Durham University

Advanced power conversion for future propulsion systems

Fault-tolerant control & Condition monitoring

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November 2018

Outline

- Durham University at a glance
- Introduction to Reliability in power converters
- Introduction to Fault Tolerant Control (FTC) and Fault Detection (FD) in PE
- Quick overview of fault-tolerant power electronic designs
- Research Examples

Facts and figures

A world top 100 university

Ranked '97 th in tile *THE World UntversHy Ranking s (2018)* and 74th in the QS *W of1.d University Rankings (2019)*

A top UK university

Sth in The *Compl ete UrniJe rsHy Guide 201B,.* and 5th in *The* nmes and *The Sunday Times Good University Guide 2018-*

26 departments or schools

Offering over 200 undergraduate and 130 taught postgraduate oourses, and many research progiramm es.

Over 4,000 staff members

Over 40% of academic staff are non-UK origin _

Three faculties

Arts and Humanities, Science, and Social Science and Health_

16 Colleges

Durham's di stinctive residential and e ducational co mmunities.

A topuniversity for employability

Ranked in til e world top 40 for til e employab ility of our students by blue-chip companies w orld-wide *QS Worrd U niversity Rankings (201 9)*

30% of students are of non-UK ongm

150 countries represented! i n our staff and student bodies, creating a diverse social and academic community _

A total student population of 18,031 (2017/18)

Made up of un dergraduate ancl po s tg raclua te students, from home ancl internationaL

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- Introduction to Fault Tolerant Control (FTC) and Fault Detection (FD) in PE
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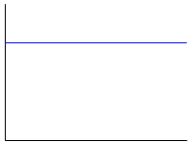
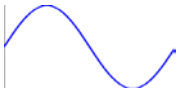
The Power Electronics Revolution

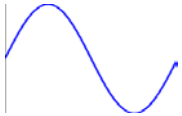


Direct Current (DC)

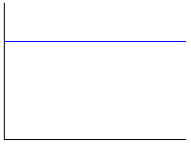
Power electronic converter
(Solar inverter)



Alternative Current (AC)

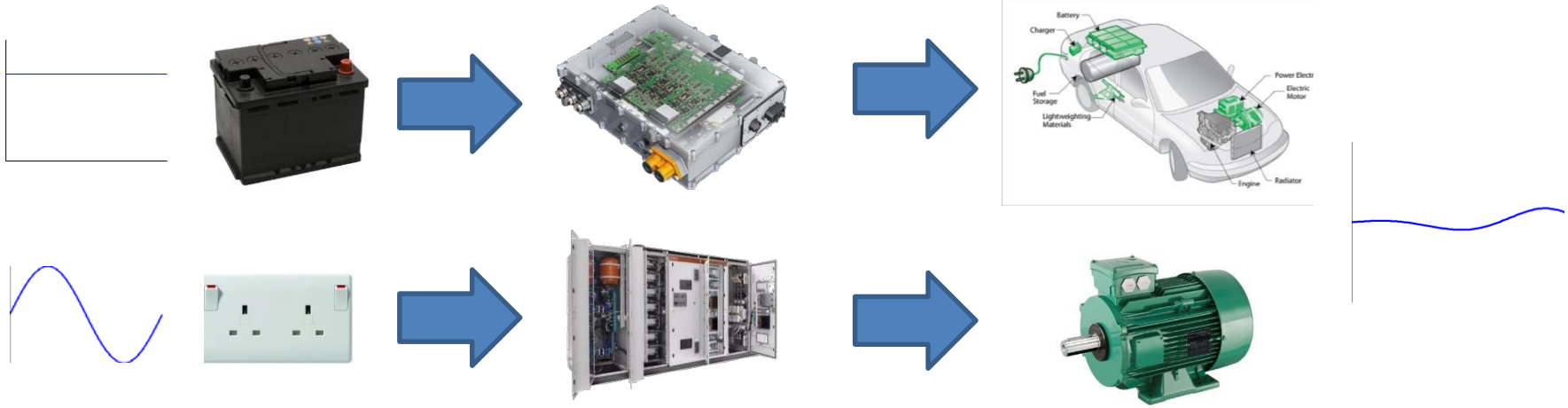


Power electronic converter
(Charger)



The Power Electronics Revolution

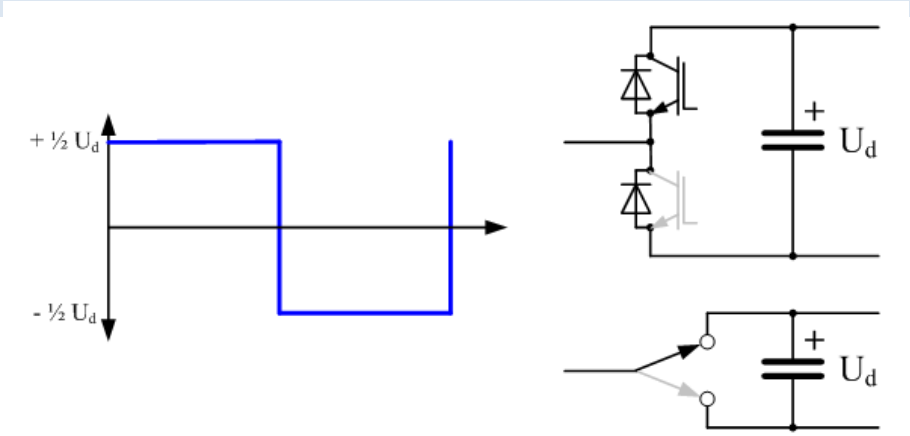
Power electronic converter
(electric drive)



