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Thermal Modeling and Characterization of Capacitor Banks for MW Power Converters

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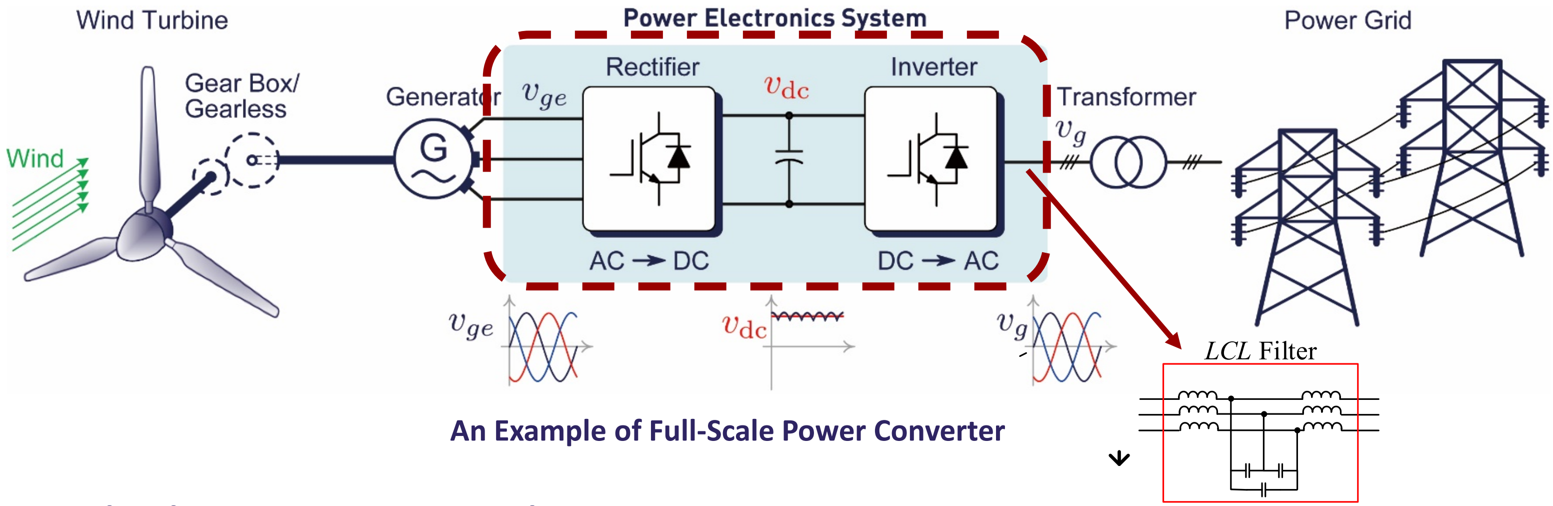
▶ Background

Application



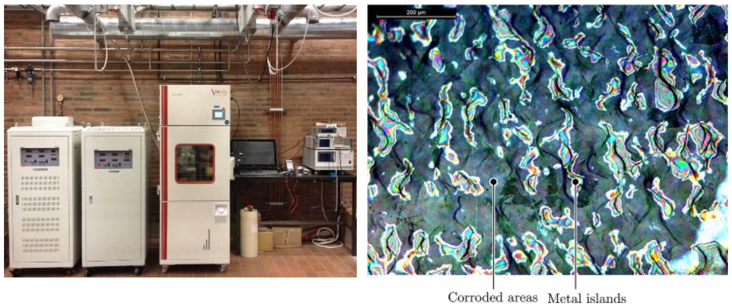
An Example of Full-Scale Power Converter

- MW-level power converters use large capacitor banks for DC-side and AC-side filter, such as wind turbine applications
- AC-side capacitors interface with power stacks and grid, which is reliability-critical due to highly dynamic operation conditions
- Understanding the failure mechanisms of the AC-side capacitors and design for reliability and robustness to fulfill application requirement are important.

