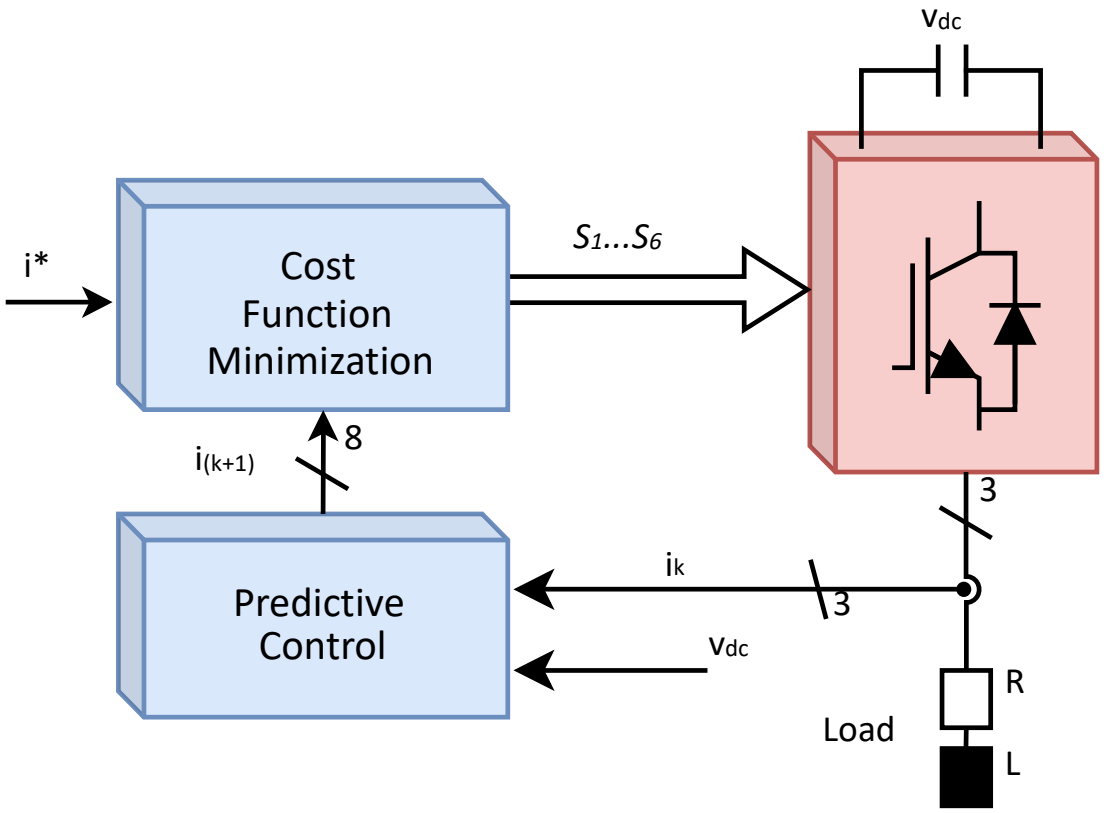
Valid Switching States of the VSI

#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

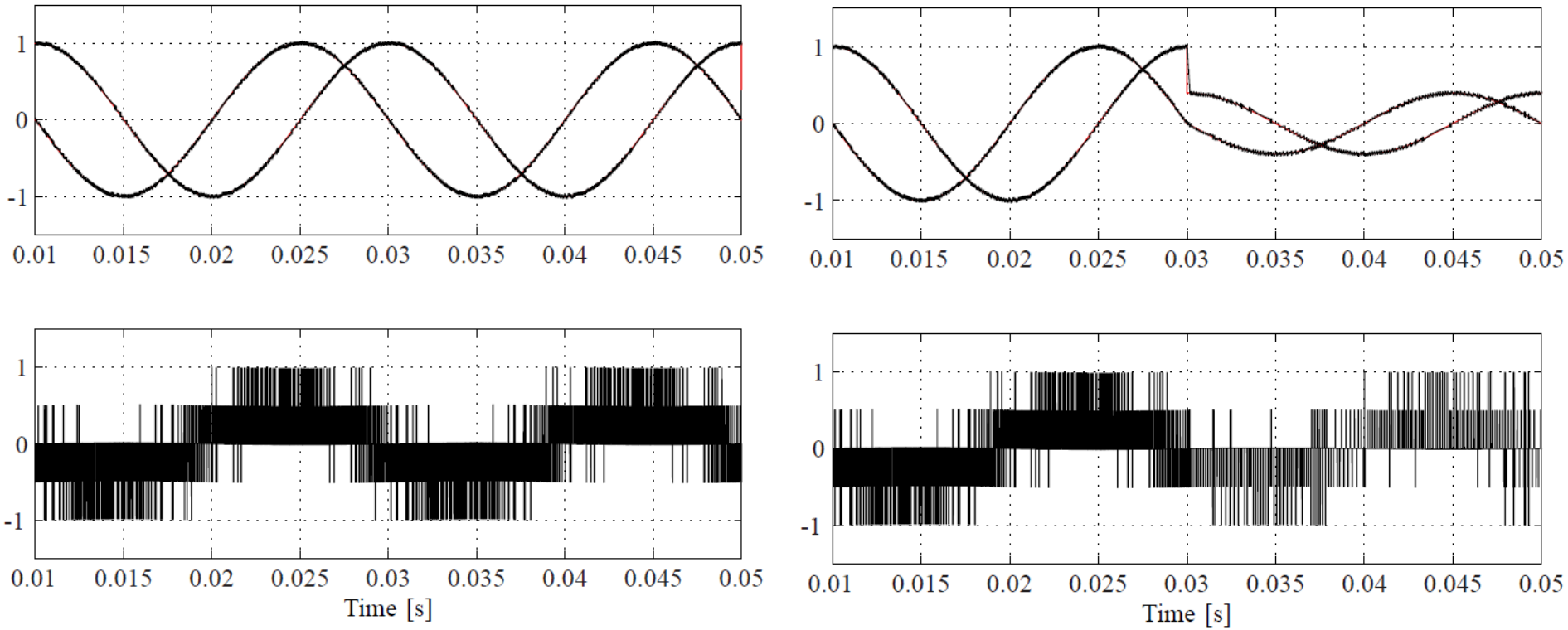
$$g(k+1) = \left(\mathbf{i}^{*} - \mathbf{i}^{k+1}\right)^{2}$$

- The current error must be zero
- From the valid switching states, the one that minimizes the cost function is selected to be applied in the next sampling time

- PCC of a Two Level Voltage Source Inverter: Control Scheme



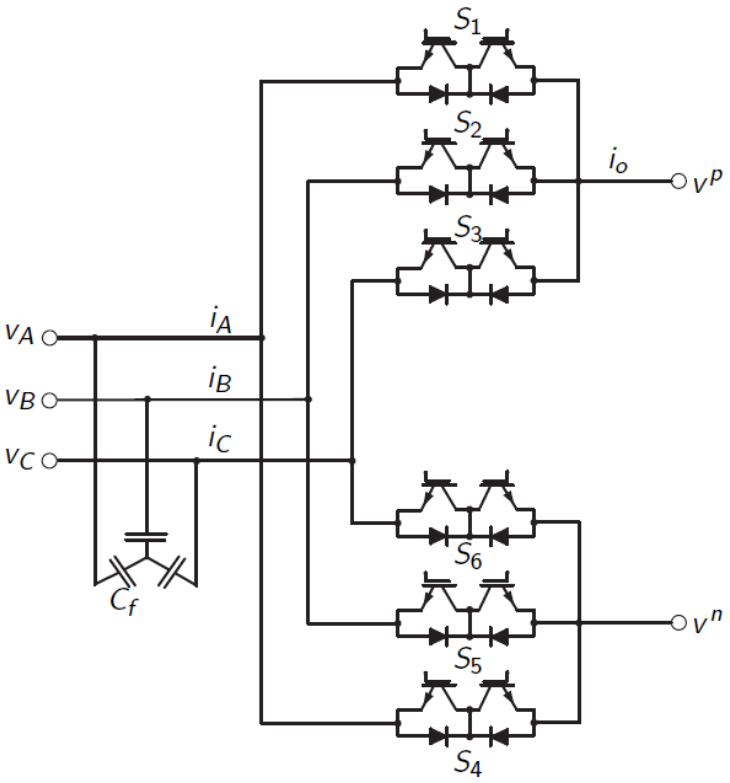
- PCC of a Two Level Voltage Source Inverter: Simulated Results



Predictive Control for Power Converters and Electrical Drives

Model Predictive Control for a Single-Phase Matrix Converter

- MPC of a Single-Phase Matrix Converter: Mathematical Model

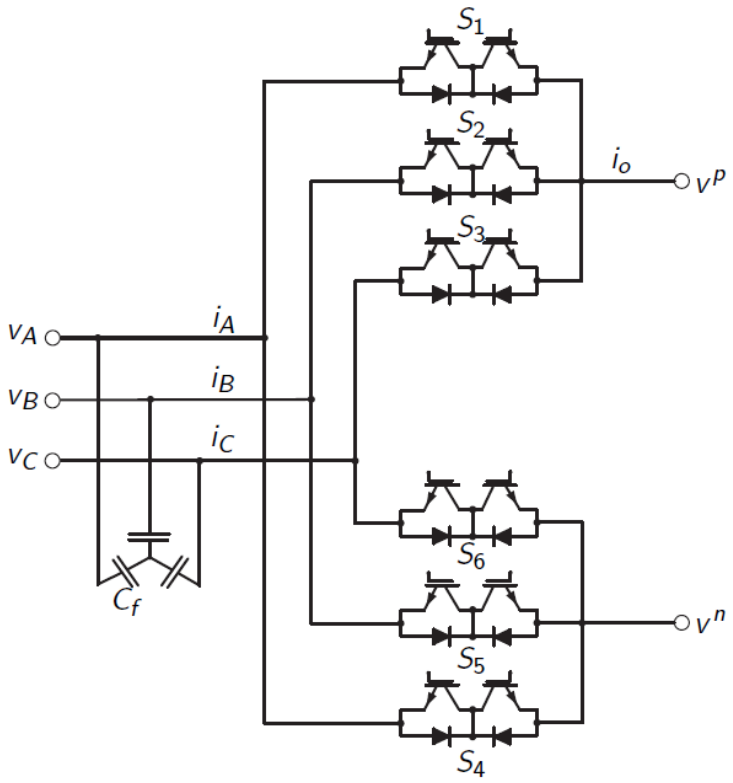


$$v^p = \begin{bmatrix} S_1 & S_2 & S_3 \end{bmatrix} \mathbf{v_i},$$

$$v^n = \begin{bmatrix} S_4 & S_5 & S_6 \end{bmatrix} \mathbf{v_i}.$$

$$\mathbf{i_i} = \begin{bmatrix} S_1 - S_4 \\ S_2 - S_5 \\ S_3 - S_6 \end{bmatrix} i_o. \qquad (1)$$

- MPC of a Single-Phase Matrix Converter: Nine Valid Switching States



$$v^p = \begin{bmatrix} S_1 & S_2 & S_3 \end{bmatrix} \mathbf{v_i},$$

$$v^n = \begin{bmatrix} S_4 & S_5 & S_6 \end{bmatrix} \mathbf{v_i}.$$

$$\mathbf{i_i} = \begin{bmatrix} S_1 - S_4 \\ S_2 - S_5 \\ S_3 - S_6 \end{bmatrix} i_o. \qquad (1)$$

#	S_1	S_2	S_3	S_4	S_5	S_6	v^p	v^n	i_A	i_B	i_C
1	0	0	1	0	0	1	v_C	v_C	0	0	0
2	0	1	0	0	1	0	v_B	v_B	0	0	0
3	1	0	0	1	0	0	v_A	v_A	0	0	0
4	0	0	1	0	1	0	v_C	v_B	0	$-i_o$	i_o
5	0	0	1	1	0	0	v_C	v_A	$-i_o$	0	i_o
6	0	1	0	0	0	1	v_B	v_C	0	i_o	$-i_o$
7	0	1	0	1	0	0	v_B	v_A	$-i_o$	i_o	0
8	1	0	0	0	0	1	v_A	v_C	i_o	0	$-i_o$
9	1	0	0	0	1	0	v_A	v_B	i_o	$-i_o$	0

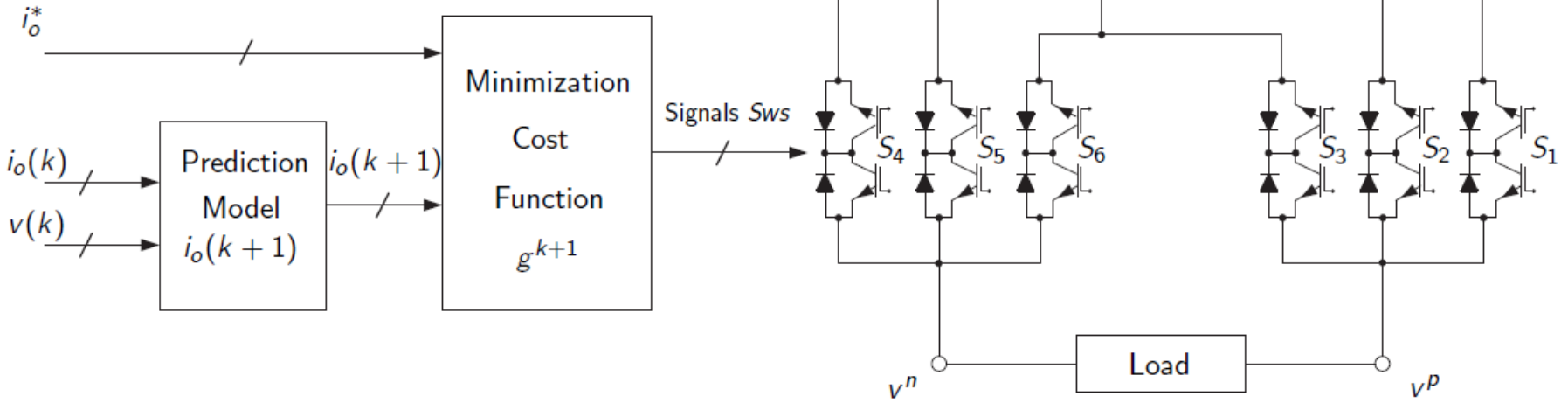
- MPC of a Single-Phase Matrix Converter: Control Scheme

Predictive model:

$$i_o(k+1) = (T_s/L)v(k) + (1 - RT_s/L)i_o(k).$$

Cost function optimization:

$$g(k+1) = (i_o^*(k+1) - i_o(k+1))^2.$$



- MPC of a Single-Phase Matrix Converter: Results

Simulation

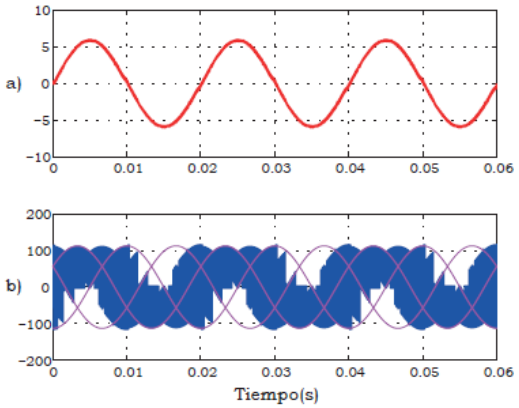


Fig. 1: i_o = 6 Apk ; f_o = 50 Hz ; f_s = 40 kHz ; v_i = 112 V pk;

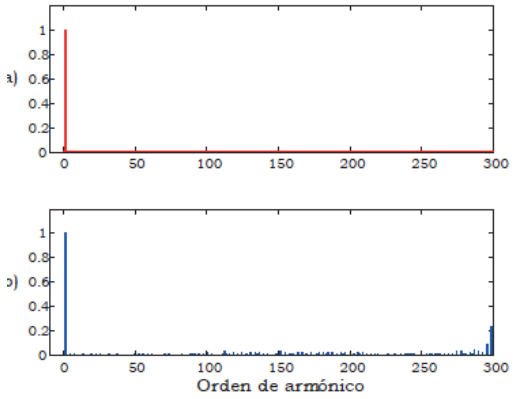


Fig. 3: i_o = 6 Apk ; f_o = 50 Hz ; f_s = 40 kHz ; v_i = 112 V pk;

Experimental

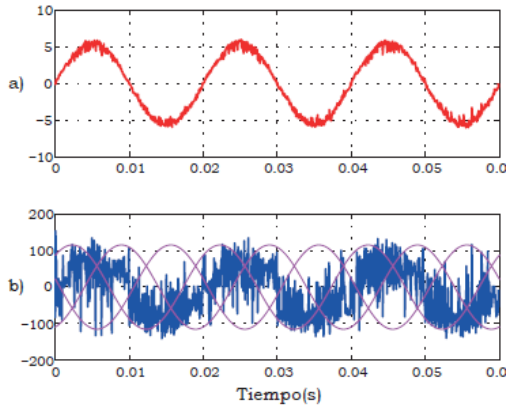


Fig. 2: i_o = 6 Apk ; f_o = 50 Hz ; f_s = 40 kHz ; v_i = 112 V pk;

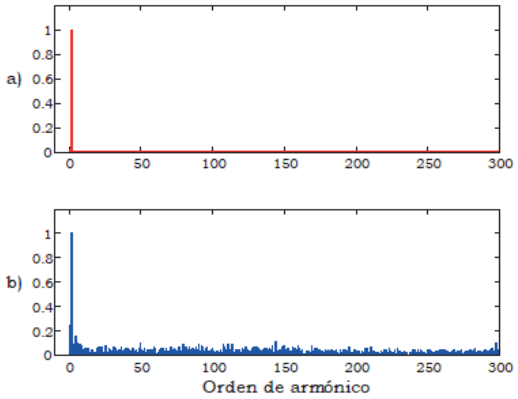


Fig. 4: i_o = 6 Apk ; f_o = 50 Hz ; f_s = 40 kHz ; v_i = 112 V pk;

Simulation

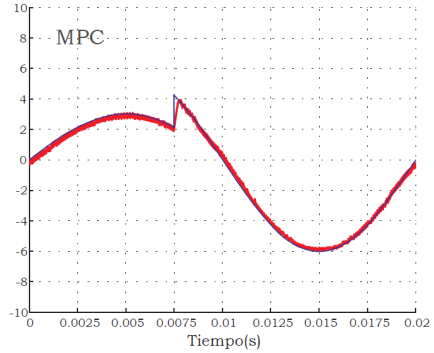


Fig. 3: i_o = 3 – 6Apk ; f_o = 50 Hz ; f_s = 40 kHz ; v_i = 112 V pk;

Experimental

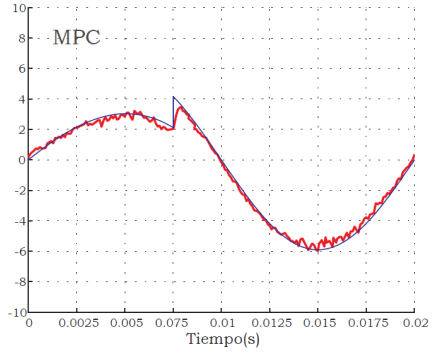
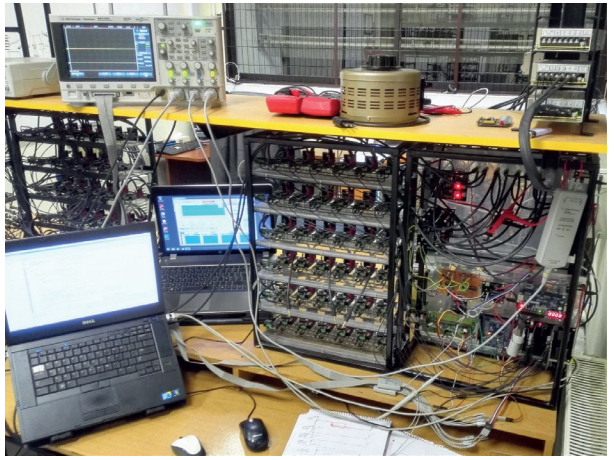
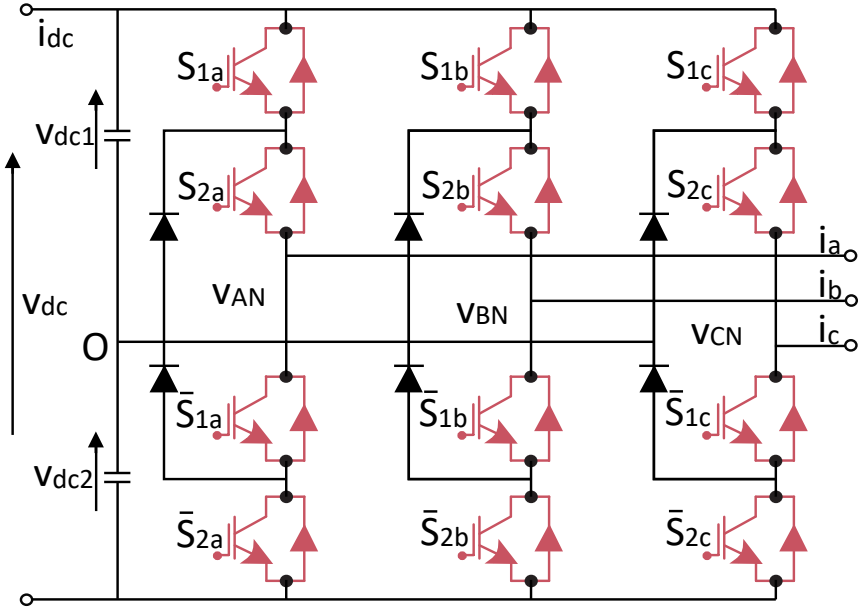


Fig. 4: i_o = 3 – 6Apk ; f_o = 50 Hz ; f_s = 40 kHz ; v_i = 112 V pk;

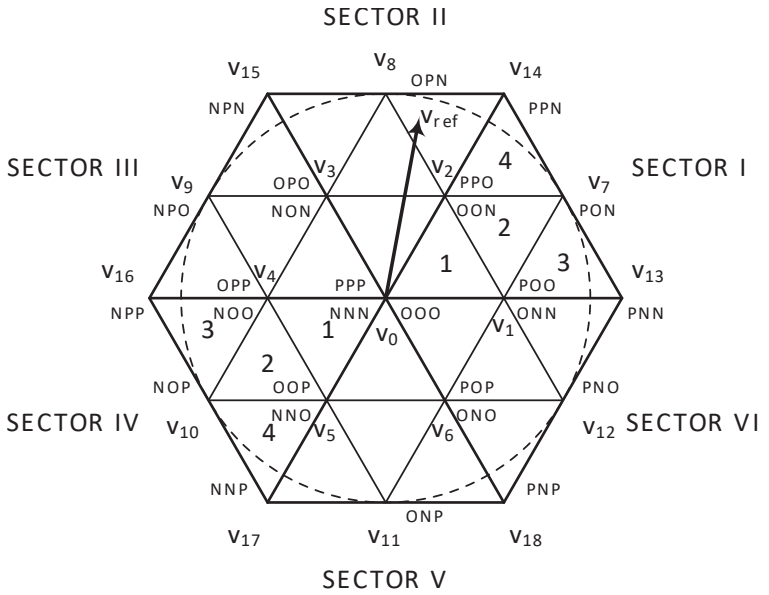


Model Predictive Control for an NPC Inverter

- NPC Inverter: Topology and Switching States

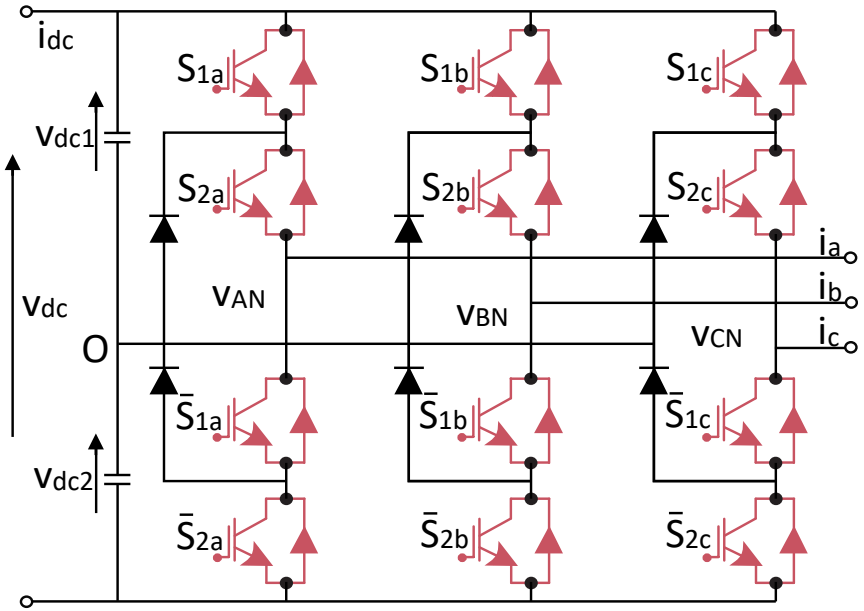


S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0



- Widely used in industry for high power medium voltage power conversion and drives
- 12 commutation devices
- 27 valid switching states