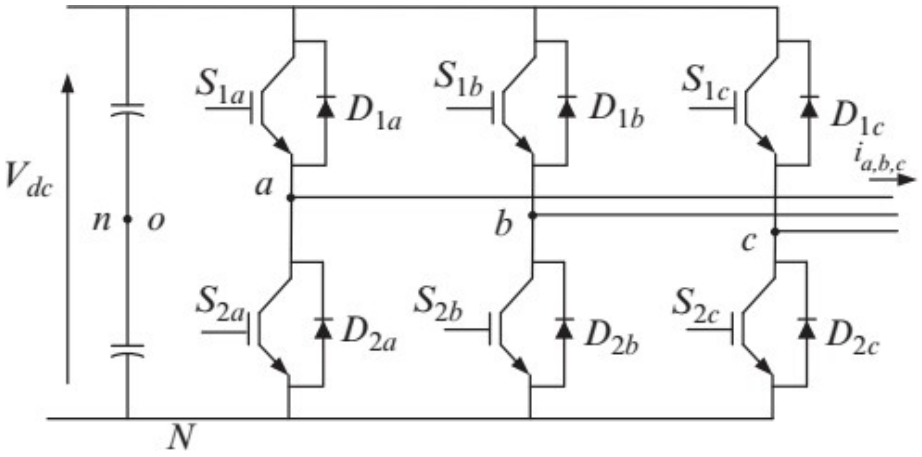
Power electronic converter
(electric drive)

Power Converters

- IGBT Converters:



- Two-level converter:
  - One of the most common topologies
  - controlled by Pulse Width Modulation (PWM)

