

*Détection de défauts au sein d'onduleurs  
et reconfiguration de la commande pour  
l'entraînement d'une machine synchrone  
à aimants permanents*

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Co-promoteur: Prof. Michel KINNAERT



# Plan

## 1. Introduction

- research topic
- different fault types
- objectives

## 2. Inverter fault detection

## 3. Fault tolerant topologies

## 4. Control reconfiguration

## 5. Conclusions and perspectives

# Research topic

- PhD research topic:

« Fault tolerance of permanent magnet synchronous machines and associated static converters - design and validation of innovative topologies »

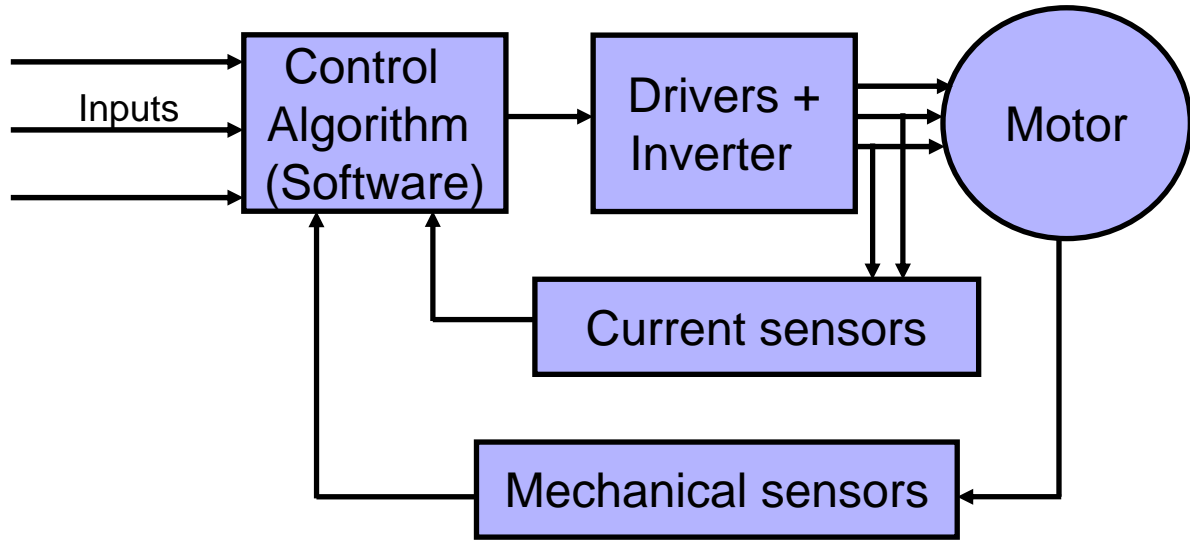
- BEAMS Energy

- FRIA grant

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

- sensor faults (position, current,...)

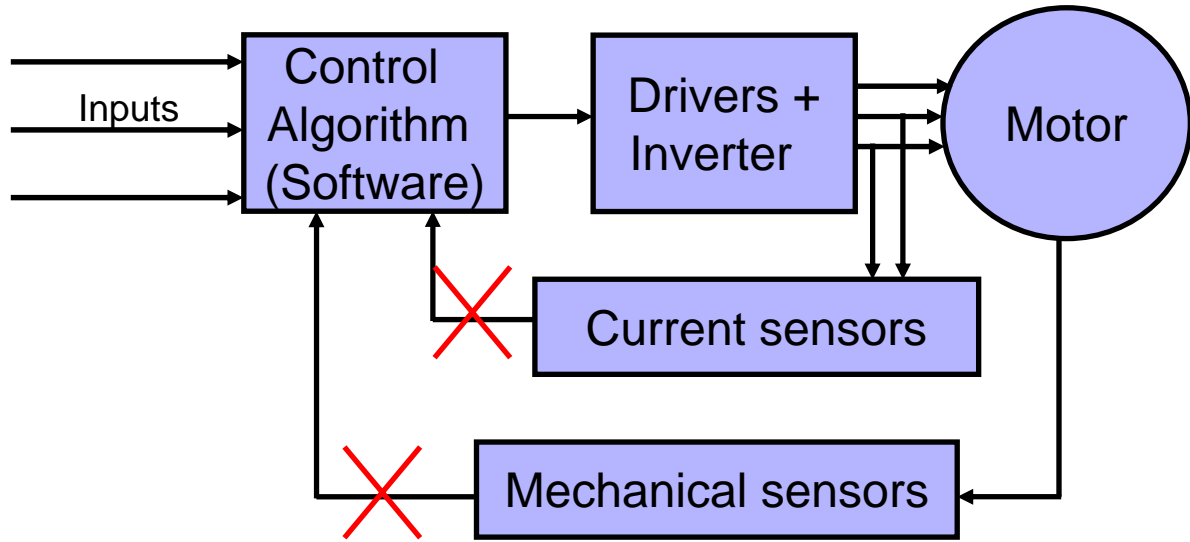


- electrical faults (inverter, machine,...)

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

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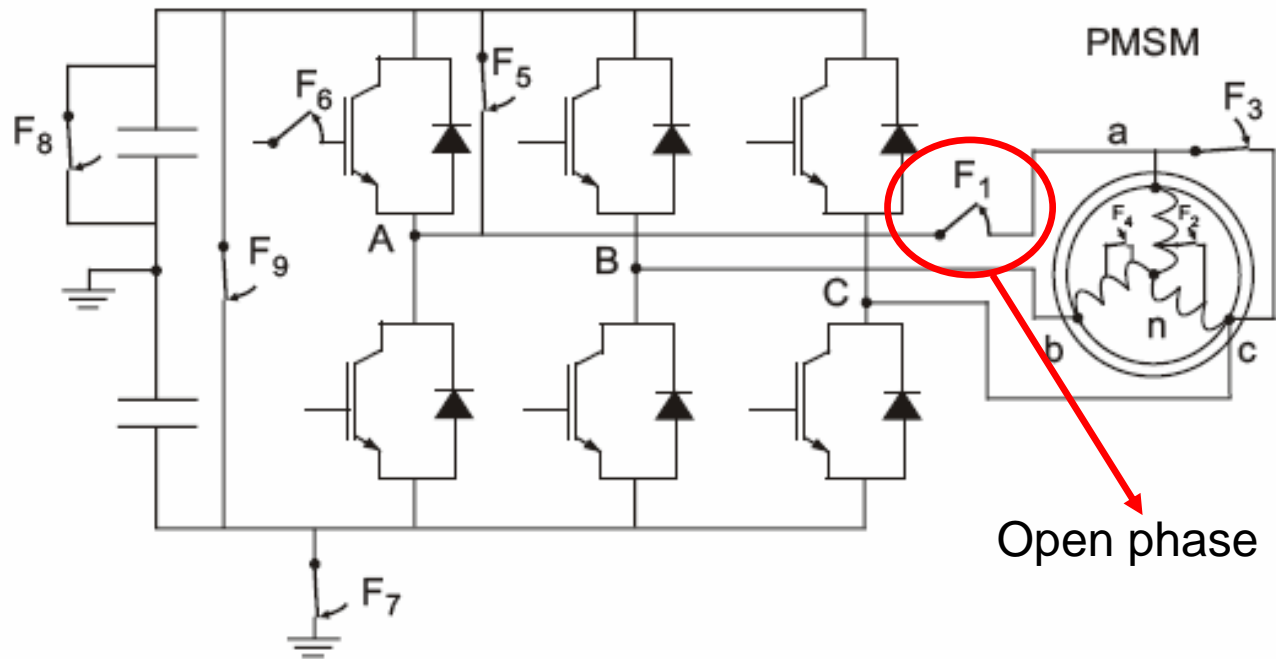


- electrical faults (inverter, machine,...)

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

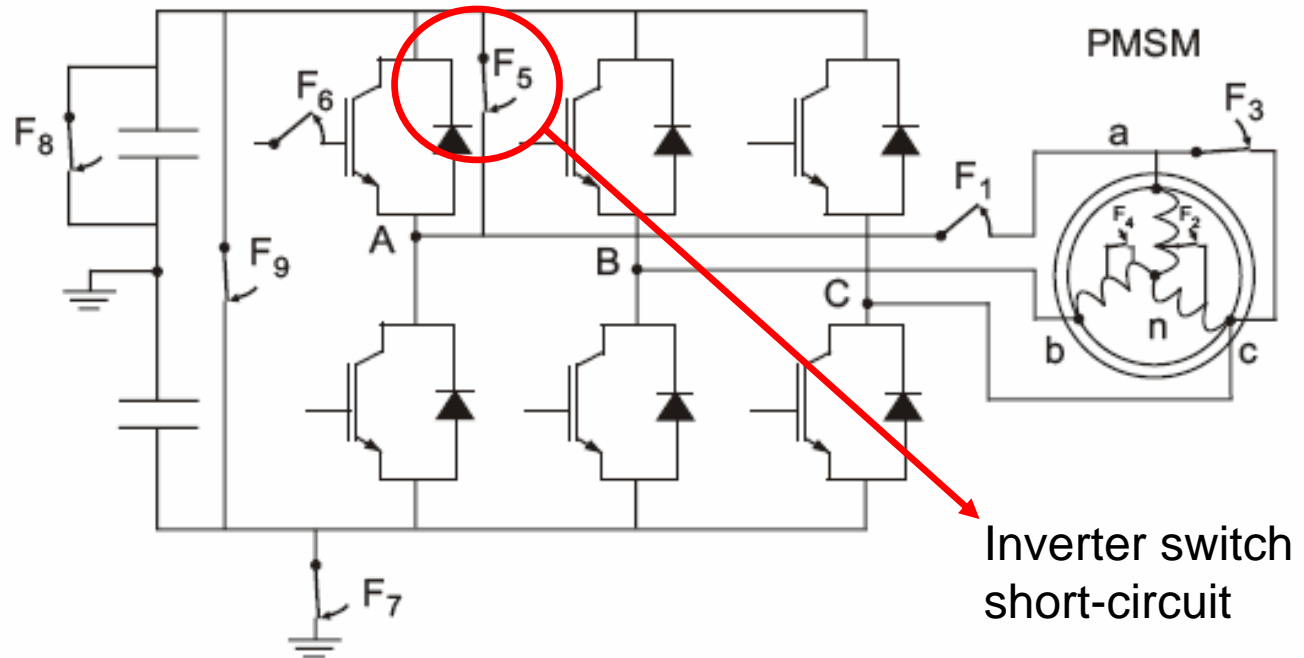
- sensor faults (position, current,...)
- electrical faults (inverter, machine,...)



