

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

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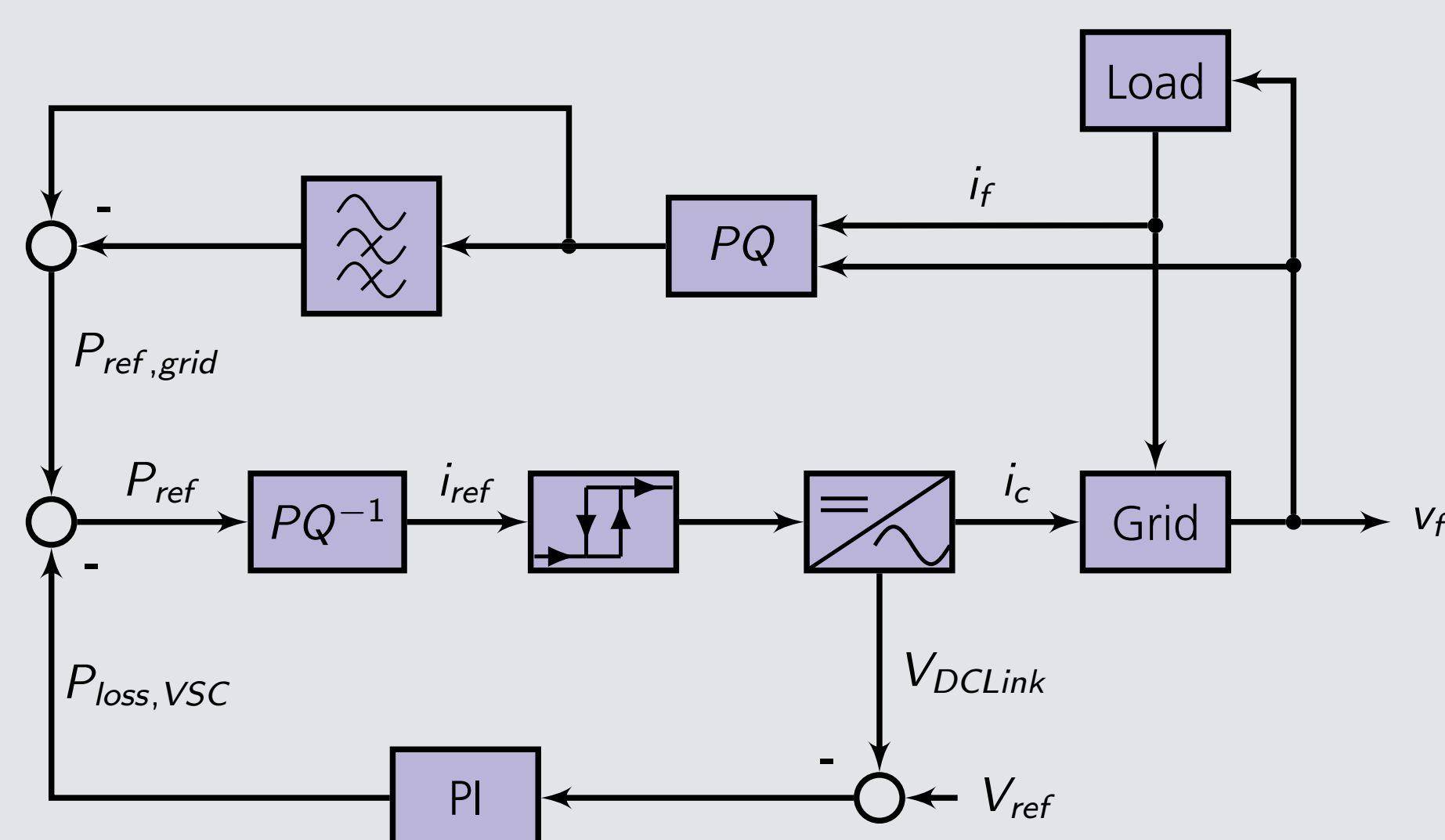
INTRODUCTION

- 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 classic well-tested method to compensate harmonics relies on the instantaneous reference frame (IRP) theory
- A novel approach: “Linear State Signal Shaping Model Predictive Control” (LSSS MPC), could be utilized to compensate harmonics using shape classes, without the need to design filters for different load scenarios

