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http://emrwebsite.org

# « Control strategy of a dual-motor drive using EMR»

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## - Outline -



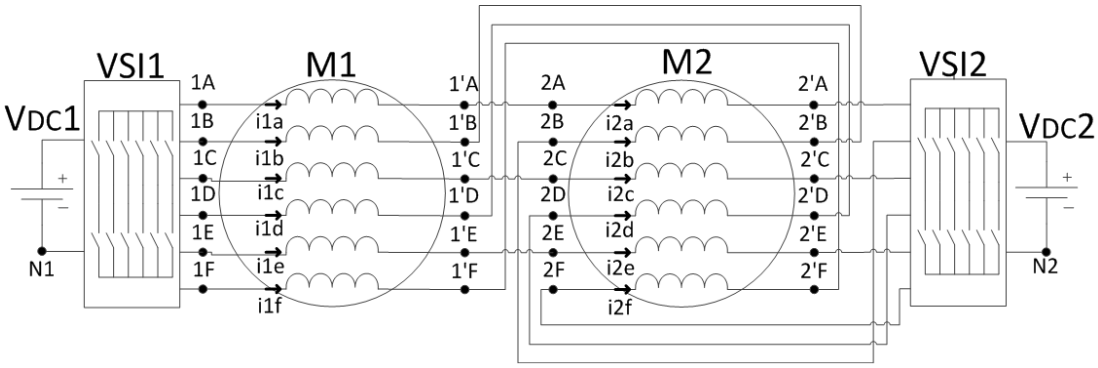
1. **Introduction**
   - Application and History of a DUAL MOTOR TOPOLOGY :RIMM
   - Invented RIMM topology : WORKING Principle

2. **EMR Structure and Control of RIMM**

3. **Control strategies in fault mode**
   - $V_{h1} = 0$
   - $I_{h1} = 0$
   - Complete reconfiguration

4. **Conclusion**

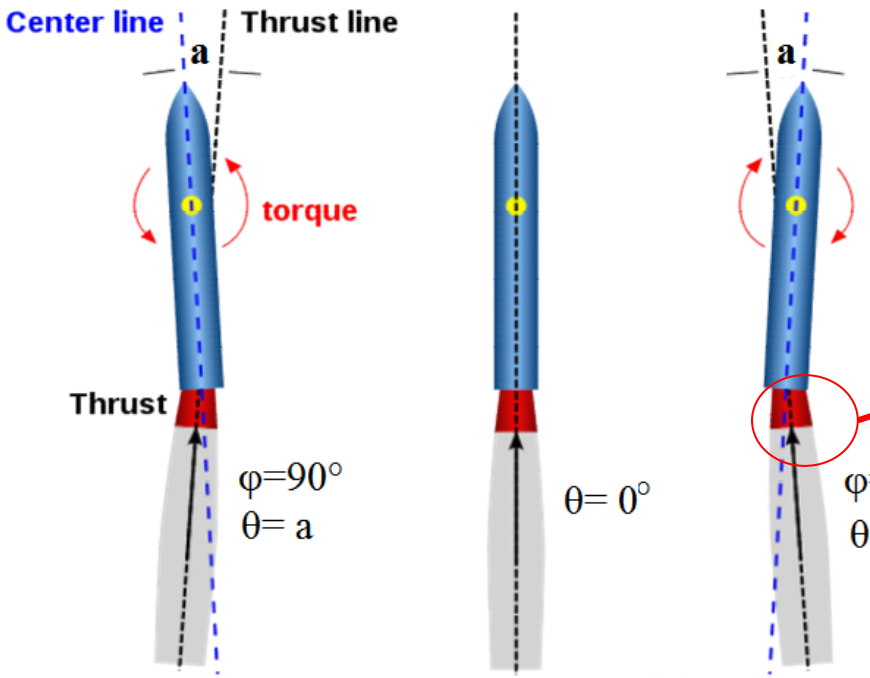
# « PART 1 : INTRODUCTION »

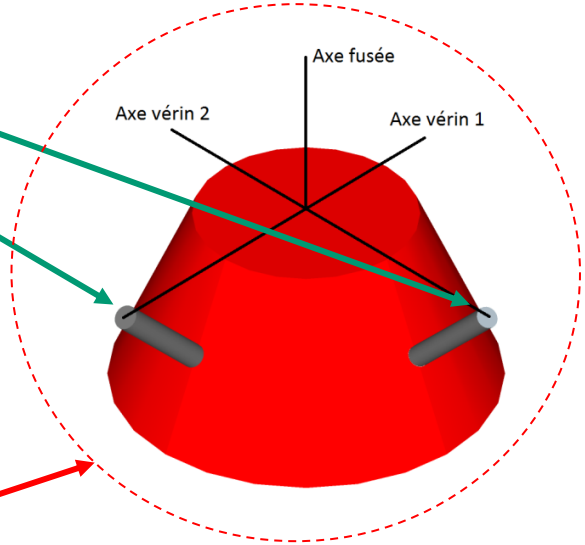



COMPLEX TO IMAGINE, DESIGN AND CONTROL?

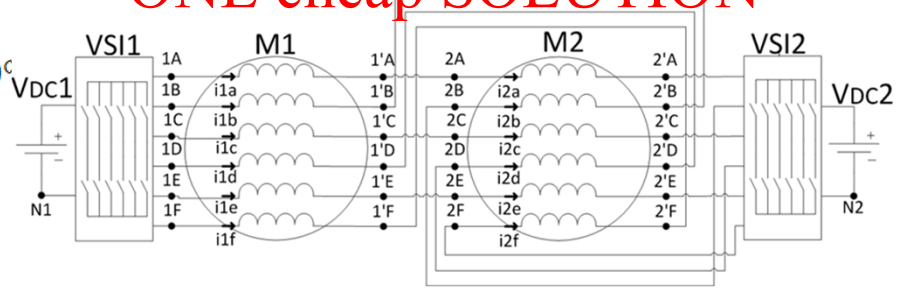
# TVC = Thrust Vector Control for ARIANE

- **Control of the thrust orientation during 15 minutes**
  - 2 **electromechanical actuators** placed 90° from each other;
  - 2 degrees of freedom: θ and φ;
  - Independent torques and speeds




ONE cheap SOLUTION



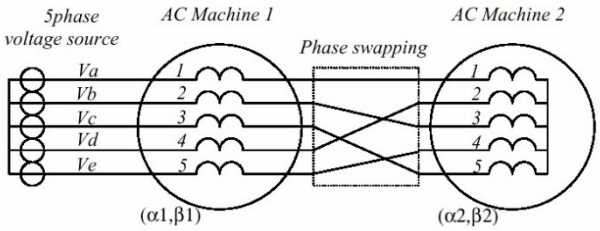
# « Control Strategy of a dual-motor drive using EMR »

## - History of the TOPOLOGY -



2000 — Patent « Gataric » Two-5-phase Induction Machines

INDEPENDENT Speed/Torque ?????




2001 — FVG How?

