Reliability of power electronic converters for offshore wind turbines

A main topic in the research project:

"Power Electronics for Reliable and Energy Efficient Renewable Energy Systems"

Short name: **OPE**

Duration: 2009-2014

Financing: The Research Council of Norway and three industry partners

Web: www.sintef.no/OPE

Magnar Hernes SINTEF Energy Research
Magnar.Henes@sintef.no

TOPICS

Topic

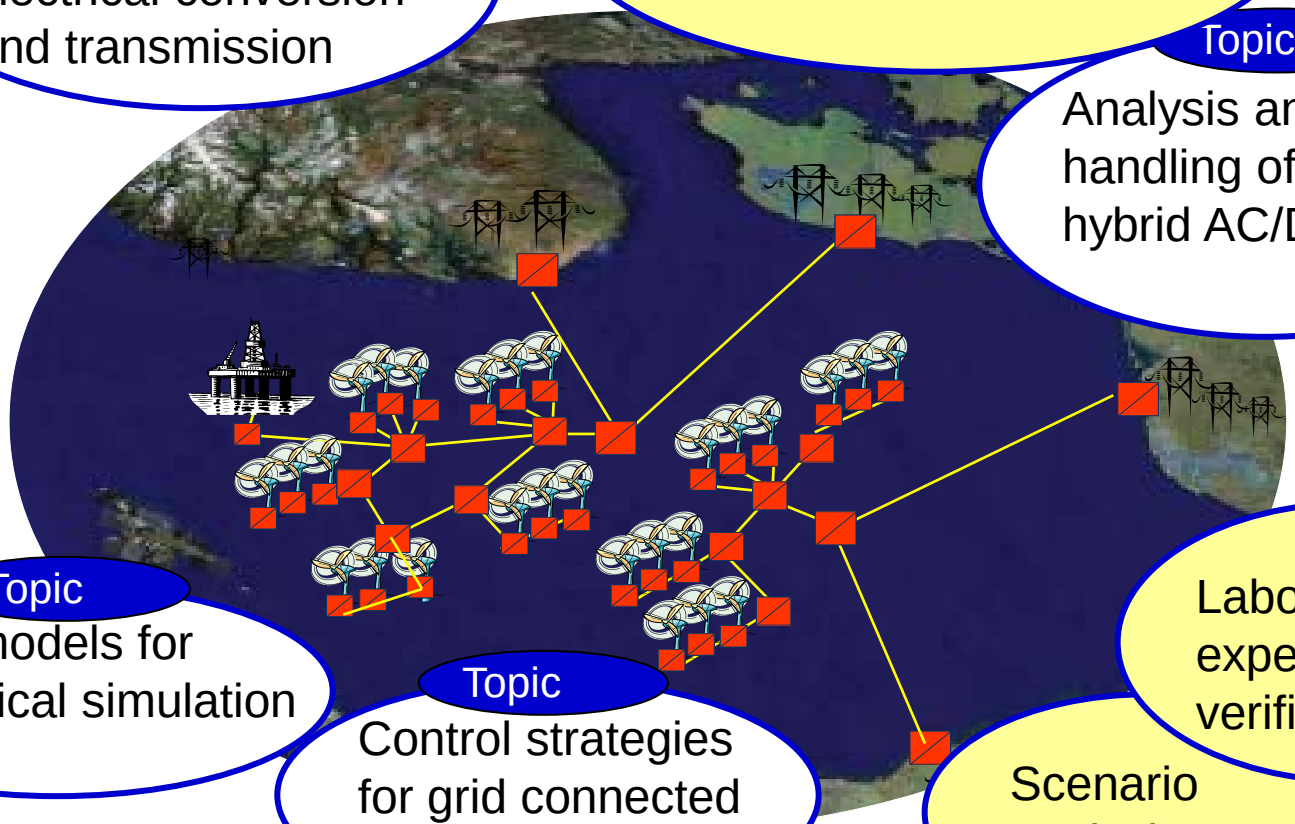
Energy efficient electrical conversion and transmission

Topic

Reliable power electronics for renewable energy systems

Topic

Analysis and fault handling of advanced hybrid AC/DC grids



Topic

New models for numerical simulation

Topic

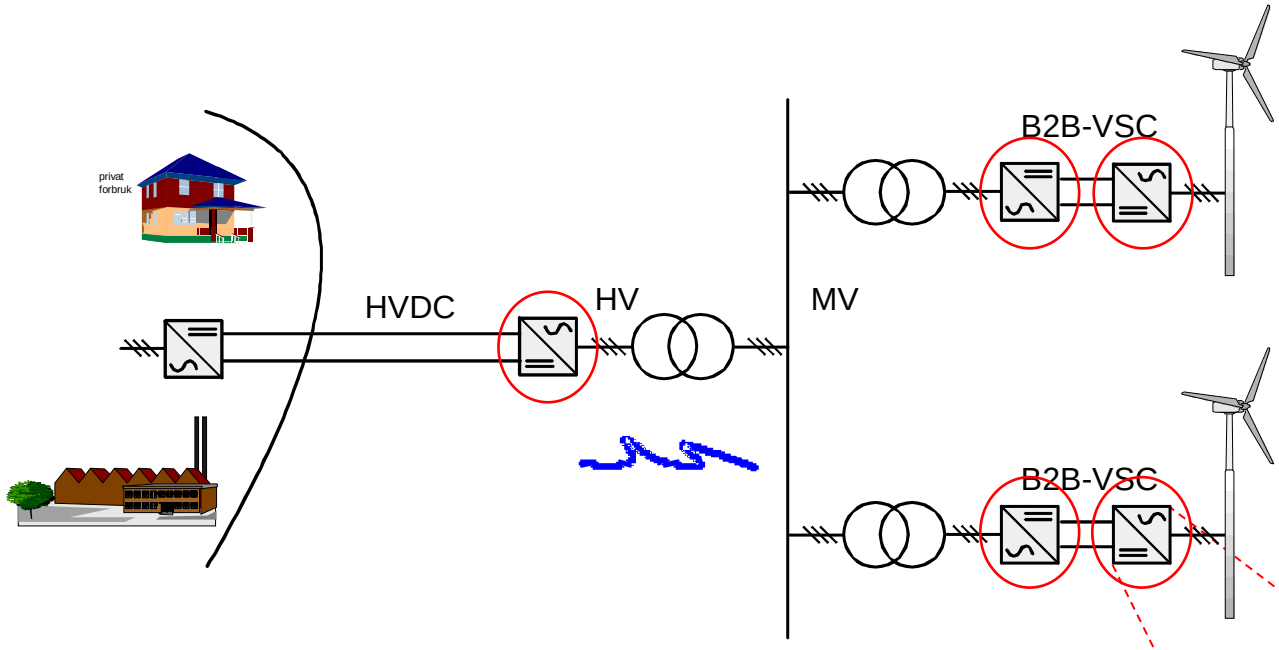
Control strategies for grid connected converters

Laboratory experiments & verifications

Scenario analysis

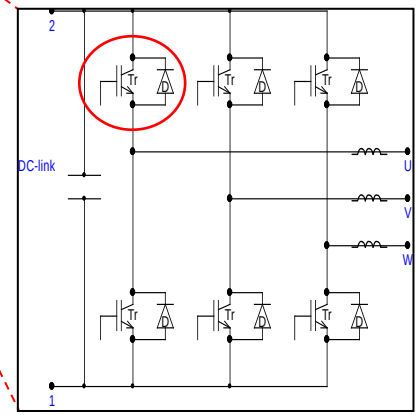
Reliable and Energy Efficient Renewable Energy Systems

Power electronics for wind farm power conversion

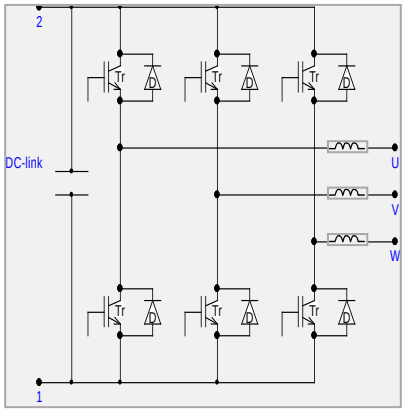


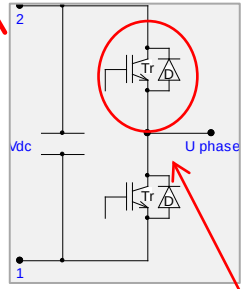
IGBT = **I**nsulated **G**ate **B**ipolar **T**ransistor

