

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

Carlos Cateriano Yáñez^{1,2}, Kathrin Weihe¹, Georg Pangalos², and Gerwald Lichtenberg¹

¹Hamburg University of Applied Sciences, Faculty Life Sciences, Ulmenliet 20, 21033 Hamburg

²Fraunhofer 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,

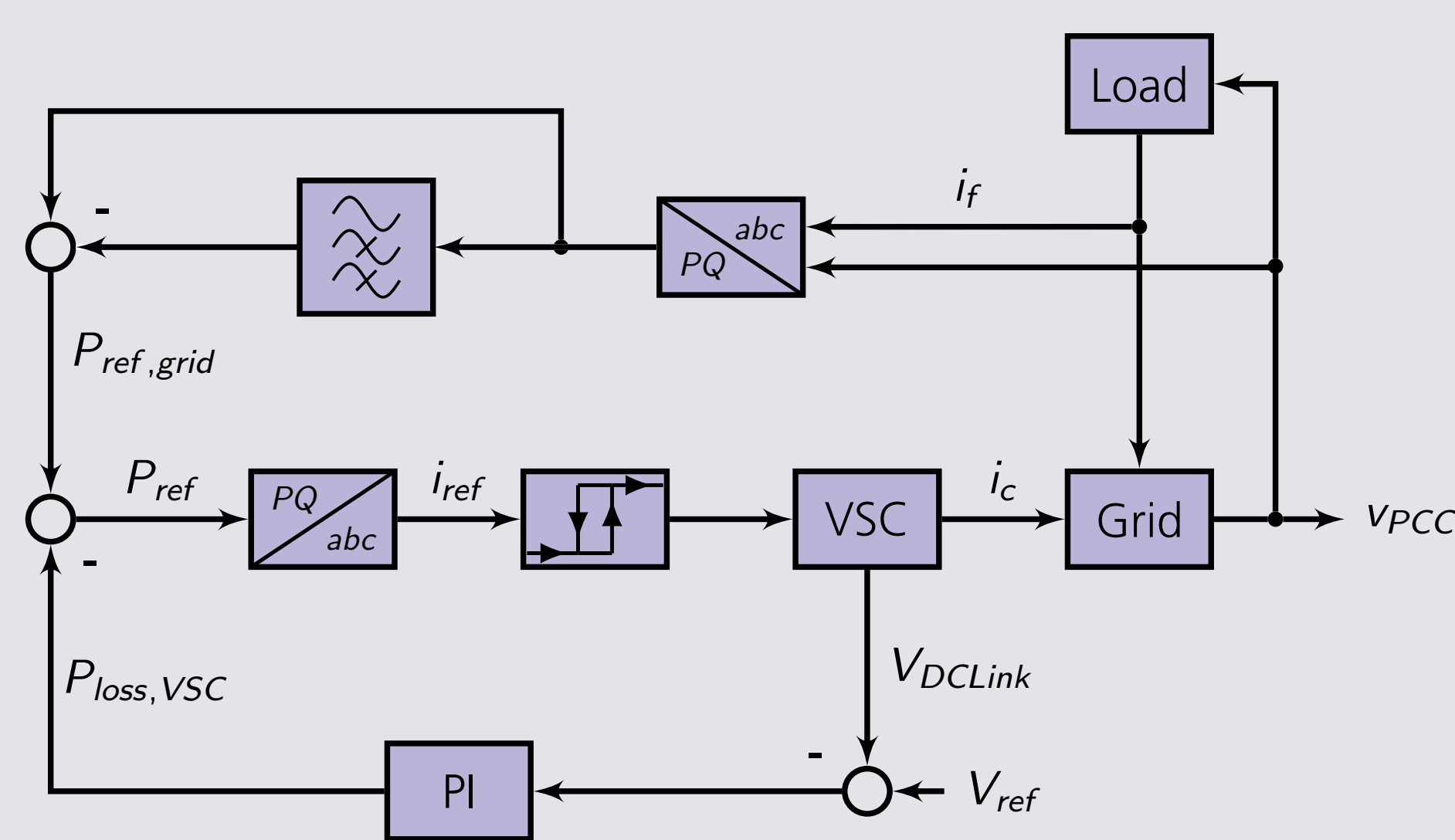
INTRODUCTION

- 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” (LS³MPC), could be utilized to compensate harmonics using shape classes, without the need to design filters for different load scenarios

