Model-Based E-Drive Dimensioning

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MathWorks
AUTOMOTIVE CONFERENCE 2020
EUROPE

Agenda

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01
E-Mobility @ ZF

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ZF Technology Domains

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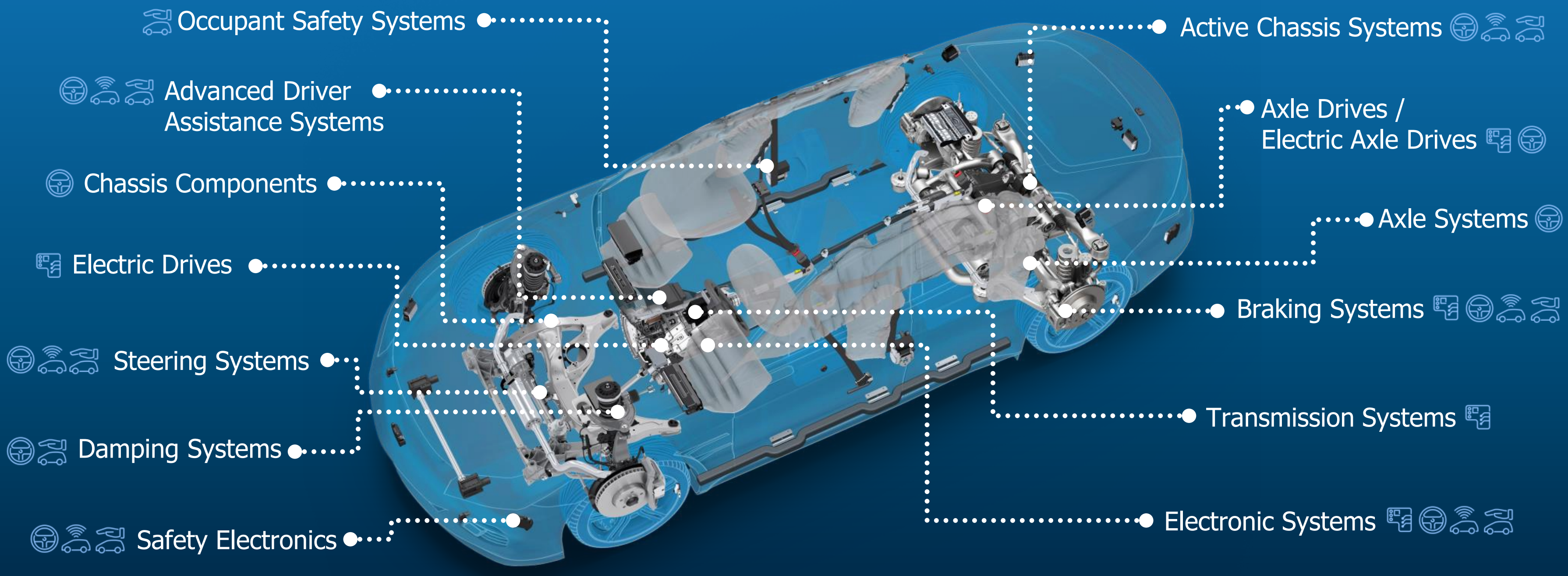
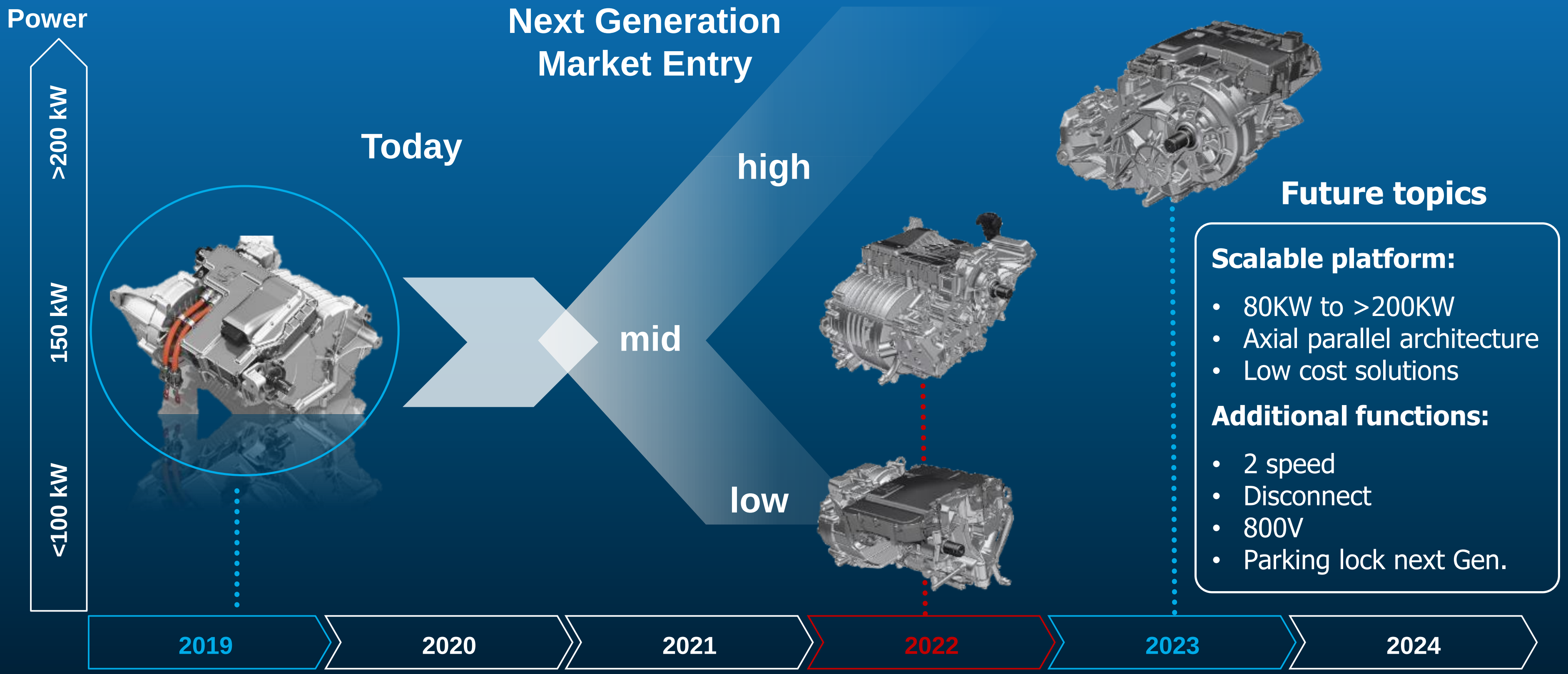
ZF Systems Expertise