2L-VCS = 2-level Voltage Source Converter



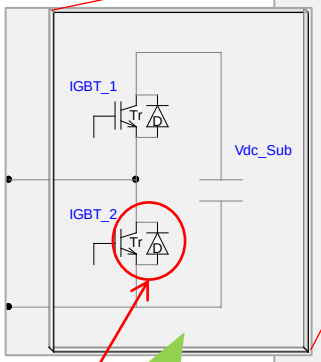
Converter topologies for MV and HV applications

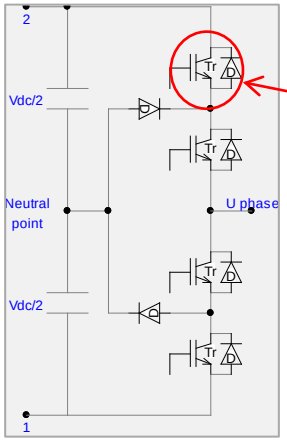


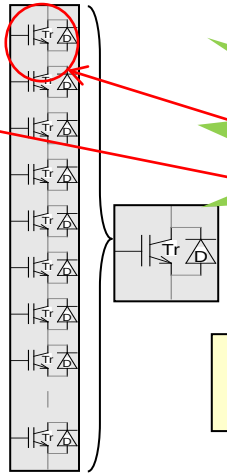


2L-VCS (one phase-leg)

Modular Multilevel Converter - MMC







Test objects for reliability investigations

Series connection of IGBTs

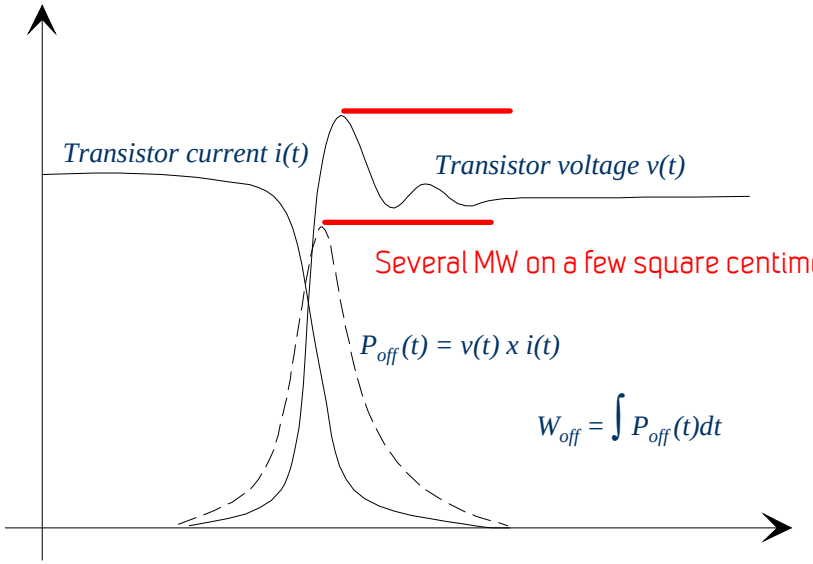
3L-VCS (one phase-leg)

Due to voltage limitation of single IGBTs, MV and HV converters need more complex topologies and/ or series connection of IGBTs

Reliability of power semiconductors - Failure modes

- Spontaneous failures due to overloads
  - Related to power semiconductor chips
  - Thermal overload and overvoltage
  - Exceeding V/I safe operating area for the device
- Failures triggered by external environment
  - E.g. intrusion of humidity
  - E.g. cosmic radiation
- Failures due to aging or exhaustion
  - Mechanical and electrical termination of the chips
  - Packaging and encapsulation

Project focus



Typical turn-off behaviour for a controllable power semiconductor

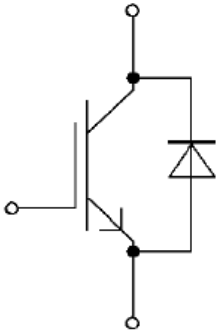
- Mostly chip related:
  - Spontaneous failures
  - Cosmic radiation
- Mostly related to packaging
  - Ageing or exhaustion
  - Intrusion of humidity in chip insulation

IGBT packaging

- Mainly two technologies
  - Planar bonded modules
  - Press-pack housing

- A 750A/ **6500V** IGBT module from Infineon

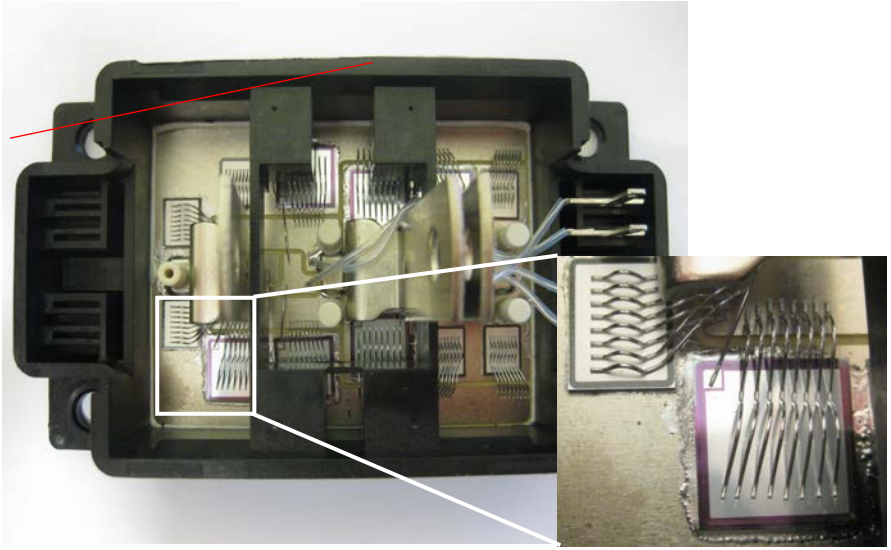
- Both can contain both IGBT chips and antiparallel free-wheeling diodes



- An 1800A/ **4500V** press-pack IGBT from Westcode

Planar bonded IGBT modules

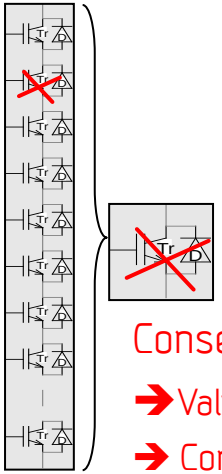
- Main failure mechanisms:
  - Bond wire lift off
  - Solder layer disconnect



- Thorough investigations and publications

$$N_f = K \cdot \Delta T_J^{\beta_1} \cdot e^{\left(\frac{\beta_2}{T_J+273}\right)} \cdot t_{on}^{\beta_3} \cdot I^{\beta_4} \cdot V^{\beta_5} \cdot D^{\beta_6} \quad (T_j=T_{low} \text{ in } °C)$$

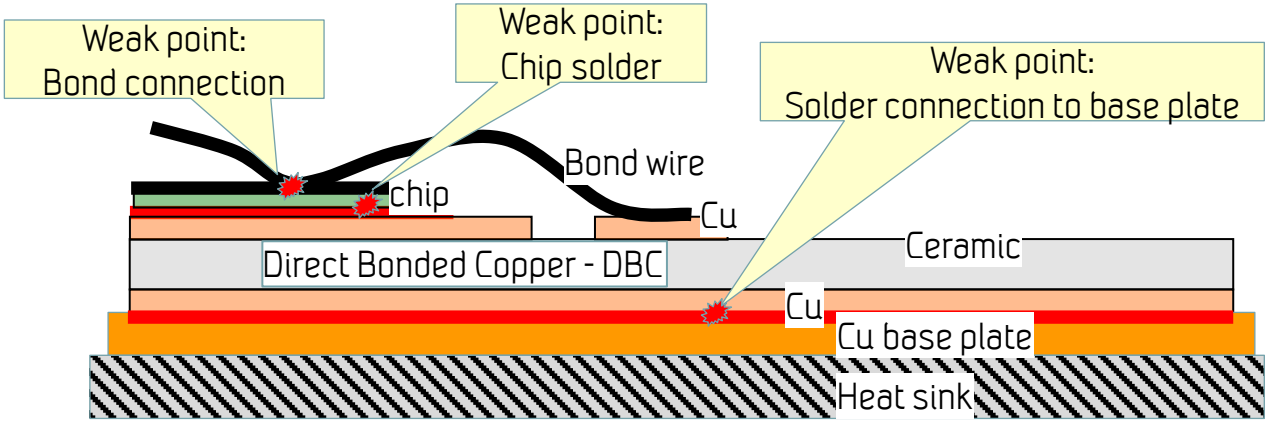
- Failure mode
  - **Failure to break**



Consequence:

