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Changes for the Better

Robust On-line Junction Temperature Estimation of IGBT Power Modules based on Von during PWM Power Cycling

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Prognostics Framework for Power Semiconductor IGBT Modules through Monitoring of the On-State Voltage

IWIPP conference
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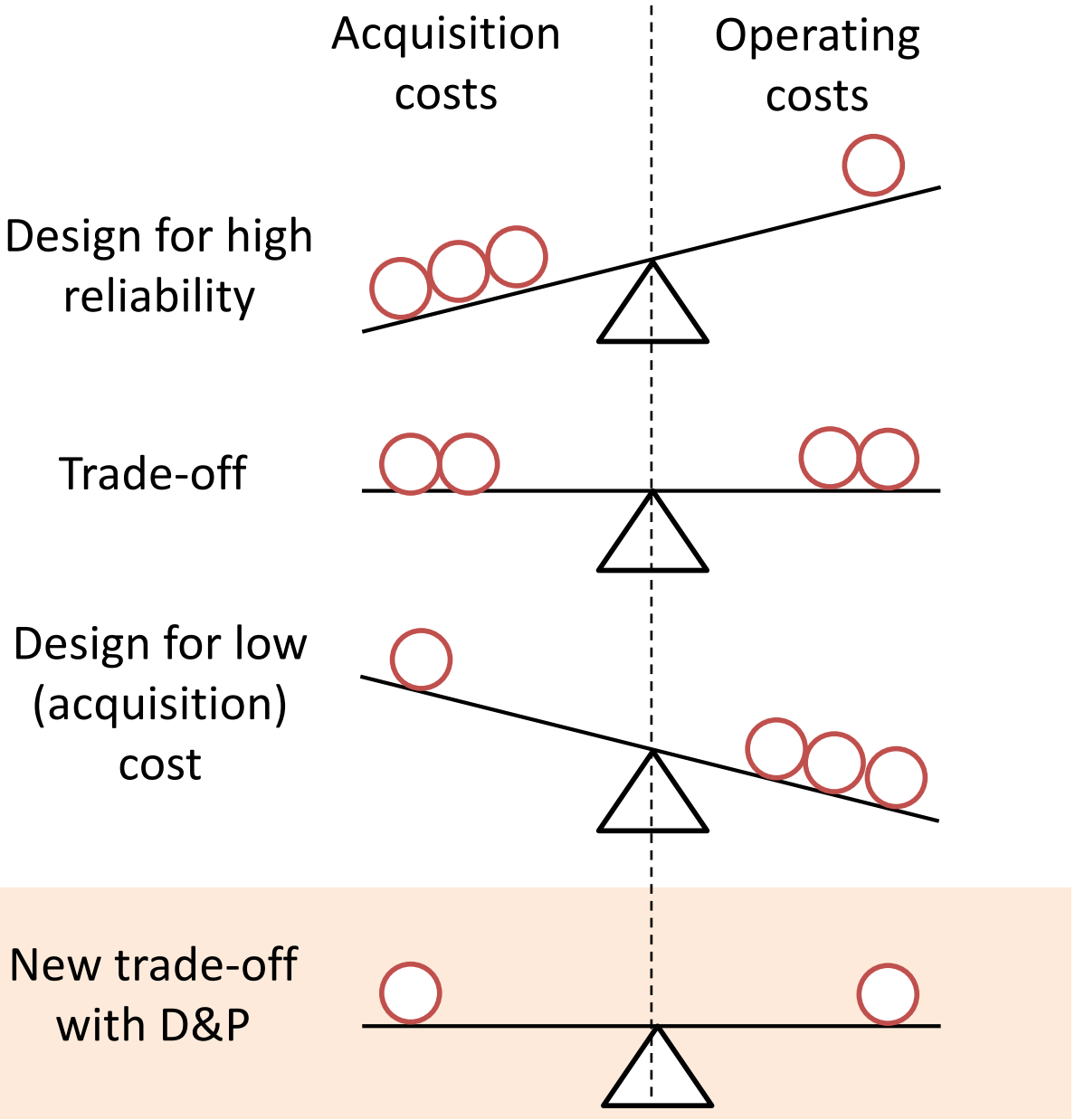
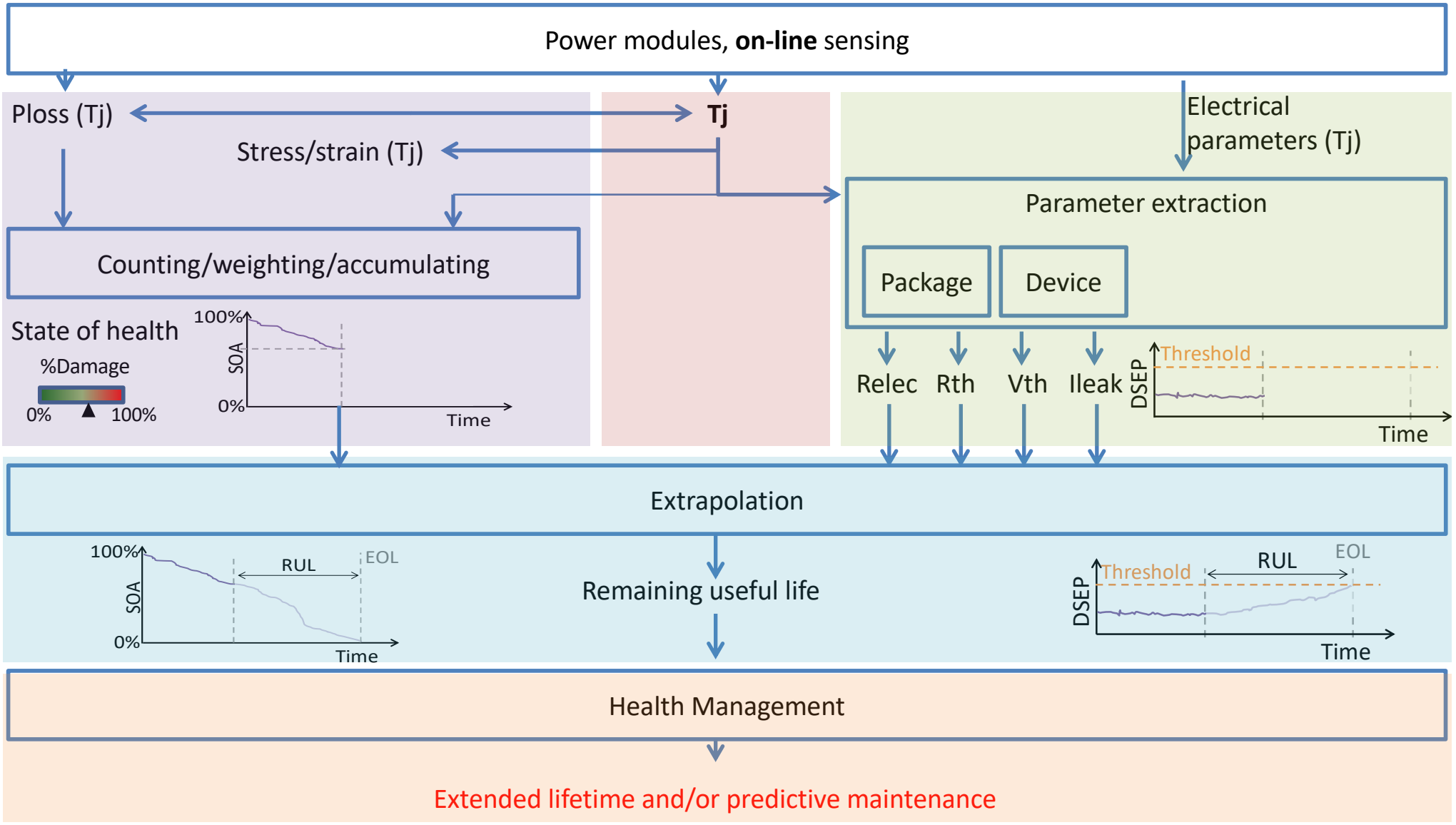
Introduction to Diagnostics & Prognostics (D&P)



- Design for reliability:
  - Trade-off: cost VS reliability
  - Reliability objectives (e.g. 15years for Automotive)
- D&P breaks this relation and promises benefits in:
  - Availability
  - Security
  - Reliability
  - Design
  - Life-cycle cost

