EMR'22
HES-SO Sion
June 2022

EMR'22 Summer School
"Energetic Macroscopic Representation"

EMR-based Modelling and Control of LC-filtered Inverter

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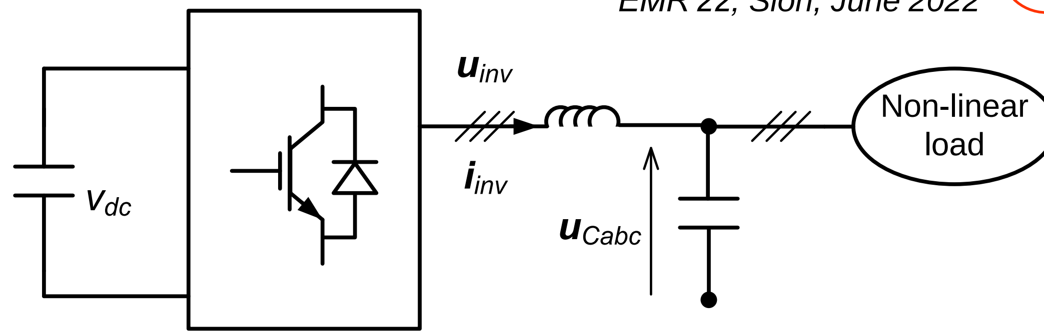
electric - Transport, Energy Storage and Conversion



Increased renewable energy

Increased electric vehicles

V2G, etc.

Grid-forming inverter (GFI)