Electrified Powertrain: Vehicle Motion Control: Automated Driving: Integrated Safety:

ZF electrifies everything on wheels
From bikes and cars to trucks and buses

Roadmap Electric Vehicle Drive



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02
E-Drive Concept

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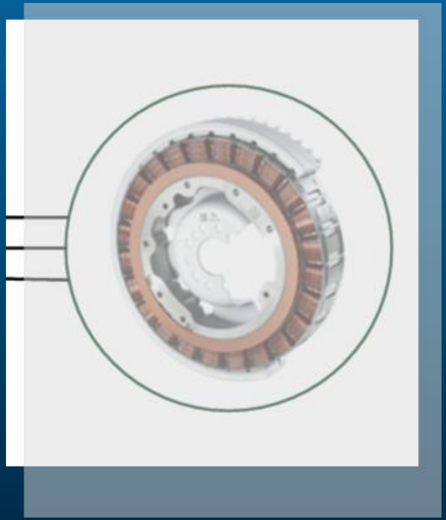
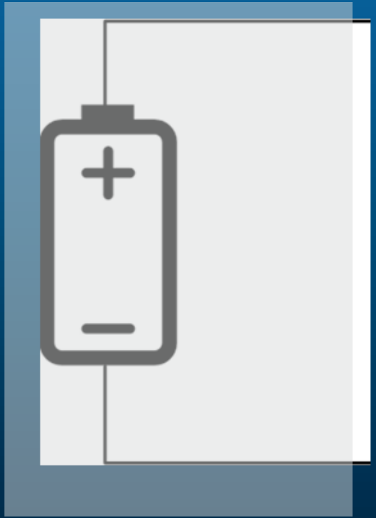
Components of an E-Drive System

