

AVL SET GmbH

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SET

INVERTER TESTING

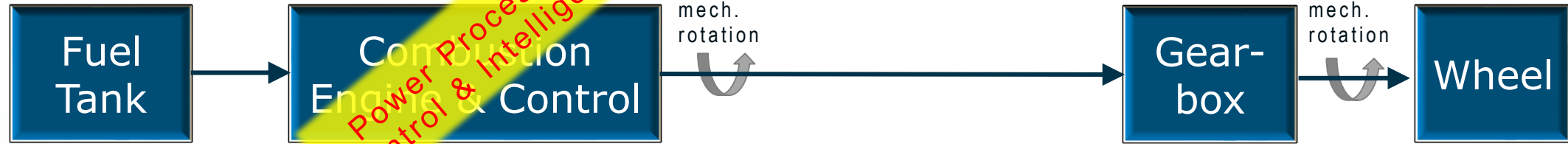
Tackling the challenges of the new power processor in electric drives

The Inverter plays a key role



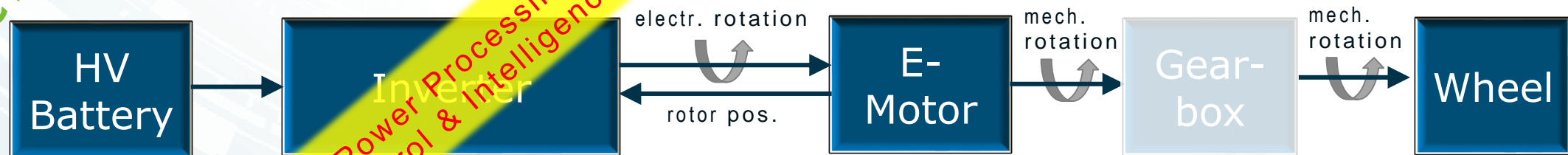
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ICE



Energy, stored in the fuel tank is transferred into rotating kinetic energy by the combustion engine which acts as the “power processor”. The gear box matches the rotation speed and torque to the wheels.

ELECTRIC



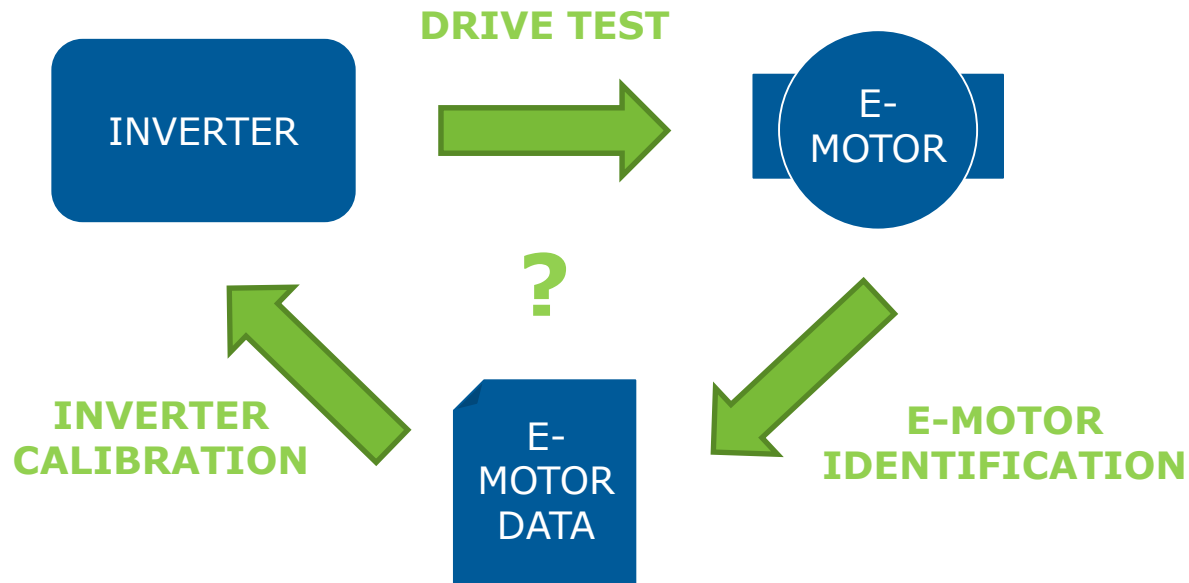
Energy, stored in the HV Battery is transferred into rotating electrical energy by the inverter, which acts as the “power processor”. The electrical motor acts as an actuator and is part of the inverter's closed loop control scheme. A gearbox is not always required.

THE BASIC LAW FOR FAST PROGRESS &
CONSISTENT RESULTS...

ISOLATED COMPONENT TESTING

Typical issue today:

Inverter test and **e-motor test** are not clearly isolated...



Triangle of uncertainties...

- Does real e-motor match with the design target?
- Is given e-motor data correct?
 - data quality
 - temperature correlation
- Inverter control laws approved?