1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

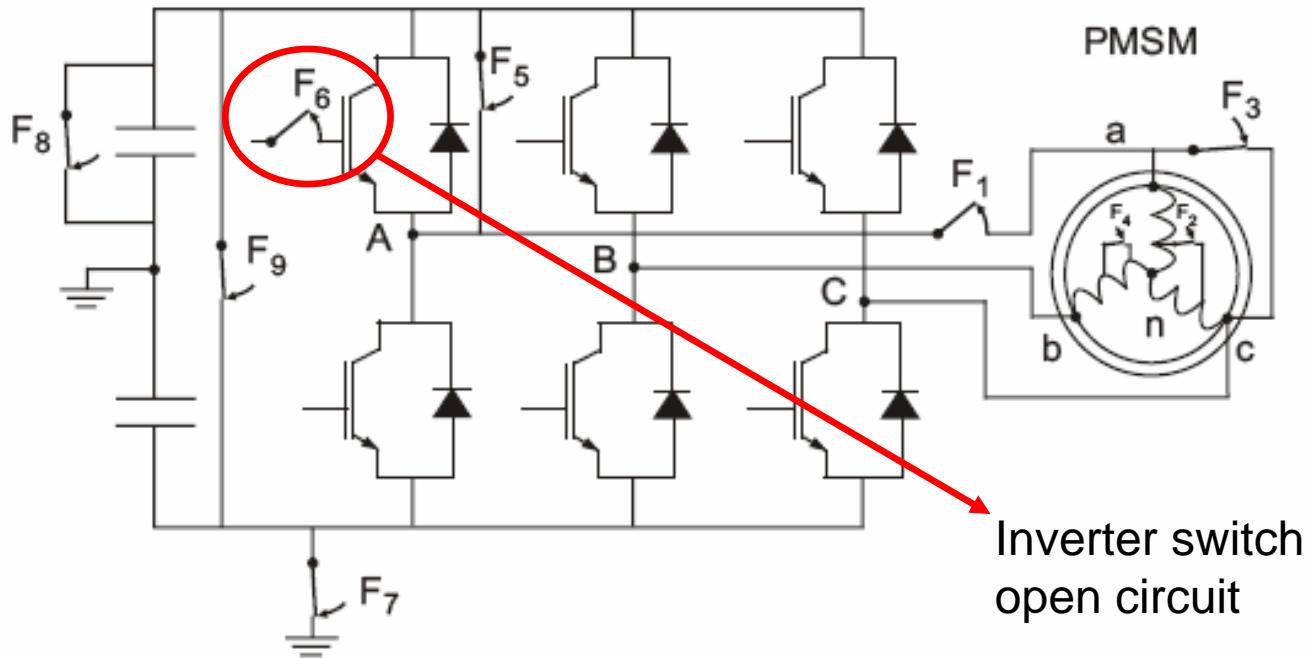
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1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

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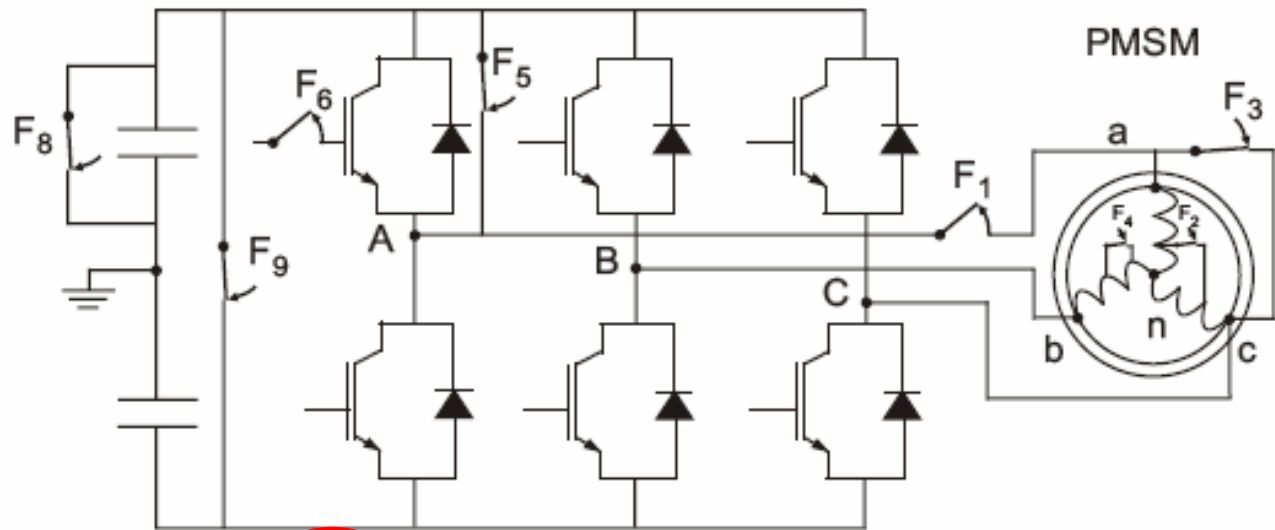


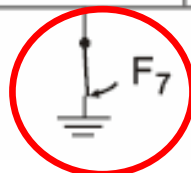
Inverter switch open circuit

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

- sensor faults (position, current,...)
- electrical faults (inverter, machine,...)



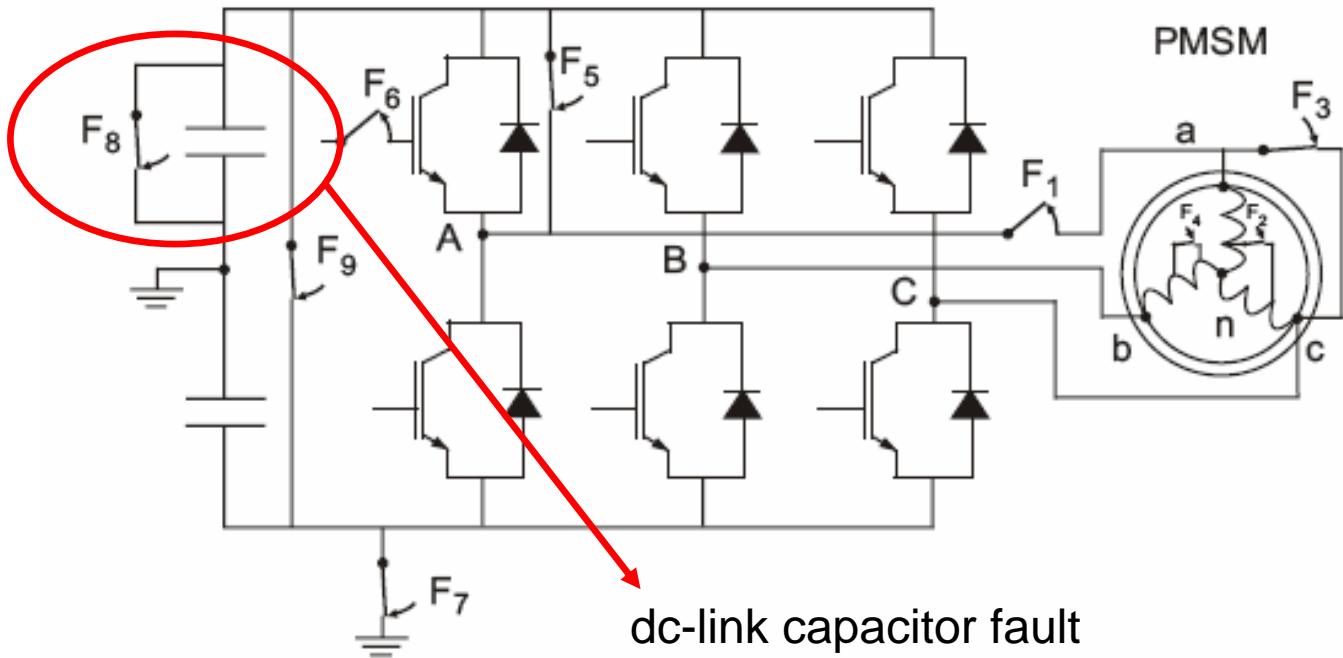
  $F_7$  → dc-link fault

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

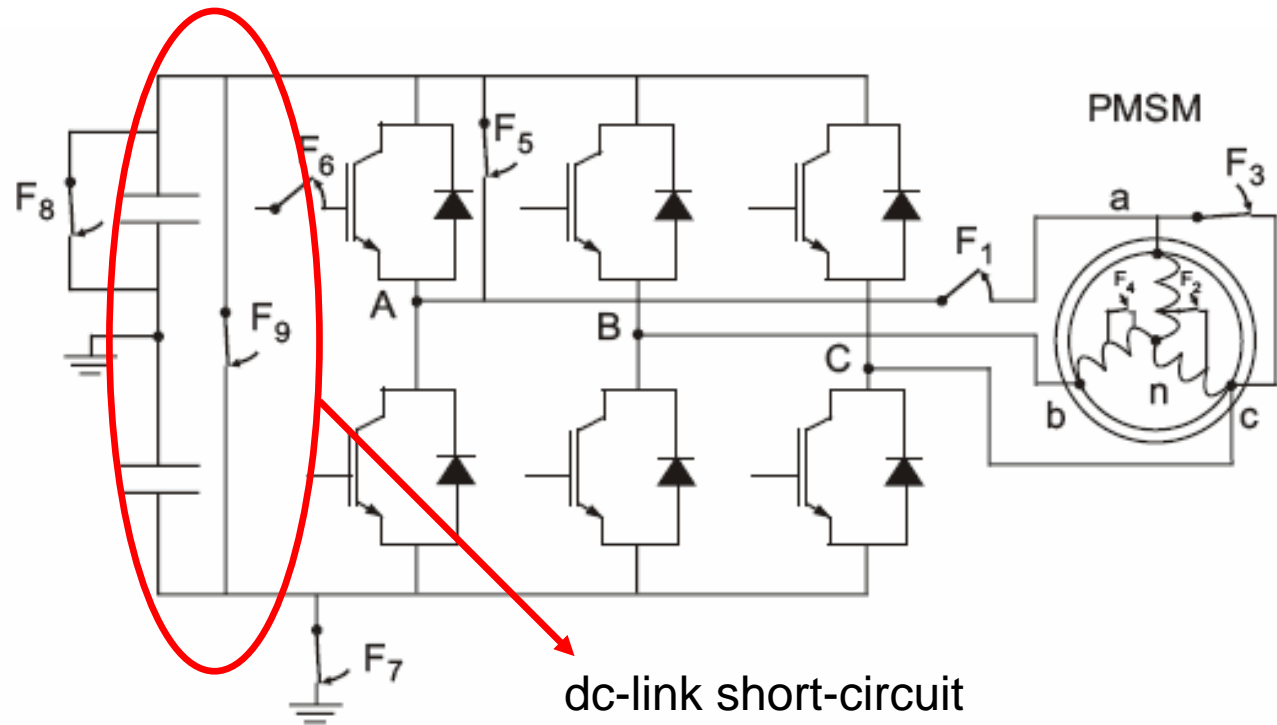
- sensor faults (position, current,...)
- electrical faults (inverter, machine,...)