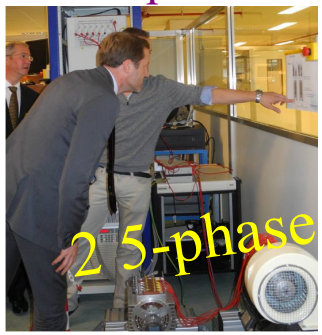
2005 — EPE Control for sinus synchronous (Semail/Levi) thanks to EMR

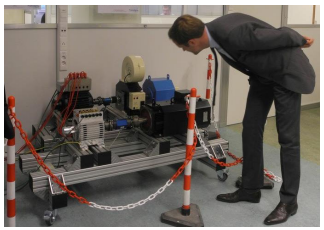
PRACTICAL USE?

EFFICIENCY

2014 — THALES Proof Concept ESA

EMR to explain



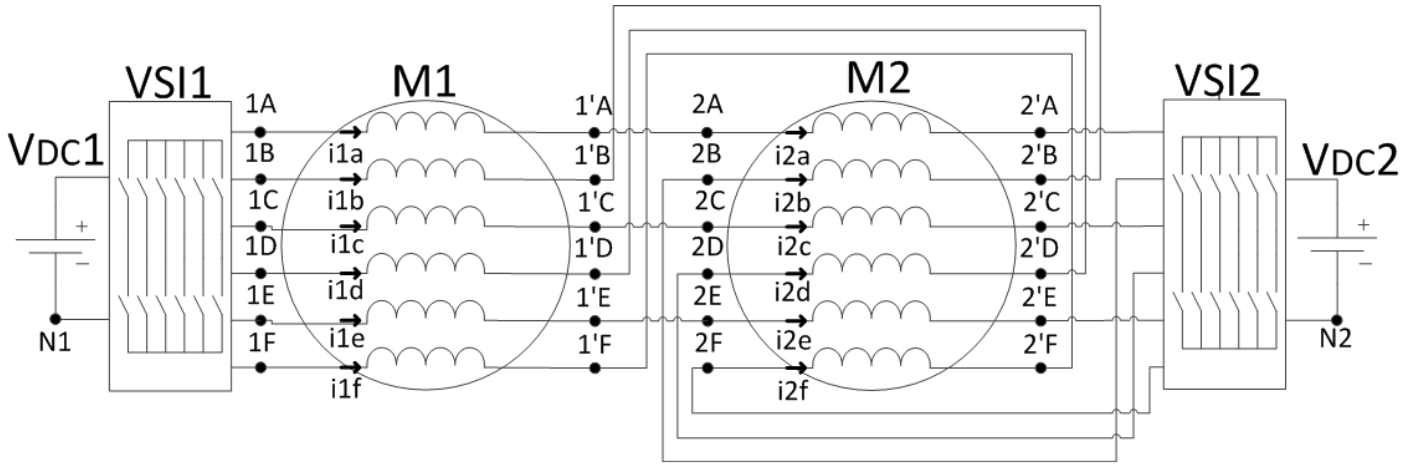
2017 — Patent RIMM **6-phase** for new PAYLOAD FVG/EMR for design

(Redundant Inverter Multiple Machines)

[4] R. Michel, M. Bekemans, M. Guillaume, E. Semail, « Device for controlling two multiphase motors », Patent EP2903155 (B1) — 2017-07-05,

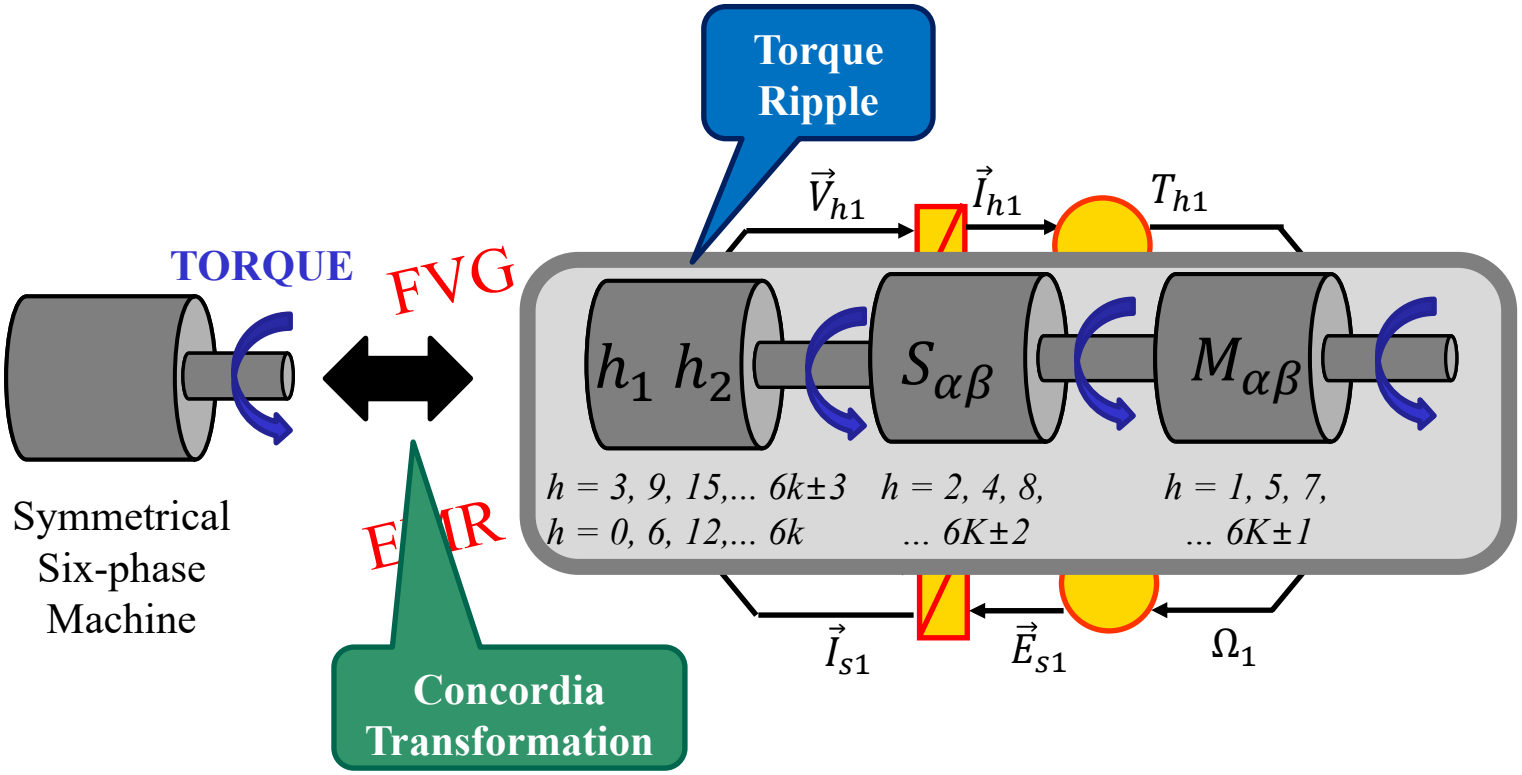
RIMM (Redundant Inverter Multiple Machines) topology [1,4]