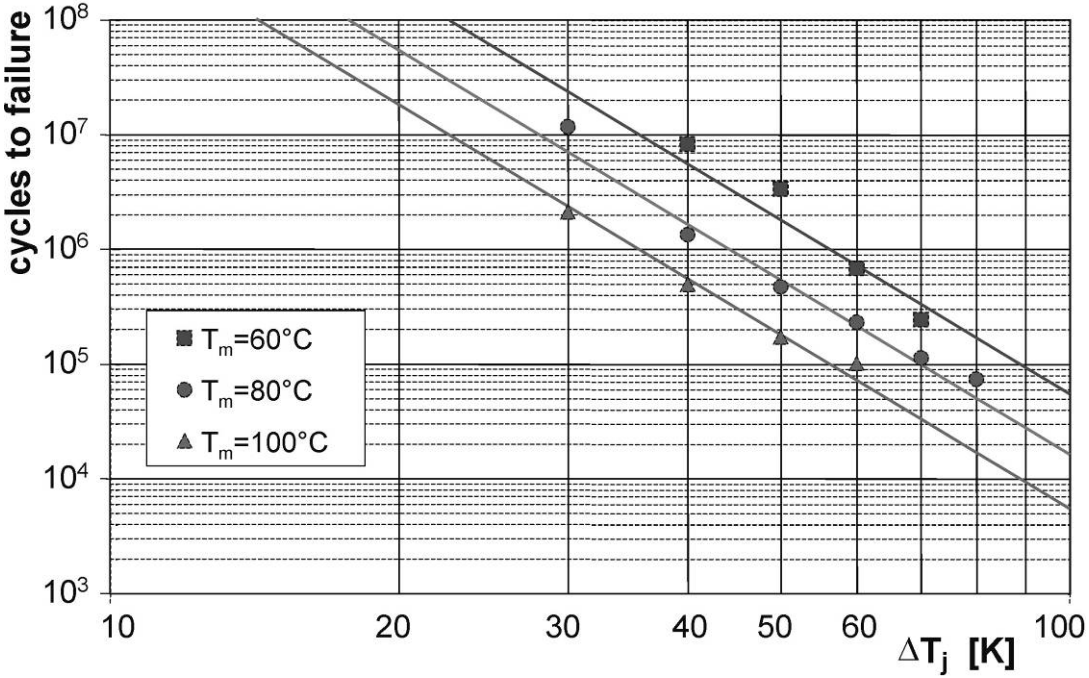
➔ Valve failure

➔ Converter failure



Life time curves – no of cycles to failure

Experience data from modules:

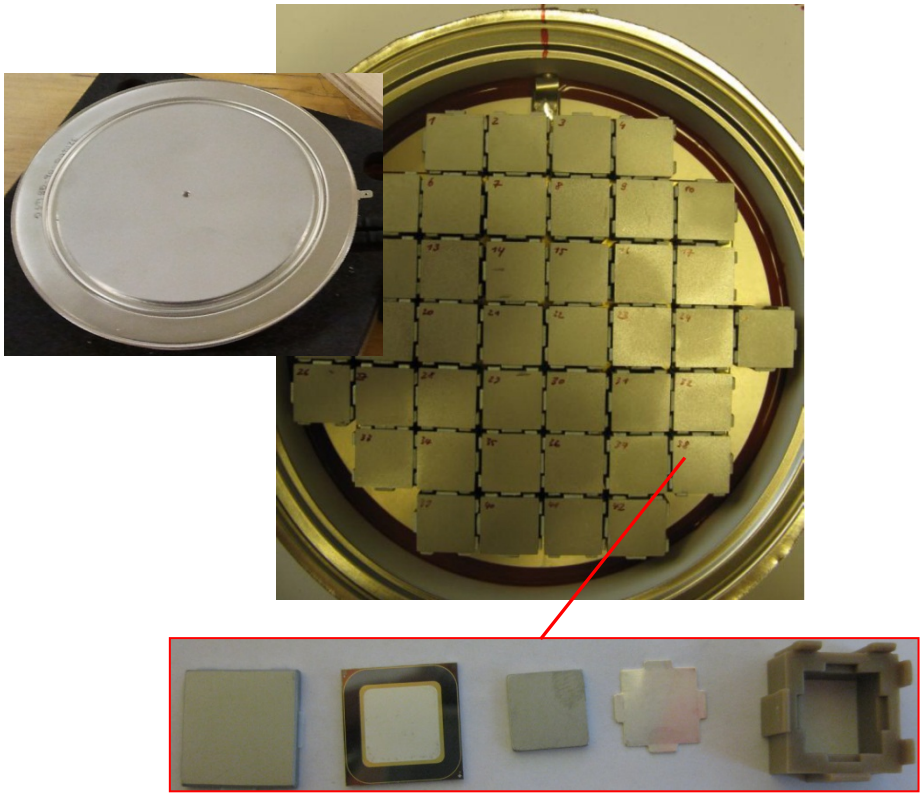


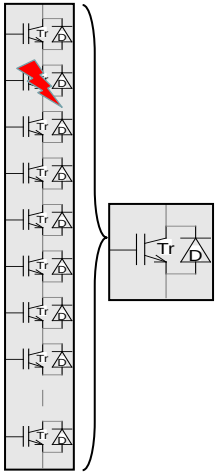
Lifetime dependent on:

- ΔT
- T_{max}
- dT/dt
- t_{on}
- I_{Load}
- control strategy
- and more….

Press-pack IGBTs

- Failure mechanisms:
  - ***Limited knowledge***
- Few publications on failure mechanisms and reliability
- Failure mode
  - **Expected failure to short**





Consequence:

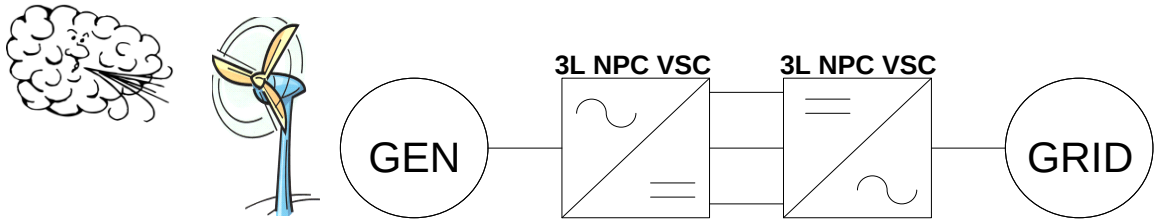
➔ Valve still functional

➔ Reduced voltage margins to failure

Main focus on reliability of press-pack IGBTs in the OPE project

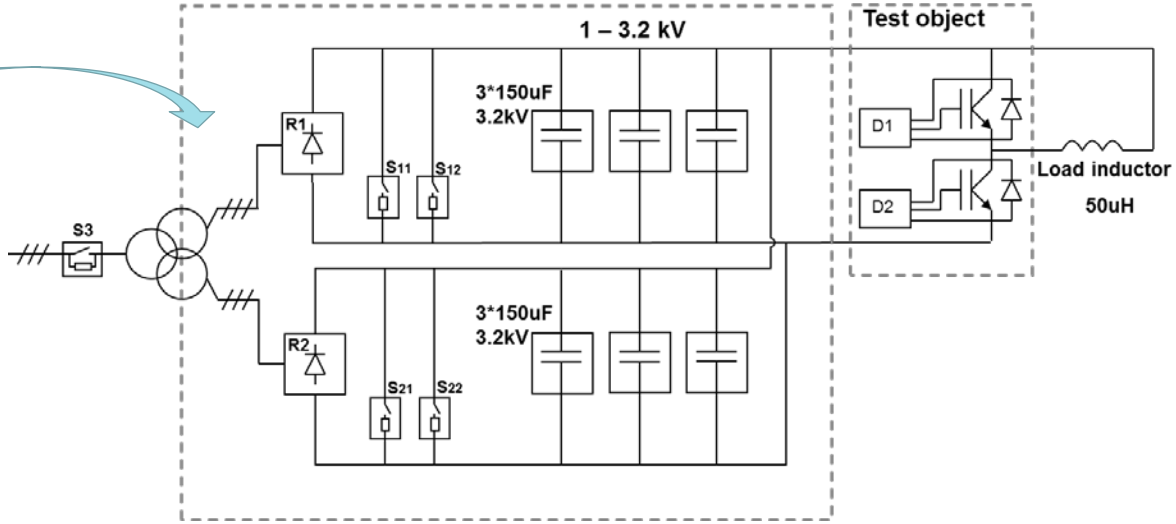
- The OPE project prioritized reliability of press pack devices for the following reasons:
  - Limited published information regarding failure mechanisms and power cycling life time
  - Press-pack devices are very relevant in medium voltage wind power applications due to series connection capabilities (fail-to short-circuit)
  - Special power cycling stress condition for wind power converters (wind fluctuations, low motor side frequency etc.)
- Then we need to know:
  - Load profiles for the application, e.g. power cycling due to wind fluctuations
  - Stress levels related to grid side and generator side load conditions (power frequency, cos φ etc.)
  - Stress levels related to the converter power circuit and controls (topology, switching frequency etc)
- Theoretical work
- Experimental work