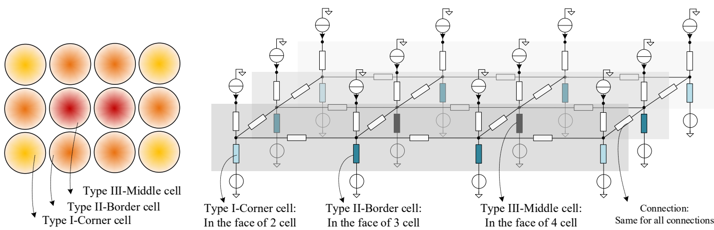
Capacitor bank for the grid-side filter

▶ Background

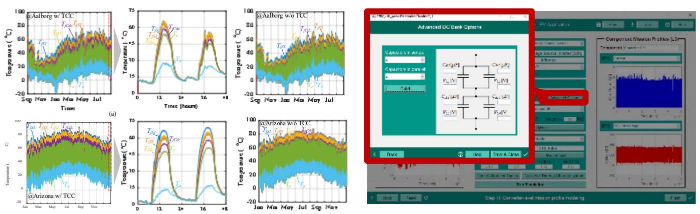
Capacitor Research at Aalborg University



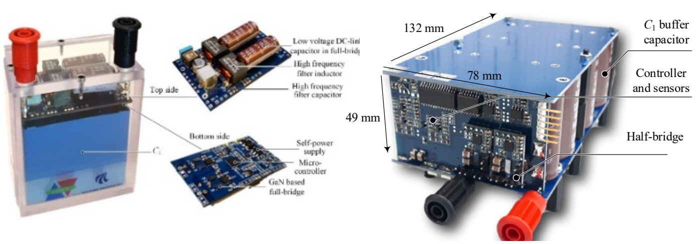
- **Application-oriented and failure-mechanism specific degradation testing of capacitors**
- **Capacitor failure analysis**



- **Thermal modeling of capacitor banks (analytical models, FEM, testing)**
- **Capacitor bank optimization**



- **Long-term mission profile based capacitor lifetime modeling, condition monitoring**
- **Software tool development**

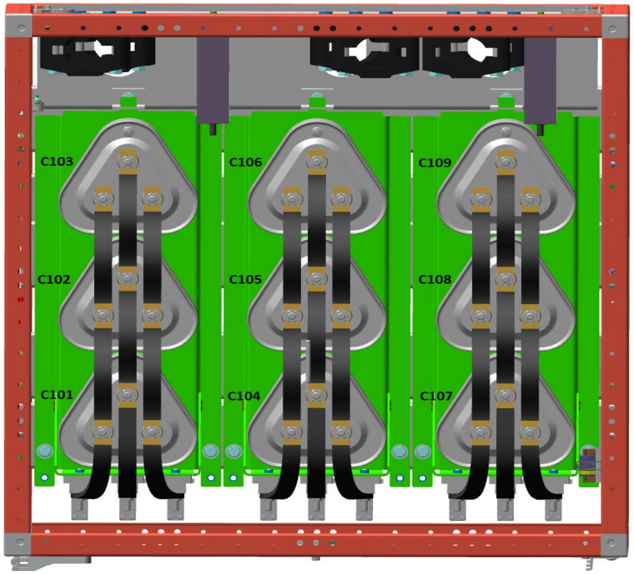


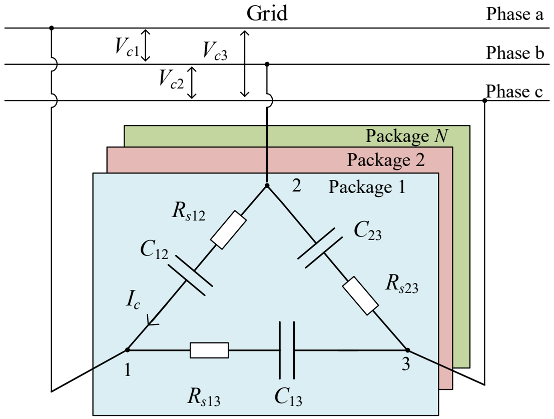
- **Active capacitors (two-terminal, cost-constrained)**