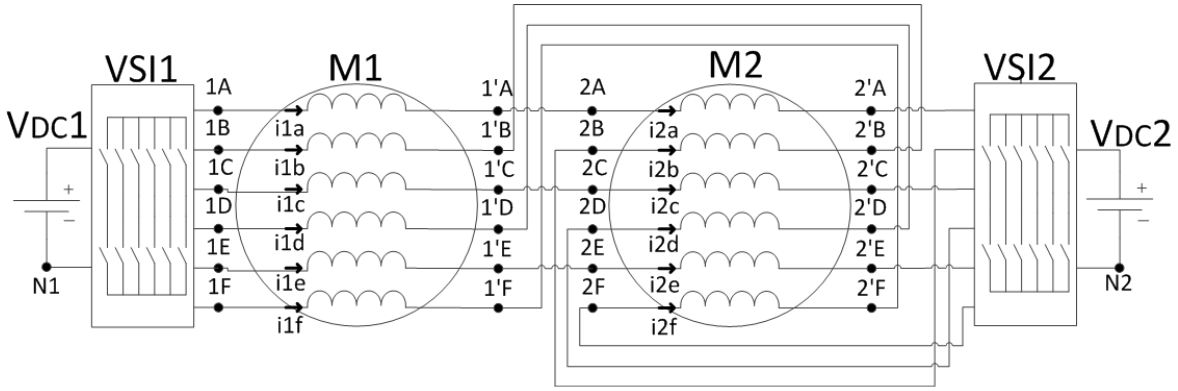
- 2 6-phase series coupled PMSM;
- Special electric coupling
- 2 voltage sources;
- 12 inverter legs (24 transistors);
- 6 current sensors;




[1] T. J. dos Santos Moraes, N. K. Nguyen, E. Semail, F. Meinguet, et M. Guerin, « Dual-Multiphase Motor Drives for Fault-Tolerant Applications: Power Electronic Structures and Control Strategies », *IEEE Transactions on Power Electronics*, p.572-580, janv 2018.

