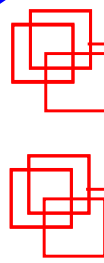


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# Similarities between a Modular Multilevel Converter and an innovative combined traction/charging system for EVs

Dr. X.Kestelyn, Dr. W. Lhomme, Dr. P. Delarue  
L2EP, ENSAM-Université Lille1, France

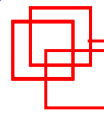


1. Context
2. Expected Outcomes
3. Modelling and Representation
4. Deduced Control
5. Conclusion

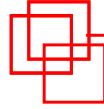
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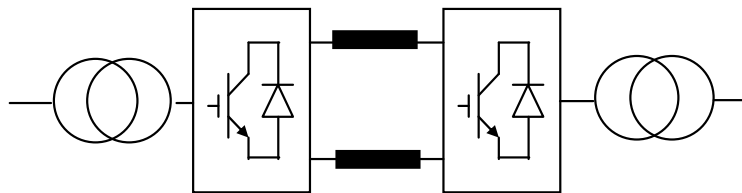
**« CONTEXT »**

# « Similarities between MMC and Sofraci system »

## - Context MMC (Modular Multilevel Converter) -

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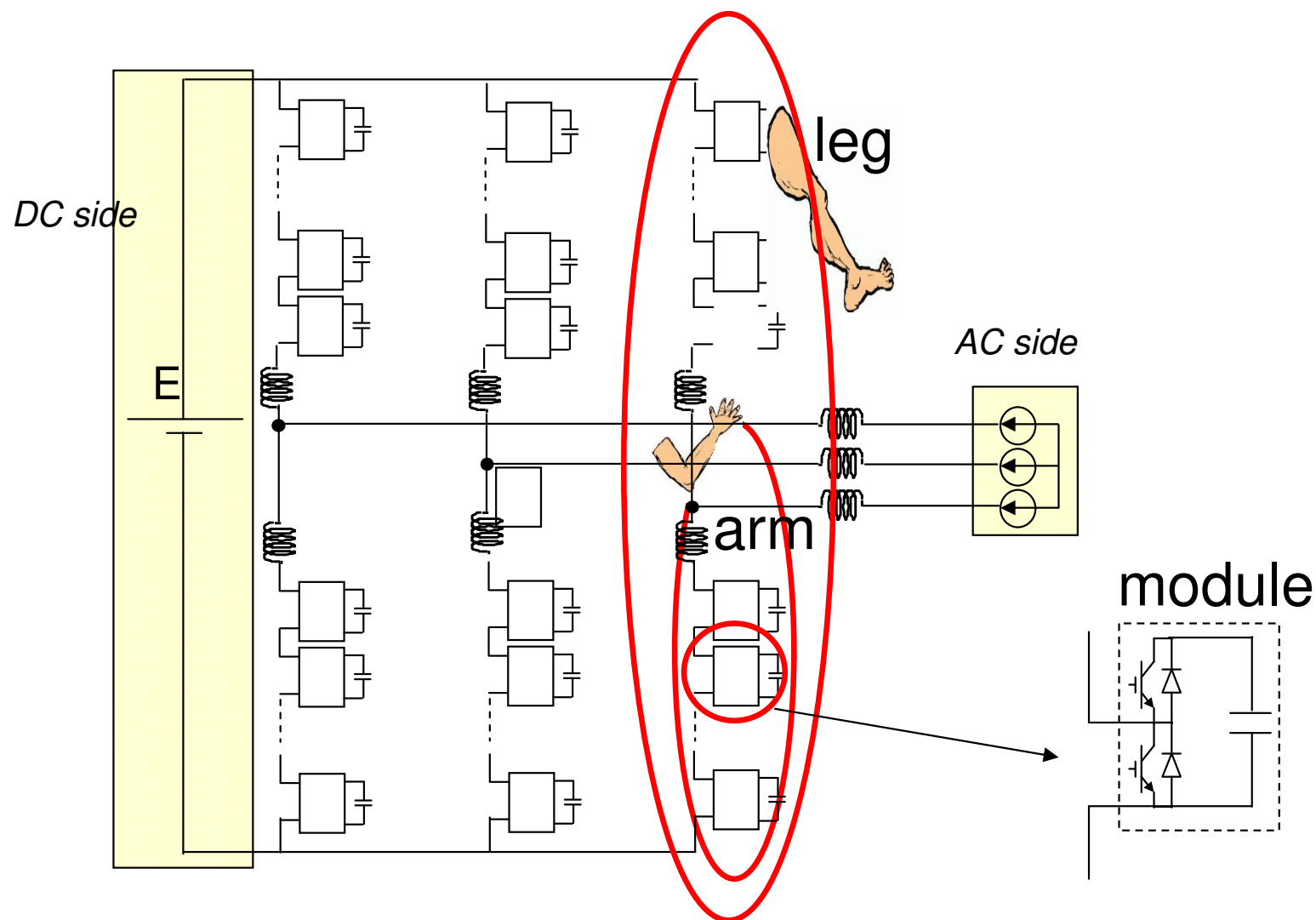
4



### France-Spain HVDC link

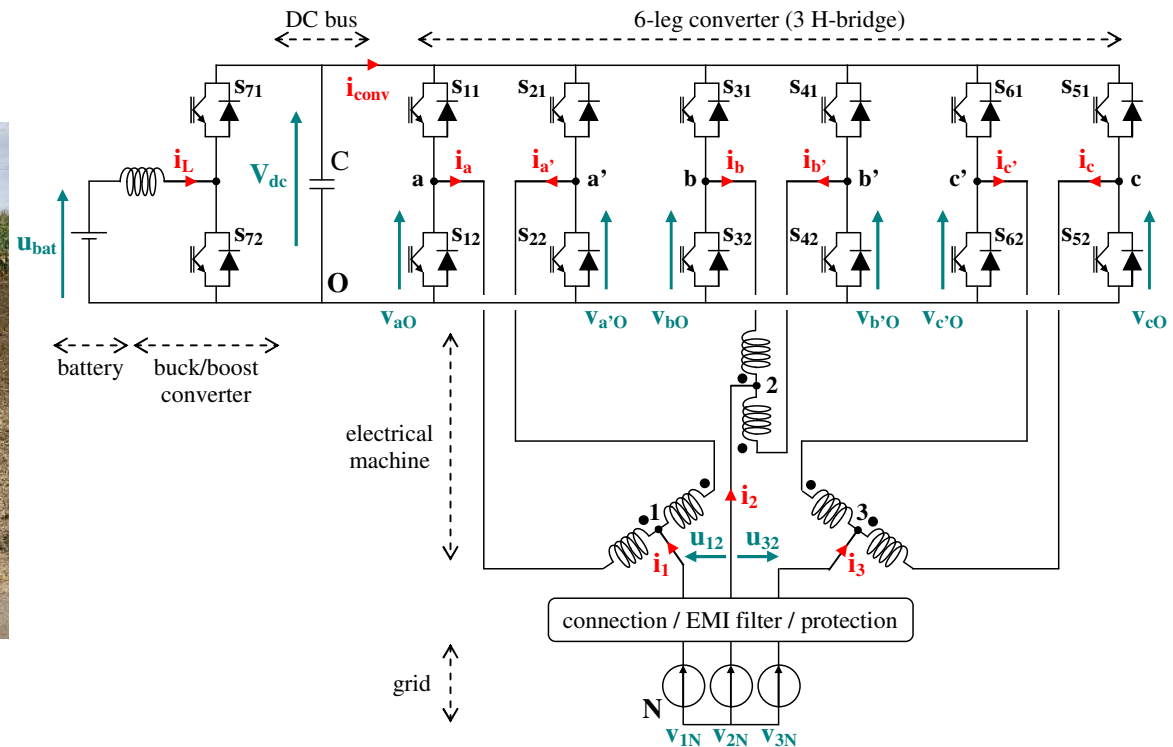
high power  $\rightarrow 2 \times 1 \text{ GW}$