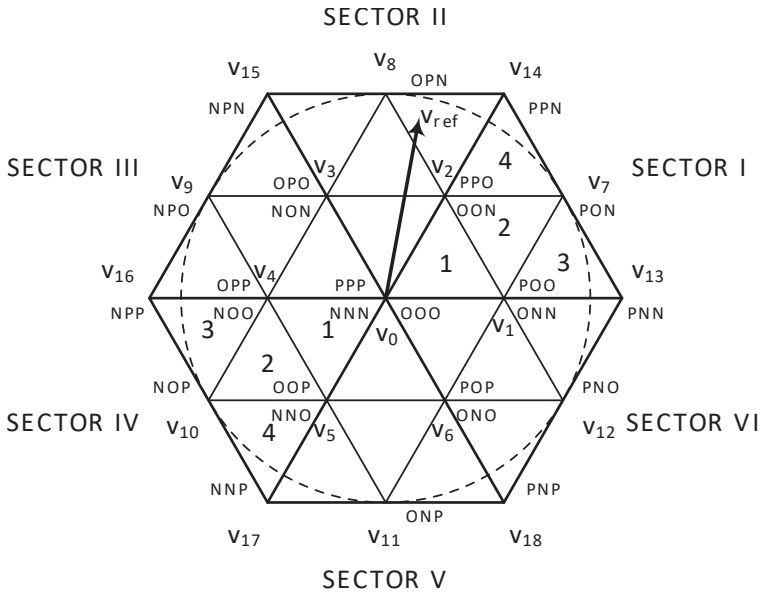
- NPC Inverter: Converter Model



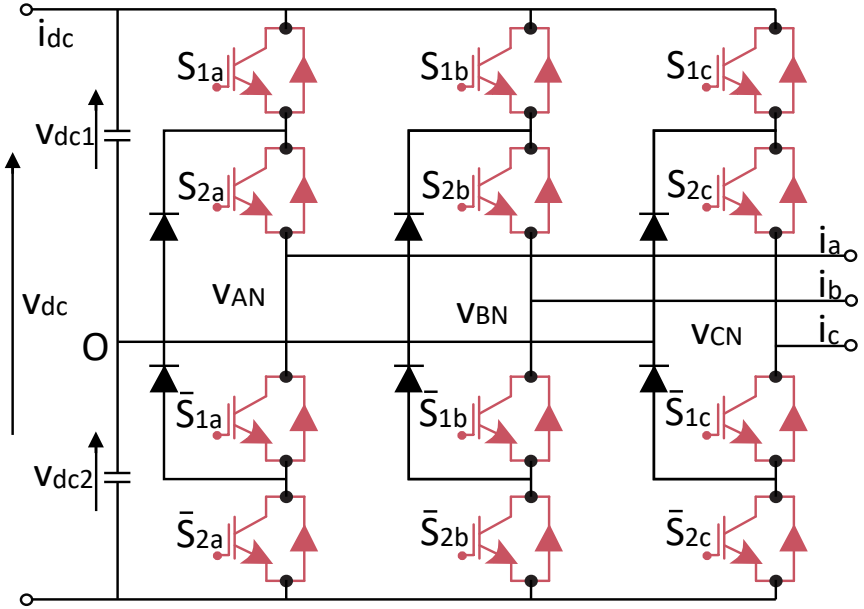
$$v_{xN} = v_{dc1} S_{1x} + v_{dc2} S_{2x}, \quad x = a, b, c$$

$$\frac{d\, v_{dc1}}{dt} = \frac{i_{dc1}}{C_1}$$
$$\frac{d\, v_{dc2}}{dt} = \frac{i_{dc2}}{C_2}$$

S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0

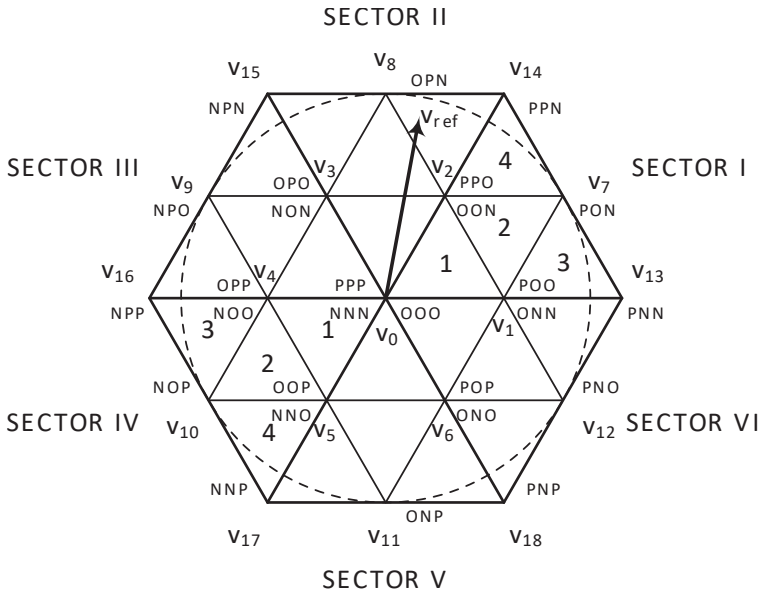


- NPC Inverter: Load Model

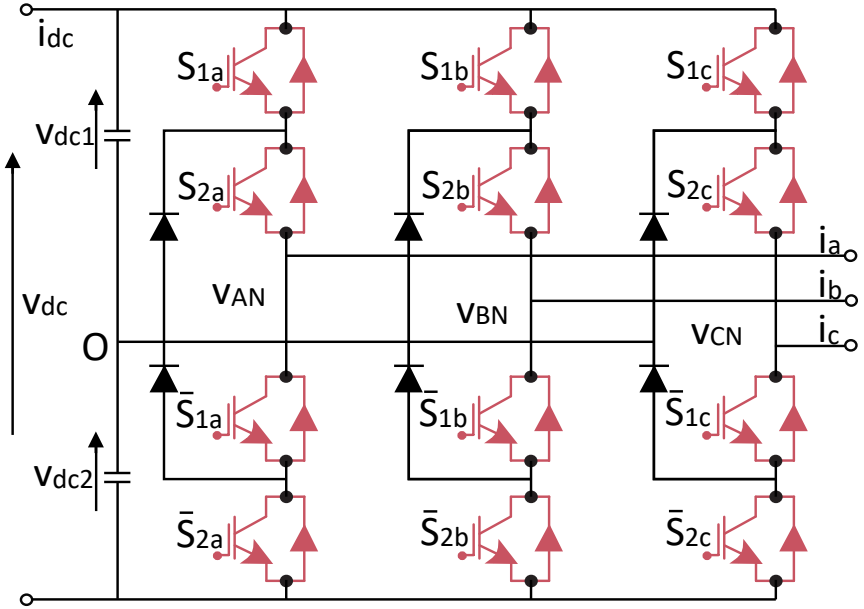


$$\mathbf{v} = L\frac{d\mathbf{i}}{dt} + R\mathbf{i}$$

S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0



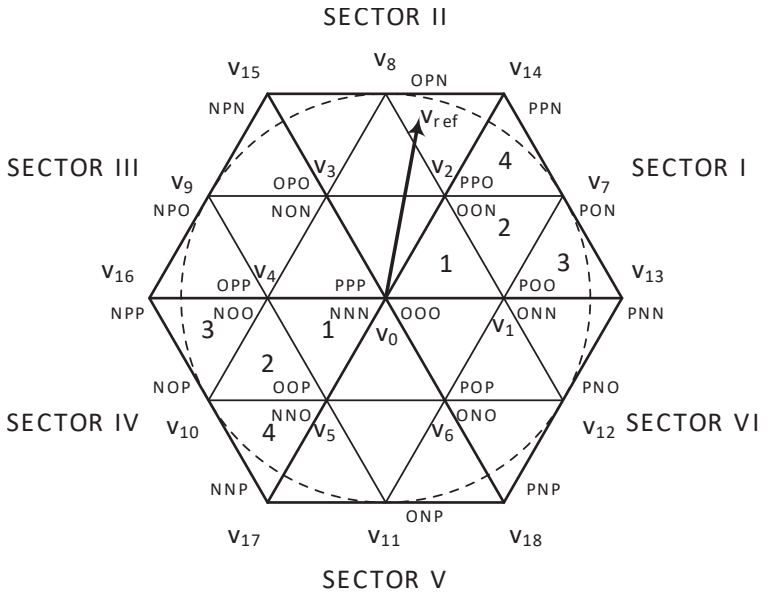
- PCC of an NPC Inverter: Discrete Model



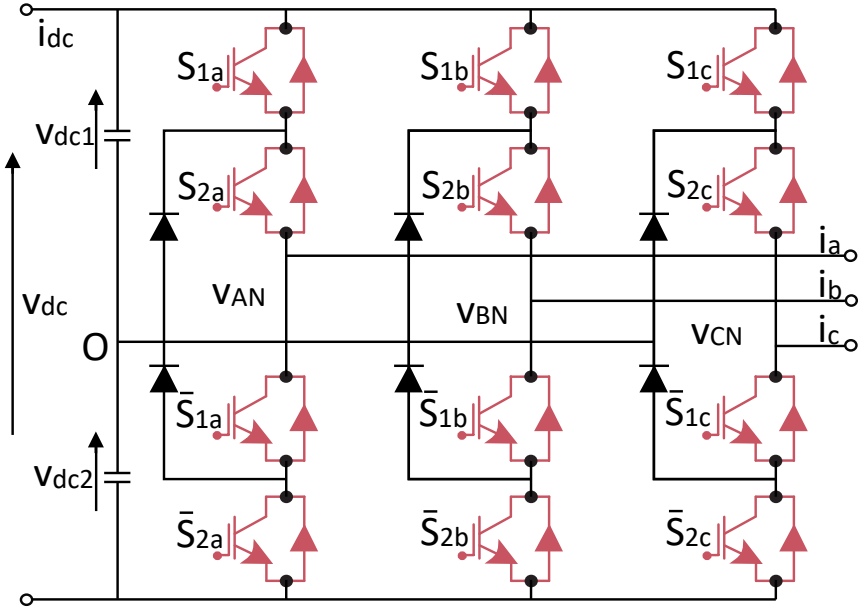
$$\mathbf{i}^{k+1} = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}^k + \frac{T_s}{L}\mathbf{v}^k$$

$$v_{dcx}^{k+1} = v_{dcx}^k + \frac{T_s}{C_x} i_{cx}^{k+1},\ x = 1, 2$$

S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0

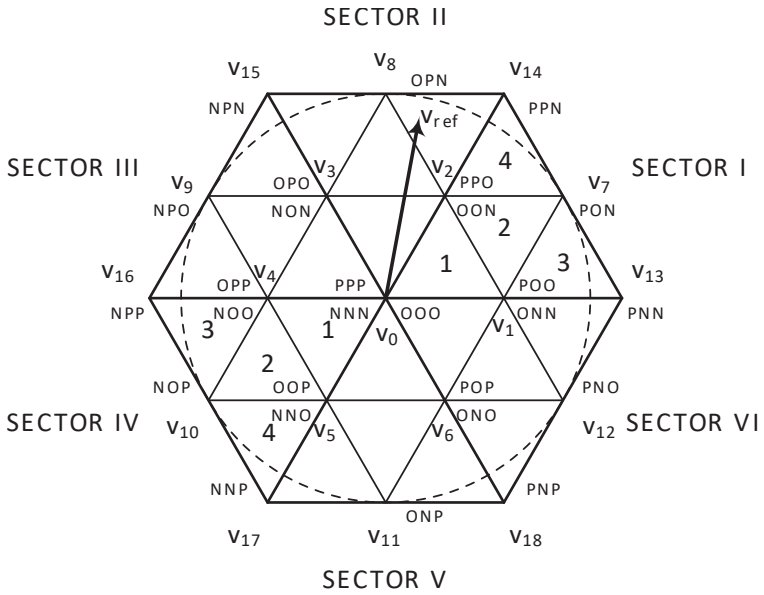


- PCC of an NPC Inverter: Cost Function

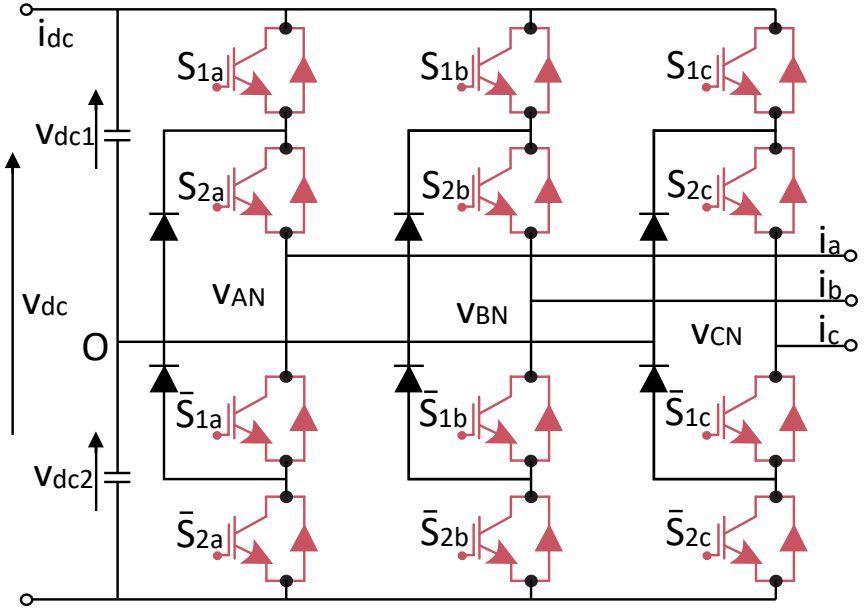


$$g^{k+1} = {g_{track}}^{k+1} + {g_{bal}}^{k+1}$$

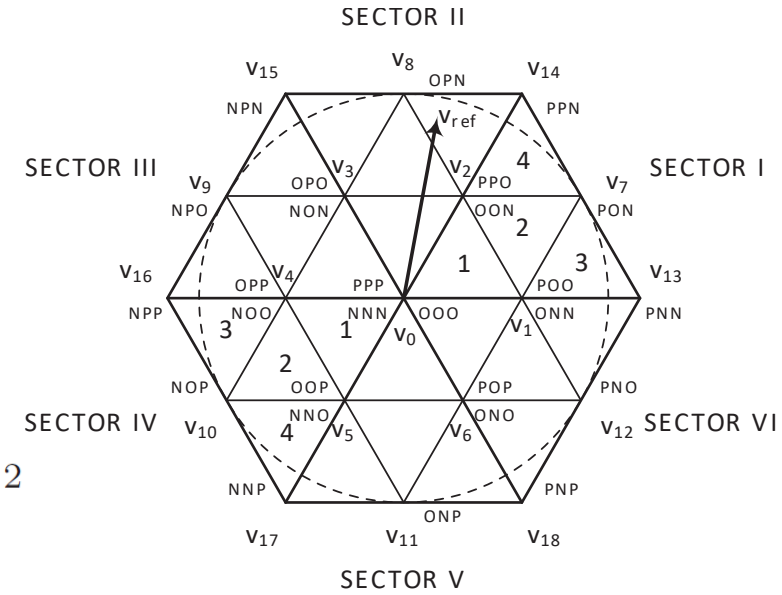
S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0



- PCC of an NPC Inverter: Cost Function



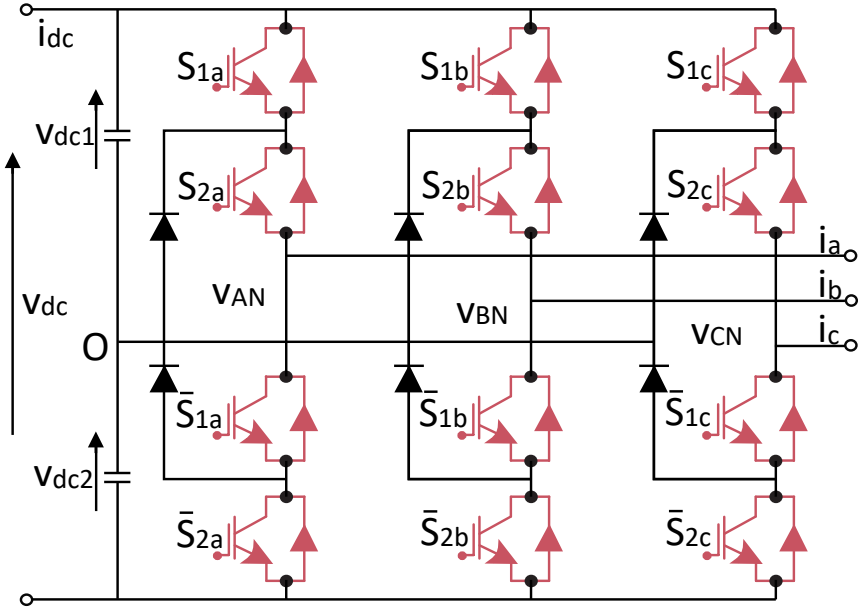
S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0



$$g^{k+1} = {g_{track}}^{k+1} + {g_{bal}}^{k+1}$$

$${g_{track}}^{k+1} = [i_a^* - {i_a}^{k+1}]^2 + [i_b^* - {i_b}^{k+1}]^2 + [i_c^* - {i_c}^{k+1}]^2$$

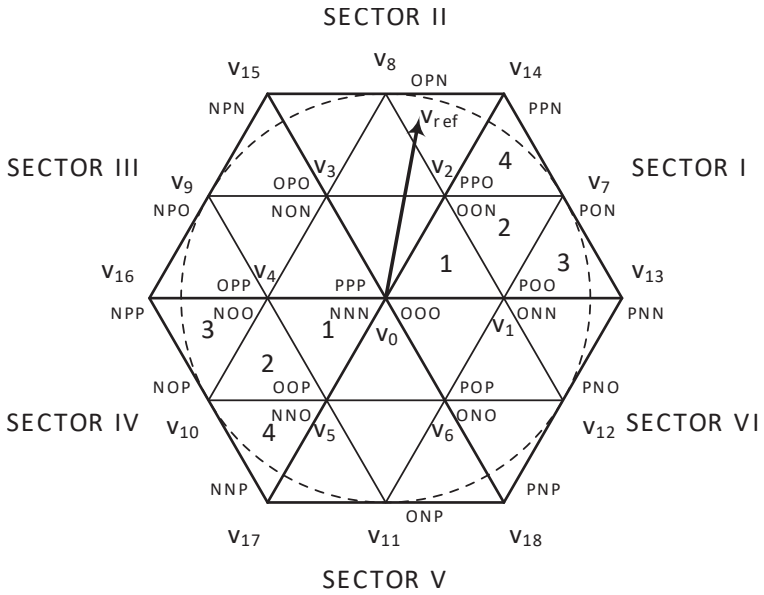
- PCC of an NPC Inverter: Cost Function



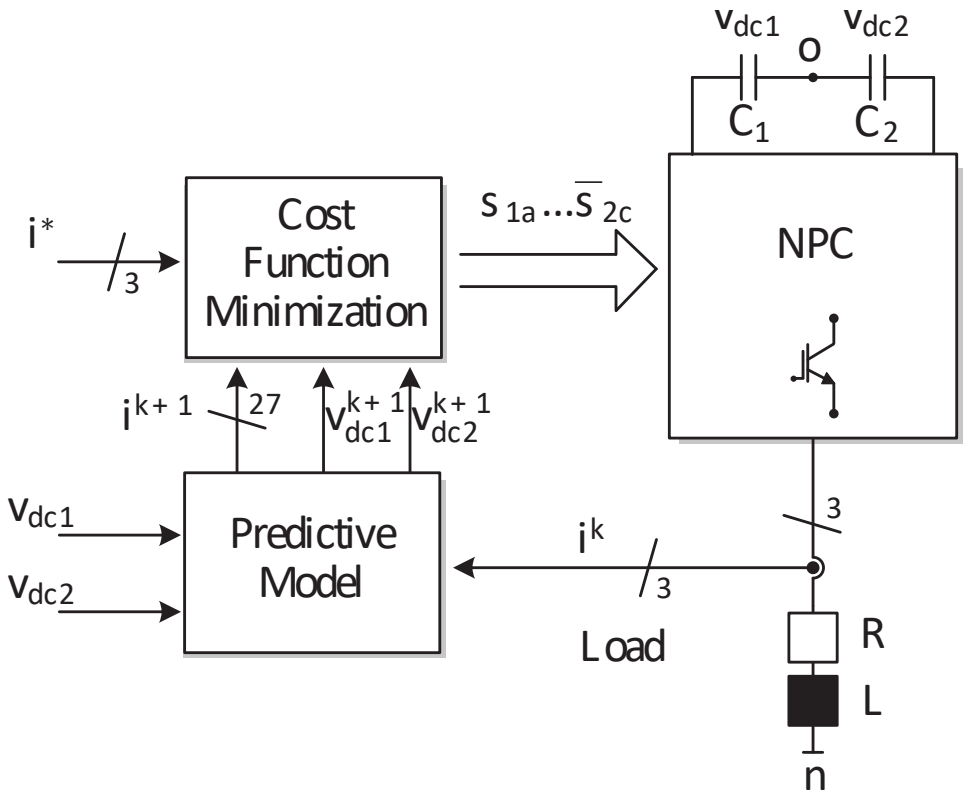
$$g^{k+1} = {g_{track}}^{k+1} + {g_{bal}}^{k+1}$$

$${g_{bal}}^{k+1} = \lambda_{dc} * \left[{v_{dc1}}^{k+1} - {v_{dc2}}^{k+1}\right]^2$$

S_x	S_{1x}	S_{2x}	$\bar{S}_{1x}$	$\bar{S}_{2x}$	v_{xn}
1	1	1	0	0	$v_{dc\,1} + v_{dc\,2}$
0	0	1	1	0	$v_{dc\,2}$
− 1	0	0	1	1	0

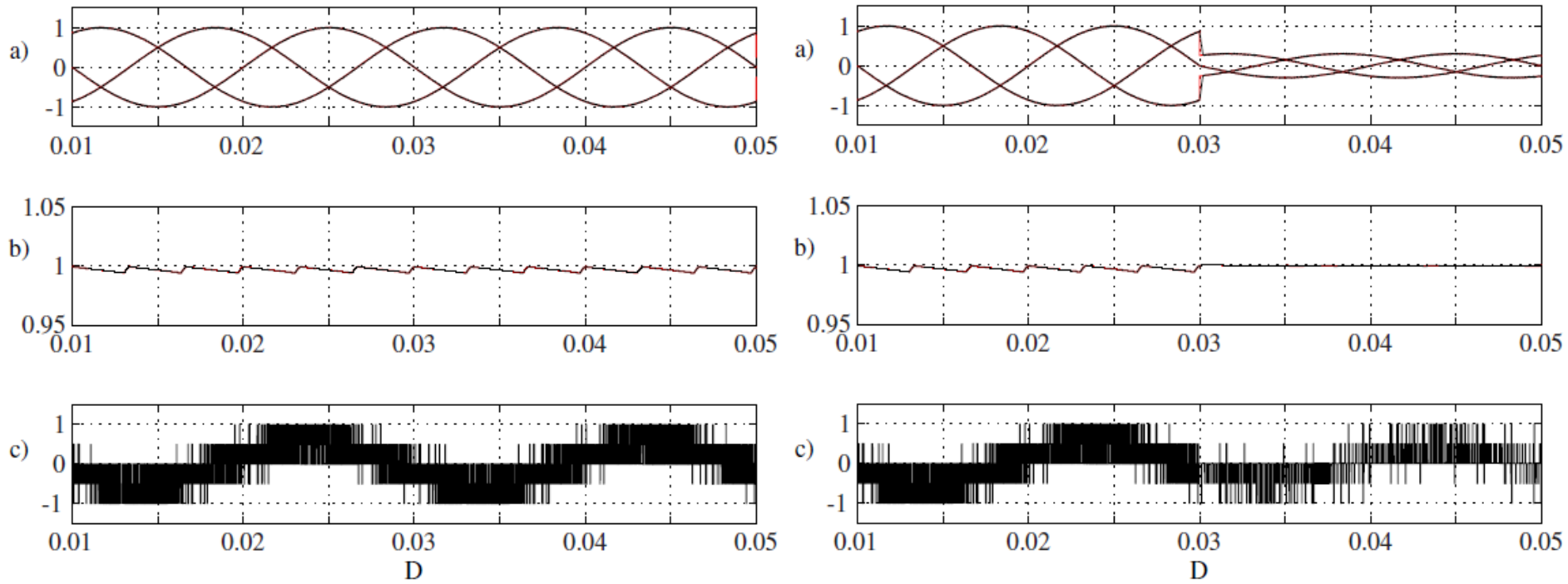


- PCC of an NPC Inverter: Control Scheme



- The NPC inverter presents a high number of switching states, compared to the two levels inverter.
- The behavior of the system is predicted for each possible switching state of the NPC inverter.
- The switching state that minimizes a given cost function is selected to be applied during the next sampling interval.

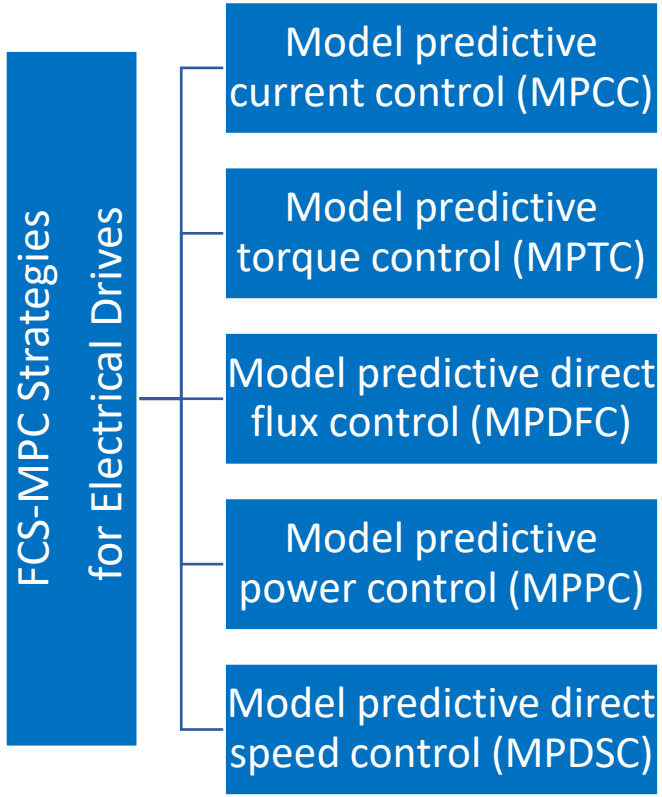
- PCC of an NPC Inverter: Simulated Results



MPC applied to Electrical Drives

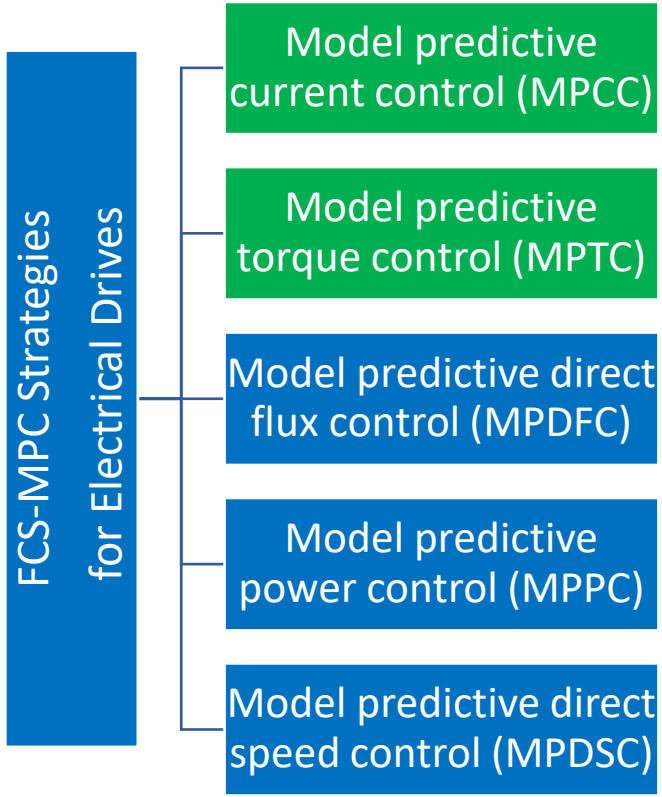
- MPC Strategies for Electrical Drives

- Various FCS-MPC strategies have been proposed for high-performance control of electric machines.