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives



# Different fault types

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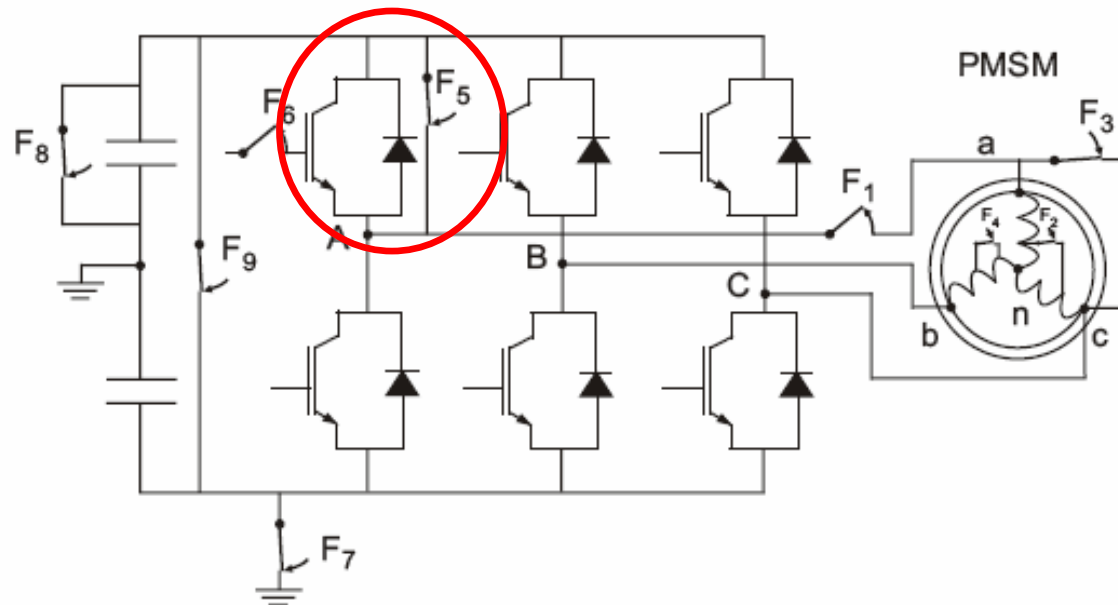


dc-link short-circuit

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Different fault types

- sensor faults (position, current,...)
  - electrical faults (inverter, machine,...)
- Inverter switch short-circuit: one of the most critical!!!



1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Objectives

To do as well as possible when a fault occurs...

## Sensor faults:

- detection and localisation (software)
- reconfiguration (software)
- sensorless control

## Electrical faults:

- detection and localisation (hardware/software)
- isolation
- reconfiguration (hardware/software)

1. Introduction
  - research topic
  - different fault types
  - objectives
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Plan

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

➤ Some commercial drivers include fault detection:

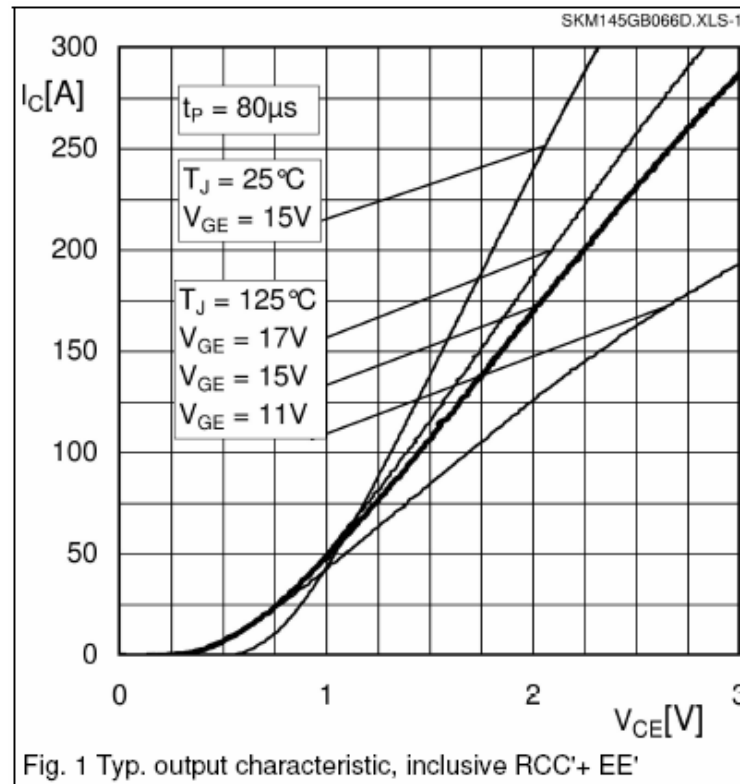
- overcurrent protection
- short-circuit protection ( $V_{ce}$  monitoring)
- gate-undervoltage protection
- gate-overnvoltage protection
- thermal protection

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

- short-circuit protection ( $V_{ce}$  monitoring)

## IGBTs characteristic curve

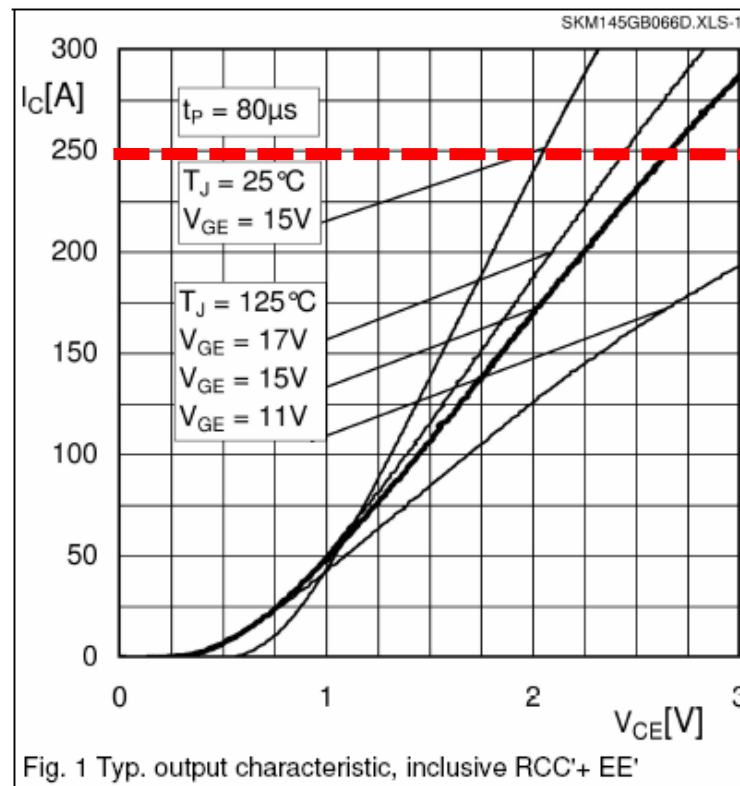


1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

- short-circuit protection ( $V_{ce}$  monitoring)

## IGBTs characteristic curve



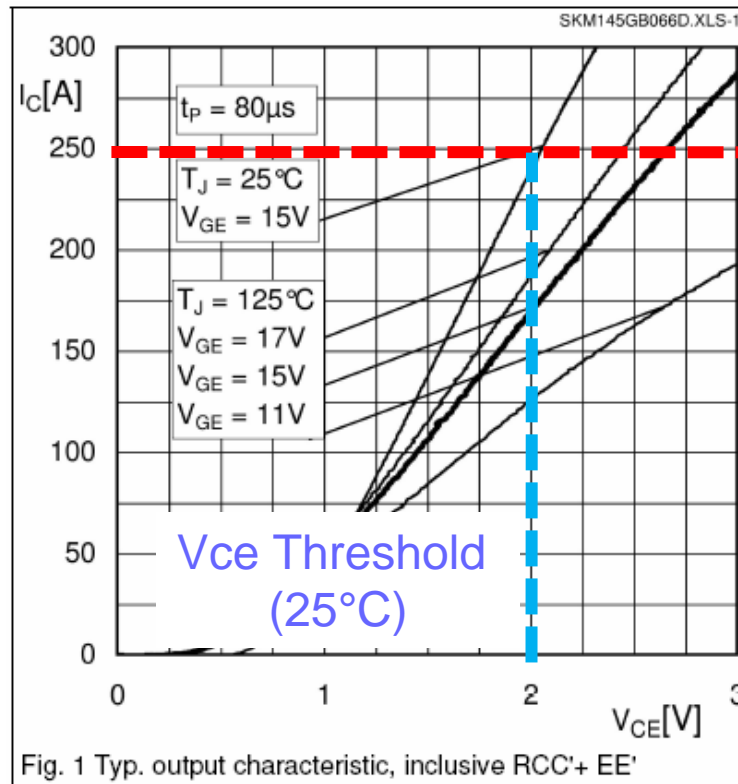
Current  
Threshold

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

- short-circuit protection ( $V_{ce}$  monitoring)

