

# Power Quality Compensation for Smart Grids by Model-based Predictive Control

Carlos Cateriano Yáñez<sup>1,2</sup>, Kathrin Weihe<sup>1</sup>, Georg Pangalos<sup>2</sup>, and Gerwald Lichtenberg<sup>1</sup>

<sup>1</sup>Hamburg University of Applied Sciences, Faculty Life Sciences, Ulmenliet 20, 21033 Hamburg

<sup>2</sup>Fraunhofer ISIT, Application Center Power Electronics for Renewable Energy Systems, Steindamm 94, 20099 Hamburg

{carlos.caterianoyanez, kathrin.weihe, gerwald.lichtenberg}@haw-hamburg.de, georg.pangalos@isit.fraunhofer.de,

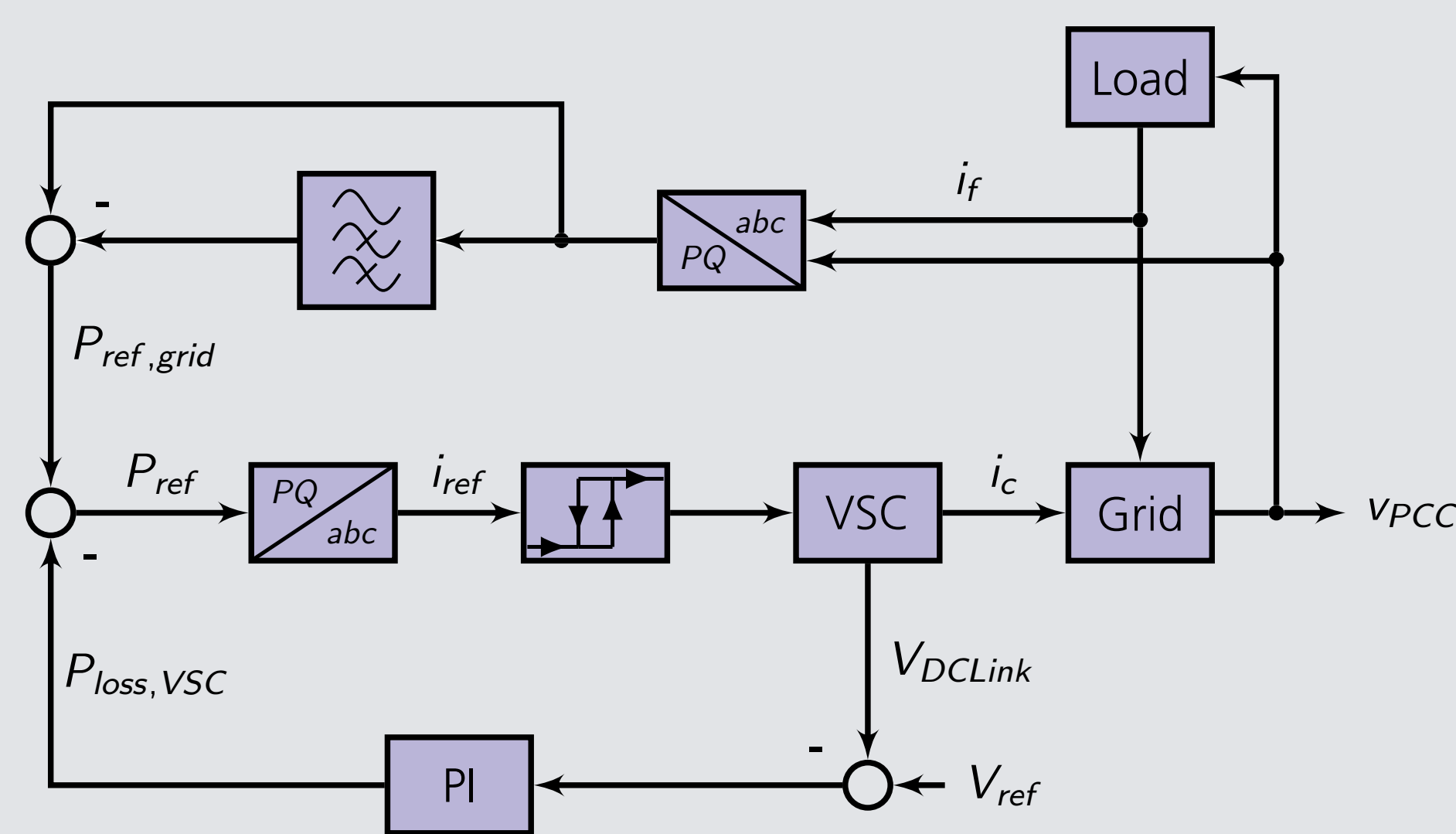
## INTRODUCTION

- High order harmonics in the electrical grid introduced by switching converters need to be compensated to avoid damage and energy loss
- Classic active power filter (APF) controllers are capable of compensating harmonics, but are not flexible under variable load scenarios
- A state-of-the-art method to compensate harmonics relies on the instantaneous reference frame (IRP) theory