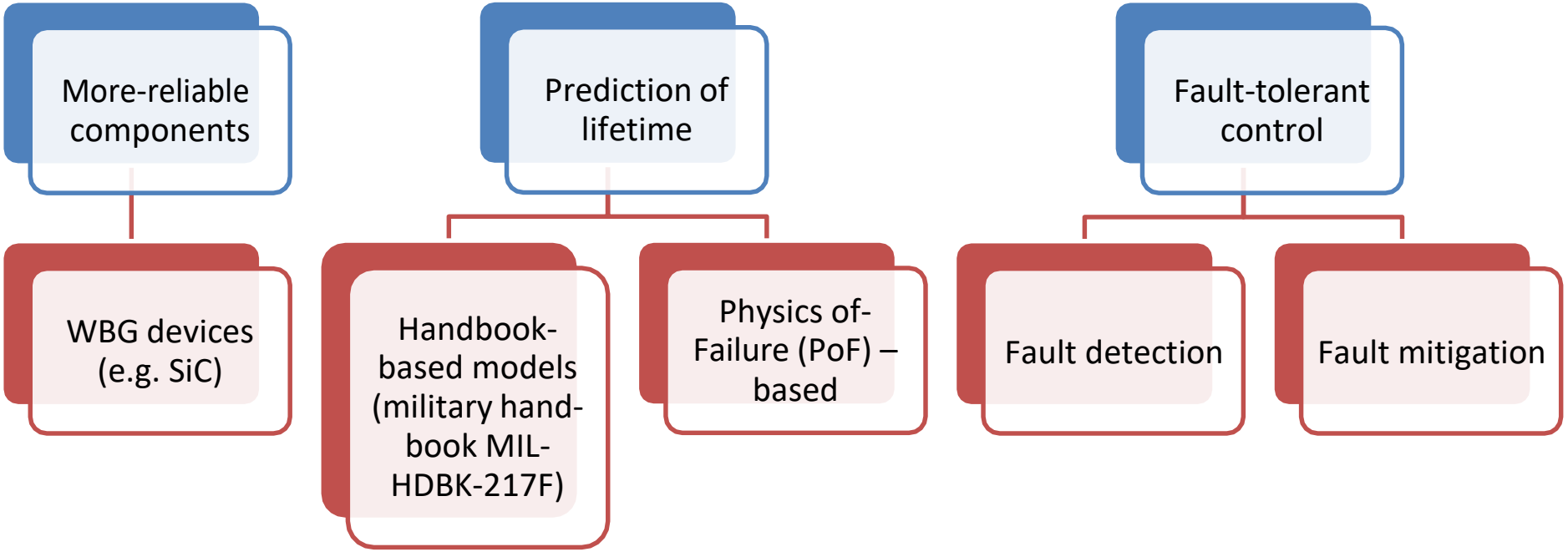


Three-phase two-level converter

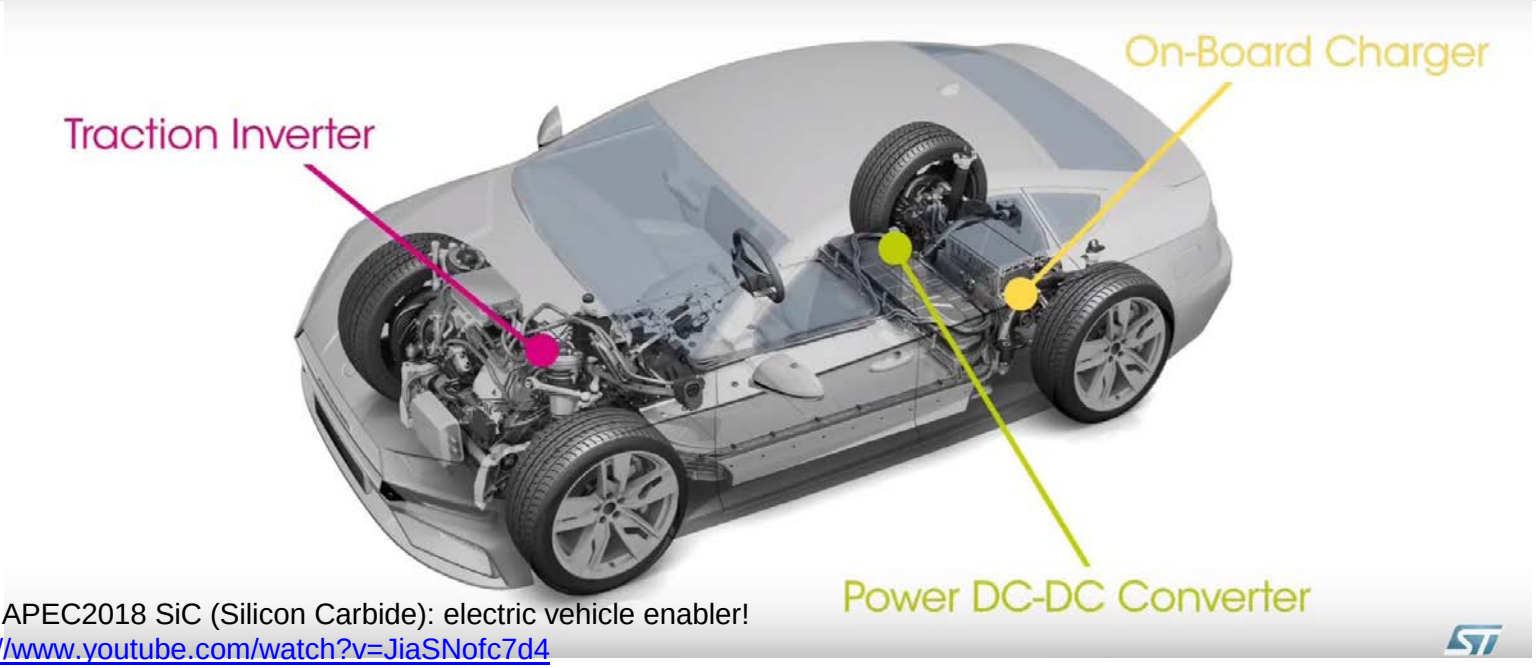
Research Areas in Power Electronics

- Vast and growing applications of power electronics:
  - Power system (HVDC, FACTS, Power Quality,..)
  - Renewable Energy Integration
  - Electric drives
  - Electric Vehicles
  - Consumer Electronics
  - …
- Research:
  - **Reliability and FTC**

Reliability Studies



Trends in power converter design:



ST at APEC2018 SiC (Silicon Carbide): electric vehicle enabler!
https://www.youtube.com/watch?v=JiaSNofc7d4

- Newer components (SiC devices)
- Integration, integration, integration!

Fault diagnosis

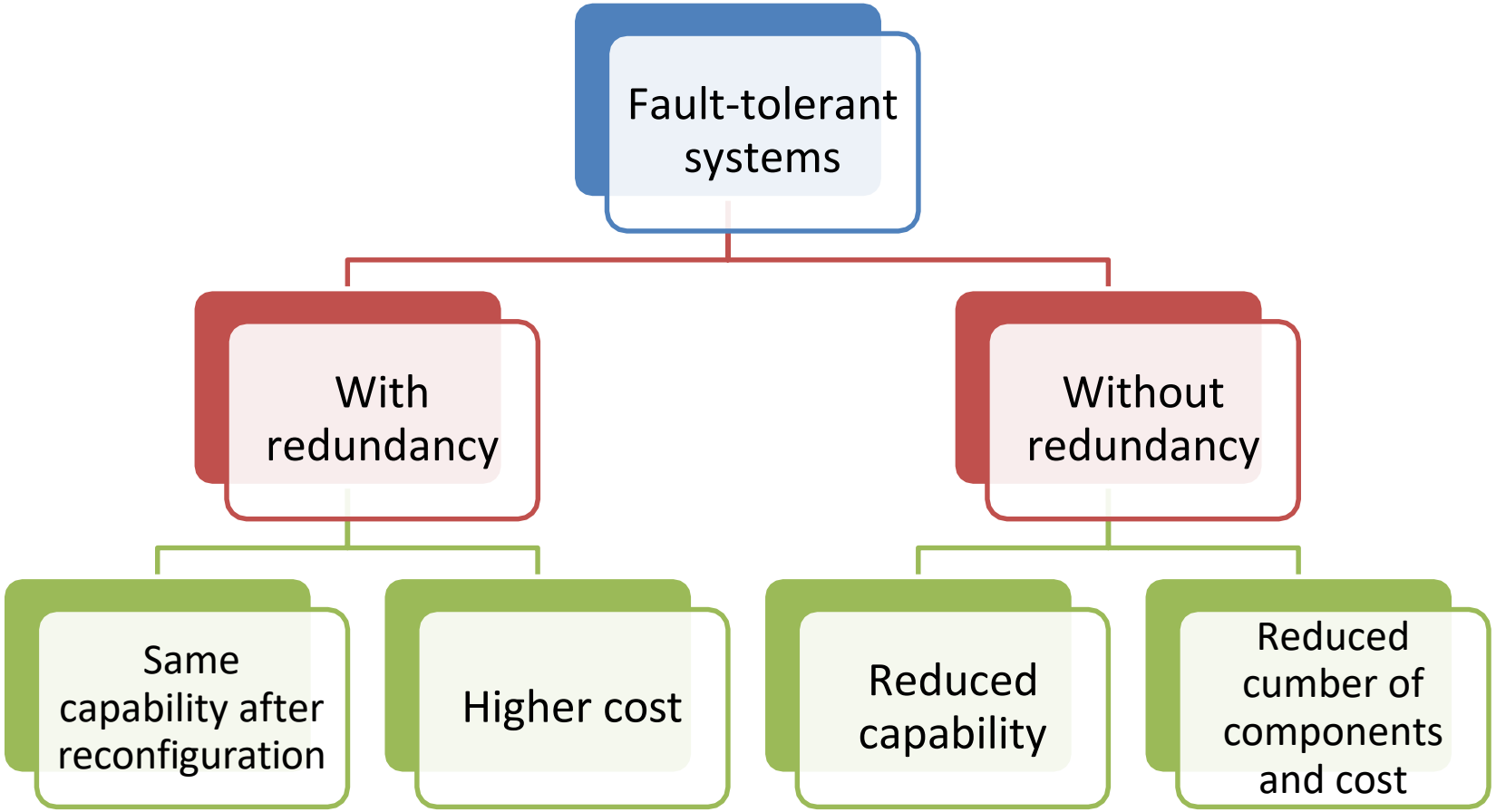
- First stage for a fault-tolerant operation:

Fault detection

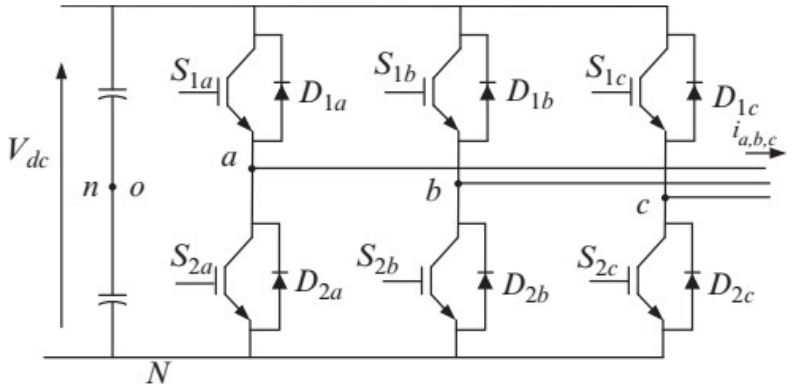
- **Accurate** and **timely** detection and protection to prevent fault propagation and catastrophic results.
- Fault detection methods:
  - Based on information of input or output current or voltage at converter terminals
  - Based on current or voltage information of devices.

Fault-tolerant operation

– A fault in a component or subsystem does not cause the overall system to malfunction



Fault detection for two-level AC/DC systems



Direct measurement of output voltages

Real systems

Measurement and discretizing errors

Error due to inherent delays

Two criterion for the fault detection

Magnitude criteria

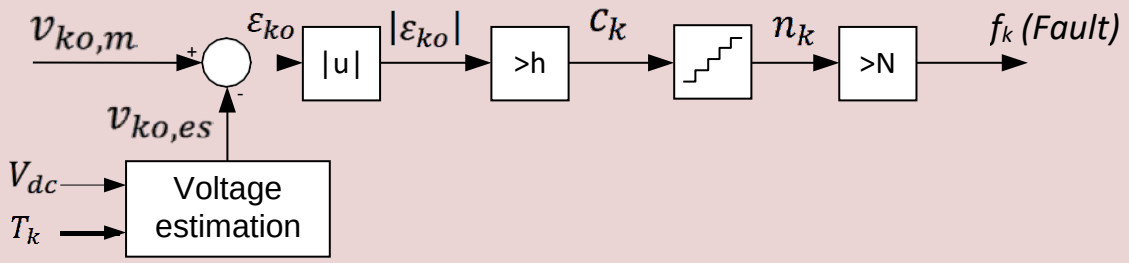
- If the magnitude of error is large enough

Time criteria

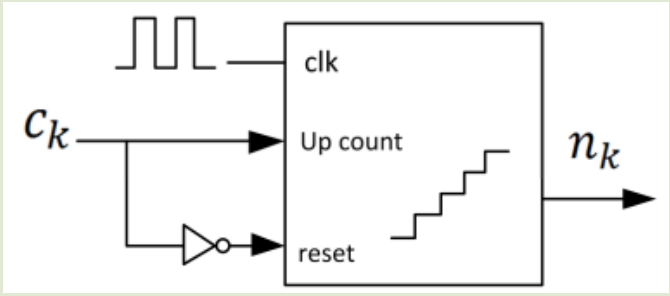
- If the error duration is sufficiently large