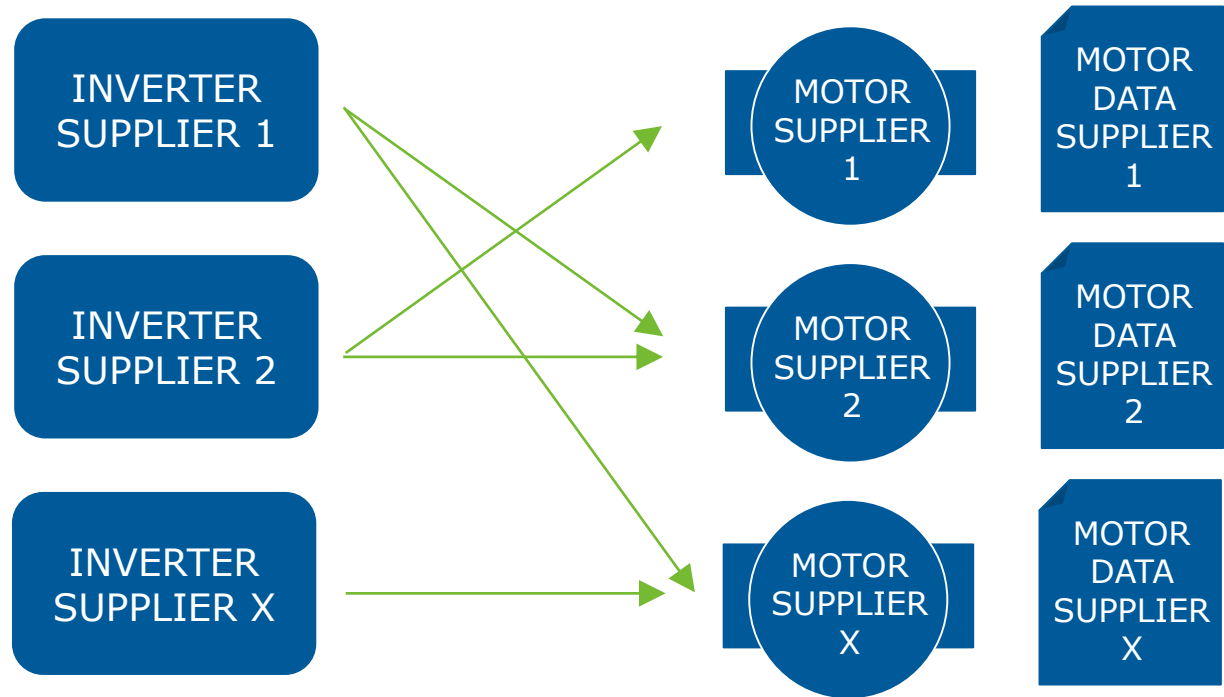
Motor issues can be seen as inverter problems and versus vice...

Isolated component testing is a key factor for successful system design

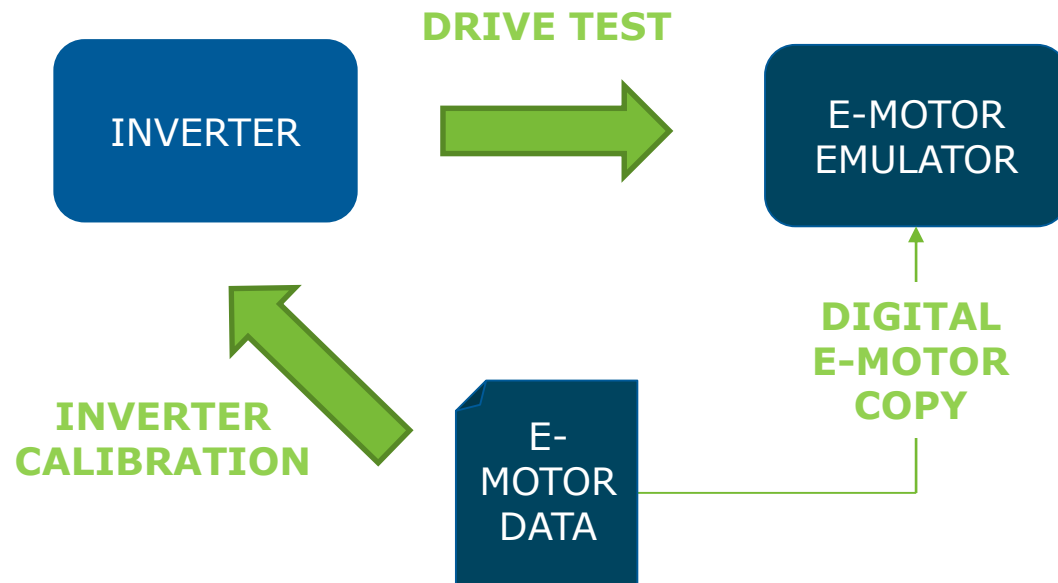
Inverter Test / E-Motor Test – Different Testbeds



Multiple dependencies and uncertainties do not allow efficient performance test and comparison



Breaking the triangle of uncertainties and dependencies: inverter test without a real motor!