Electrical machine

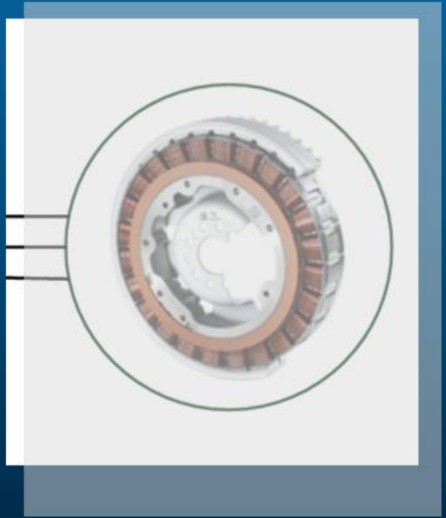


Components of an E-Drive System

Energy source



Electrical machine



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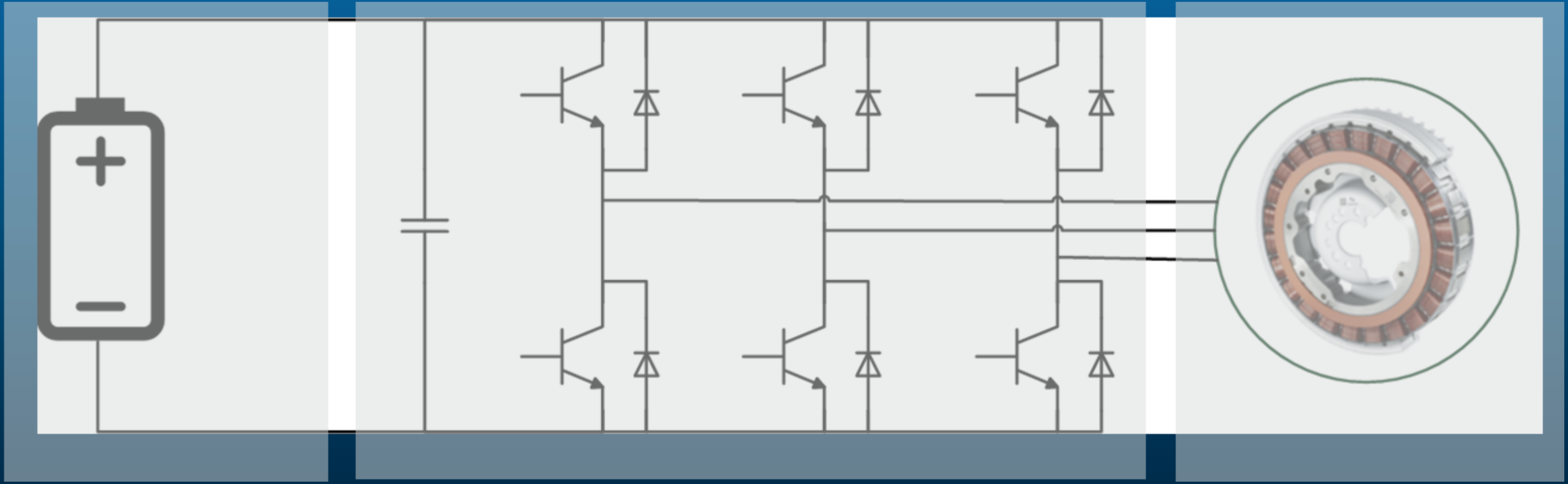
Components of an E-Drive System

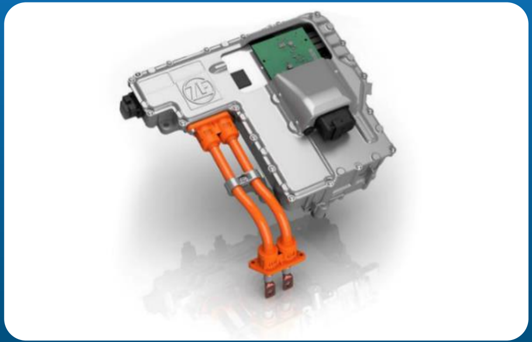
Energy source

Power Inverter

Electrical machine



Power Inverter vs. Electric Cettle



Volume	4.1 dm^3	3.0 dm^3
Power Output	150 kW	2.2 kW
Max. Power Loss	5 kW	0
(Heating) Power / Area	139 W/cm^2	19 W/cm^2

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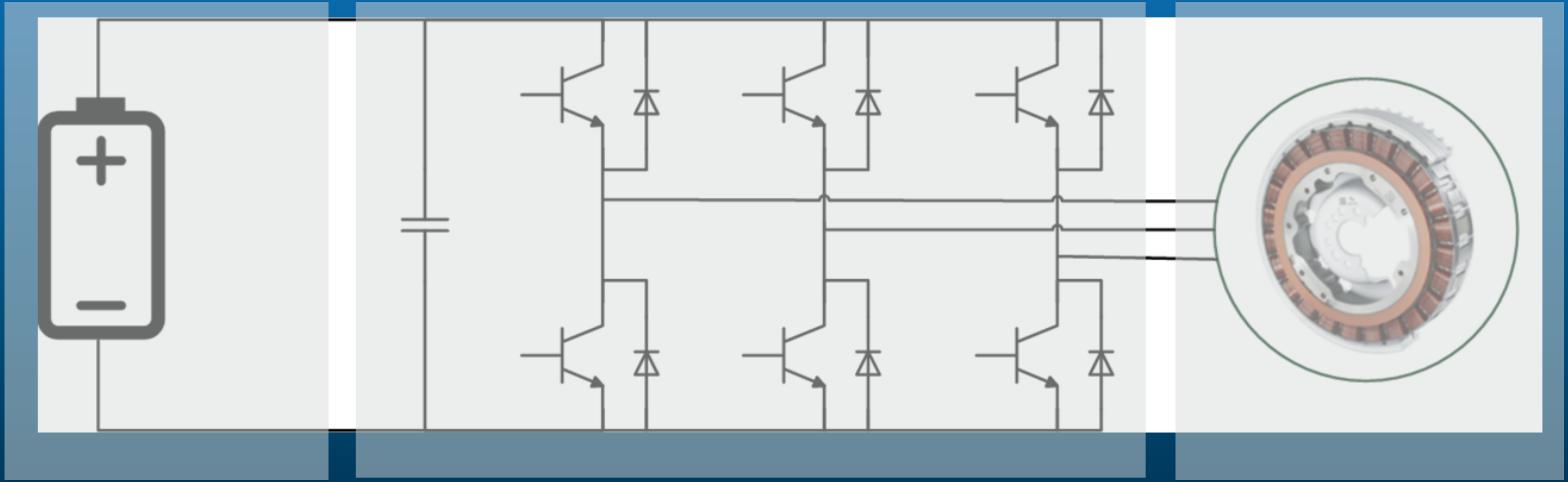
Power Inverter in action - „139W/cm²“

Components of an E-Drive System

Energy source

Power Inverter

Electrical machine



CHALLENGE: Development of an E-Drive system that is
- efficient,
- highly performant and
- very resistant to damages.

