LAAS Days
Research & Technology

# Hybrid control for power converters

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# Energy efficiency in converters

Why are power converters important?

Relevant issues in converters:

> High efficiency:
- economic and environmental value of wasted,
- cost of dissipated energy,
- improved profitability of the investment in electronic market.

> Reliability of the power converters: high useful life.

... **thus, automatic control presents a special relevance.**

# Energy efficiency in converters

## Control objectives

- To design efficient control methodologies for a wide class of electronic converters.
- To guarantee an efficient energy conversion.
- To reduce energy dissipation.

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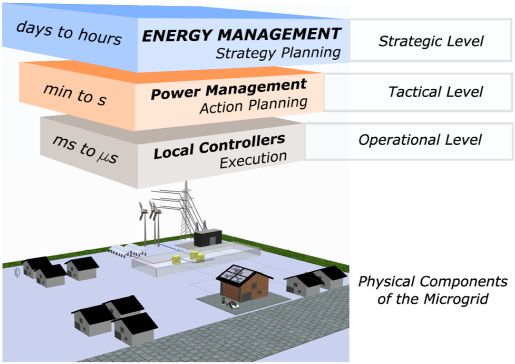
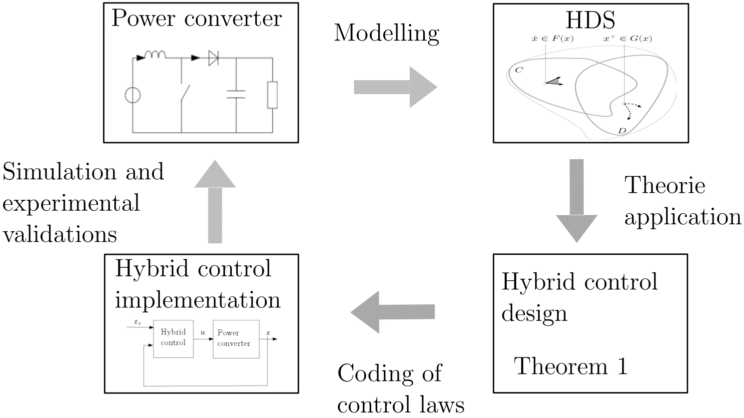
## Hierarchical control in microgrid



# Methodology

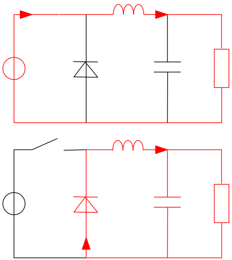


# Power converters

Buck converter

Switch on
(u=1)

Switch off
(u=0)



| Dynamic | Converter |
|---|---|
| Continuous | voltage, current |
| Discrete | switching signal |

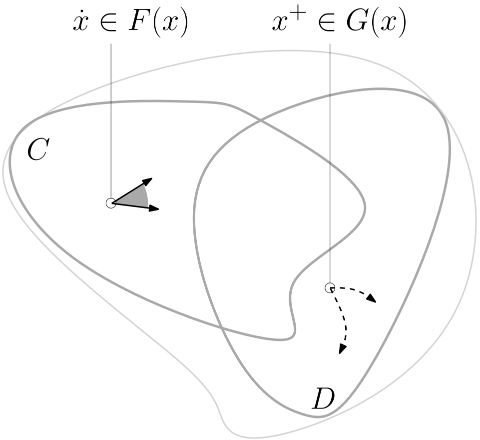
- Many works with averaging procedure: [Sira-Ramirez et al. Springer Science & Business Media, 06], [Foryth et al. IET98], [Olaya et al. IET10], [Tse et al. IEEE TPE92].
- Hybrid control techniques: [Mariéthoz et al. IEEE TAC10], [Geromel et al. IEEE TAC08], [Hetel et al. IEEE TAC 3] [Theunisse et al. TCASI15]