Frequency control

Control LC filtered inverter toward GFI

System protection

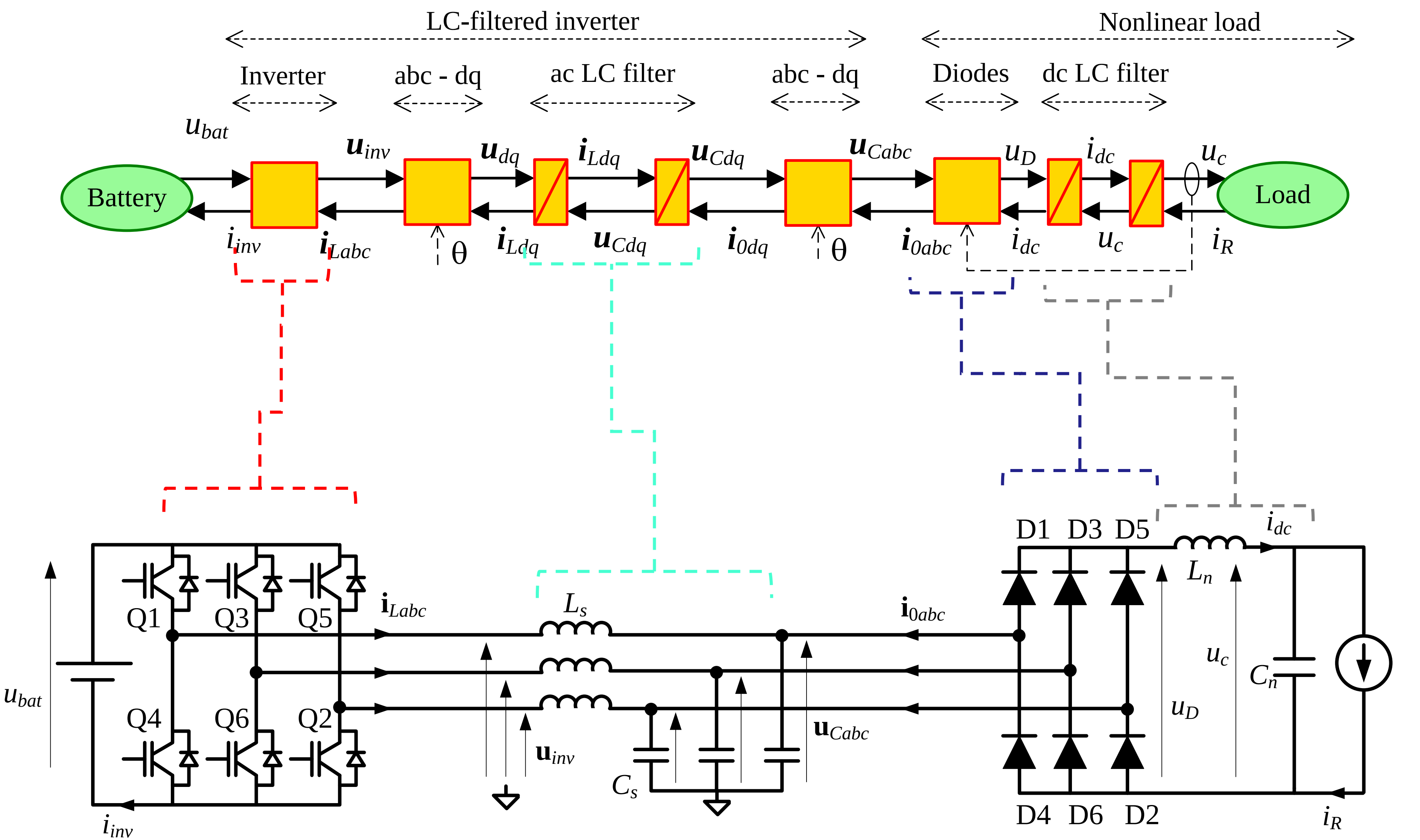
Novel SMC control method

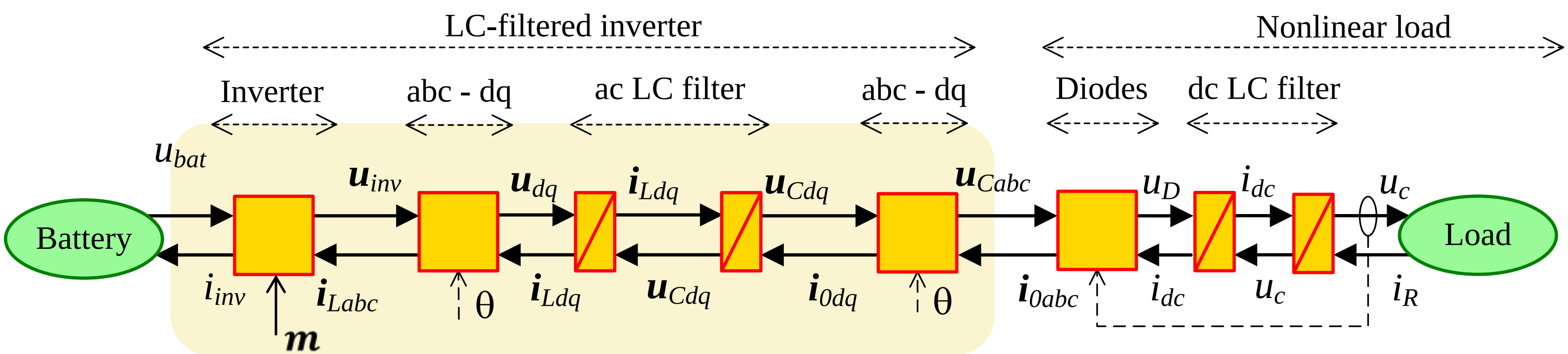
1. Modelling and control of a LC-filtered inverter
2. Novel sliding mode current controller
3. Simulations and results
4. Conclusions and Perspectives

MODELLING AND CONTROL OF A LC-FILTERED INVERTER

EMR-based modelling and control of LC-filtered inverter

- System representation using EMR [Bouscayrol 2012] -





ac LC filter

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \frac{1}{L_s s + R_s} \begin{bmatrix} u_d - u_{Cd} + i_{Lq}\omega L_s \\ u_q - u_{Cq} - i_{Ld}\omega L_s \end{bmatrix}$$

$$\begin{bmatrix} u_{Cd} \\ u_{Cq} \end{bmatrix} = \frac{1}{C_s s} \begin{bmatrix} i_{Ld} - i_{0d} + u_{Cq}\omega C_s \\ i_{Lq} - i_{0q} - u_{Cd}\omega C_s \end{bmatrix}$$