Case study: A medium voltage PWM 3L-NPC VSC for 3.3 kV AC

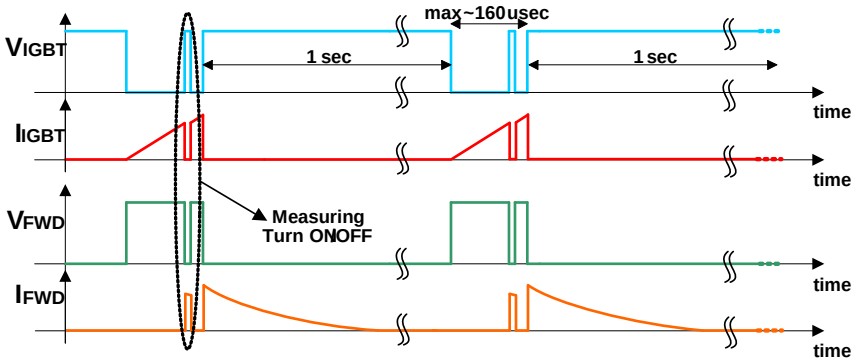


- DC link voltage ~ 5 kV
- 3.3 kVac (LL voltage)
- Switching frequency ~ 1500 Hz +/-
- 5 MVA (connected to a 3.6 MW wind turbine gen.)
- IGBT: Press-pack1800 A/4500 V

Test Cell for mapping switching characteristics of HV IGBTs



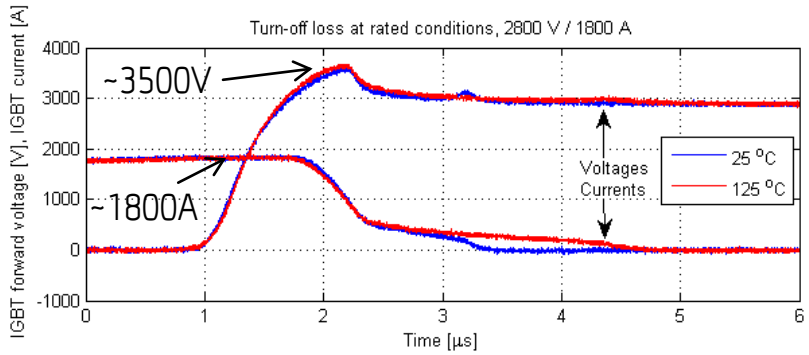
- Present Test Cell with 0-5 kV DC-link
- Planned to be extended to 10kV

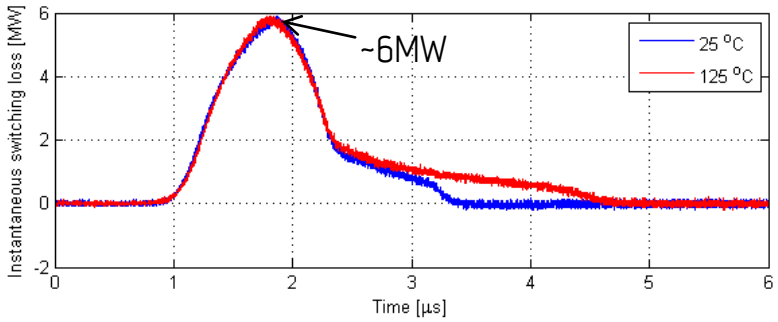


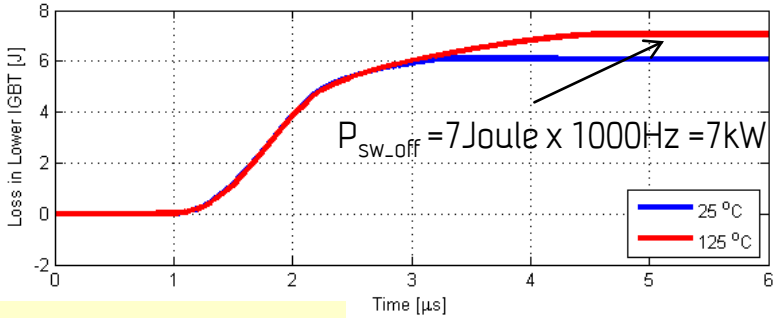
- "Double-pulse" waveform for measuring IGT turn-on and turn off waveform
- External liquid (silicon oil) heating/cooling circuit for temperature control (5- 50 ^{0}C)