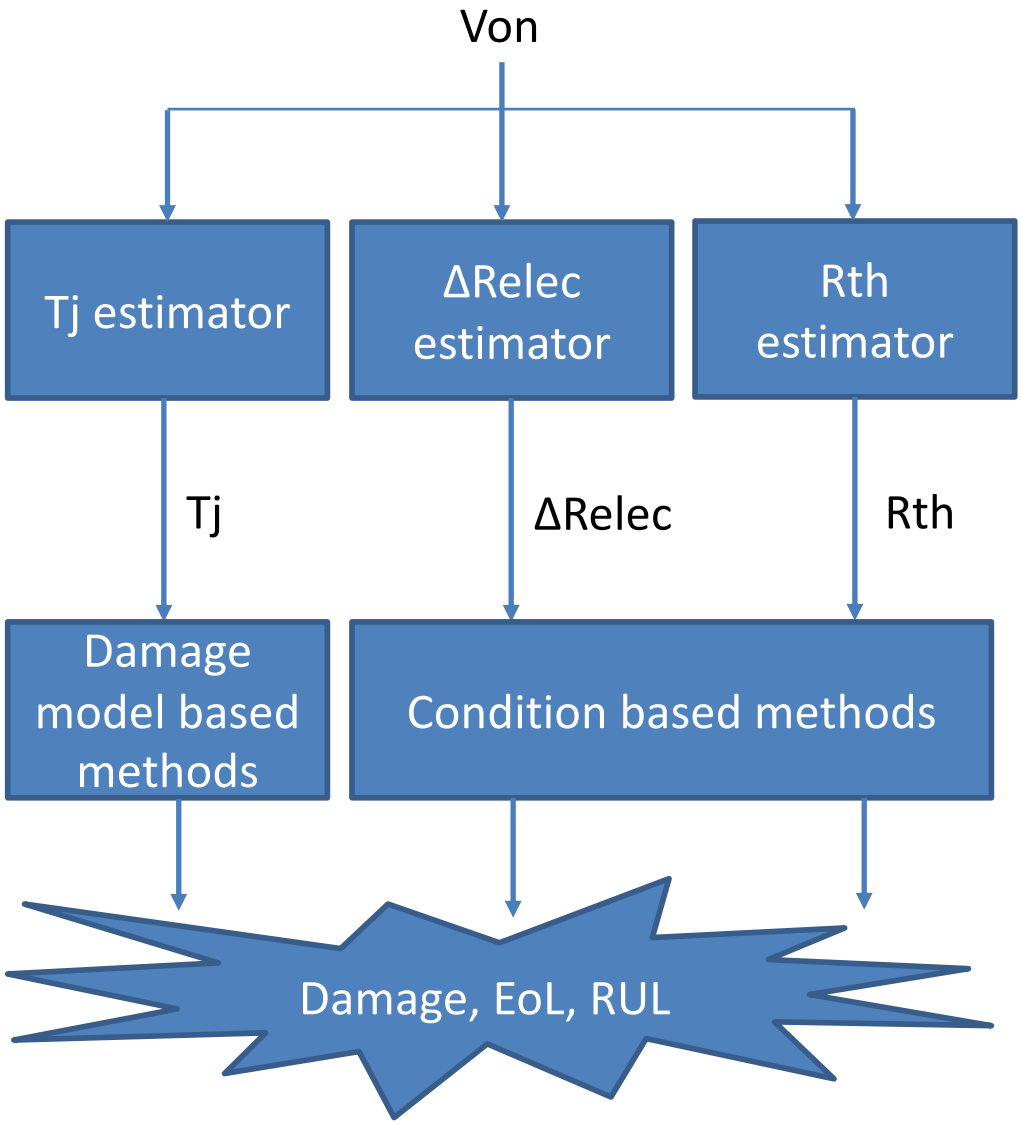
A review on D&P for power modules



1) Tj estimation 2) Condition monitoring 3) Stress counting 4) Extrapolation 5) Health management

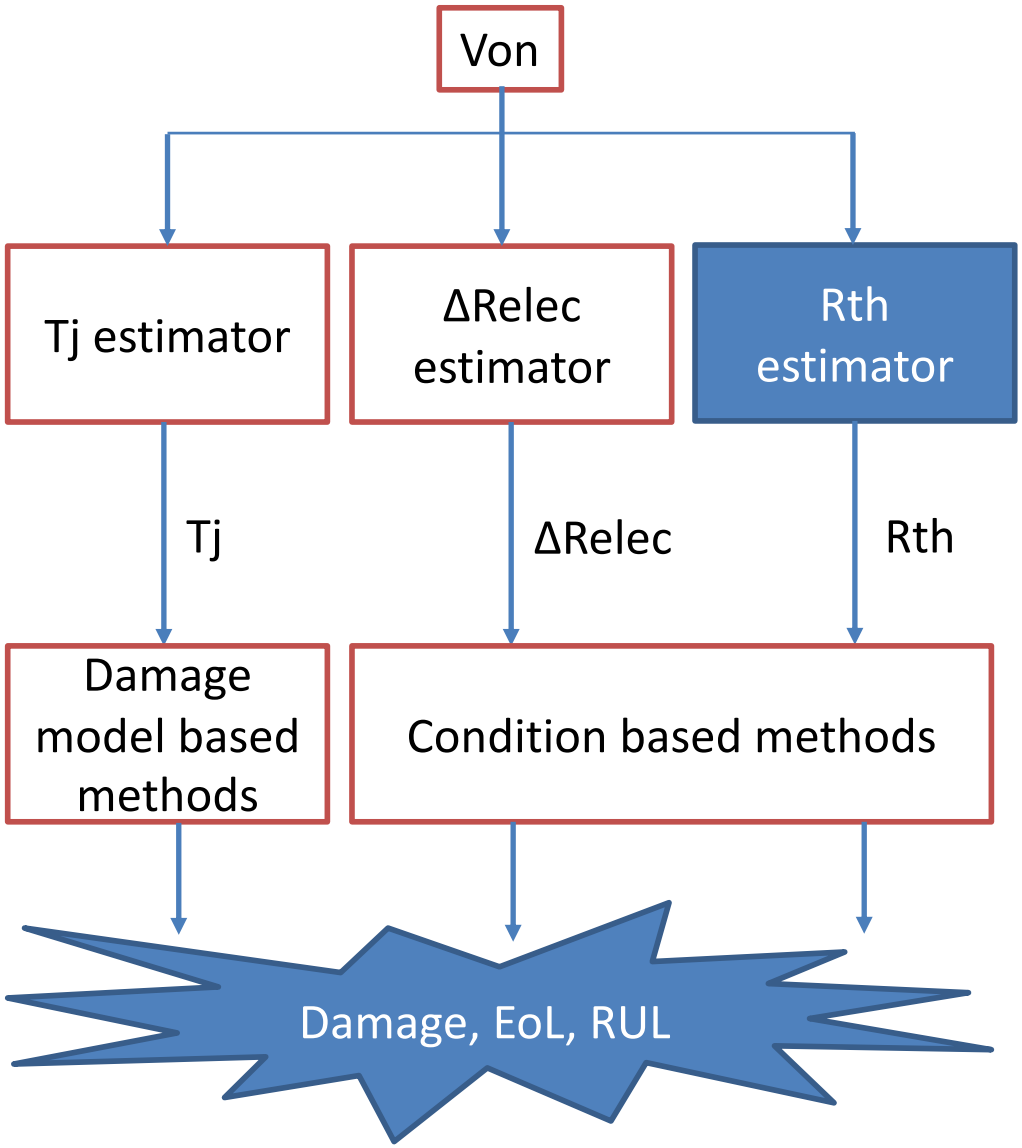
Von as a Temperature-SEP and Damage-SEP

- Pros of Von
  - Von is both a DSEP and a TSEP
    - ⇒Allows using a combination of methods
  - Von is applicable to IGBTs and Diodes
- Cons
  - Von is both a DSEP and a TSEP
    - ⇒Discrimination needed
  - Von depends on current and presents variability from device to device
    - ⇒Individual calibration needed



Outline

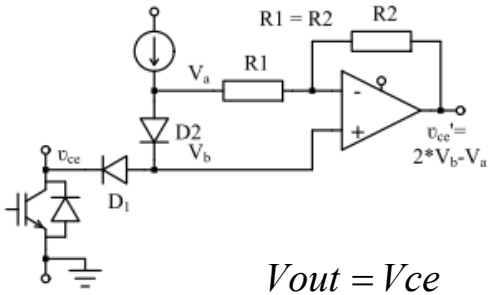
- Introduction
- Von sensor
- ΔRelec estimation
- Tj estimation
- Prognostic algorithm



Von sensor: review

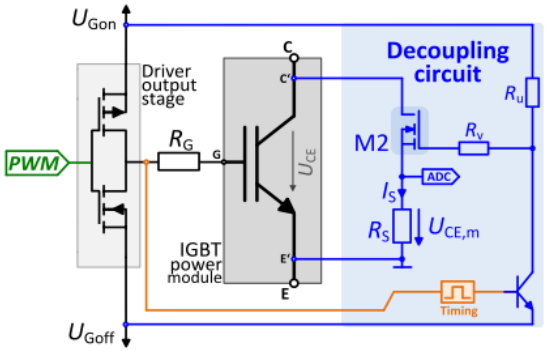
Number	Clamp method	Pros	Cons
1	De-sat style with 2 thermally-coupled HV diodes in series	Fast	• Fundamental issue with dispersion in diode thermal sensitivity
2	Active MOSFET clamp	Fast	• Requirement of (SiC) HV switches which are necessarily high-cost • Complex control
3	Depletion mode MOSFET	Fast	• Requirement of HV depletion mode MOSFET which is not common
4	R-D clamp	Simple	• Trade-off rapidity/ power consumption