# Hybrid Dynamical Systems

$\mathcal{H} = (\mathcal{C}, \mathcal{D}, F, G)$

- $n \in \mathbb{N}$ (state dimension)
- $\mathcal{C} \subseteq \mathbb{R}^n$ (flow set)
- $\mathcal{D} \subseteq \mathbb{R}^n$ (jump set)
- $F : \mathcal{C} \rightrightarrows \mathbb{R}^n$ (flow map)
- $G : \mathcal{D} \rightrightarrows \mathbb{R}^n$ (jump map)

$$\mathcal{H} : \begin{cases} \dot{x} \in F(x), & x \in \mathcal{C} \\ x^+ \in G(x), & x \in \mathcal{D} \end{cases}$$



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# Hybrid control design

## Theorem 1

Consider $\eta \in (0,1)$ and matrices $P > 0 \in \mathbb{R}^{n\times n}$ and $Q > 0 \in \mathbb{R}^{n\times n}$, satisfying
$A_i^T P + PA_i + 2Q < 0, \qquad \forall i \in \mathbb{K}.$
Then attractor $\mathcal{A} := \{(x,u) : x = x_e, u \in \mathbb{K}\}$ is uniformly globally asymptotically stable (UGAS) for hybrid system

$$\mathcal{H}: \begin{cases} (\text{FLOW}) \begin{bmatrix} \dot{x} \\ \dot{u} \end{bmatrix} = \begin{bmatrix} A_u x + B_u V_{in} \\ 0 \end{bmatrix} & (x,u) \in \mathcal{C} \\ (\text{JUMP}) \begin{bmatrix} x^+ \\ u^+ \end{bmatrix} \in \begin{bmatrix} x \\ \underset{i\in\mathbb{K}}{\text{argmin}}\,(x - x_e)^T P(A_i x + B_i V_{in}) \end{bmatrix} & (x,u) \in \mathcal{D}, \end{cases} \quad (1)$$

$$\text{where} \quad \mathcal{C} := \{(x,u) : \tilde{x}^T P(A_u x + B_u V_{in}) \le -\eta \tilde{x}^T Q \tilde{x}\} \quad (2)$$

$$\mathcal{D} := \{(x,u) : \tilde{x}^T P(A_u x + B_u V_{in}) \ge -\eta \tilde{x}^T Q \tilde{x}\},. \quad (3)$$

[C. Albea Sanchez et al CDC 2015]..

## Theorem 2

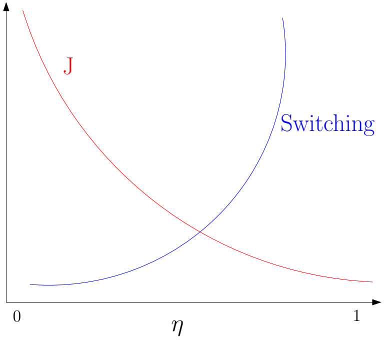
Consider hybrid system. If

$$C_i^T C_i \leq Q, \quad \forall i \in \mathbb{K}, \tag{4}$$

then the following bound holds along any solution $\xi = (x, u) \to \mathbb{R}^n \times \mathbb{K}$ of (1)–(3):

$$J(\xi) \leq \eta^{-1} \tilde{x}(0,0)^T P \tilde{x}(0,0), \tag{5}$$

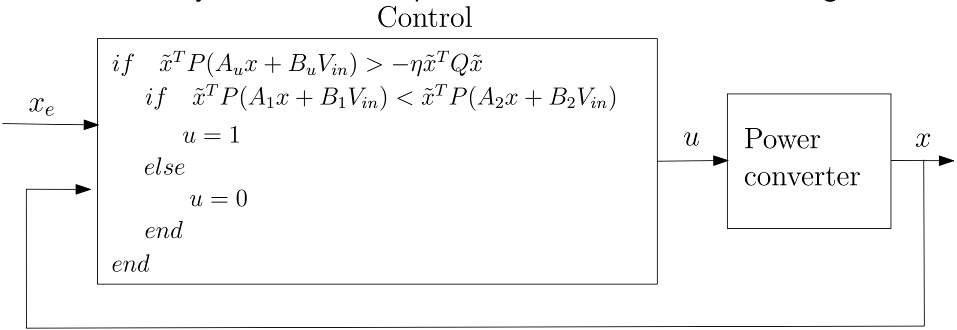
where $\tilde{x}(t,j) = x(t,j) - x_e$.