## Decomposition of a multiphase machine in fictitious machines [2]



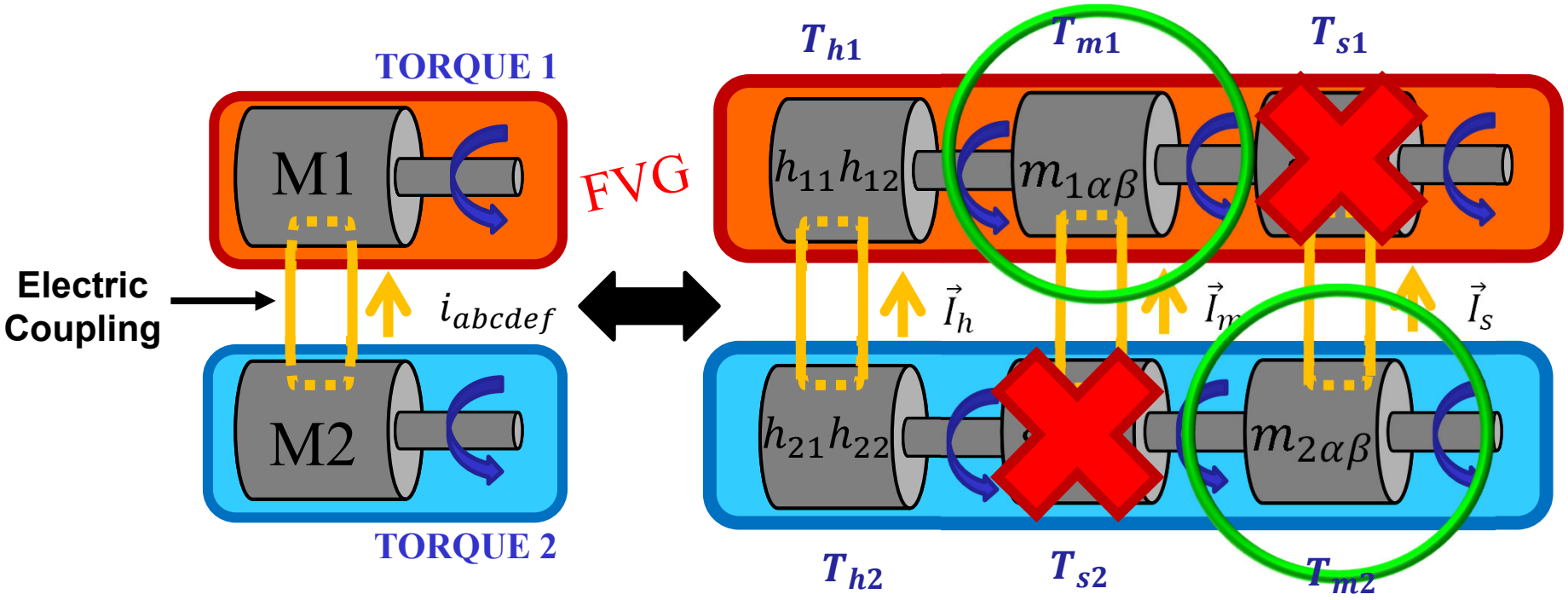



**Secondary machines of 6-phase symmetric machines**

**Main machines electric decoupled**

**Do NOT generate torque**

Back-EMF even-harmonics are null **[1], [2]**



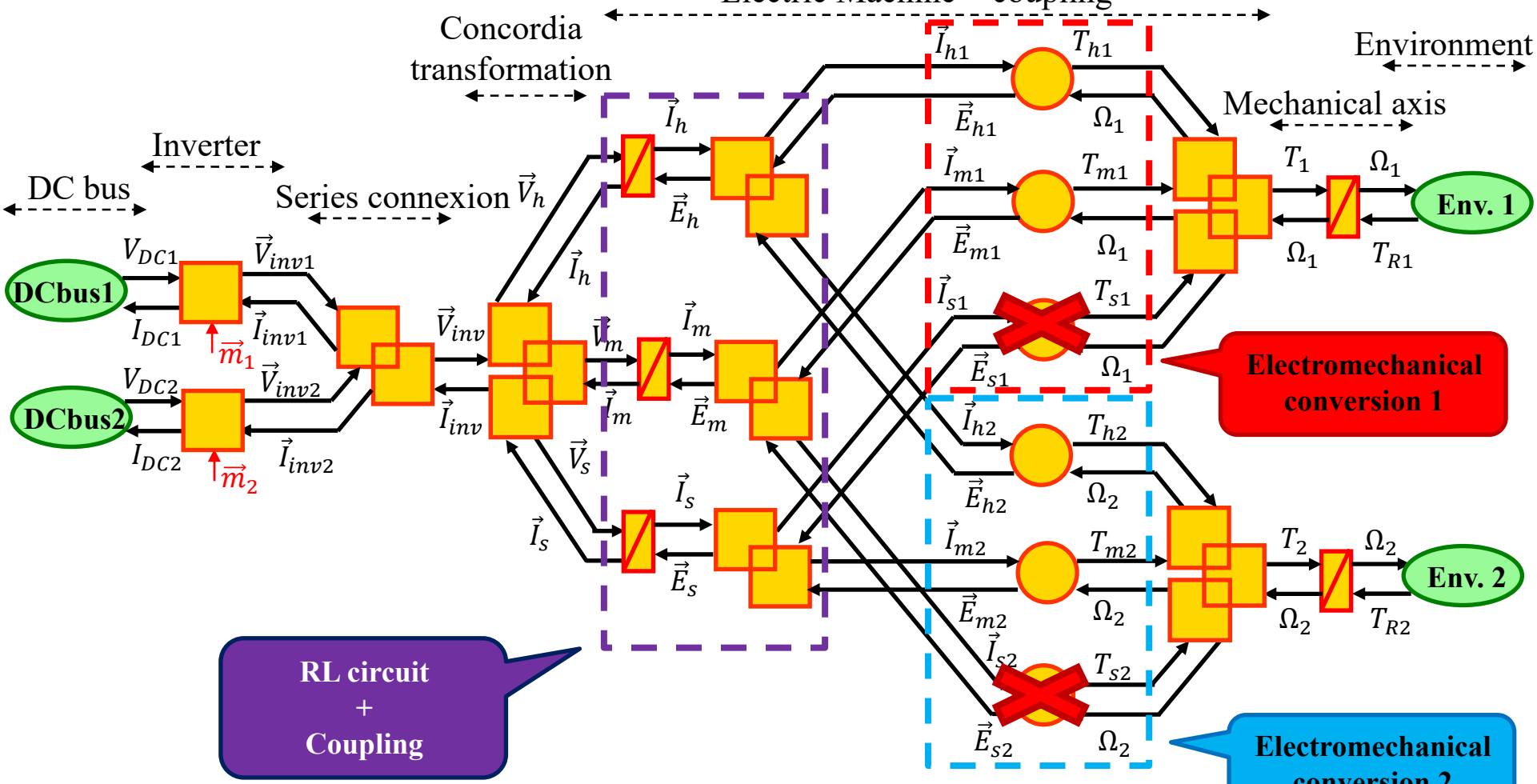

# « PART 2 : EMR STRUCTURE »

A tool for designing DRIVE

## - EMR Structure -



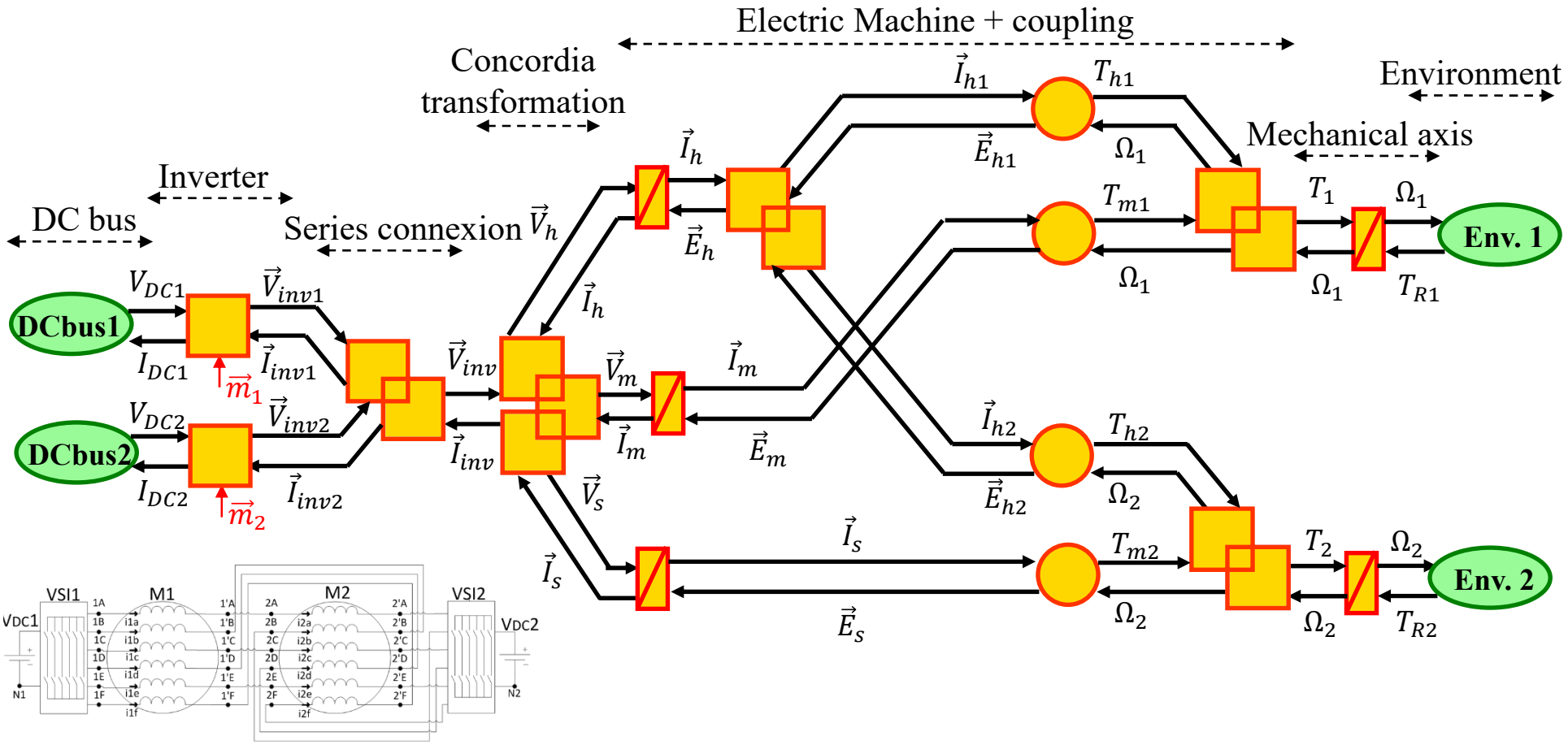





Independent speed /torque ?