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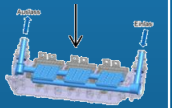
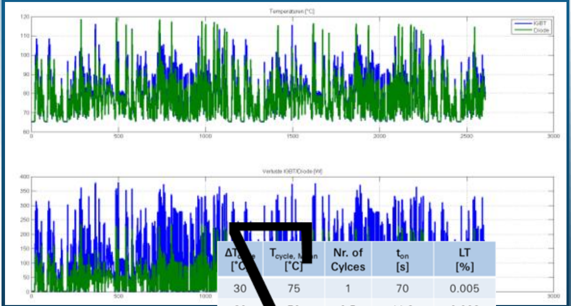
Fields of Application of Matlab/Simulink @ ZF E-Drive Systems

Component Dimensioning and Hardware Development

- Efficiency calculations
- Capacitor dimensioning
- Semiconductor module dimensioning
- Cooling concept
- Lifetime considerations

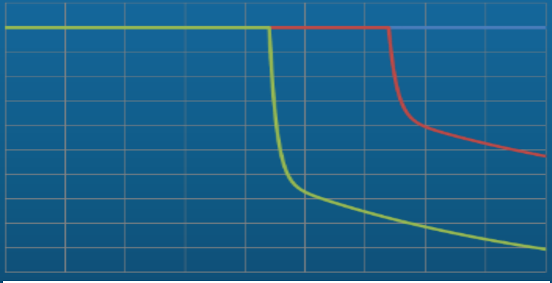


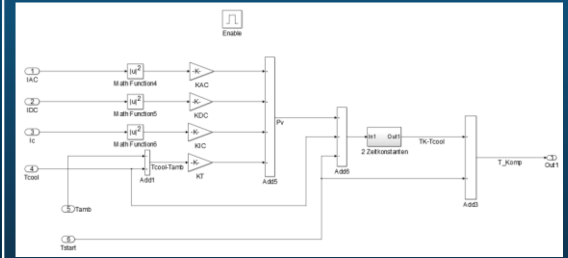


ΔT [°C]	$T_{cycle, mean}$ [°C]	Nr. of Cylces	t_{on} [s]	LT [%]
30	75	1	70	0.005
20	70	0,5	11,2	0.002
5	77	0,5	1,9	0.0001
…	…	…	…	
		∑		70

Functions and Software Development

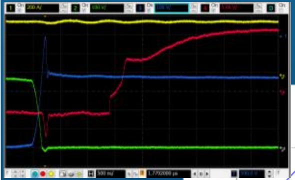
- Derating strategy
- Modulation methods
- Controller design

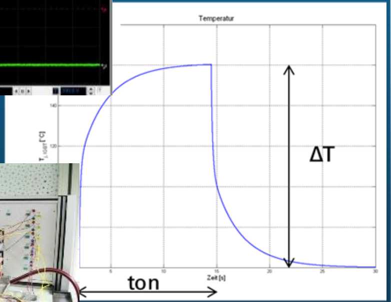




Validation and Verification

- Measurement evaluations (e.g. Double Pulse, Zth, Power Hill)
- Parameter identification for simulations
- Evaluation of generated data