Implementation of fault detection algorithm

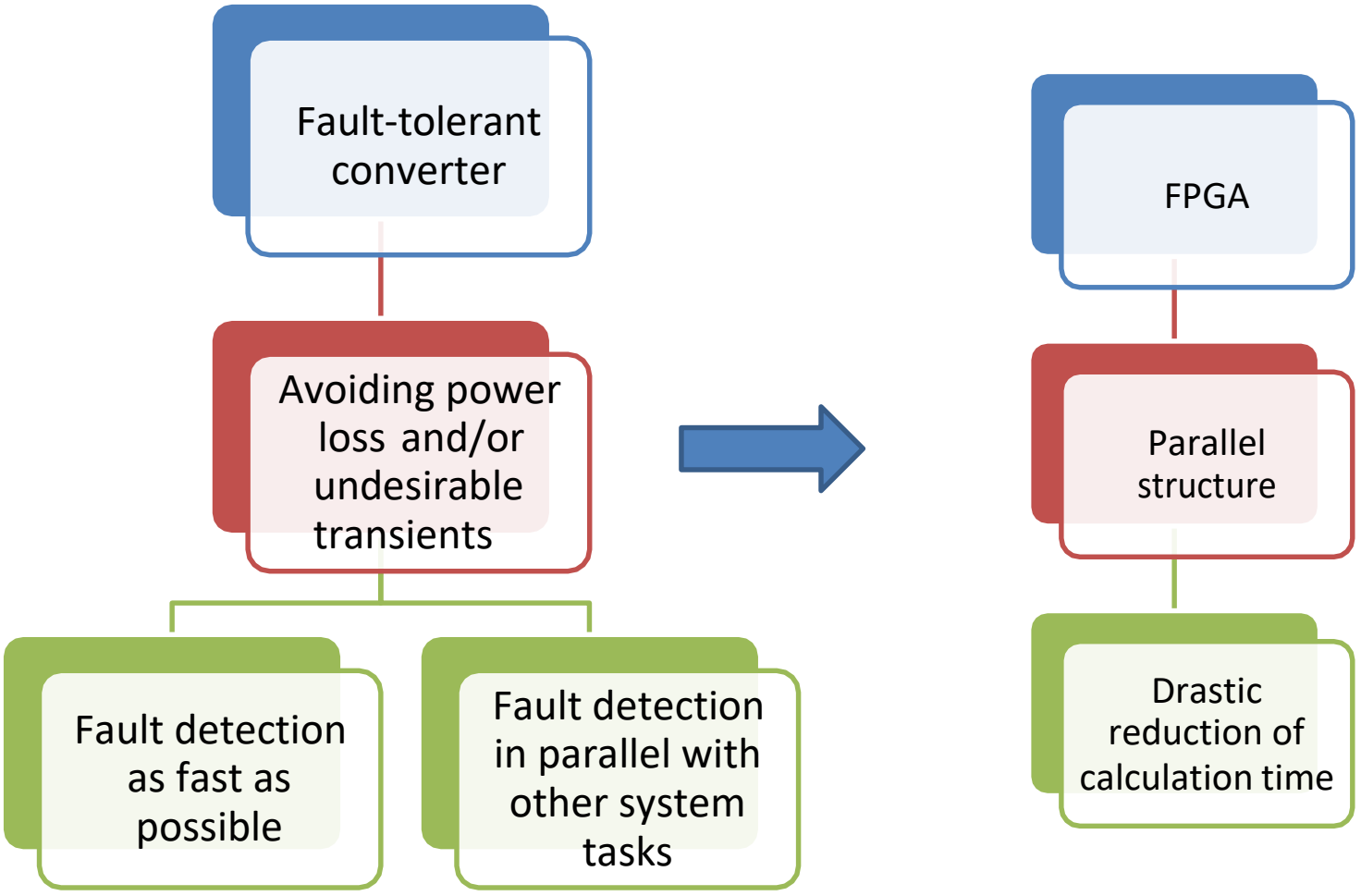
General scheme of the fault detection



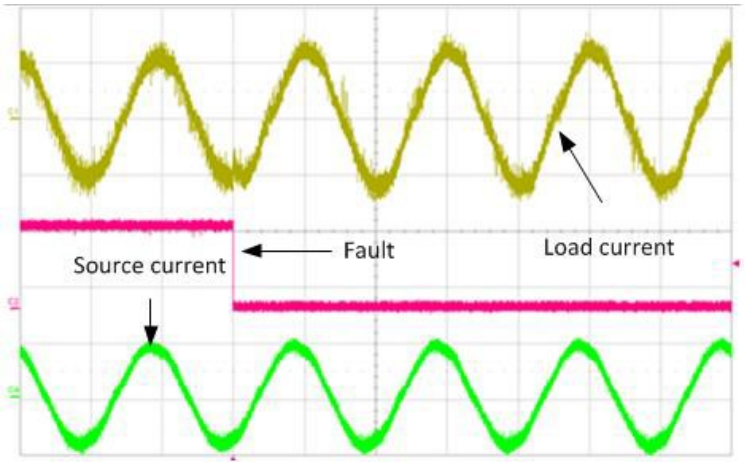
Principle of operation of the fault duration counter