APPLICATION PROBLEM

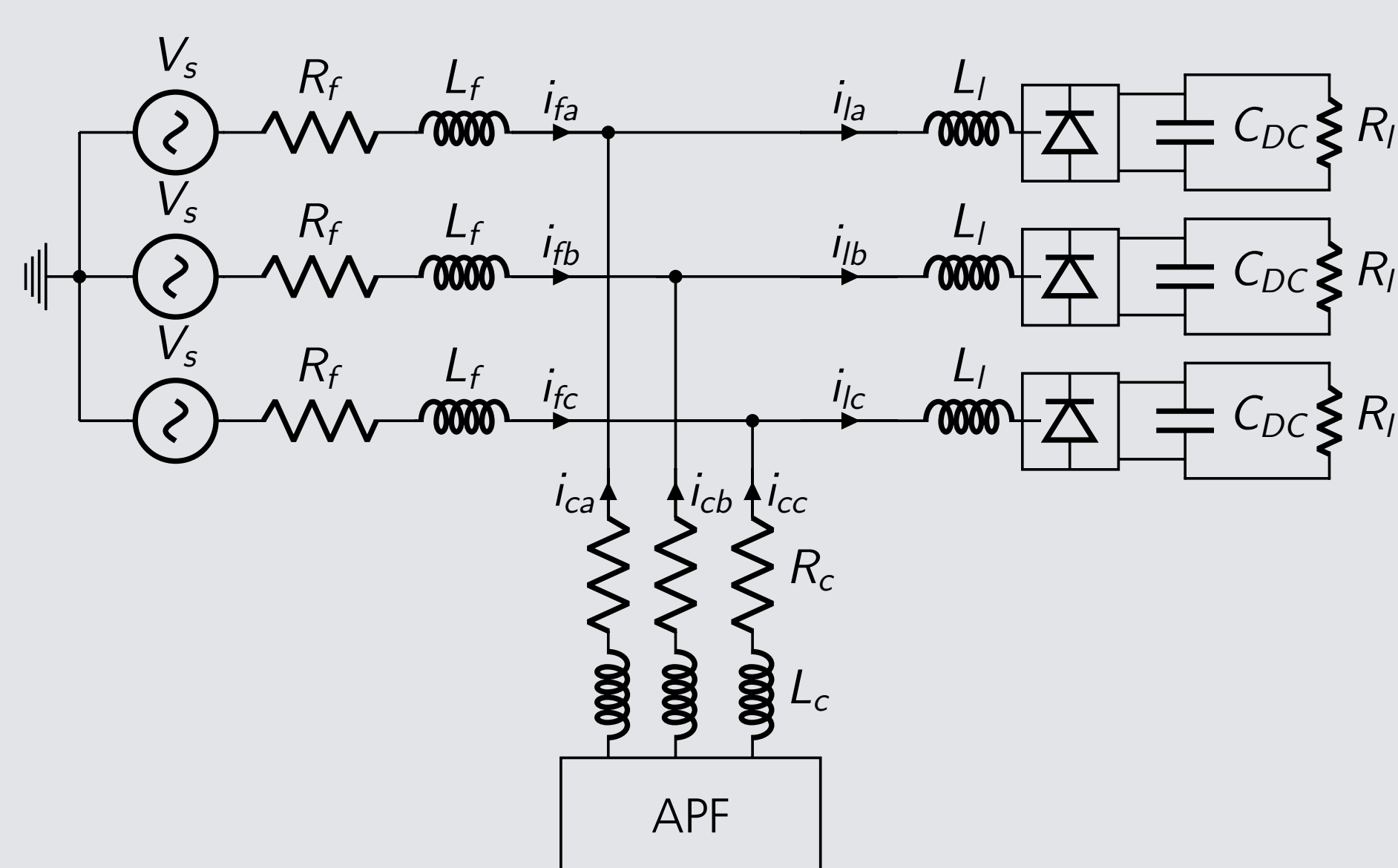
- Could the LS³MPC improve the grid quality compared to a classic IRP APF controller?
- A simulation is set up to evaluate both controller types under different load scenarios