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03
Matlab Inverter Model

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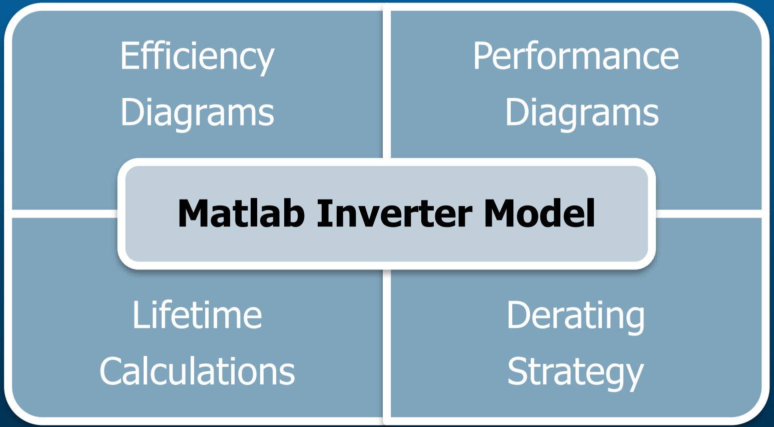
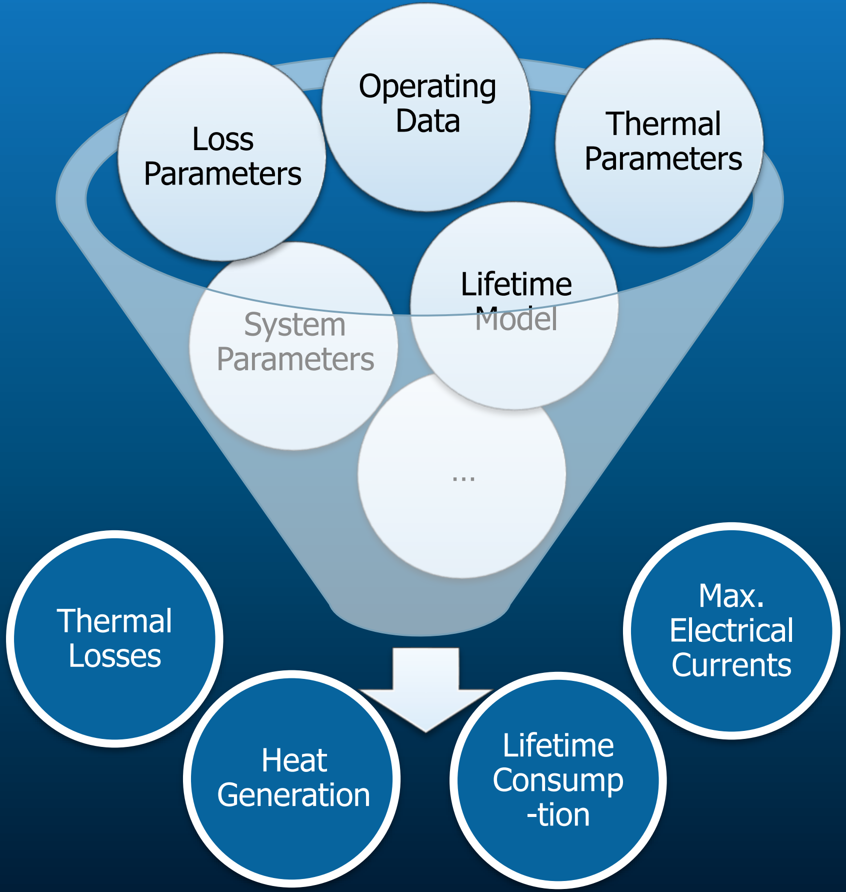
Matlab Inverter Model





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Structure Inverter Model

Lines of Matlab Code

~10,000

Σ Simulink Blocks

>>3,000

ca. 10 years of development

04
Applications

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04-1
Efficiency and Performance Calculations

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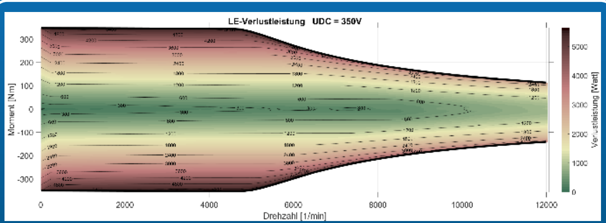
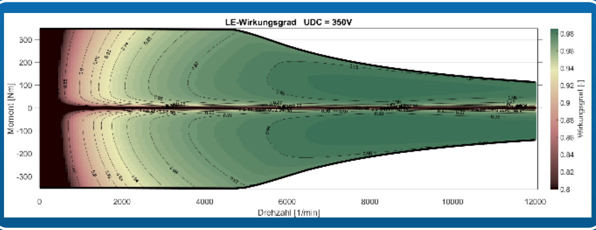
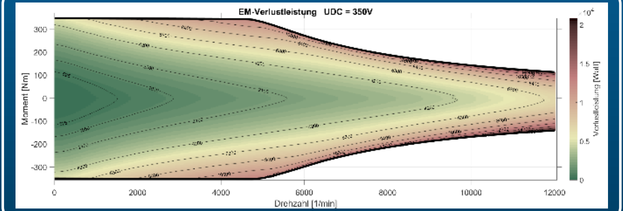
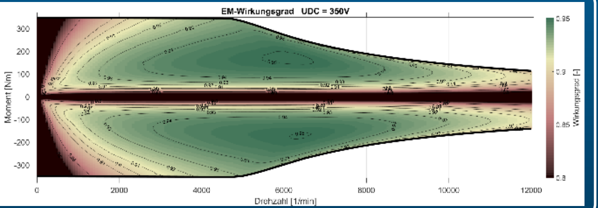
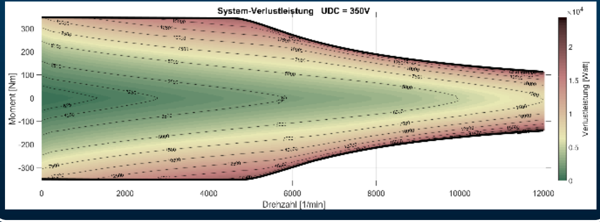
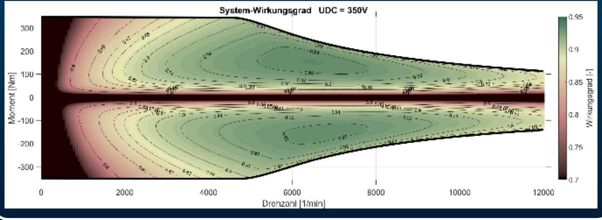
CO_2 reduction: Every gram counts