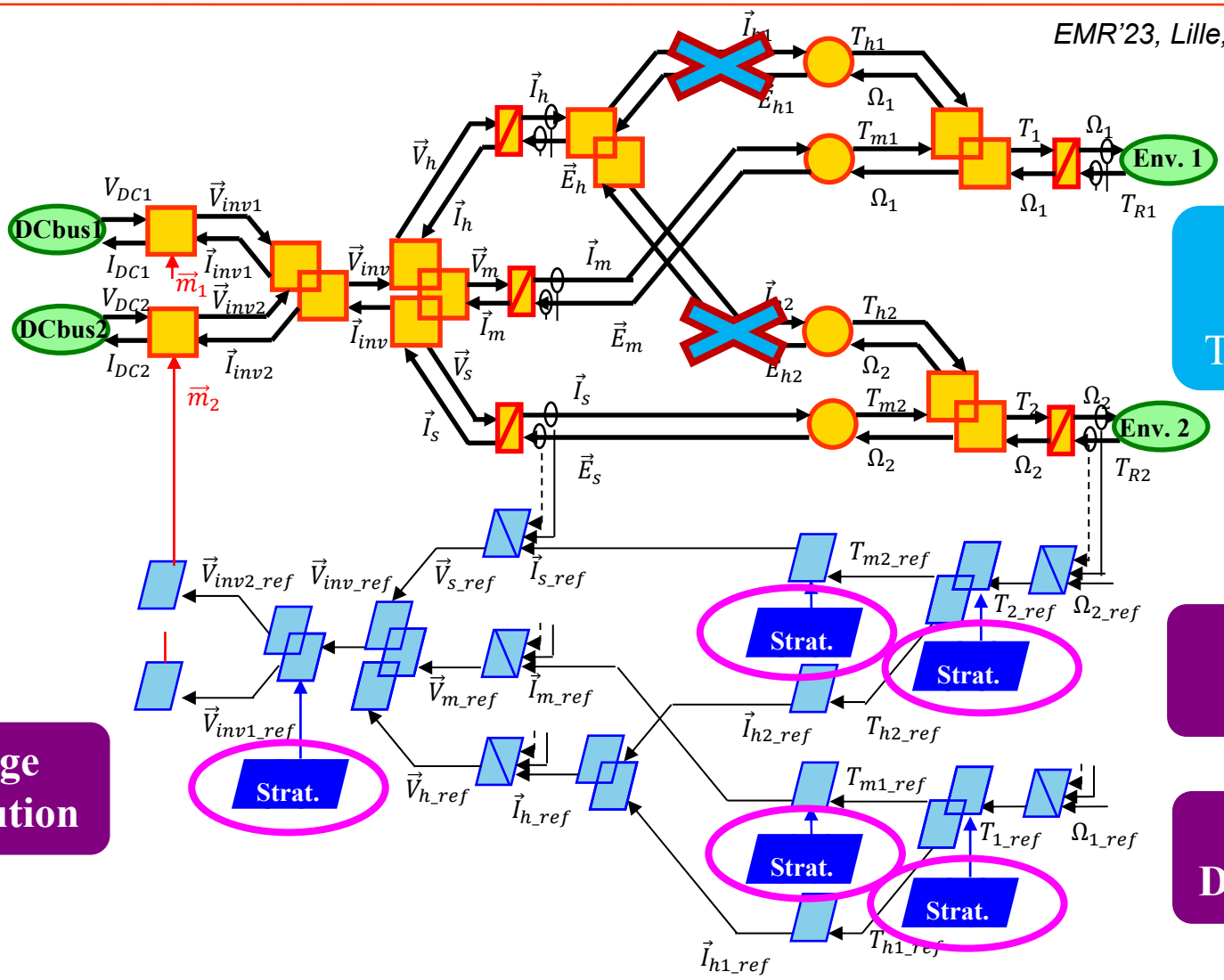
Partial Solution by machine design

# Reduced modeling with assumption of negligeable $E_{s2}$ $E_{s1}$ EMFs



## - EMR Structure -






$T_{h1}$ and $T_{h2}$ = Torque Ripple

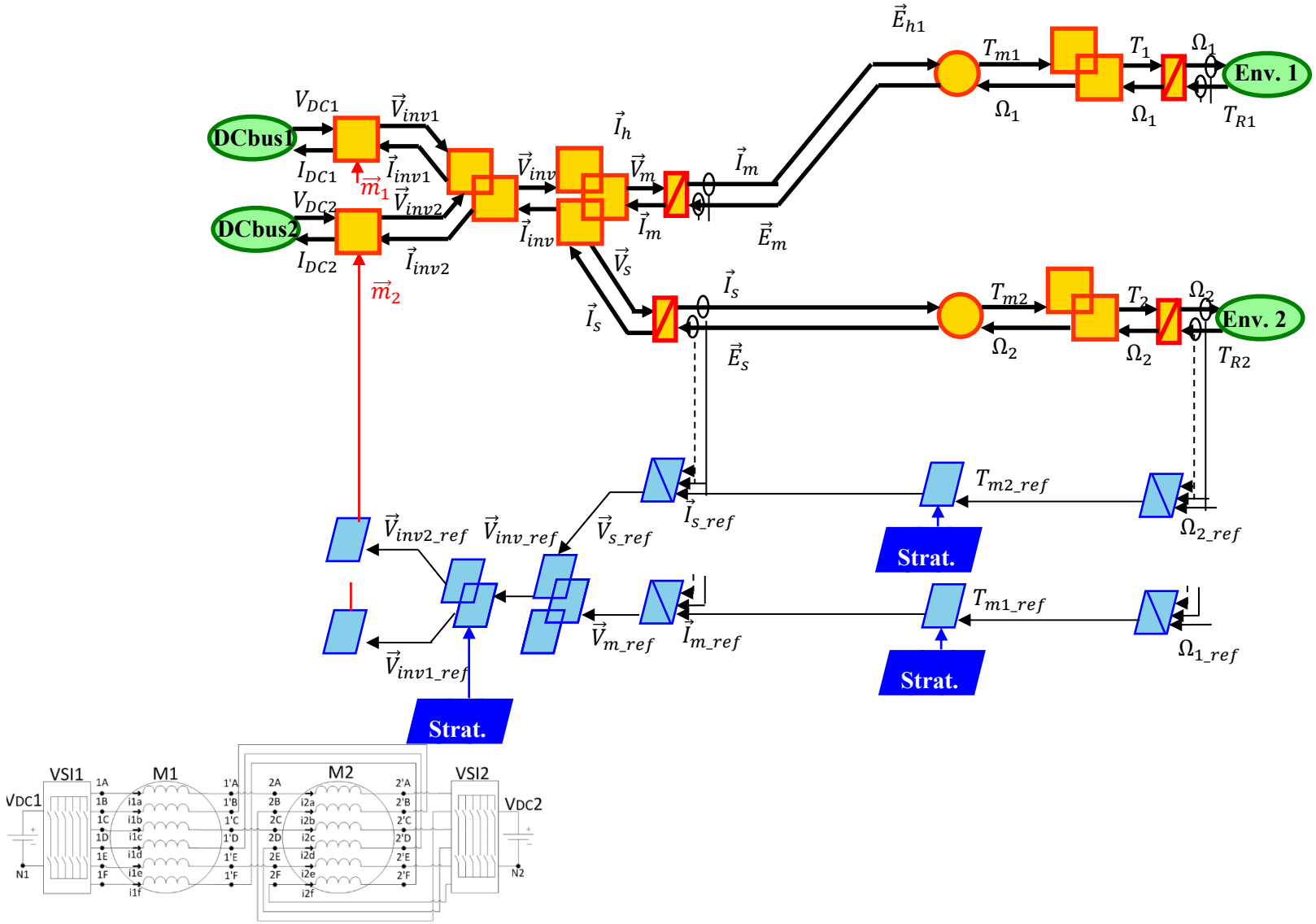
**MTPA Strategy**

**Voltage distribution**

**Torque Distribution**

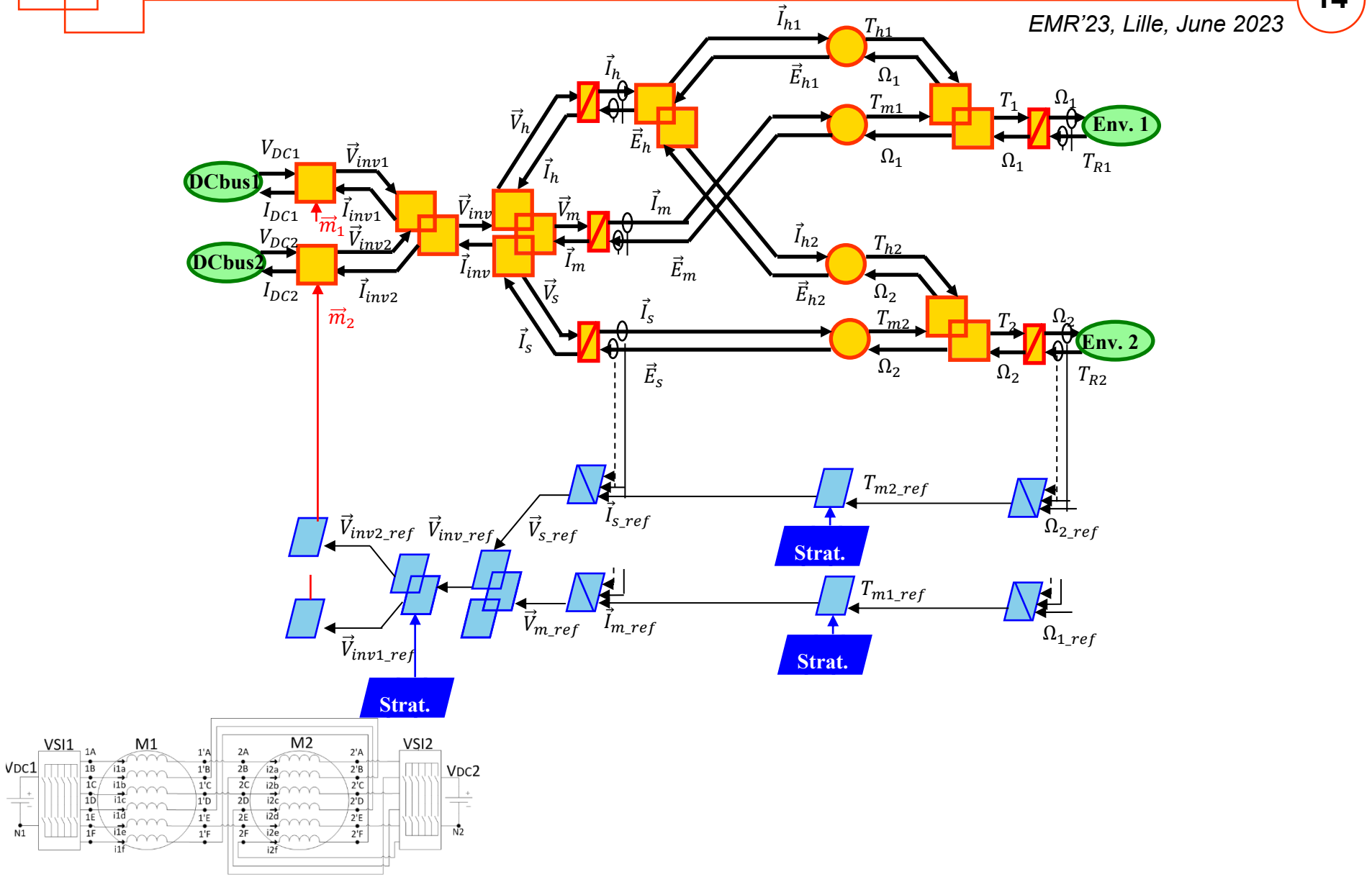
## - EMR Structure -





## - EMR Structure -





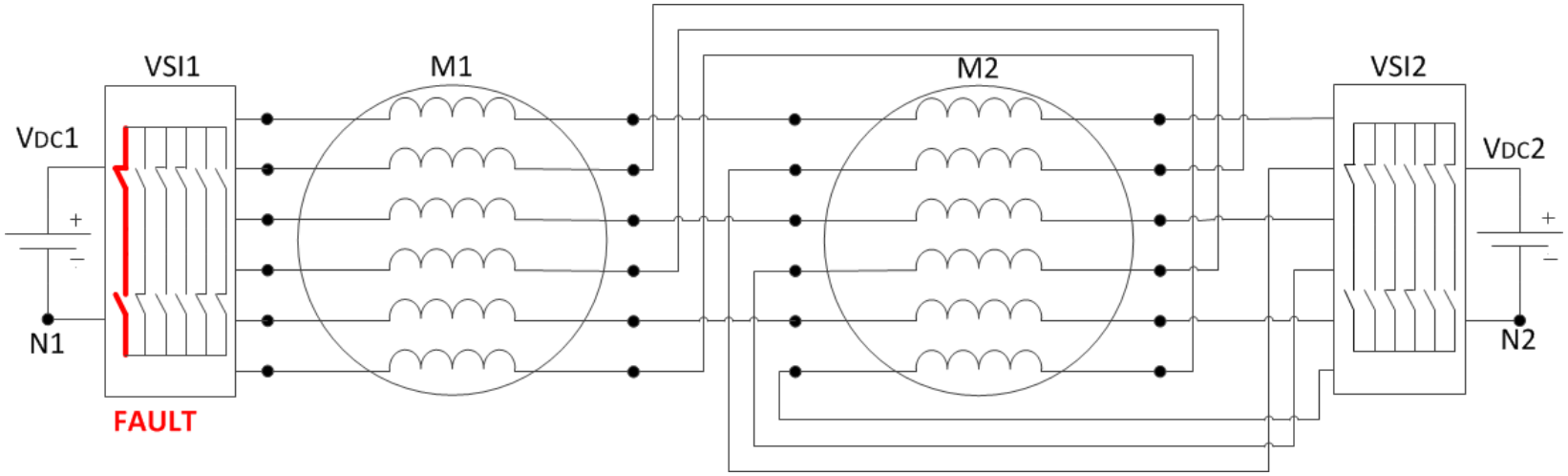