Park transformation

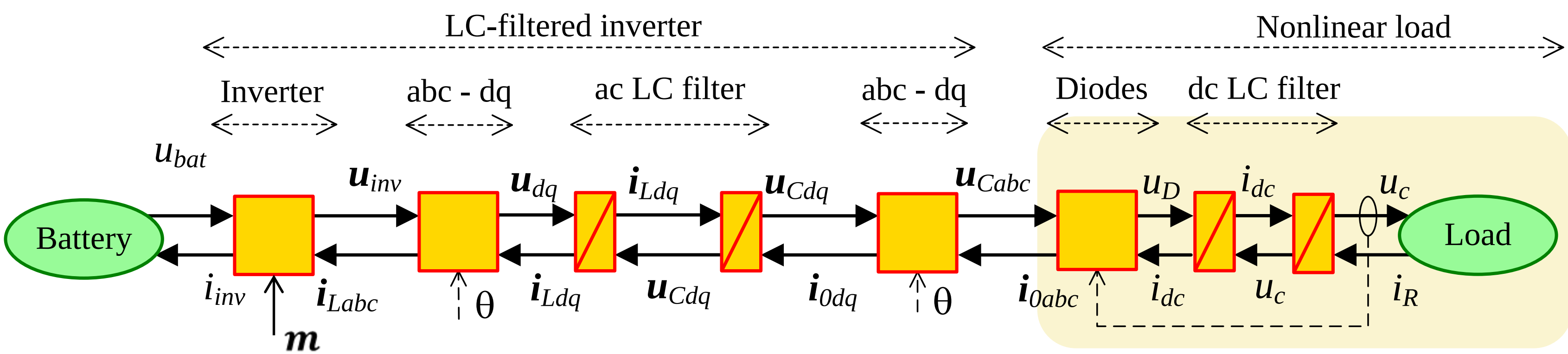
$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix}$$

where $\theta = \arctan(\frac{u_\beta}{u_\alpha})$

EMR-based modelling and control of LC-filtered inverter

- Nonlinear load -



❖ Diodes principle

If $i_{dc} > 0$ or $u_{dc} > u_c$,

then $u_D = u_{dc}$

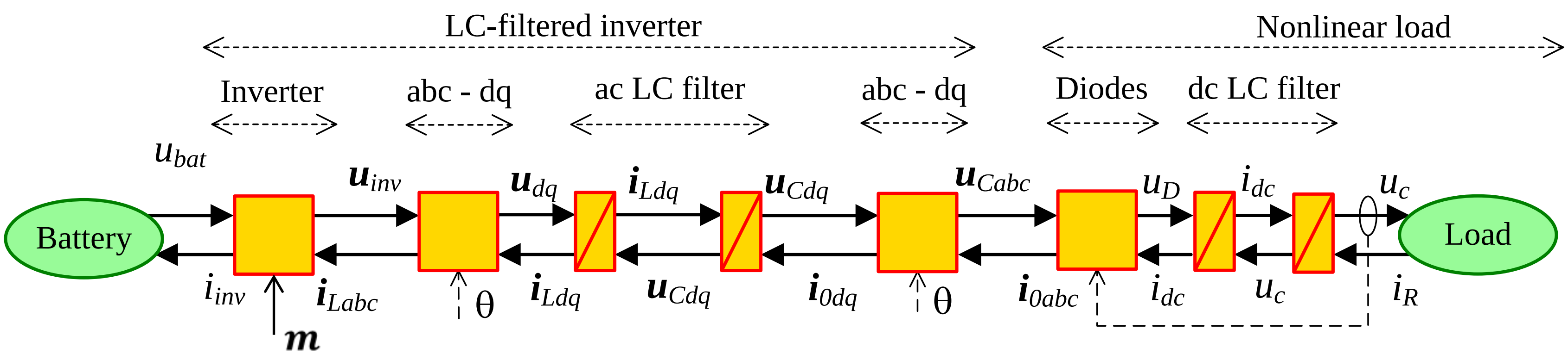
else $u_D = u_c$.