1



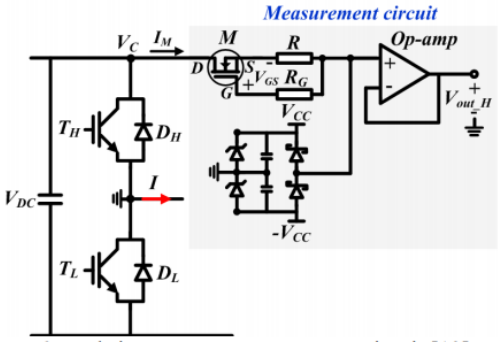
Example of desat style clamp (U. of Aalborg)

2



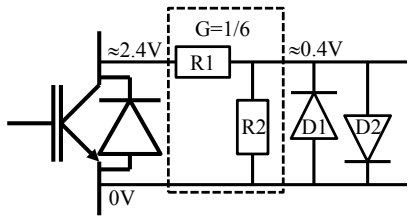
Example of active MOSFET clamp (U. of Bayreuth)

3



Example of desat style clamp (U. of Aalborg)

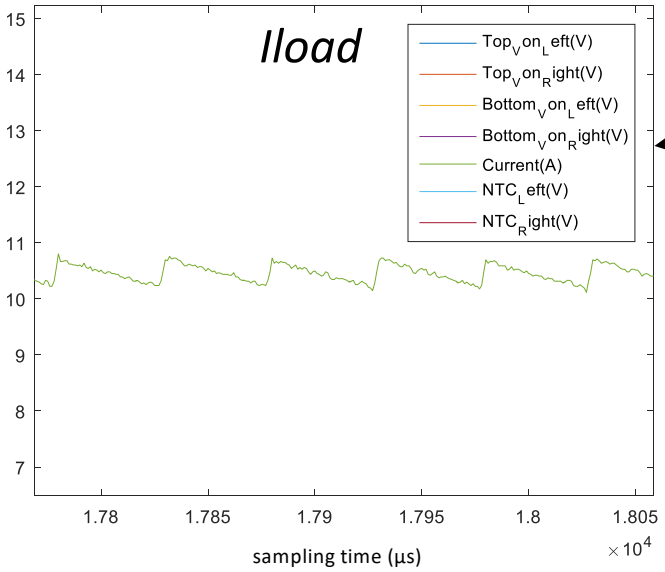
4

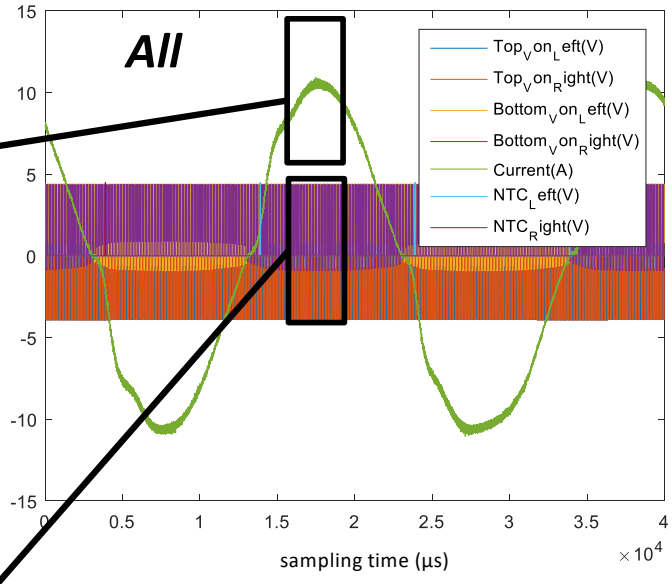


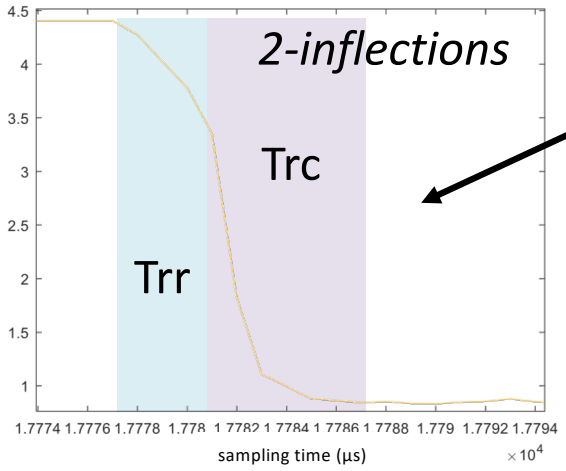
Example of R-D clamp (MERCE)

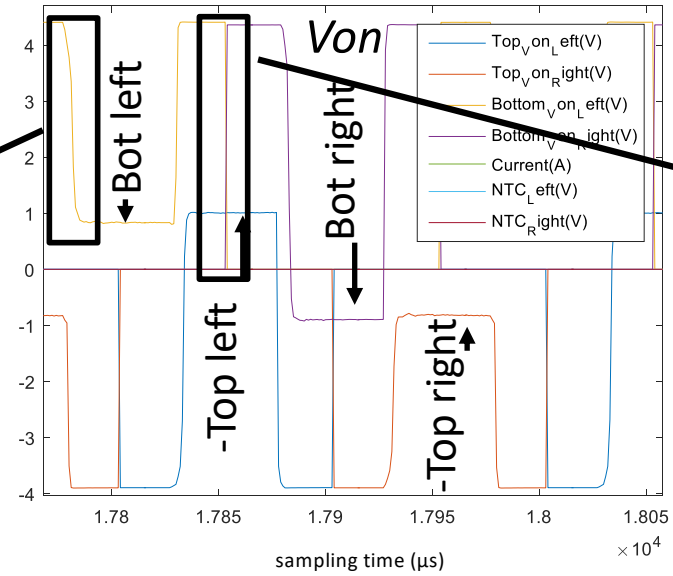
Von sensor: development & results

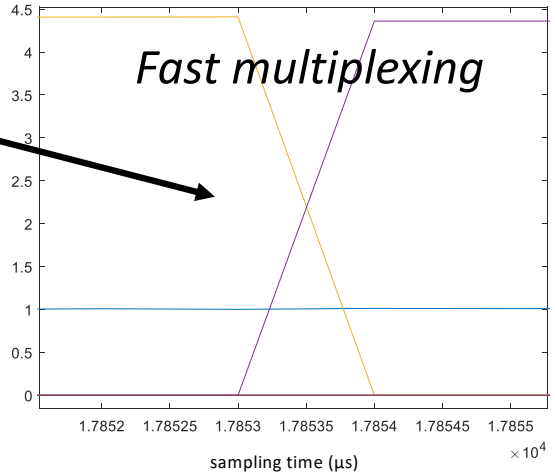
- Time-response: 8µs
- Precision: ±3,5mV
- Multiplexing:
  - Reduces cost related to Diff AOP, ADC and isolator (+ FPGA channel):
  - Multiple control strategies possible
- Cost: 8€ per switch