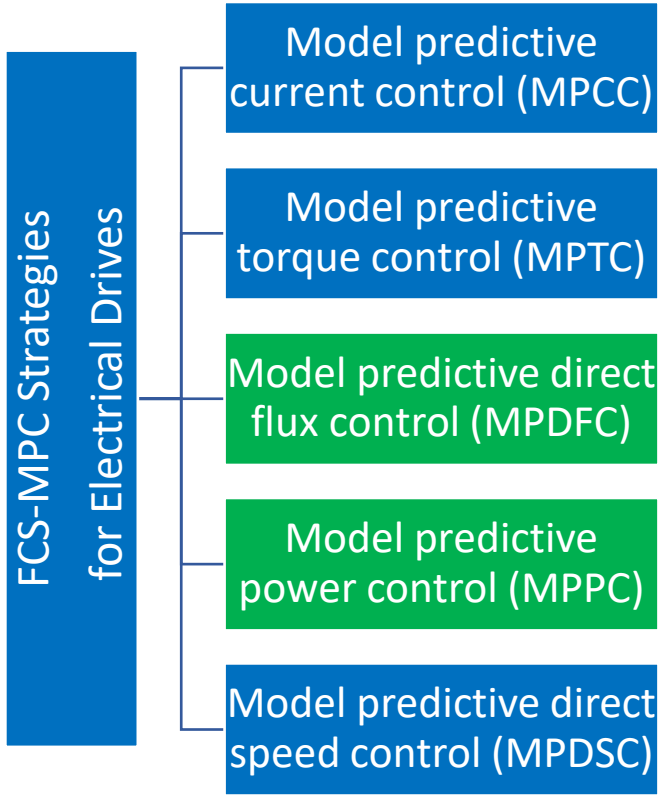
- MPC Strategies for Electrical Drives

- Various FCS-MPC strategies have been proposed for high-performance control of electric machines.
- Of these, model predictive current control (MPCC) and model predictive torque control (MPTC) are quite popular.



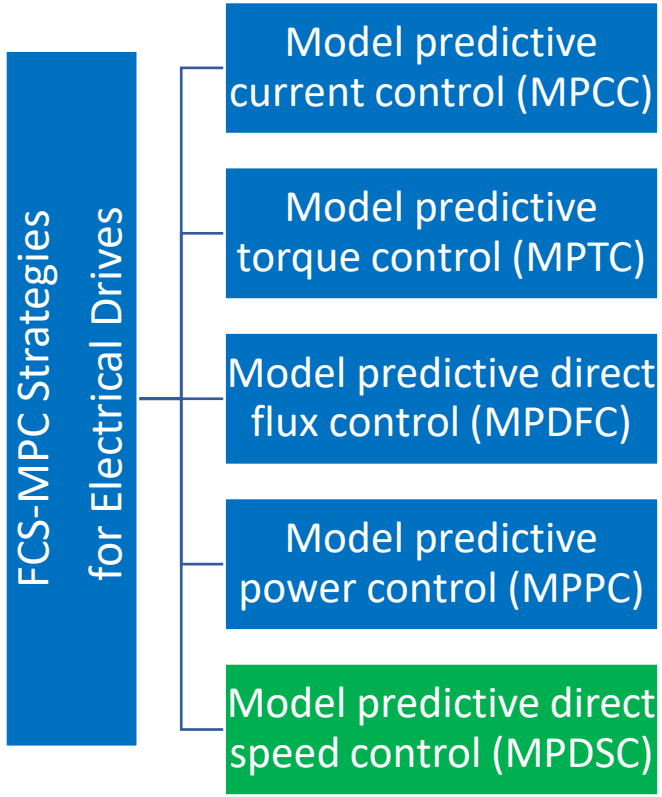
- MPC Strategies for Electrical Drives

- Various FCS-MPC strategies have been proposed for high-performance control of electric machines.
- Of these, model predictive current control (MPCC) and model predictive torque control (MPTC) are quite popular.
- Model predictive direct flux control (MPDFC) and model predictive power control (MPPC) are strong candidates to MPTC as they eliminates the weighting factor in MPTC.



- MPC Strategies for Electrical Drives

- Various FCS-MPC strategies have been proposed for high-performance control of electric machines.
- Of these, model predictive current control (MPCC) and model predictive torque control (MPTC) are quite popular.
- Model predictive direct flux control (MPDFC) and model predictive power control (MPPC) are strong candidates to MPTC as they eliminates the weighting factor in MPTC.
- Model predictive direct speed control (MPDSC) eliminates the cascaded control structure of previous FCS-MPC strategies to improve the control performance. However, it requires load information, which is costly to measure.



- Application of FCS-MPC Strategies for PMSM Control

PMSM model:

$$\dot{\mathbf{x}}_t = \mathbf{f}(\mathbf{x}_t, \mathbf{u}_t) + \mathbf{w}_t$$
$$\mathbf{z}_t = \mathbf{h}(\mathbf{x}_t) + \mathbf{v}_t$$

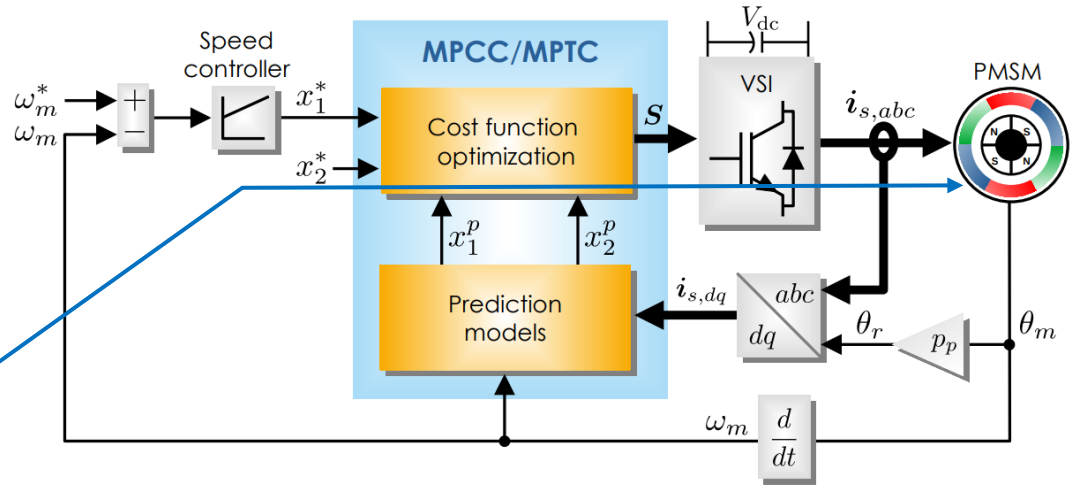
where

$$\mathbf{x}_t = \begin{bmatrix} i_d \\ i_q \\ \omega_m \end{bmatrix}, \mathbf{u}_t = \begin{bmatrix} v_d \\ v_q \end{bmatrix}, \mathbf{h}(\mathbf{x}_t) = \begin{bmatrix} i_d \\ i_q \\ \omega_m \end{bmatrix},$$

$$\mathbf{f}(\mathbf{x}_t, \mathbf{u}_t) = \begin{bmatrix} \frac{1}{L_s} v_d - \frac{R_s}{L_s} i_d + p_p \omega_m i_q \\ \frac{1}{L_s} v_q - \frac{R_s}{L_s} i_q - p_p \omega_m i_d - \frac{p_p}{L_s} \omega_m \psi_{\mathrm{pm}} \\ \frac{3}{2} \frac{p_p}{J_t} \psi_{\mathrm{pm}} i_q - \frac{B_t}{J_t} \omega_m - \frac{\tau_l}{J_t} \end{bmatrix}$$

After applying forward Euler discretization, the discrete PMSM model can be obtained as follows:

$$\mathbf{x}_{k+1} = \mathbf{x}_k + T_s \cdot \mathbf{f}(\mathbf{x}_t, \mathbf{u}_t)$$



Block diagram of MPCC and MPTC strategies for PMSM control ($x_1 = i_q, x_2 = i_d$ for MPCC; $x_1 = \tau_e, x_2 = \|\psi_s\|$ for MPTC).

- Application of MPCC Strategy for PMSM Control

MPCC strategy

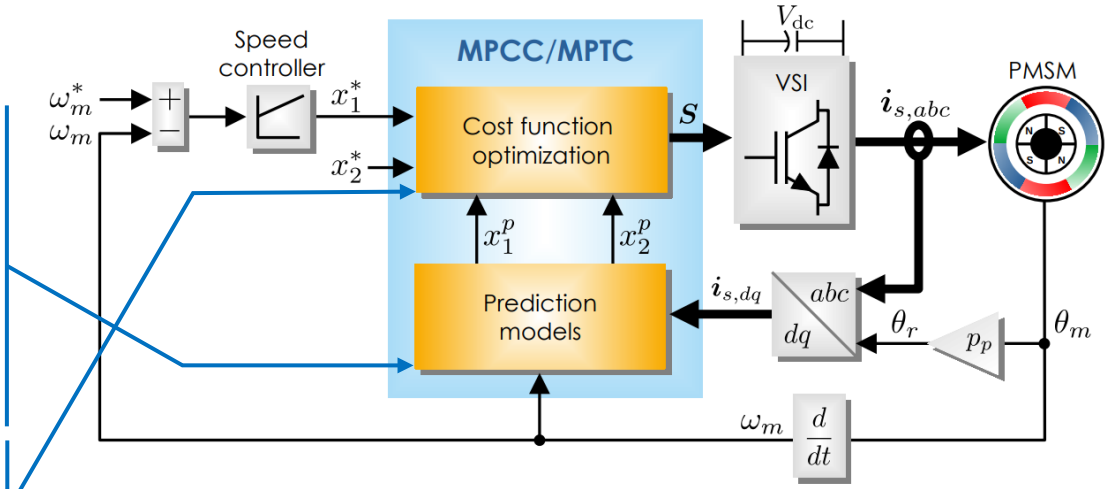
- **Stator current predictions:**

$$i_{d,k+1}^{p} = \left(1 - \frac{R_s T_s}{L_s}\right) i_{d,k} + p_p T_s \omega_{m,k} i_{q,k} + \frac{T_s}{L_s} v_{q,k}$$

$$i_{q,k+1}^{p} = \left(1 - \frac{R_s T_s}{L_s}\right) i_{q,k} - p_p T_s \omega_{m,k} i_{d,k} - \frac{T_s p_p}{L_s} \omega_{m,k} \psi_{\mathrm{pm}} + \frac{T_s}{L_s} v_{q,k}$$

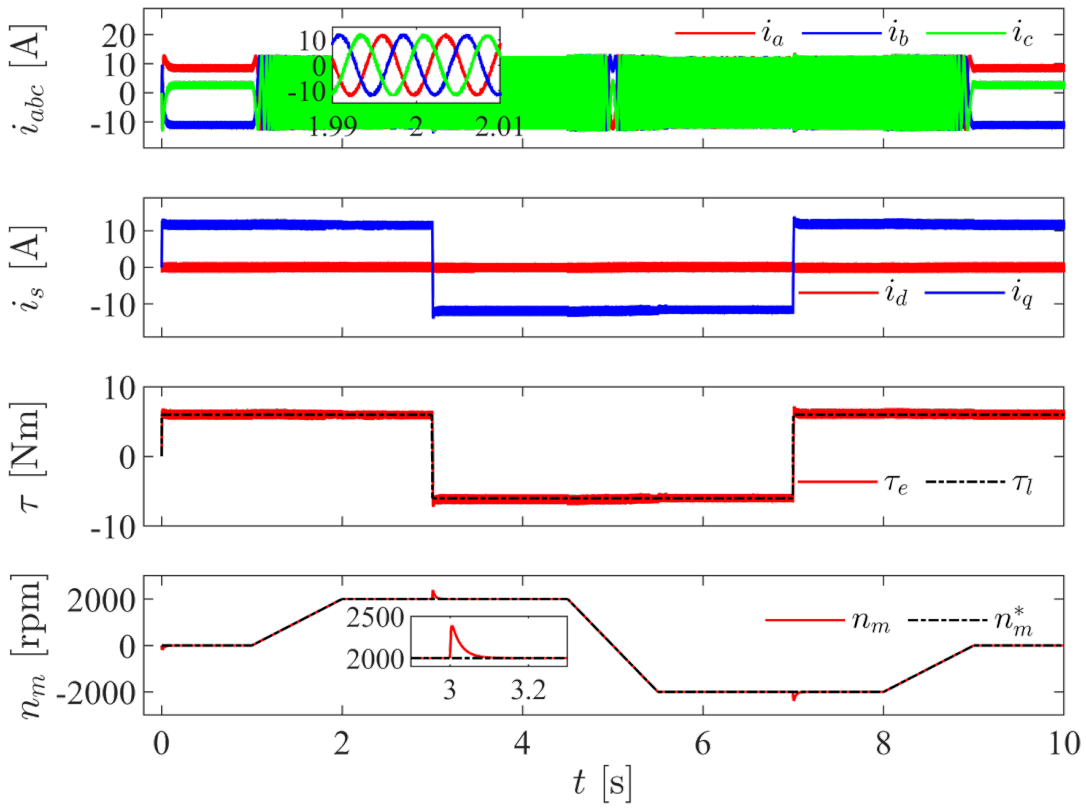
- **Cost function:**

$$g = \left|i_d^* - i_{d,k+1}^{p}\right| + \left|i_q^* - i_{q,k+1}^{p}\right|$$

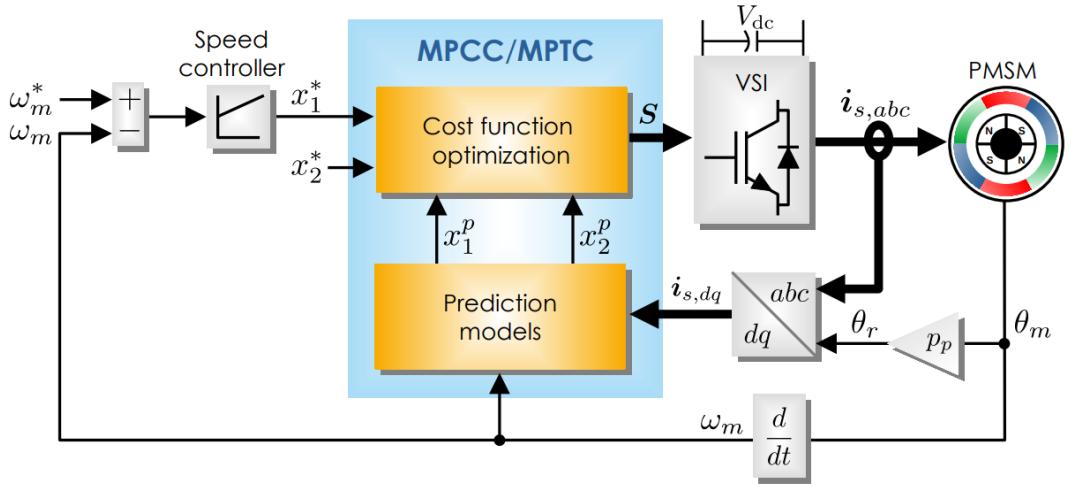


Block diagram of MPCC and MPTC strategies for PMSM control ($x_1 = i_q, x_2 = i_d$ for MPCC; $x_1 = \tau_e, x_2 = \|\psi_s\|$ for MPTC).

- Application of MPCC Strategy for PMSM Control - Results



Results: control performance under four-quadrant operation



Block diagram of MPCC and MPTC strategies for PMSM control ($x_1 = i_q, x_2 = i_d$ for MPCC; $x_1 = \tau_e, x_2 = \|\psi_s\|$ for MPTC).

- Application of MPTC Strategy for PMSM Control

MPTC strategy

- **Stator current predictions:**

$$i_{d,k+1}^{p} = \left(1 - \frac{R_s T_s}{L_s}\right) i_{d,k} + p_p T_s \omega_{m,k} i_{q,k} + \frac{T_s}{L_s} v_{q,k}$$

$$i_{q,k+1}^{p} = \left(1 - \frac{R_s T_s}{L_s}\right) i_{q,k} - p_p T_s \omega_{m,k} i_{d,k} - \frac{T_s p_p}{L_s} \omega_{m,k} \psi_{\mathrm{pm}} + \frac{T_s}{L_s} v_{q,k}$$

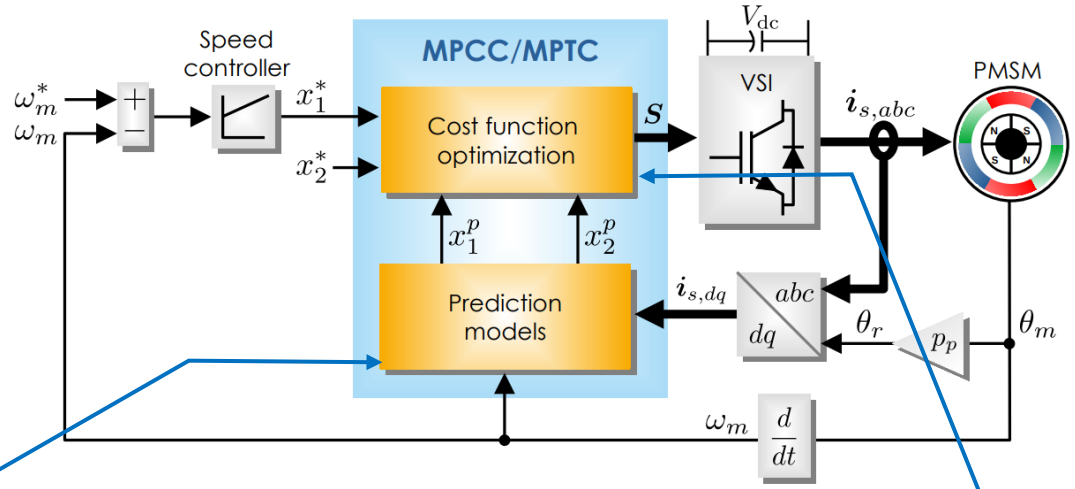
- **Flux prediction:**

$$\psi_{d,k+1}^{p} = L_d i_{d,k+1}^{p} + \psi_{\mathrm{pm}}$$

$$\psi_{q,k+1}^{p} = L_q i_{q,k+1}^{p}$$

- **Torque prediction:**

$$\tau_{e,k+1}^{p} = 1.5 p_p \left(\psi_{d,k+1}^{p} i_{q,k+1}^{p} - \psi_{q,k+1}^{p} i_{d,k+1}^{p}\right)$$

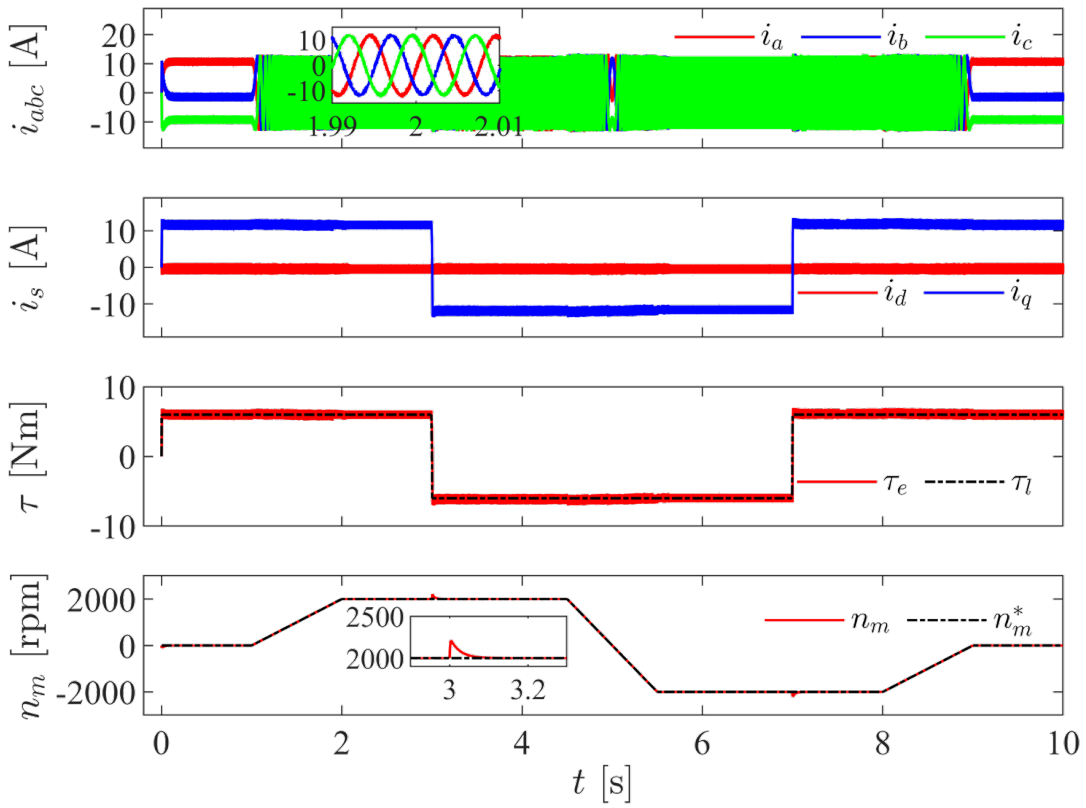


Block diagram of MPCC and MPTC strategies for PMSM control ($x_1 = i_q, x_2 = i_d$ for MPCC; $x_1 = \tau_e, x_2 = \|\psi_s\|$ for MPTC).

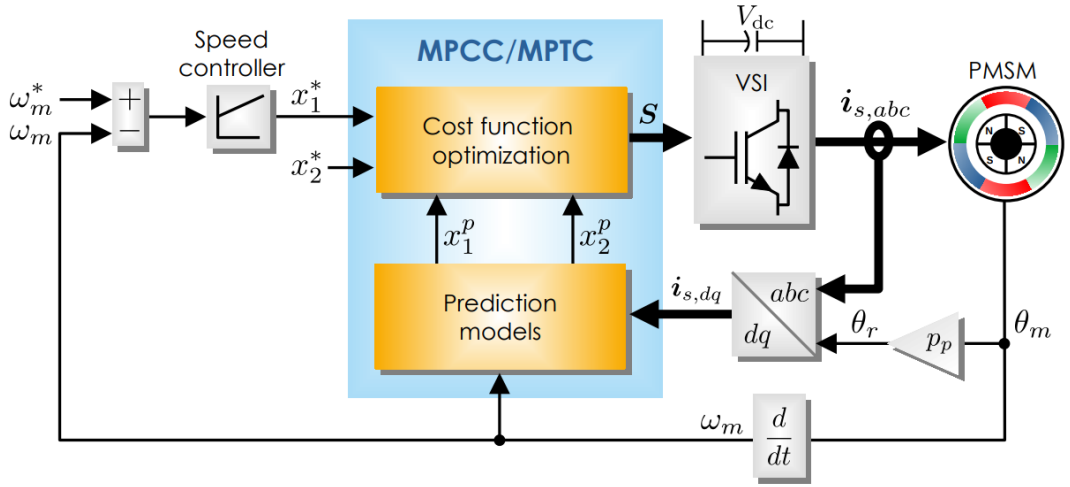
- **Cost function:**

$$g = \left|\tau_e^{*} - \tau_{e,k+1}^{p}\right| + \lambda_\psi \left|\left|\boldsymbol{\psi}_s^{*}\right| - \left|\boldsymbol{\psi}_{s,k+1}^{p}\right|\right|$$

- Application of MPTC Strategy for PMSM Control - Results

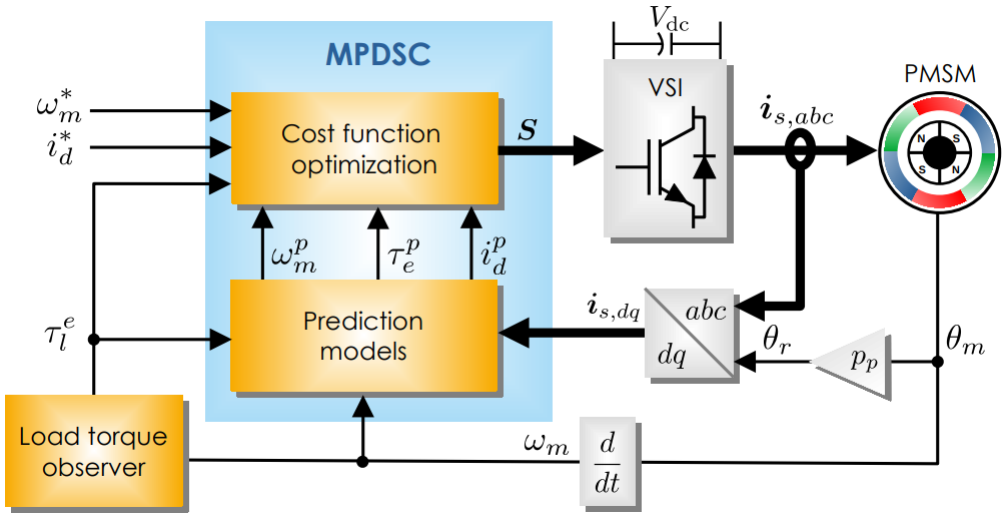


Results: control performance under four-quadrant operation



Block diagram of MPCC and MPTC strategies for PMSM control ($x_1 = i_q, x_2 = i_d$ for MPCC; $x_1 = \tau_e, x_2 = \|\psi_s\|$ for MPTC).