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 the grid

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t) + \mathbf{E}\mathbf{d}(t)$$

where

$$\mathbf{x}(t) = \left(v_l \quad \frac{di_c}{dt} \quad \frac{di_l}{dt} \right)^T \in \mathbb{R}^3 \quad \mathbf{u}(t) = \frac{d^2 i_c}{dt^2}$$

and

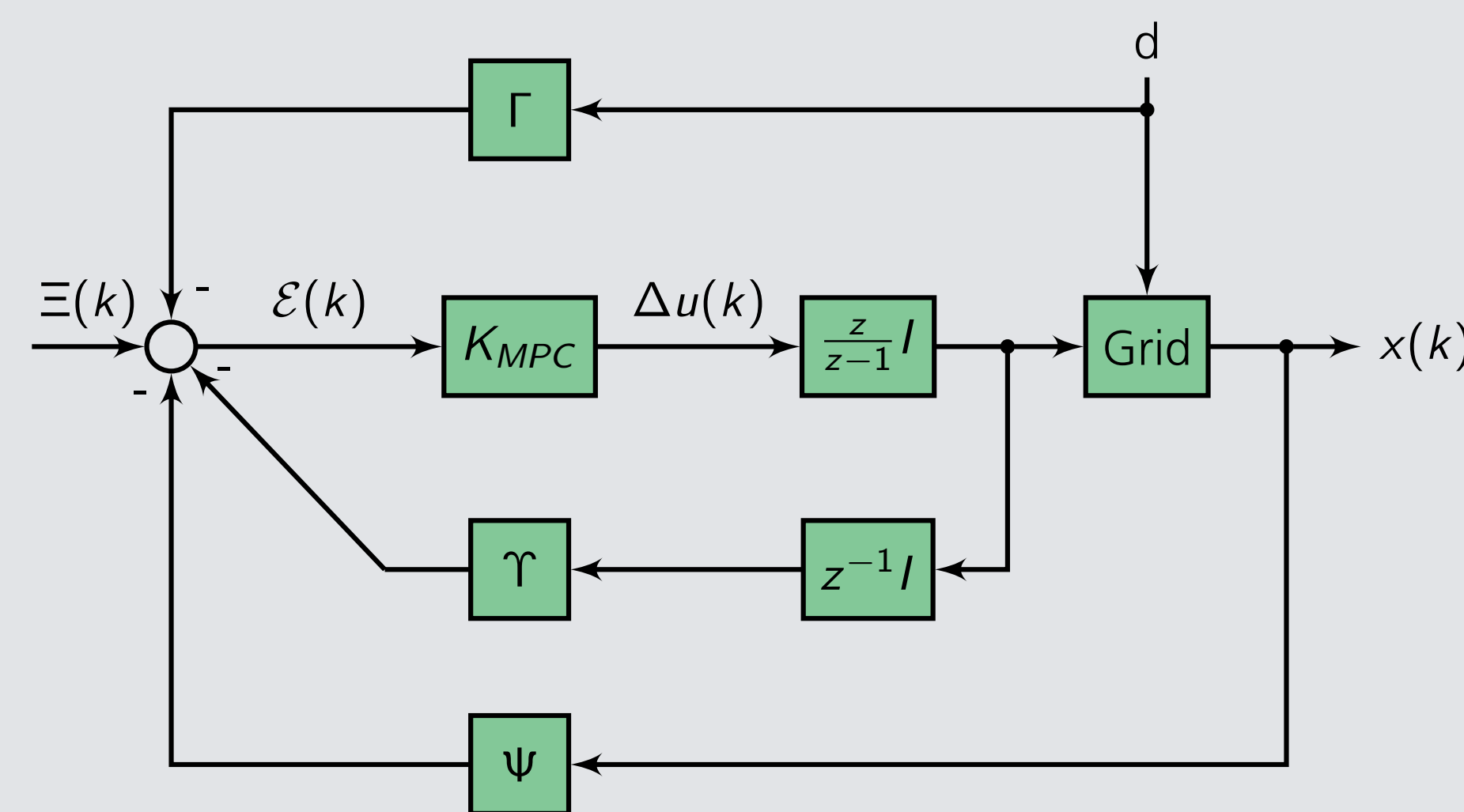
$$\mathbf{A} \in \mathbb{R}^{3 \times 3}, \quad \mathbf{B} \in \mathbb{R}^{3 \times 1}, \quad \mathbf{E} \in \mathbb{R}^{3 \times 1}.$$