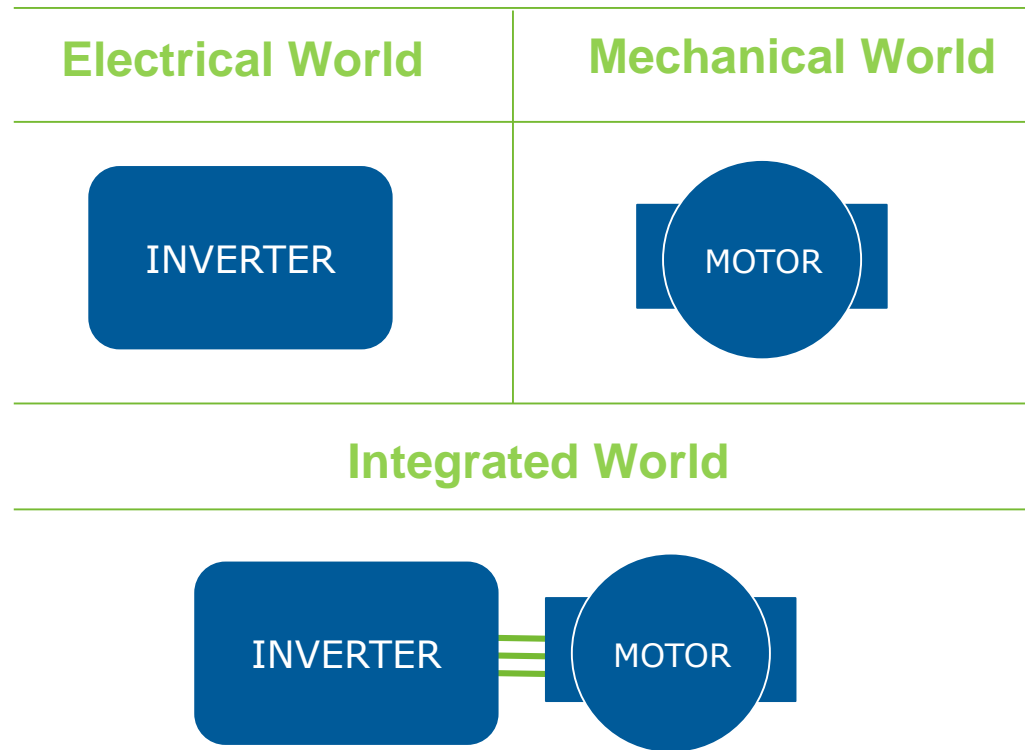
Benefits at a glance:

- Test of inverter and motor are fully independent (decoupled)
- No variation between calibration data and the virtual motor for the drive test
- Real motor not required for inverter test
- No influences from the mechanical load system
- Testing with a motor library
- Easy fault injection testing

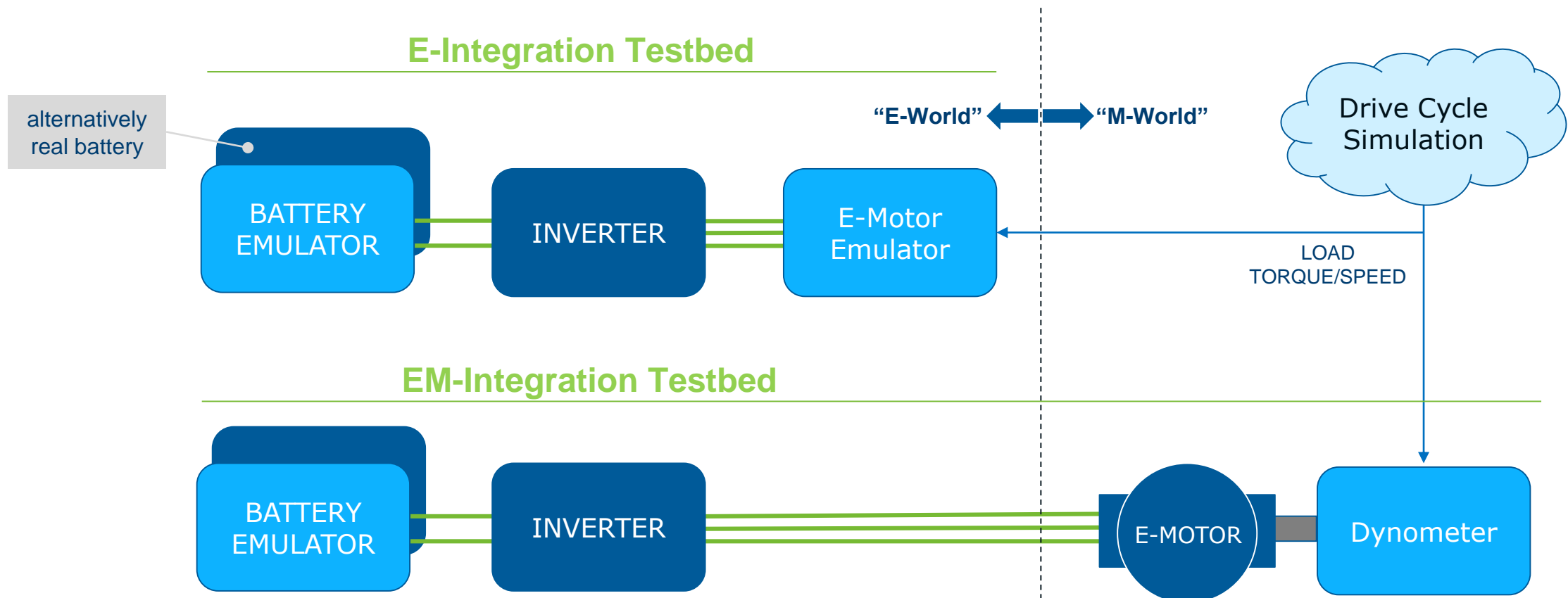
Inverter Test / E-Motor Test – Different Testbeds