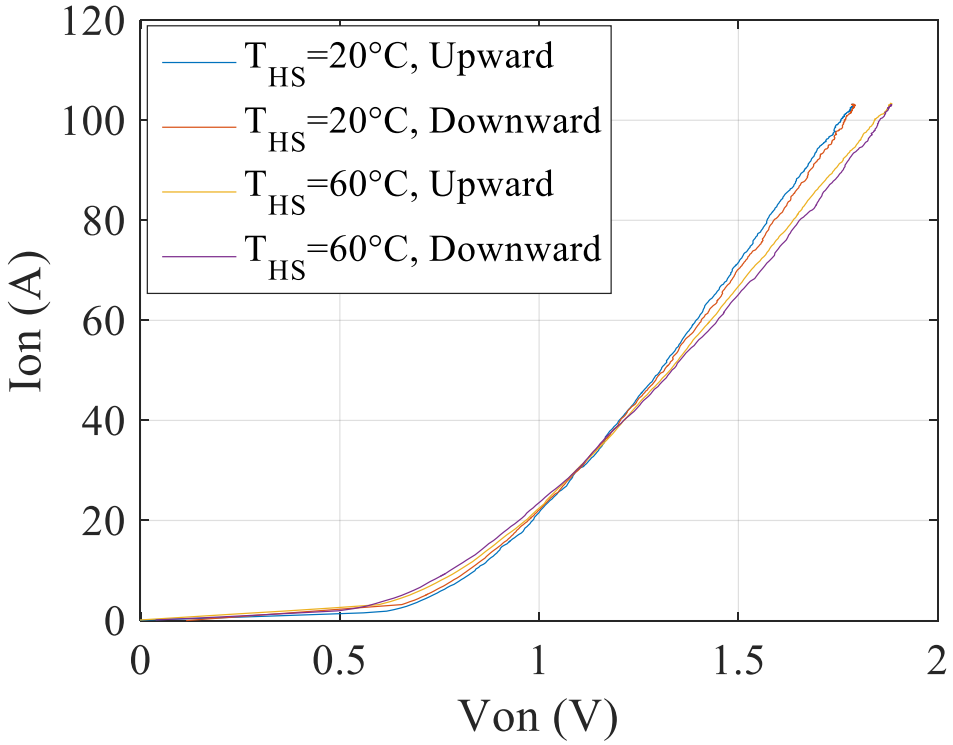




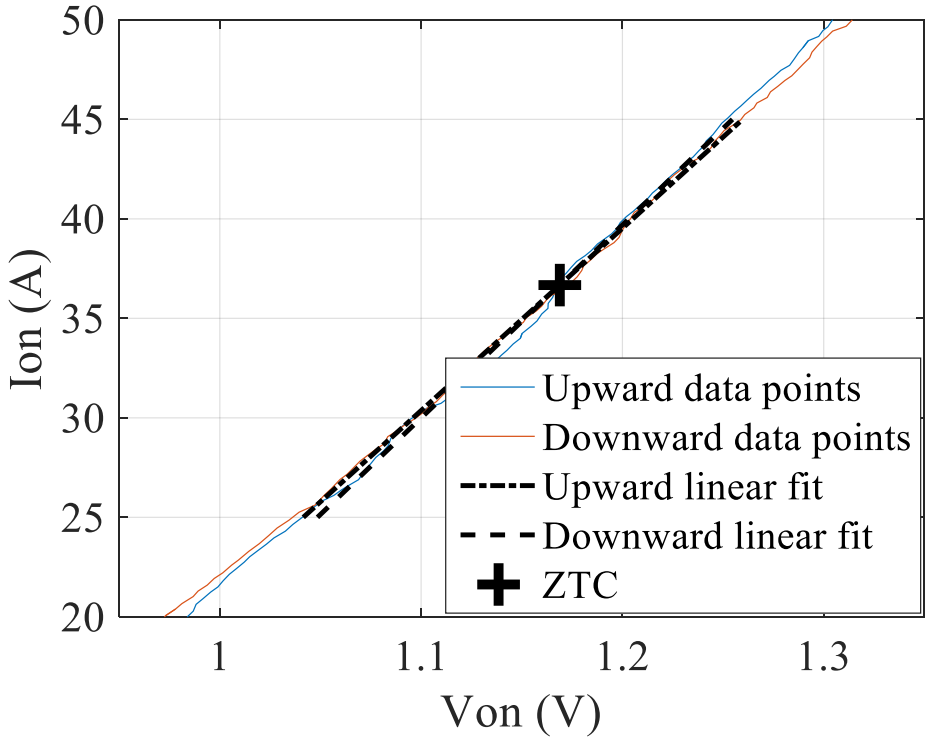
Non Confidential / Export Control: NLR

ΔRelec estimation: identification of ZTC current

- Motivation: more than 5A dispersion of ZTC current between identical devices/modules
- 2 strategies:
  - Acquisition at different heat-sink temperature
  - Acquisition at low modulating frequency



On-line Ion(Von) at 2 heatsink temperatures of 20°C and 60°C



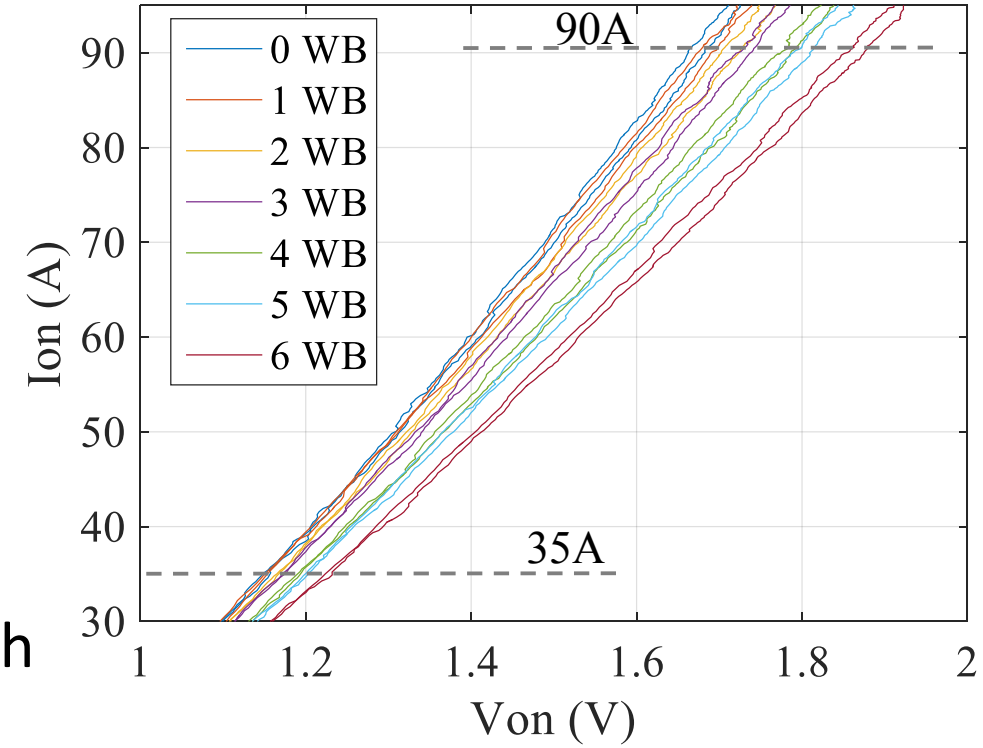
On-line Ion(Von) at a same heatsink temperature and during increasing and decreasing current with linear fit

ΔRelec estimation: sensitivity to WB lift-off

- Wire-bond sectioning experiment
- Sensitivity is proportional to current (2.6 ratio)

⇒ Specification for Von sensor:

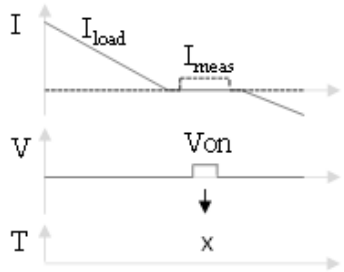
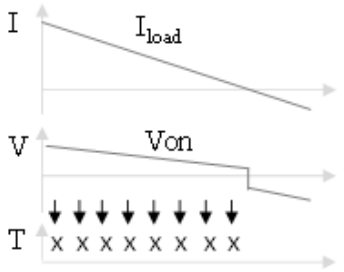
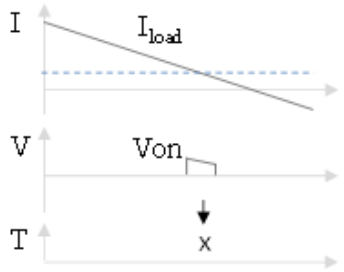
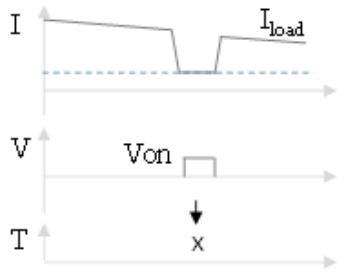
  - High accuracy (mV level) for “early” prognostics
  - High precision (e.g. through additional filtering)



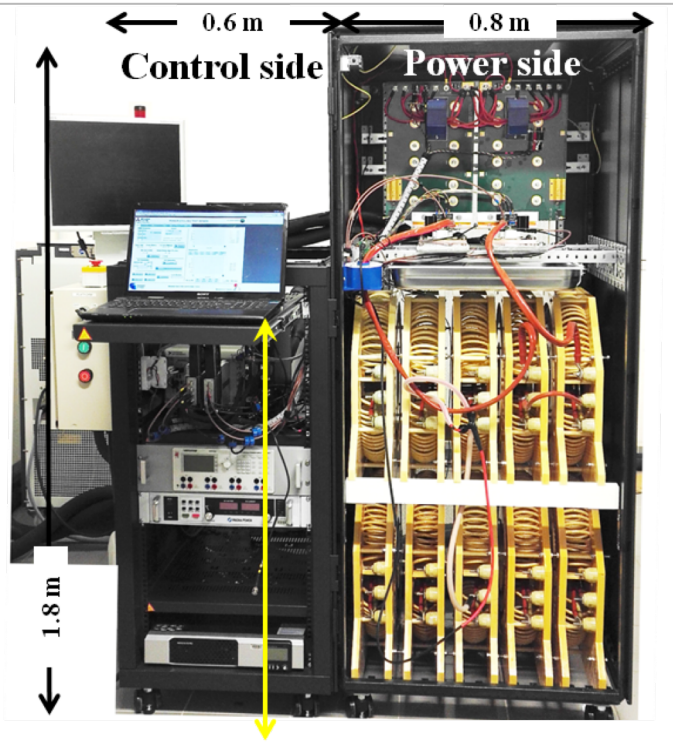
On-line Ion(Von) at with sectioned wire-bonds