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

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

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*³ \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

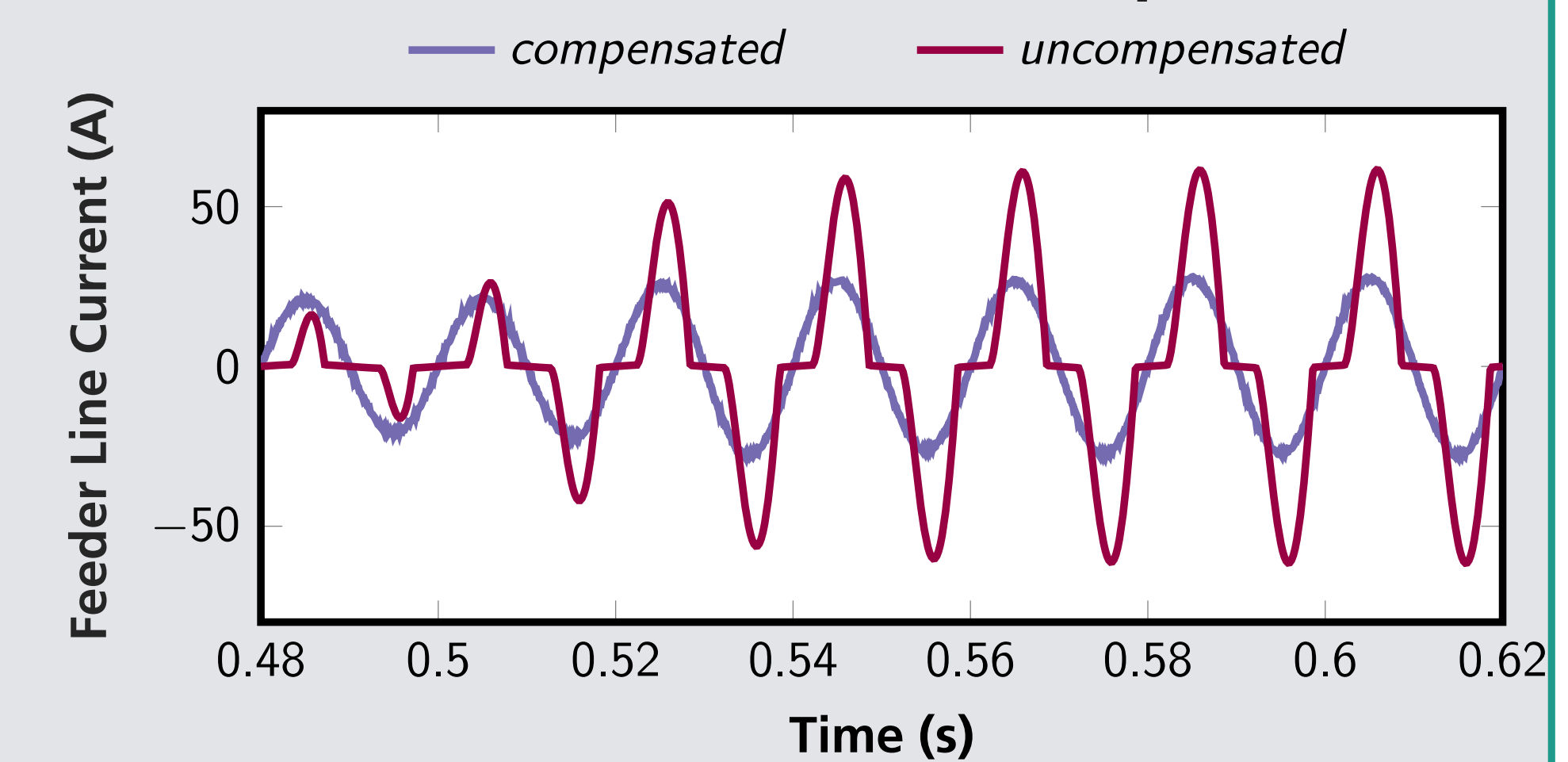
$$\mathbf{X}(k) = \begin{pmatrix} x(k-1) & x(k) & x(k+1) \end{pmatrix}^T,$$

for all times k .

