



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

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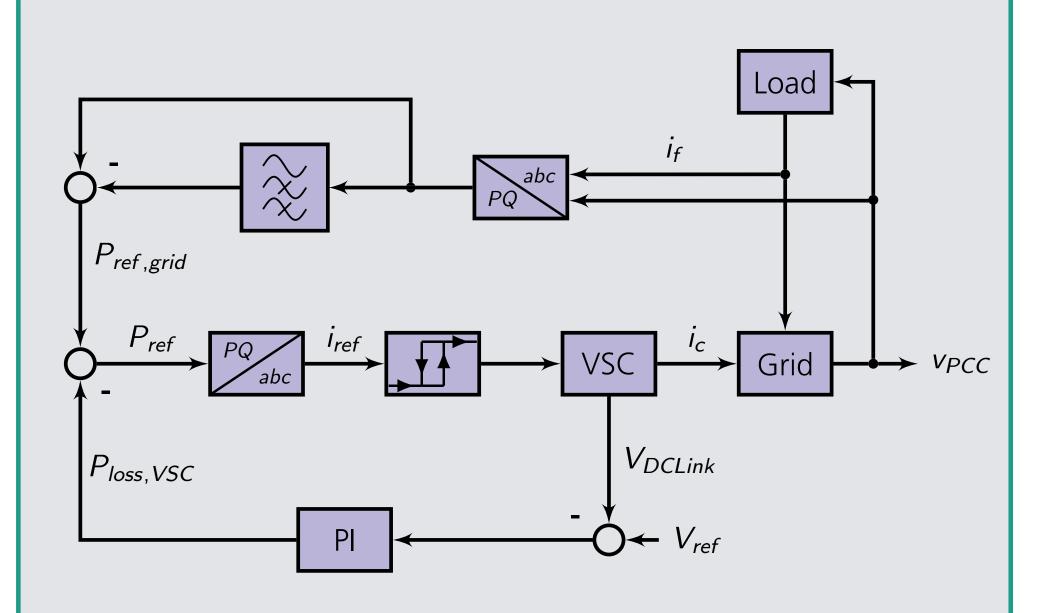
#### INTRODUCTION

- 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 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



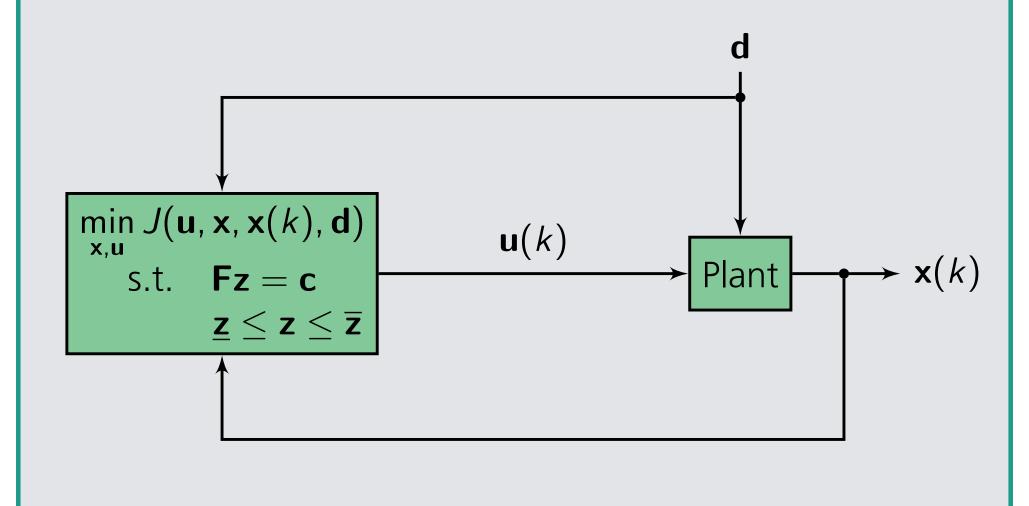
- Clarke and p-q transformation are used
- A high pass filter extracts harmonics
- A hysteresis band controller steers the voltage source converter