Switching reduction $\to$ Dissipated energy reduction and increase of the lifespan.

# Hybrid control implementation

Implementation of hybrid control in a power converter with 2 functioning modes.



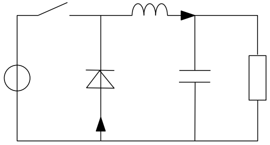

$x = [i_L, v_C]$. $x$ is a vector with the inductance current and capacitance voltage.

# Example of applications

Illustrative examples of the results obtained with the HDS methodology on:

- DC-DC converter: buck and boost
- DC-AC converter: half-bridge

# Buck converter



Desired equilibrium: $x_e = \begin{bmatrix} 0.8 & 40 \end{bmatrix}^T$, $\lambda_e = [0.43 \quad 0.57]$

Th. 1 provides the following control matrix:

$$P = \begin{bmatrix} 0.28 & 0.47 \\ 0.47 & 1.16 \end{bmatrix} \cdot 10^{-2},$$

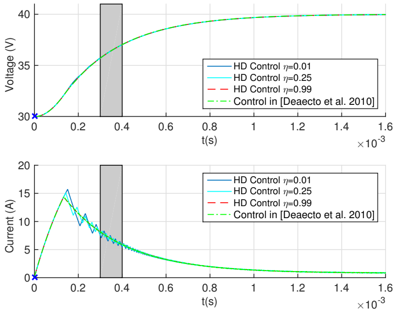



Figure: Voltage and current evolutions.

# Buck converter

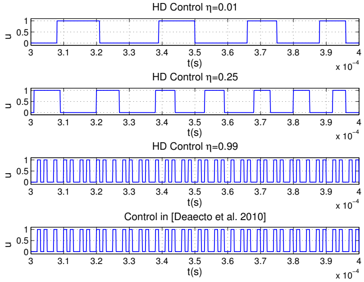



Figure: Zoom of switching controller in the buck converter.

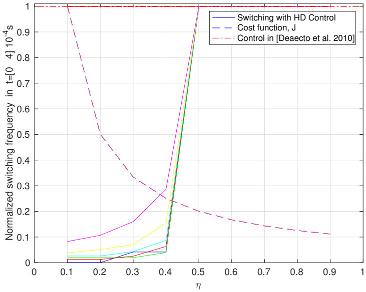
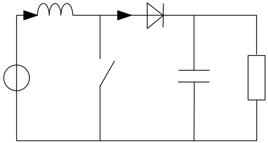



Figure: Evolution of the normalized switching frequency w.r.t. $\eta$ for different initial conditions in the buck converter.

# Boost converter



Desired equilibrium: $x_e = \begin{bmatrix} 3 & 120 \end{bmatrix}^T$,

$\lambda_e = [0.22 \quad 0.78]$

Th. 1 provides the following control matrix:

$$P = \begin{bmatrix} 1.45 & 0.09 \\ 0.09 & 2.48 \end{bmatrix} \cdot 10^{-2}$$

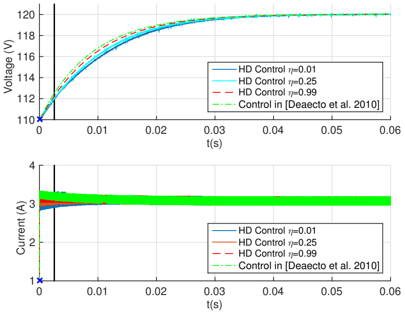



Figure: Voltage and current evolutions.