	1% Von increase	Average Von jump	5% voltage increase
@ High current of 90A	18mV	33.2mV	90mV
@ ZTC of 35A	7mV	12.8mV	35mV

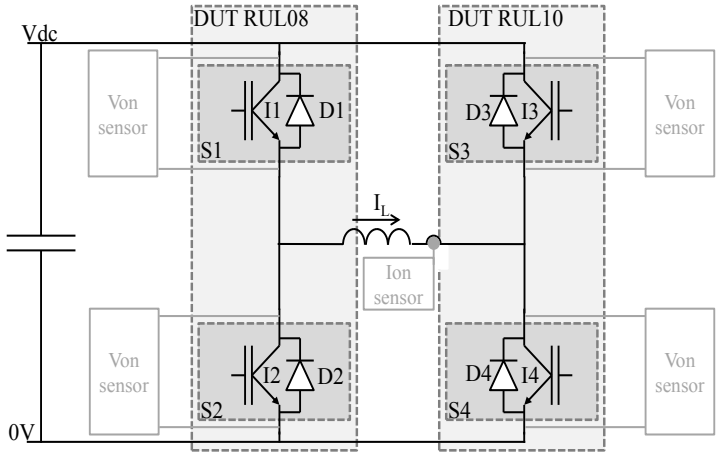
Tj estimation with Von: review

	Method 1: Von @ low measurement current	Method 2: Von @ any load current	Method 3: Von @ low load-current	Method 4: Von @ low load-current pulses
Features				
Cost and calibration effort	★☆☆☆☆ - Von sensor - Specific current source - By-pass circuit	★★★☆☆ → ★★★★☆ (this paper demonstrates the use of a reduced calibration data) - Von sensor - Current sensor - High calibration effort (calibration versus both temperature and current)		
Intrusiveness and bandwidth	★★☆☆☆ - Disconnects the power-device from power during measurement	★★★★★ - Does not interact with normal operation - Can be performed at each switching period	★★★☆☆ - Does not interact with normal operation - Can be performed twice per modulating period of an inverter	★★★☆☆ - Modifies the load current during 100µs to 200µs - Each temperature estimation impacts load current and EMI
Accuracy	★★★★☆ - The main issue is the cool-down during the delay before measurement	★★☆☆☆ - Self-heating in calibration - High influence of the interconnect temperature - Low sensitivity for some current values close to ZTC - Uncertainty on current	★★★★☆ - Uncertainty on current	
Robustness	★★★★★	★☆☆☆☆ - High sensitivity to wire-bond degradation	★★☆☆☆ → ★★★★☆ (this paper demonstrates a means to estimate and compensate for the wire-bond degradation) - Medium sensitivity to wire-bond degradation	
References	[4] [5] [6]	[7] [8] [9]	-	[11]

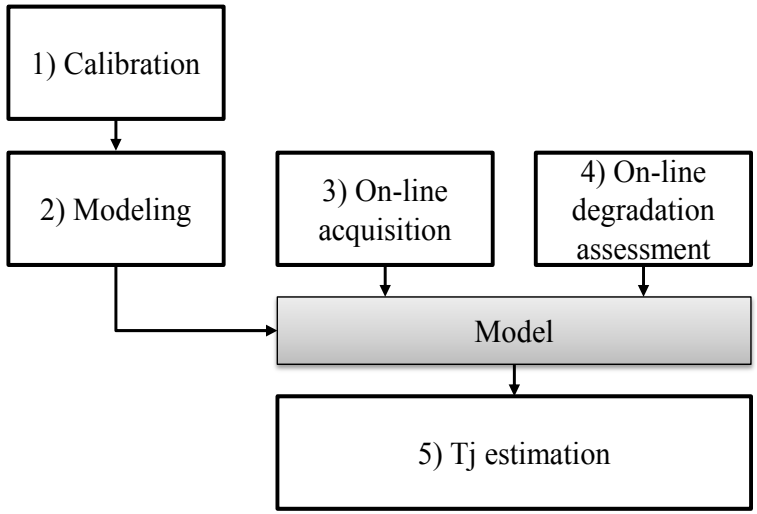
Tj estimation with Von at low load current pulse