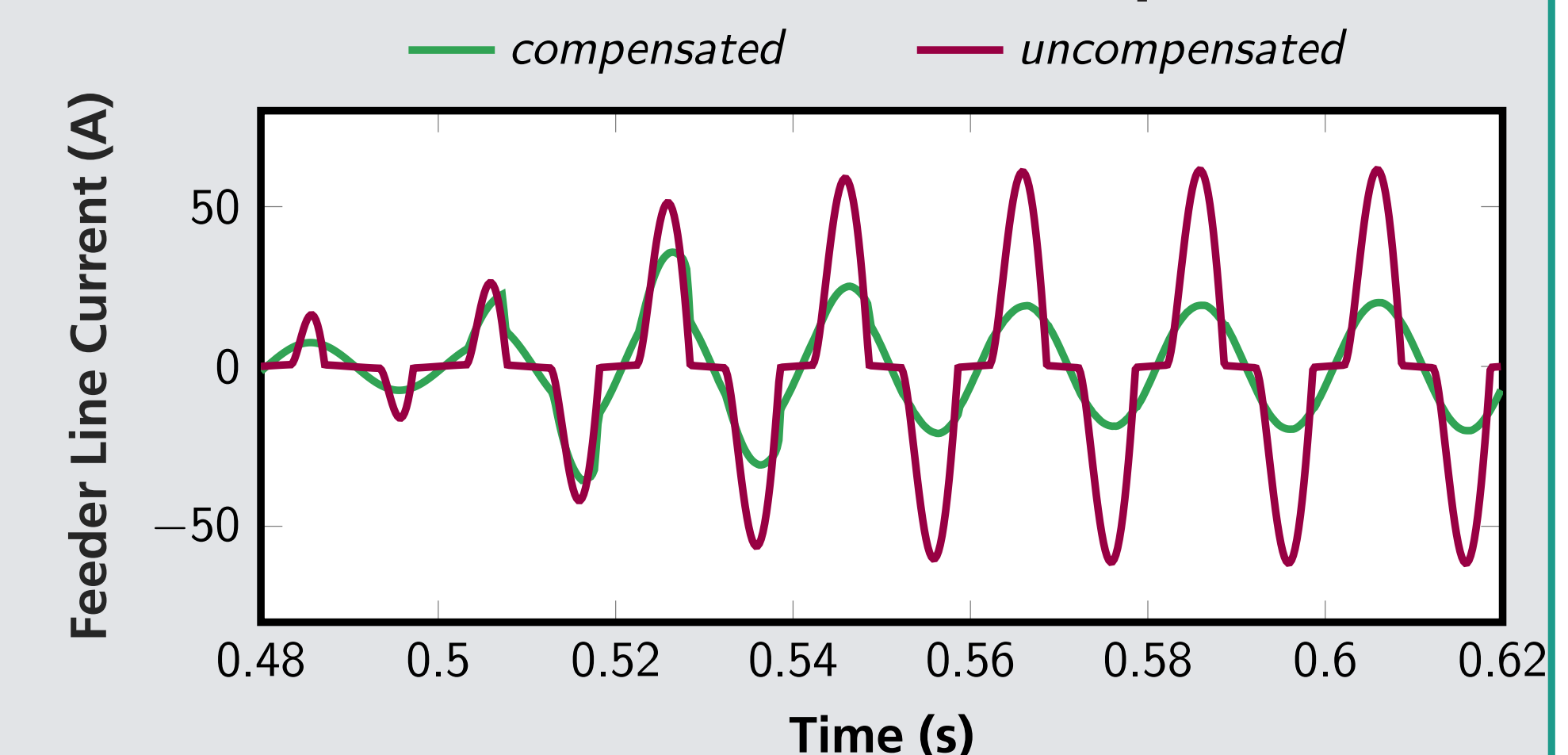
³Cateriano Yáñez, C., Pangalos, G., and Lichtenberg, G. (2018). An approach to linear state signal shaping by quadratic model predictive control. In *European Control Conference (ECC) 2018*