## IGBTs characteristic curve



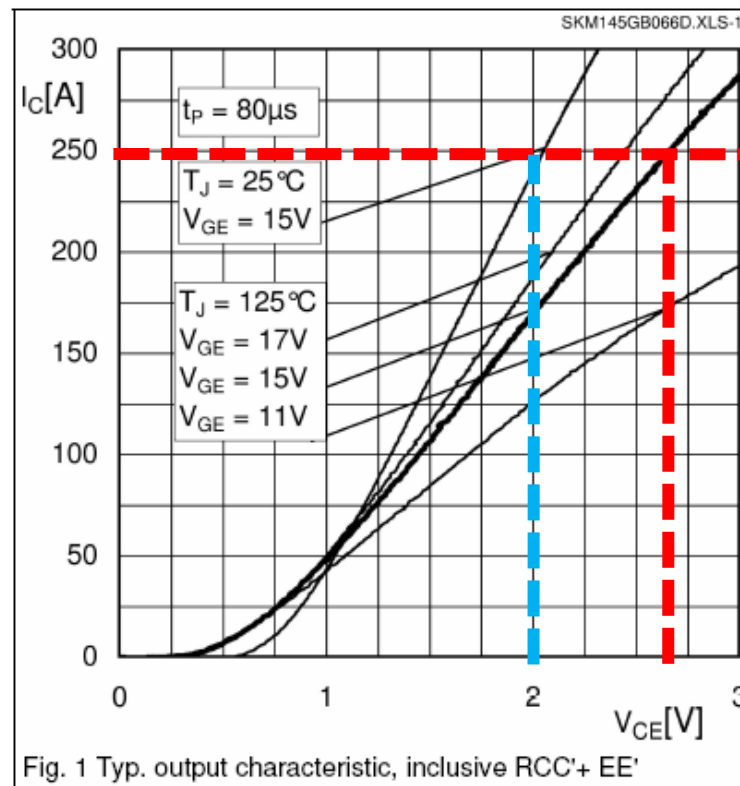
Current Threshold

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

- short-circuit protection ( $V_{ce}$  monitoring)

## IGBTs characteristic curve



Current  
Threshold

Vce Threshold  
(125°C)

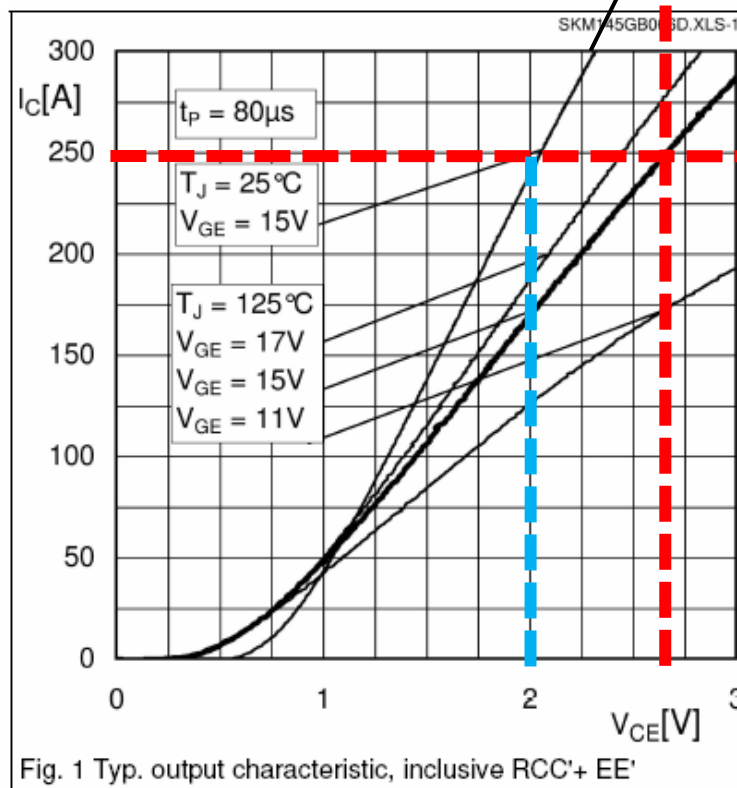
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

- short-circuit protection ( $V_{ce}$  monitoring)

IGBTs characteristic curve

+ de 400 A !!!



Current Threshold

Vce Threshold (125°C)

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

Example:

- driver core Semikron Skyper 32R



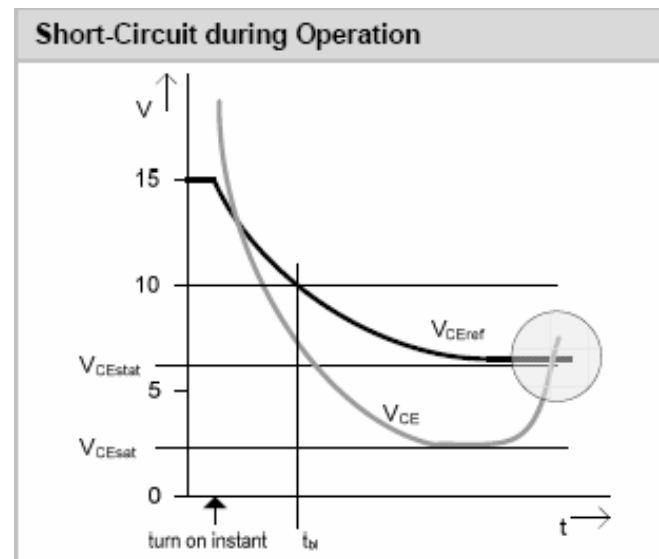
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

Example:

- driver core Semikron Skyper 32R

→ short circuit protection by  $V_{ce}$  monitoring



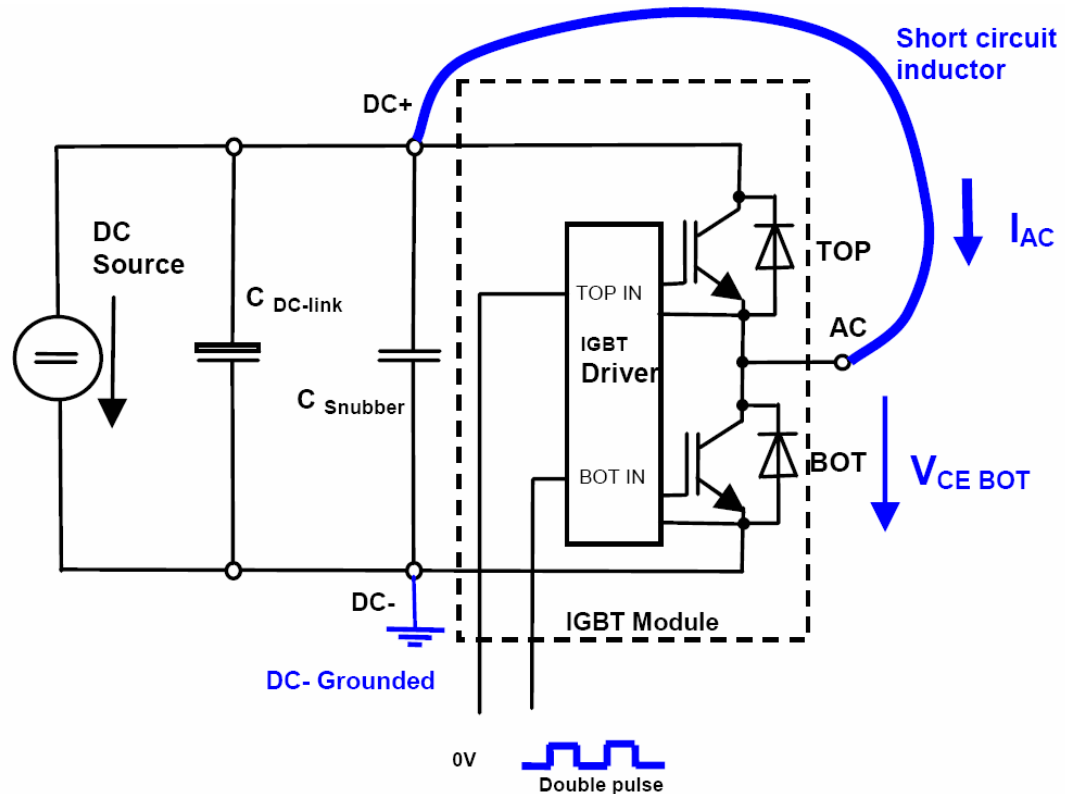
→ shutdown of the leg in case of fault

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

Tests have been realised in collaboration with S.A.B.C.A. on the driver core Semikron Skyper 32R