# PREDICTIVE CONTROLLER

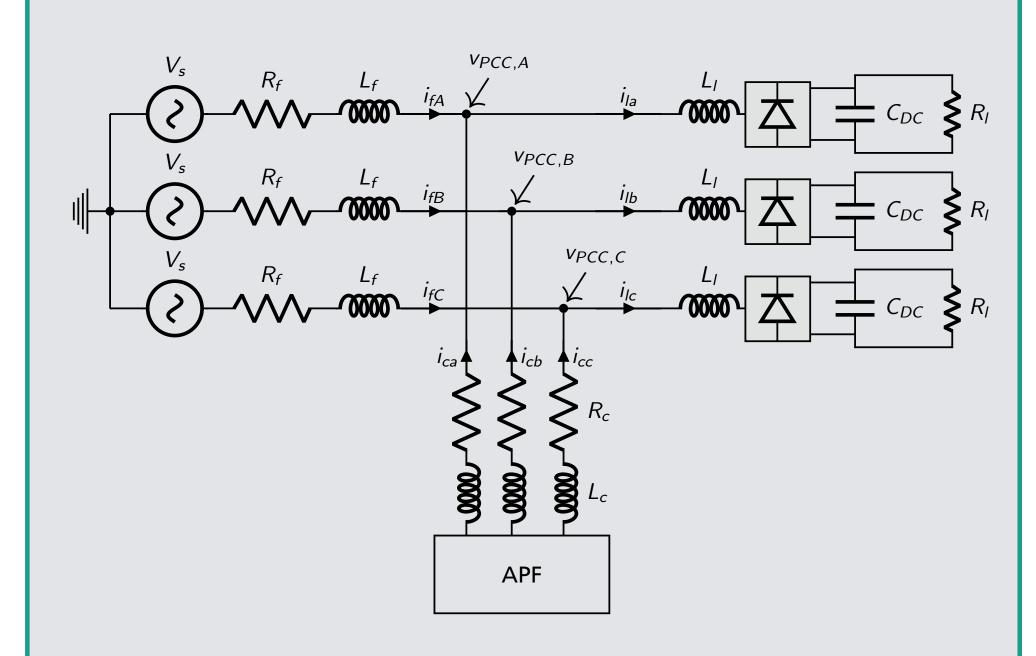
The MPC minimizes the cost function

$$J = \|\mathbf{X}(k) - \Xi(k)\|_{\mathbf{Q}}^{2} + \|\mathbf{U}(k)\|_{\mathbf{R}}^{2}.$$

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



## 3-PHASE GRID MODEL



Active power filter in shunt configuration

# LINEAR SHAPE CLASS

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

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

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> V is given as

$$\mathbf{V}=\left(\begin{array}{ccc}1&(\omega t_s)^2-2&1\end{array}
ight)\in\mathbb{R}^{1 imes 3}$$
 .

The state error weight matrix Q is built using V by transferring the control goal to the optimization problem

$$\min_{\mathbf{X}(k)} (\mathbf{VX}(k))^2$$
,

where

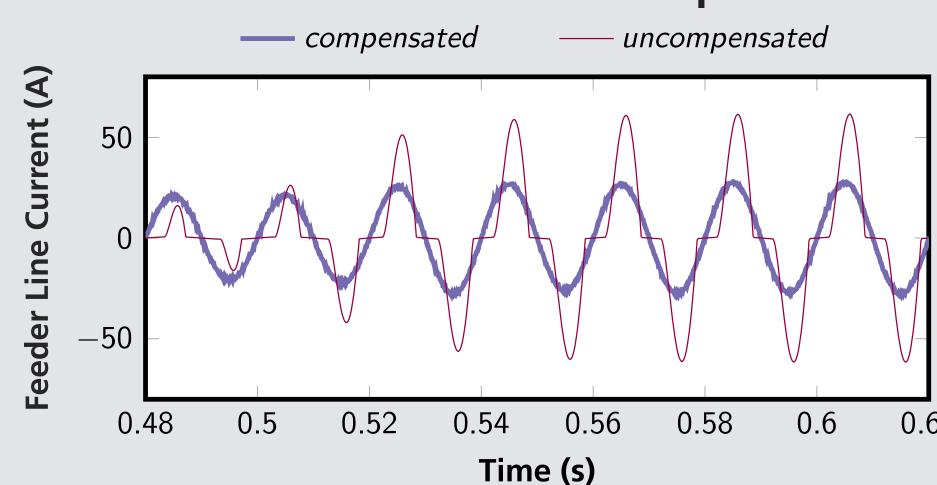
$$\mathbf{X}(k) = \begin{pmatrix} x(k-1) & x(k) & x(k+1) \end{pmatrix}^{\mathsf{T}},$$

for all times k.