Test bench

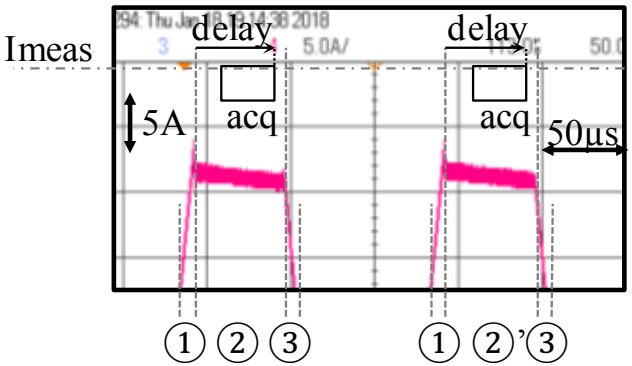


Topology



Method

1) Calibration

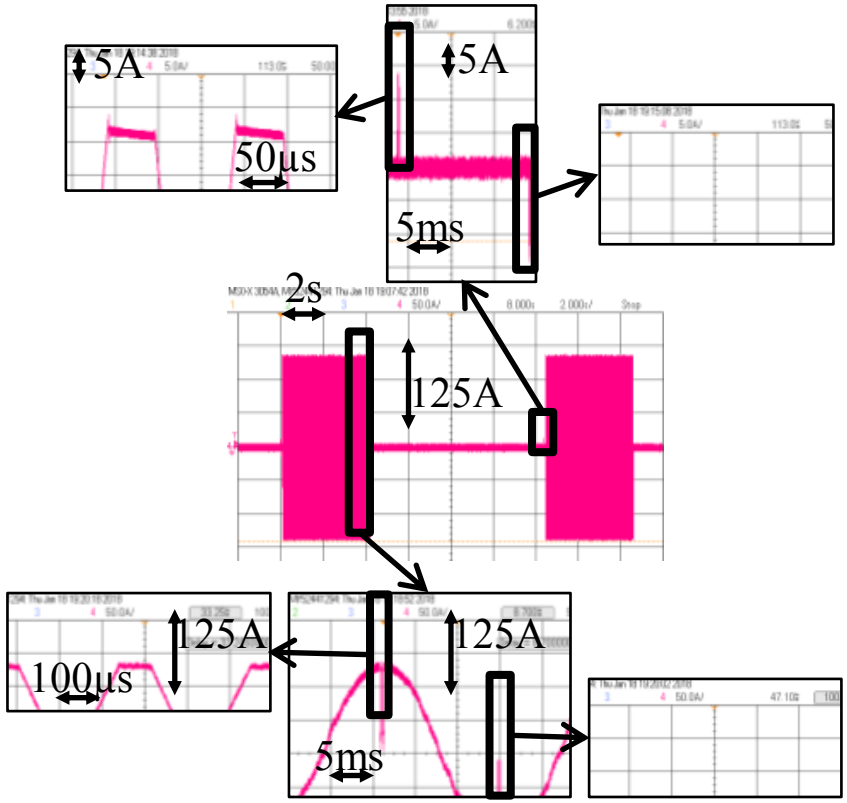


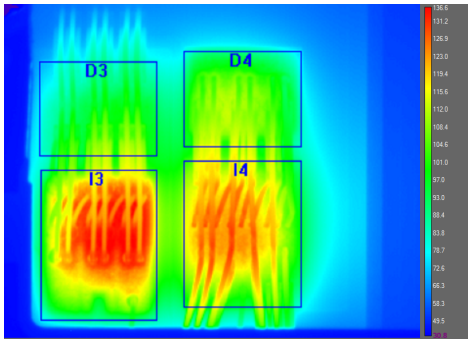
2) Modeling

$$Von = (a \cdot Tj + b) \cdot Ion + (c \cdot Tj + d + e \cdot Tj^2)$$

Tj estimation with Von: results

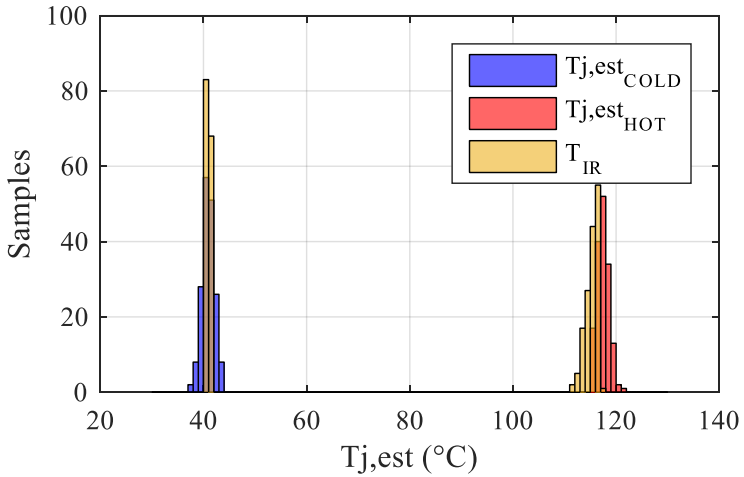
3) On-line acquisition



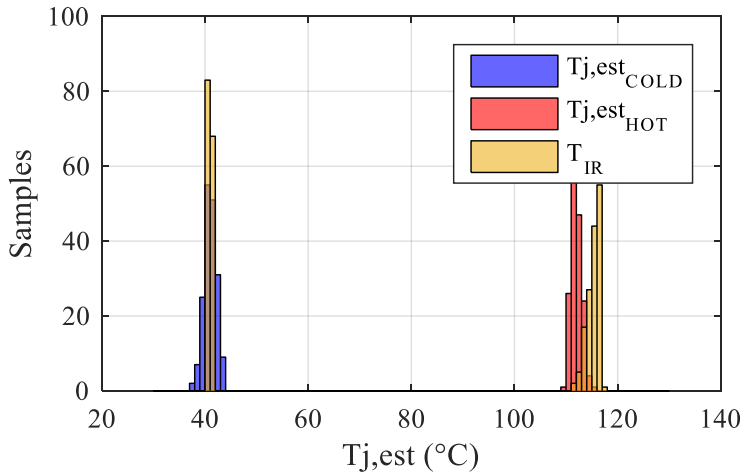


IR observation

5) Tj estimation with full calibration dataset (20°C to 160°C)

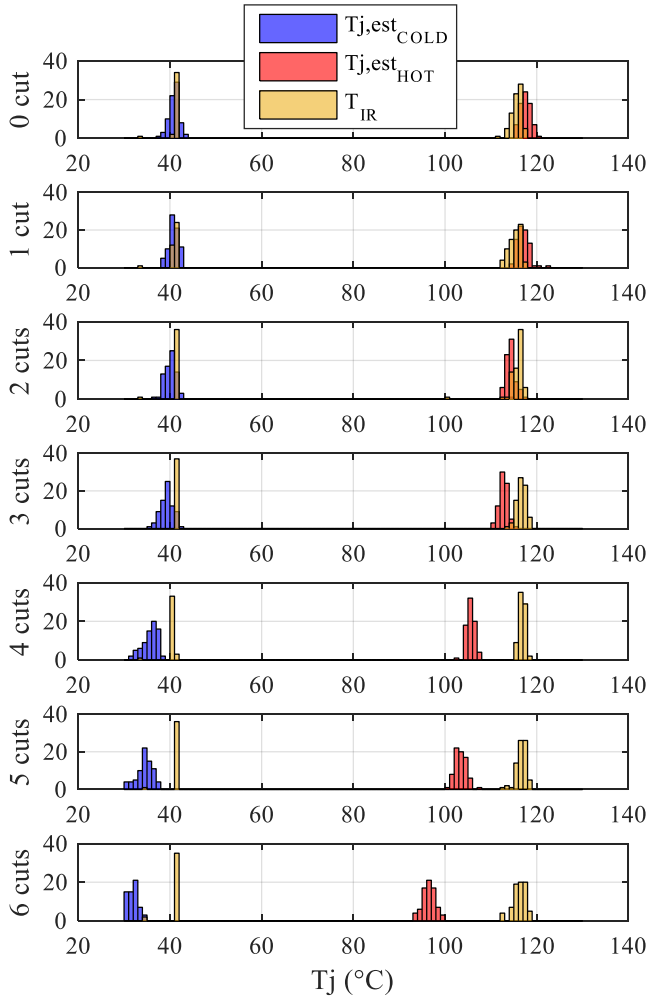


5) Tj estimation with reduced calibration dataset (20°C to 70°C)

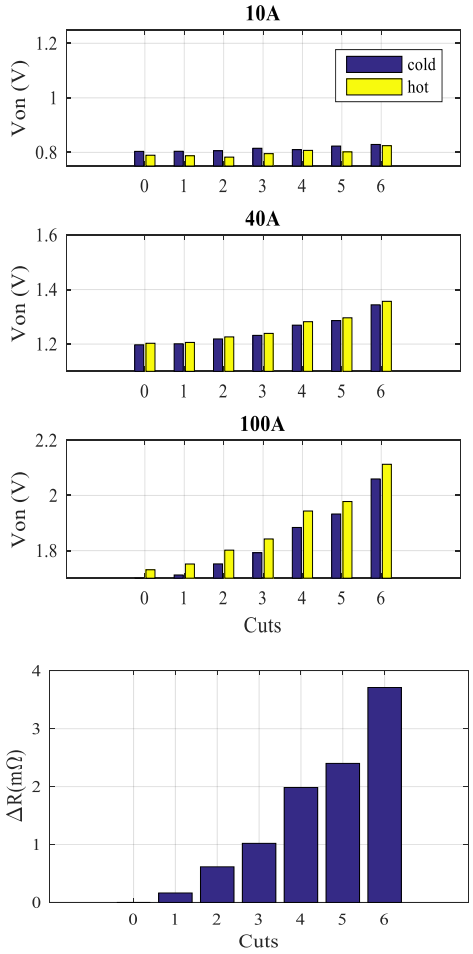


Tj estimation with Von: robustness

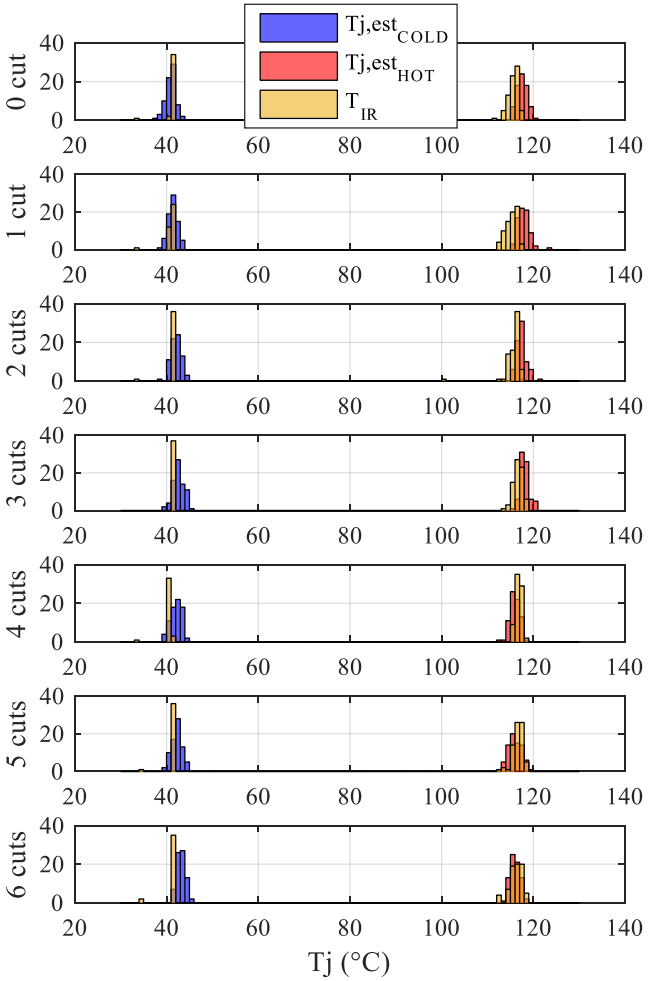
5) Tj estimation with wire-bond cuts without correction of degradation