- Application of MPDSC Strategy for PMSM Control



Block diagram of MPDSC strategy.

- Application of MPDSC Strategy for PMSM Control

MPDSC strategy

- **Stator current predictions:**

$$i^p_{d,k+1} = \left(1 - \frac{R_s T_s}{L_s}\right) i_{d,k} + p_p T_s \omega_{m,k} i_{q,k} + \frac{T_s}{L_s} v_{q,k}$$

$$i^p_{q,k+1} = \left(1 - \frac{R_s T_s}{L_s}\right) i_{q,k} - p_p T_s \omega_{m,k} i_{d,k} - \frac{T_s p_p}{L_s} \omega_{m,k} \psi_{\mathrm{pm}} + \frac{T_s}{L_s} v_{q,k}$$

- **Flux prediction:**

$$\psi^p_{d,k+1} = L_d i^p_{d,k+1} + \psi_{\mathrm{pm}}$$

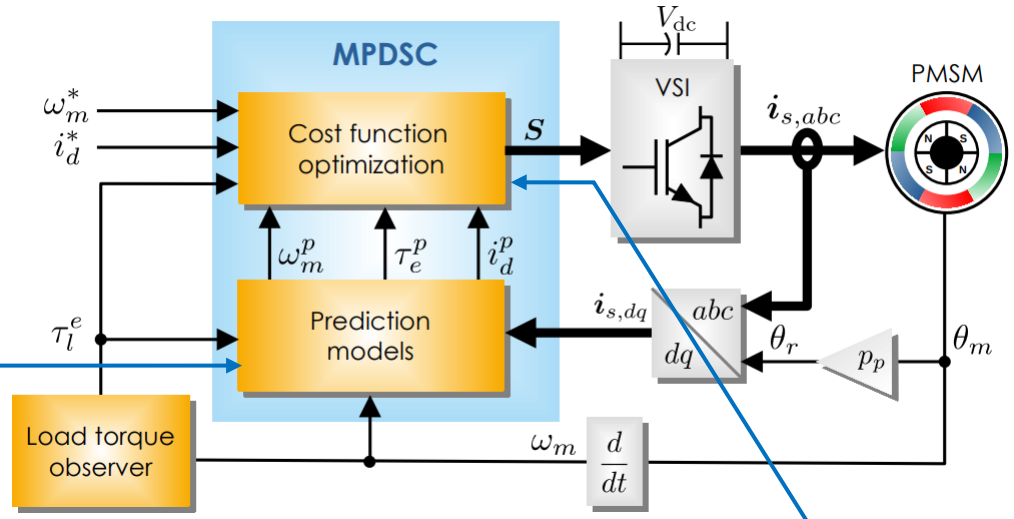
$$\psi^p_{q,k+1} = L_q i^p_{q,k+1}$$

- **Torque prediction:**

$$\tau^p_{e,k+1} = 1.5 p_p \left(\psi^p_{d,k+1} i^p_{q,k+1} - \psi^p_{q,k+1} i^p_{d,k+1}\right)$$

- **Speed prediction:**

$$\omega^p_{m,k+1} = \frac{T_s}{J_t} \tau^p_{e,k+1} + \left(1 - \frac{T_s B_t}{J_t}\right) \omega_{m,k} - \frac{T_s}{J_t} \tau^e_{l,k}$$

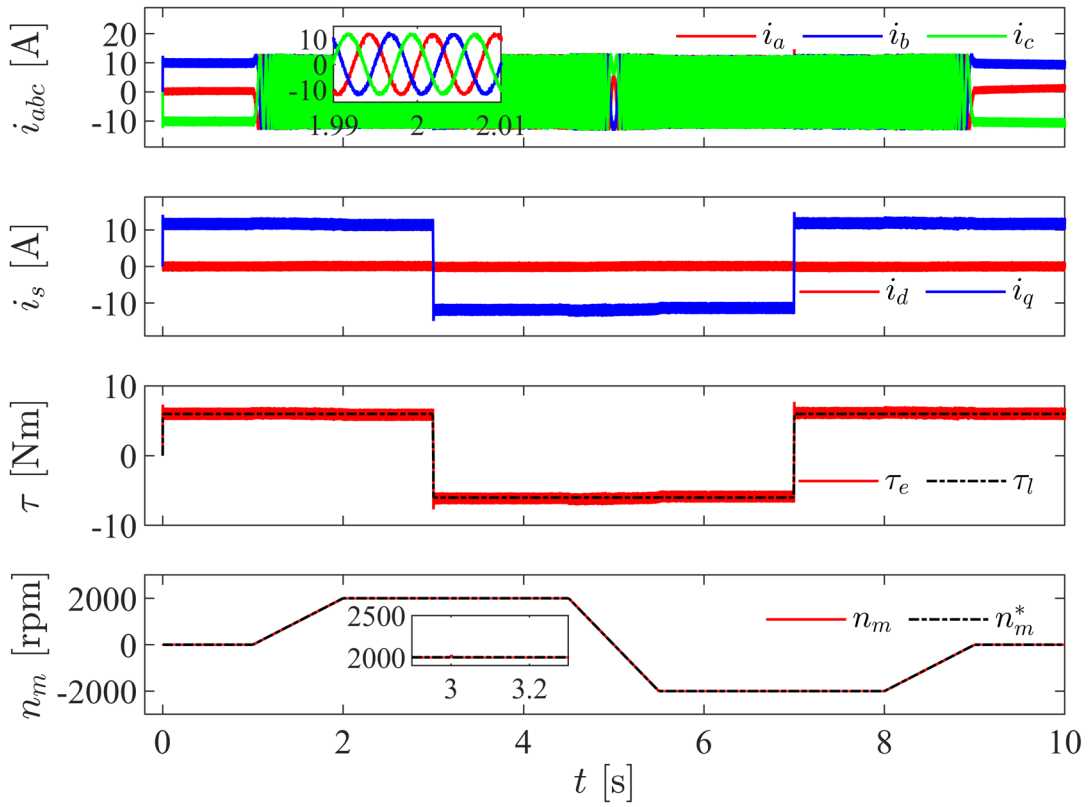


Block diagram of MPDSC strategy.

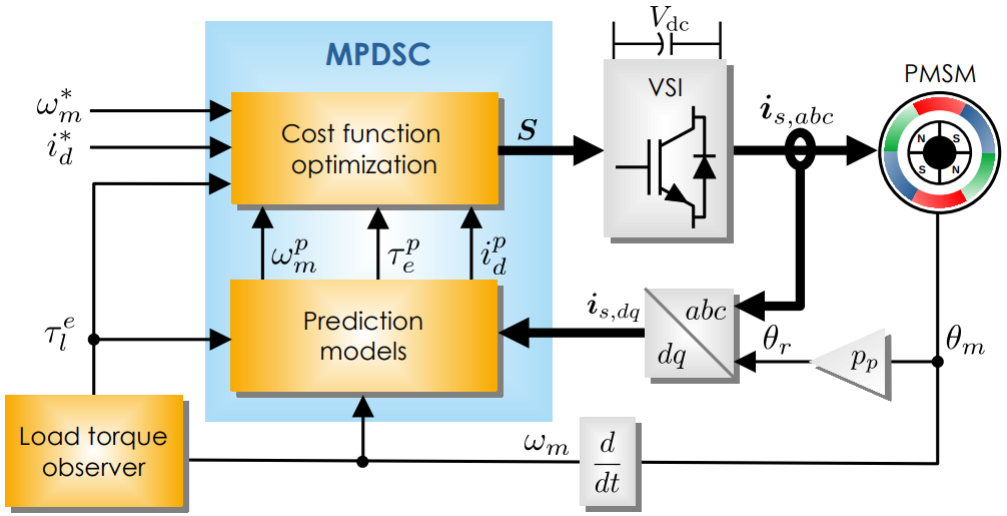
- **Cost function:**

$$g = \lambda_\omega \left(\omega^*_m - \omega^p_{m,k+1}\right)^2 + \lambda_\tau \left(\tau^p_{e,k+1} - \tau^e_{l,k+1}\right)^2 + \lambda_i \left(i^*_d - i^p_{d,k+1}\right)^2$$

- Application of MPDSC Strategy for PMSM Control - Results



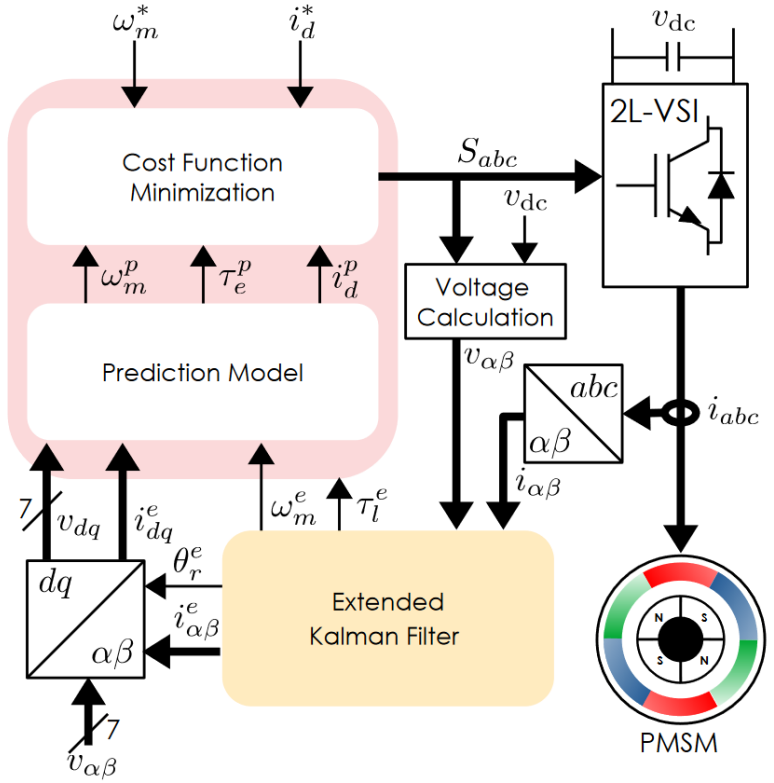
Results: control performance under four-quadrant operation



Block diagram of MPDSC strategy.

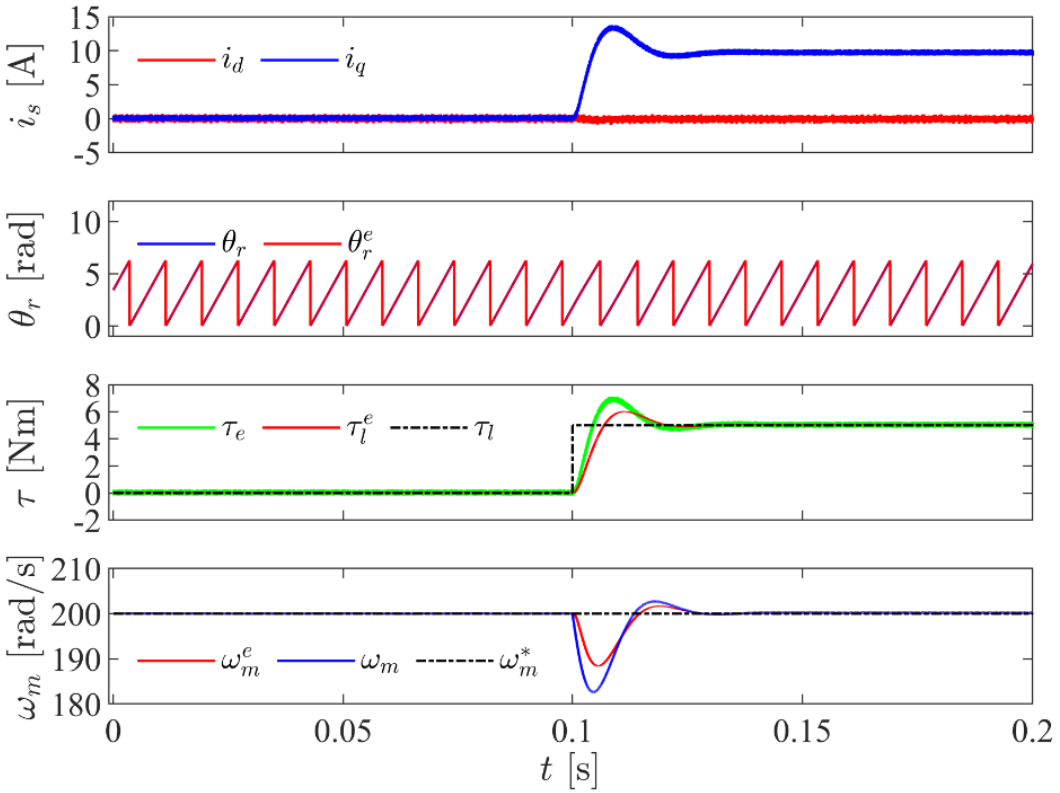
- Sensorless MPDSC Strategy for PMSM Control

- Measuring load torque is a costly solution; therefore, it is a well-accepted approach to estimate it using an estimator/observer.
- Speed is often measured by an encoder mounted to the shaft but depending on the application, it may not be possible to mount a speed sensor. Also, it is not a cost-effective way.
- In such cases, combining sensorless control and MPC strategies is a viable option.
- For this purpose, an observer, e.g., an EKF can be designed to estimate position, speed, and load torque, as shown in the figure. Because EKF makes it possible to estimate all these states using a single observer.

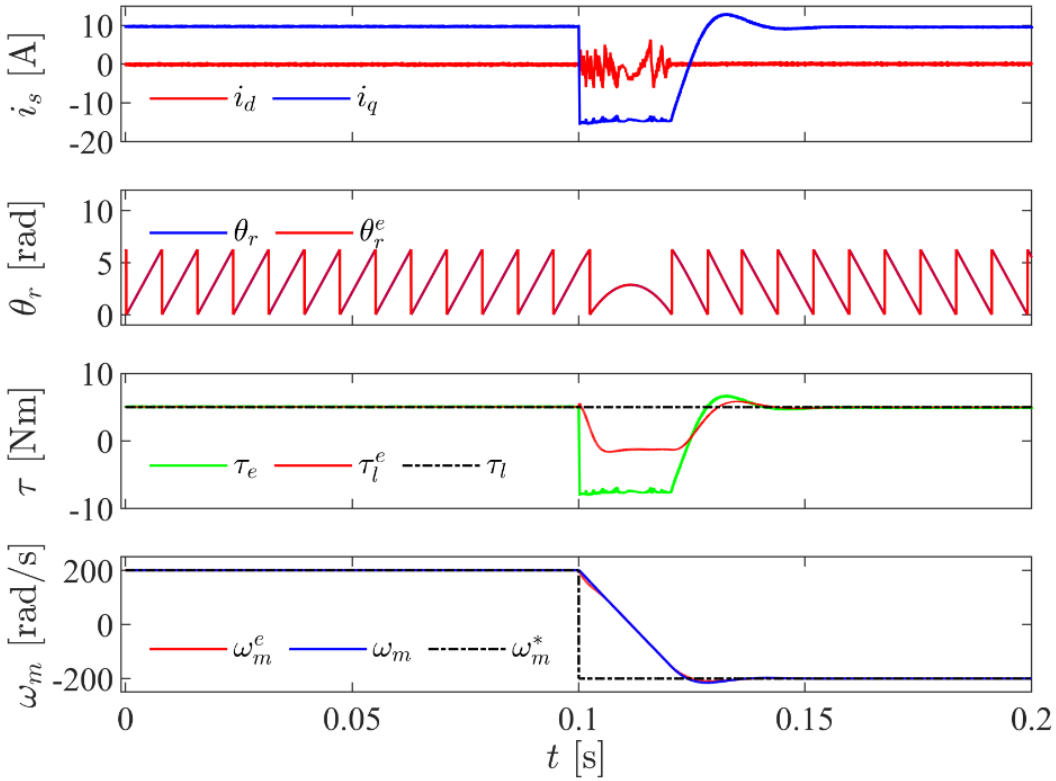


Block diagram of the sensorless PDSC of PMSM.

- Sensorless MPDSC Strategy for PMSM Control

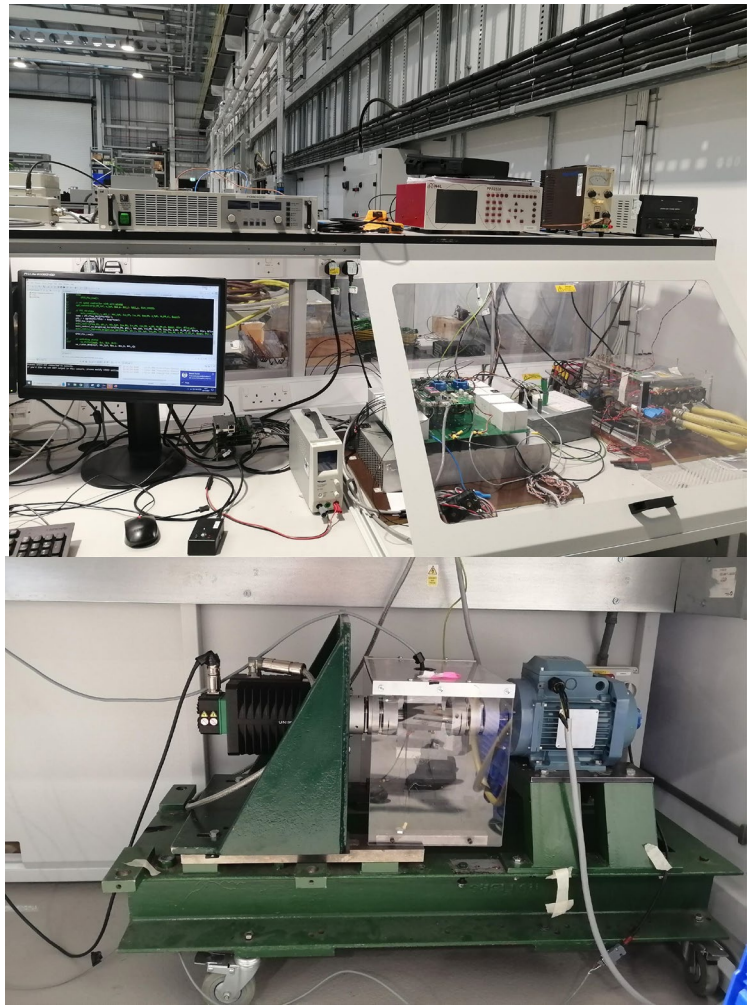


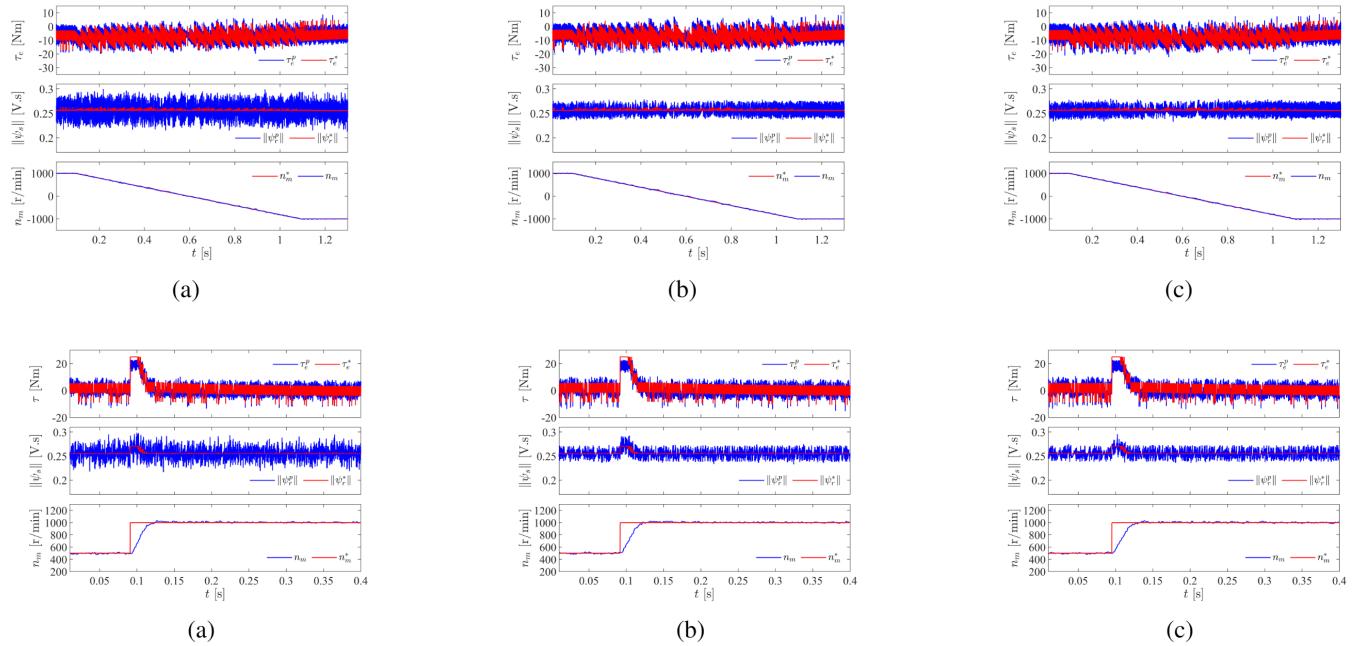
Performance of sensorless MPDSC-based PMSM drive under load changes at 200 rad/s.



Performance of sensorless MPDSC-based PMSM drive under speed reversals with a load of 5 Nm.

Experimental Implementation of MPC Strategies for the PMSM





Experimental results: (a) conventional MPTC; (b) DM-based MPTC using Euclidean norm; (c) Proposed DM-based MPTC

Technical Issues for the Implementation of Predictive Control

- Examples of Cost Function for Power Electronics Applications

Several ways to represent the same control objective.

$$g = |x^* - x^p|$$

$$g = (x^* - x^p)^2$$

$$g = \left| \int_k^{k+1} (x^*(t) - x^p(t))dt \right|$$

Reference Tracking

Application	Cost function
CSC-AFE	$g = \lvert q \rvert + \lambda \lvert \hat{i}_L - i_L^* \rvert$
	$g = (q)^2 + \lambda \left(\hat{i}_L - i_L^* \right)^2$
	$g = \lvert \hat{i}_k - i_k^* \rvert$
VSC-AFE	$g = \lvert \hat{i}_k - i_k^* \rvert + \lambda_n n_c$
	$g = \left(\hat{i}_k - i_k^* \right)^2$
	$g = \left(\hat{P} - P^* \right)^2 + \left(\hat{Q} - Q^* \right)^2$
Motor drive	$g = \left(\hat{T} - T^* \right)^2 + \lambda \left(\hat{\psi} - \psi^* \right)^2$
VSC-UPS	$g = (\hat{v}_o - v_o^*)^2$
Statcom	$g = \left(\hat{i}_k - i_k^* \right)^2$
Matrix converter	$g = \lvert \hat{i}_L - i_L^* \rvert + \lambda \lvert \hat{Q} - Q^* \rvert$
	$g = \left(\hat{i}_L - i_L^* \right)^2 + \lambda \left(\hat{Q} - Q^* \right)^2$
HVDC	$g = g_1 + g_2 + g_3$
	$g_1 = \lvert \hat{i}_{jk} - i_{jk}^* \rvert$
	$g_2 = \lambda_{Ck} \sum_i \lvert \hat{V}_{cijk} - \frac{V_{dc}}{n} \rvert$
	$g_3 = \lambda_{zk} \lvert \hat{i}_{zjk} \rvert$

- Selection of Cost Functions: Switching Frequency Minimization

$$g = (i_\alpha^* - i_\alpha^p)^2 + (i_\beta^* - i_\beta^p)^2 + \lambda_n n$$

$$n = |S_a(k) - S_a(k-1)| + |S_b(k) - S_b(k-1)| + |S_c(k) - S_c(k-1)|$$

Table III: Total harmonic distortion for each λ_n and the average of switches commutations.