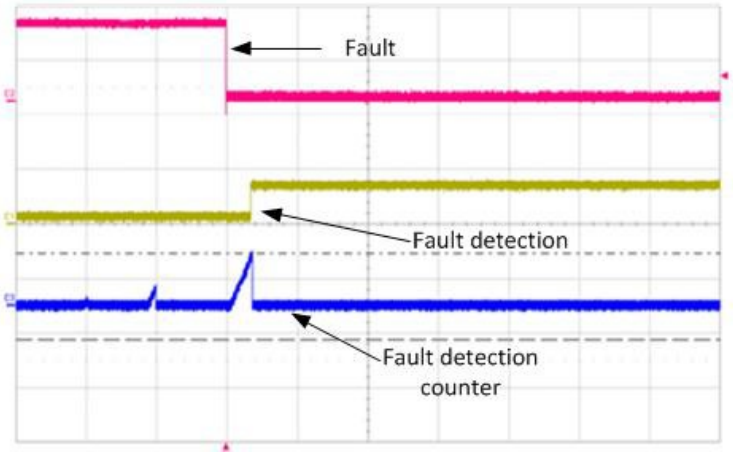


Digital target selection

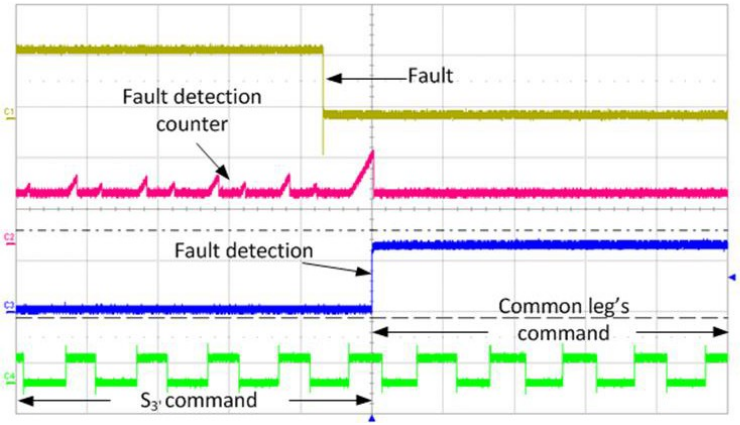


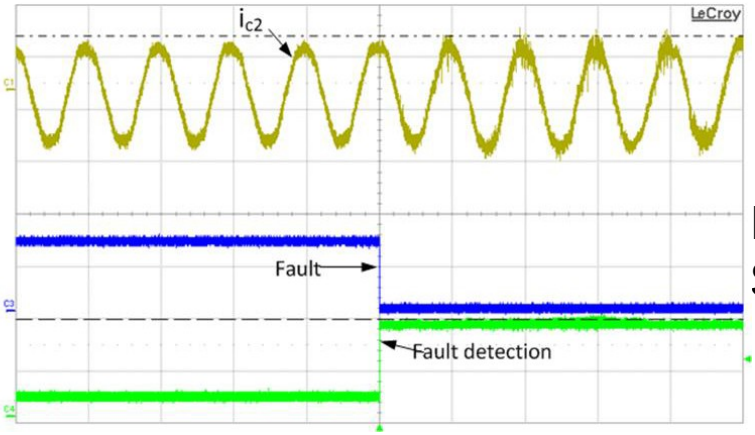
Experimental Verification





Linear Load

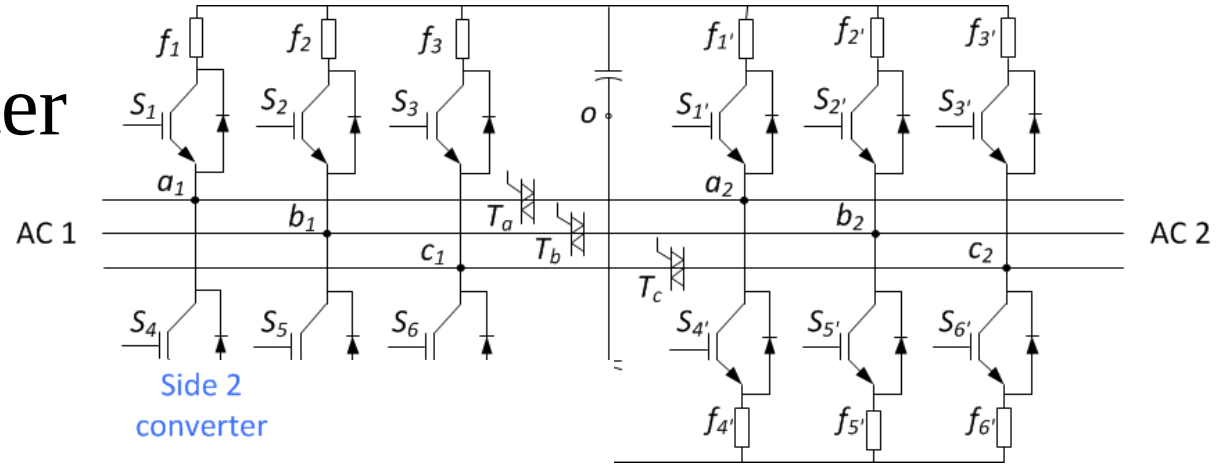


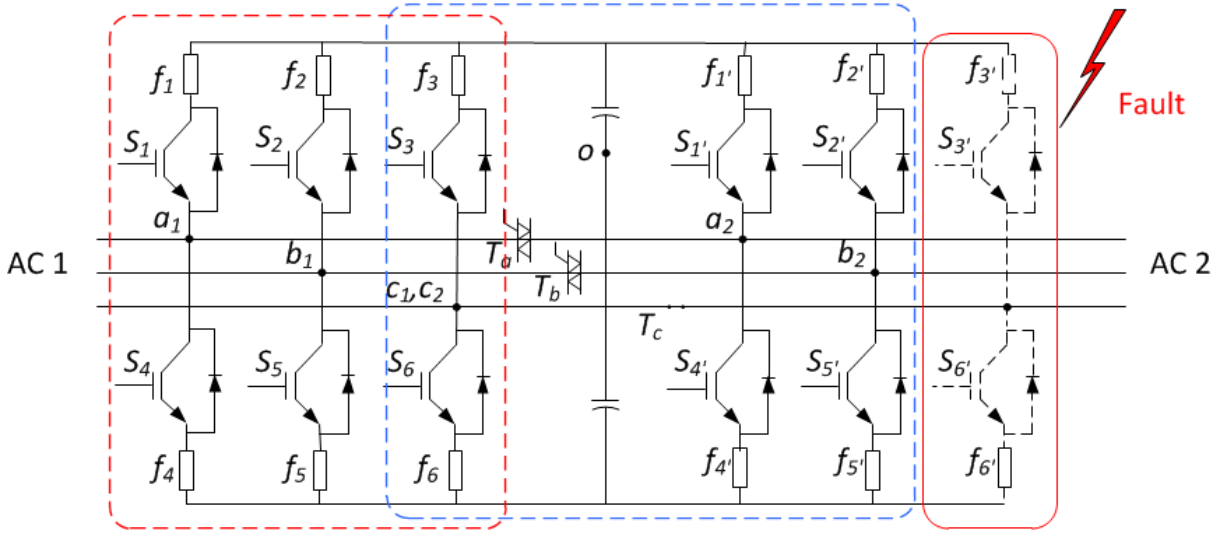


Induction motor System

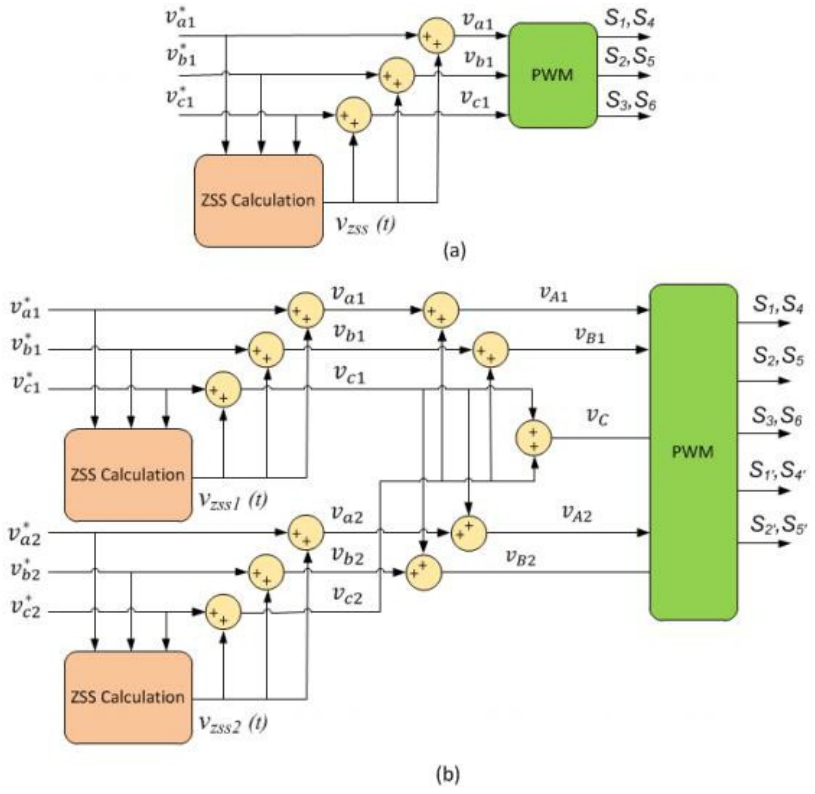
6-leg converter without redundancy

- 6/5 leg converter





PWM and FD for 6/5 leg converter



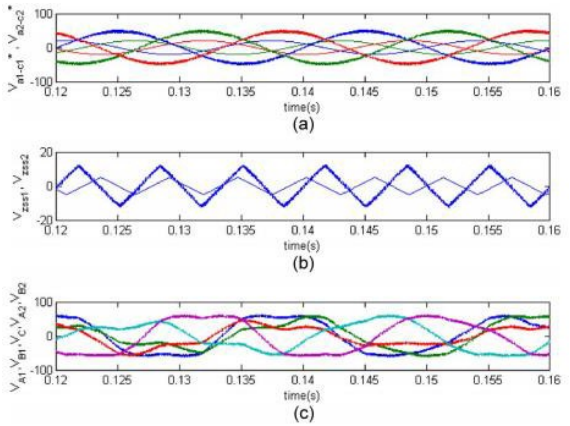