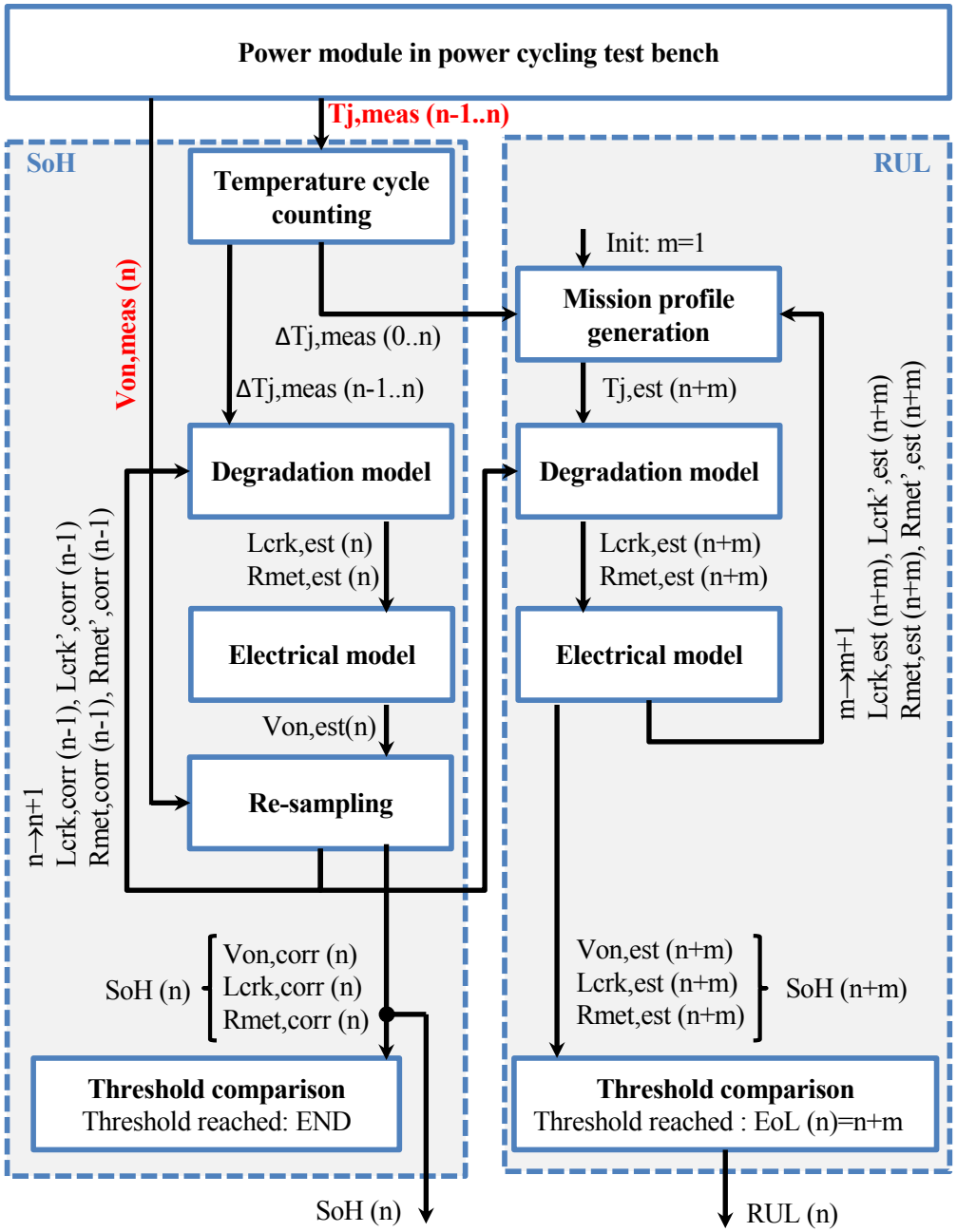
4) On-line degradation assessment



5) Tj estimation with wire-bond cuts with correction of degradation

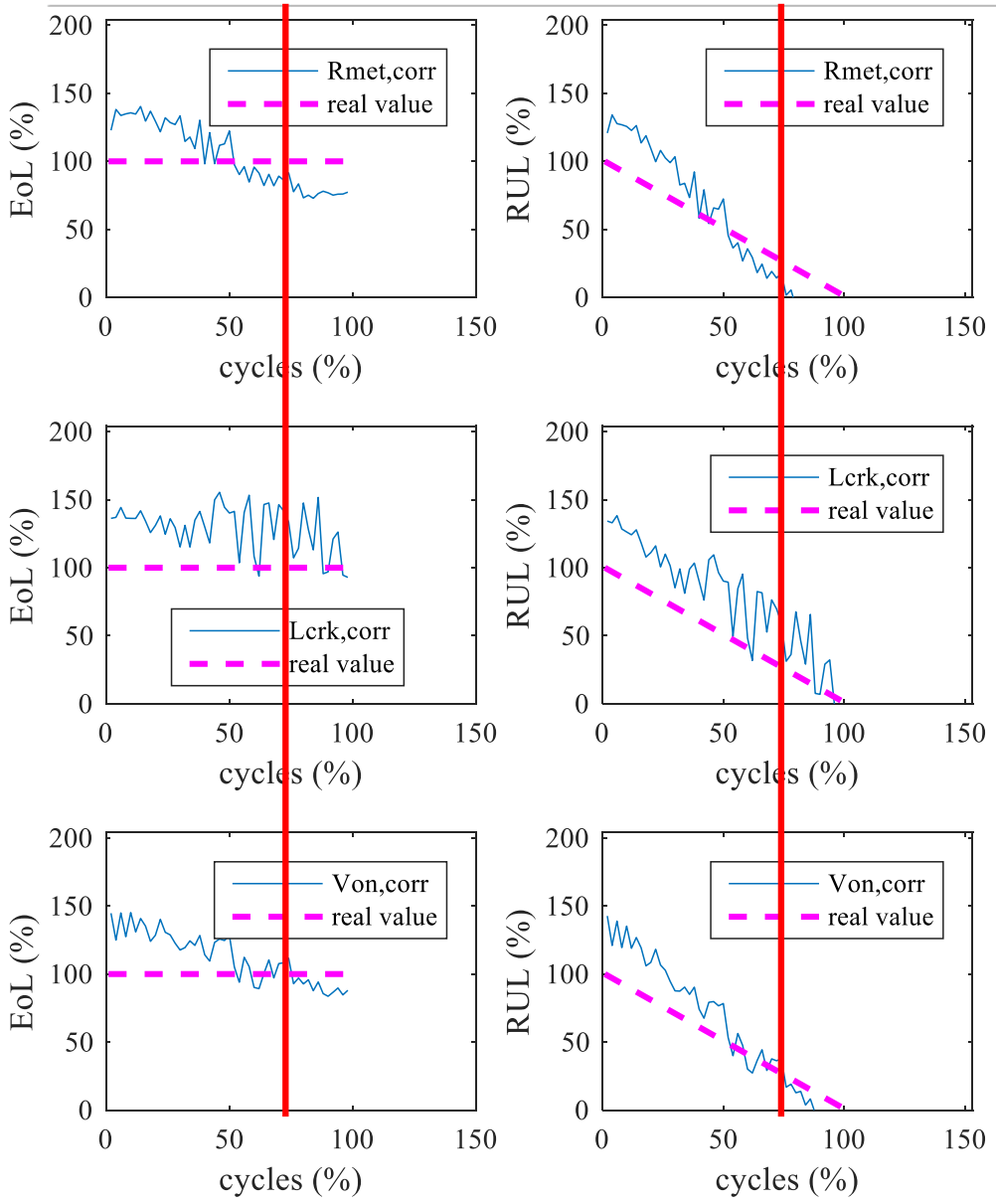


Prognostic algorithm: concept

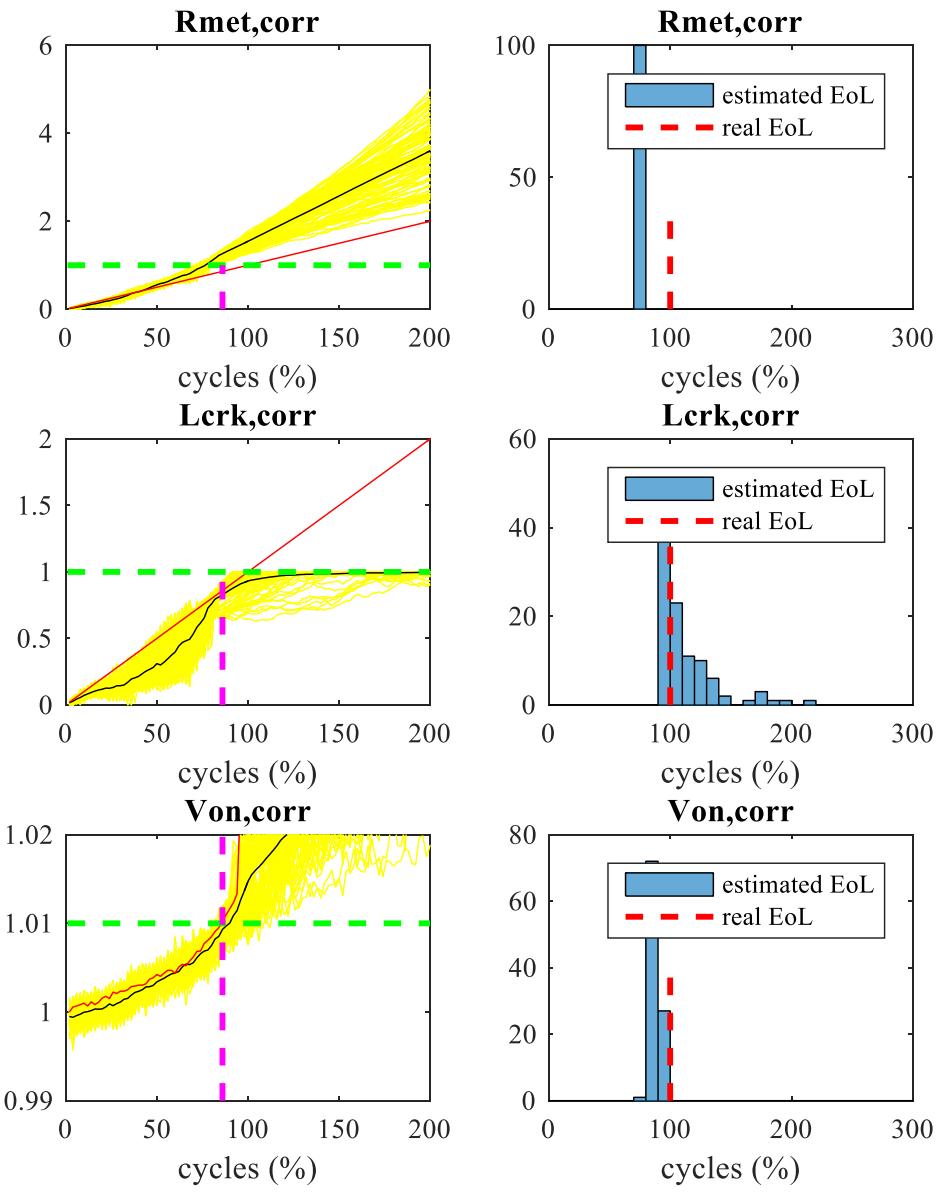


- Algorithm based on Von evolution prior to first WB lift-off.
- Degradation model:
  - Coffin-Manson + Miner rule
- Electrical model:
  - Linear increase of crack length and metallization, calibrated with training tests
