



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

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MOTIVATION

- 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

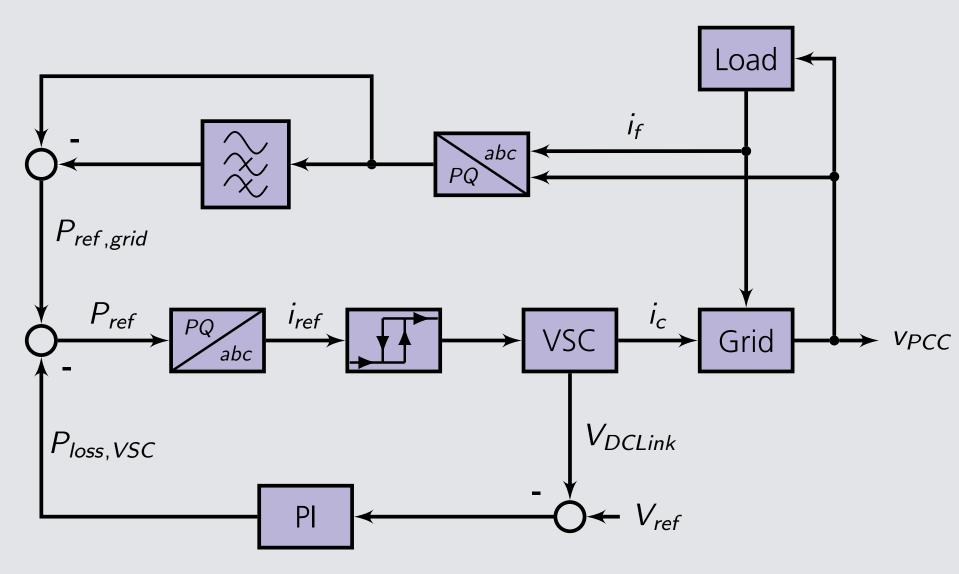
APPLICATION PROBLEM

A novel approach: "Linear State Signal Shaping Model Predictive Control" (LS³MPC), to compensate harmonics using shape classes has been developed

- Could the LS³MPC improve the grid quality compared to a classic APF controller?
- Could the LS³MPC adapt under variable load scenarios?

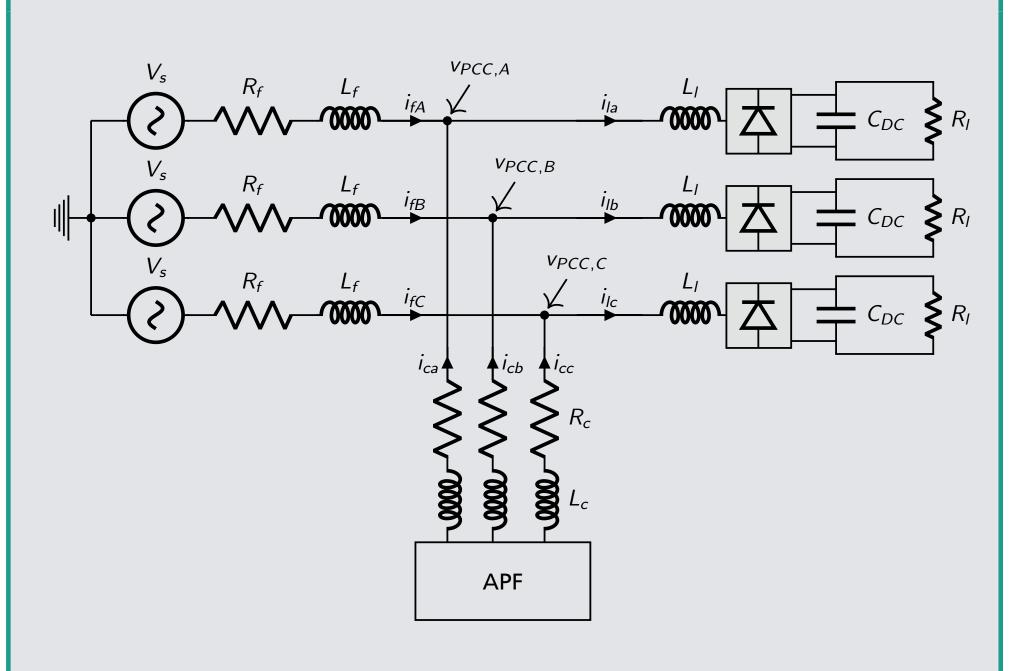
CLASSIC IRP CONTROLLER

A state-of-the-art classic APF controller to compensate harmonics relies on the instantaneous reactive power (IRP) theory