- A novel approach: “Linear State Signal Shaping Model Predictive Control” (LS<sup>3</sup>MPC), could be utilized to compensate harmonics using shape classes, without the need to design filters for different load scenarios

## APPLICATION PROBLEM

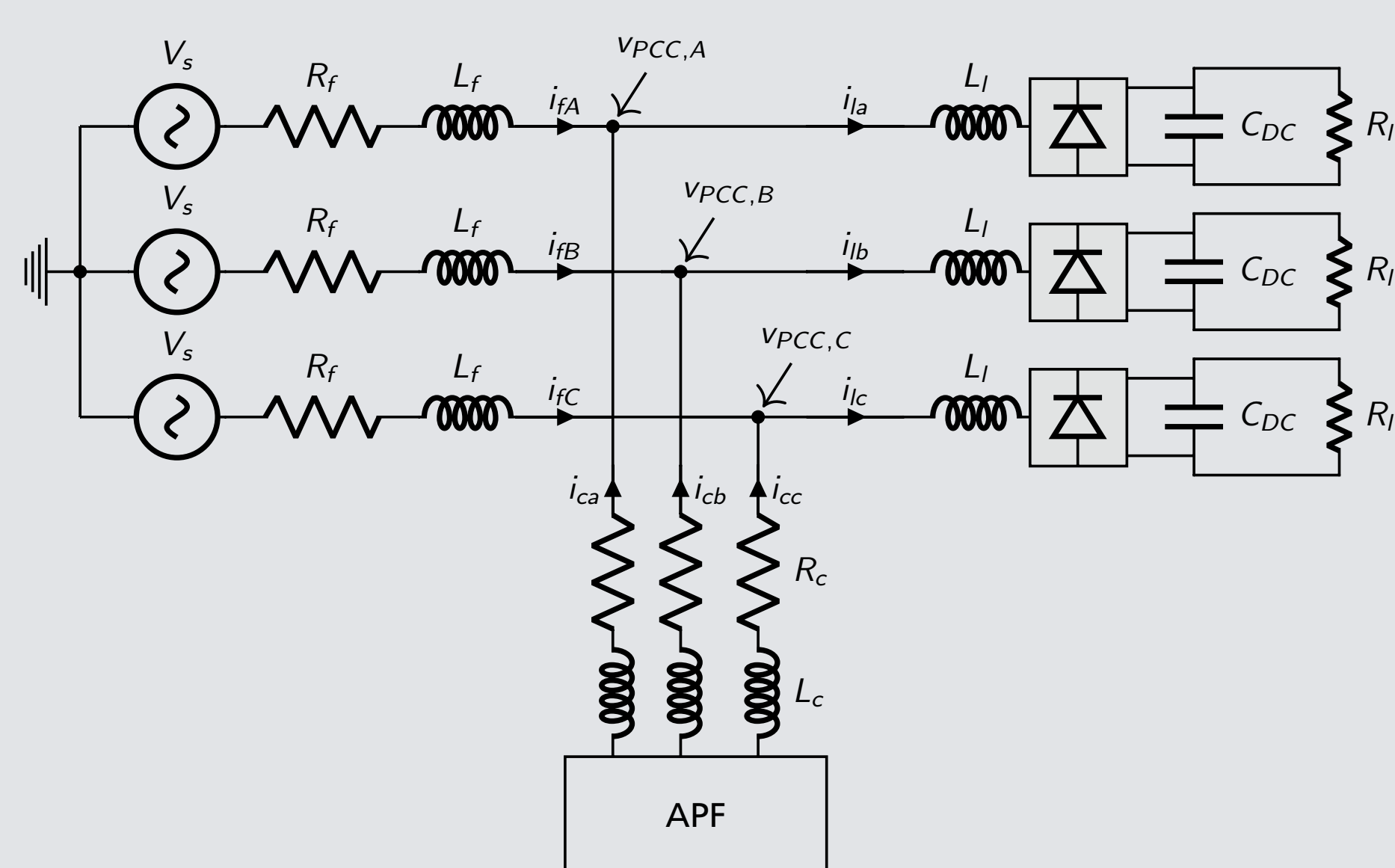
- Could the LS<sup>3</sup>MPC improve the grid quality compared to a classic IRP APF controller?
- A simulation is set up to evaluate both controller types under different load scenarios