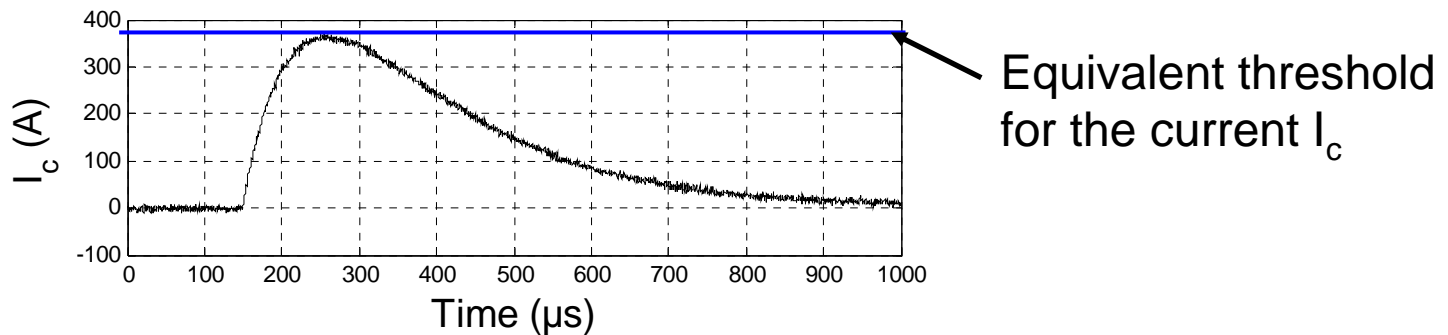
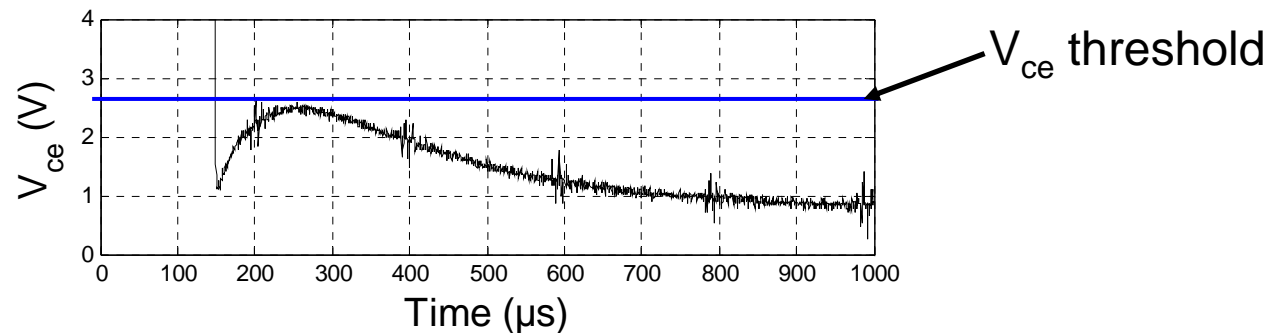
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives



# Inverter fault detection

Tests on the driver core Semikron Skyper 32R

Results: case 1 ( $V_{ce}$  below the threshold)



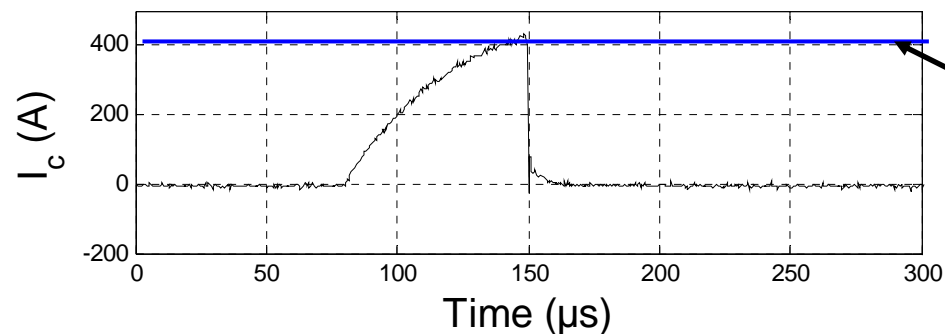
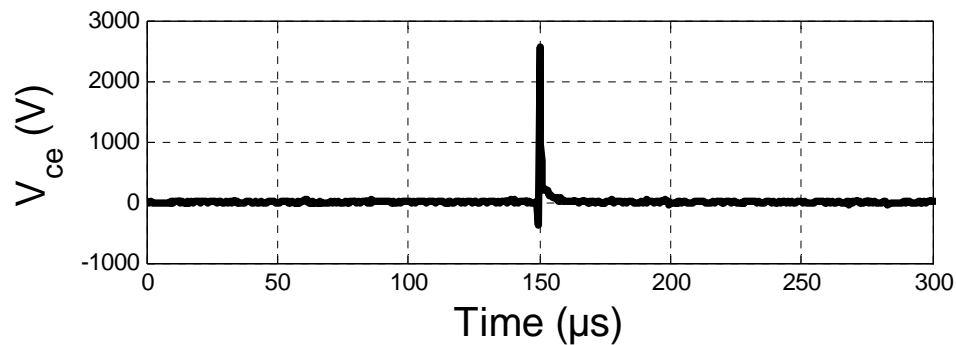
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Inverter fault detection

Tests on the driver core Semikron Skyper 32R

Results: case 2 ( $V_{ce}$  above the threshold)

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives



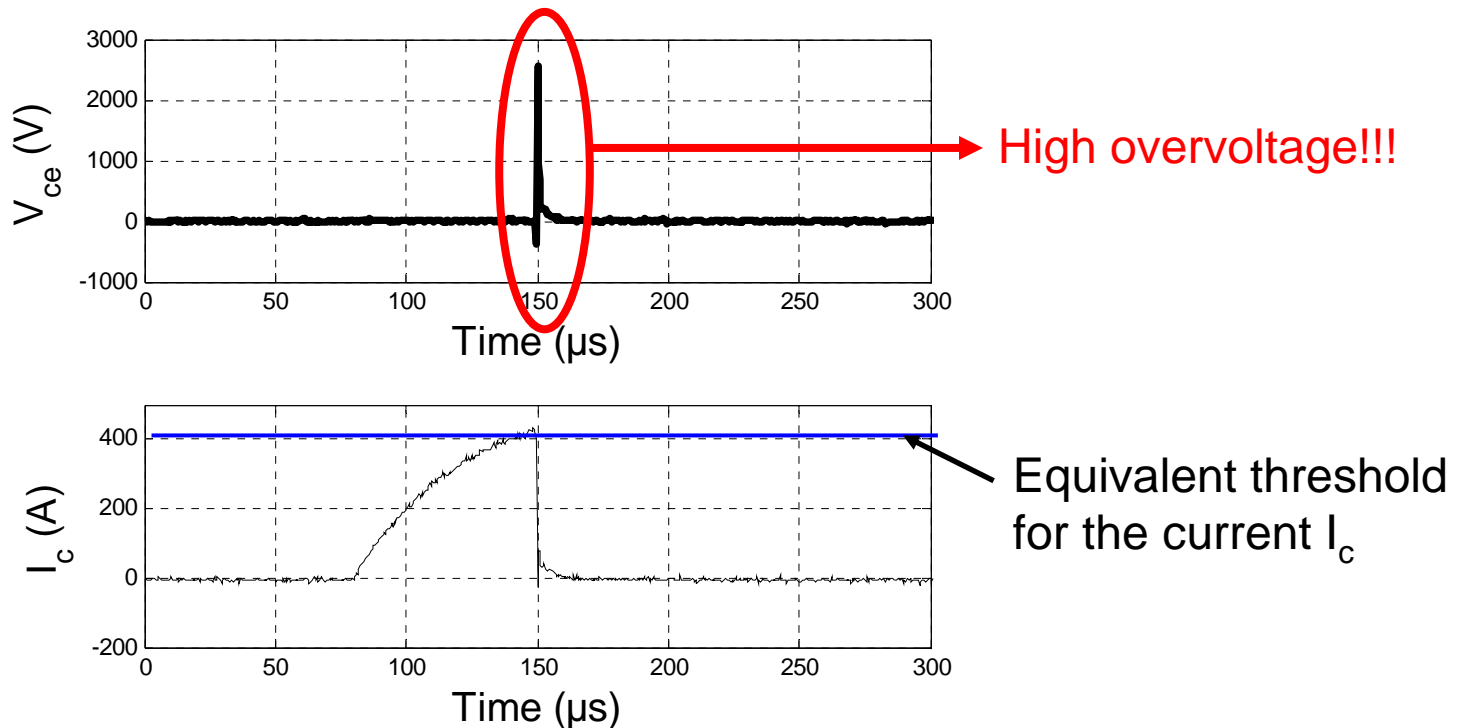
Equivalent threshold  
for the current  $I_c$

# Inverter fault detection

Tests on the driver core Semikron Skyper 32R

Results: case 2 ( $V_{ce}$  above the threshold)

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives



# Inverter fault detection

Overvoltage is dangerous for the other switches

→ we need to reduce the induced voltage to avoid the propagation of the fault

→ new development of the protection:

« soft turn-off »

... to be tested ...

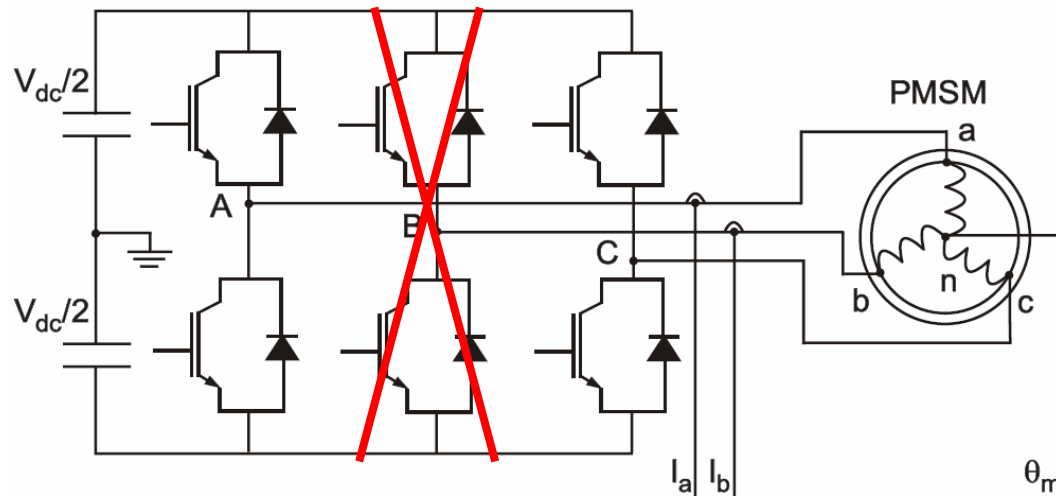
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Plan

1. Introduction
2. Inverter fault detection
- 3. Fault tolerant topologies**
4. Control reconfiguration
5. Conclusions and perspectives

# Fault-tolerant topologies

In case of a single fault in the inverter, the faulty leg can be removed from the system... Then?