Removing complexity: ... by independent component test with different testbeds

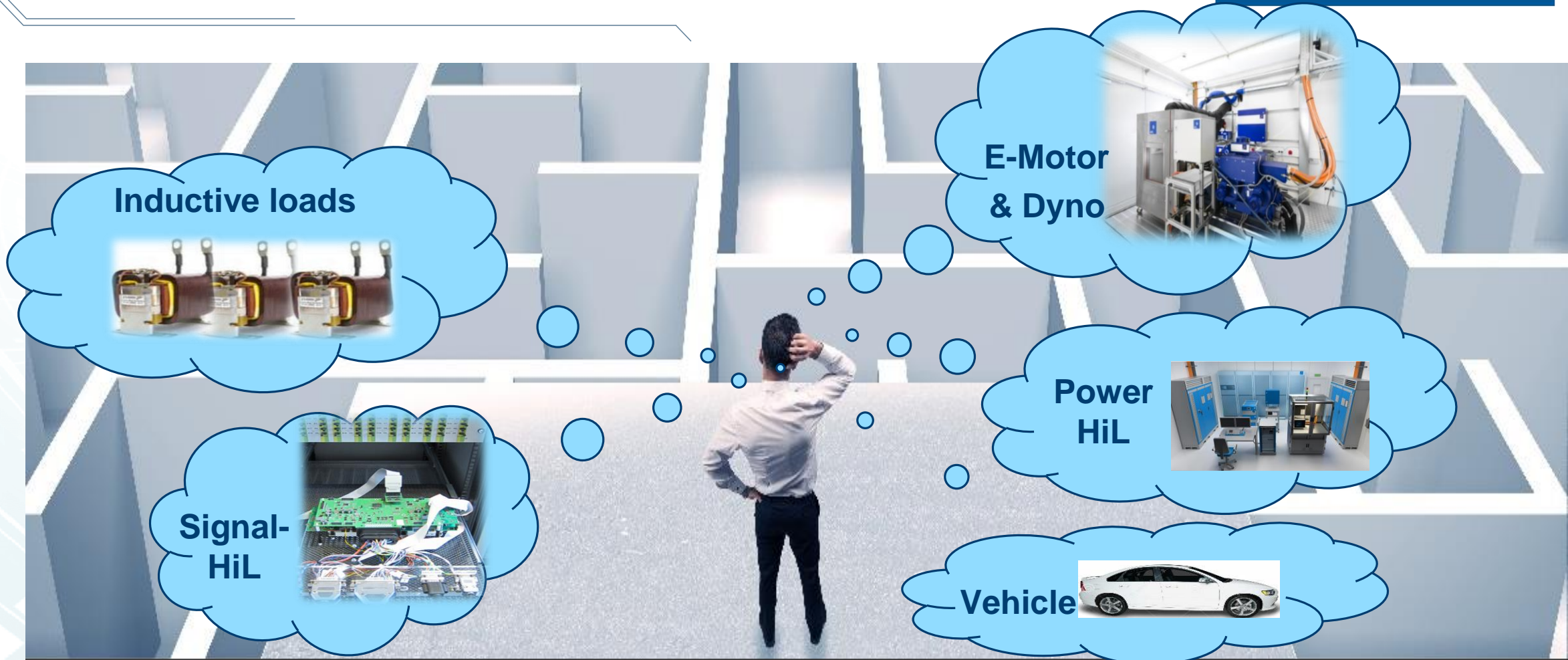


Removing complexity: ... by separation of integration layers



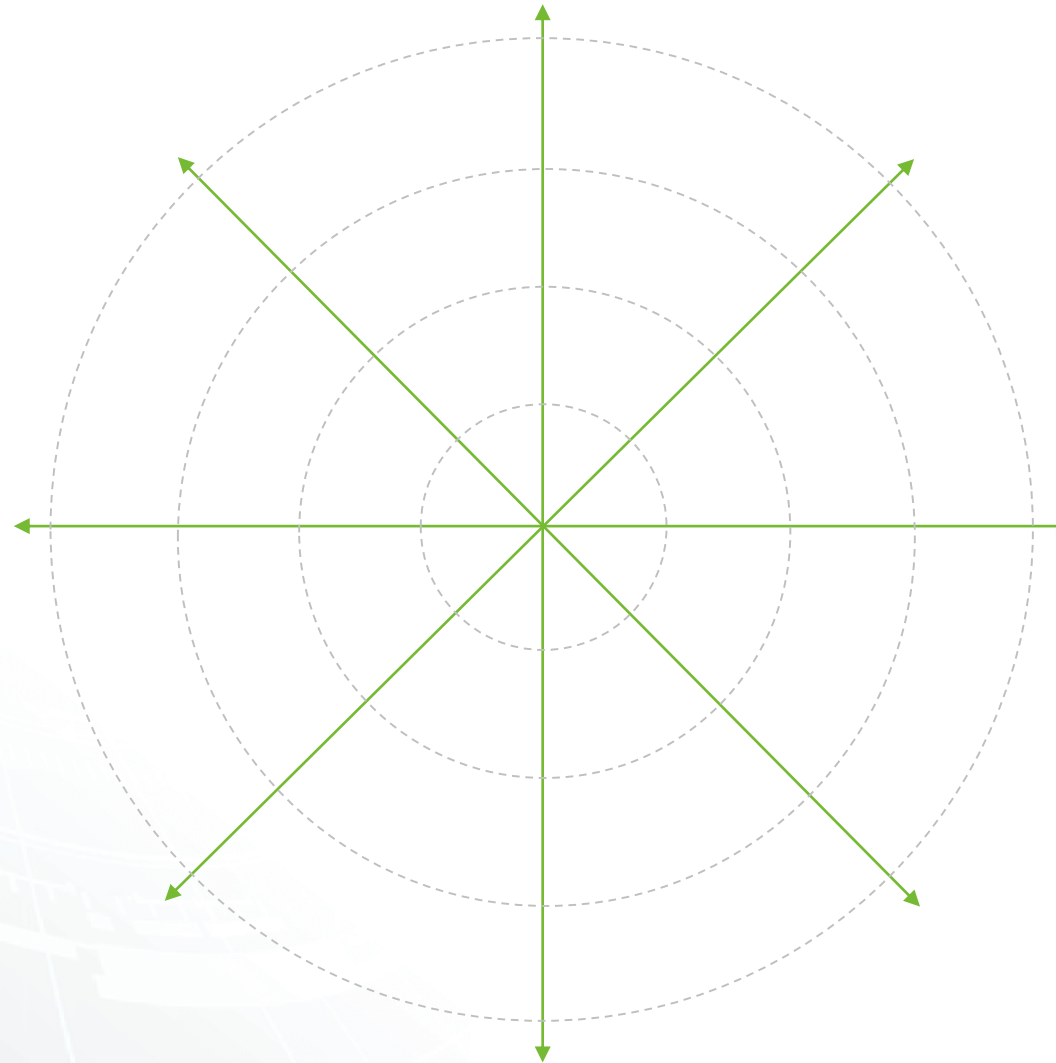
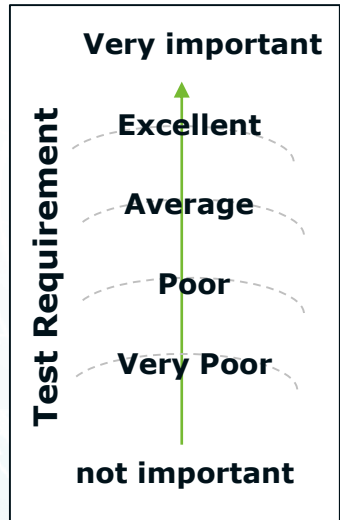
TEST COVERAGE vs. TEST EFFORT
... IS THE KEY FIGURE OF TESTING COSTS

How to test the inverter?



Which test concept gives us the best test coverage vs. effort?