- Resampling:
  - Particle filter
- Validation: DC PC data.

Prognostic algorithm: results



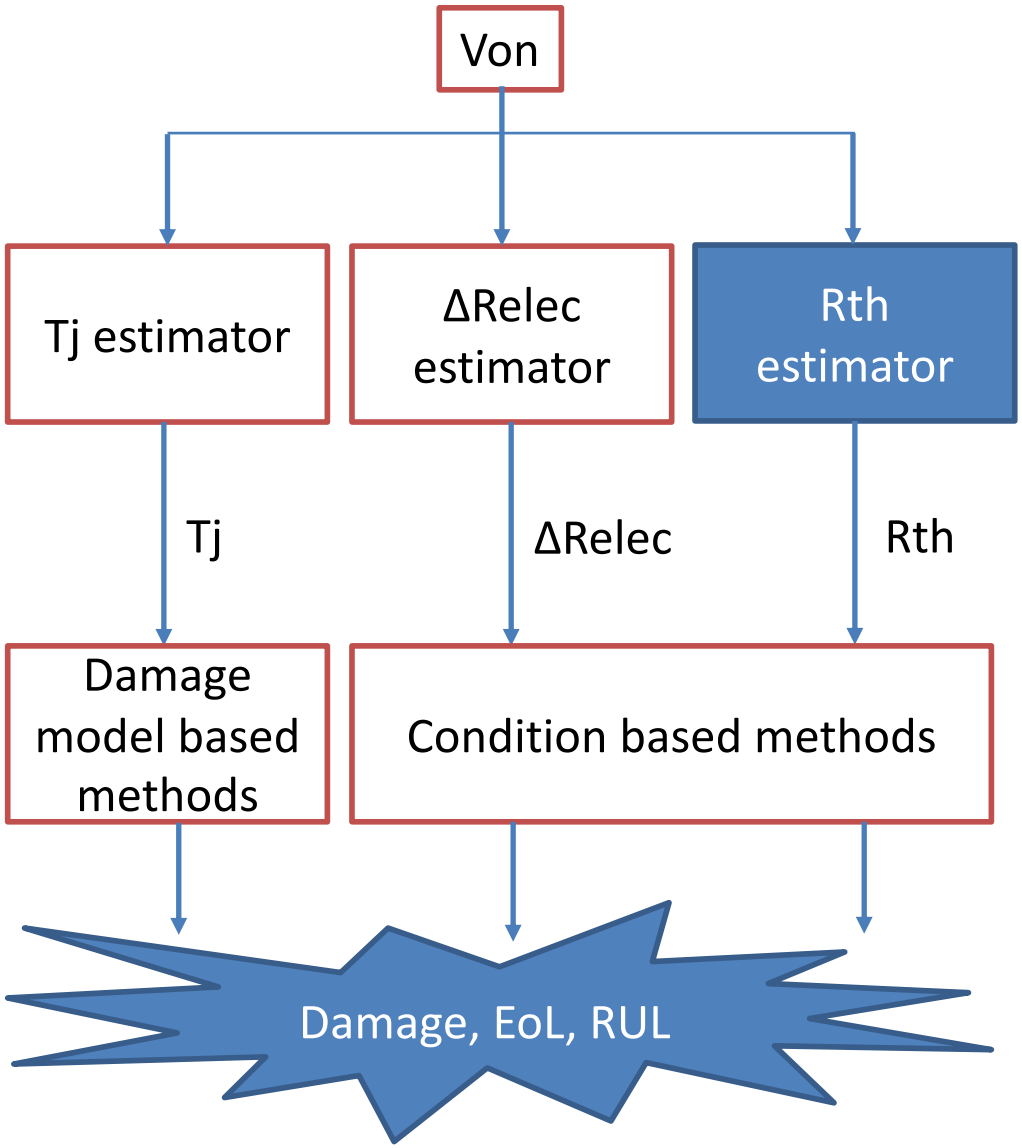
Mean estimation of the EoL and RUL as a function of number of cycle for a DUT.

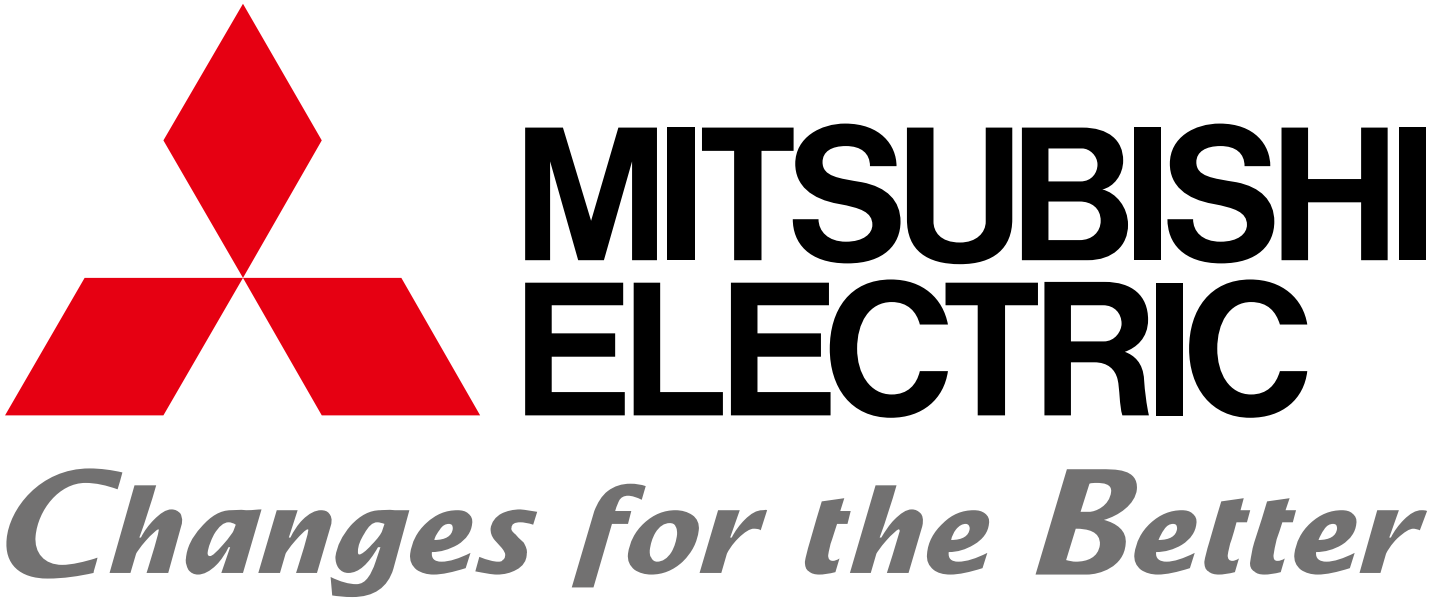


Details of the algorithm activated after 75% cycles.

Conclusion/Outline

- Introduction
- Von sensor
- ΔRelec estimation
- Tj estimation
- Prognostic algorithm

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