APPLICATION PROBLEM

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

CLASSIC IRP CONTROLLER



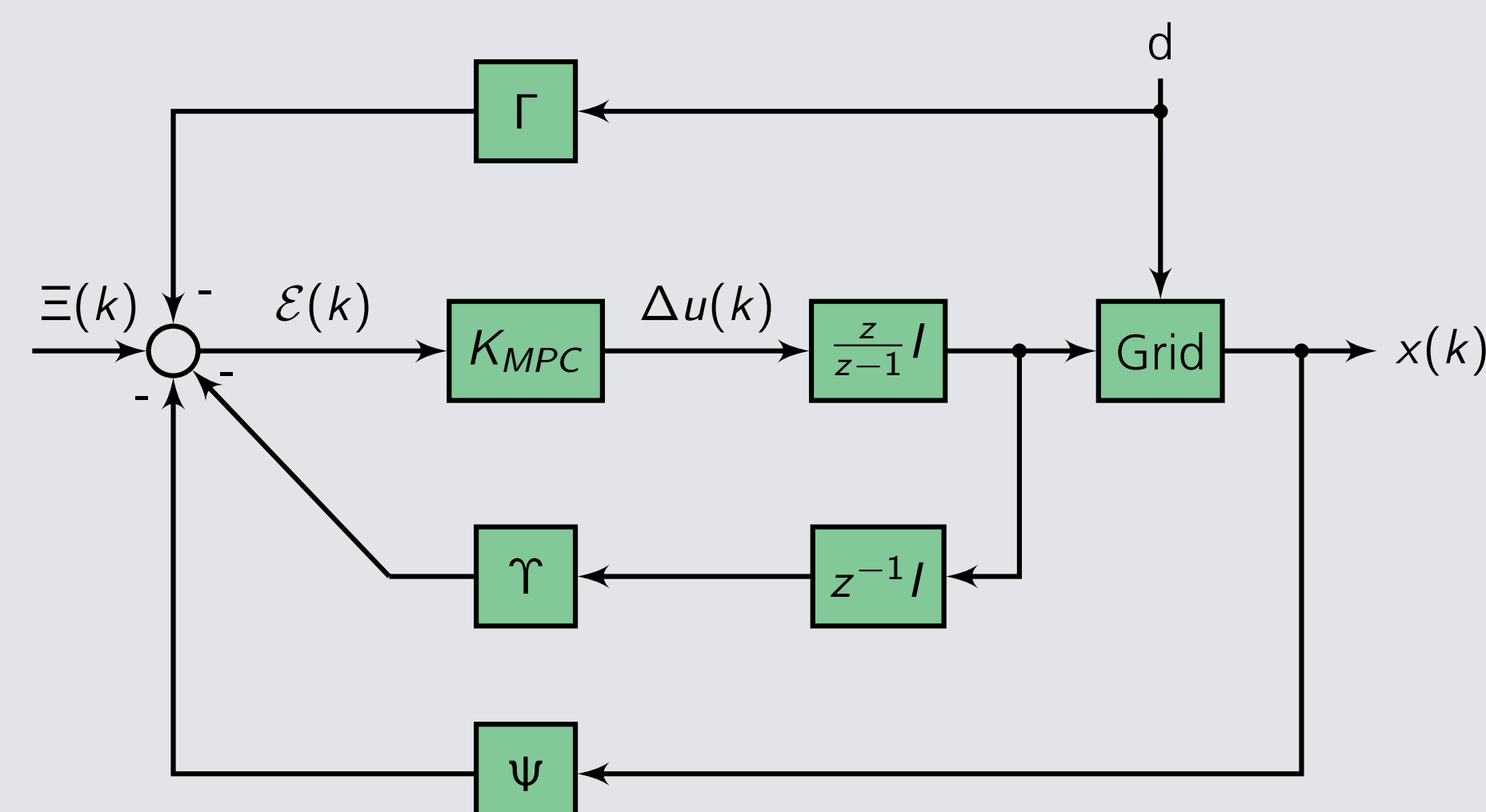
- Clarke and p-q transformation are used
- A high pass filter extracts harmonics
- A hysteresis band controller steers the voltage source converter