Fig. 5. Example of five-leg reference generation. (a). Two sets of three-phase references. (b). Two ZSSs. (c). Resulted five-leg references.

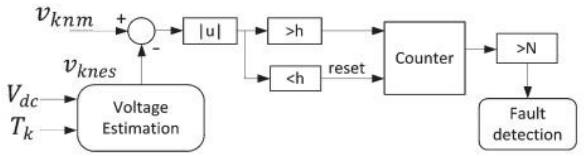


Fig. 8. Fault detection scheme.

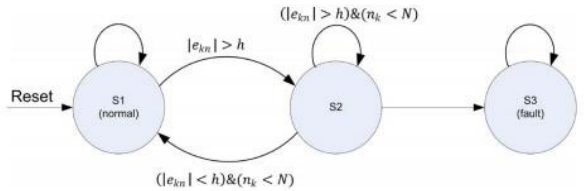


Fig. 9. State-flow diagram of the fault detection scheme.

Experimental results for 6/5 leg converter

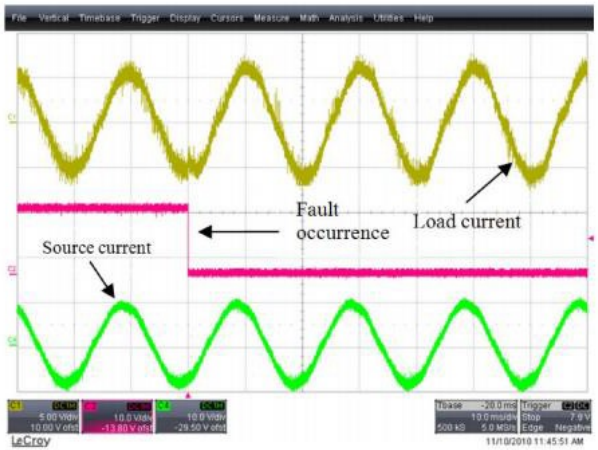


Fig. 21. Experimental results-from top to bottom: Load current (5 A/div), Fault, source current (10 A/div)—(x-axis: 10 ms/div).