λ_n	THD of i_a	N° commutations (average)
1.8	24.20 %	5
1.2	17.38 %	6
0.4	6.69 %	18
0.09	2.08 %	57

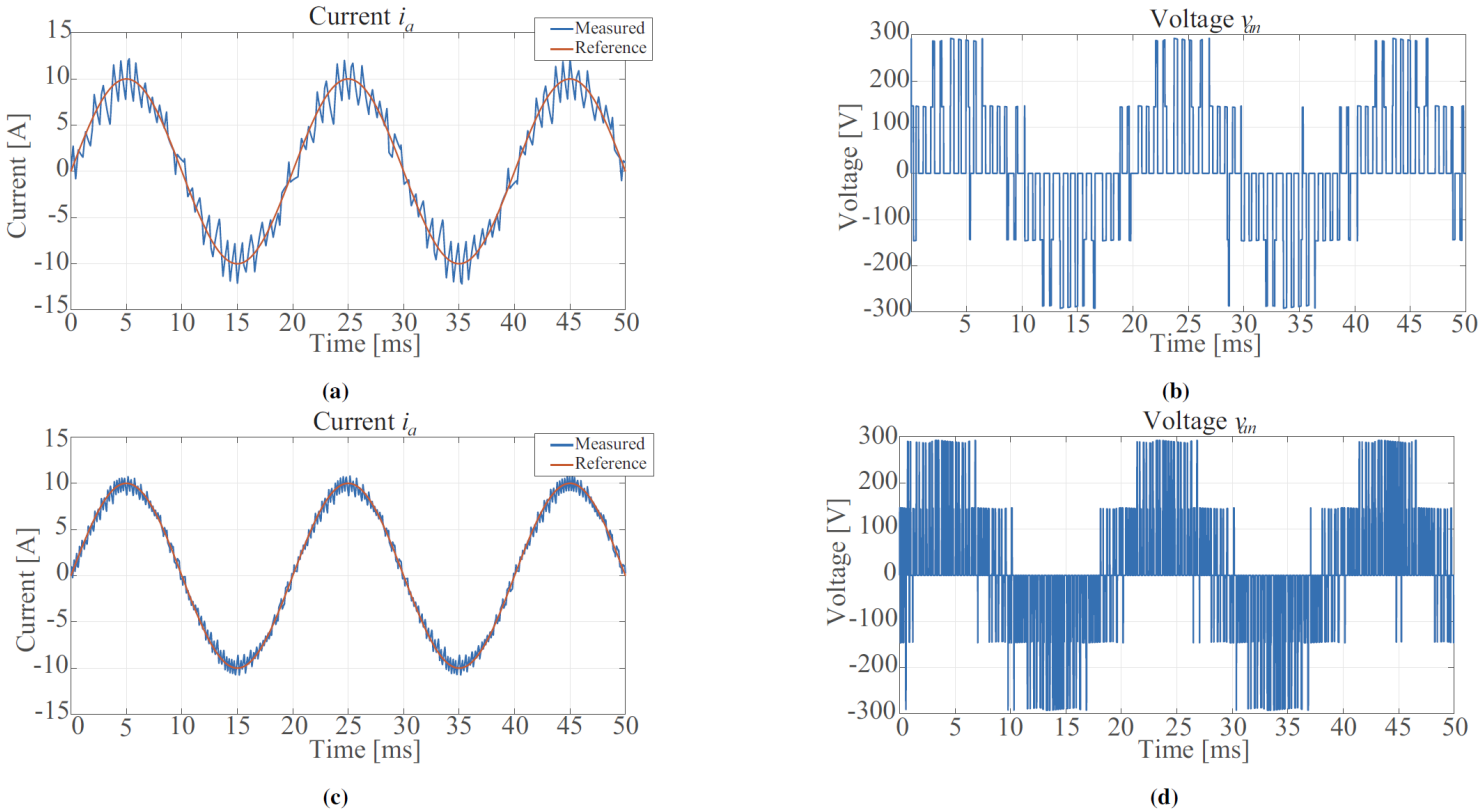


Figure 3: Current i_a and voltage v_{an} for different values of λ_n. $\lambda_n = 1.2$ (a) y (b), $\lambda_n = 0.4$ (c) y (d).

- Selection of Cost Functions: Strict Restrictions

$$g = (i_\alpha^* - i_\alpha^p)^2 + (i_\beta^* - i_\beta^p)^2 + f_{lim}(i^p)$$

$$f_{lim}(\mathrm{i}_{\alpha\beta}{}^p) = \begin{cases} \infty & \text{si} \quad -i_{max} > \mathrm{i}_\alpha^p \ (o \ \mathrm{i}_\beta^p) > i_{max} \\ 0 & in\ other\ case \end{cases} \quad (1$$

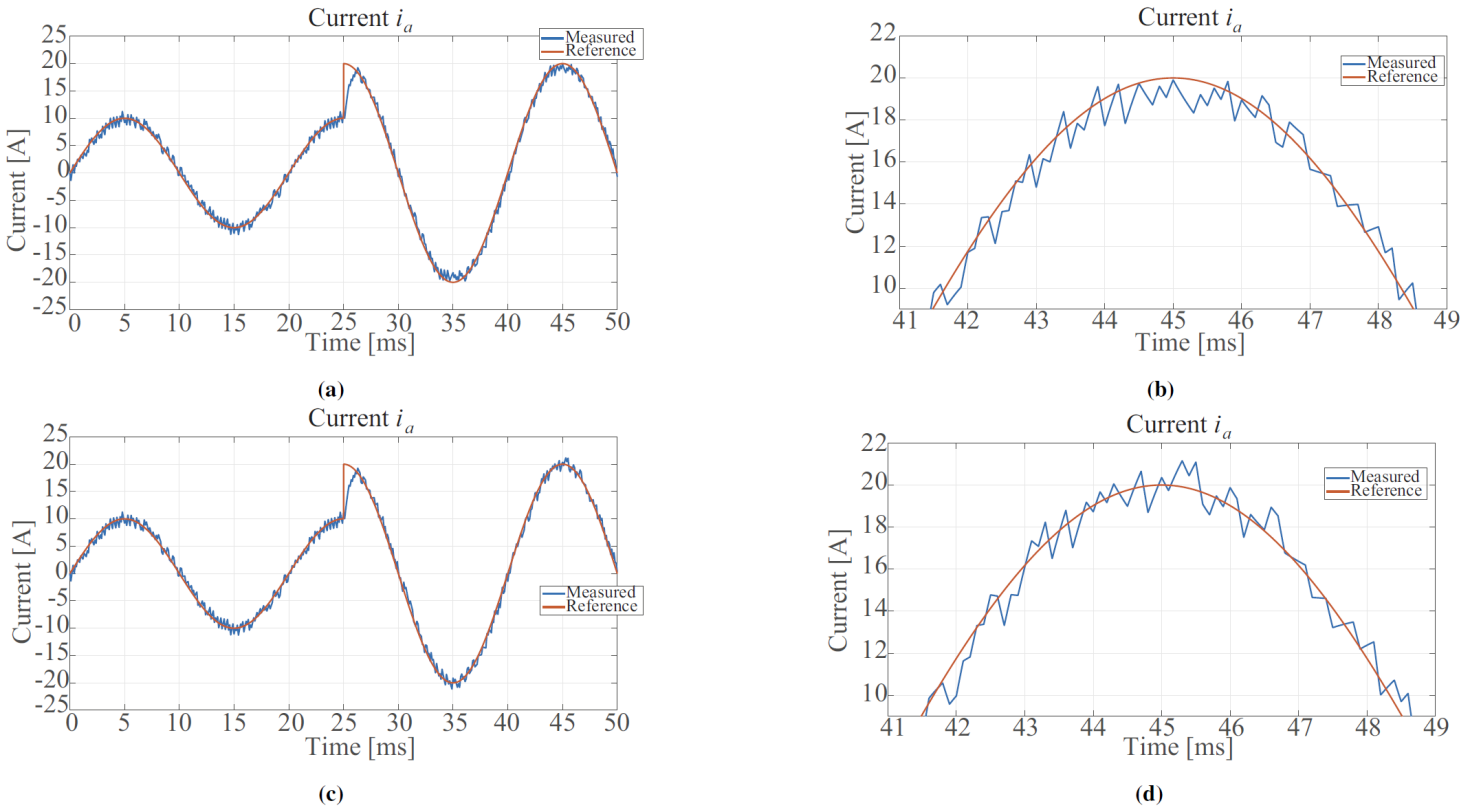


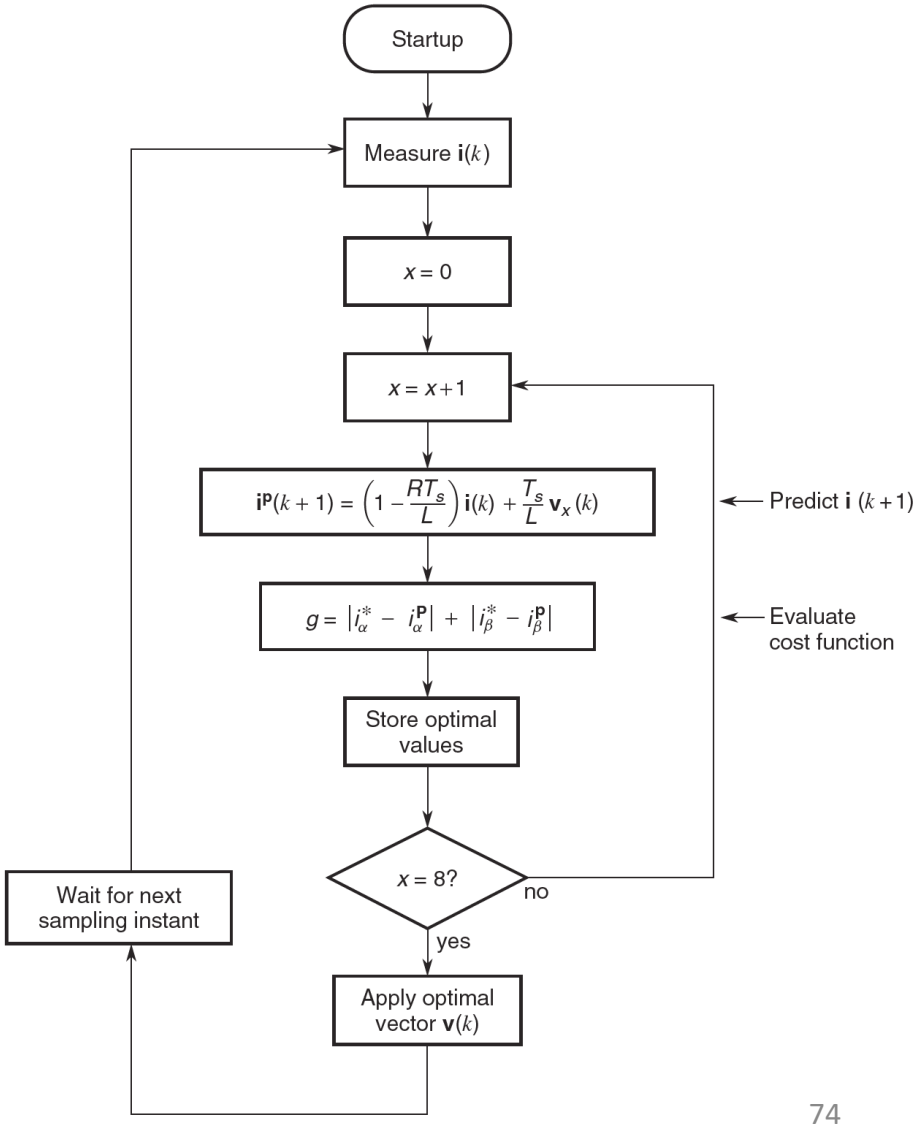
Figure 4: (a) Current i_a with limitation, (b) zoom of the current i_a with limitation, (c) current i_a without limitation and (d) zoom of the current i_a without limitation.

- Delay Compensation

- Experimental implementation of MPC requires a **large number of calculations**, which generates an important time delay in the actuation.
- The **delay can deteriorate the performance** of the system.
- To avoid this issue, a **delay compensation technique is required**.

$$g = \left|i_\alpha^*(k+1) - i_\alpha^{\mathbf{p}}(k+1)\right| + \left|i_\beta^*(k+1) - i_\beta^{\mathbf{p}}(k+1)\right|$$

$$\mathbf{i}^{\mathbf{p}}(k+1) = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}(k) + \frac{T_s}{L}\mathbf{v}(k)$$

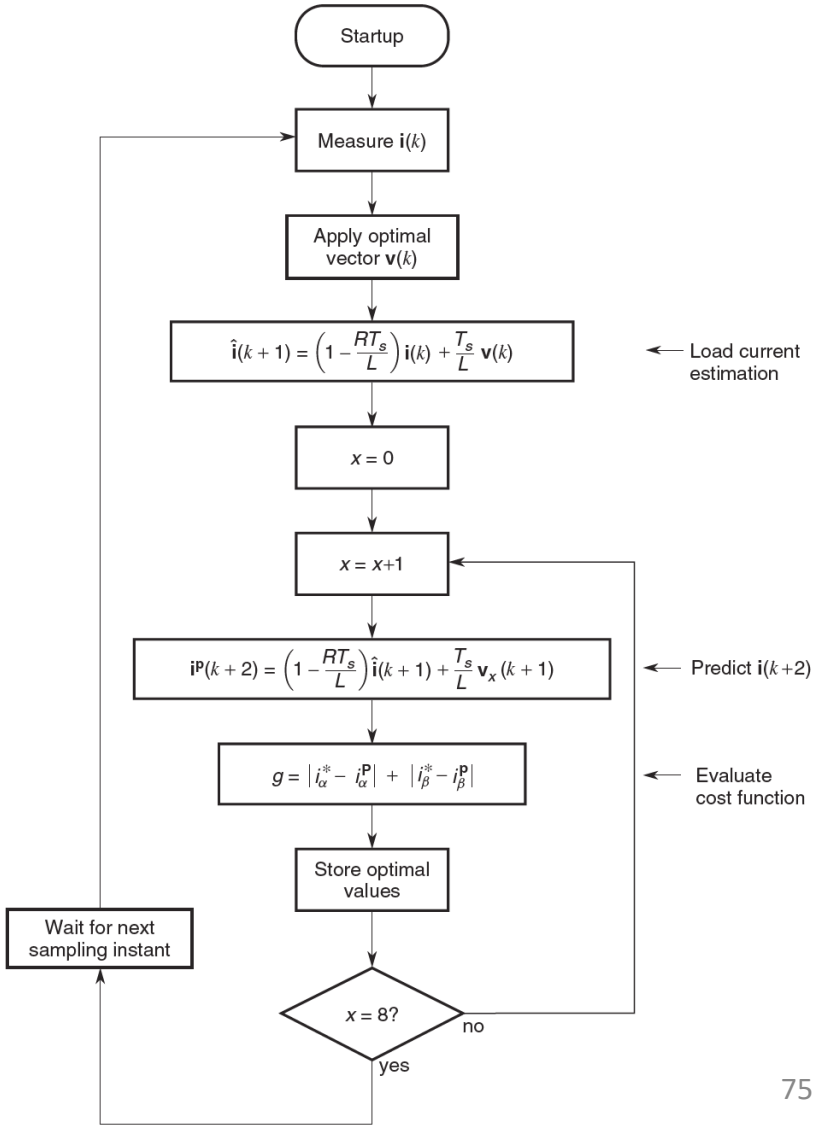


- Delay Compensation

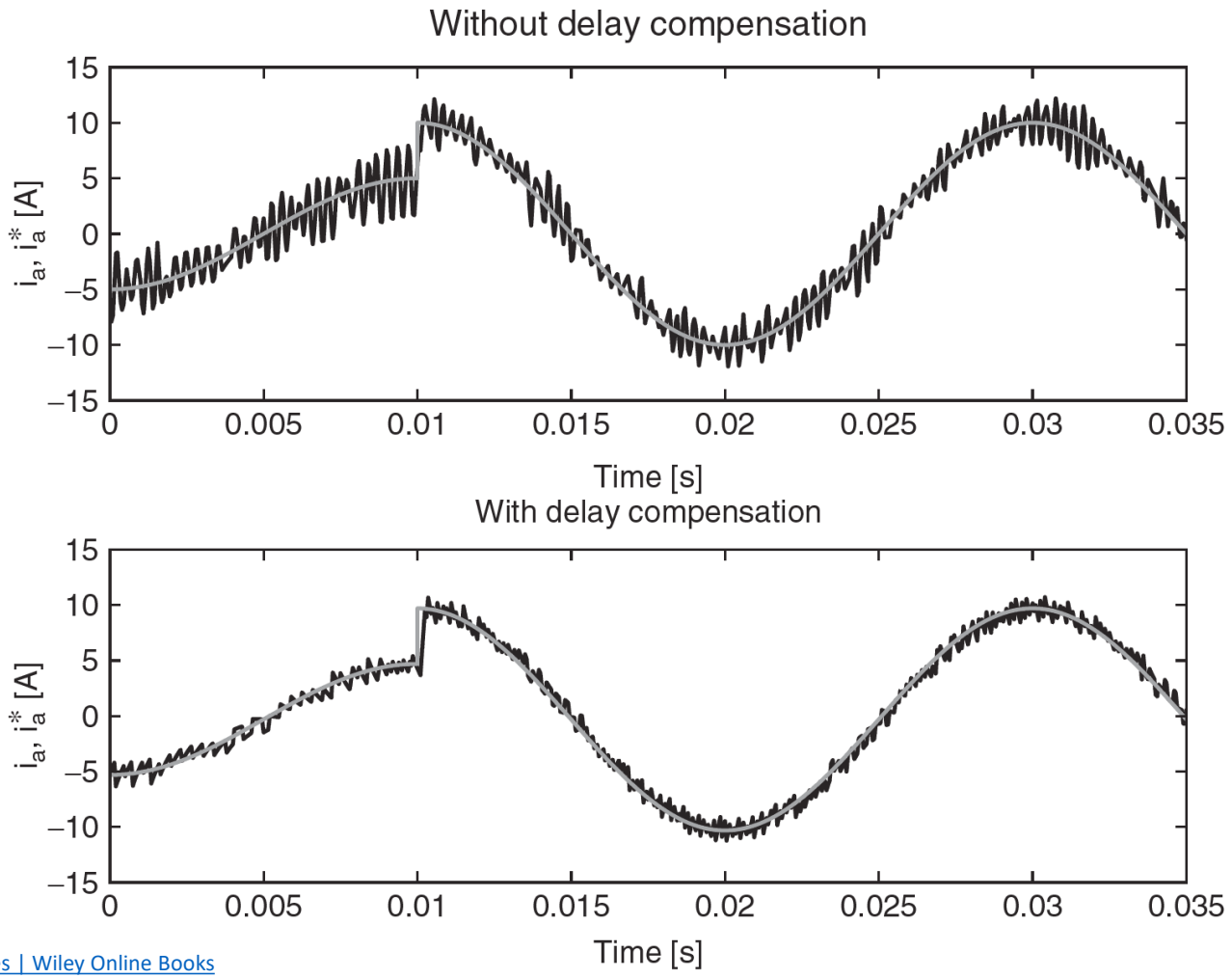
- Application of the new **optimal voltage vector** is moving to the **beginning**.
- The **estimation of the currents** at time t_{k+1} is added.
- The estimated currents are **used for the predictions** for all the available switching states.

$$g = |i_\alpha^*(k+2) - i_\alpha^{\mathbf{p}}(k+2)| + |i_\beta^*(k+2) - i_\beta^{\mathbf{p}}(k+2)|$$

$$\mathbf{i}^{\mathbf{p}}(k+2) = \left(1 - \frac{RT_s}{L}\right)\hat{\mathbf{i}}(k+1) + \frac{T_s}{L}\mathbf{v}(k+1)$$



- Delay Compensation



Predictive Control of Power Converters and Electrical Drives | Wiley Online Books

- Selection of Weighting Factors

$$g = \lambda_x \left\| x^* - x^p \right\| + \lambda_y \left\| y^* - y^P \right\| + \ldots + \lambda_z \left\| Z^* - z^p \right\|$$

- Weighting factors are required when several control objectives are considered.
- To reduce the error, these values must be carefully adjusted.
- There are no theoretical, analytical, or numerical methods to adapt these factors.
- They are determined by empirical procedures.

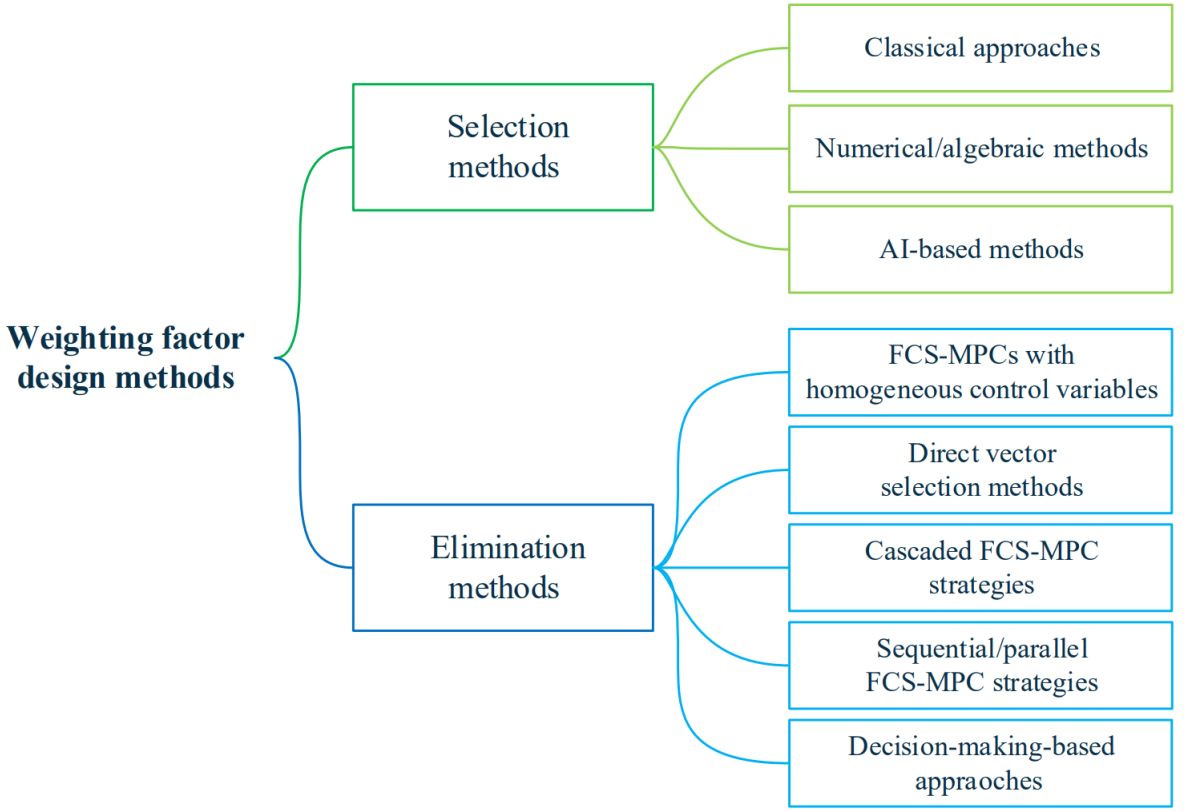
A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives | IEEE Journals & Magazine | IEEE Xplore

- Weighting Factor Design Methods

- Weighting factor design methods can be divided into two main groups: weighting factor selection methods and weighting factor elimination methods.

- 1st group of studies consists of classic approaches, numerical/algebraic methods, meta-heuristic optimization methods, and artificial intelligence (AI)-based methods.

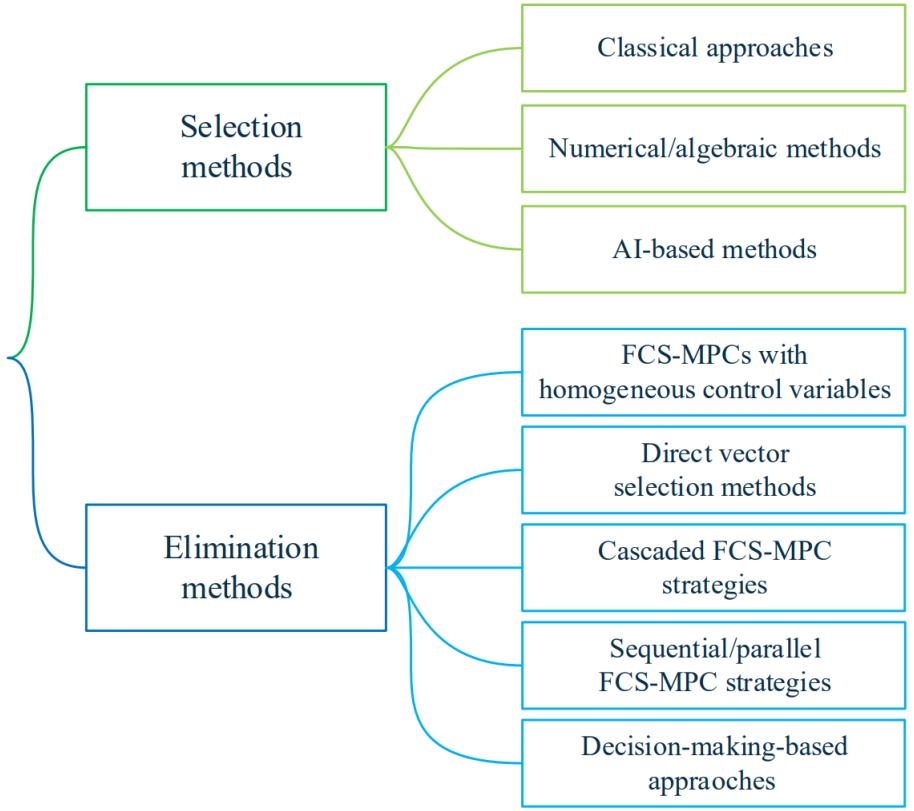
- 2nd group of studies includes MPCs with homogeneous control variables, direct vector selection methods, sequential/parallel MPC strategies, and decision-making (DM)-based approaches.



A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives | IEEE Journals & Magazine | IEEE Xplore

- Comparison of Weighting Factor Design Methods

- Weighting factor design methods can be divided into two main groups: weighting factor selection methods and weighting factor elimination methods.