PREDICTIVE CONTROLLER

The MPC minimizes the cost function

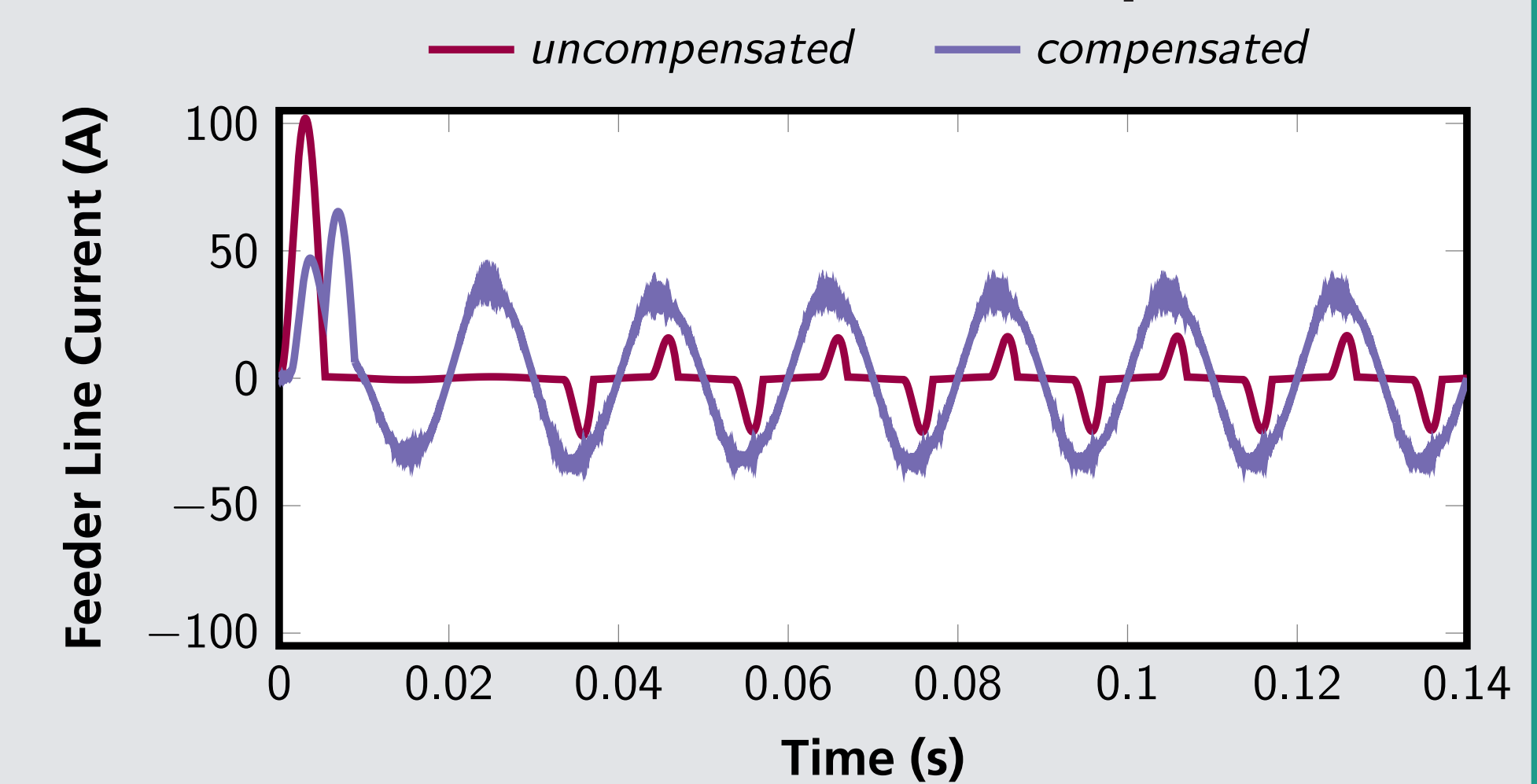
$$J = \|\mathbf{X}(k) - \Xi(k)\|_Q^2 + \|\mathbf{U}(k)\|_R^2.$$