# « PART 3 : Control strategy in fault mode »

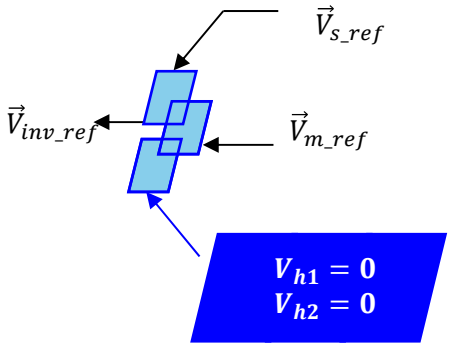
TESTING THE DIFFERENT STRATEGIES

**Fault:**

**Short-circuited Transistor**

- One of the most common drive faults
- One transistor blocked at the "on" state;
- Protection opens the other transistor of the faulty leg;

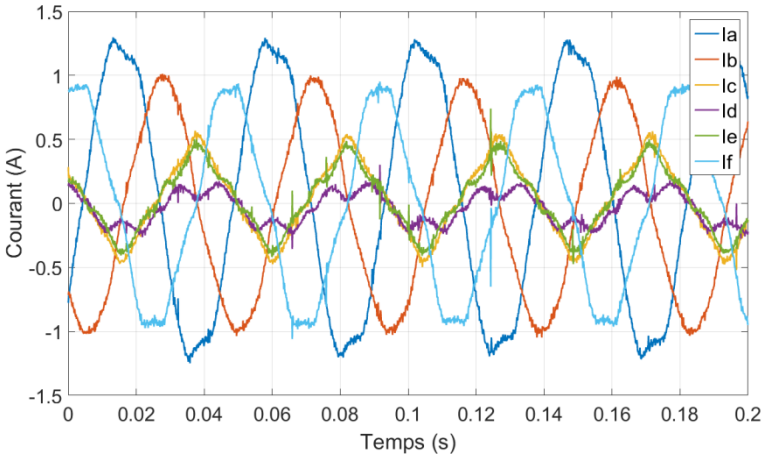




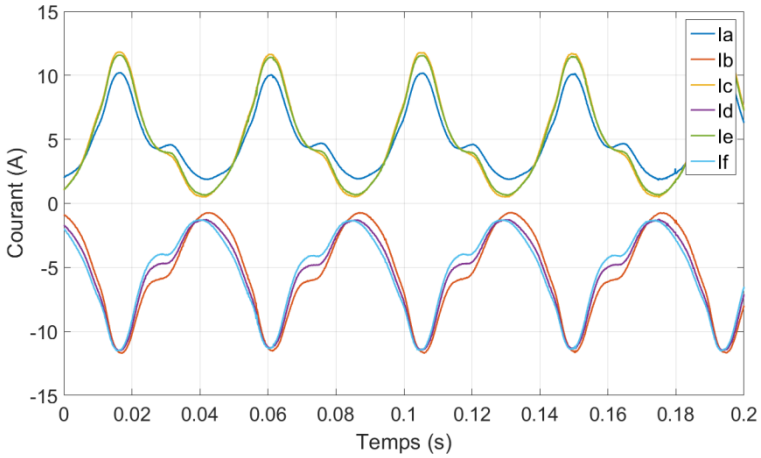

- **Simple** implementation BUT;
- High currents in degraded mode (9 times higher);
- Constant component on the currents;