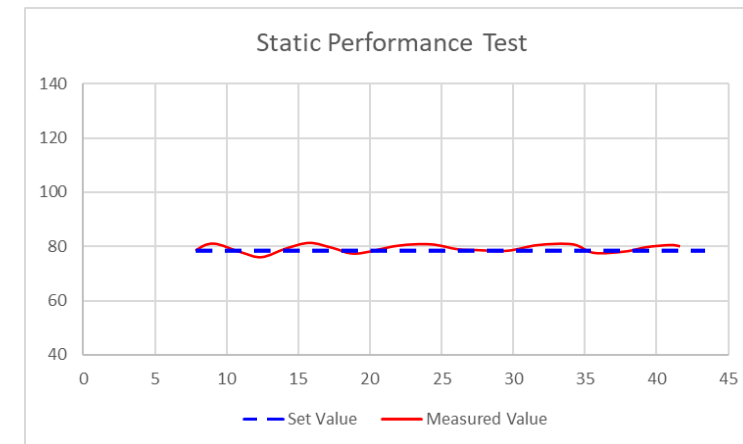
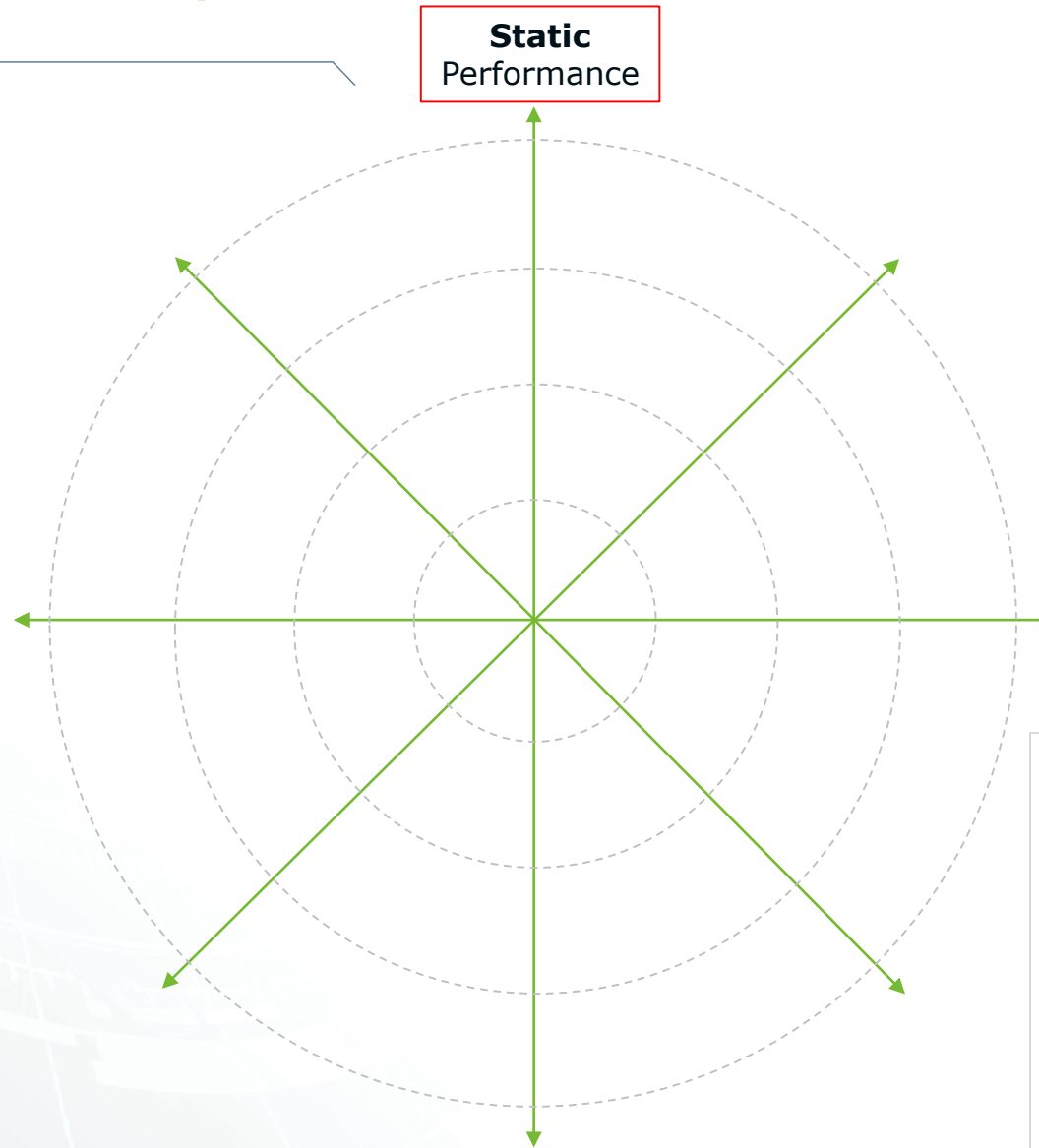
R&D Inverter Test Requirements