Conventional drivelines

Hybrid drivelines

Electric drivelines

Example of Loss and Efficiency Calculation

	Losses	Efficiency
Power Electronics		
Electrical Machine		
E-Drive System		

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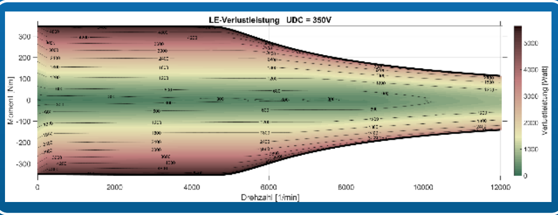
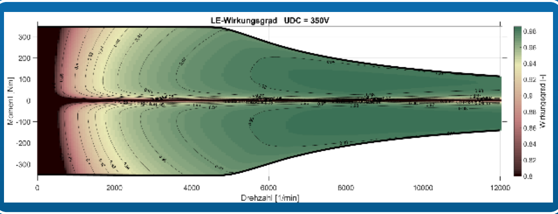
Example of Loss and Efficiency Calculation

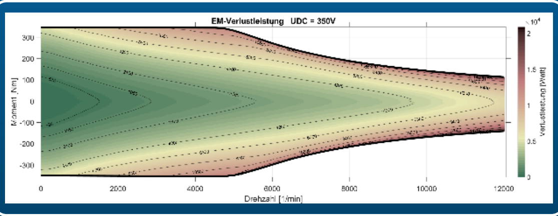
Losses | Efficiency

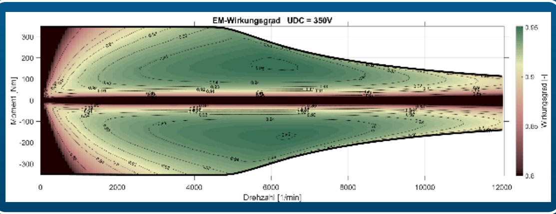
Power Electronics



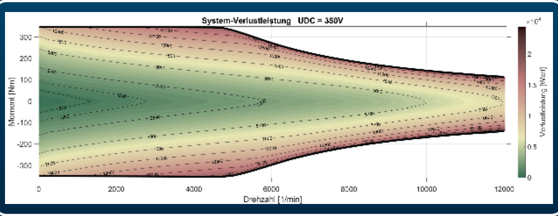


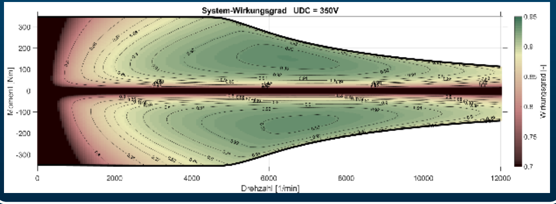
Electrical Machine





E-Drive System





→ Losses and efficiency of entire E-Drive system calculated over torque and speed range

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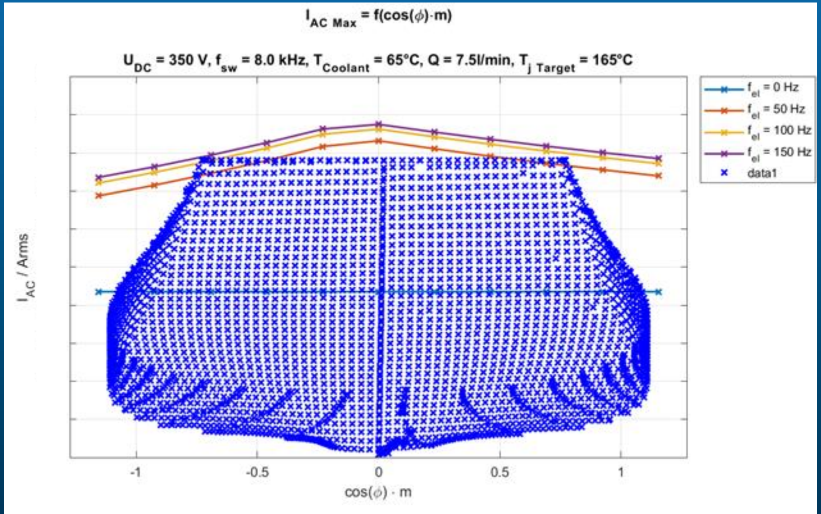
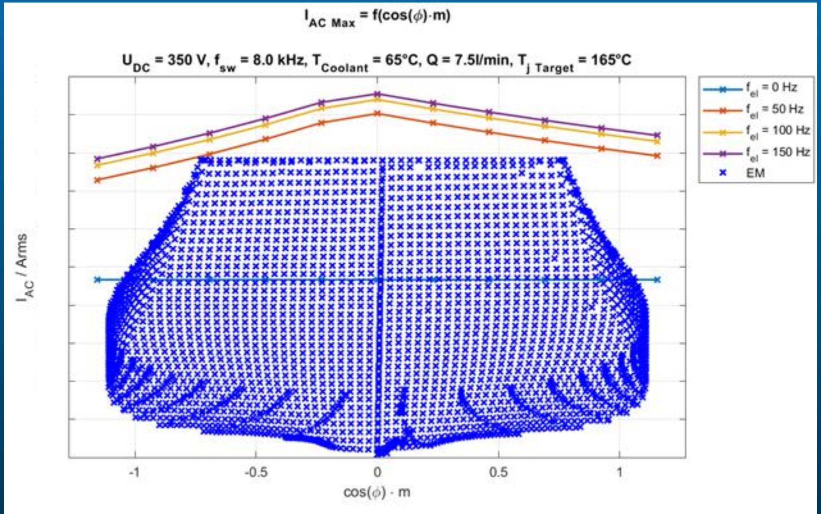
Matching of E-Machine and Power Inverter