high voltage  $\rightarrow 400 \text{ kVAC}, 640 \text{ kVDC}$

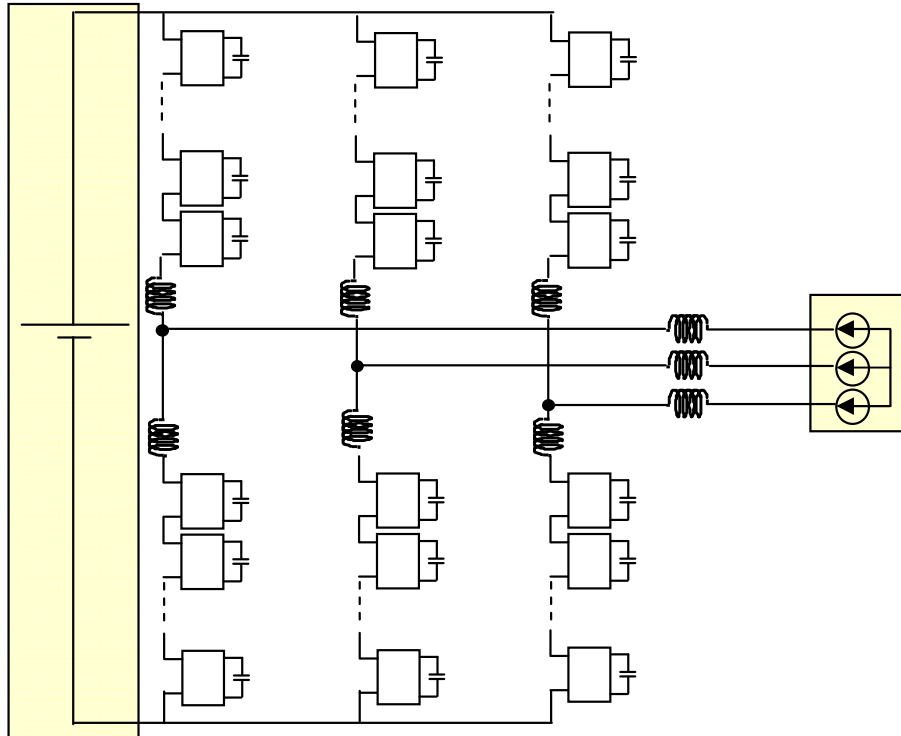


### High-power on-board charging system for electrical vehicles

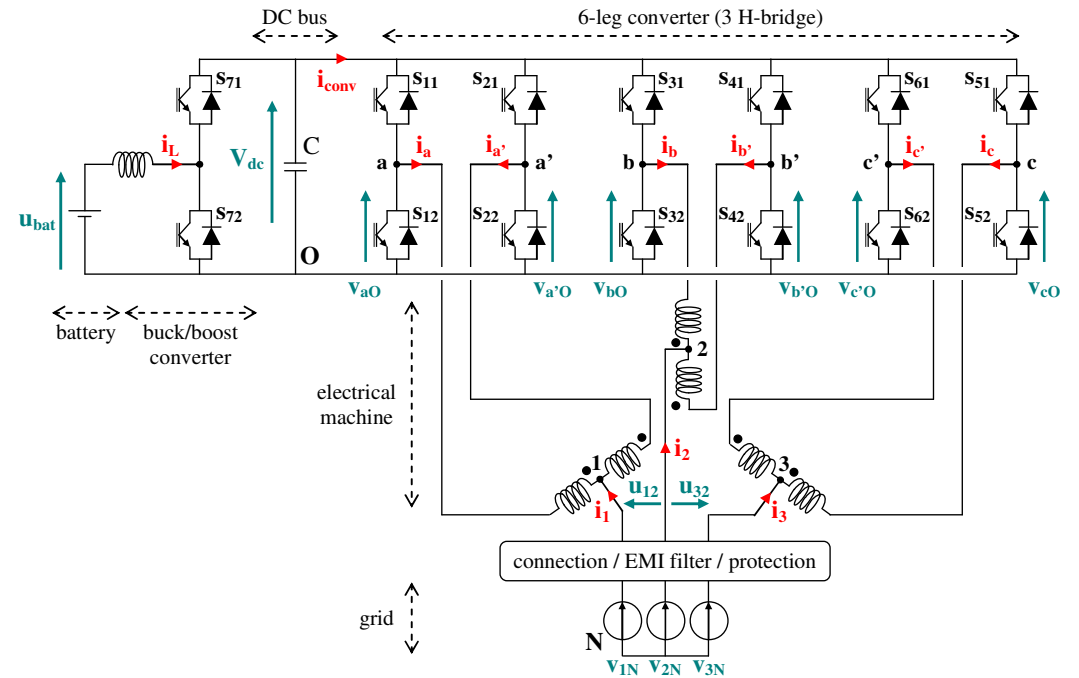
- SOFRACI project from VALEO (several patents)
- Only one structure for traction and charge (one- or three- phase)
- During charging operation : No torque production without the use of contactors



### MMC



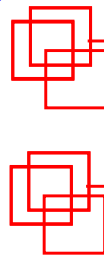
### SOFRACI system



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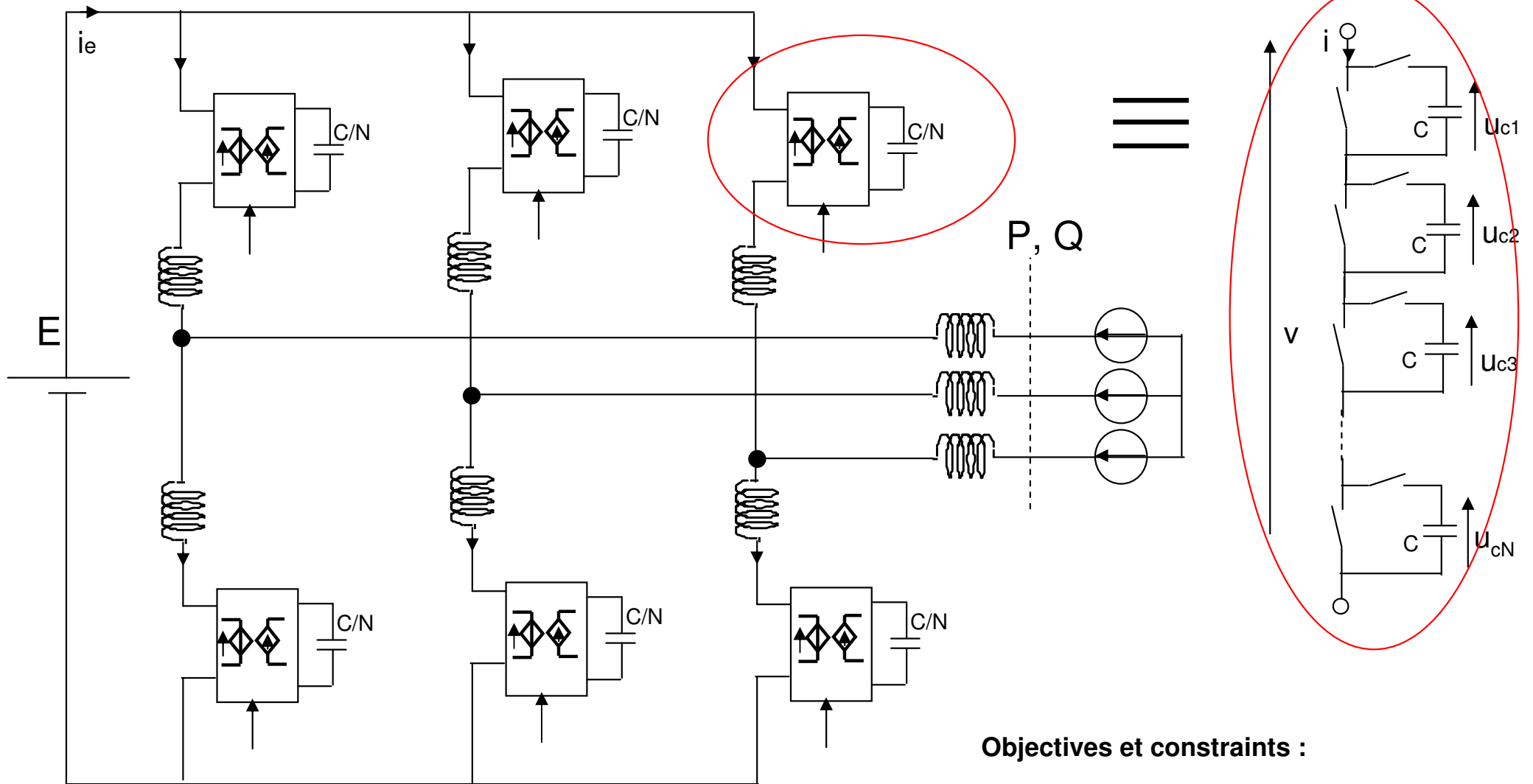