OVERVIEW OF WF DESIGN METHODS

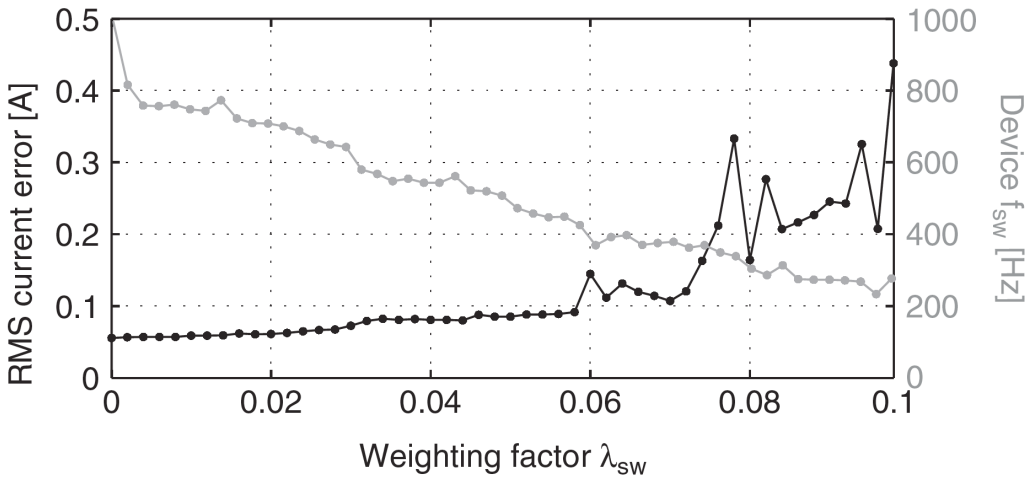
	Control performance	Flexibility	Design complexity	Computational complexity
Classic approaches	✗✗	✓✓	✗✗	✓✓
Numerical/algebraic methods	✗	✗	✗	✓
Meta-heuristic optimization methods	✗	✓✓	✗✗	✓✓
AI-based methods	✓✓	✗	✗✗	✗
MPCs with unifying cost functions	✓	✗✗	✓✓	✓
Direct vector selection methods	✓	✗✗	✓✓	✓✓
Sequential/parallel MPC strategies	✓✓	✓	✗	✗
Decision-making-based methods	✓✓	✓	✓	✗

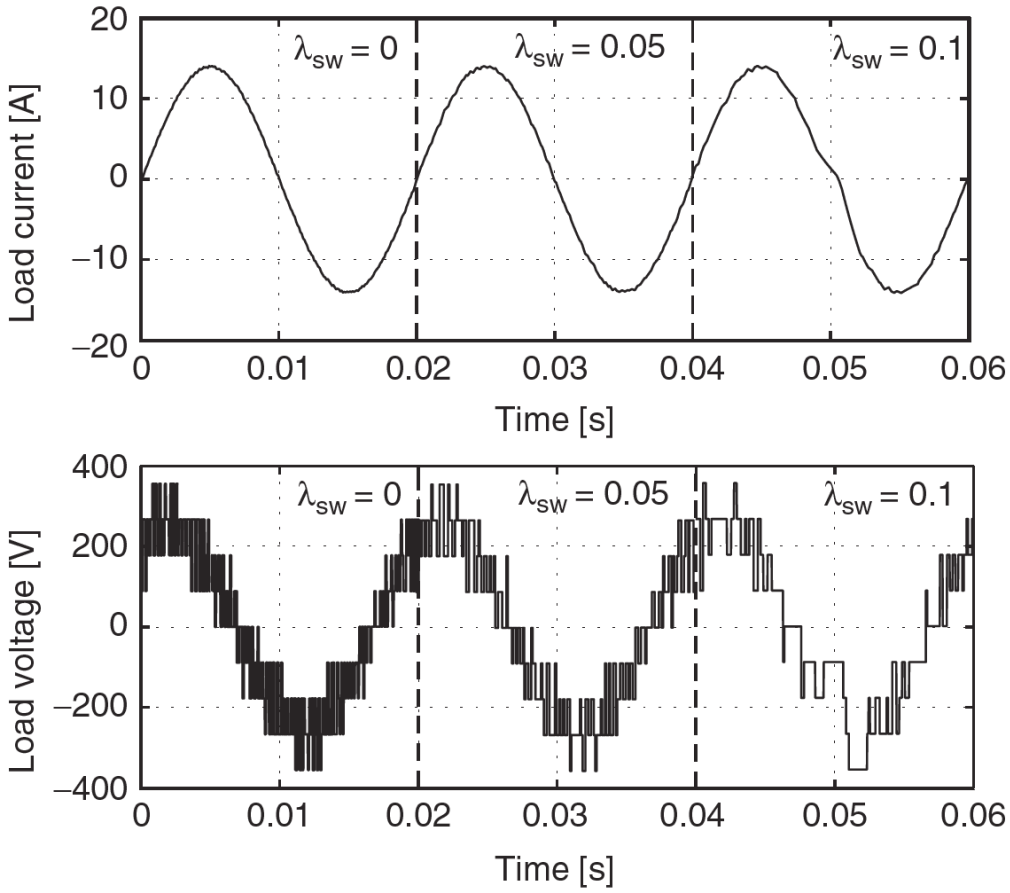
A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives | IEEE Journals & Magazine | IEEE Xplore

- Selection of Weighting Factors: Examples

Switching Frequency Reduction

$$g = |i_\alpha^* - i_\alpha^{\mathbf{p}}| + |i_\beta^* - i_\beta^{\mathbf{p}}| + \lambda_{sw} n_{sw}^p$$



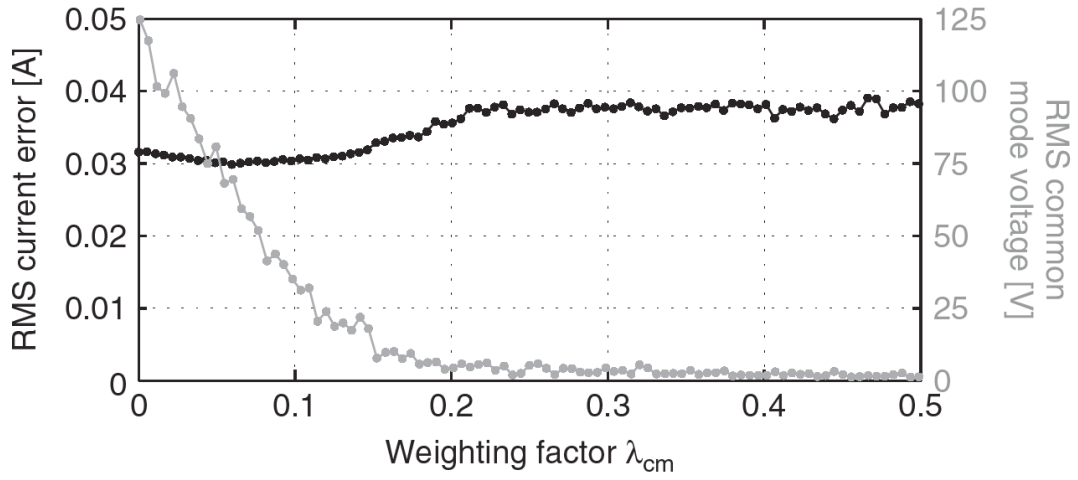


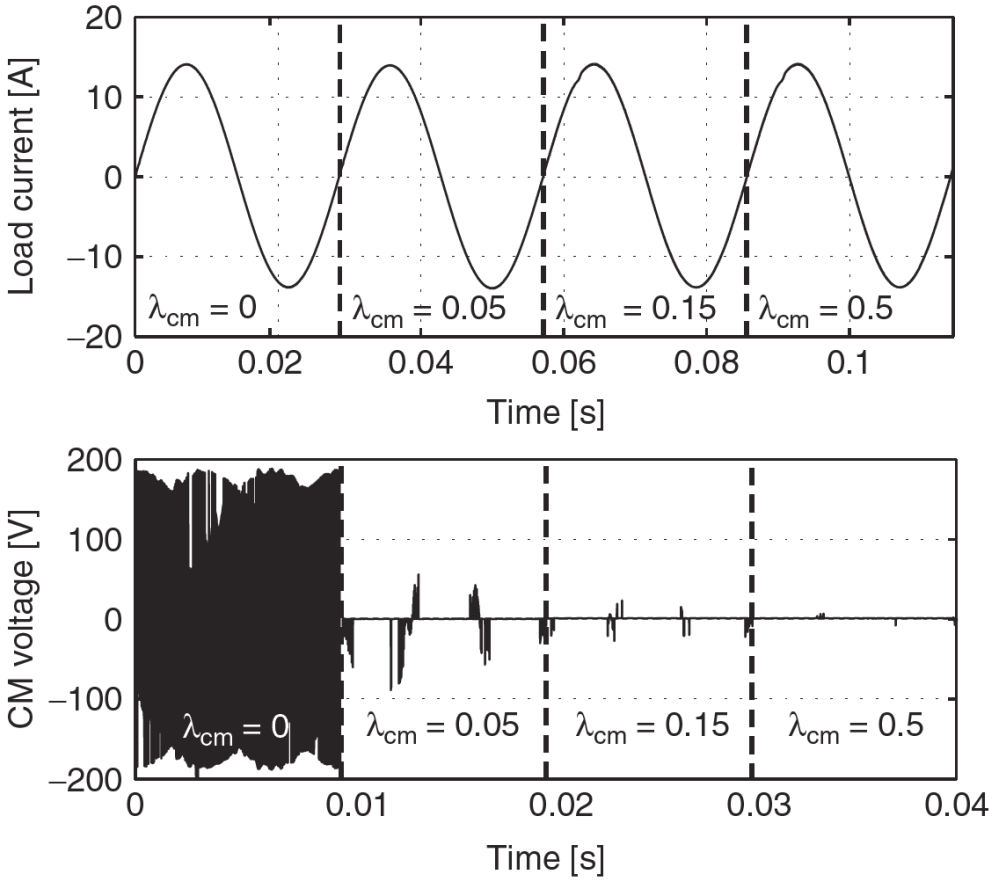
A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives | IEEE Journals & Magazine | IEEE Xplore

- Selection of Weighting Factors: Examples

Common-Mode Voltage Reduction

$$g = |i_\alpha^* - i_\alpha^{\mathbf{p}}| + |i_\beta^* - i_\beta^{\mathbf{p}}| + \lambda_{cm}|V_{cm}^p|$$



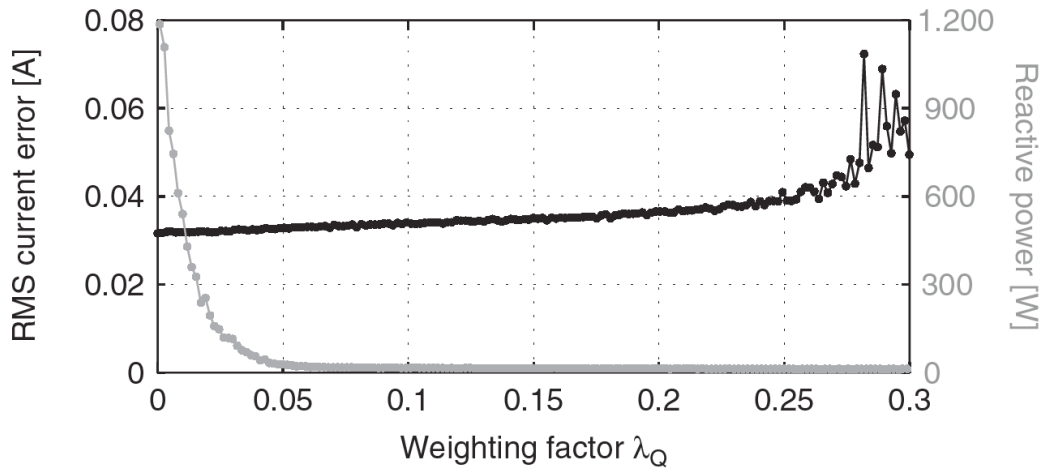


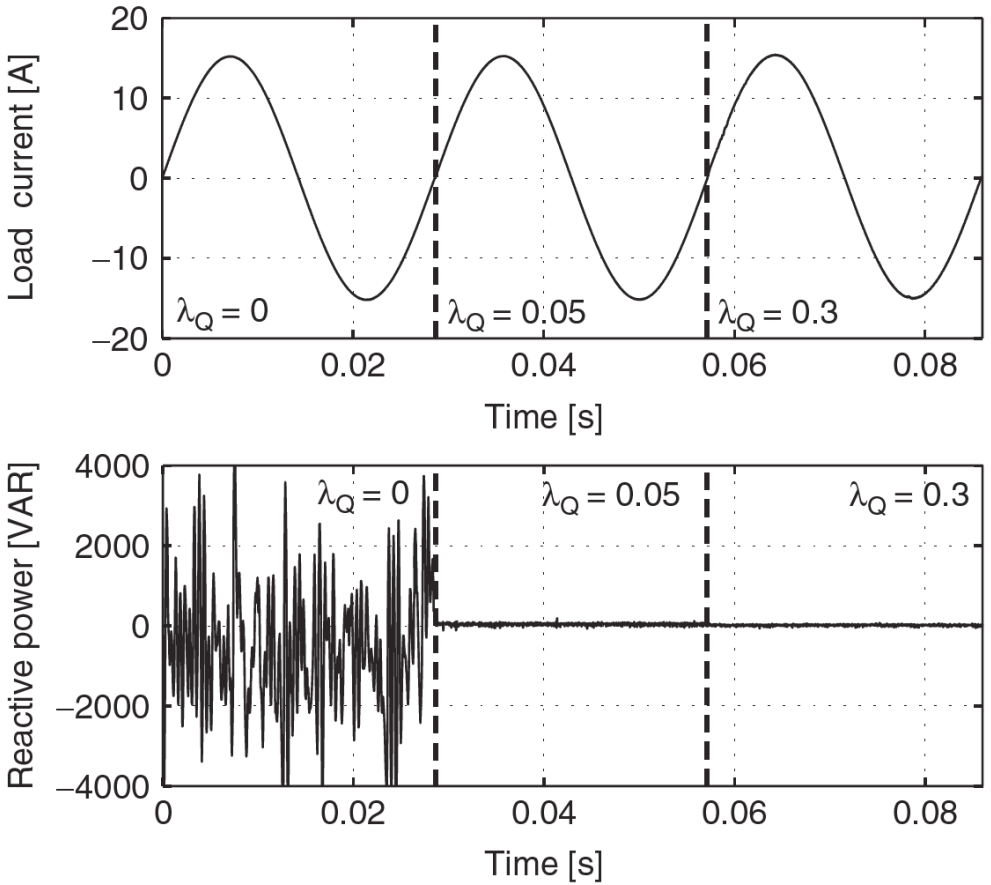
A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives | IEEE Journals & Magazine | IEEE Xplore

- Selection of Weighting Factors: Examples

Input Reactive Power Reduction

$$g = |i_\alpha^* - i_\alpha^p| + |i_\beta^* - i_\beta^p| + \lambda_Q |Q^p|$$



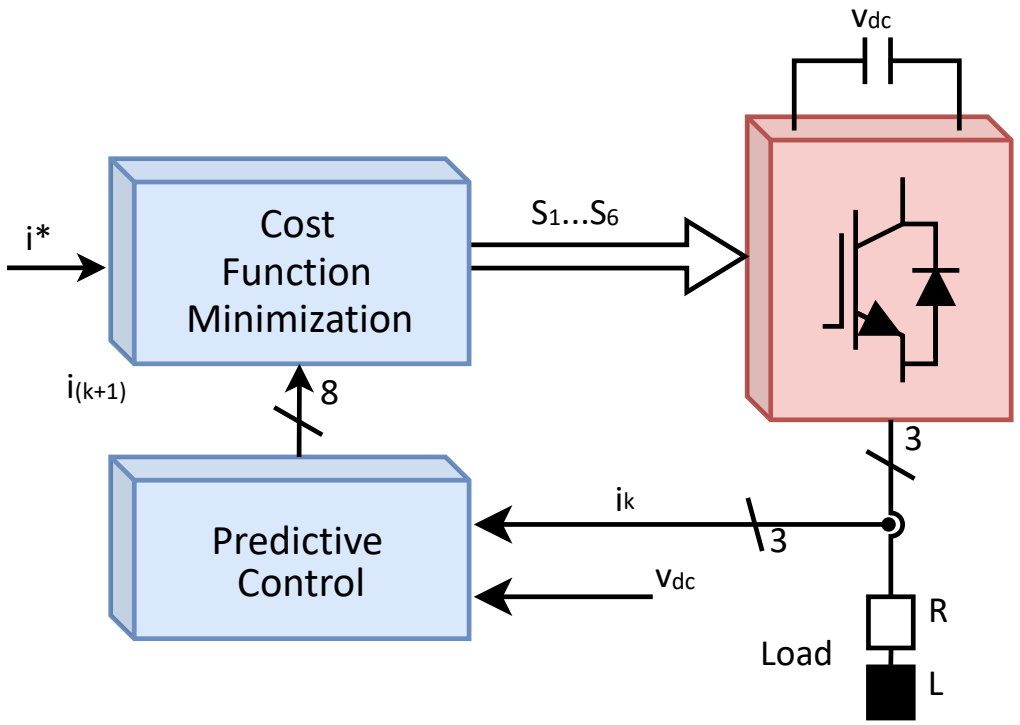


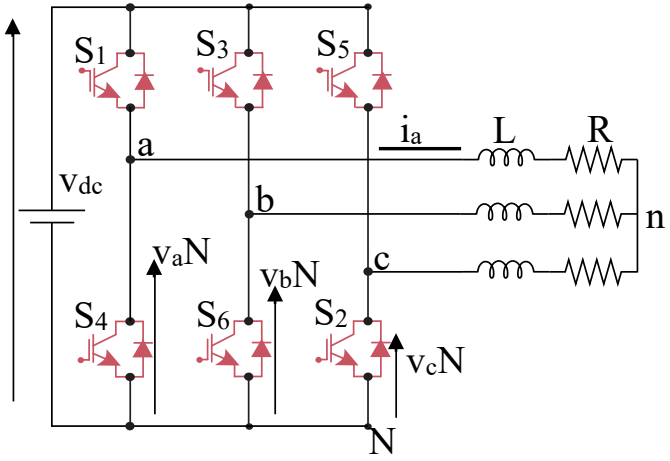
A Review on Weighting Factor Design of Finite Control Set Model Predictive Control Strategies for AC Electric Drives | IEEE Journals & Magazine | IEEE Xplore

Trends and Challenges of Predictive Control

Modulated MPC for Power Converters

- PCC of a Two-Level Voltage Source Inverter: Control Scheme

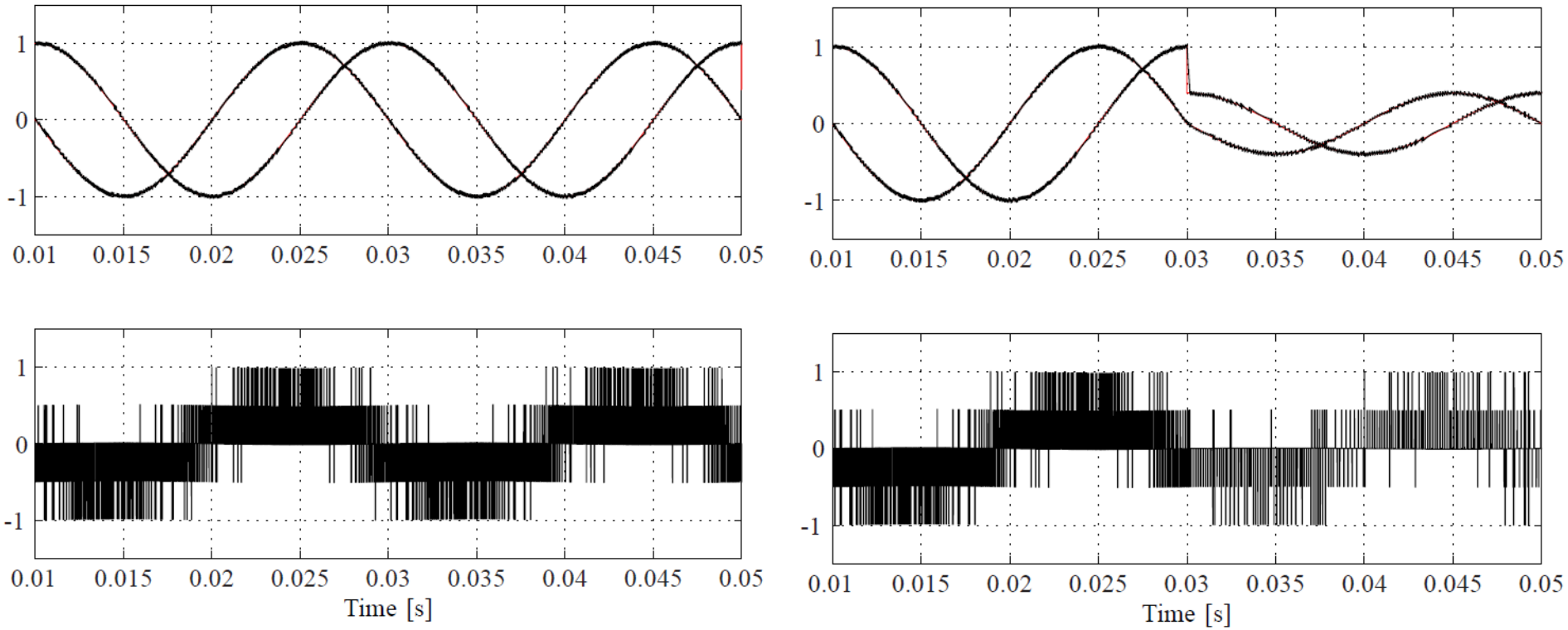




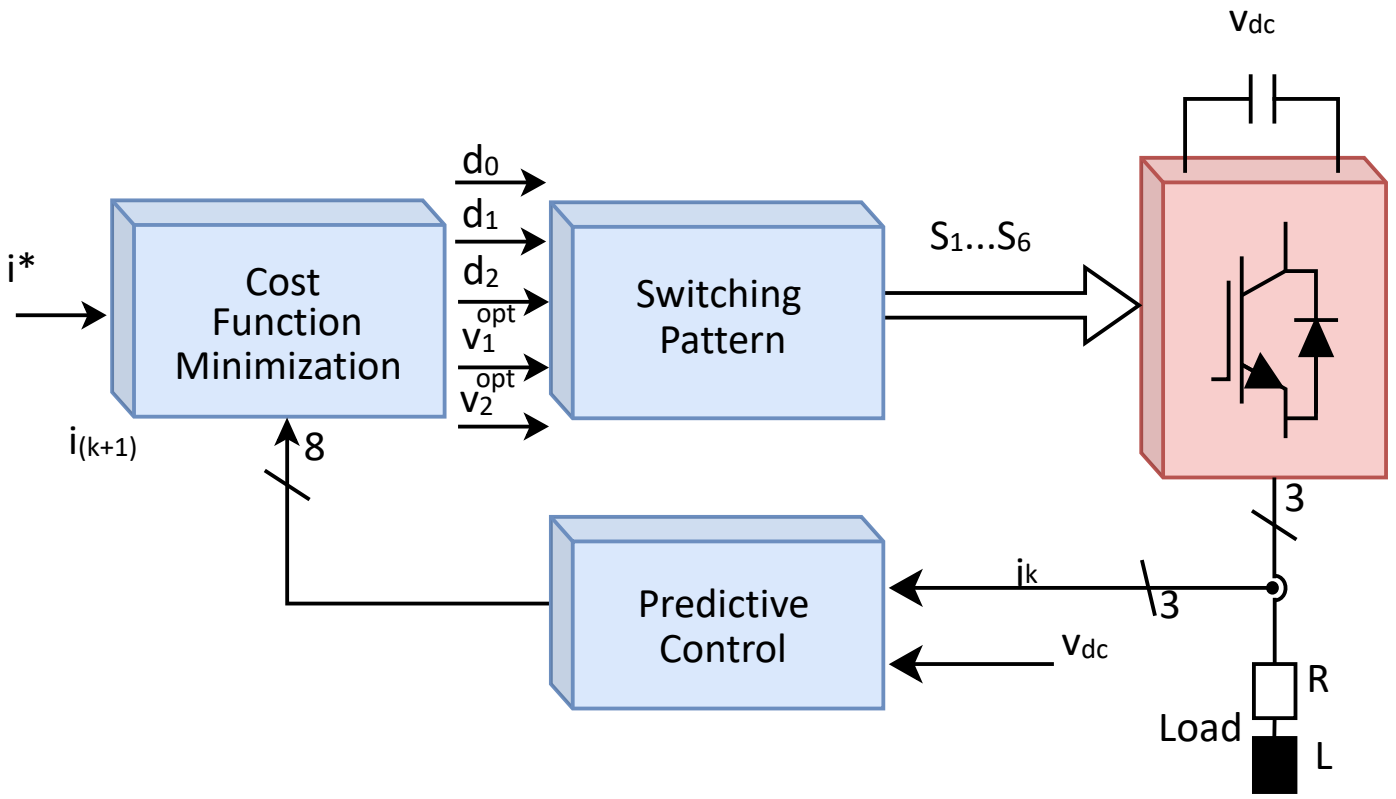
Valid Swiching state of the VSI

#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1

- Modulated MPC for the Three-Phase Voltage Source Inverter: Results

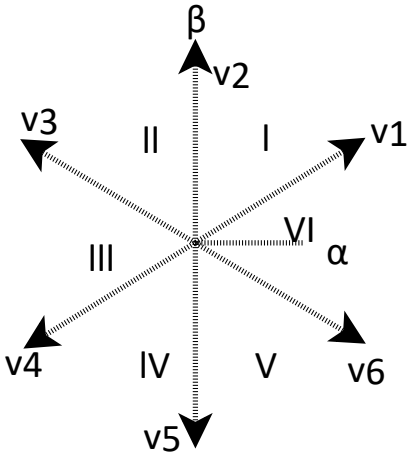


- Modulated MPC for the Three-Phase VSI: Control Scheme



Valid Swiching state of the VSI

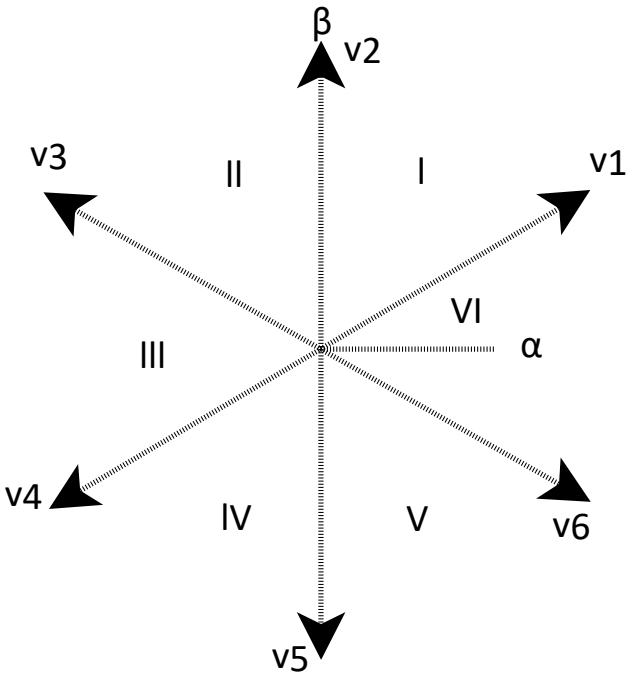
#	S_{r1}	S_{r2}	S_{r3}	S_{r4}	S_{r5}	S_{r6}
1	1	1	0	0	0	1
2	1	1	1	0	0	0
3	0	1	1	1	0	0
4	0	0	1	1	1	0
5	0	0	0	1	1	1
6	1	0	0	0	1	1
7	1	0	1	0	1	0
8	0	1	0	1	0	1