# Boost converter

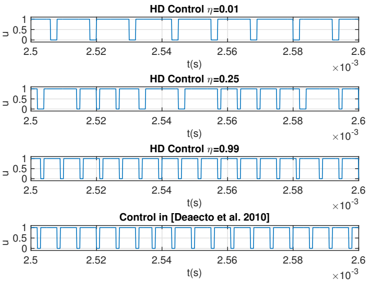



Figure: Zoom of the switching controller in the boost converter.

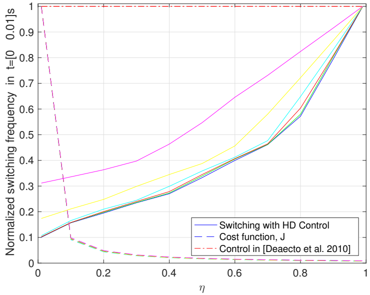
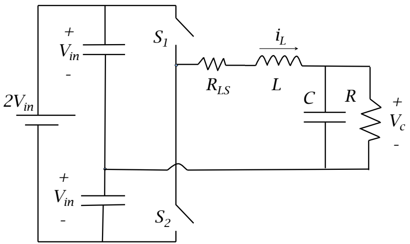


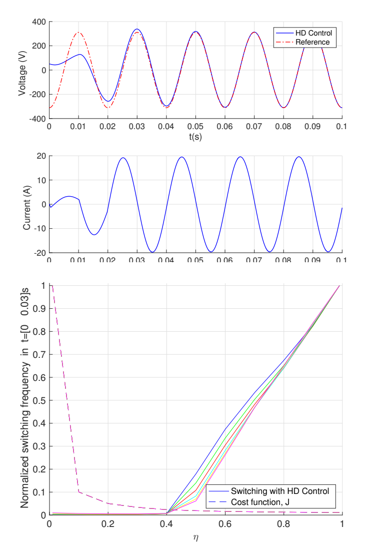

Figure: Evolution of the normalized switching frequency w.r.t. $\eta$ for different initial conditions in the boost converter.

# Half-bridge converter

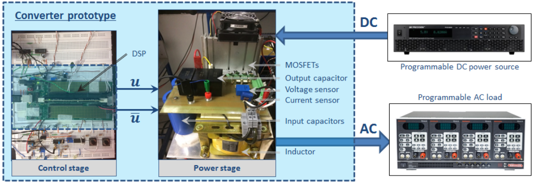


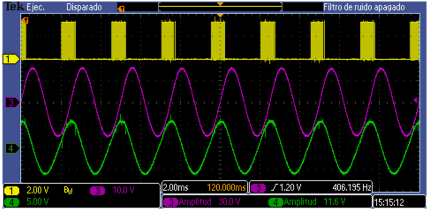

Desired equilibrium: $x_e = \begin{bmatrix} 9\sin(2\pi 60t + 86^\circ) \\ 120\sqrt{(2)}\sin(2\pi 60t) \end{bmatrix}$,
$\lambda_e = [\lambda_1 \quad 1-\lambda_1]$
$\lambda_1 = 0.5 + 0.003\sin(2\pi 60t) + 0.34cos(2\pi 60t)$ Th. 1 provides the following control matrix:

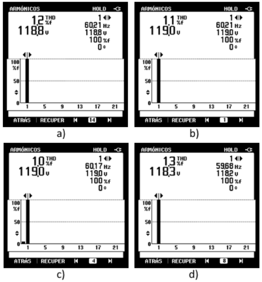
$$P = \begin{bmatrix} 24.71 & 0.1 \\ 0.1 & 0.07 \end{bmatrix} \cdot 10^{-2}$$



# Half-bridge converter




[C. Albea et al IFAC 2017]..

# Conclusion

With hybrid dynamic control we get as advantage :

- > Important reduction of switching
- > Increase of lifespan.
- > Reduction of the dissipated energy in switching.

Other applications in process:

- > DC-DC converter: quadratic boost.
- > DC-AC converter: boost inverter.
- > AC-DC converter: NPC converter.