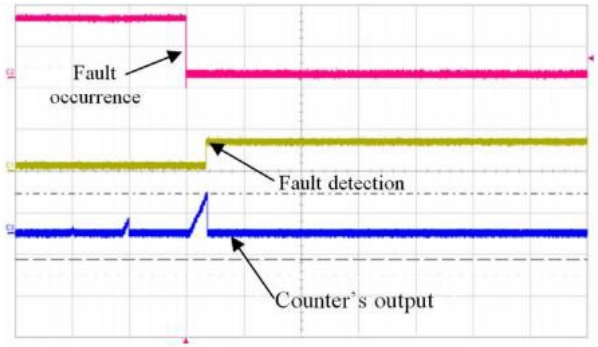


Fig. 22. From top to bottom: fault, fault detection, and counter output-(x-axis: 100 μs/div).

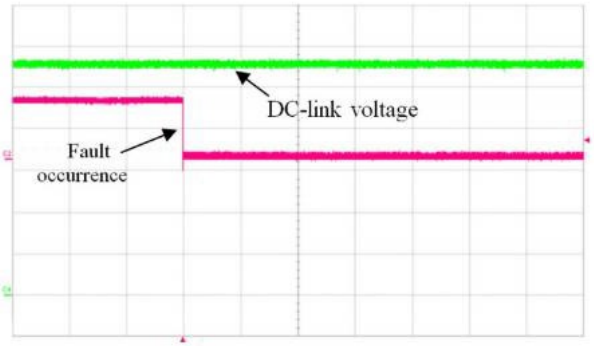


Fig. 23. From top to bottom: dc-link voltage (50 V/div), fault- (x-axis: 100 μs/div).

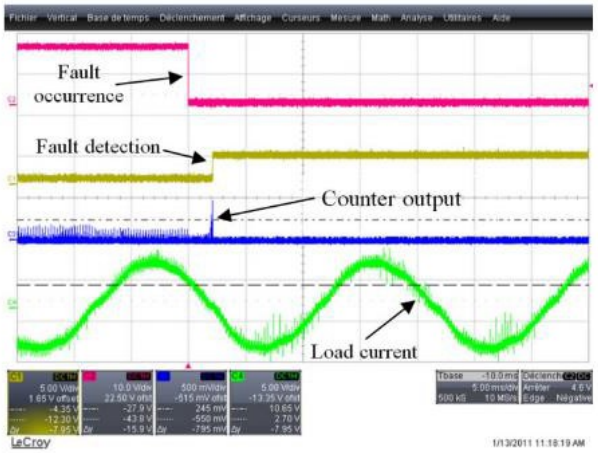
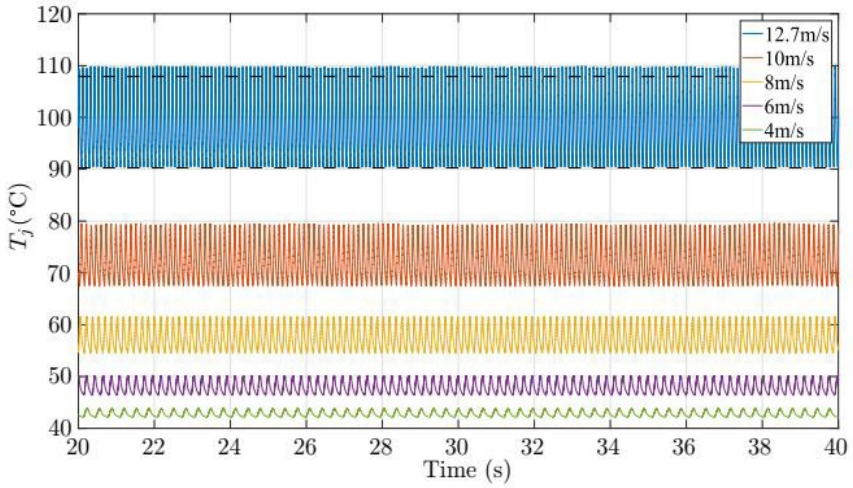
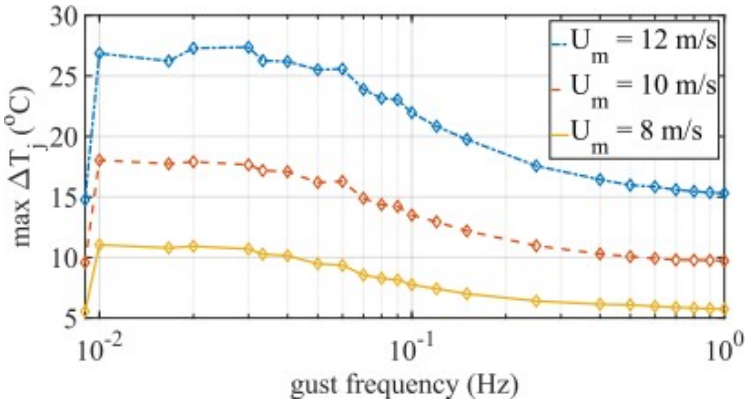


Fig. 24. Fault occurrence when $i_3' > 0$; from top to bottom: fault, fault detection, counter's output, load current (5 A/div)—(x-axis: 5 ms/div).

Thermal Cycling

- Work by colleagues in Durham University:
- Complete modelling of the whole system for accurate calculation of thermal cycling.





Smith, C. J., Crabtree, C. J., & Matthews, P. C. (2016). Impact of wind conditions on thermal loading of PMSG wind turbine power converters.

Research Impact

- Fault happens!
  - Using the outcome of our research in Durham University:

    We can continuously monitor converter's condition

    Fault is less likely to happen

    Fault is detected and mitigated quickly

Many thanks for you attention

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