**« EXPECTED OUTCOMES »**

# « Similarities between MMC and Sofraci system »

- **MMC** : Equivalent topology / control objectives -

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**Objectives et constraints :**

- P and Q control with PFC
- control of the voltages  $u_c$

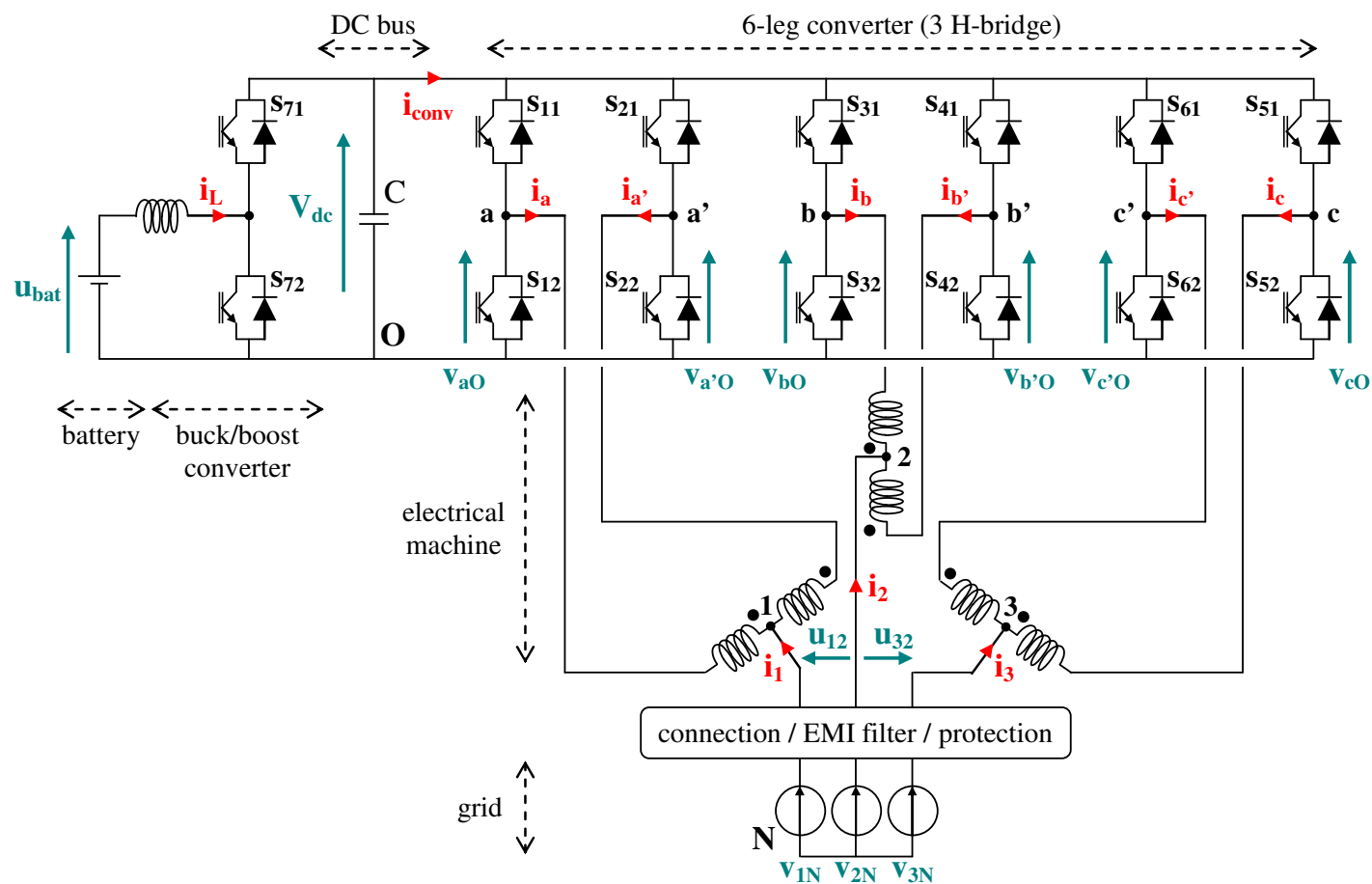
**Independent** state variables: 11 (5 currents + 6 voltages)

**Independent** tuning variables: 6



For the SOFRACI System the objectives and constraints are :

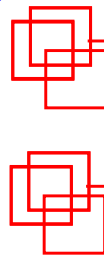
- during traction mode : to control the torque and the flux of the machine
- during charging mode : to control power grid with PFC and to don't produce torque



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**« MODELLING  
and  
REPRESENTATION »**

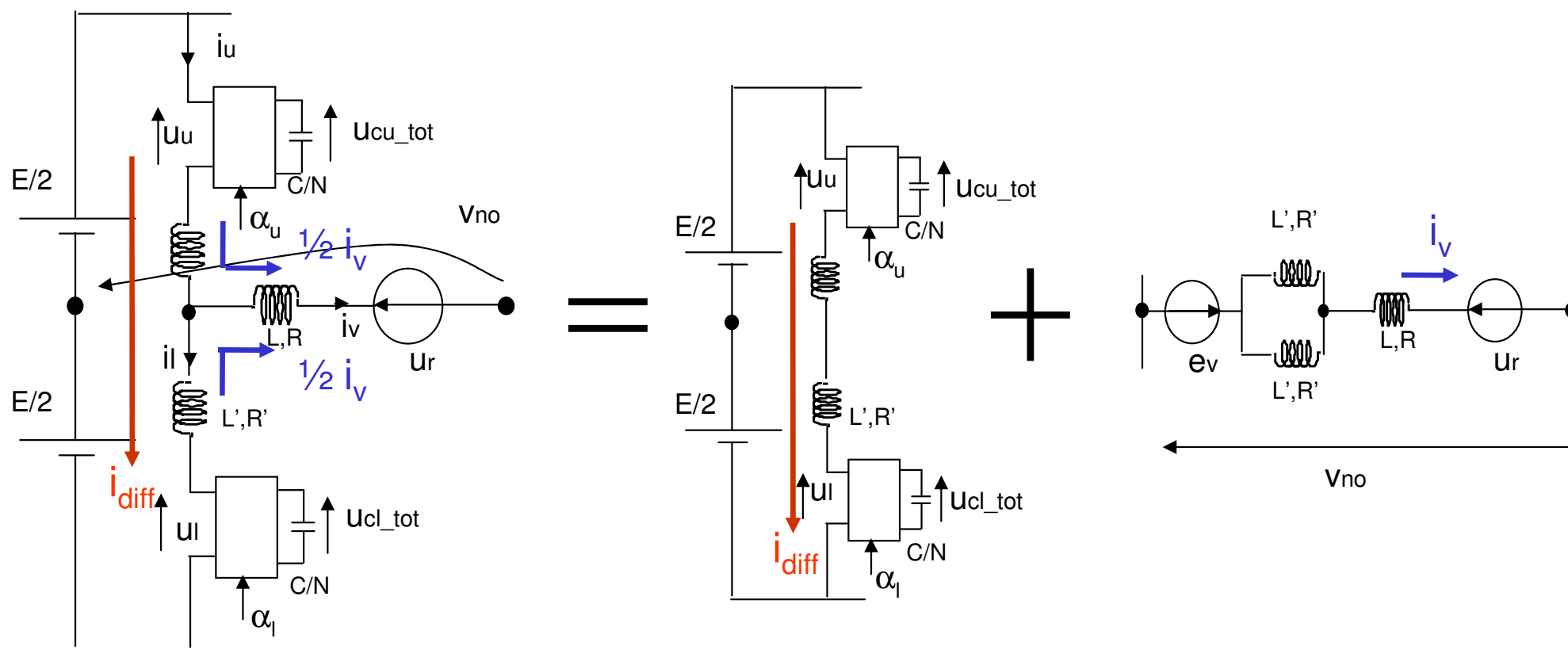
Equations (with eventual change of variables) must lead to a decoupled state representation.