SIMULATION STUDIES

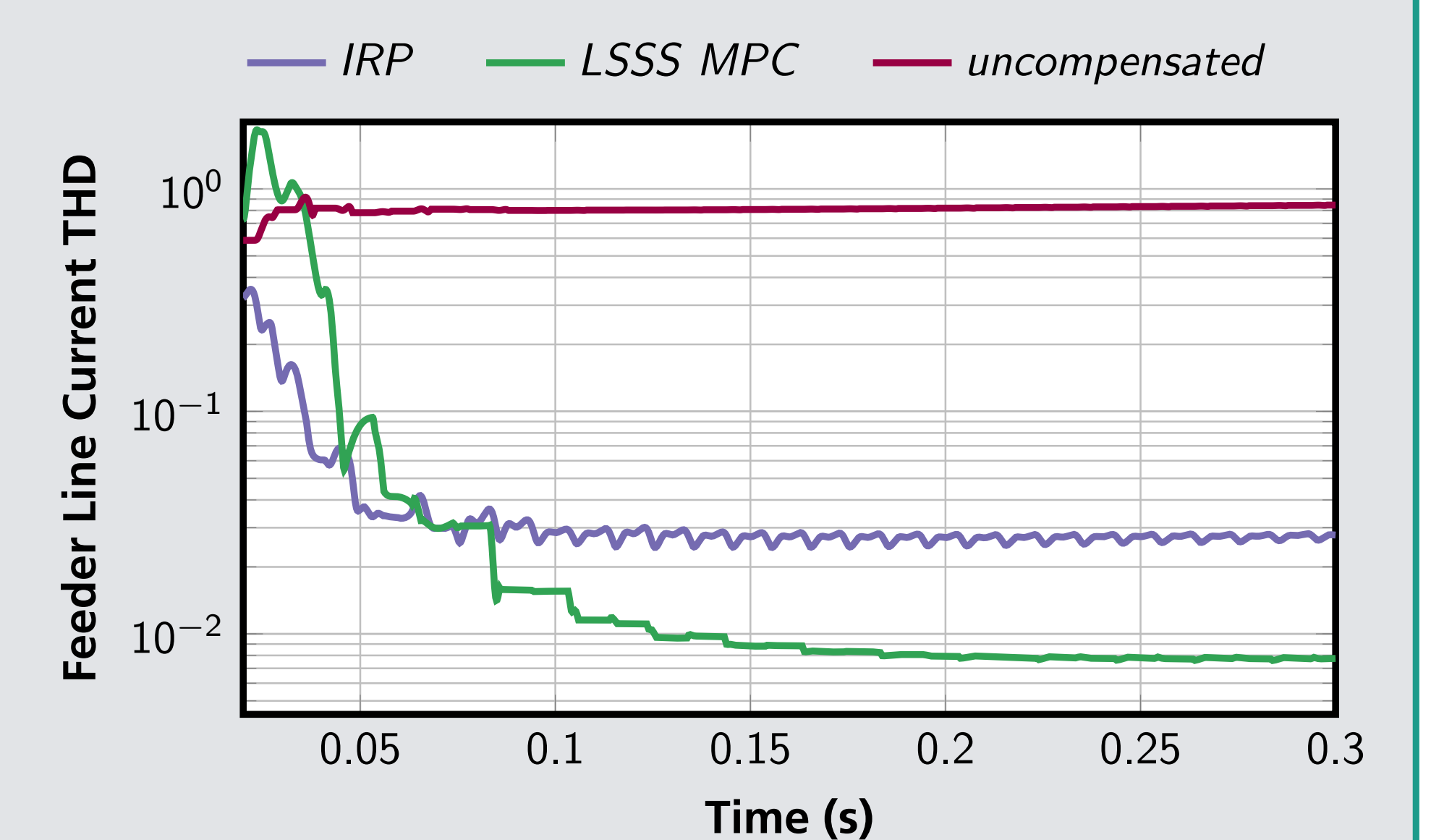
IRP APF harmonic current compensation:



LS³MPC harmonic current compensation:



Total harmonic distortion (THD):



Results for different load scenarios:

Load scenario	THD (v_f)		THD (i_f)	
	IRP	LS ³ MPC	IRP	LS ³ MPC
100 Ω	0.65%	0.17%	4.35%	0.78%
9 Ω	0.45%	0.35%	0.75%	1.57%
2 Ω	1.15%	0.35%	3.75%	1.33%

CONCLUSION

- The LS³MPC can successfully improve the THD compensation of an APF
- Classic IRP rely on high pass filter design for a given load scenario, while LS³MPC can inherently adapt to a wider variety
- Current research on LS³MPC focuses on enabling reactive power compensation