▶ Case Study

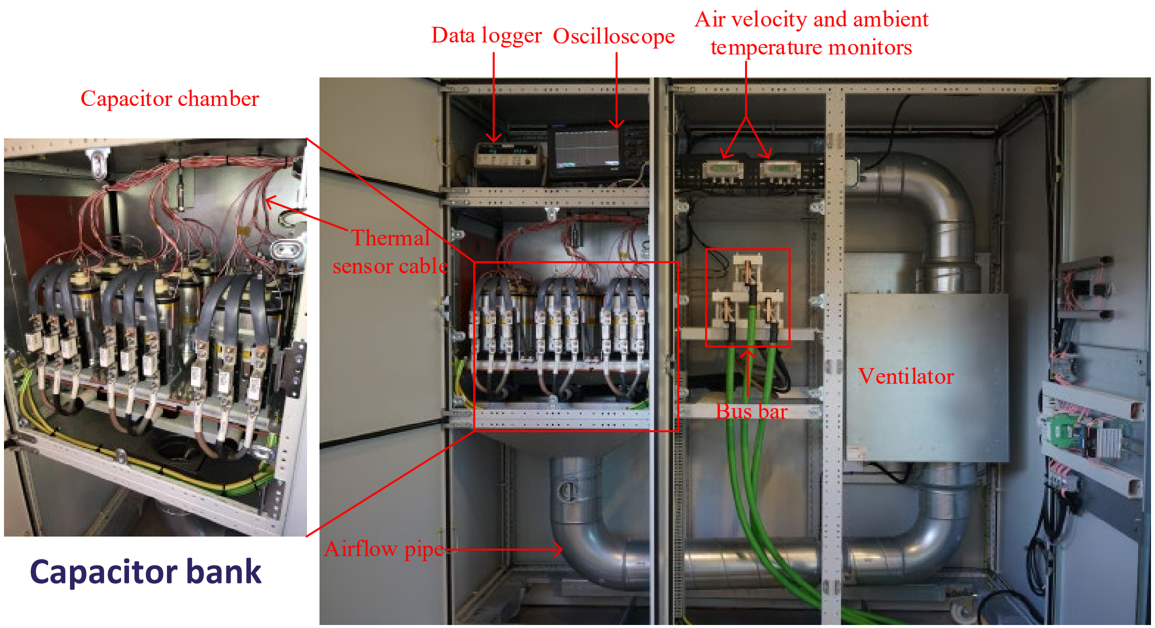
Thermal characterization of capacitor banks for MW power converters

- Delta-connection three-phase capacitors in each component
- Metallized Polypropylene, dry dielectric, 50 kVar each/690 Vac
- The capacitor bank consists of 9 three-phase capacitors
- Forced-air cooling





► Testing Setup



Capacitor bank

Each capacitor has 3 internal thermal sensors (1 sensor/phase) and 3 thermal sensors on the case (1 sensor/phase)