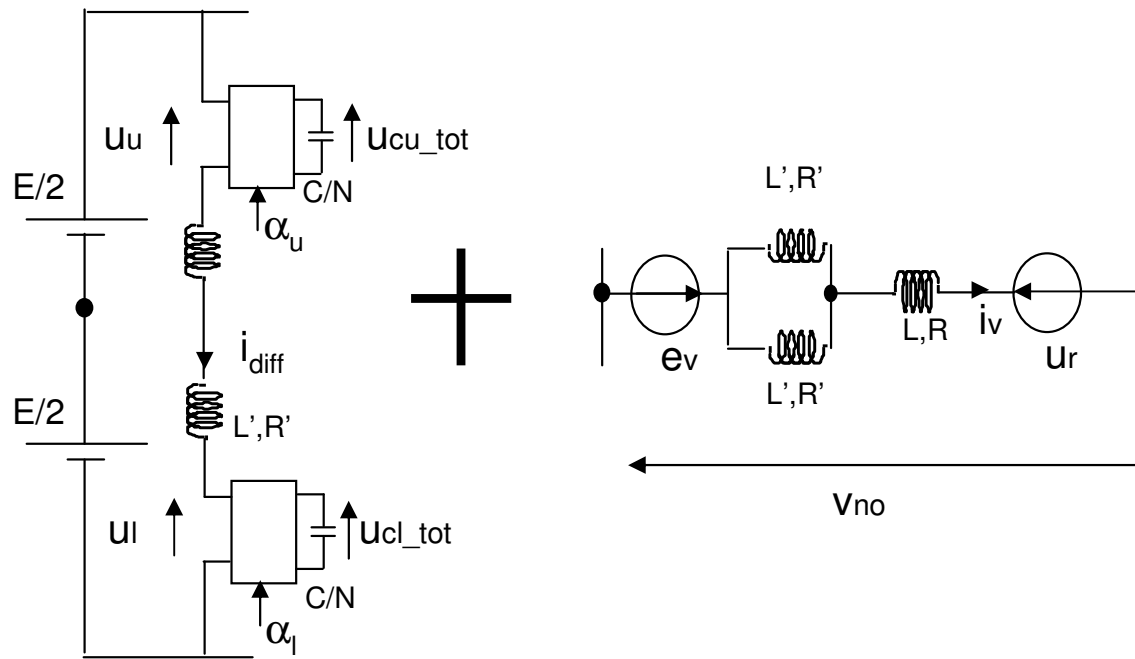
Kirchhoff's current law:

$$i_v = i_u - i_l$$

Change of variables:

$$i_{diff} = \frac{i_u + i_l}{2} \quad e_v = \frac{u_l - u_u}{2} \quad u_{diff} = \frac{u_l + u_u}{2}$$





Equations :

$$e_v - e_r - v_{no} = \left(L' + \frac{L}{2}\right) \frac{di_v}{dt} + \left(R' + \frac{R}{2}\right) i_v \quad \xrightarrow{d, q} \quad \text{x2}$$

$$\frac{E}{2} - u_{diff} = L \frac{di_{diff}}{dt} + R i_{diff} \quad \text{x3}$$

---


$$u_l = \alpha_l u_{cl-tot} \quad \alpha_l i_l = i_{cl} = \frac{C}{N} \frac{du_{cl-tot}}{dt} \quad \text{x6}$$

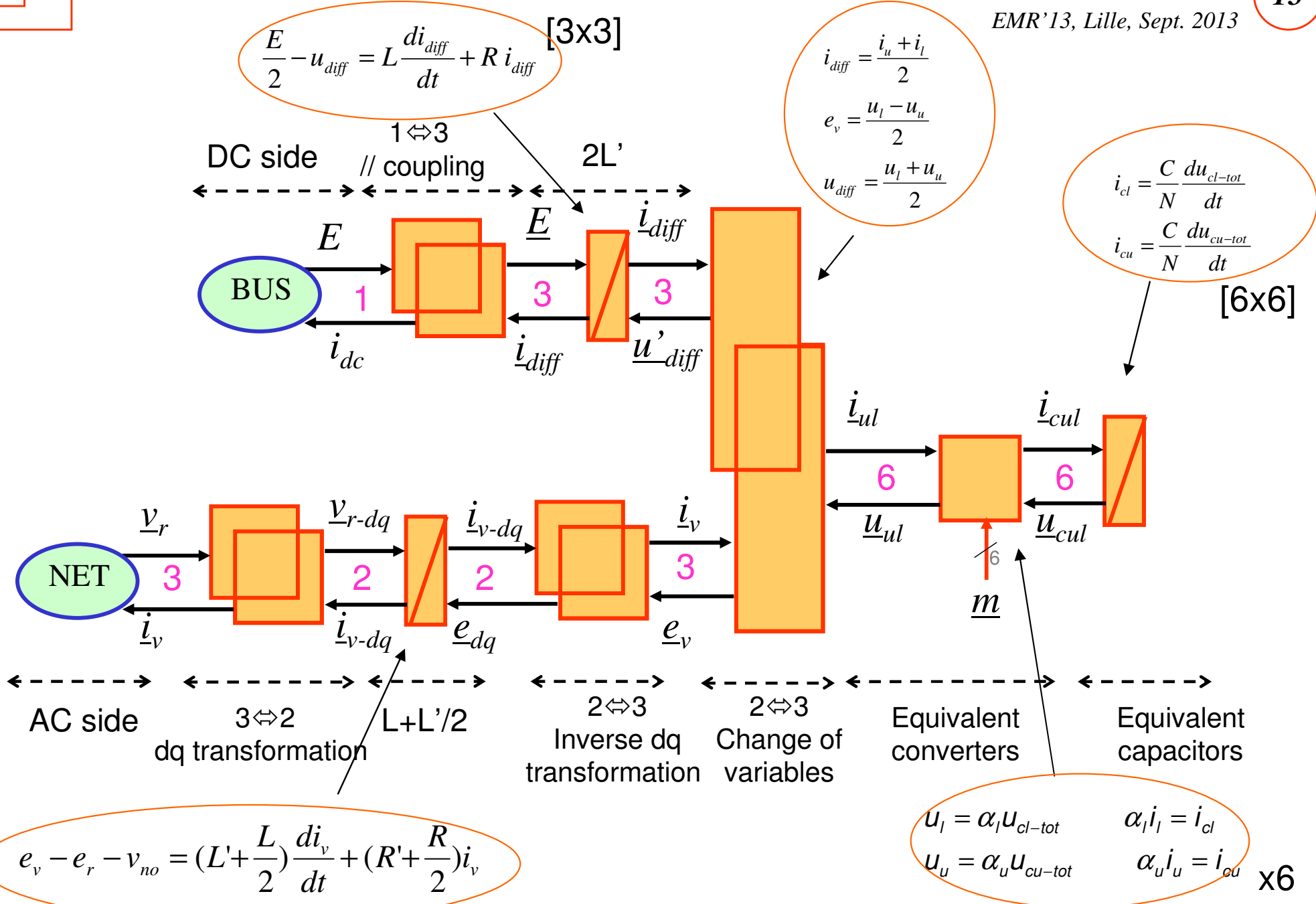
$$u_u = \alpha_u u_{cu-tot} \quad \alpha_u i_u = i_{cu} = \frac{C}{N} \frac{du_{cu-tot}}{dt}$$