## CLASSIC IRP CONTROLLER



- Clarke and p-q transformation are used
- A high pass filter extracts harmonics
- A hysteresis band controller steers the voltage source converter

## 3-PHASE GRID MODEL



Active power filter in shunt configuration

## WHITE-BOX MODELING

Linear state space model of per phase

$$\mathbf{x}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{B}u(k) + \mathbf{E}d(k)$$

where

$$\mathbf{x}(k) = \begin{pmatrix} i_f \\ i_c \end{pmatrix} \in \mathbb{R}^2 \quad u(k) = i_{c0} \in \mathbb{R} \quad d(k) = \begin{pmatrix} v_s \\ i_{f0} \end{pmatrix}^T \in \mathbb{R}^2$$

and

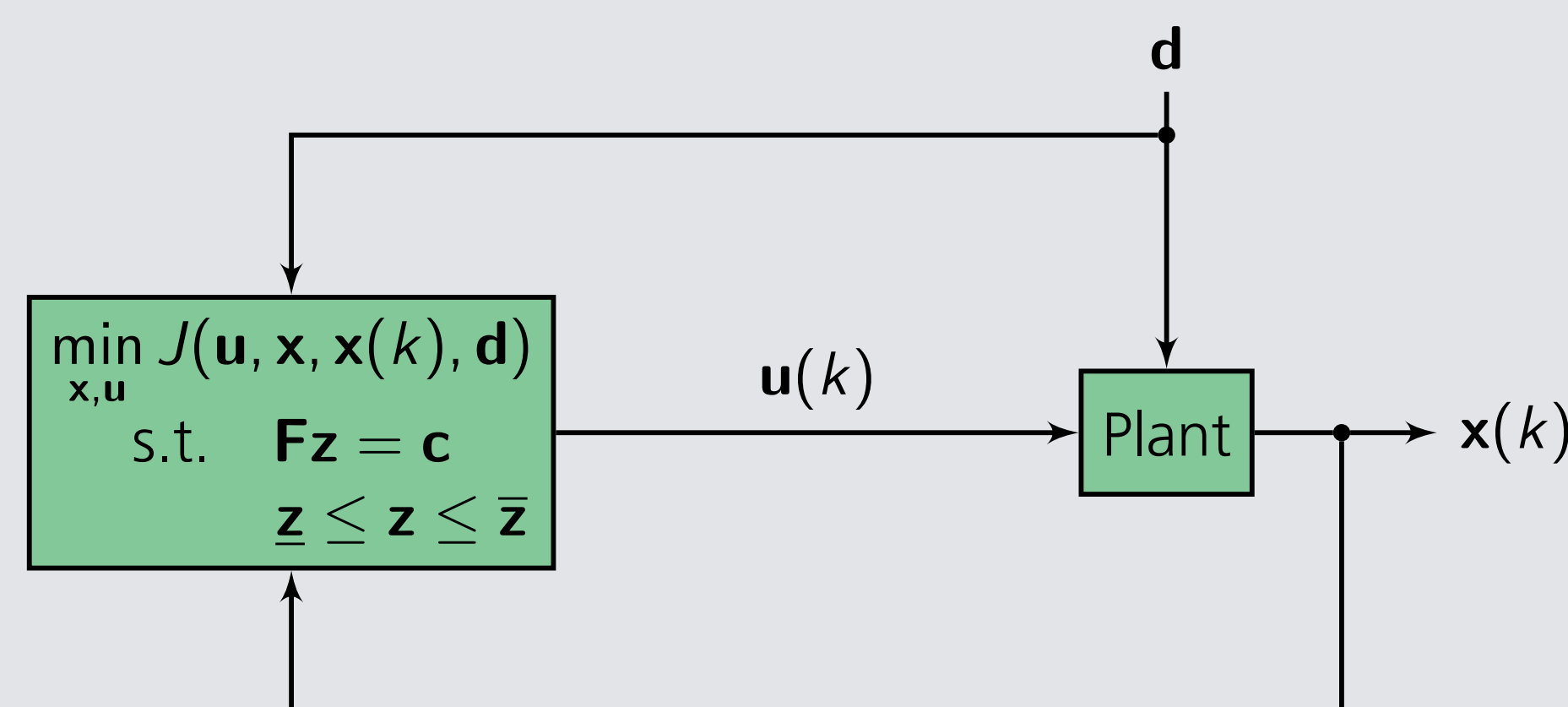
$$\mathbf{A} \in \mathbb{R}^{2 \times 2}, \quad \mathbf{B} \in \mathbb{R}^{2 \times 1}, \quad \mathbf{E} \in \mathbb{R}^{2 \times 2}.$$