R&D Inverter Test Requirements



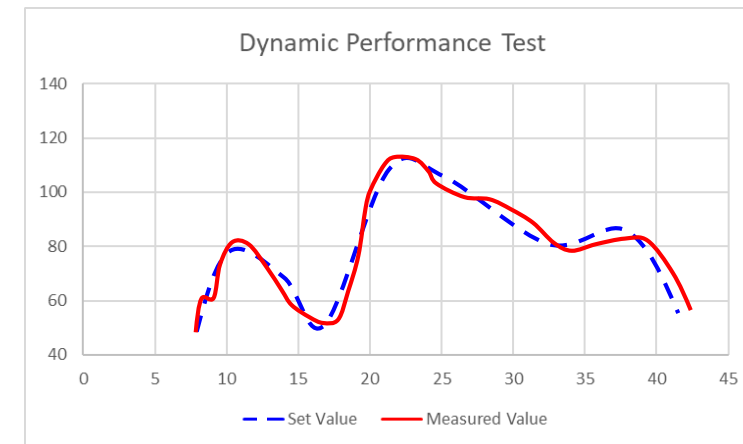
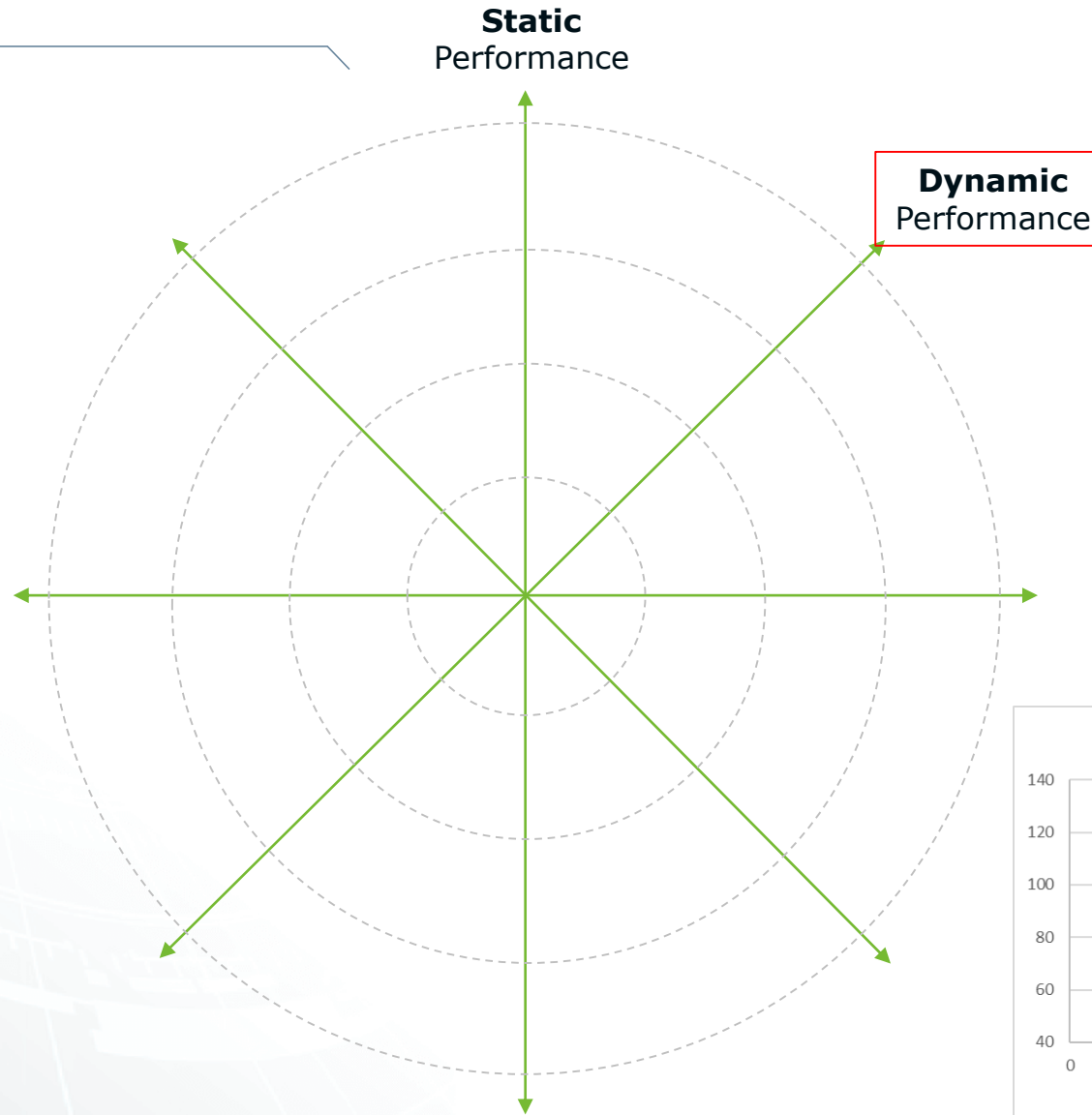
Static Performance Test: measure the capability of the unit under test to set and maintain a static operating point with high accuracy and stability.