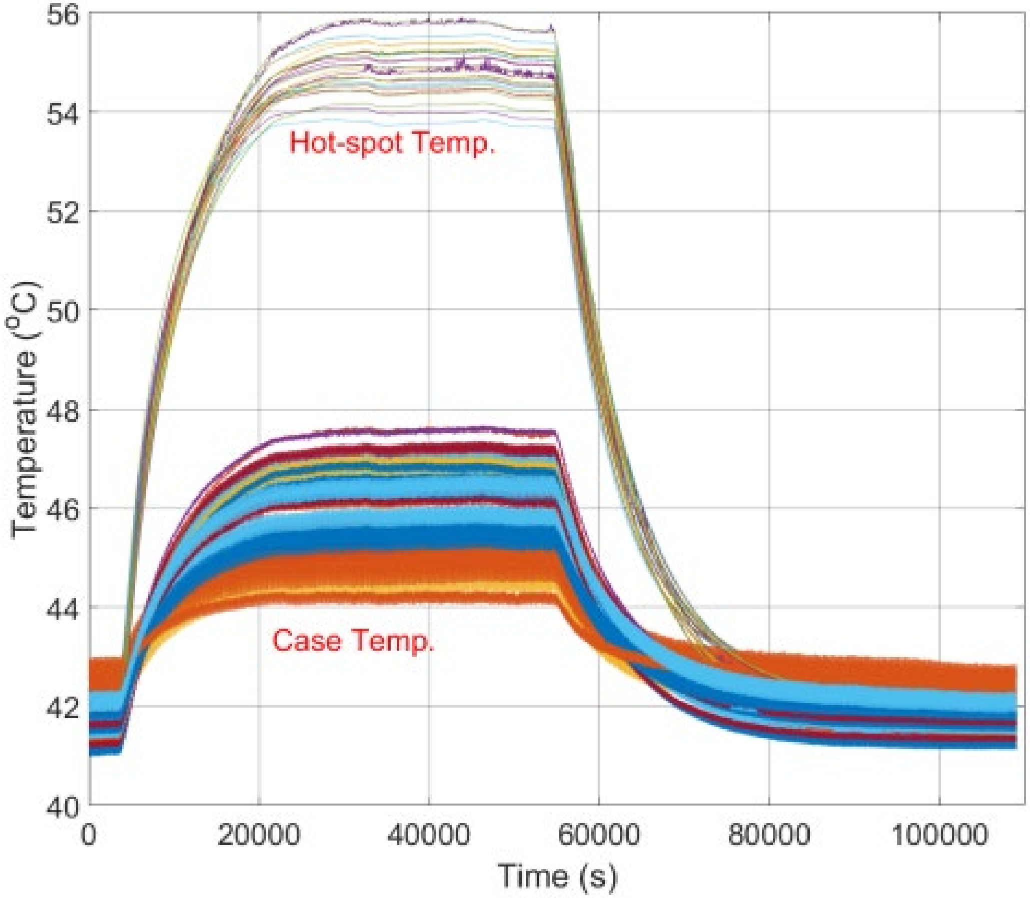
Testing Capability

Lab power sources - from 400 Vac to 11 kVac, up to 400 kVA for 400 Vac and 690 Vac up to 2 MVA 11kVac

- Capacitor bank thermal characterizations
- Capacitor bank abnormal operation emulation (test at extreme conditions)
- Ambient temperature can be controlled up to 50°C (forced air)

▶ Thermal Characterization Results

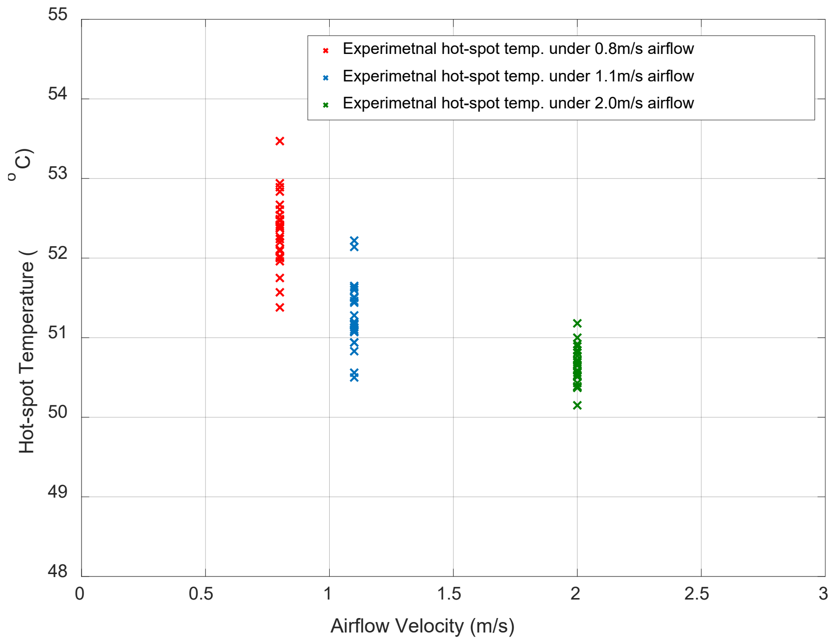
One of the testing conditions



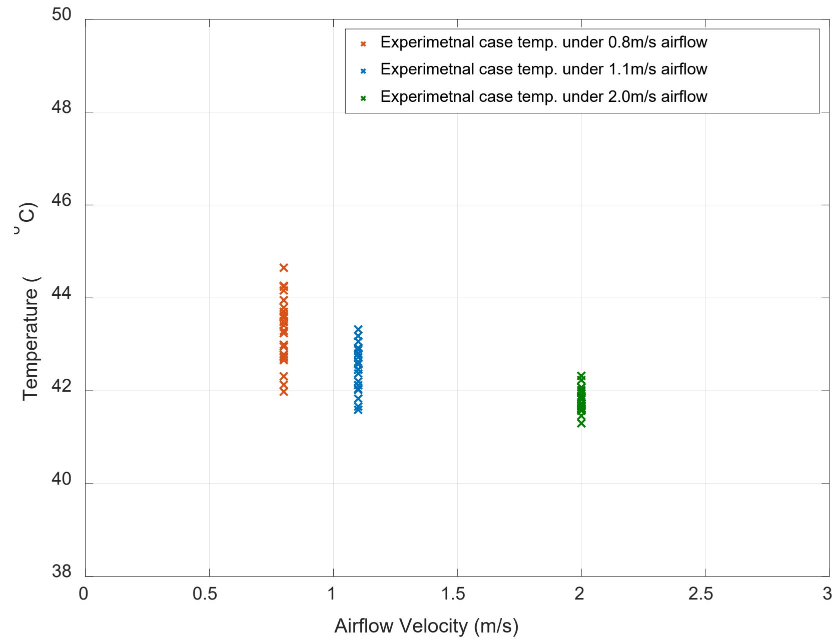
Heater temp. setting = 40°**C;** Inlet cooling air velocity = 0.3m/s