## PREDICTIVE CONTROLLER

The MPC minimizes the cost function

$$J = \|\mathbf{X}(k) - \Xi(k)\|_Q^2 + \|\mathbf{U}(k)\|_R^2.$$

Solved by constrained sparse quadratic programming (QP), with close loop behavior:



## LINEAR SHAPE CLASS

The shape of a sine wave is described by the homogeneous ODE

$$\frac{d^2 x(t)}{dt^2} + \omega^2 x(t) = 0$$

and approximated in discrete time with

$$x(k-1) + ((\omega t_s)^2 - 2)x(k) + x(k+1) = 0.$$

From this difference equation the *linear shape class*<sup>3</sup>  $\mathbf{V}$  is given as

$$\mathbf{V} = \begin{pmatrix} 1 & (\omega t_s)^2 - 2 & 1 \end{pmatrix} \in \mathbb{R}^{1 \times 3}.$$

The state error weight matrix  $\mathbf{Q}$  is built using  $\mathbf{V}$  by transferring the control goal to the optimization problem

$$\min_{\mathbf{x}(k)} (\mathbf{V}\mathbf{x}(k))^2,$$

where

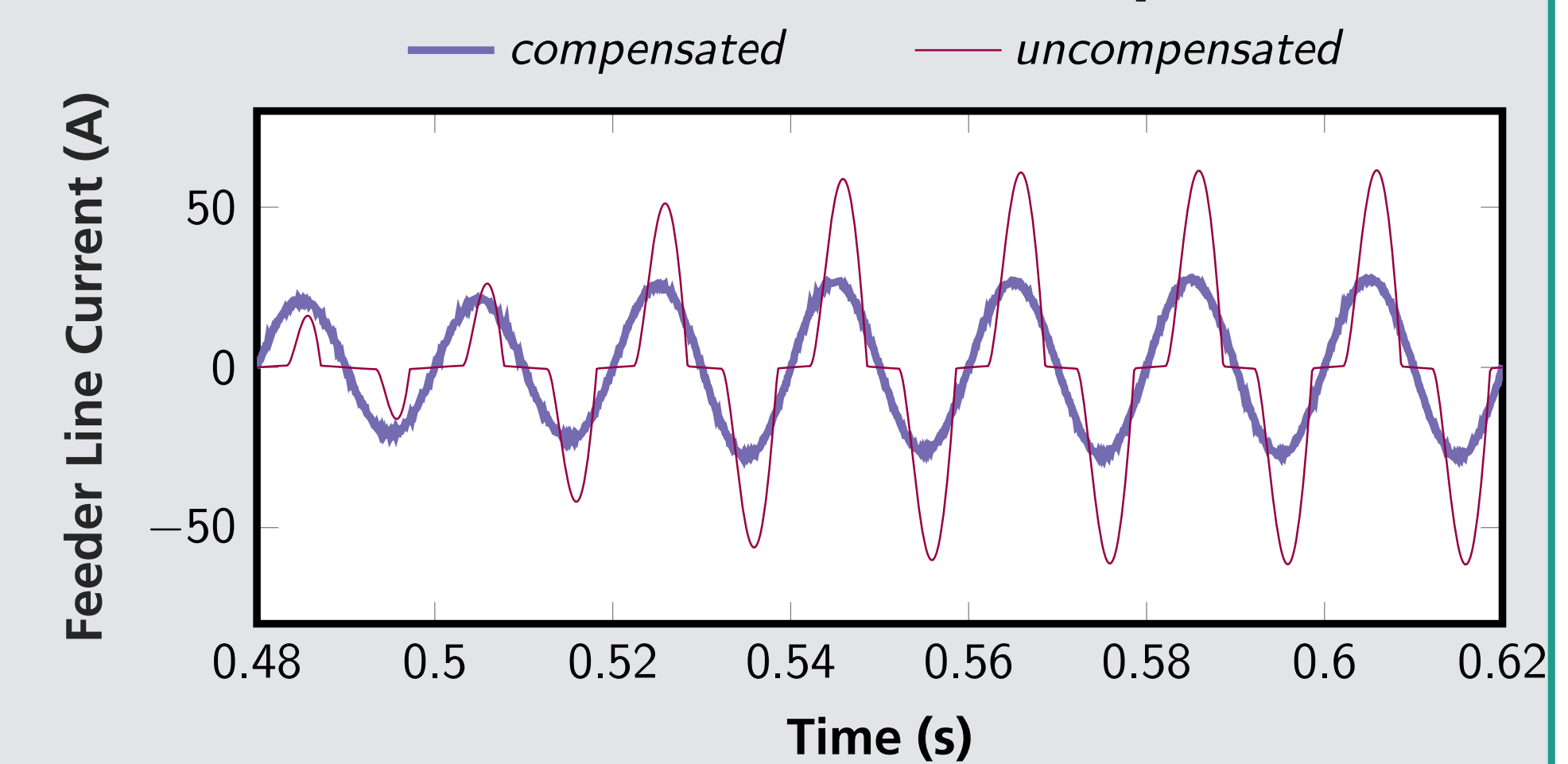
$$\mathbf{X}(k) = \begin{pmatrix} x(k-1) & x(k) & x(k+1) \end{pmatrix}^T,$$

for all times  $k$ .