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

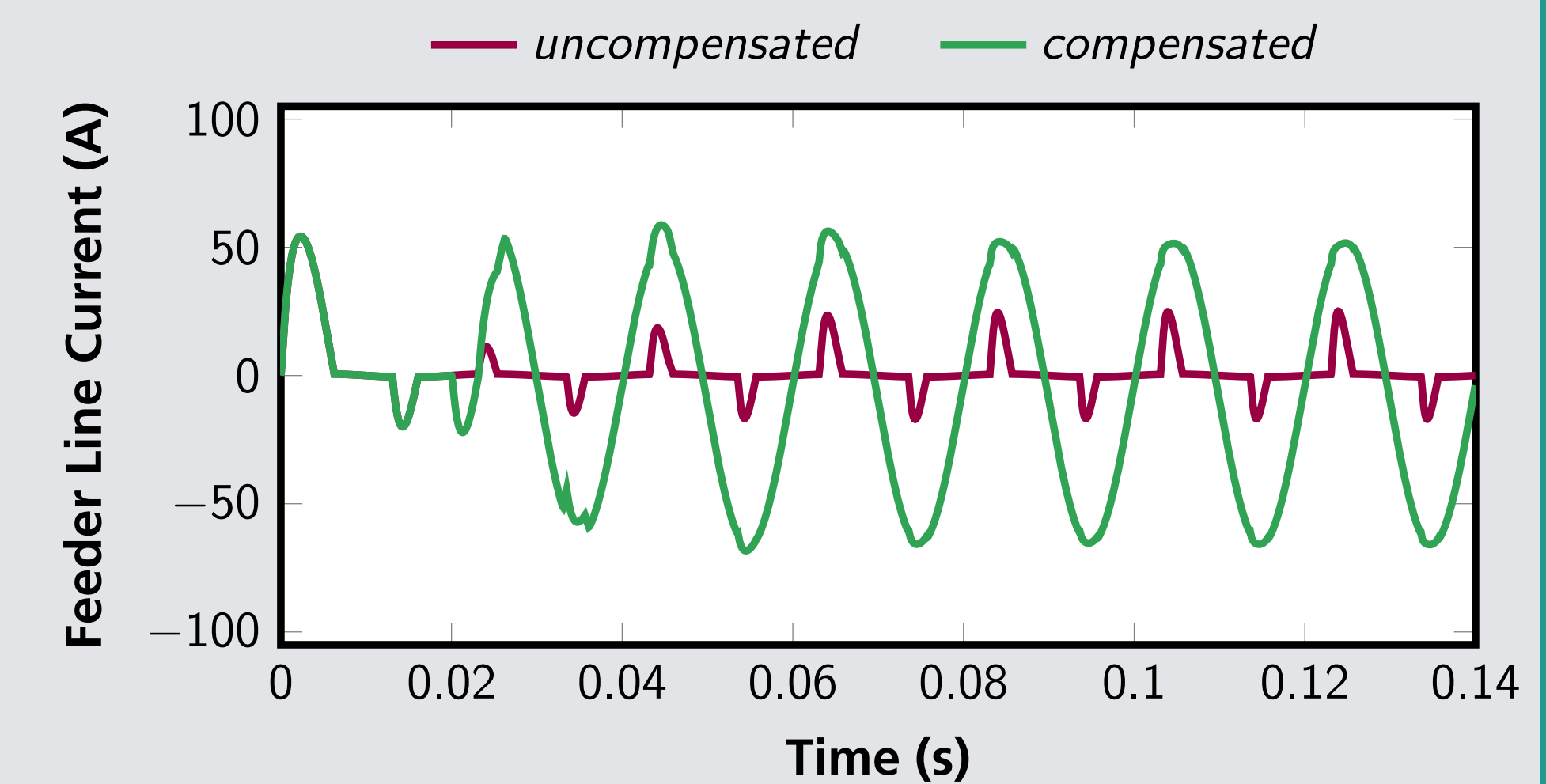


SIMULATION STUDIES