Turn-off waveforms with DC-link 2800V and turn-off current 1800A

Test object:
1800A/4500V press-pack IGBT

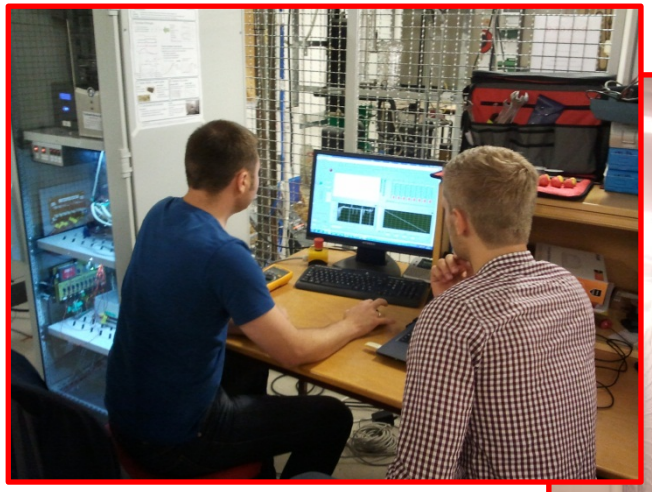


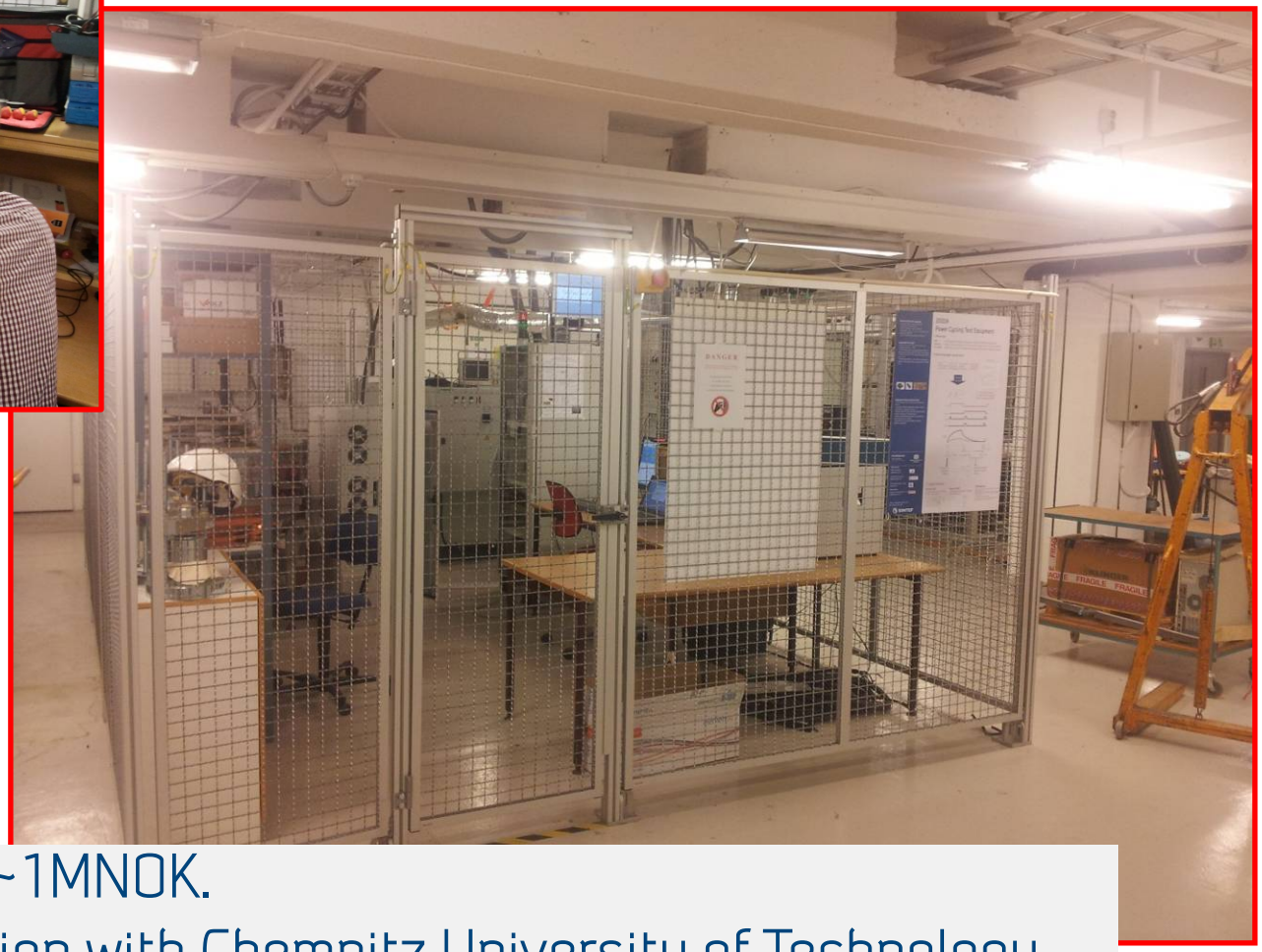




$P_{total}=P_{sw\_off}+P_{sw\_on}+P_{cond}$

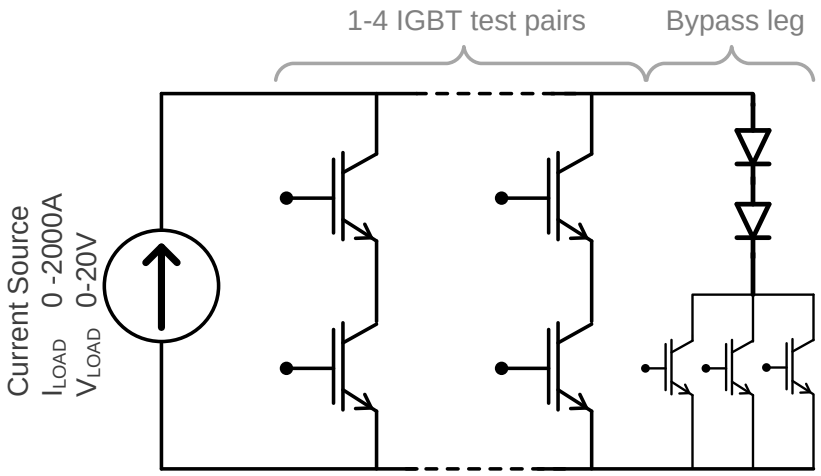
Power Cycling Tester for life-time testing of high-power IGBTs (2000 A)

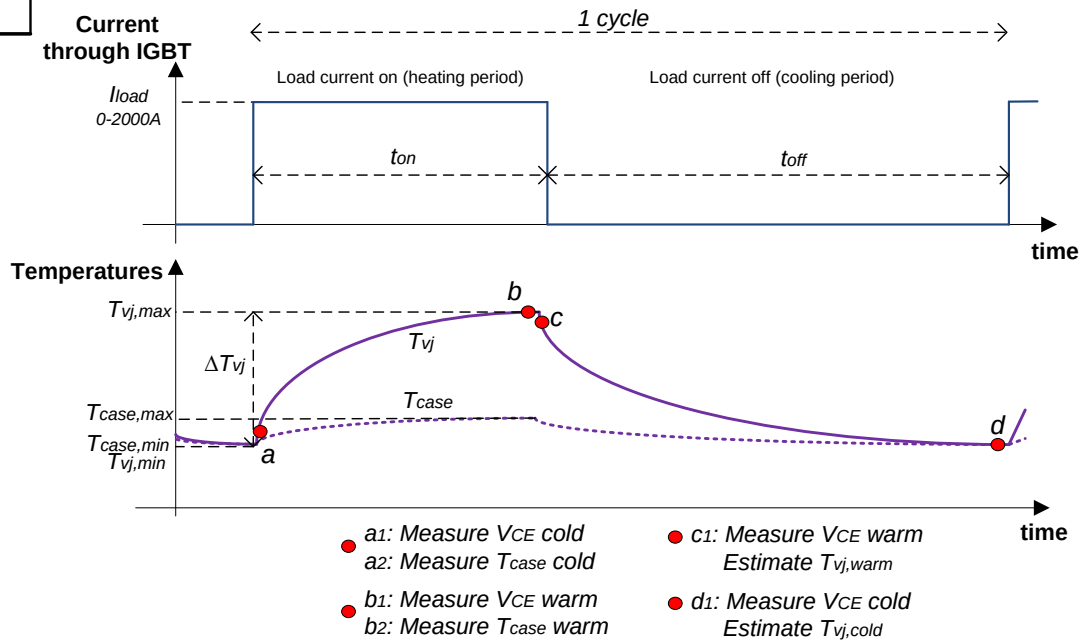




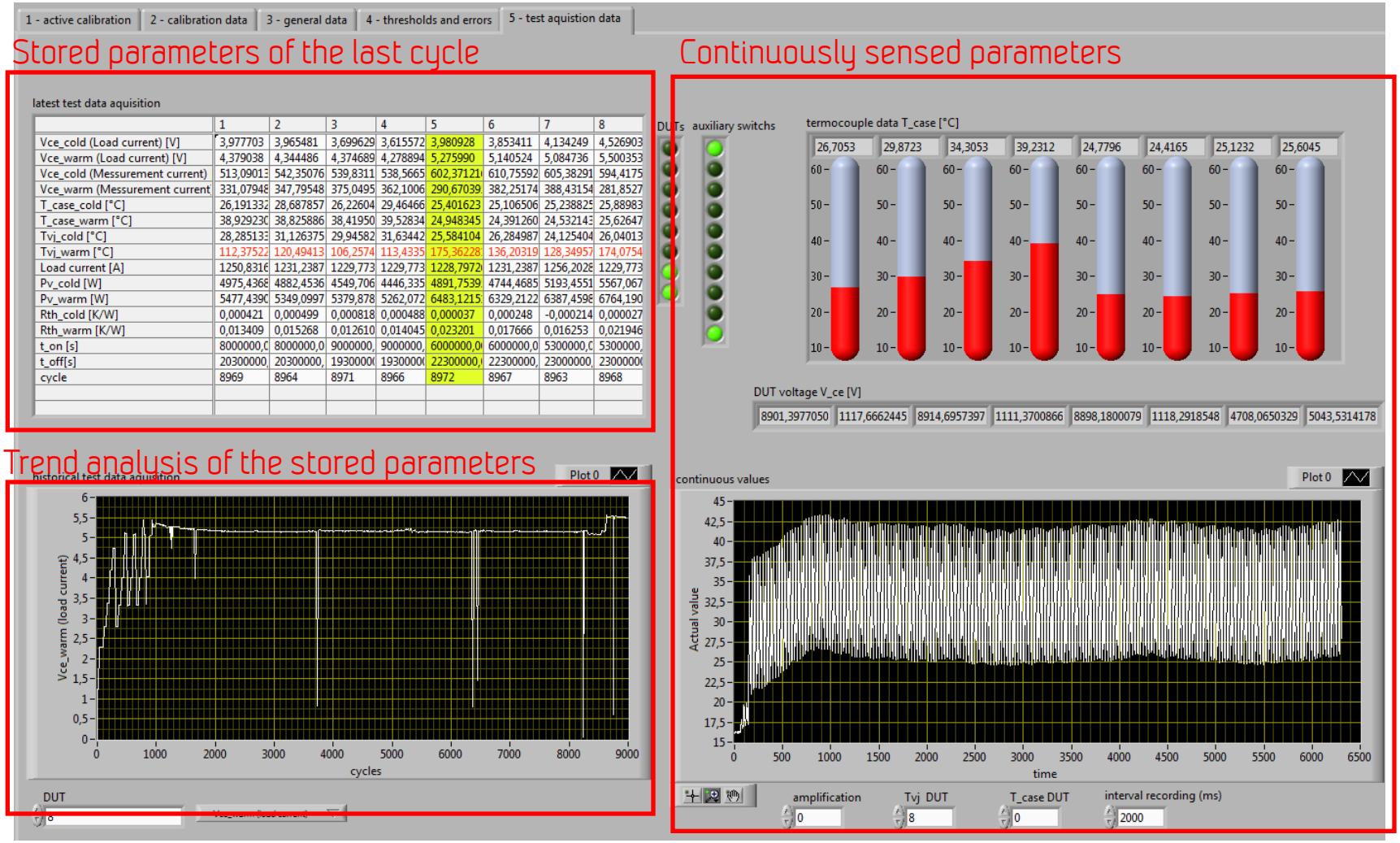
Project investment of ~1MNOK.
Developed in cooperation with Chemnitz University of Technology