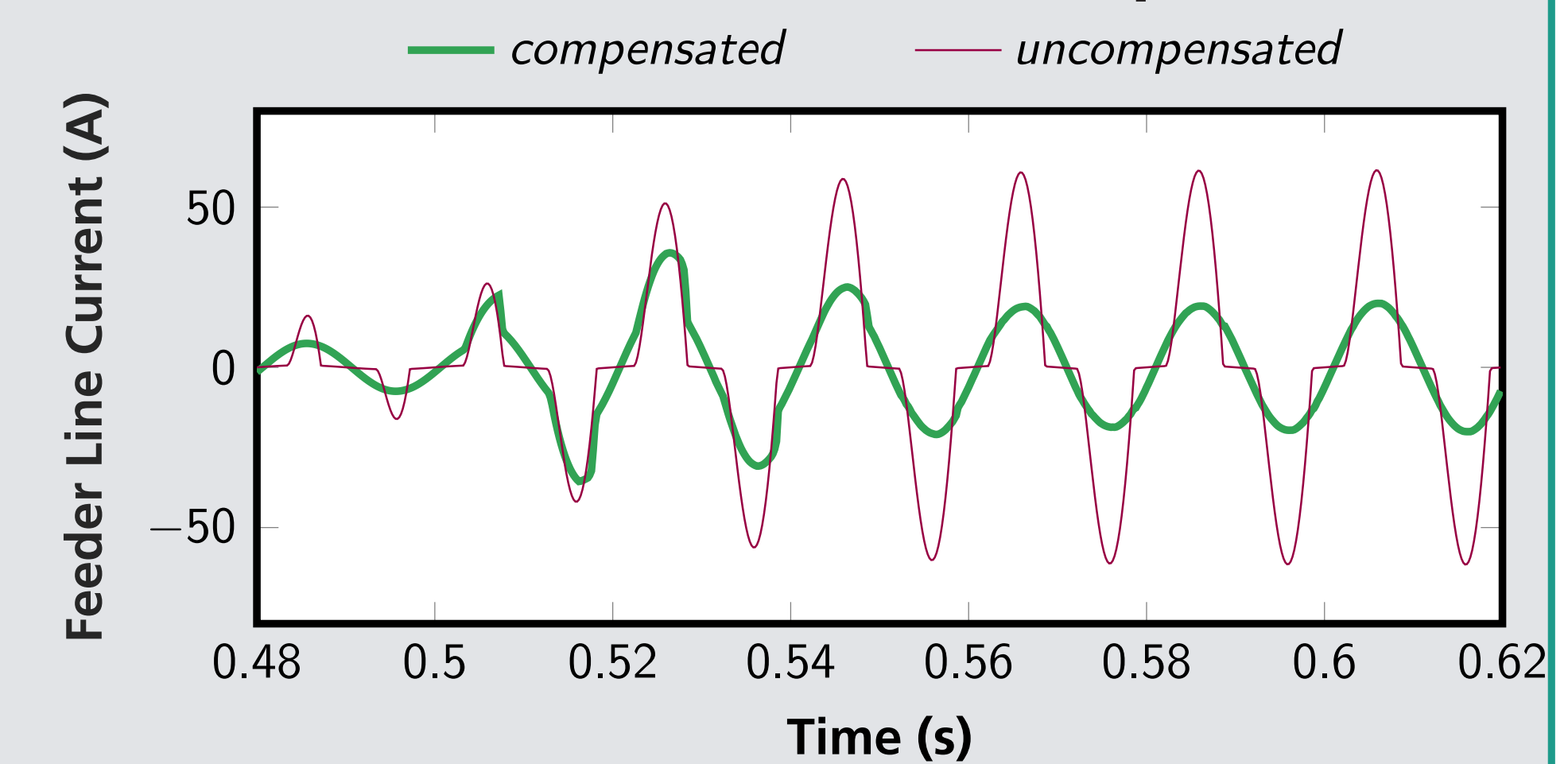
<sup>3</sup>Cateriano Yáñez, C., Pangalos, G., and Lichtenberg, G. (2018). An approach to linear state signal shaping by quadratic model predictive control. In *European Control Conference (ECC) 2018*