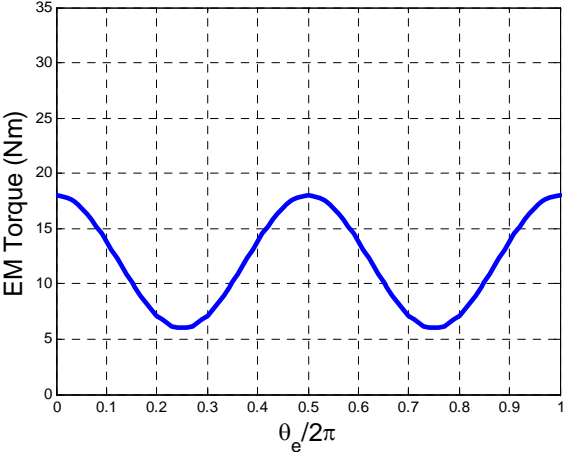
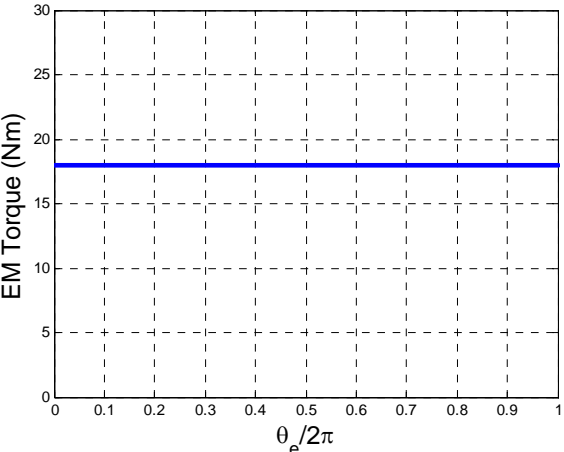
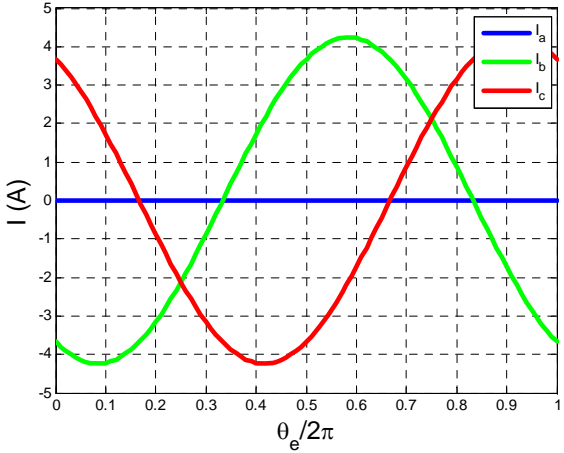
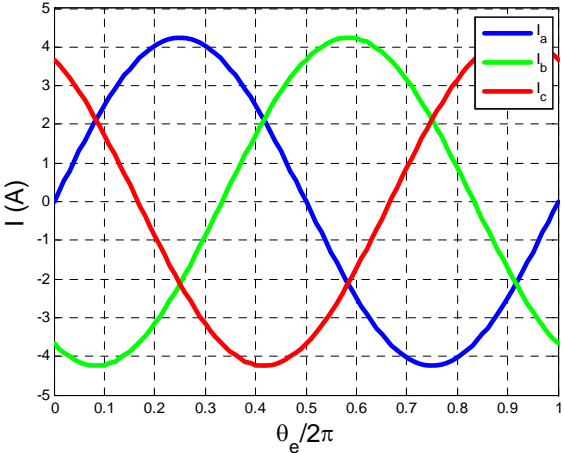
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Fault-tolerant topologies

When one phase opens:

before the fault

after the fault



1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

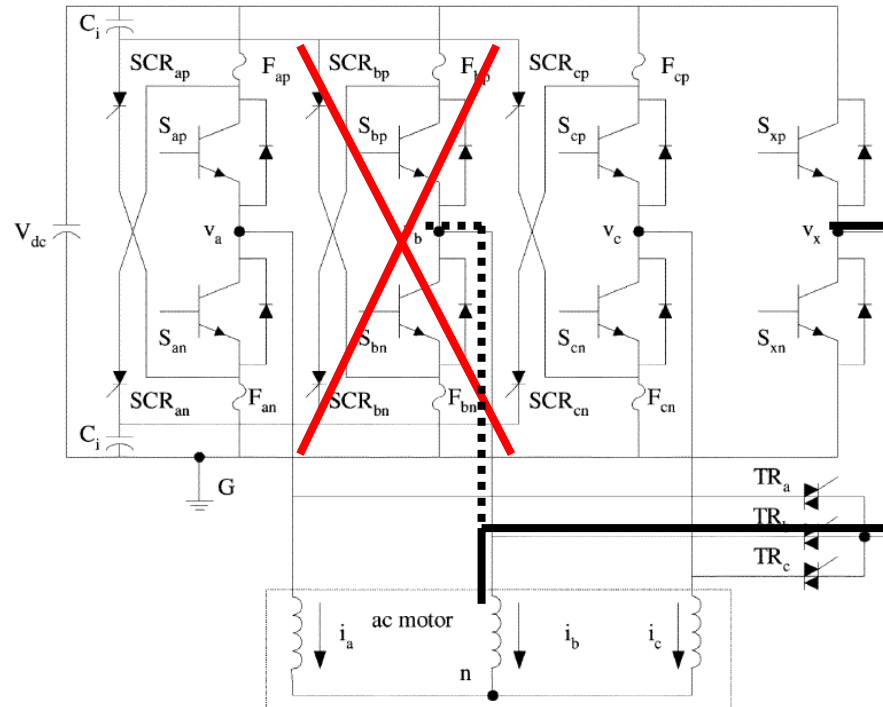
# Fault-tolerant topologies

We need to add an amount of redundancy.

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Fault-tolerant topologies

We need to add an amount of redundancy.  
 Example: a four-leg inverter with a back-up leg

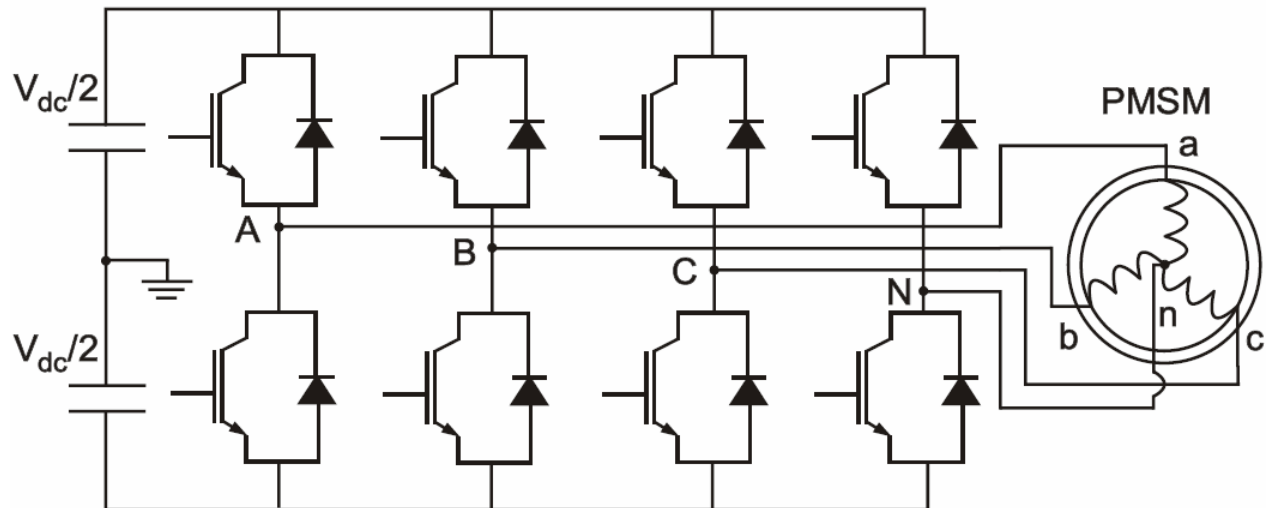


1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Fault-tolerant topologies

## Two ways to use the fourth leg:

- as a back-up leg
- connected to the neutral point of the machine



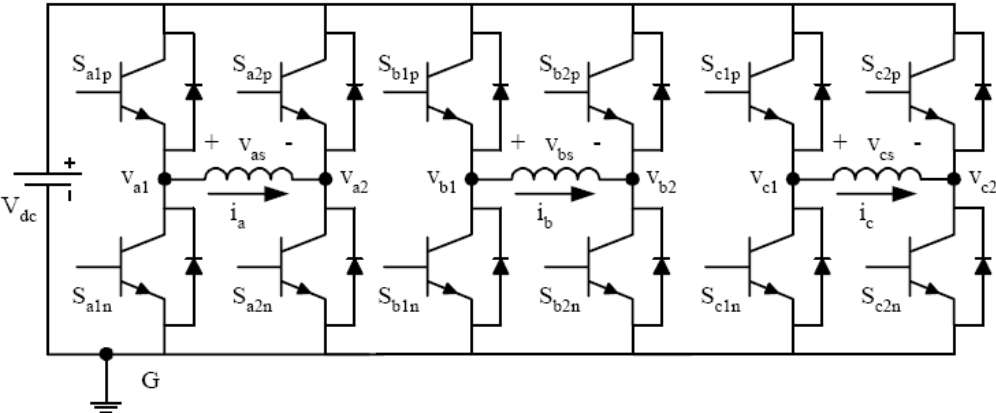
1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Fault-tolerant topologies

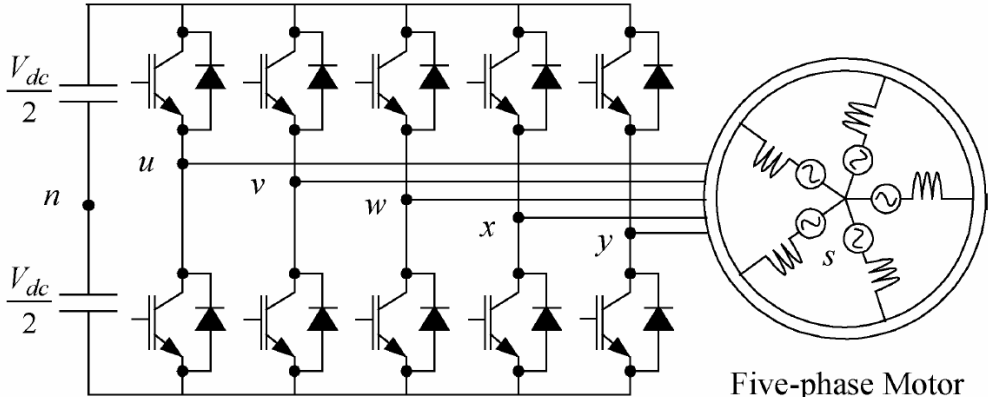
Other topologies:

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

6-leg inverter



polyphase machines



Five-phase PWM Inverter

Five-phase Motor

# Plan

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. **Control reconfiguration**
5. Conclusions and perspectives

# Control reconfiguration

Reconfiguration consists in this case in changing the system and its control law in order to obtain performance as good as possible after a fault has occurred.