Operation of the Power Cycling Tester



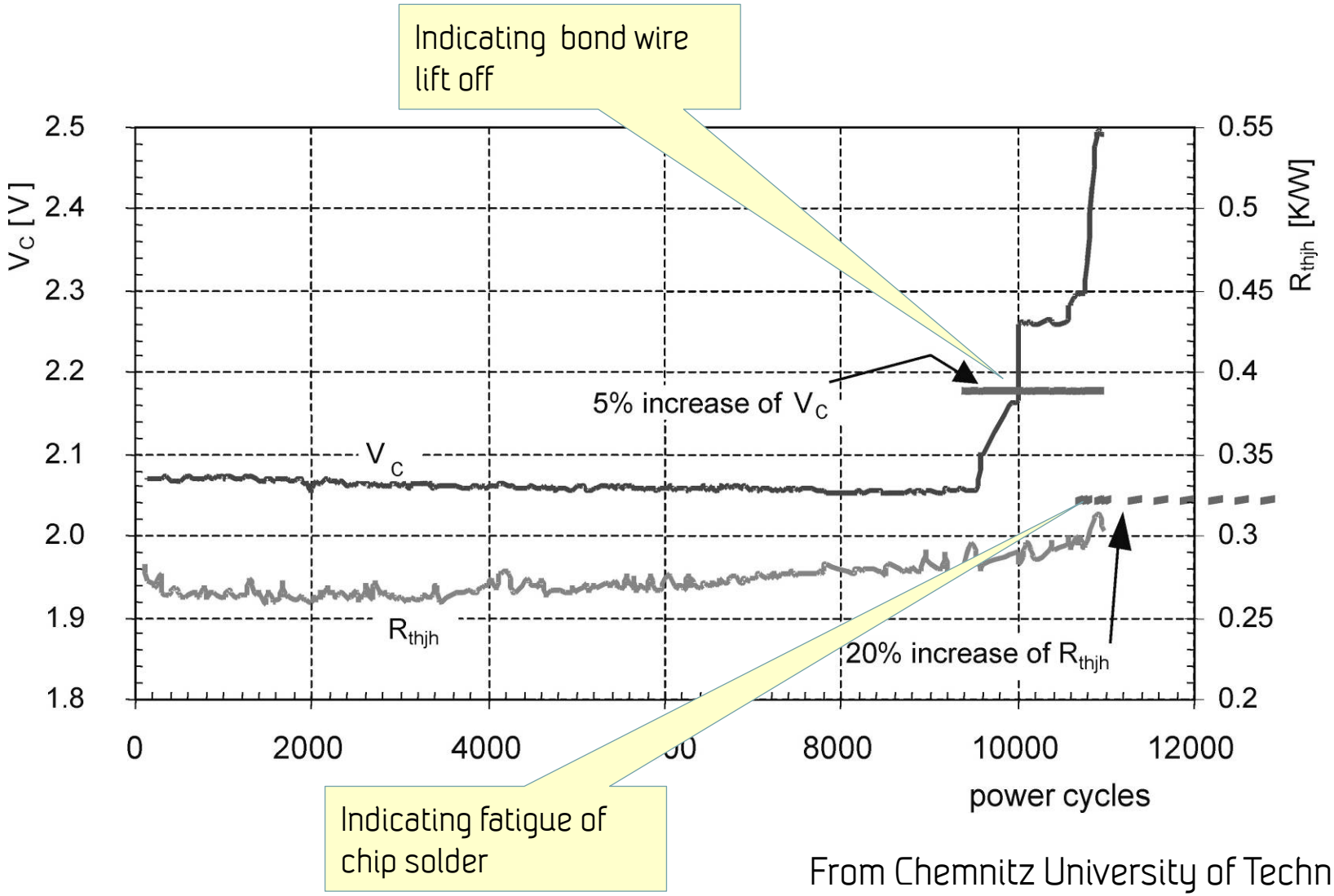


OPE Power Cycling Tester – Control screen



	1	2	3	4	5	6	7	8
Vce_cold (Load current) [V]	3,977703	3,965481	3,699629	3,615572	3,980928	3,853411	4,134249	4,526903
Vce_warm (Load current) [V]	4,379038	4,344486	4,374689	4,278894	5,275990	5,140524	5,084736	5,500353
Vce_cold (Messurement current)	513,09013	542,35076	539,8311	538,5665	602,37121	610,75592	605,38291	594,4175
Vce_warm (Messurement current	331,07948	347,79548	375,0495	362,1006	290,67039	382,25174	388,43154	281,8527
T_case_cold [°C]	26,191332	28,687857	26,22604	29,46466	25,401623	25,106506	25,238825	25,88983
T_case_warm [°C]	38,929230	38,825886	38,41950	39,52834	24,948345	24,391260	24,532143	25,62647
Tvj_cold [°C]	28,285133	31,126375	29,94582	31,63442	25,584104	26,284987	24,125404	26,04013
Tvj_warm [°C]	112,37522	120,49413	106,2574	113,4335	175,36228	136,20319	128,34957	174,0754
Load current [A]	1250,8316	1231,2387	1229,773	1229,773	1228,7972	1231,2387	1256,2028	1229,773
Pv_cold [W]	4975,4368	4882,4536	4549,706	4446,335	4891,7539	4744,4685	5193,4551	5567,067
Pv_warm [W]	5477,4390	5349,0997	5379,878	5262,072	6483,1215	6329,2122	6387,4598	6764,190
Rth_cold [K/W]	0,000421	0,000499	0,000818	0,000488	0,000037	0,000248	-0,000214	0,000027
Rth_warm [K/W]	0,013409	0,015268	0,012610	0,014045	0,023201	0,017666	0,016253	0,021946
t_on [s]	8000000,0	8000000,0	9000000,	9000000,	6000000,0	6000000,0	5300000,0	5300000,
t_off[s]	20300000,	20300000,	19300000	19300000	22300000,	22300000,	23000000,	23000000
cycle	8969	8964	8971	8966	8972	8967	8963	8968