## SIMULATION STUDIES

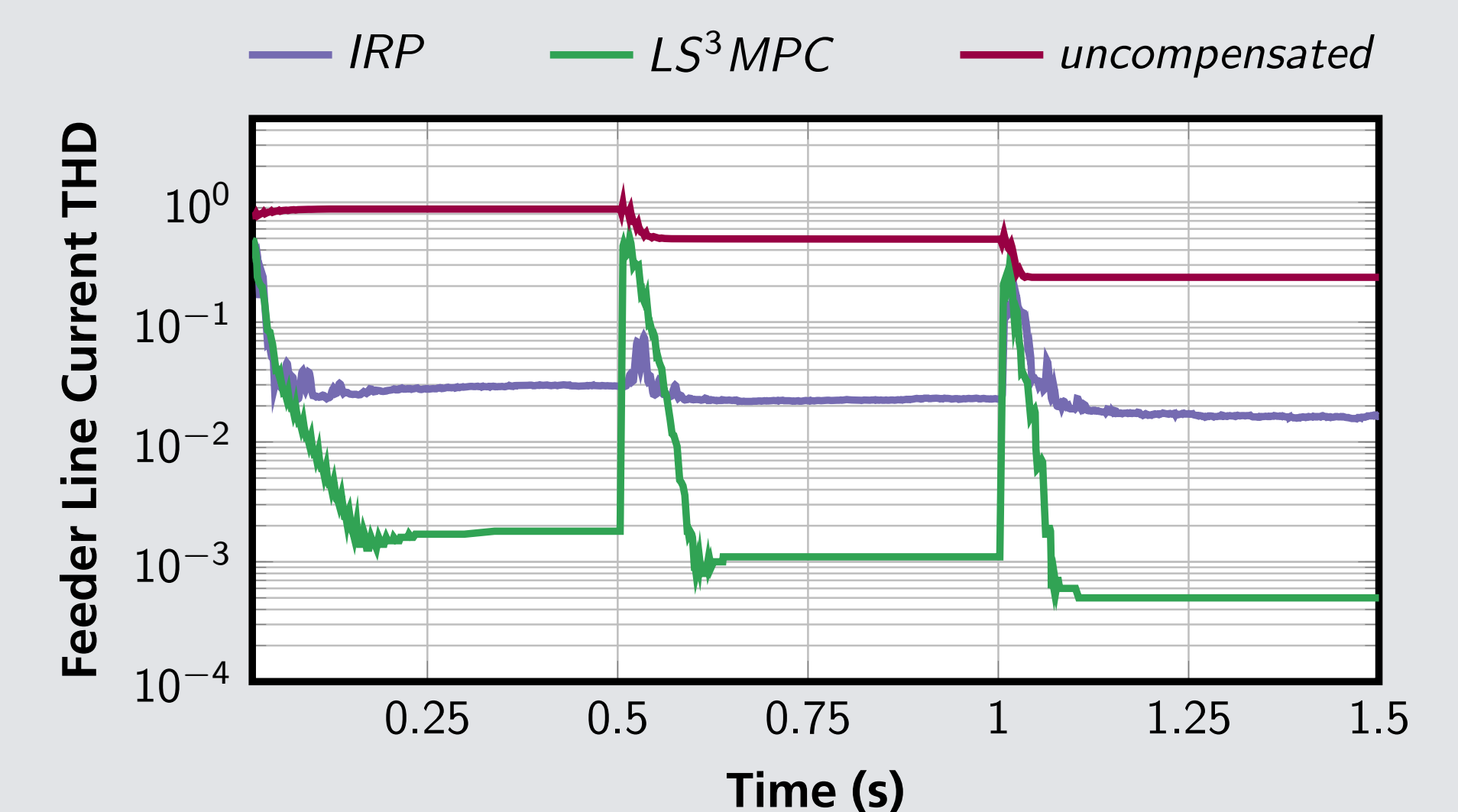
IRP APF harmonic current compensation:



LS<sup>3</sup>MPC harmonic current compensation:



Total harmonic distortion (THD):



Results for different load scenarios:

Load scenario	THD ( $v_{PCC}$ )		THD ( $i_f$ )	
	IRP	LS <sup>3</sup> MPC	IRP	LS <sup>3</sup> MPC
100 $\Omega$	1.07%	0.01%	6.68%	0.18%
9 $\Omega$	0.75%	0.02%	2.72%	0.11%
2 $\Omega$	0.85%	0.07%	2.56%	0.05%

## CONCLUSION

- The LS<sup>3</sup>MPC can successfully improve the THD compensation of an APF
- Classic IRP rely on high pass filter design for a given load scenario, while LS<sup>3</sup>MPC can inherently adapt to a wider variety
- Current research on LS<sup>3</sup>MPC focuses on enabling reactive power compensation