→ Left inverter undersized, right one appropriate for electrical machine

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04-2
Lifetime Prediction

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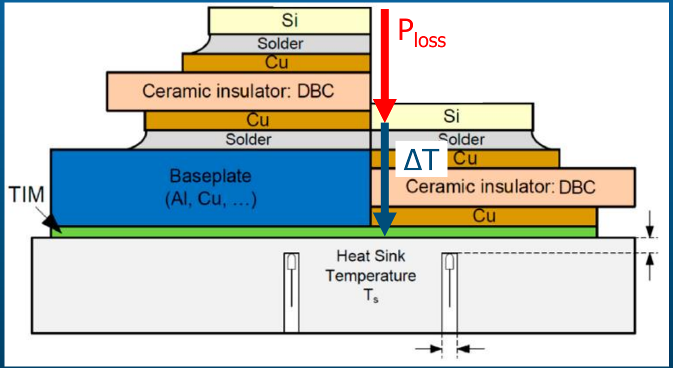
Lifetime Simulation Semiconductor

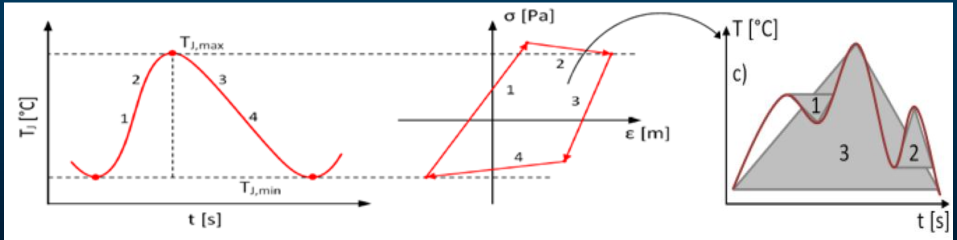
- Different extension coefficients result in thermal stress.
- Each junction can absorb a certain amount of energy and will fail afterwards.



$$P_{Loss} = f(I_{ac}, f_{sw}, U_{dc}, T_{KM}, ..)$$

Image source:
G. Farks, D. Schweitzer, Z. Sarkany, M. Rencz
On the Reproducibility of Thermal Measurements and of Related Thermal Metrics in Static and Transient Tests of Power Devices

- To predict time to failure of each junction, thermal stress has to be described mathematically.



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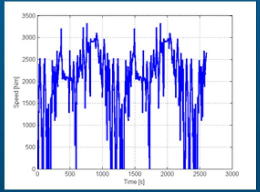
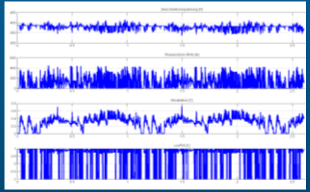
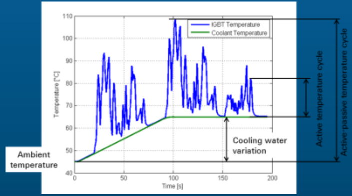
Workflow Lifetime Predicition

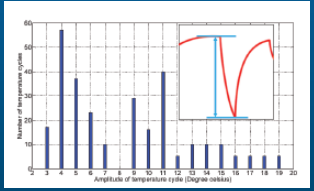
Coolant Temperature
+ Coolant Flow Rate

„Mission Profile“ of Electr. Drive (M, v, U_{Batt}) → Simulation Model EM → „Mission Profile“ of Power Electronics (U_{DC}, I, $\cos\varphi$, m, f_{el}) → Simulation Model PE → Temperature Profile Semiconductor (T_{IGBT}, T_{Diode}) → Rainflow Classification → Load Cycle of Semiconductor (ΔT-Histogram)









Power Cycling Stability → Lifetime Consumption per Temperature Rise → Palmgren Miner → Lifetime Consumption of Semiconductors → Weibull Distribution → Probability of Failure of Semiconductors

Input of Power Cycling Test Results

ΔT_{cycle} [°C]	$T_{cycle, Mean}$ [°C]	Nr. of Cylces	t_{on} [s]	LT [%]
30	75	1	70	0.005
20	70	0,5	11,2	0.002
5	77	0,5	1,9	0.0001
...	...	...	...	
	∑			70