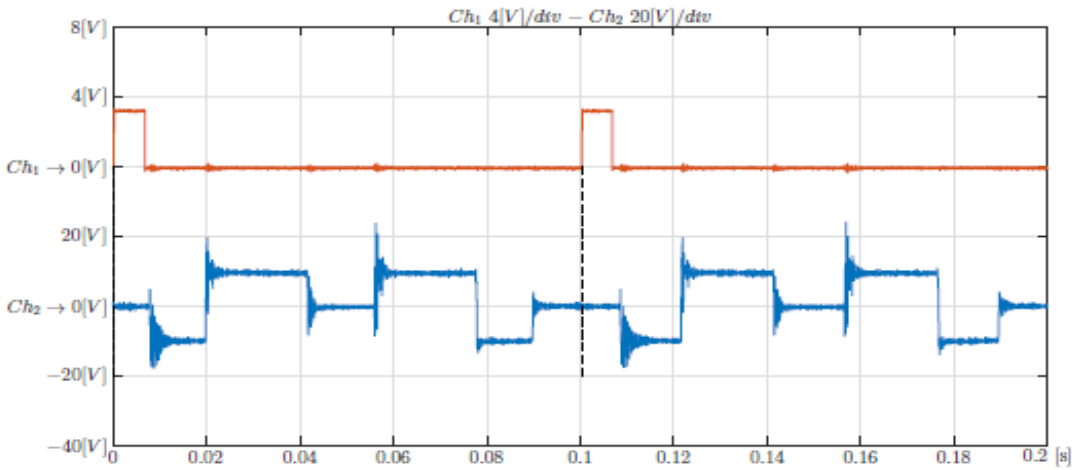
- Modulated MPC for the Three-Phase Voltage Source Inverter

$$g(k+1) = d_1 g_1 + d_2 g_2$$

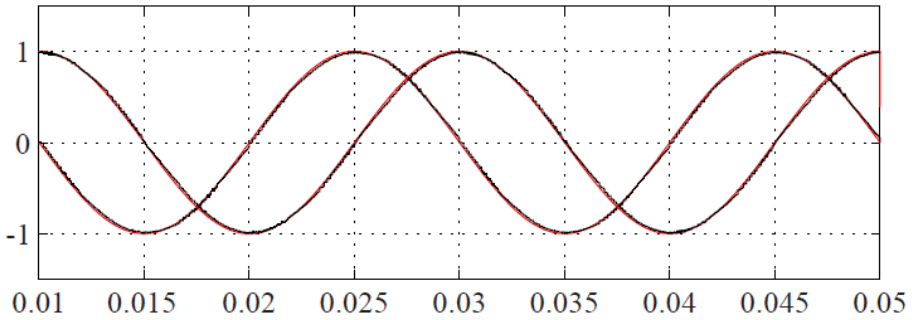
$$\begin{aligned} d_0 &= T_s g_1 g_2 / (g_0 g_1 + g_1 g_2 + g_0 g_2) \\ d_1 &= T_s g_0 g_2 / (g_0 g_1 + g_1 g_2 + g_0 g_2) \\ d_2 &= T_s g_0 g_1 / (g_0 g_1 + g_1 g_2 + g_0 g_2) \end{aligned}$$

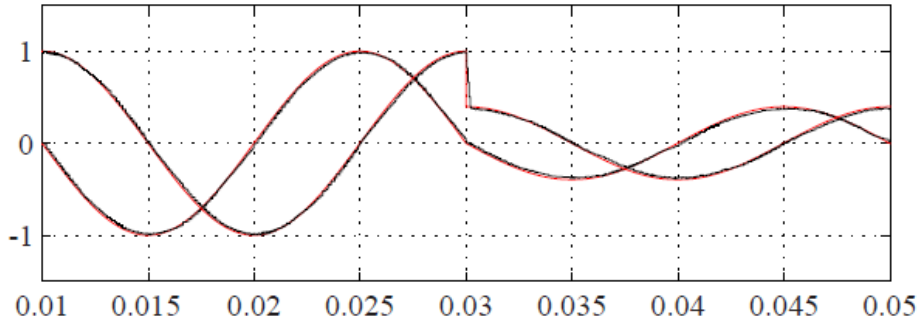


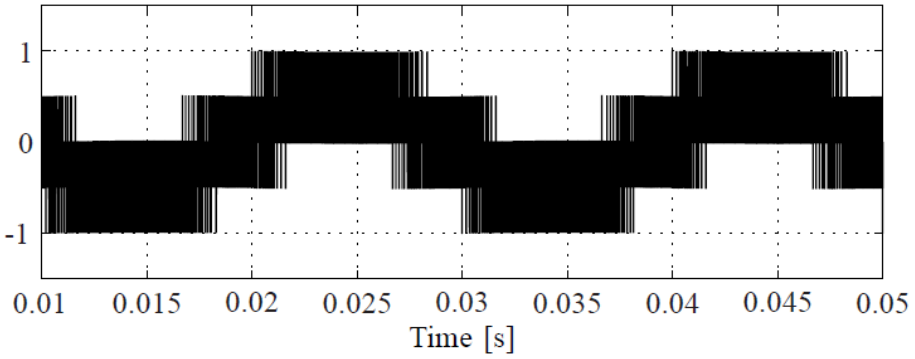
$$\begin{aligned} d_0 &= K/g_0 \\ d_1 &= K/g_1 \\ d_2 &= K/g_2 \\ d_0 + d_1 + d_2 &= T_s \end{aligned}$$

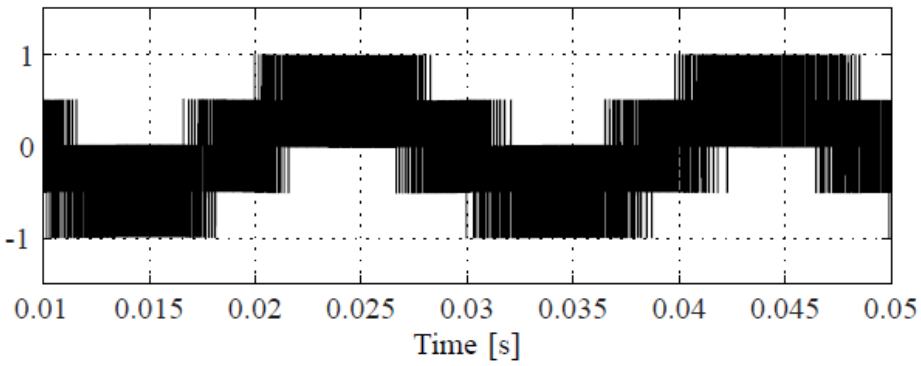


- Modulated MPC for the Three-Phase Voltage Source Inverter: Results

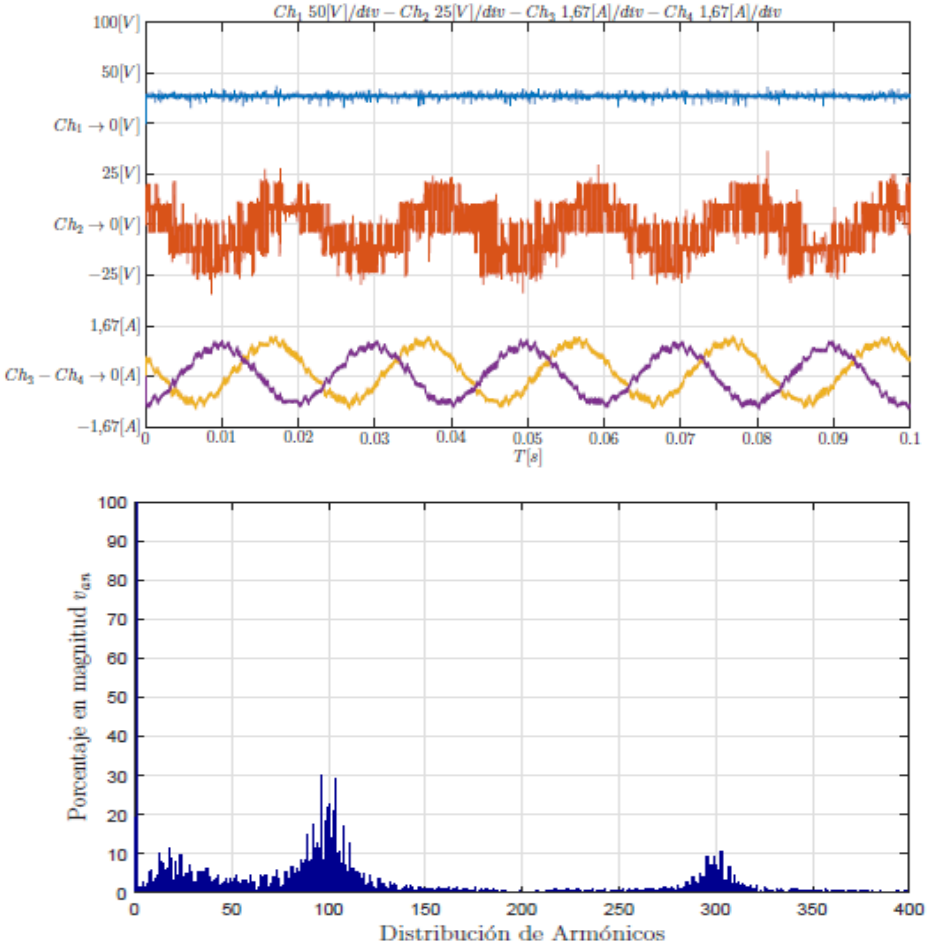




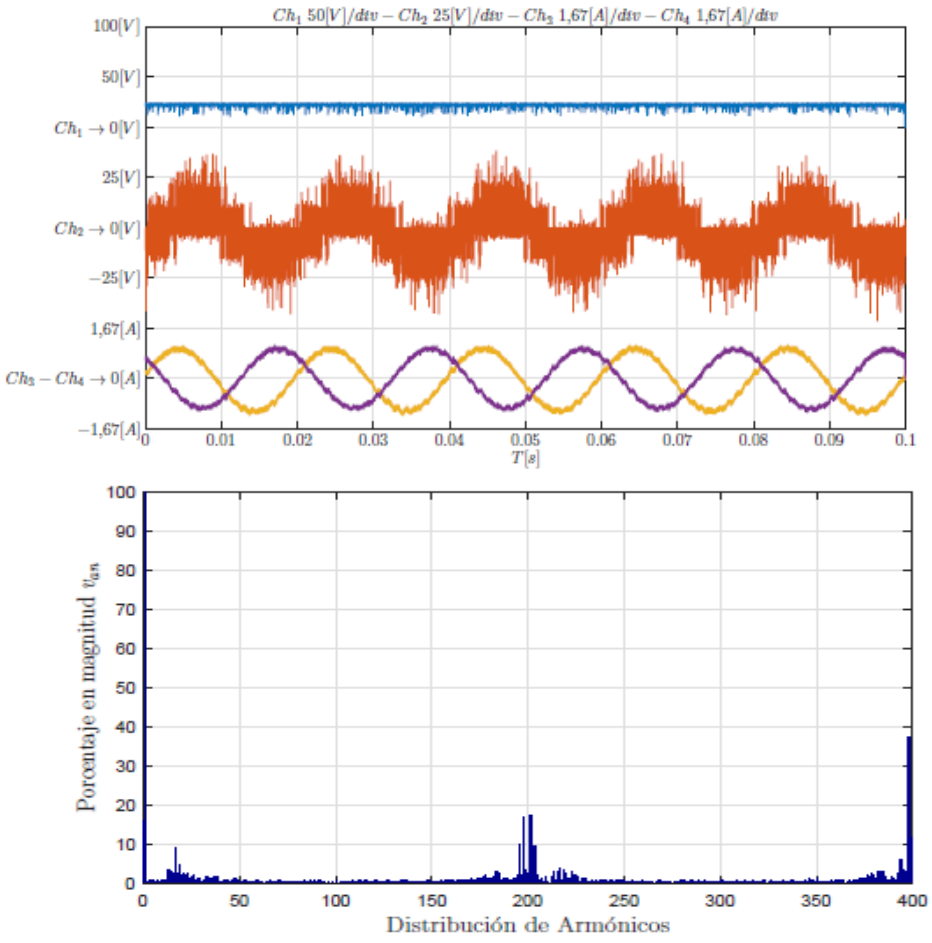




- Modulated MPC for the Three-Phase VSI : Experimental Results



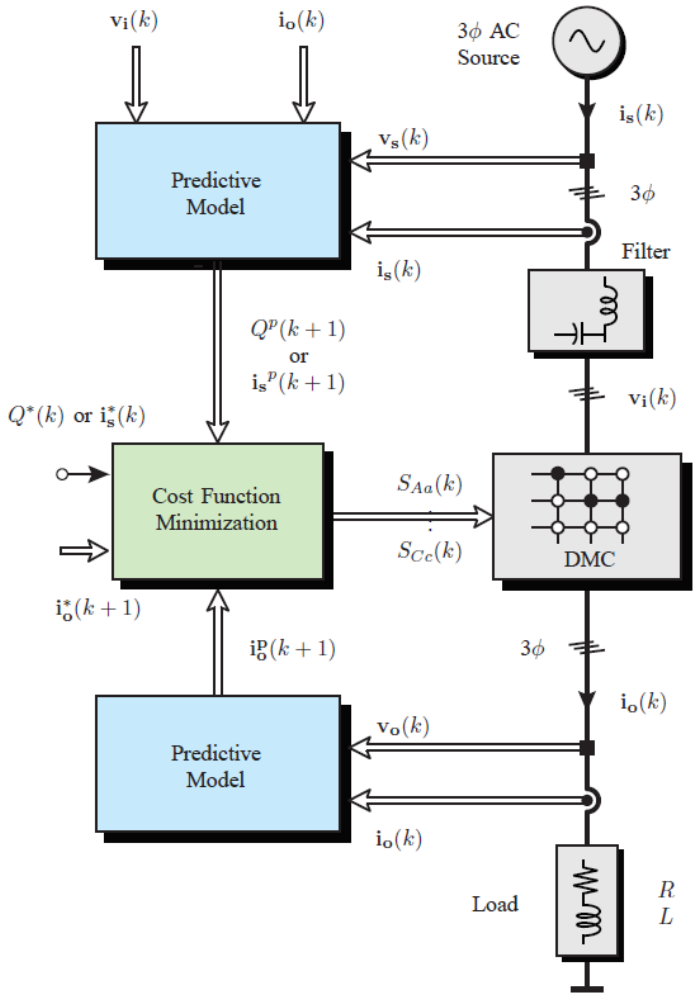
Classical MPC



Modulated MPC

Sequential MPC for Power Converters

- Predictive Control Strategies for the DMC



- The main idea of Model Predictive Control

- **Both input and output stages are controlled simultaneously** using a predictive model of the instantaneous reactive power and a predictive model of the load.

- A weighting factor is necessary in order to provide more priority to the instantaneous reactive input power of the load currents.

-The **cost function is evaluated for each of the twenty-seven** available switching states of the DMC.

-The **optimal switching state which will be applied** to the converter in the next sampling instant, is selected by **minimizing the cost function**.

- Predictive Control Strategies for the DMC: Introduction

- **Model Predictive Control: General Concept**

  - **Despite the vast progress of MPC, there are still some issues that need to be solved:**

    - **The control for the DMC and other power converters implies high computational costs**
      - Every sampling instant **all the available switching states** of the converter **are evaluated** in the cost function.
      - The DMC has **27 available switching states**.
      - Some available solutions: **implementation in FPGAs or faster digital signal processors**.

    - **The correct selection of weighting factors:**
      - Especially **when there are several control objectives**.
      - The correct selection has a **significant effect on the system performance**.
      - Despite there are some solutions, most of them are **tedious, complex and expensive**.

- Sequential MPC for a Direct Matrix Converter

Article

Sequential Model Predictive Control of Three-Phase Direct Matrix Converter

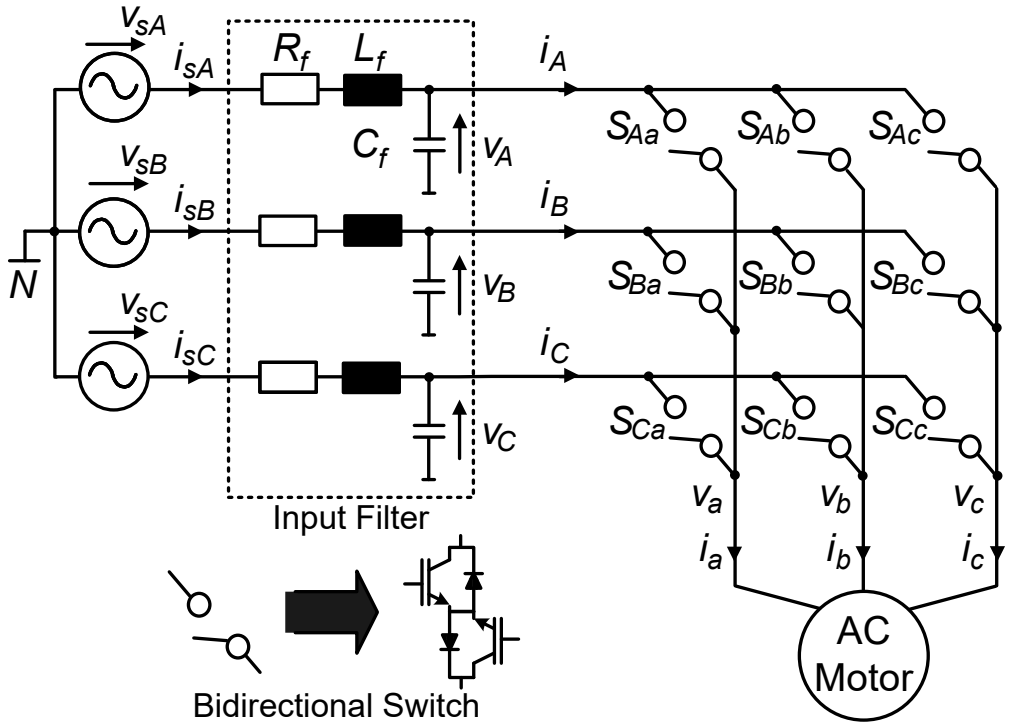
Jianwei Zhang, Margarita Norambuena, Li Li, David Dorrell and Jose Rodriguez

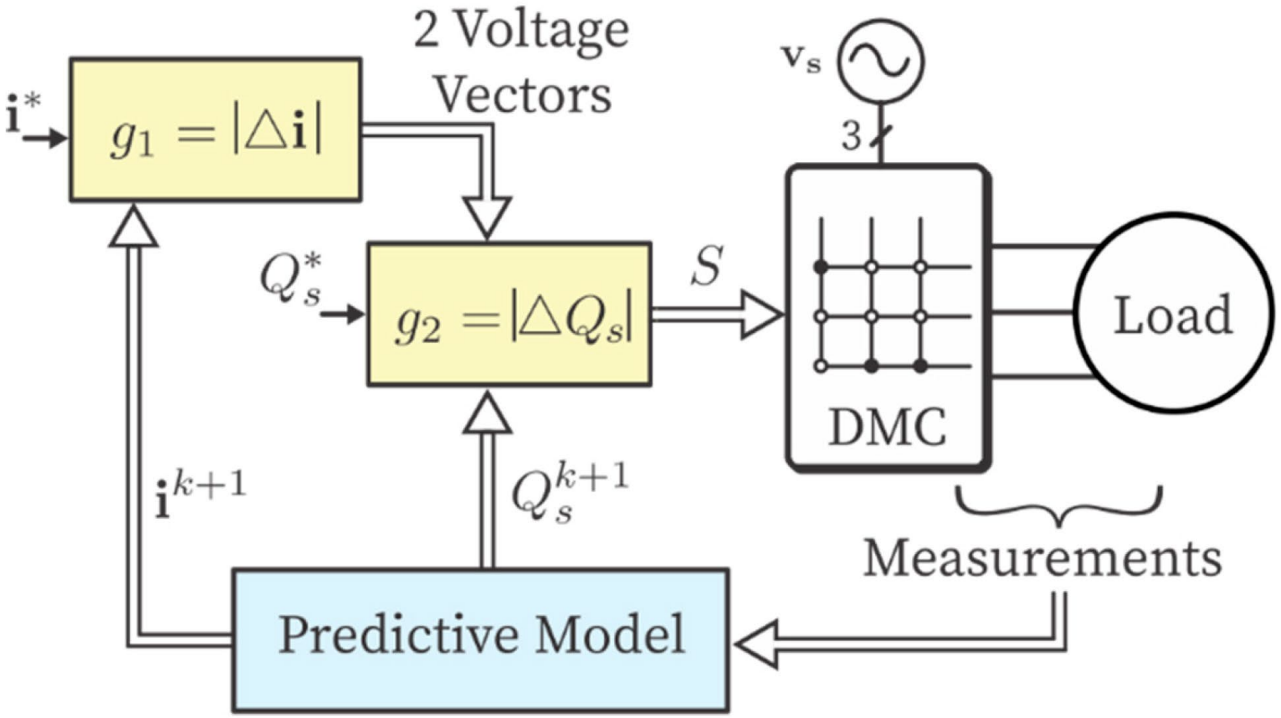
Special Issue
Control in Power Electronics

Edited by
Prof. Dr. George Weiss and Prof. Dr. Yoash Levron

Energies | Free Full-Text | Sequential Model Predictive Control of Three-Phase Direct Matrix Converter (mdpi.com)

- Sequential MPC for a Direct Matrix Converter

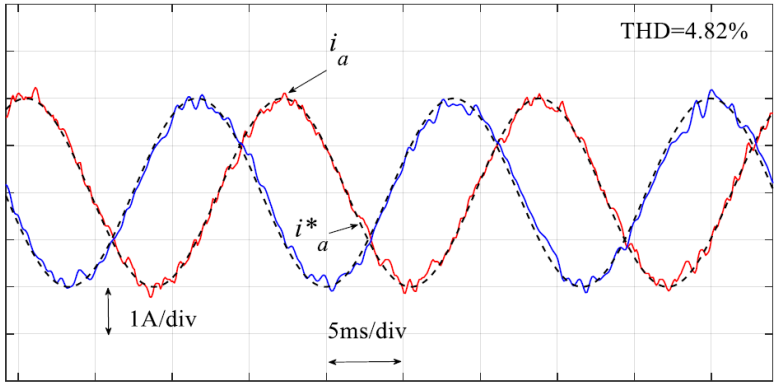




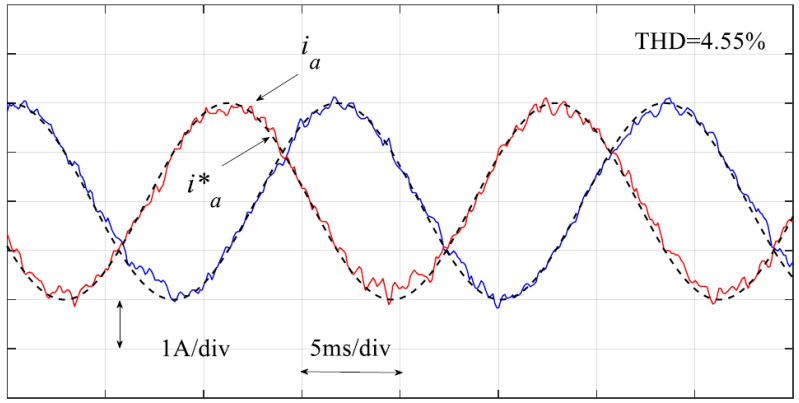
Block diagram of the Sequential Model Predictive Control for the Direct Matrix Converter

Energies | Free Full-Text | Sequential Model Predictive Control of Three-Phase Direct Matrix Converter (mdpi.com)

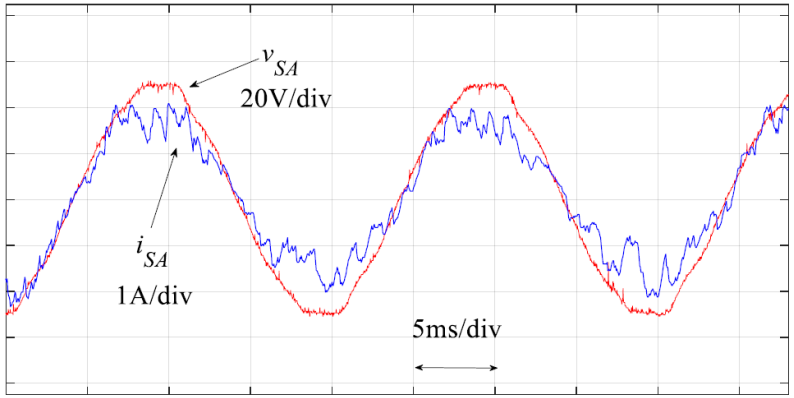
- Sequential MPC for a Direct Matrix Converter



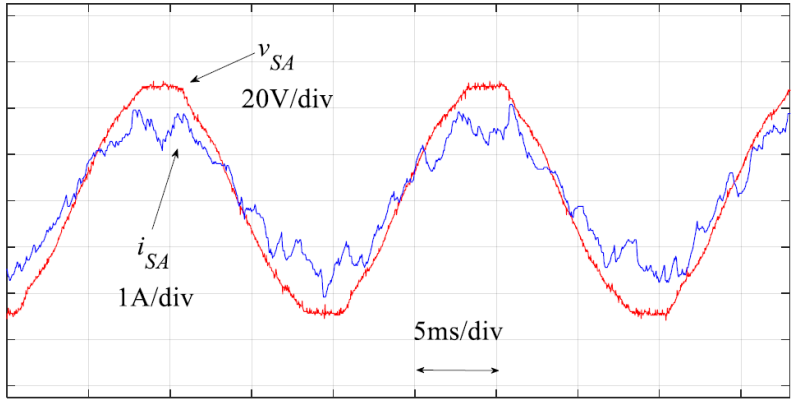
Load currents and references - classic MPC



Load currents and references - proposed SMPC



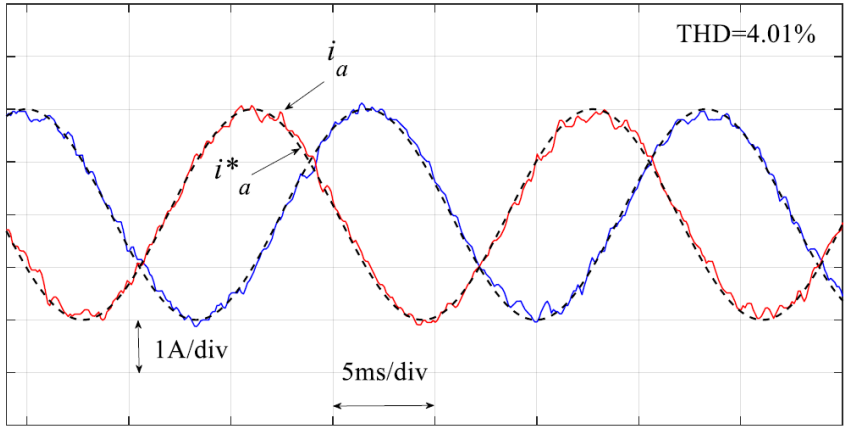
Input current and voltage - classic MPC



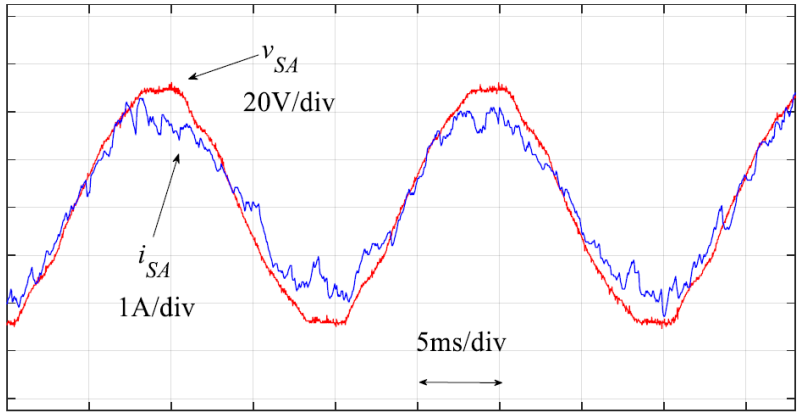
Input current and voltage - proposed SMPC

Energies | Free Full-Text | Sequential Model Predictive Control of Three-Phase Direct Matrix Converter (mdpi.com)

- Sequential MPC for a Direct Matrix Converter



Load currents and references - proposed MPC



Input current and voltage - proposed SMPC

The execution time of the proposed SMPC (67 us) is reduced appreciably compared with the traditional MPC (81 us).