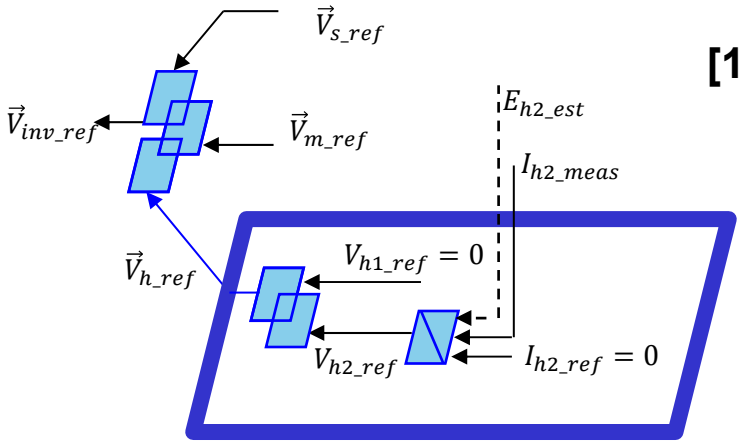
## EXPERIMENTAL RESULTS

### Currents in Normal Mode




### Currents in Degraded Mode



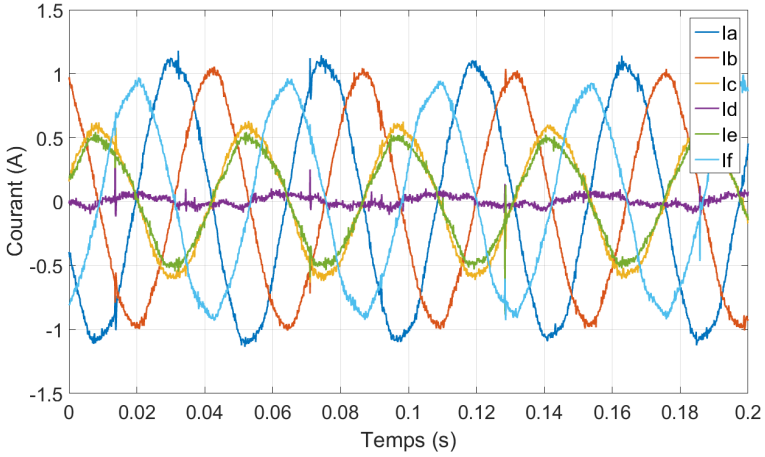



**[1]**

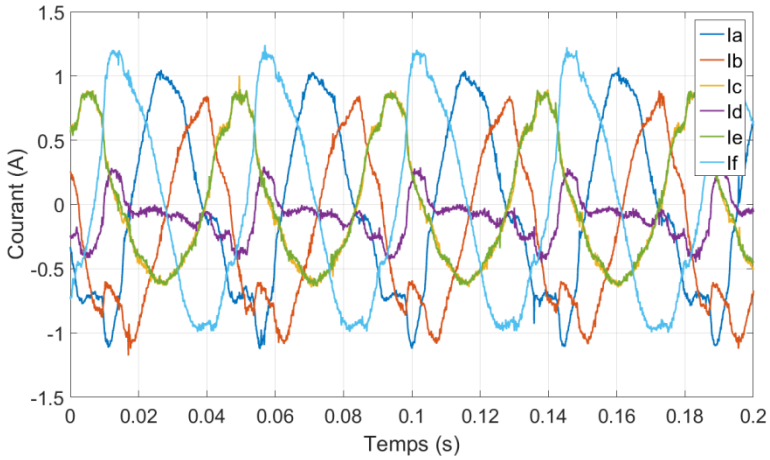
- Lower currents;
- Non-linear behavior;
- No degrees of freedom for the degraded mode;

## EXPERIMENTAL RESULTS

### Currents in Normal Mode



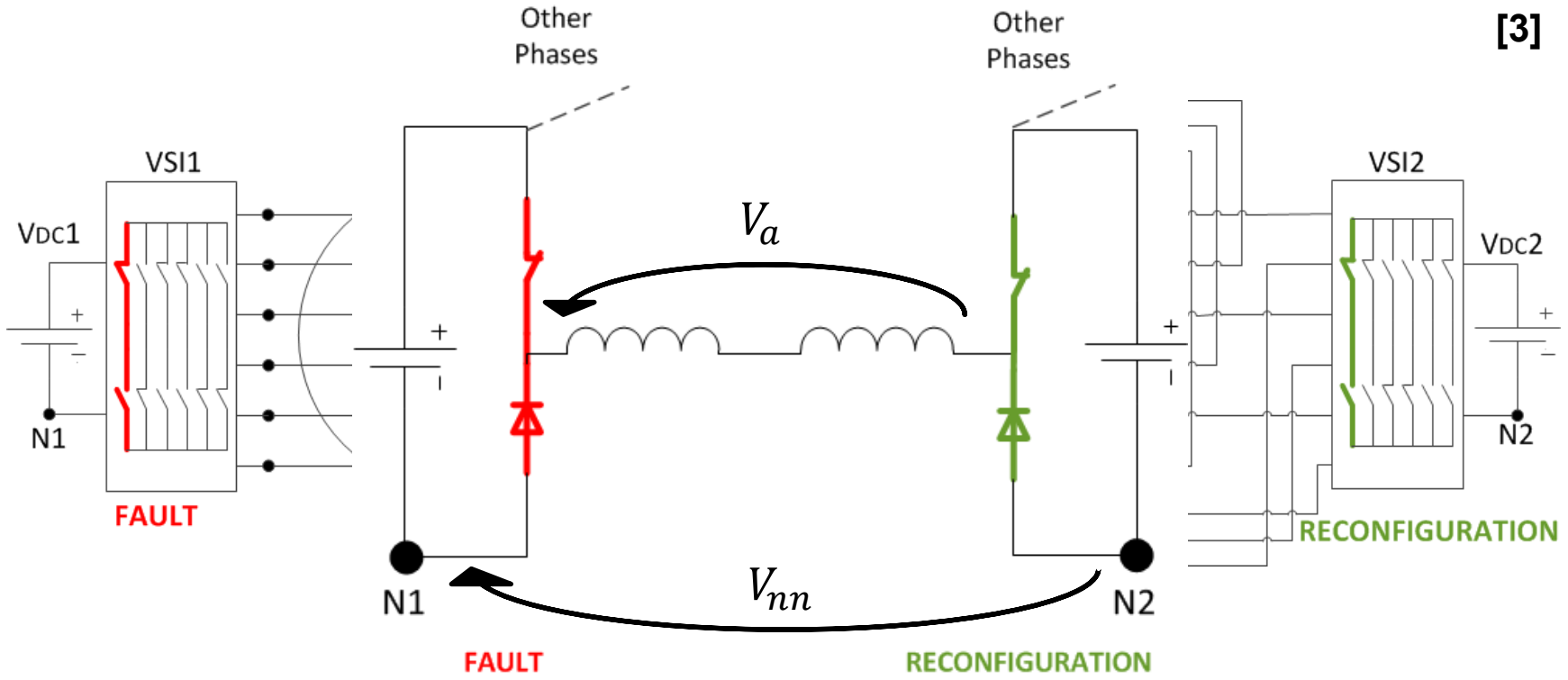

### Currents in Degraded Mode



## - Complete Reconfiguration -



[3]