$\sum$

ΔT [°C]	$T_{cycle,}$ [°C]	Nr. of Cylces	t_{on} [s]	LT [%]
30	75	1	70	0.005
20	70	0,5	11,2	0.002
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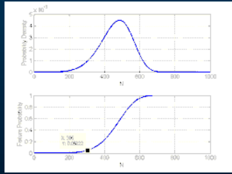
	∑			70



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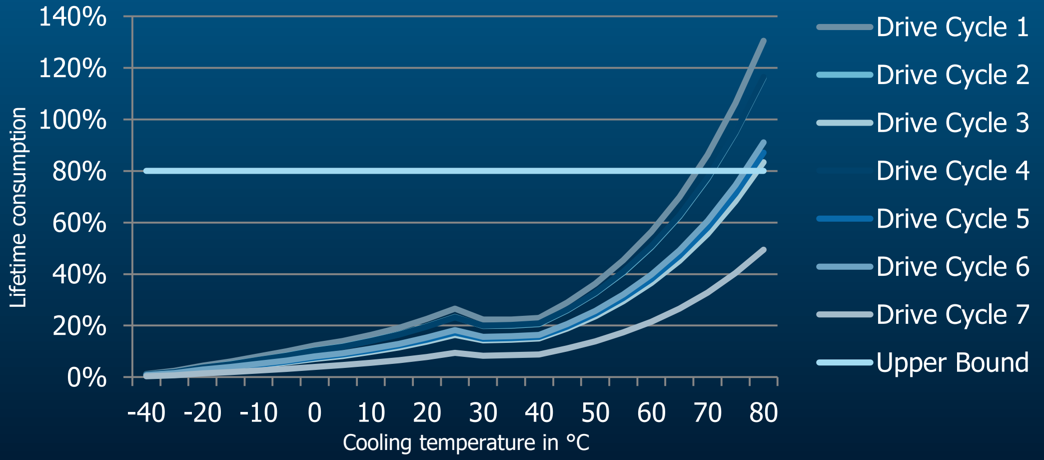
Example of Lifetime Prediction

	Cooling temperature in °C																				
	-40	-30	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
Drive Cycle 1	1,255%	2,409%	4,481%	6,046%	8,104%	10,021%	12,313%	13,961%	16,357%	19,063%	22,560%	26,583%	22,326%	22,372%	22,964%	28,918%	36,264%	45,296%	56,361%	69,869%	86,308%
Drive Cycle 2	1,051%	2,013%	3,734%	5,032%	6,734%	8,382%	10,373%	11,960%	14,125%	16,591%	19,713%	23,320%	19,845%	20,034%	20,600%	25,923%	32,485%	40,546%	50,412%	62,444%	77,073%
Drive Cycle 3	0,716%	1,365%	2,522%	3,391%	4,528%	5,658%	7,031%	8,204%	9,753%	11,539%	13,770%	16,365%	14,232%	14,544%	15,034%	18,883%	23,618%	29,419%	36,504%	45,124%	55,578%
Drive Cycle 4	1,043%	1,994%	3,691%	4,967%	6,640%	8,268%	10,237%	11,835%	13,999%	16,474%	19,598%	23,216%	19,935%	20,229%	20,848%	26,205%	32,800%	40,889%	50,776%	62,818%	77,437%
Drive Cycle 5	0,765%	1,461%	2,703%	3,636%	4,858%	6,060%	7,518%	8,734%	10,358%	12,223%	14,563%	17,278%	14,925%	15,185%	15,653%	19,667%	24,607%	30,662%	38,060%	47,065%	57,991%
Drive Cycle 6	0,819%	1,563%	2,891%	3,888%	5,195%	6,475%	8,023%	9,294%	11,001%	12,954%	15,412%	18,256%	15,674%	15,888%	16,360%	20,556%	25,720%	32,051%	39,786%	49,201%	60,626%
Drive Cycle 7	0,398%	0,760%	1,406%	1,893%	2,530%	3,170%	3,950%	4,631%	5,526%	6,561%	7,856%	9,365%	8,241%	8,489%	8,827%	11,098%	13,894%	17,324%	21,518%	26,627%	32,830%
Distr. Cold	0,10%	0,20%	0,30%	0,70%	2,00%	3,00%	5,00%	15,00%	26,10%	25,70%	13,30%	5,00%	2,00%	1,00%	0,50%	0,10%	0,00%	0,00%	0,00%	0,00%	0,00%
Distr. Hot	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,10%	0,50%	0,50%	1,30%	2,20%	4,70%	14,00%	27,10%	25,80%	14,70%	6,70%	1,60%



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05
Conclusion & Outlook

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Conclusion & Outlook

Conclusion

- Challenge: E-Drive system → efficient, highly performant and persistent
- Development of Matlab/Simulink environment:
  enables evaluation of efficiency, performance, lifetime
- Entire E-drive system can be correctly dimensioned, improved and optimized by simulation!

Outlook

- Increase of level of automation
- Combining Matlab/Simulink environment with CAD-, FEM- and CFD-simulation environments
- Integration of EMC simulation in our simulation environment

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Questions & Answers

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