Plot from measurement of planar bonded modules

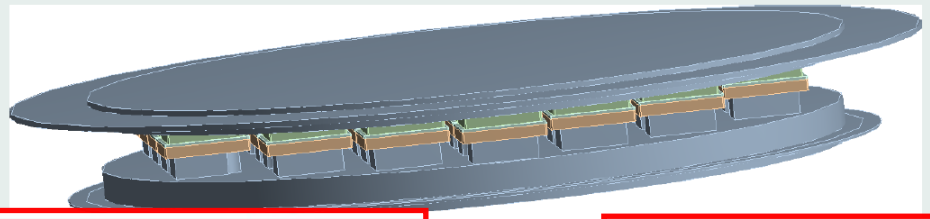


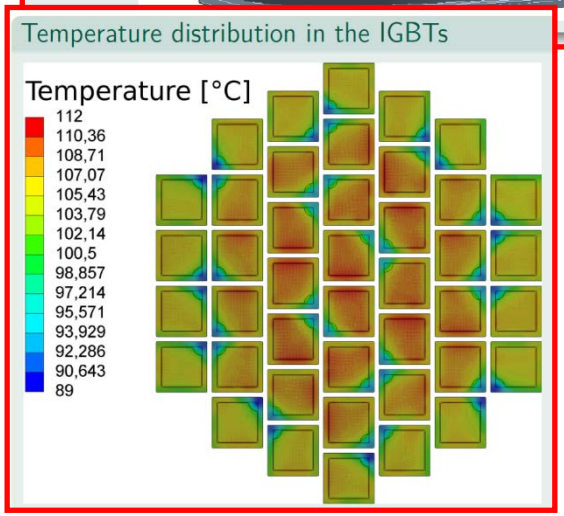
From Chemnitz University of Technology

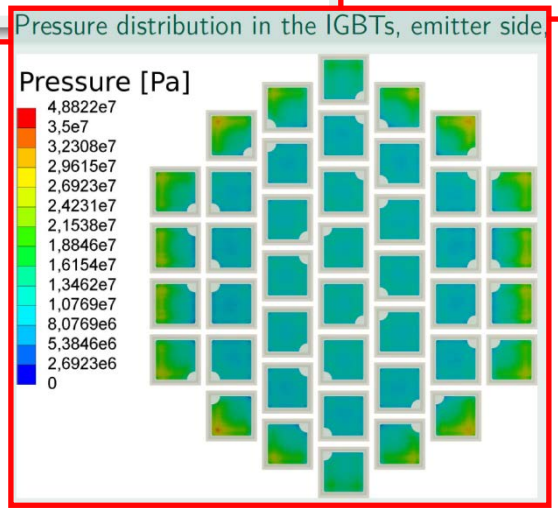
Power Cycling Tester with 4x modules + 4x press packs

Modelling press-pack IGBT for stress analysis
Work by PhD student Tilo Poller at Chemnitz University of Technology

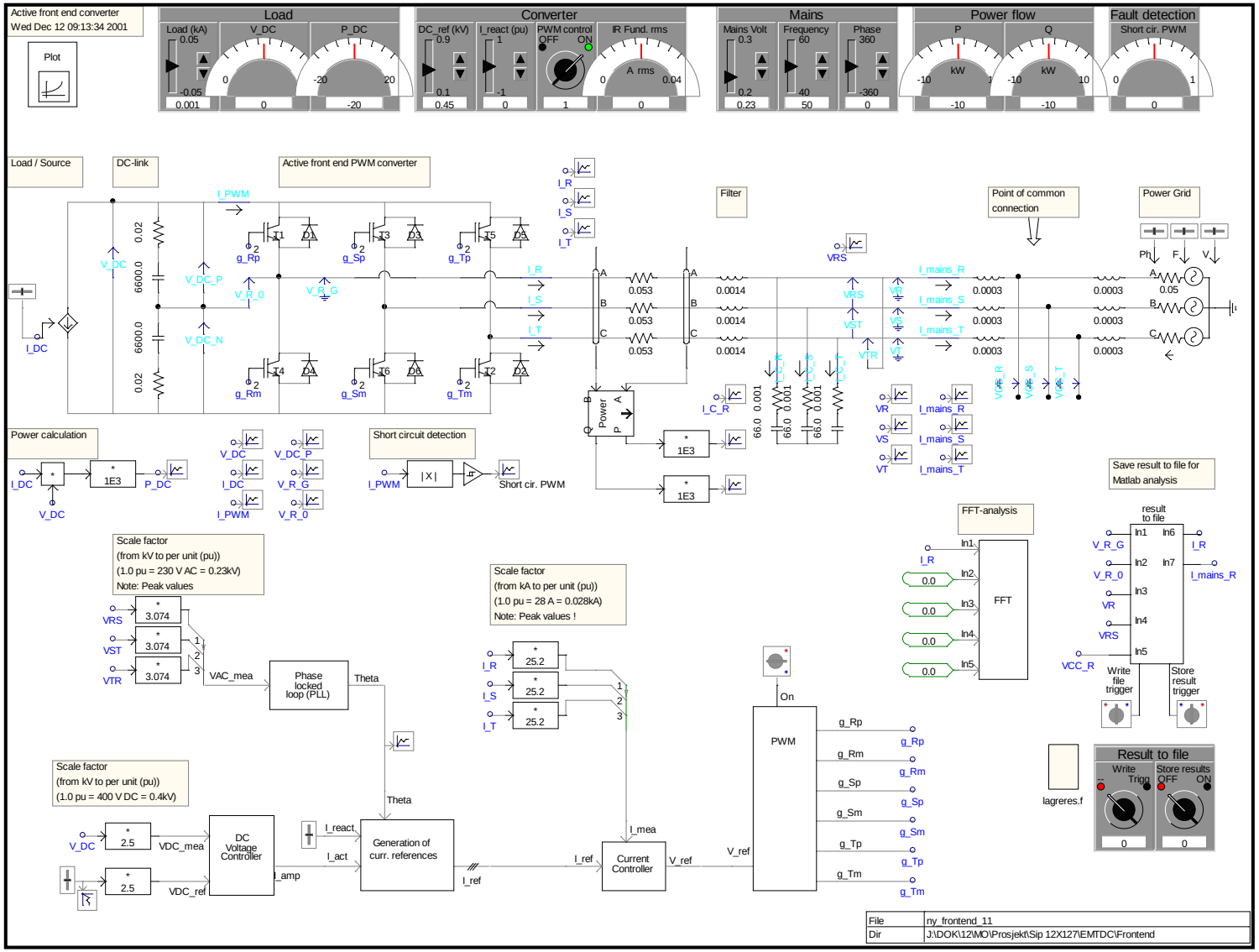
- 3D Full model
- 350 k elements
- 1.3 M nodes
- 148 contact layers



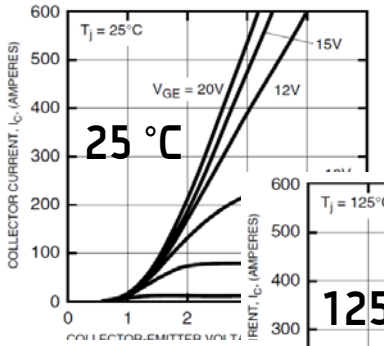


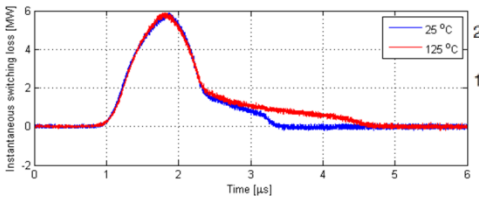


Simulation model of (PSCAD) of PWM Voltage Source Converter



IGBT loss calculator in PSCAD with thermal network add-on





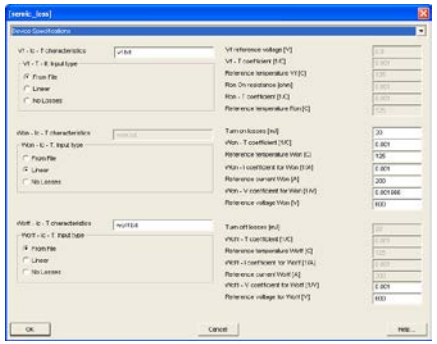
Curves or measurements

XDATA:
x1
x2

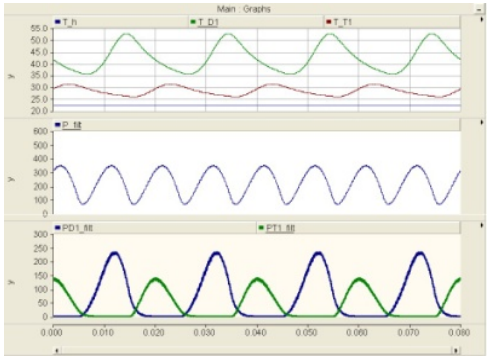
YDATA:
y1
y2
y3

ZDATA:
x1y1
x1y2
x1y3
x1y1
x1y2
x1y3

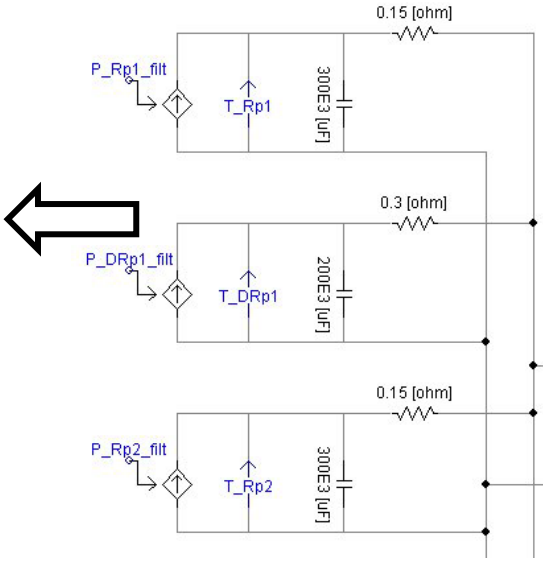
ENDFILE:

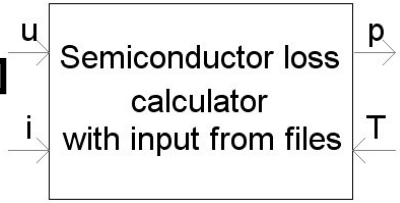


Input file with loss data



Simulations





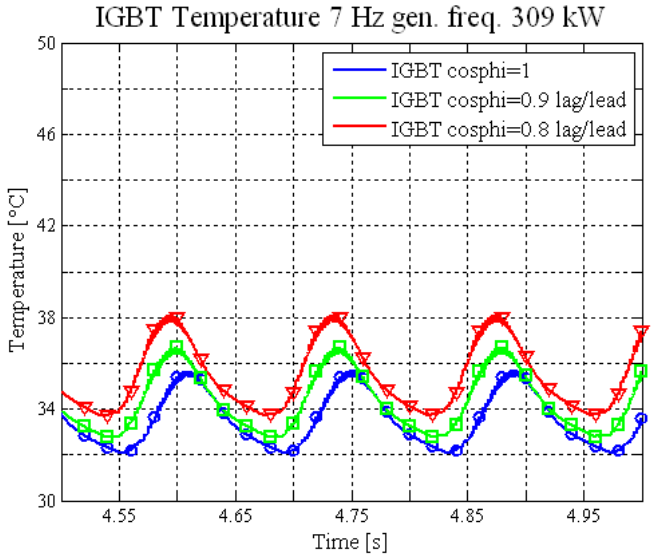
Simulated load dependent swings of IGBT hotspot temperature

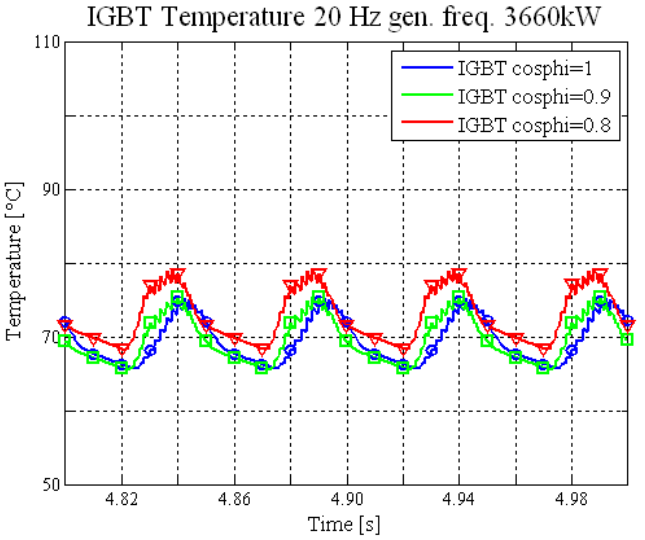
Motive:

- Combine laboratory measurements with numerical simulations to estimate efficiency and lifetime of power semiconductors

Simulated temperature swings affected by:

- Switching frequency
- Line-side and generator side power frequency, cos φ etc,
- Filter ripple current
- Wind fluctuations
- ..and more





Methodology for power cycling lifetime estimation

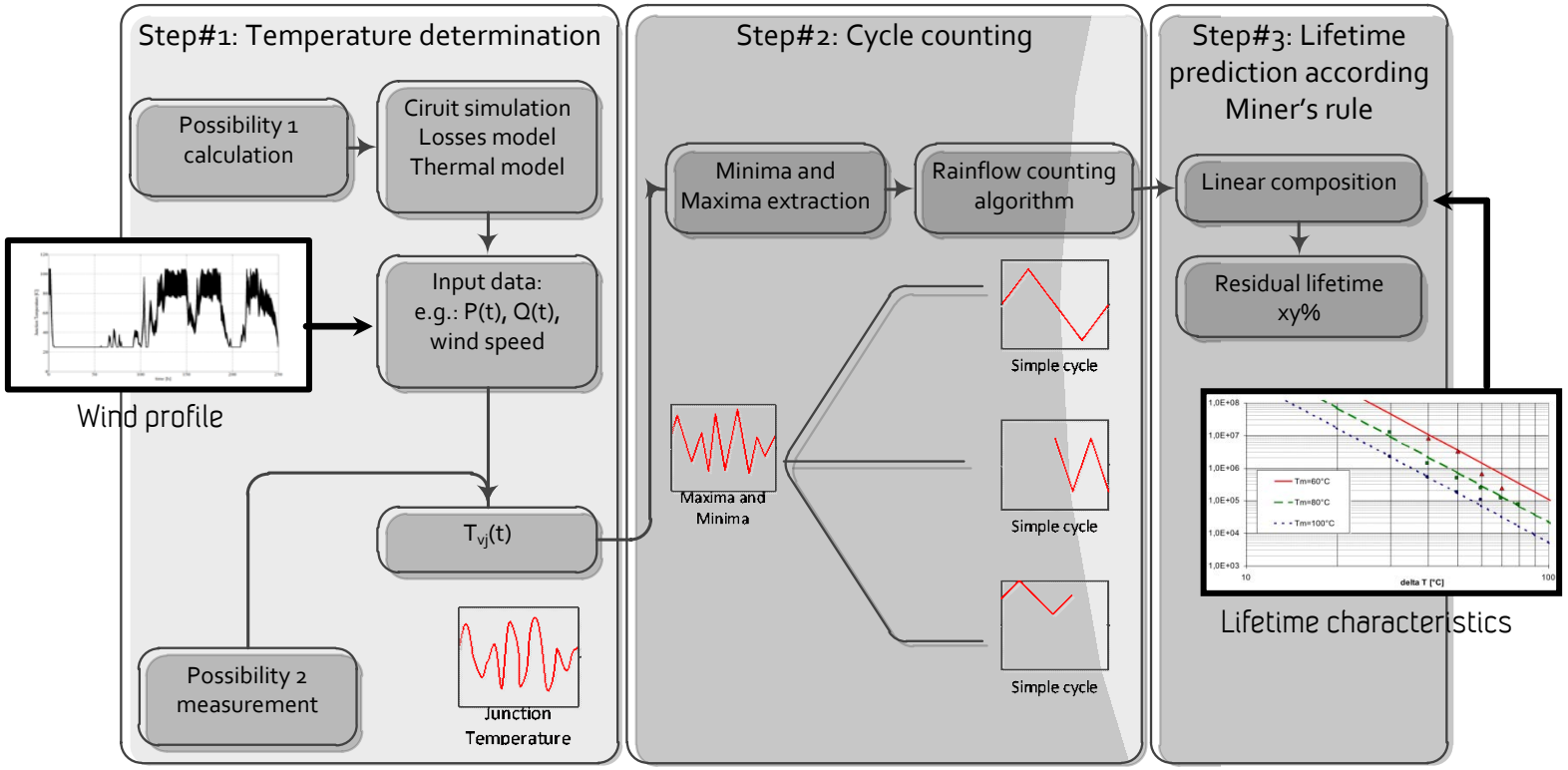


TABLE VI. SUMMARY OF LIFETIME CONSUMPTION

device	*∑LRN*	*∑LR*	*LR*	*Lifetime*
	[p.u]	[p.u.]	[p.u.]	[years]
IGBT, CGe	0.039	0.0719	0.111	17.8
IGBT, CGr	0.047	0.057	0.104	19.3
Diode, CGe	0.083	1.244	1.327	1.51
Diode, CGr	0.016	0	0.016	122

Example:
If not oversized lifetime for the generator side diode can be very short!

Planned continuing activities on converter reliability

- Completion of the reliability work in the OPE project (deadline 30th June 2014)
  - Continue power cycling of IGBTs
    - Press-packs and modules
    - Power Cycling of single chips (master student work)
  - Post processing of result
  - Final reporting and publications
- Develop a new research project for continuation of converter reliability topics
  - Together with colleagues at Chemnitz University of Technology
  - Start-up spring 2015
  - Exploit results and ideas from OPE
  - Address VSC converter applications for HV collecting and transmission systems
  - Power cycling capabilities assuming various converter topologies and AC/DC systems
  - New methods for condition monitoring, predicting rest life-time etc.

Thank you for your attention !