# « Similarities between MMC and Sofraci system »

## - MMC : EMR -

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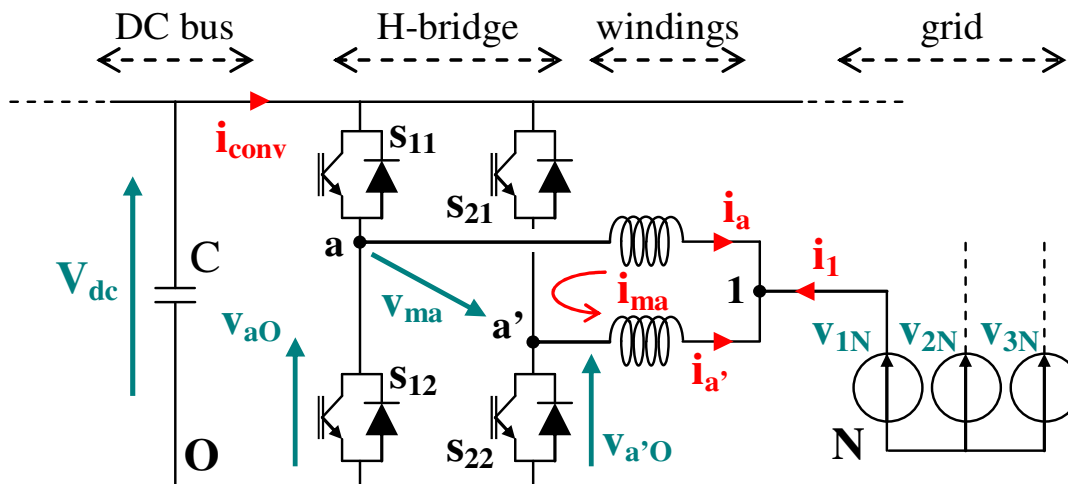


[2x2] (with dq transformation)

The initial system is modelled by a 6x6 strongly coupled inductance matrix :

$$L_s = \begin{bmatrix} L+l_l & -L & M & -M & M & -M \\ -L & L+l_l & -M & M & -M & M \\ M & -M & L+l_l & -L & M & -M \\ -M & M & -L & L+l_l & -M & M \\ M & -M & M & -M & L+l_l & -L \\ -M & M & -M & M & -L & L+l_l \end{bmatrix}$$

A change of variable is used in order to simplify the representation of the model of the system



$$i_{ma} = \frac{i_{a'} - i_a}{2}$$

$$V_{ma} = V_{a'O} - V_{aO}$$

This change of variable leads to two simpler sub-systems

**Motor side:**

$$\underline{v}_m - \underline{e}_m = \frac{d}{dt} \left[ L_{s\_tract} \underline{i}_m \right] + R_{s\_tract} \underline{i}_m \quad R_{s\_tract} = 2 \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix}$$

Identical to classical three-phase machines

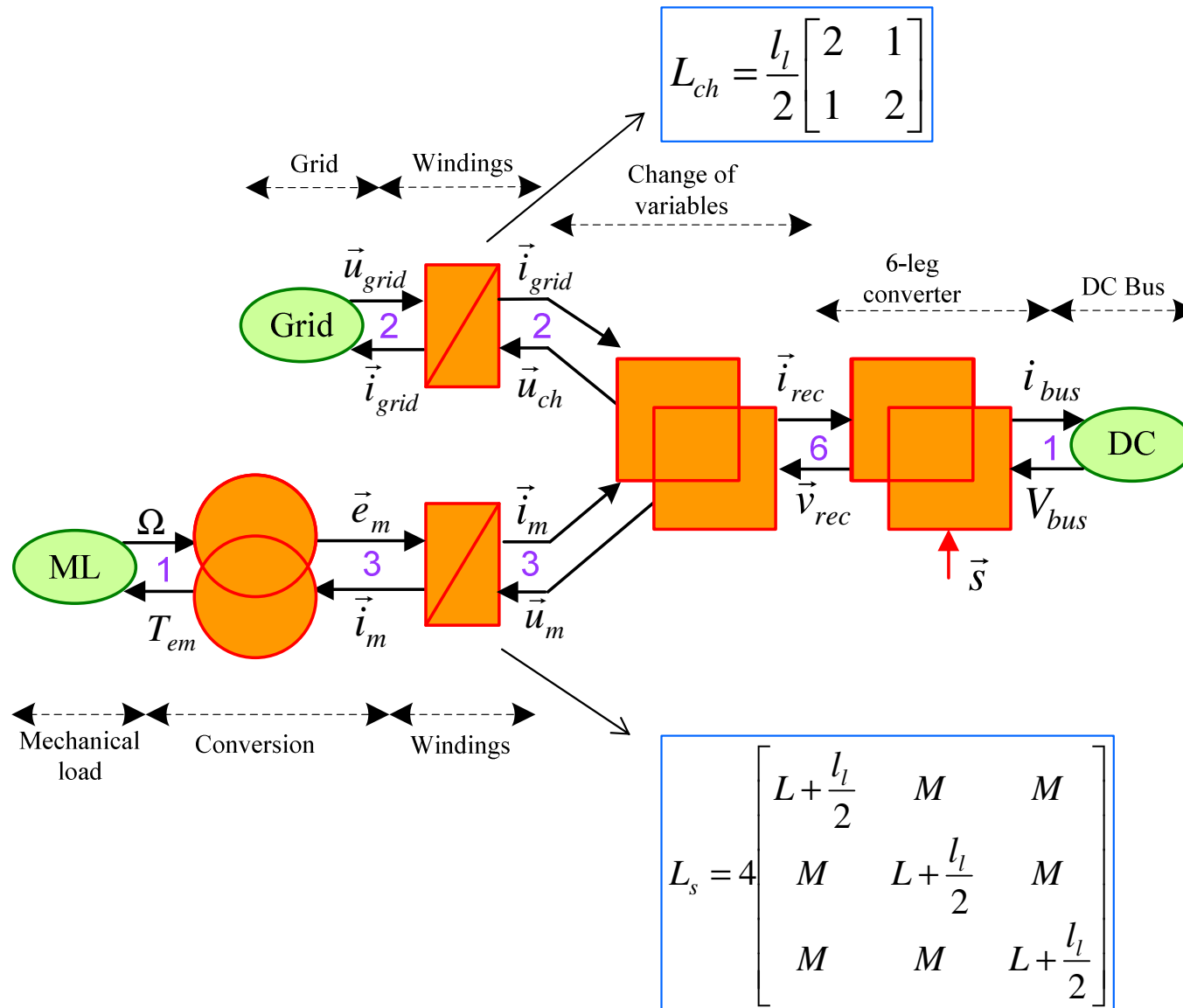
$$L_{s\_tract} = 4 \begin{bmatrix} L + l_l / 2 & M & M \\ M & L + l_l / 2 & M \\ M & M & L + l_l / 2 \end{bmatrix}$$

**Grid side:**

$$\underline{u}_{grid} - \underline{u}_l = \frac{d}{dt} \left[ L_{s\_grid} \underline{i}_{grid} \right] + R \underline{i}_{grid} \quad R_{s\_grid} = \frac{R_s}{2} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$$

Linked only to the leakage inductance

$$L_{s\_grid} = \frac{l_l}{2} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$$

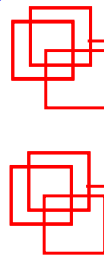




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# « **DEDUCED CONTROL** »