On-state diodes	u_{dc}	i_{0a}	i_{0b}	i_{0c}
D1, D6	$u_{Ca} - u_{Cb}$	i_{dc}	$-i_{dc}$	0
D1, D2	$u_{Ca} - u_{Cc}$	i_{dc}	0	$-i_{dc}$
D3, D2	$u_{Cb} - u_{Cc}$	0	i_{dc}	$-i_{dc}$
D3, D4	$u_{cb} - u_{Ca}$	$-i_{dc}$	i_{dc}	0
D5, D4	$u_{Cc} - u_{Ca}$	$-i_{dc}$	0	i_{dc}
D5, D6	$u_{Cc} - u_{Cb}$	0	$-i_{dc}$	i_{dc}

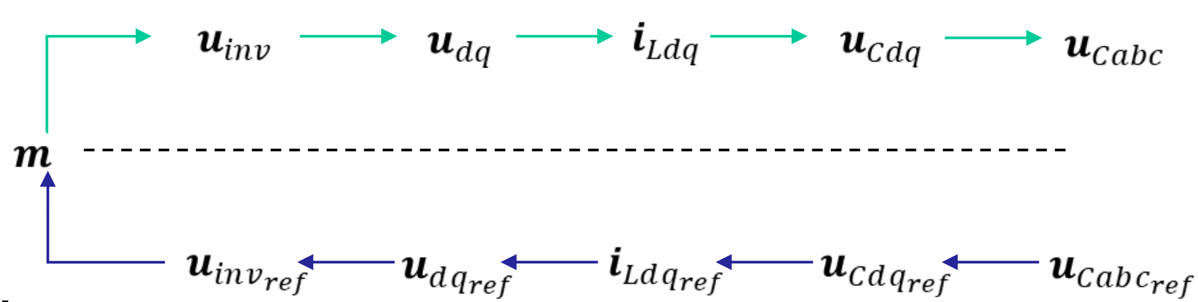
❖ dc LC filter

$$i_{dc} = \frac{1}{L_n s}(u_D - u_c)$$

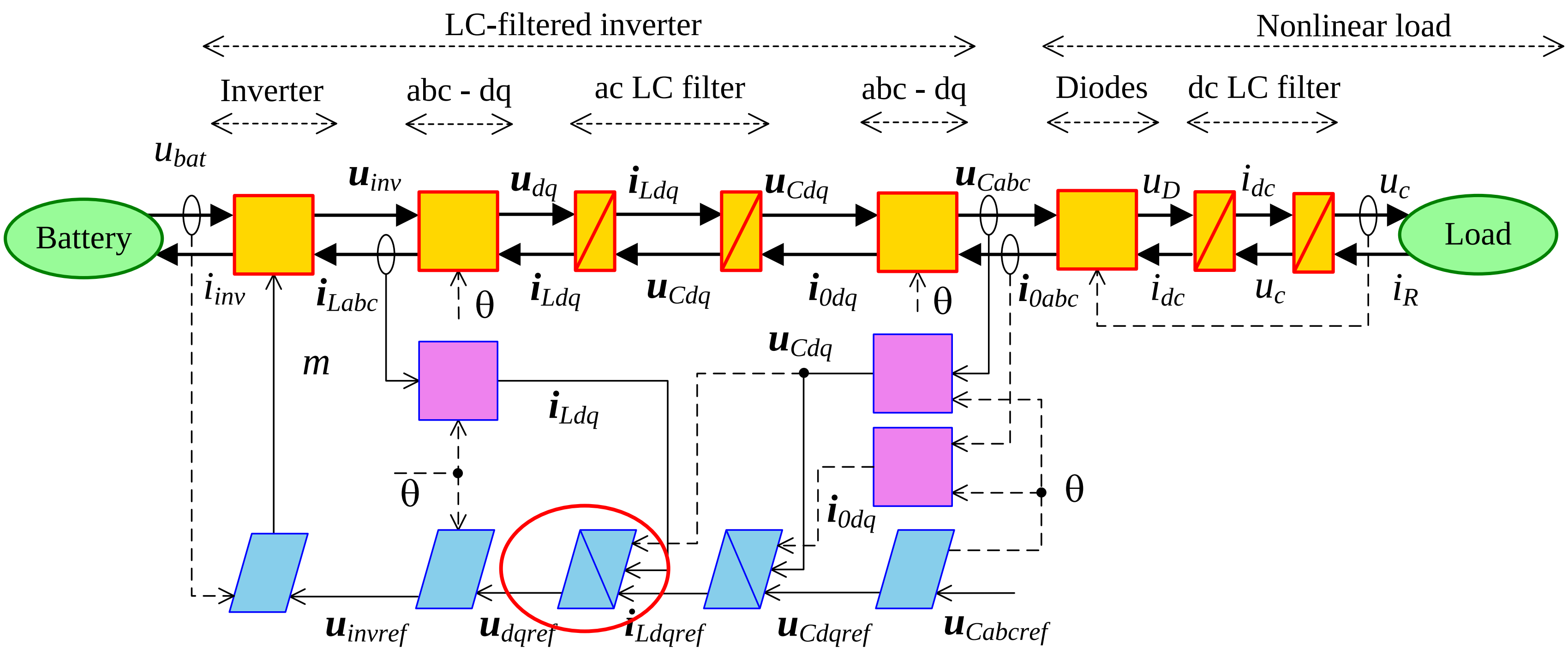
$$u_c = \frac{1}{C_n s}(i_{dc} - i_R)$$



❖ **Tunning path:**



❖ **Control path:**



Focus of this work

❖ **Disadvantages of the controller**

Non-linear load → **Needs quick response**

DSP sampling rate → **Limit the PI controller bandwidth**