- 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

$$x(k+1) = Ax(k) + Bu(k) + Ed(k)$$

where

$$\mathbf{x}(k) = \begin{pmatrix} i_f \\ i_c \end{pmatrix} \in \mathbb{R}^2 \qquad \mathbf{u}(k) = i_{c0} \in \mathbb{R}$$

$$\mathbf{d}(k) = \begin{pmatrix} v_s i_{l0} \end{pmatrix}^{\mathsf{T}} \in \mathbb{R}^2$$

and

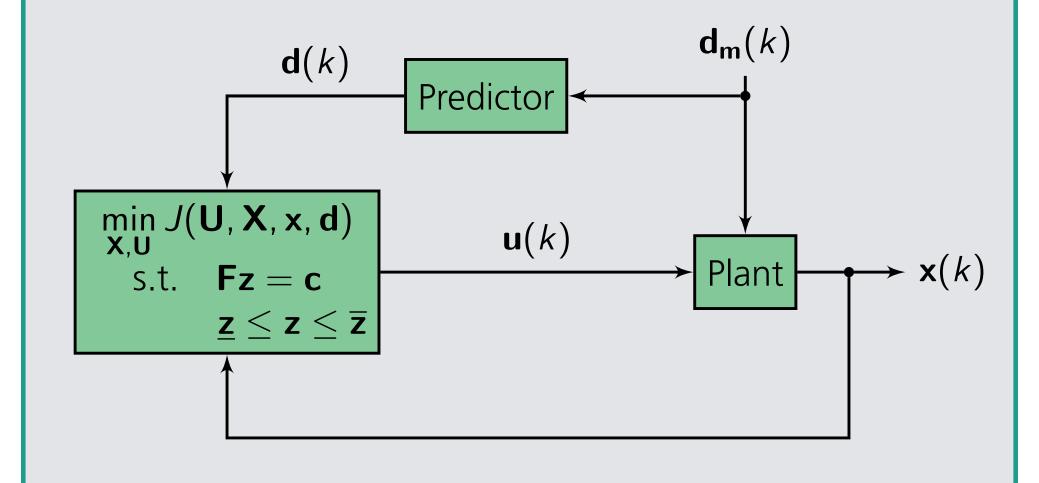
 $\mathbf{A} \in \mathbb{R}^{2 \times 2}$, $\mathbf{B} \in \mathbb{R}^{2 \times 1}$, $\mathbf{E} \in \mathbb{R}^{2 \times 2}$.

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:



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 class³ V is given as

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

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

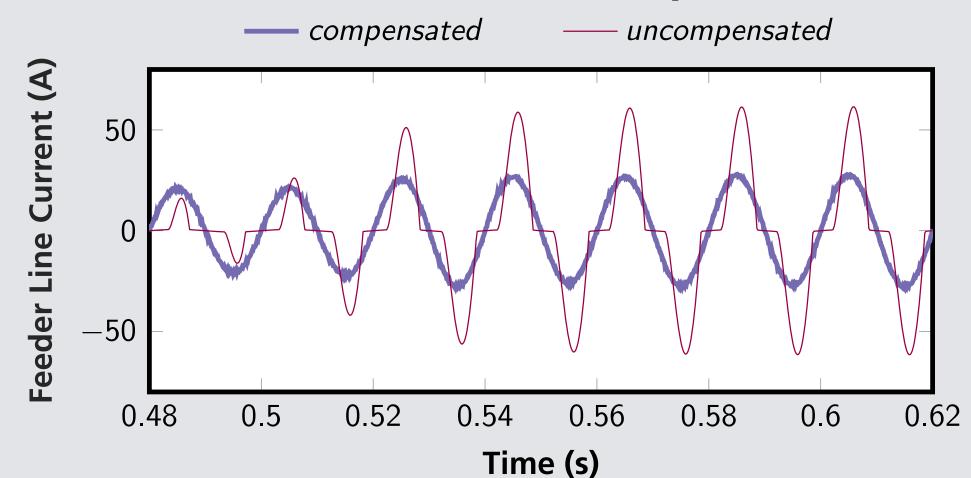
$$\mathbf{X}(k) = \begin{pmatrix} x(k-1) & x(k) & x(k+1) \end{pmatrix}^{\mathsf{T}},$$

for all times k.