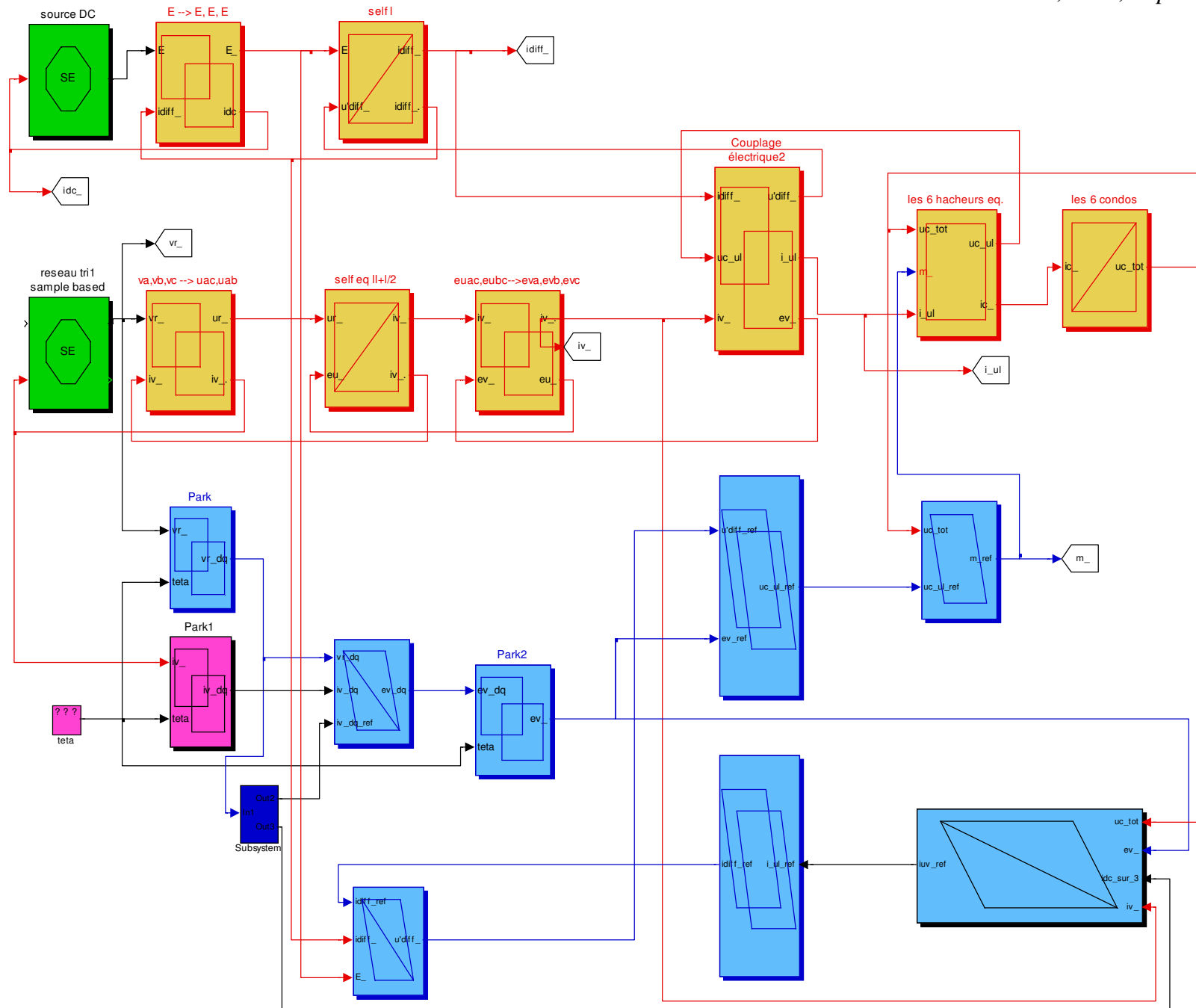


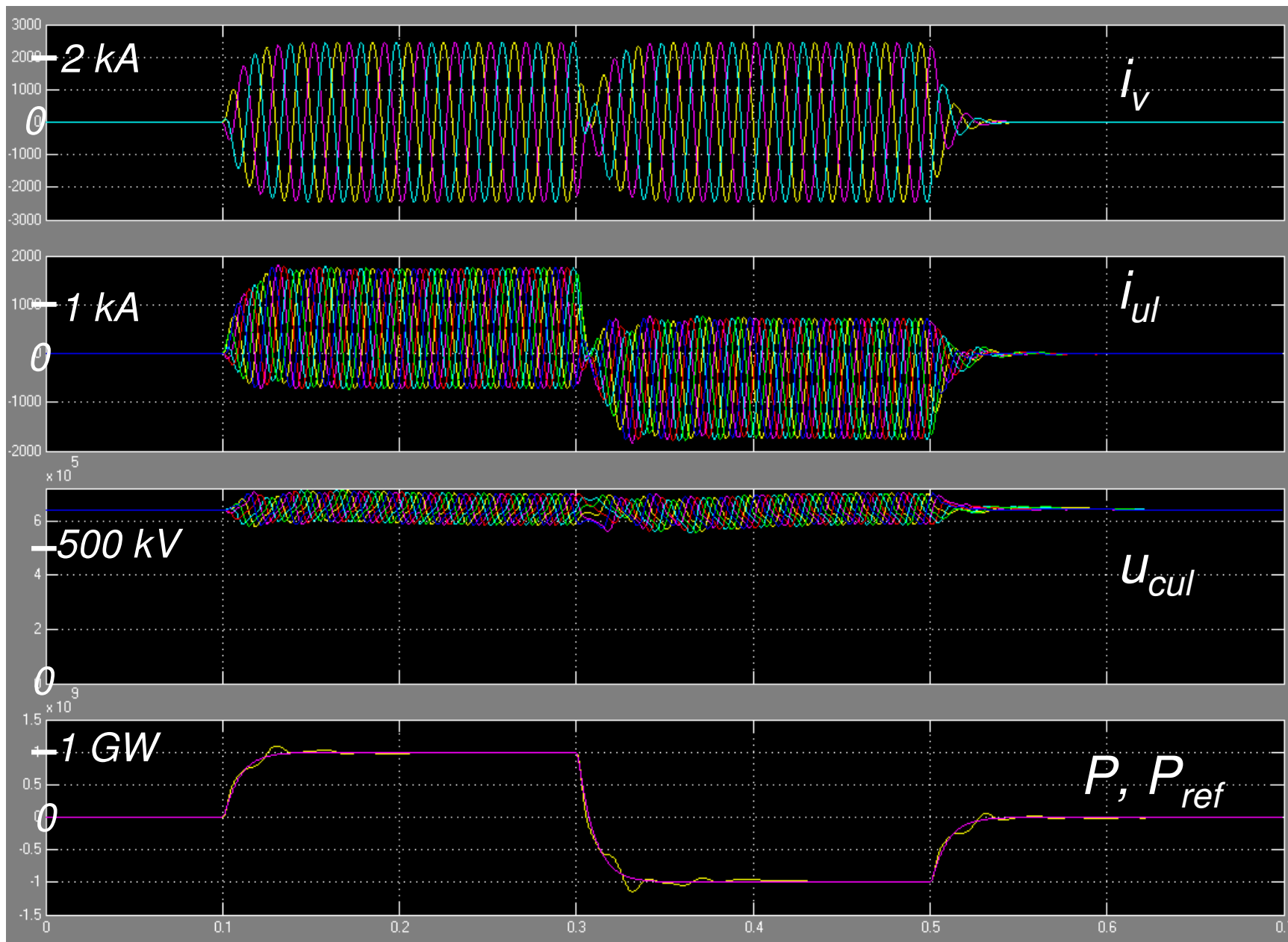
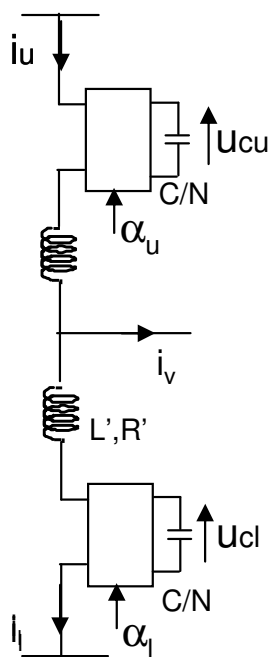
# « Similarities between MMC and Sofraci system »