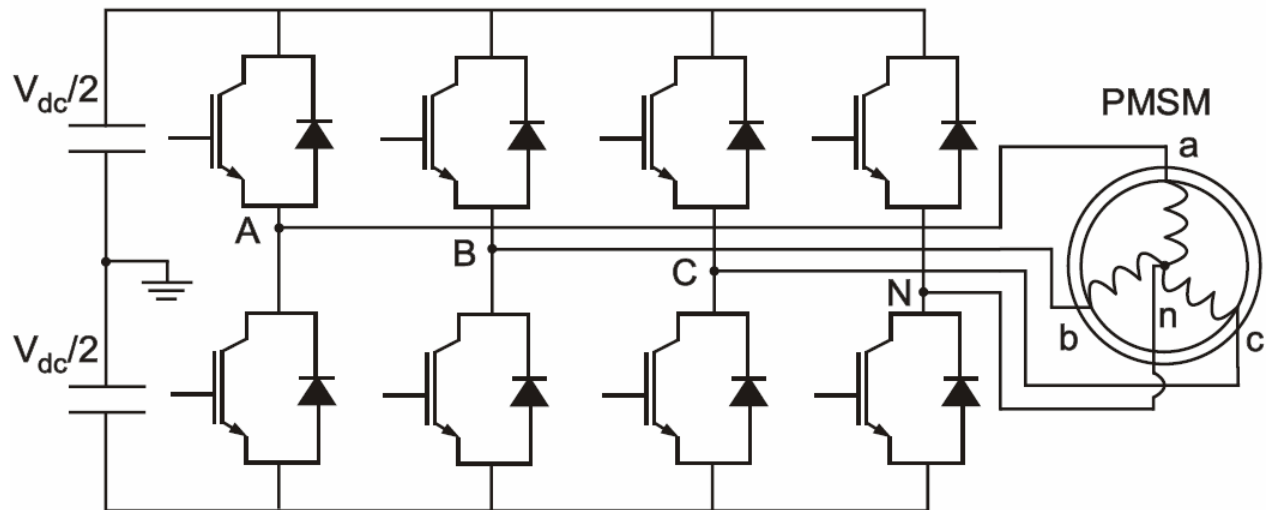
→ it depends on:

- the fault
- the remedy
- the topology
- the type of control

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Control reconfiguration

## Choice of topology: the four-leg inverter with connected neutral point

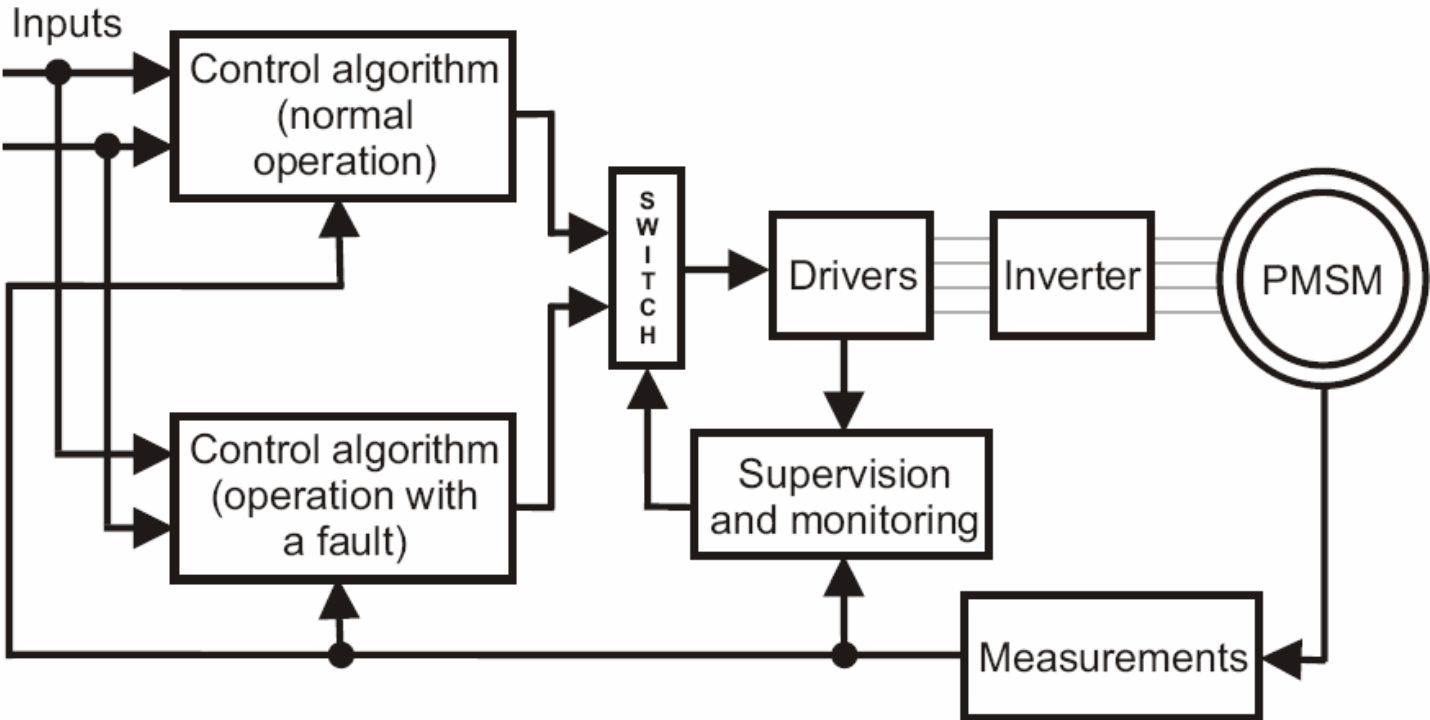


1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

# Control reconfiguration

## Reconfiguration scheme

- 1. Introduction
- 2. Inverter fault detection
- 3. Fault tolerant topologies
- 4. Control reconfiguration
- 5. Conclusions and perspectives

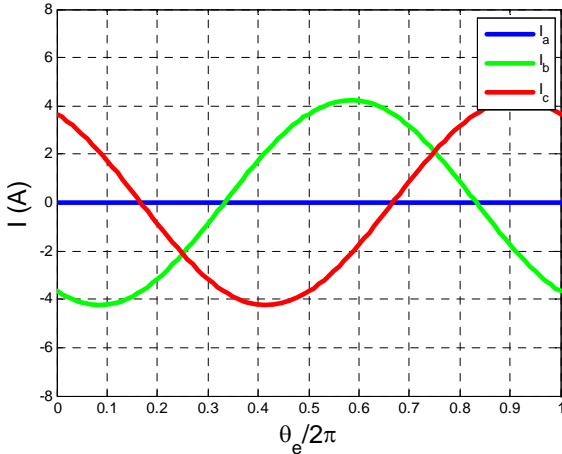


# Control reconfiguration

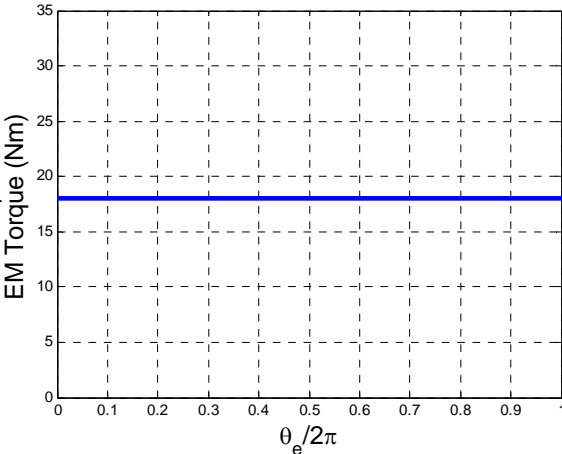
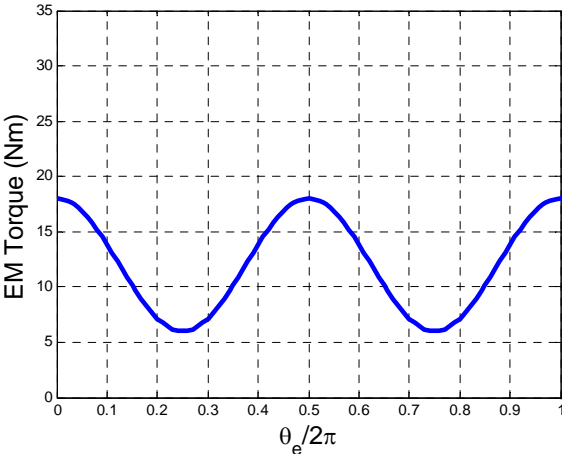
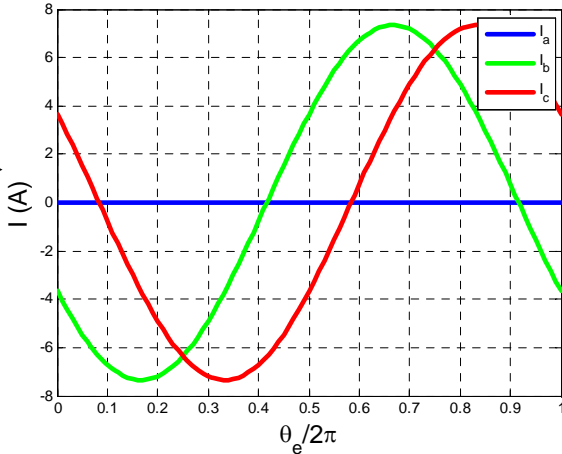
## Control with 2 active phases (1 open phase)