▶ Thermal Characterization Results

Capacitor hot-spot temp. and case temp. distributions

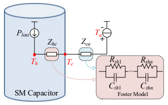


Hot-spot temperature



Case temperature

▶ Thermal Characterization Results



Thermal impedance parameters

Heater temp. setting = 40°C; Inlet cooling air velocity = 0.8m/s

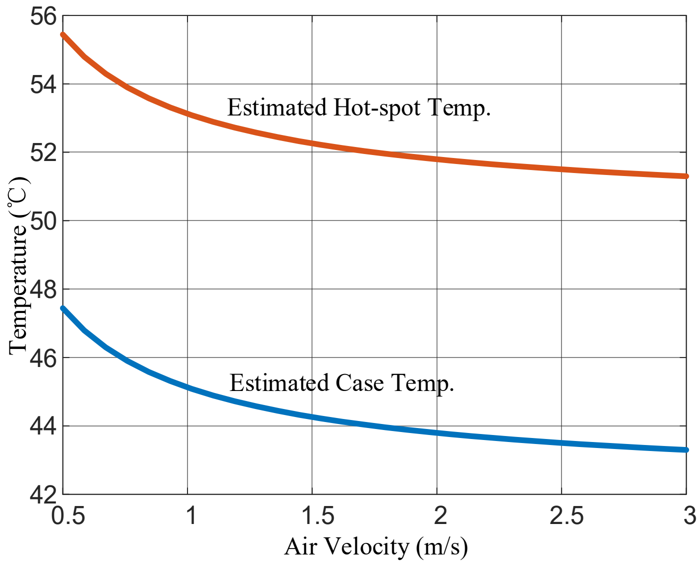
	R_{hc} (°C / W)	C_{hc} (J / °C)	R_{ca} (°C / W)	C_{ca} (J / °C)	R_{hc}+R_{ca} (°C / W)
C101.1	1.40	7071	0.99	7580	2.39
C101.2	1.42	7178	0.96	7699	2.38
C101.3	1.37	7417	1.09	7139	2.46
C102.1	1.49	6612	0.88	8849	2.37
C102.2	1.44	6886	0.93	8528	2.37
C102.3	1.46	6443	0.89	8747	2.35
C103.1	1.47	5595	0.72	11735	2.19
C103.2	1.47	5699	0.75	10369	2.22
C103.3	1.53	5136	0.61	15063	2.14
C104.1	1.40	7296	1.02	7615	2.42
C104.2	1.39	7785	1.12	7239	2.51
C104.3	1.35	7862	1.21	7056	2.56
C105.1	1.47	6588	0.98	8111	2.45
C105.2	1.36	7324	1.04	7808	2.4
C105.3	1.39	7196	1.07	7767	2.46
C106.1	1.44	6319	0.86	9431	2.3
C106.2	1.42	6581	0.86	8777	2.28
C106.3	1.67	5213	0.61	13011	2.28
C107.1	1.42	7340	1.09	7761	2.51
C107.2	1.48	7461	1.09	7766	2.57
C107.3	1.35	7662	1.21	7170	2.56
C108.1	1.40	6771	1.00	8435	2.4
C108.2	1.46	6902	1.00	8574	2.46
C108.3	1.39	6934	0.98	8763	2.37
C109.1	1.47	6249	0.81	9670	2.28
C109.2	1.44	6388	0.88	9349	2.32
C109.3	1.51	5722	0.68	10615	2.19