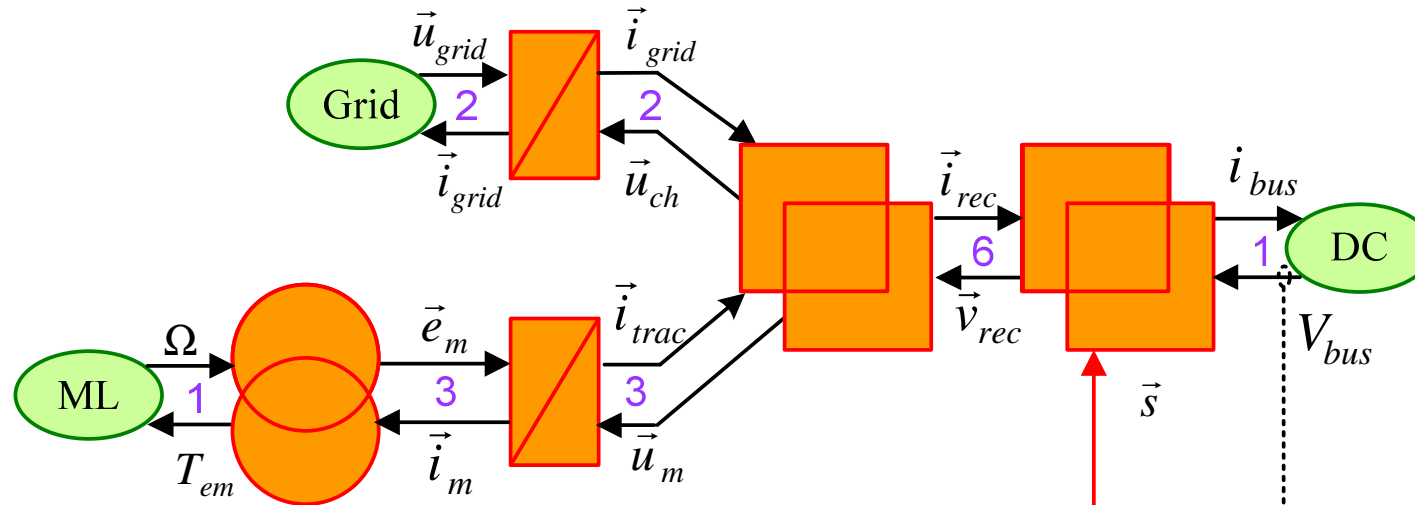
## - MMC : Matlab/simulink implementation -

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Objectives :  
P,Q

Objectives :  
T<sub>em</sub>, losses, FW

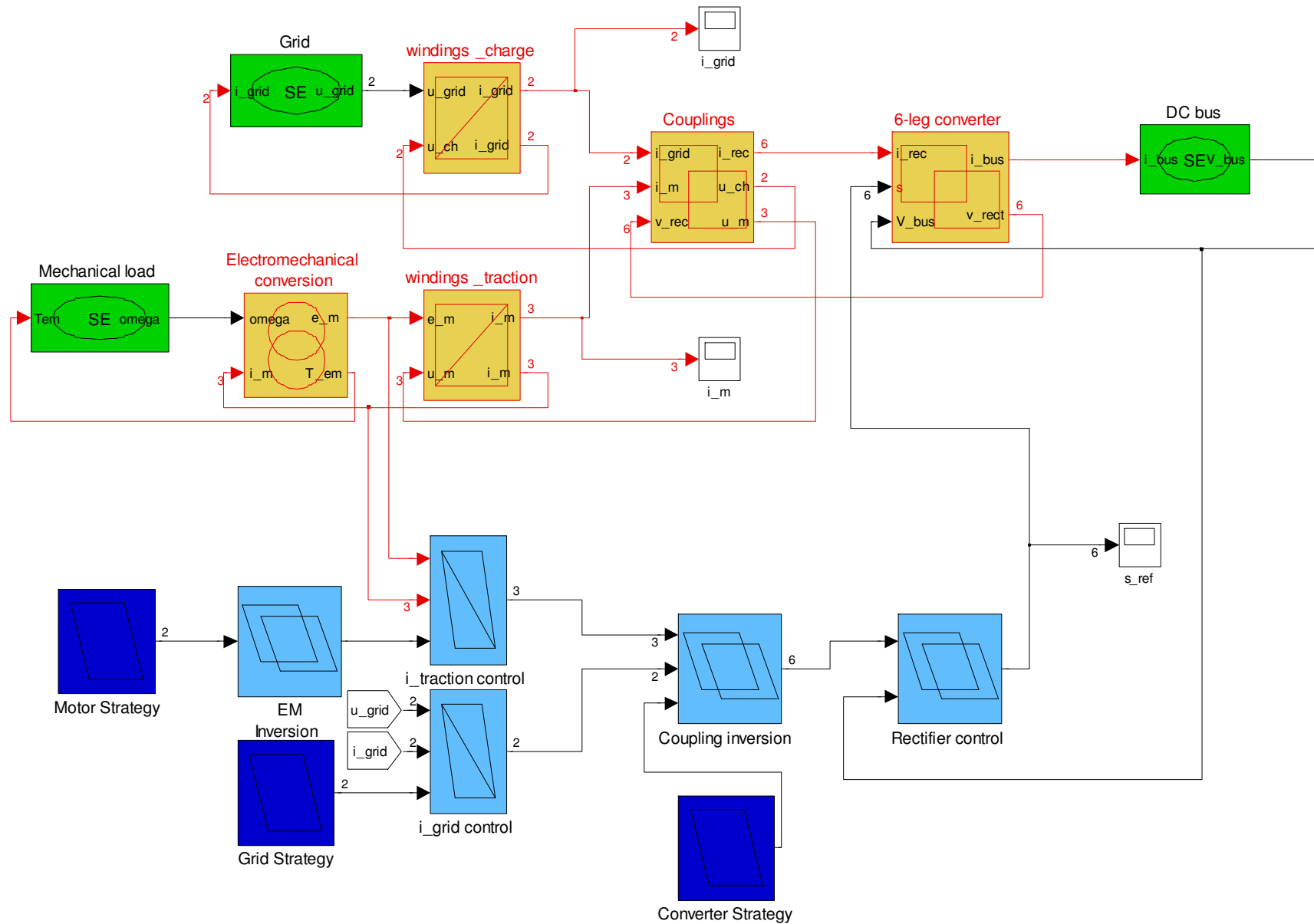
Objectives :  
DC bus or losses or EMC, or ...