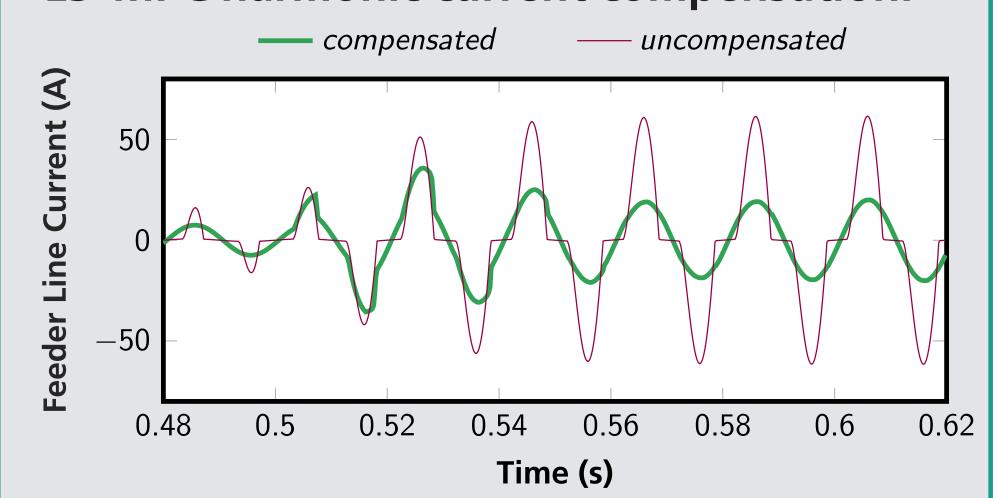
³Cateriano Yáñez, C., Pangalos, G., and Lichtenberg, G. (2018). An approach to linear state signal shaping by quadratic model predictive control. In *European Control Conference (ECC) 2018*

SIMULATION STUDIES

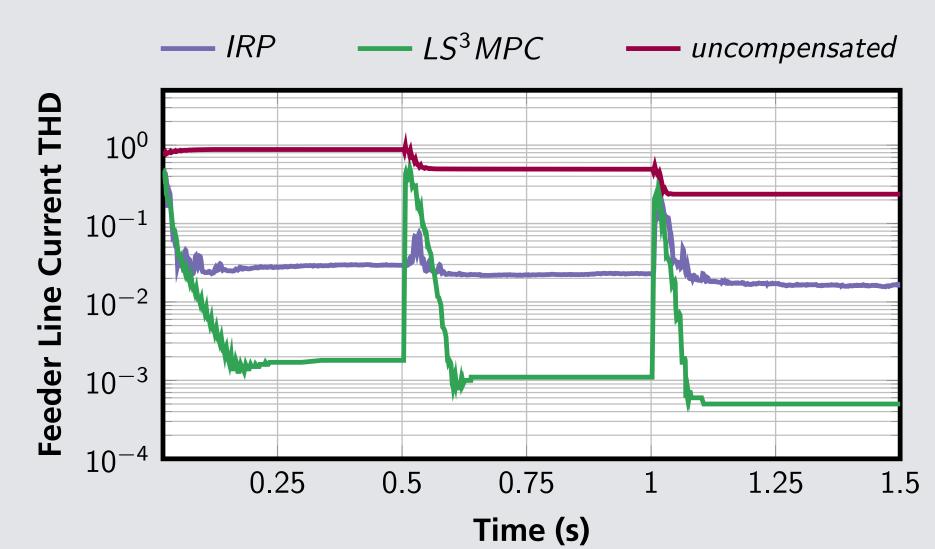
IRP APF harmonic current compensation:



LS³MPC harmonic current compensation:



Total harmonic distortion (THD):



Results for different load scenarios:

Load	THD (VPCC)		THD (<i>i</i> _f)	
scenario	IRP	LS ³ MPC	IRP	LS ³ 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 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