DSP: Digital signal processor

NOVEL SLIDING MODE CURRENT CONTROLLER

- Compare with other controllers -

Conventional SMC

Switching function as the control input

Complex to develop and implement

→ **High chattering**

Novel SMC **[HoangQM 2022]**

The average model of the system

Simple to develop and implement

Compared with PI current controller

→ **Fast response**

Without overshoot

$$\begin{cases} S_1(e) = i_{Ld} - i_{Ldref} \\ S_2(e) = i_{Lq} - i_{Lqref} \end{cases}$$

SMC reaching law

$$S(e)\frac{d\big(S(e)\big)}{dt} \leq 0$$

$$\frac{d(S(e))}{dt} = -k_{smc}sign(S(e))$$

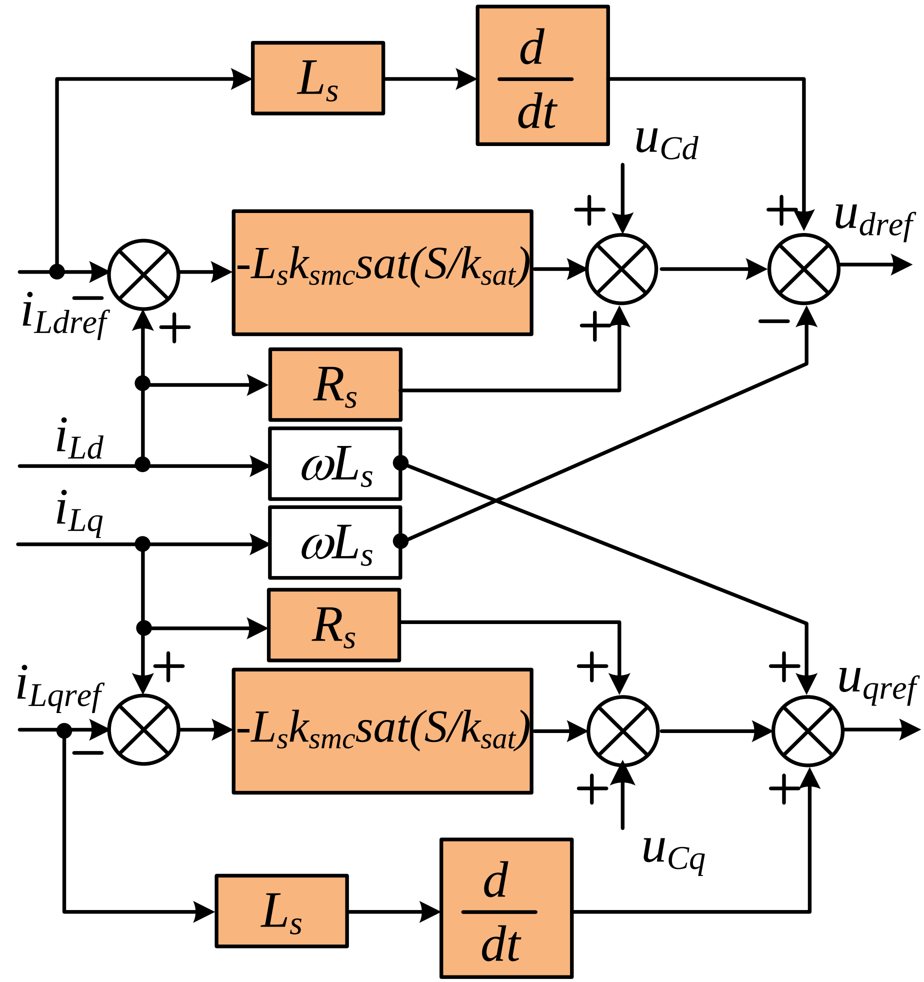
The desired voltages:

$$\begin{cases} u_{dref} = -L_s k_{smc} sat\left(\frac{S}{k_{sat}}\right) + L_s \frac{d\big(i_{Ldref}\big)}{dt} - \omega L_s i_{Lq} \\ \qquad + R_s i_{Ld} + u_{Cd} \\ u_{qref} = -L_s k_{smc} sat\left(\frac{S}{k_{sat}}\right) + L_s \frac{d\big(i_{Lqref}\big)}{dt} + \omega L_s i_{Ld} \\ \qquad + R_s i_{Lq} + u_{Cq} \end{cases}$$

- ✓ **Using saturation function $\boldsymbol{sat}(S/k_{sat})$ to reduce chattering phenomenon**
- ✓ i_{Ldref}, i_{Lqref} **are the time-varying components so the derivative is non-zero**

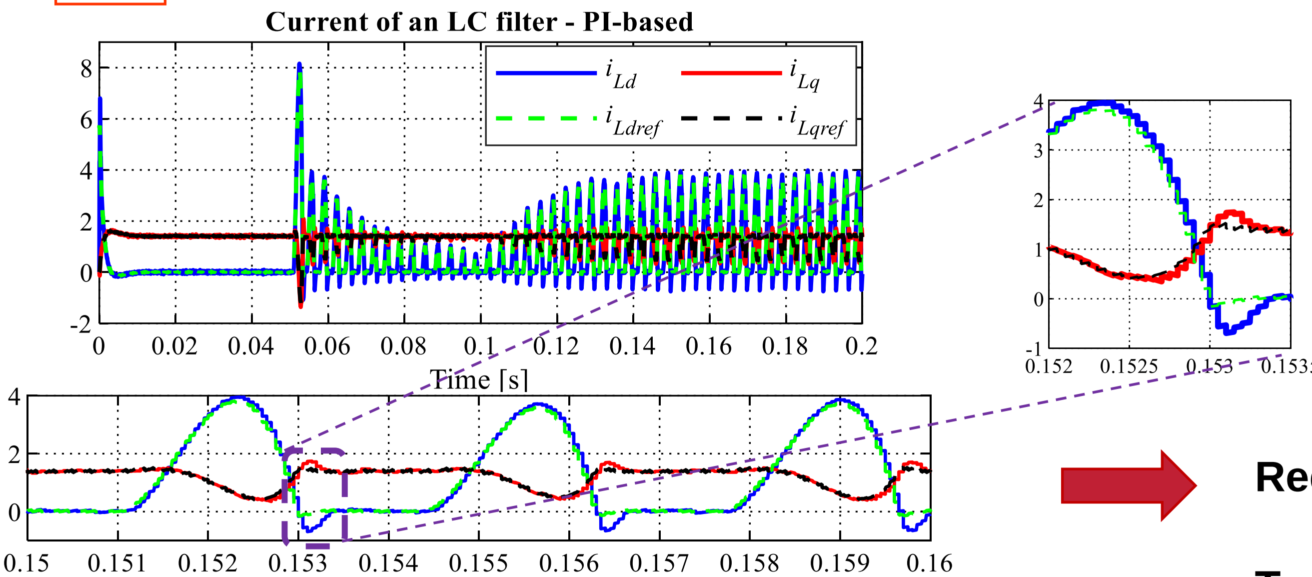
The desired voltages:

$$\begin{cases} u_{dref} = -L_s k_{smc} sat\left(\frac{S}{k_{sat}}\right) + L_s \frac{d\left(i_{Ldref}\right)}{dt} - \omega L_s i_{Lq} \\ \qquad + R_s i_{Ld} + u_{Cd} \\ u_{qref} = -L_s k_{smc} sat\left(\frac{S}{k_{sat}}\right) + L_s \frac{d\left(i_{Lqref}\right)}{dt} + \omega L_s i_{Ld} \\ \qquad + R_s i_{Lq} + u_{Cq} \end{cases}$$



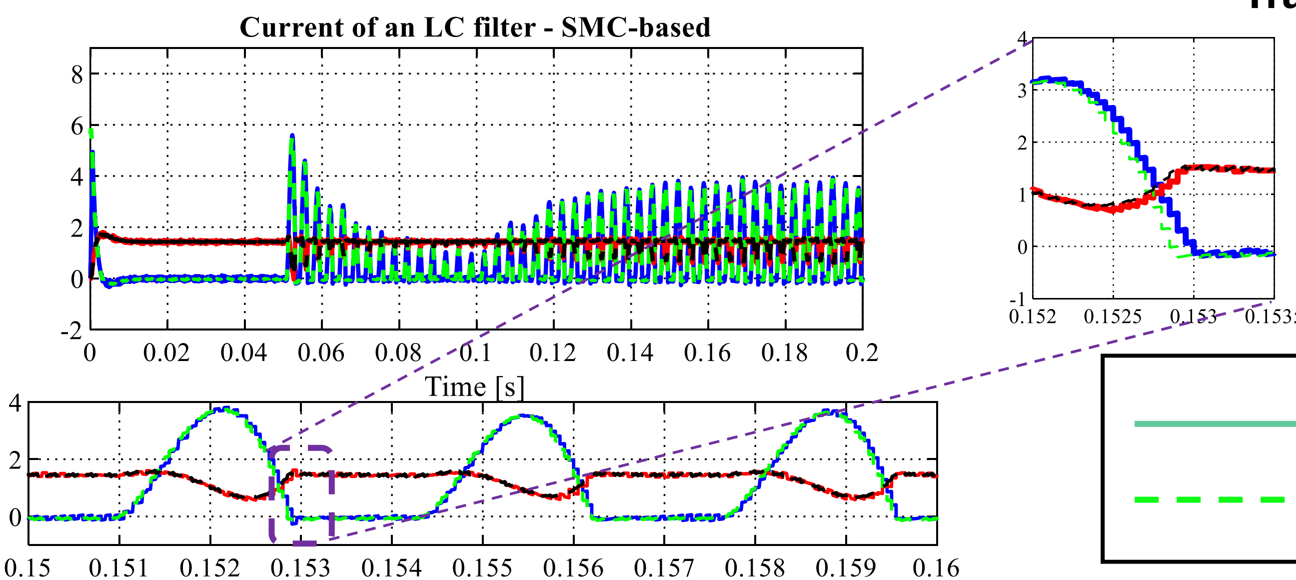
SIMULATIONS AND RESULTS

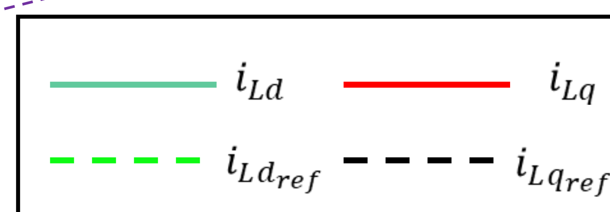
- Inductor currents -



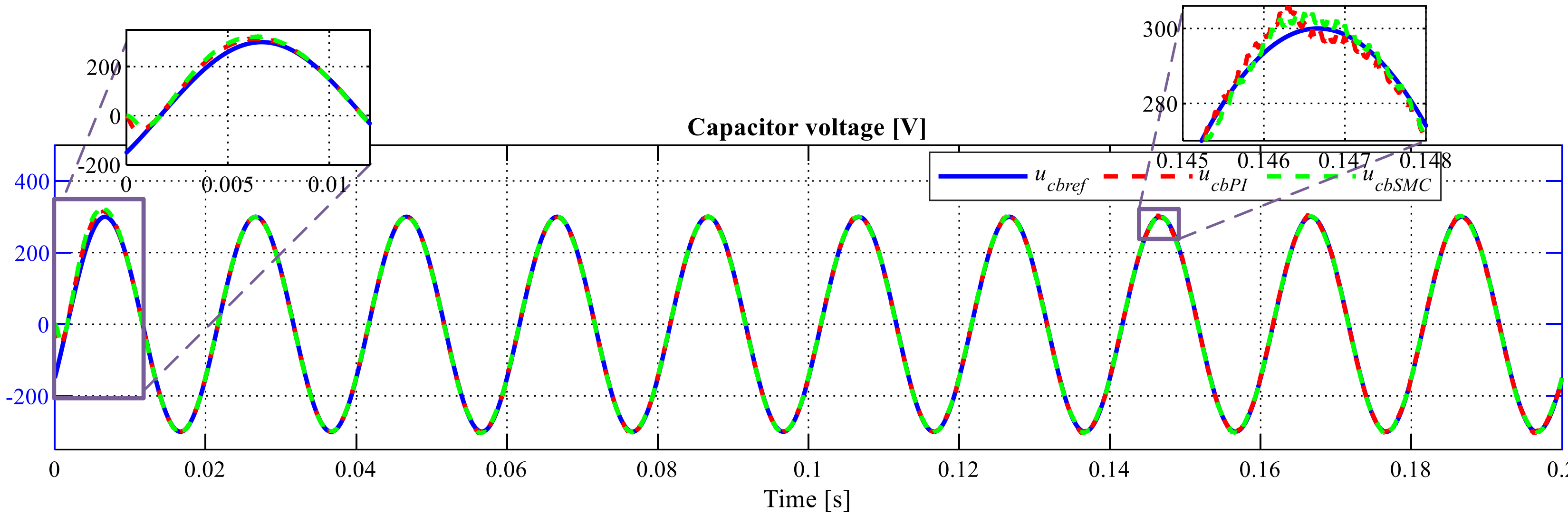
Reduce current overshoot

Track the reference current





- Capacitor voltages -



The response time equal to the desired

- Phase voltage reference
- Phase voltage with PI controller
- Phase voltage with proposed controller

CONCLUSIONS AND PERSPECTIVES

❖ Conclusions

- ✓ **Proposal and validation of a new method of decoupled sliding mode current control**
- ✓ **The approach is based on average converter model instead of conventional switching model**
- ✓ **Simulation results demonstrate the superiority over the traditional PI controller**

❖ Future works

- ➢ **To apply this method to other grid-connected power electronics converters**
- ➢ **To work on the grid-forming inverter control**

BIOGRAPHIES AND REFERENCES

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[HoangQM 2022] Q.M. Hoang; B.H. Nguyễn; T. Vo-Duy; Minh C. Ta; J.P.F. Trovão, “Decoupled Average Model-based Sliding Mode Current Control of LC-filtered Inverters in Rotating Frame”, *the 14th International Conference of TC Electrimacs Committee*, France, 2022.

Time for questions