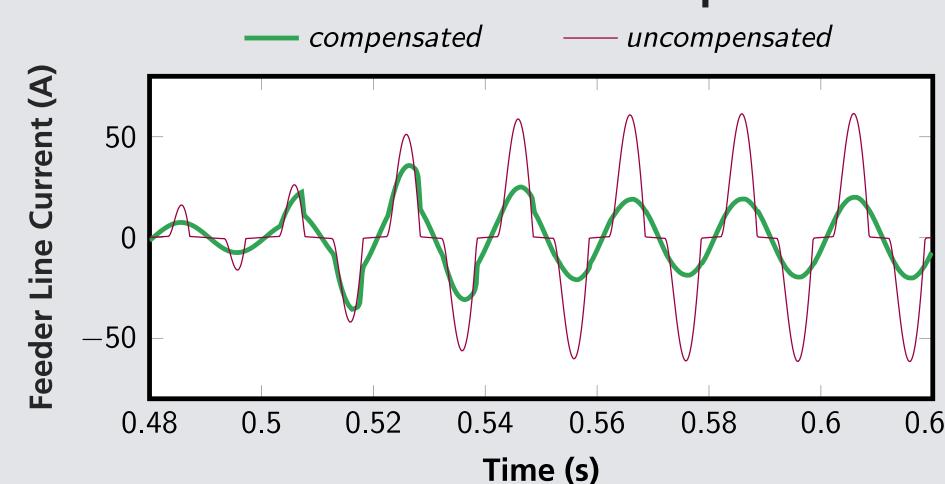
<sup>3</sup>Cateriano Yáñez, C., Pangalos, G., and Lichtenberg, G. (2018). An approach to linear state signal shaping by quadratic model predictive control. In European Control Conference (ECC) 2018

# SIMULATION STUDIES

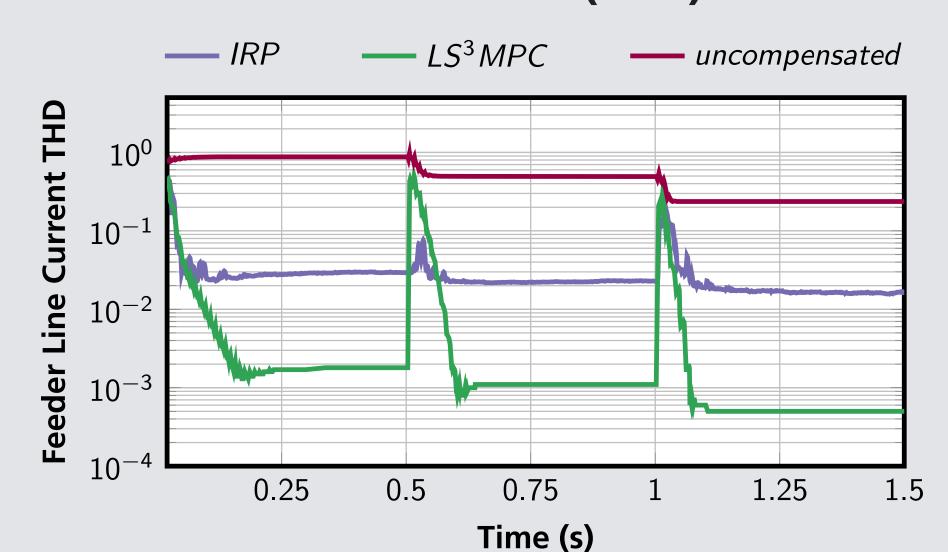
IRP APF harmonic current compensation:



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



#### **Total harmonic distortion (THD):**



Results for different load scenarios:

Load	THD (VPCC)		THD (i <sub>f</sub> )	
scenario	IRP	LS <sup>3</sup> MPC	IRP	LS <sup>3</sup> MPC
100 Ω	1.07%	0.01%	6.68%	0.18%
9Ω	0.75%	0.02%	2.72%	0.11%
2Ω	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





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

where

$$\mathbf{x}(t) = \begin{pmatrix} i_f \\ i_c \end{pmatrix} \in \mathbb{R}^2 \quad \begin{array}{l} u(t) = i_{c0} \in \mathbb{R} \\ d(t) = \begin{pmatrix} v_s i_{l0} \end{pmatrix}^{\mathsf{T}} \in \mathbb{R}^2 \end{array}$$

and

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