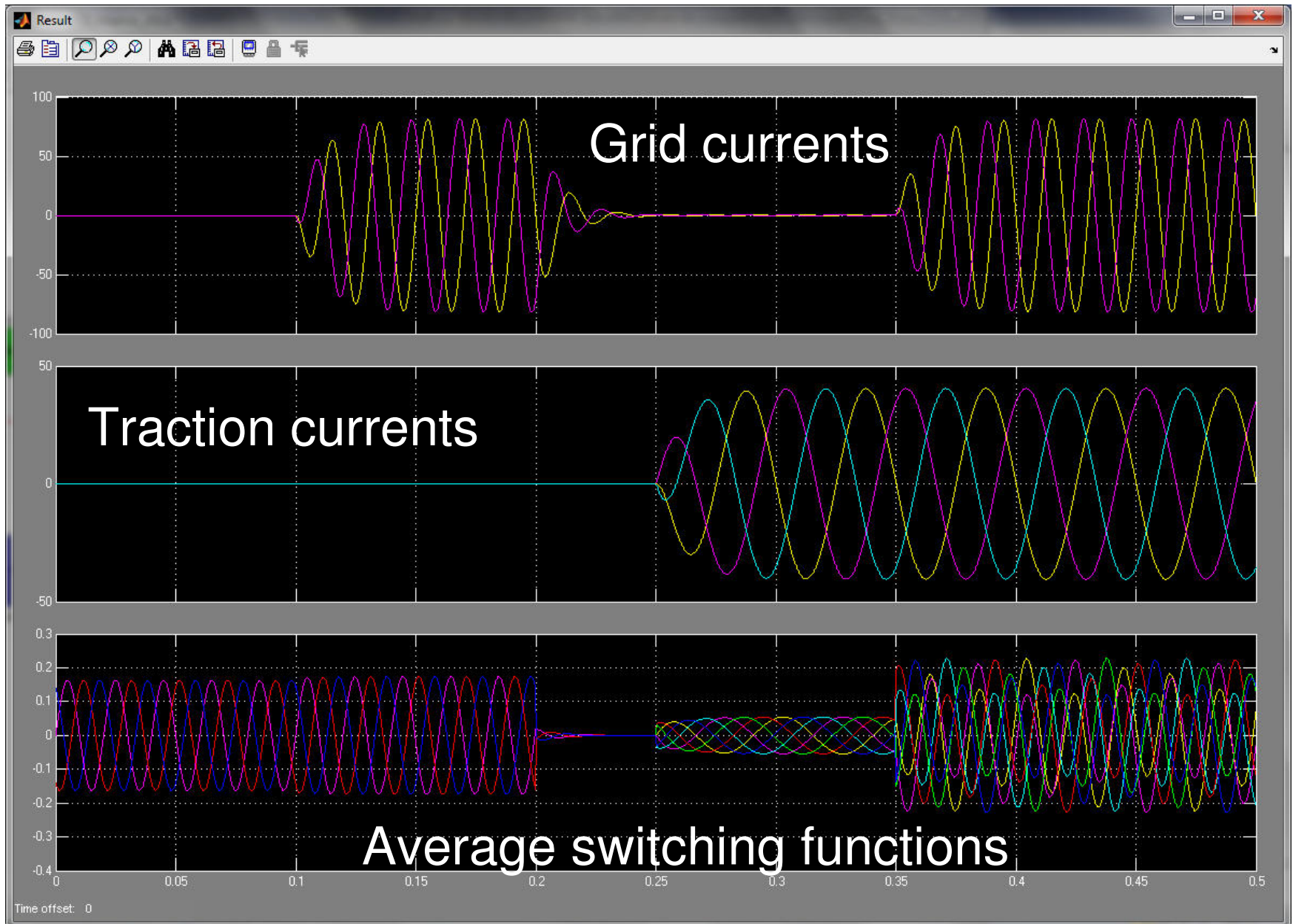
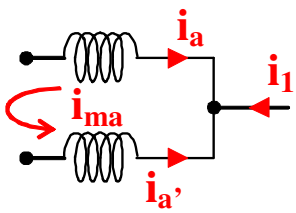
# « Similarities between MMC and Sofraci system »

## - SOFRACI : Matlab/simulink implementation -

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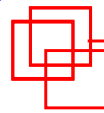




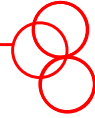
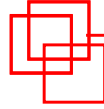
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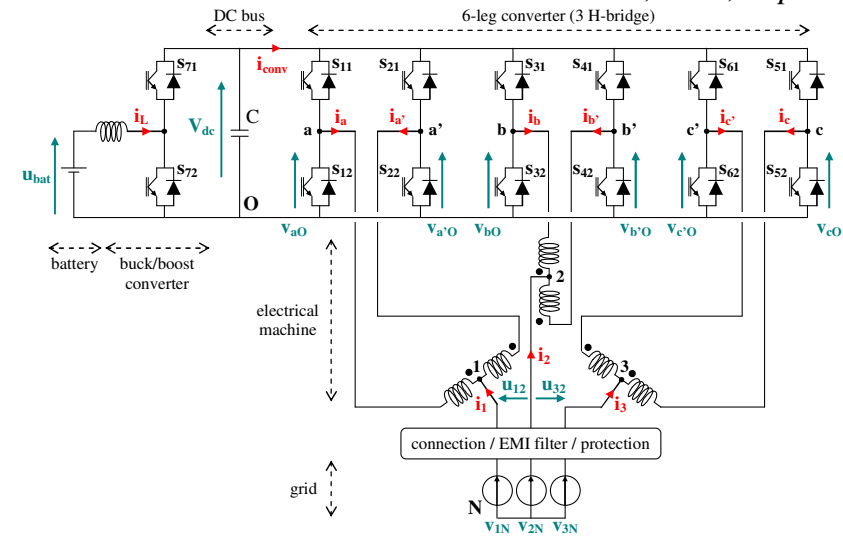
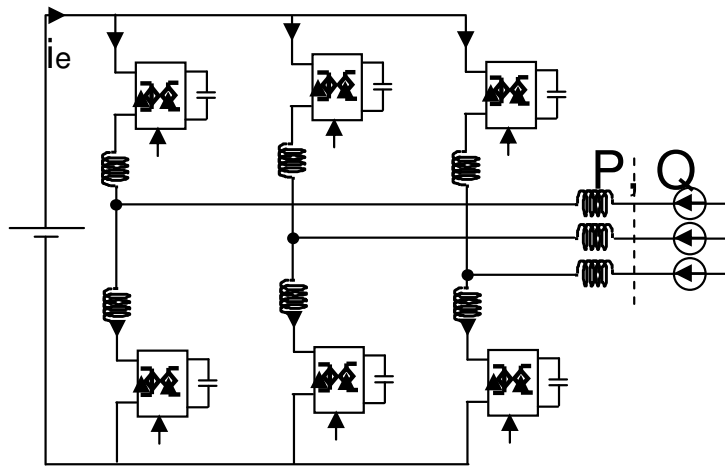


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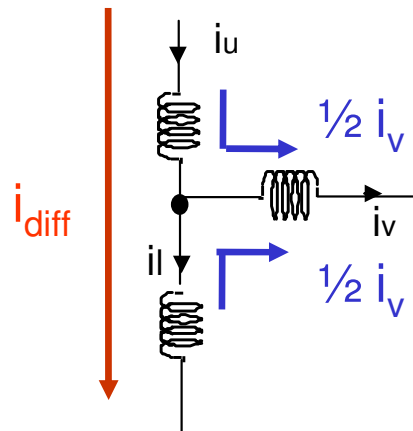
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**«CONCLUSION»**

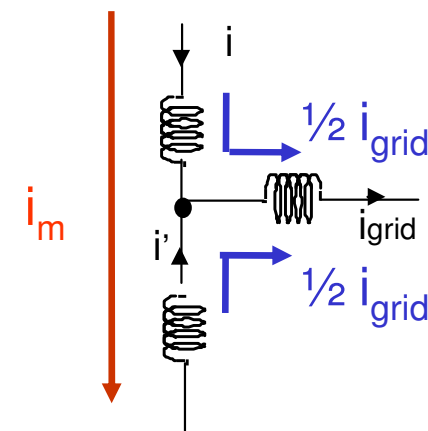


Control AC power AND capacitor voltage by controlling 5 currents

Control AC power OR torque of the electrical machine by controlling 5 currents



Same type of change of variables

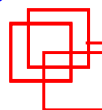


→ Thinking “Systemic” leads to global solutions often better than those obtained by “Reductionist” approaches.

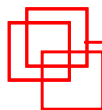
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# «**BIOGRAPHIES**»



### **Dr. Xavier KESTELYN**

Arts et Métiers ParisTech, L2EP, France

Associate Professor since 2004

PhD in Electrical Engineering at University of Lille (2003)

Research topics: EMR, Vectorial Formalism, multi-input coupled systems



### **Dr. Walter LHOMME**

Université Lille 1, L2EP, France

Associate Professor since 2008

PhD in Electrical Engineering at University of Lille (2007)

Research topics: EMR, Electric and Hybrid Vehicles, Energy Storage Subsystem



### **Dr. Philippe DELARUE**

Université Lille 1, L2EP, France

Associate Professor since 1991

PhD in Electrical Engineering at Université de Lille (1989)

Research topics: Power Electronics