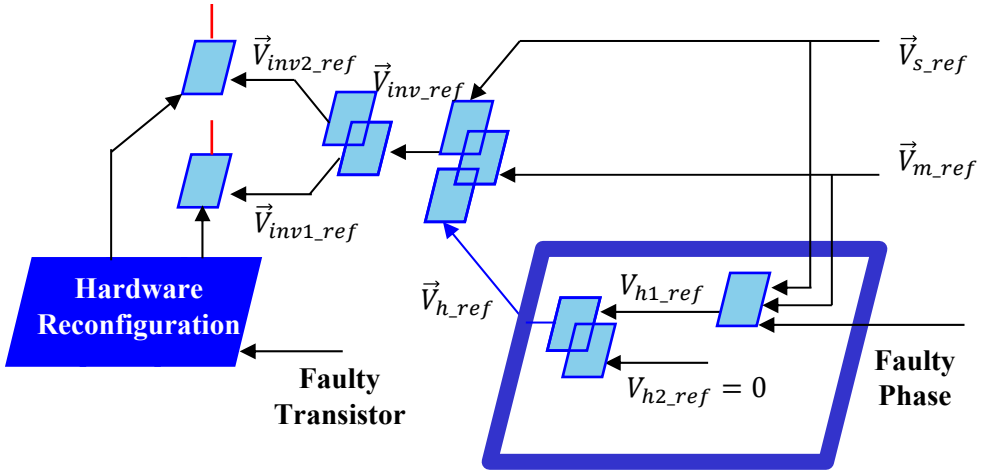

*Example: Fault in phase A*

$$V_{nn} = V_a$$
$$V_{h1} = \sqrt{6}\, V_a$$

$$V_{nn} = -\frac{1}{6}\left(V_a + V_b + V_c + V_d + V_e + V_f\right)$$
$$V_{h1} = \frac{1}{\sqrt{6}}\left(V_a + V_b + V_c + V_d + V_e + V_f\right)$$
$$V_{nn} = -\frac{1}{\sqrt{6}} V_{h1}$$

## - Complete Reconfiguration -

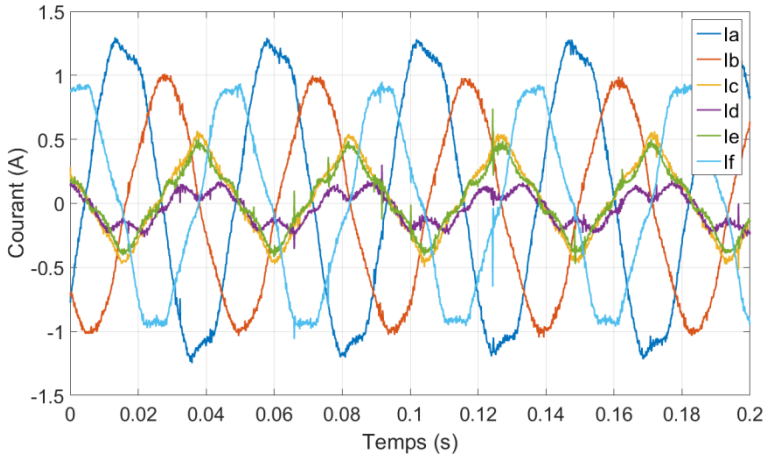




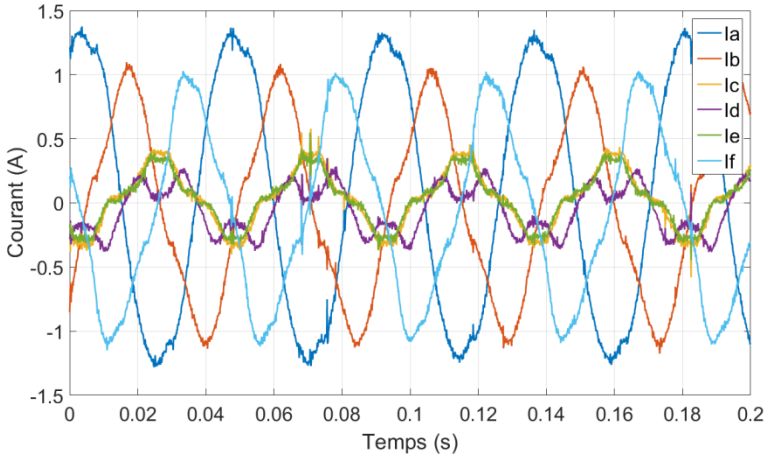

- Currents in **degraded mode** similar to currents in **normal mode;**
- Need of fault-detection;

## EXPERIMENTAL RESULTS

### Currents in Normal Mode




### Currents in Degraded Mode




# « CONCLUSION »

## Conclusion



1. **FVG and EMR as tools for analysis and design of complex system**
2. **EMR highlights the degrees of freedom that might be used in a control strategy;**
3. **In degraded mode different strategies are tested;**

Questions ?


# « BIOGRAPHIES AND REFERENCES »

**Dr. Ngac Ky NGUYEN**
Arts et Métiers ParisTech, L2EP, France
PhD in Electrical and Electronics Engineering at University of Haute Alsace (2010)
Associate Professor since 2012
Research topics: Synchronous Motors and Fault-Tolerant Multiphase Drives.

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PhD in Electrical Engineering at University of Lille (2000)
Professor since 2010
Research topics: Multiphase drives and Multi-machine Multi-converter drives

[1] T. J. dos Santos Moraes, N. K. Nguyen, E. Semail, F. Meinguet, et M. Guerin, « Dual-Multiphase Motor Drives for Fault-Tolerant Applications: Power Electronic Structures and Control Strategies », IEEE Transactions on Power Electronics, p.572-580, janv 2018.

[2] Semail, E. Levi, A. Bouscayrol, et X. Kestelyn, « Multi-machine modelling of two series connected 5-phase synchronous machines: effect of harmonics on control », *European Conference on Power Electronics and Applications*, 2005, p. 10 pp.-pp.P.10.

[3] N. K. Nguyen, F. Meinguet, E. Semail, et X. Kestelyn, « Fault-Tolerant Operation of an Open-End Winding Five-Phase PMSM Drive With Short-Circuit Inverter Fault », *IEEE Transactions on Industrial Electronics*, vol. 63, nº 1, p. 595-605, janv. 2016.

[4] R. Michel, M. Bekemans, M. Guillaume, E. Semail, « Device for controlling two multiphase motors », Patent EP2903155 (B1) — 2017-07-05,