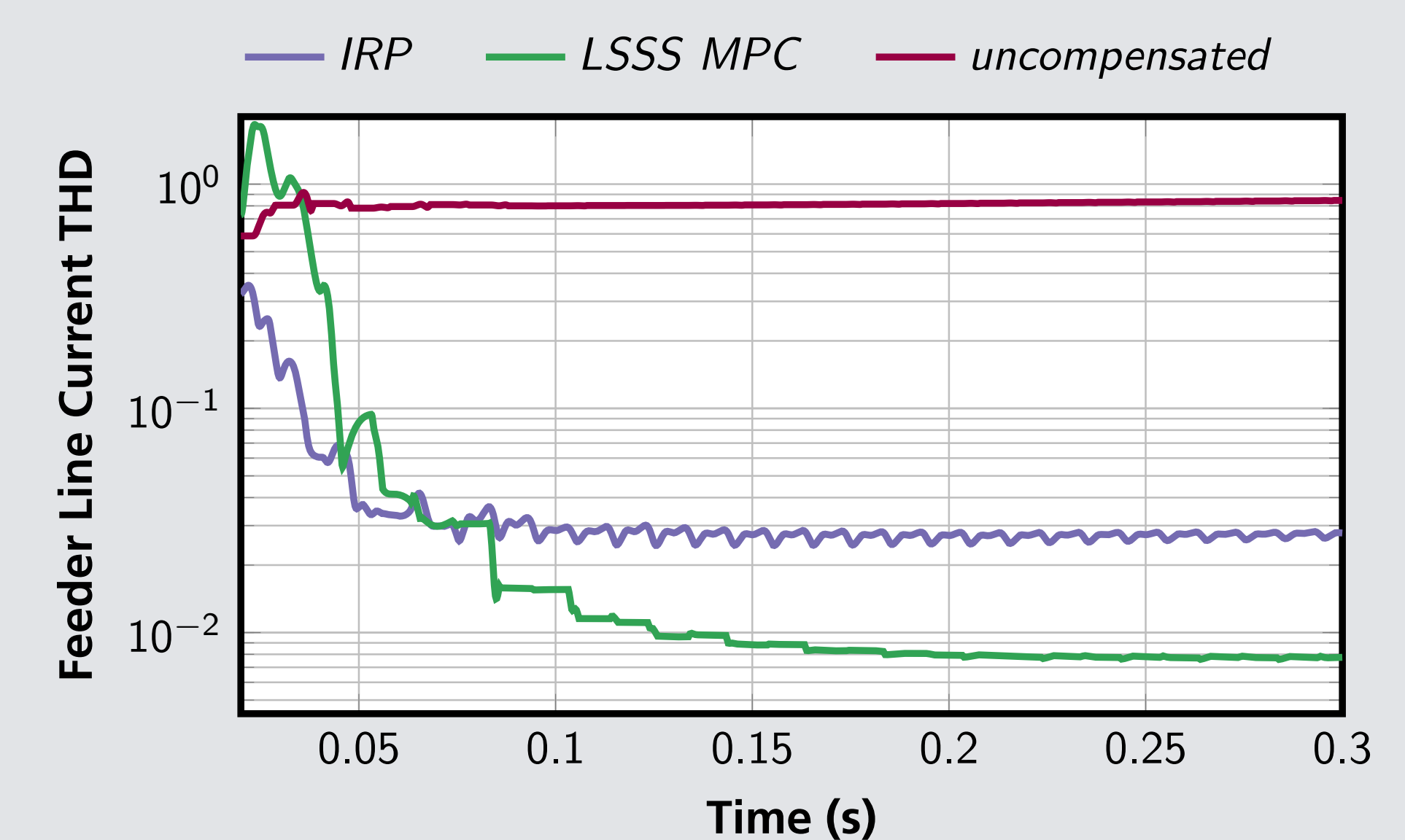
IRP APF harmonic current compensation:



LSSS MPC harmonic current compensation:



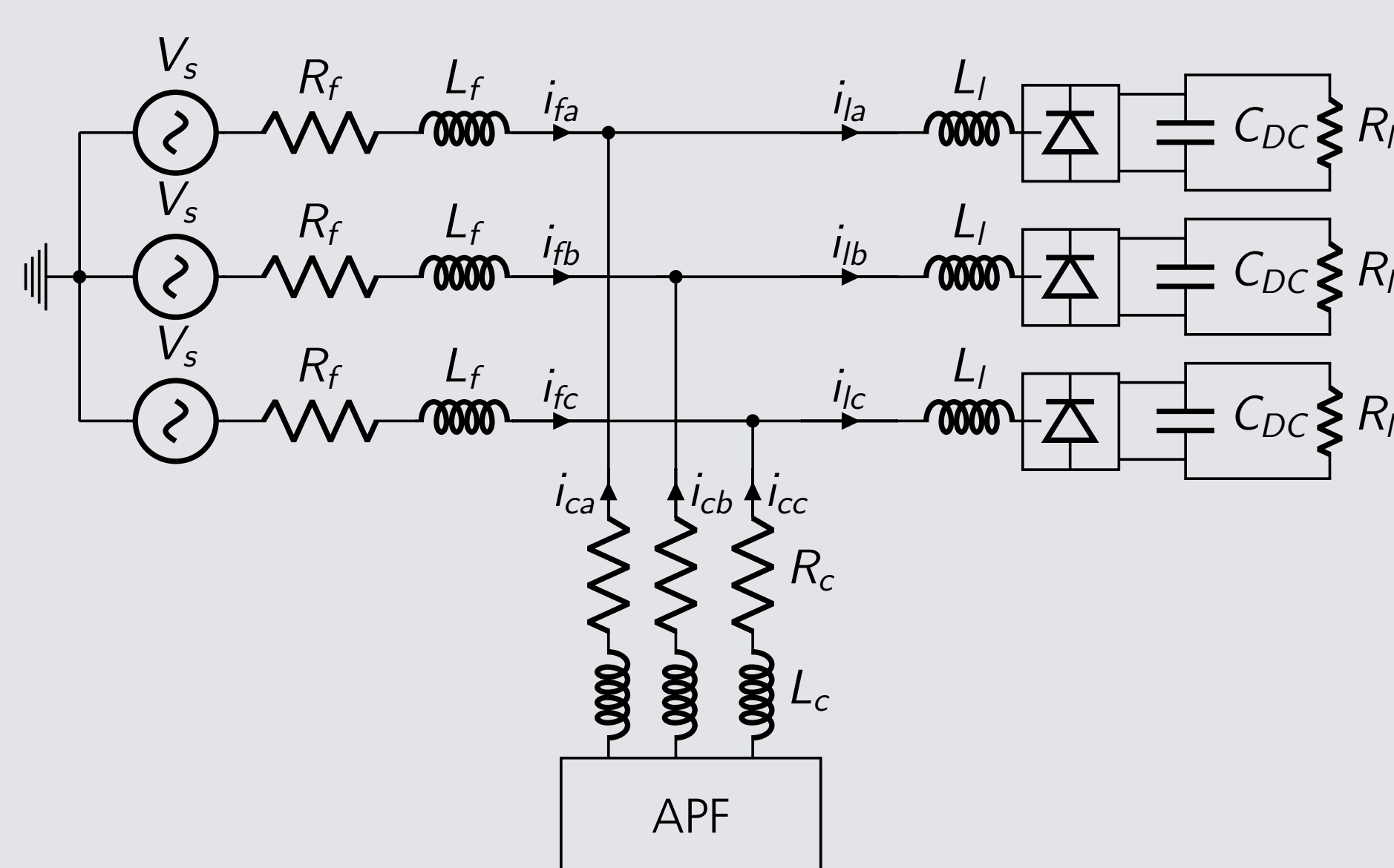
Total harmonic distortion (THD):



Results for different load scenarios:

Load scenario	THD (v_f)		THD (i_f)	
	IRP	MPC	IRP	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%

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

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

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

$$\frac{(2 + \omega^2 t_s^2)x(k) - 5x(k+1) + 4x(k+2) - x(k+3)}{t_s^2} = 0.$$

From this difference equation the *linear shape class*³ \mathbf{V} is given as

$$\mathbf{V} = \begin{pmatrix} 2 + (\omega t_s)^2 & 5 & 4 & -1 \end{pmatrix} \in \mathbb{R}^{1 \times 4}.$$

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

$$\mathbf{x}(k) = \begin{pmatrix} x(k) & x(k+1) & x(k+2) & x(k+3) \end{pmatrix}^T,$$

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*

CONCLUSION

- The LSSS MPC approach has the potential to successfully control an APF
- Classic IRP controllers rely on high pass filter design to achieve good compensation results in a given load scenario
- The LSSS MPC is capable of adapting to a wider variety of load scenarios