Heater temp. setting = 40°C; Inlet cooling air velocity = 2m/s

	R_{hc} (°C / W)	C_{hc} (J / °C)	R_{ca} (°C / W)	C_{ca} (J / °C)	R_{hc}+R_{ca} (°C / W)
C101.1	1.41	5044	0.40	14230	1.81
C101.2	1.43	5033	0.41	13194	1.84
C101.3	1.39	4834	0.44	14797	1.83
C102.1	1.49	4695	0.34	19294	1.83
C102.2	1.44	4951	0.39	17173	1.83
C102.3	1.47	4561	0.33	21672	1.8
C103.1	1.48	4142	0.30	23159	1.78
C103.2	1.48	4250	0.32	21397	1.8
C103.3	1.48	4005	0.26	27398	1.74
C104.1	1.44	4864	0.39	14996	1.83
C104.2	1.37	5406	0.46	11665	1.83
C104.3	1.42	5003	0.46	12109	1.88
C105.1	1.47	4491	0.35	16322	1.82
C105.2	1.39	4902	0.46	11843	1.85
C105.3	1.43	4607	0.39	14253	1.82
C106.1	1.46	4445	0.35	19788	1.81
C106.2	1.39	4980	0.39	13713	1.78
C106.3	1.58	4122	0.25	27075	1.83
C107.1	1.42	5077	0.45	12841	1.87
C107.2	1.51	5318	0.46	12384	1.97
C107.3	1.38	5433	0.54	11119	1.92
C108.1	1.42	4647	0.42	15179	1.84
C108.2	1.42	5039	0.45	13906	1.87
C108.3	1.42	4573	0.40	14067	1.82
C109.1	1.49	4669	0.36	16077	1.85
C109.2	1.41	4875	0.40	13963	1.81
C109.3	1.46	4416	0.30	19789	1.76

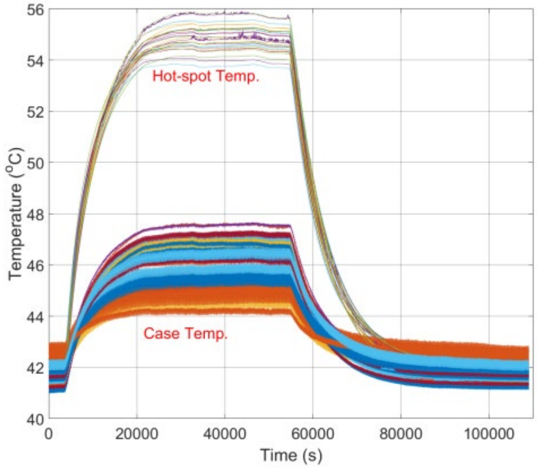
▶ Next Step of the Research

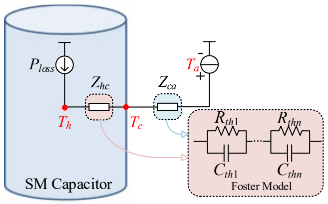
- **Analytical thermal modeling of the capacitor banks with forced-air cooling**



- **kV/kA level capacitor and capacitor bank testing facility (in connection with a national power electronics reliability testing center project X-Power), up to 5 kV and 2 kA testing capability simultaneously.**

▶ Summary





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Acknowledgement

PhD student Zhijian Yin

Postdoc Haoran Wang

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▶ Biography of Speaker

Huai Wang is currently an Associate Professor and a Research Thrust Leader with the Center of Reliable Power Electronics (CORPE), Aalborg University, Denmark. His research addresses the fundamental challenges in modelling and validation of power electronic component failure mechanisms, and application issues in system-level predictability, condition monitoring, circuit architecture, and robustness design. In CORPE, he also leads a capacitor research group including multiple PhD projects on capacitors and its applications in power electronic systems, and collaborates with various industry companies across the value chain from manufacturers to end-users of capacitors. Prof. Wang organizes and lectures 3 short Industrial/PhD courses on *Capacitors in Power Electronics Applications*, *Reliability of Power Electronic Systems*, and *Design Failure Mode and Effect Analysis (D-FMEA) of Power Electronic Converters* at Aalborg University. He has given more than 20 tutorials at leading power electronics and reliability engineering conferences (e.g., ECCE, APEC, IECON, PCIM, ESREF, etc.) and a few keynote speeches in the above research areas. He has co-edited a book on Reliability of Power Electronic Converter Systems in 2015, hold 3 patents, and filed another 5 patents in advanced passive component inventions.

Prof. Wang received his PhD degree from the City University of Hong Kong, Hong Kong, China, and B. E. degree from the Huazhong University of Science and Technology, Wuhan, China. He was a short-term visiting scientist with the Massachusetts Institute of Technology (MIT), USA, and ETH Zurich, Switzerland. He was with the ABB Corporate Research Center, Baden, Switzerland, in 2009. He received the Richard M. Bass Outstanding Young Power Electronics Engineer Award from the IEEE Power Electronics Society in 2016, for the contribution to reliability of power electronic converter systems. He is currently the Chair of IEEE PELS/IAS/IE Chapter in Denmark, and as an Associate Editor of IET Power Electronics, IET Electronics Letters, IEEE Journal of Emerging and Selected Topics in Power Electronics, and IEEE Transactions on Power Electronics.