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

references unchanged



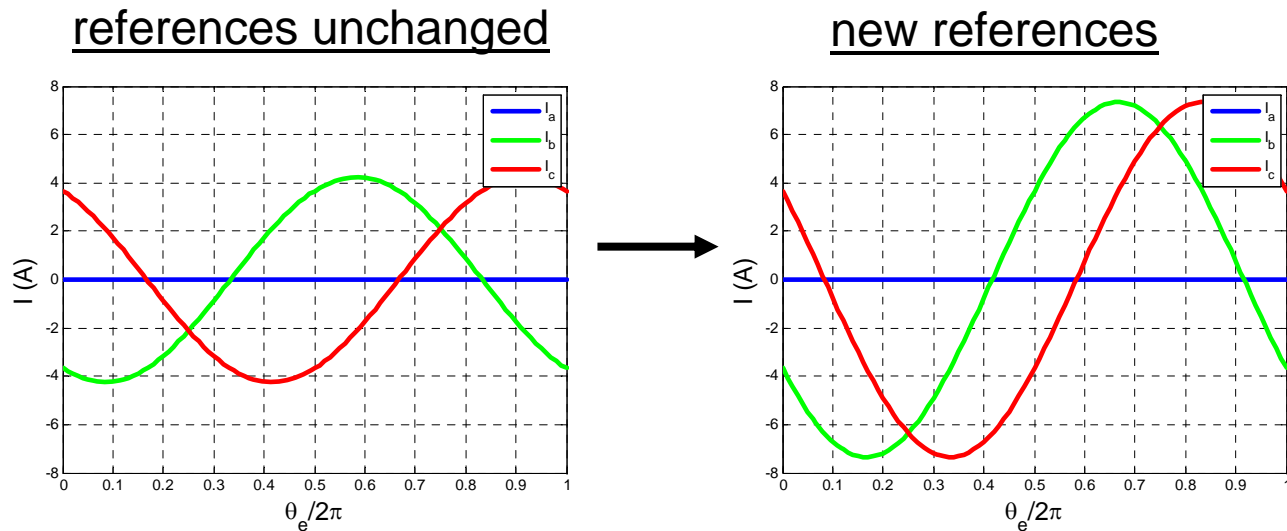
new references



# Control reconfiguration

## Control with 2 active phases + neutral

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

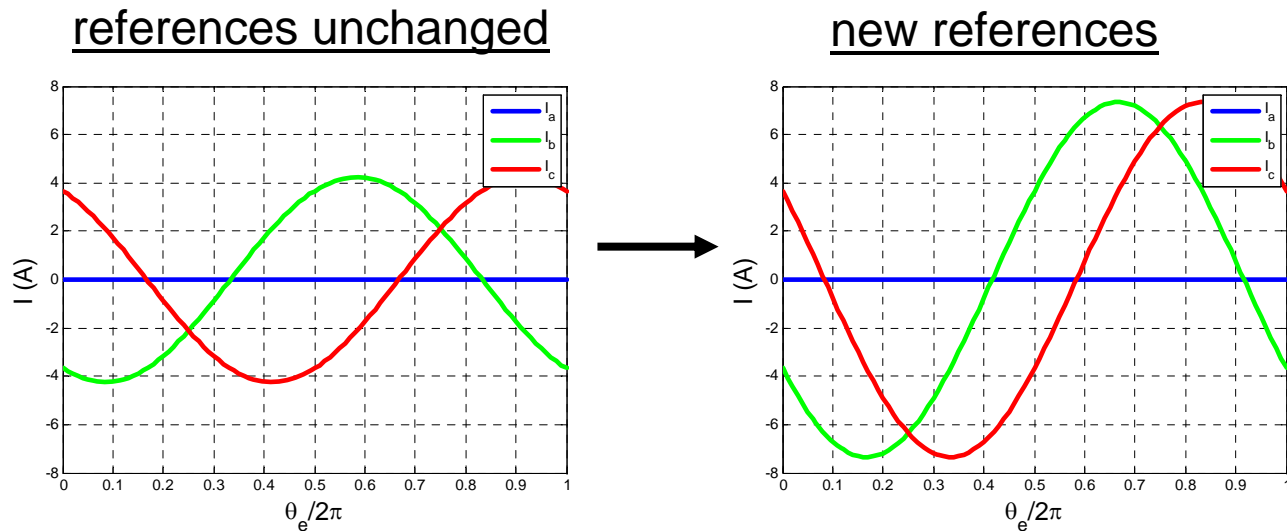


How to apply these new references?

# Control reconfiguration

## Control with 2 active phases + neutral

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives



How to apply these new references?  
 → depends on the control algorithm

# Control reconfiguration

Several controllers are frequently used:

- hysteresis current controllers
- PI controllers
- predictive current controller
- sliding mode controller
- ...

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

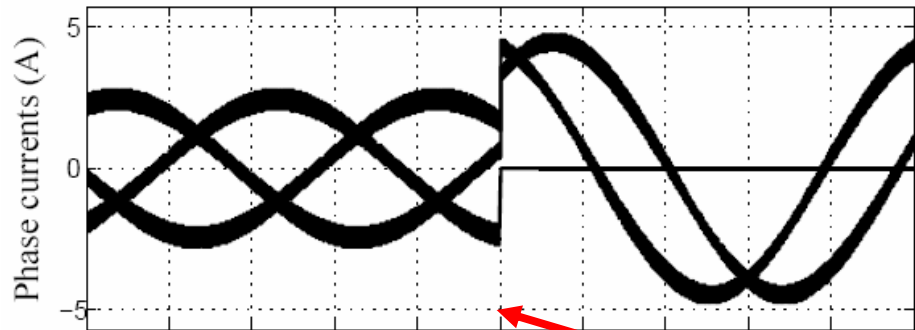
# Control reconfiguration

Control with 2 active phases + neutral

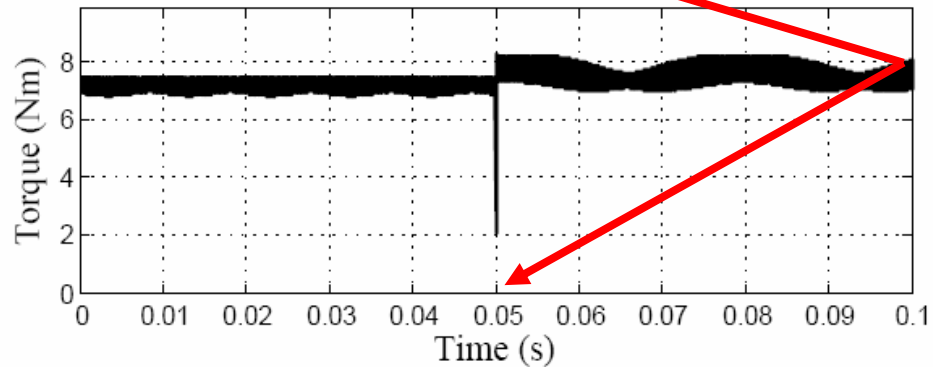
a) with hysteresis current controllers (abc)

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives

labc  
(A)



Tem  
(Nm)



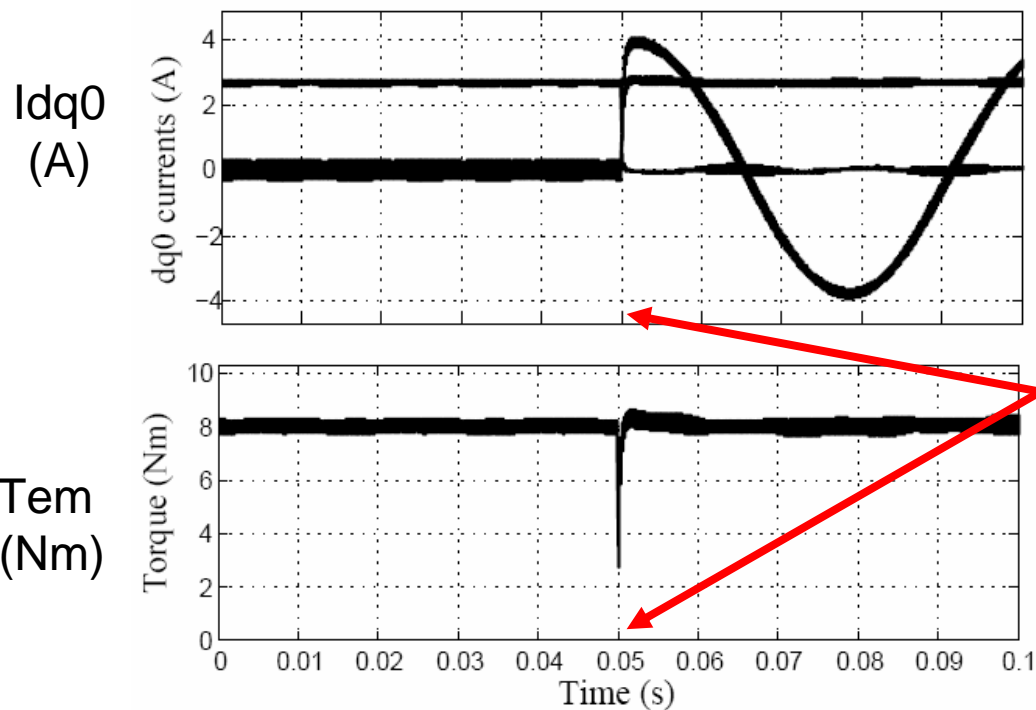
Fault

# Control reconfiguration

Control with 2 active phases + neutral

a) with hysteresis current controllers (abc)

b) with PI controller



$I_{dq0}$   
(A)

$T_{em}$   
(Nm)

Fault

# Plan

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. **Conclusions and perspectives**

# Conclusions and perspectives

- ❖ Inverter fault detection and isolation
- ❖ Different ways to obtain fault tolerance
- ❖ Reconfiguration
- ❖ Machine and sensor fault detection
- ❖ Study and design of a polyphase drive

1. Introduction
2. Inverter fault detection
3. Fault tolerant topologies
4. Control reconfiguration
5. Conclusions and perspectives