Energies | Free Full-Text | Sequential Model Predictive Control of Three-Phase Direct Matrix Converter (mdpi.com)

- Alternating Sequential MPC for a Direct Matrix Converter

Conferences > 2023 IEEE International Confe...

Alternating Sequential Model Predictive Control of Matrix Converter

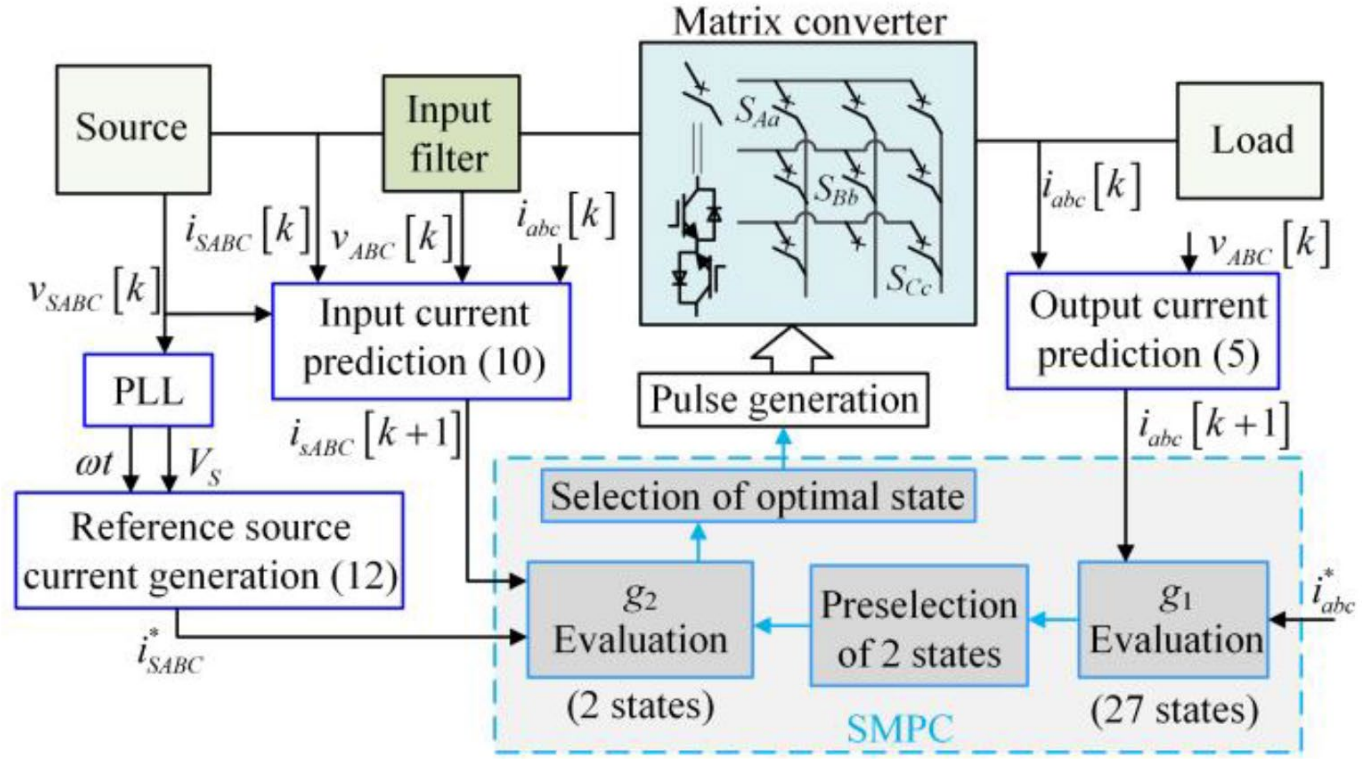
Publisher: IEEE Cite This PDF

Jianwei Zhang ; Marco Rivera ; Patrick Wheeler **All Authors**

The **cost functions are evaluated in an alternating order**. For example, g1 is evaluated before g2 in the first sampling cycle and g2 is evaluated before g1 in the next sampling cycle, and so on.

The proposed ASMPC does **not need a weighting factor** and there is **no need to specify the priority for control objectives**.

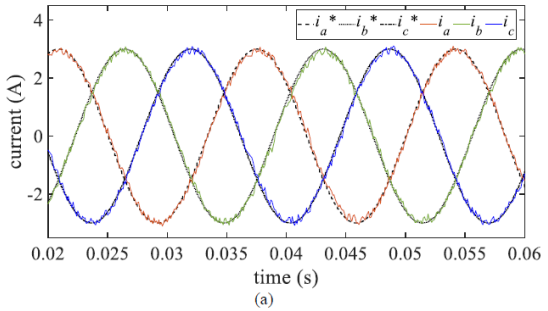
In addition, the **computational burden is reduced** because only two switch states are evaluated in the second cost function in each control interval.

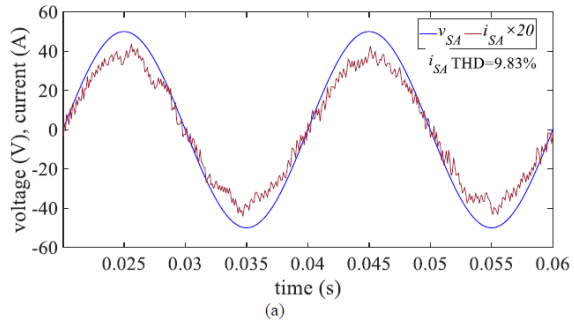


Alternating Sequential Model Predictive Control of Matrix Converter | IEEE Conference Publication | IEEE Xplore

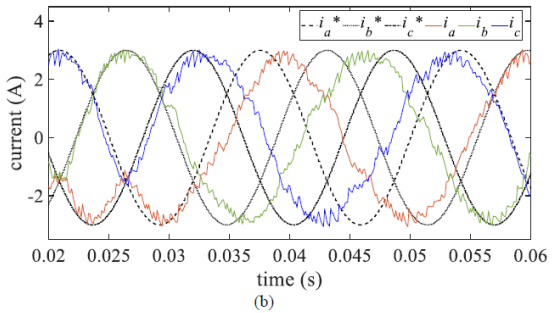
- Alternating Sequential MPC for a Direct Matrix Converter

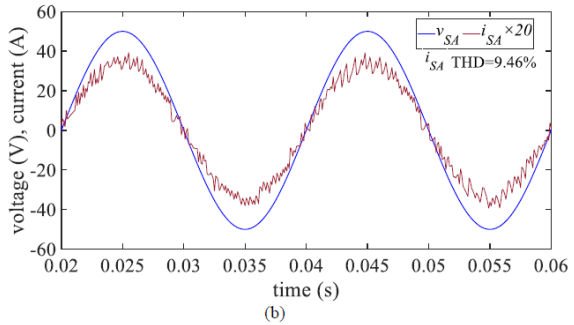
SMPC 1



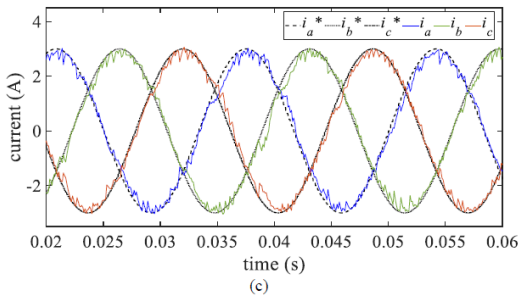


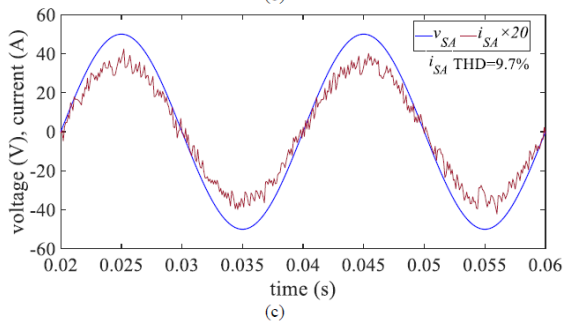
SMPC 2



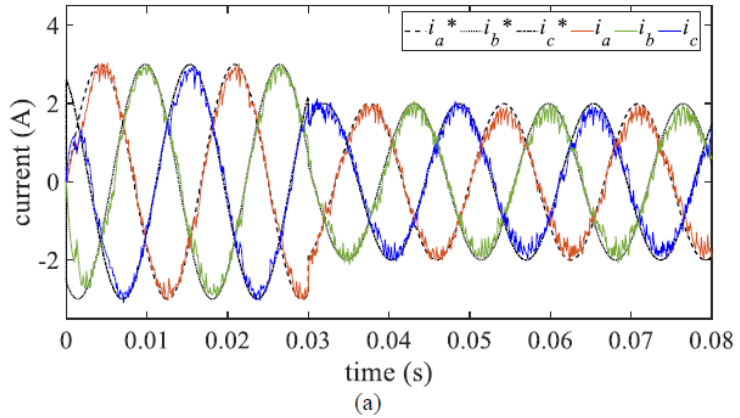


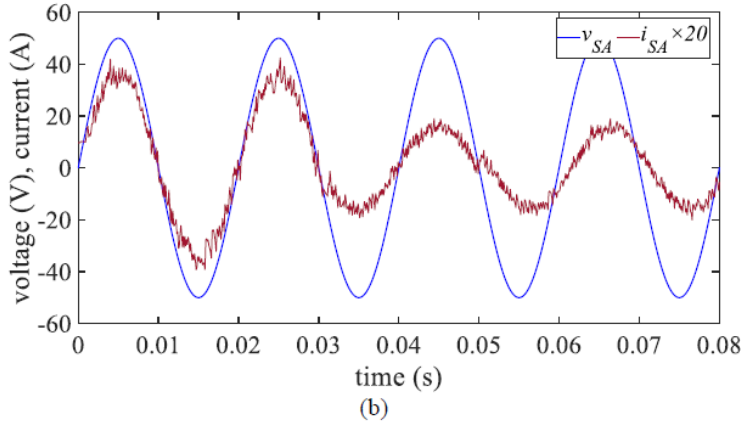
ASMPC





ASMPC transient state



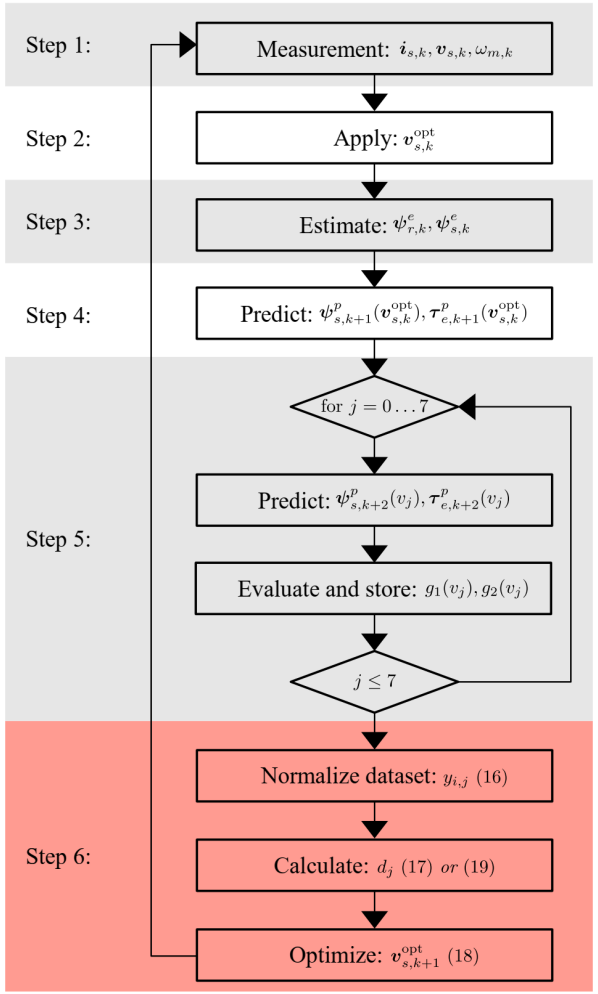


Alternating Sequential Model Predictive Control of Matrix Converter | IEEE Conference Publication | IEEE Xplore

Predictive Control for Power Converters and Electrical Drives

MPC based on Decision-Making Algorithms

- A Decision-Making Algorithm for MPC Strategies



The decision-making algorithm with the flowchart on the left has the following steps:

1. Separation of multi-objective cost function:

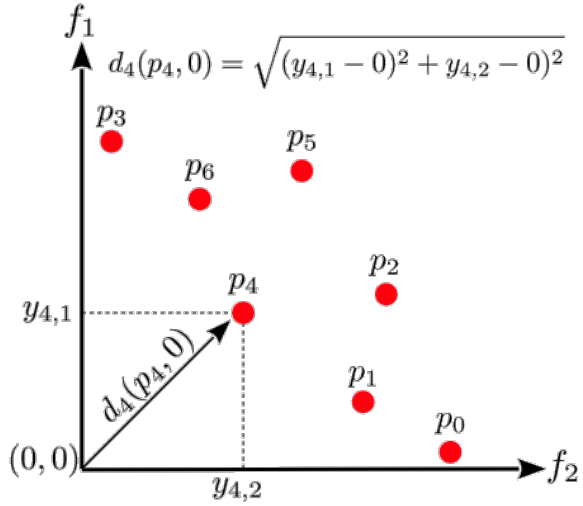
$$g_1 = \left| \tau_e^* - \tau_{e,k+2}^p \right|$$

$$g_2 = \left| \|\psi_s^*\| - \|\psi_{s,k+2}^p\| \right|$$

2. Generation of dataset:

$$x_{ij} = \begin{pmatrix} g_1(\boldsymbol{v}_0) & g_2(\boldsymbol{v}_0) & \cdots & g_n(\boldsymbol{v}_0) \\ g_1(\boldsymbol{v}_1) & g_2(\boldsymbol{v}_1) & \cdots & g_n(\boldsymbol{v}_1) \\ \vdots & \vdots & \ddots & \vdots \\ g_1(\boldsymbol{v}_m) & g_2(\boldsymbol{v}_m) & \cdots & g_n(\boldsymbol{v}_m) \end{pmatrix}$$

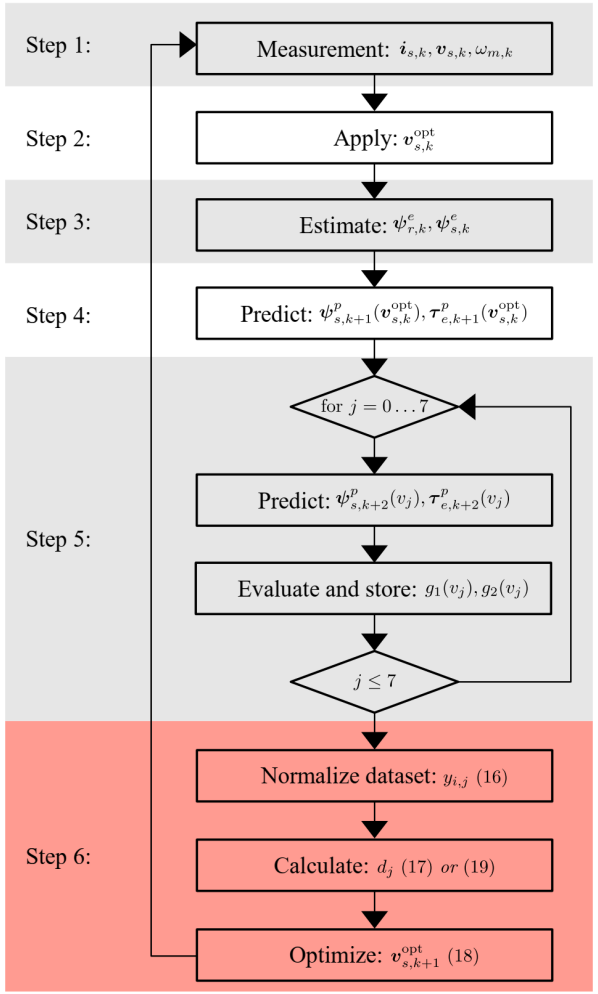
where $i \in \{1, 2, \ldots, n\}$ and $j \in \{0, 1, \ldots, m\}$ indicate the number of control objectives and voltage vectors, respectively.



Decision-making methods separately evaluate each control objective in the cost function and then use a selection algorithm to choose an optimal voltage vector.

For more information about this technique. Please click here.

- A Decision-Making Algorithm for MPC Strategies



3. Normalization of the dataset:

$$y_{ij} = \frac{x_i^{\min} - x_{ij}}{x_i^{\min} - x_i^{\max}}$$

4. Calculate the distances in the n −dimensional space using the normalized dataset

$$d_j(p_j, 0) = \sqrt{(y_{j,1})^2 + (y_{j,2})^2 + \ldots + (y_{j,n})^2}$$

or

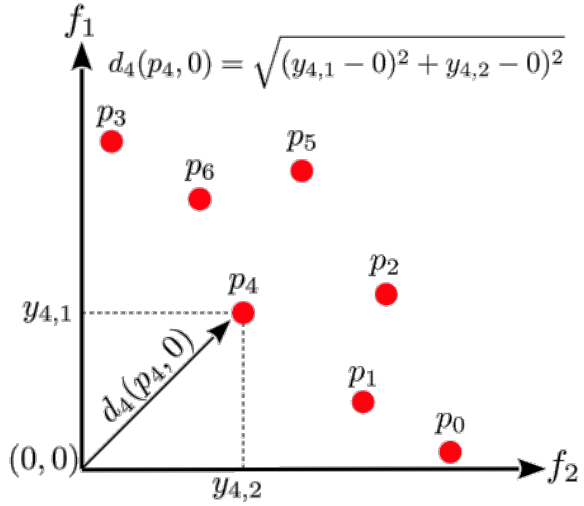
$$d_j(p_j, 0) = y_{j,1} + y_{j,2} + \ldots + y_{j,n}$$

Euclidean norm

Absolute-value norm

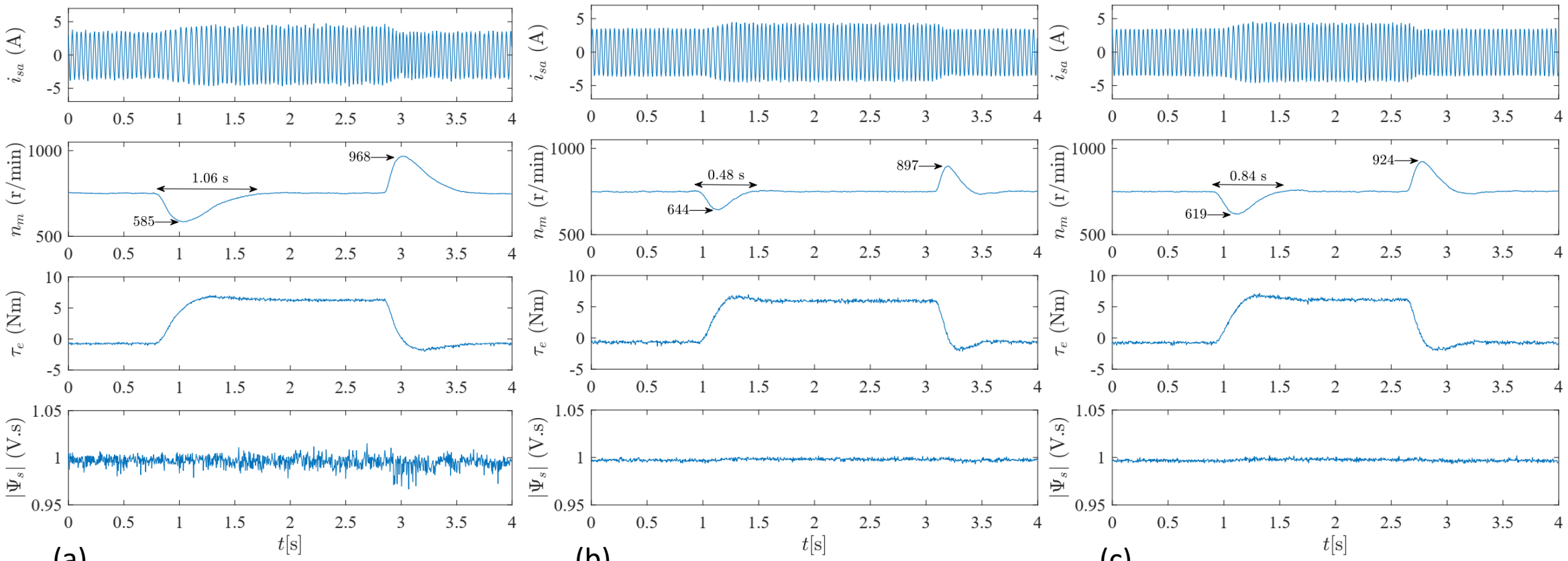
5. Select the jth voltage vector with minimum norm value:

$$v_{\text{opt}} = \arg\min_j d_j$$



For more information about this technique. Please click here.

- A Decision-Making Algorithm for MPC Strategies



Experimental results: Control performance under load changes of 6 Nm at 750 r/min (a) conventional MPTC with $\lambda_\psi = 20$ (b) DM-based MPTC with Euclidean norm (c) DM-based MPTC with absolute-value norm

Predictive Control for Power Converters and Electrical Drives

Conclusions and Final Remarks

Conclusions

- MPC presents a **different approach** for the control of power converters.
- MPC takes advantages of the **discrete nature** of the power converters.
- By using the same scheme, it is possible to control **different variables** such as: current, voltage, power, torque, flux, and others.
- **Constrains** and **non-linearities** can be easily included in the model.
- The control is **simple** and can be easily applied to any converter topology.

Conclusions

- Challenges such as the **performance improvement**, **reduction of computational cost** and the **avoidance of weighting factors** have been considered **new trends in model predictive control** and several proposals have been recently presented.

- **Modulated model predictive control** allows for improving the performance of the system with **a significant reduction of the ripple** in the controller variables.

- **Sequential model predictive control** does not require the use of **weighting factors** in the cost function. It allows for effective control of several variables at the same time.

Acknowledgments

- ANID Fondecyt Regular 1220556
- Anillo ANID - ATE220023
- CLIMAT AMSUD 21001 Project
- SERC Chile FONDAP 1523A0006
- ANID FOVI 230169
- IRCF A7C140 University of Nottingham
- ENNOBLE R02401 University of Nottingham

Discussions and Questions

Model Predictive Control for Power Electronics Applications

Prof. Marco Rivera

Marco.Rivera@nottingham.ac.uk