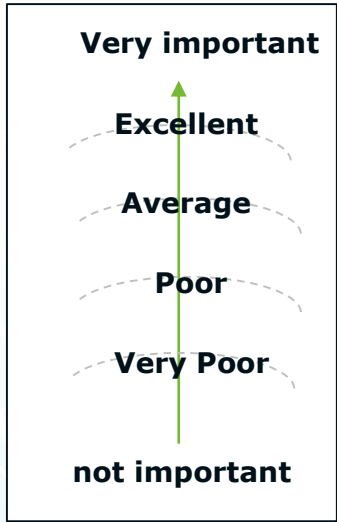
R&D Inverter Test Requirements



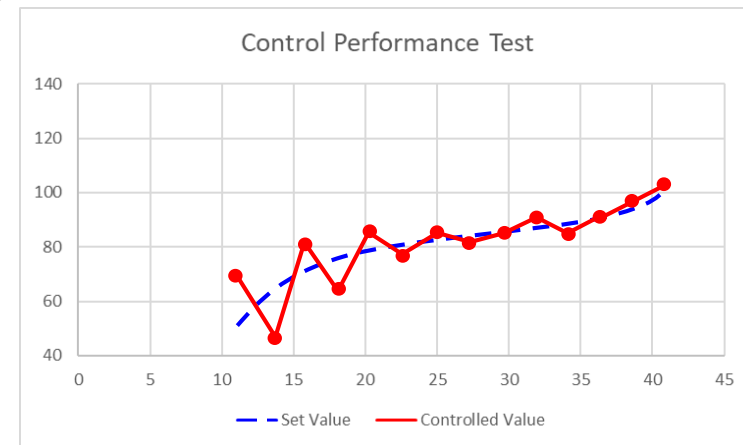
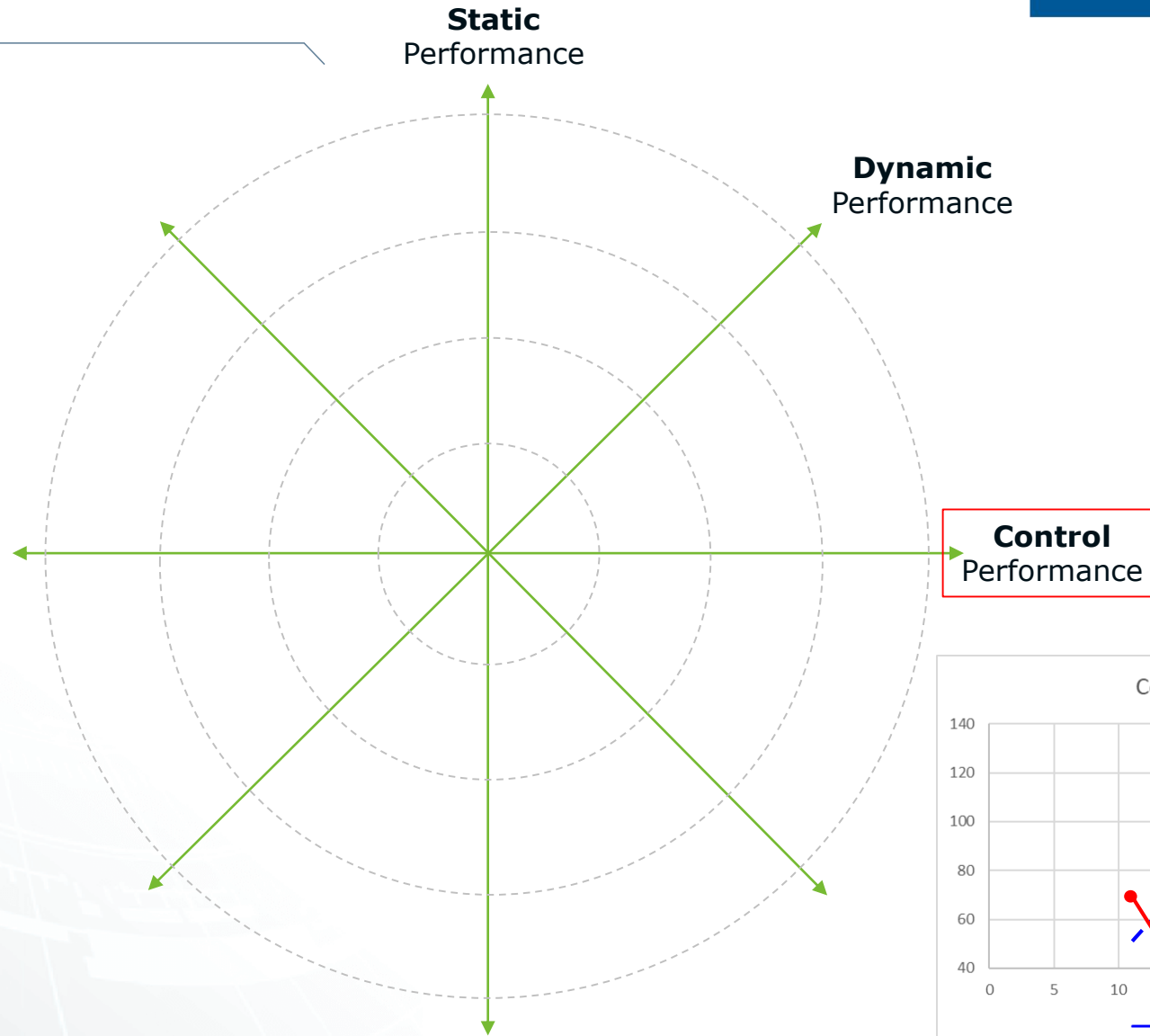
Dynamic Performance Test: measure the capability of the unit under test to follow fast-changing transients



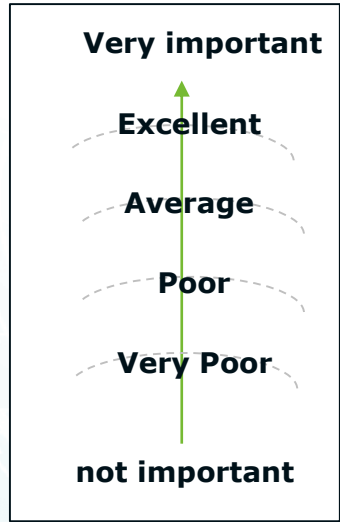
R&D Inverter Test Requirements



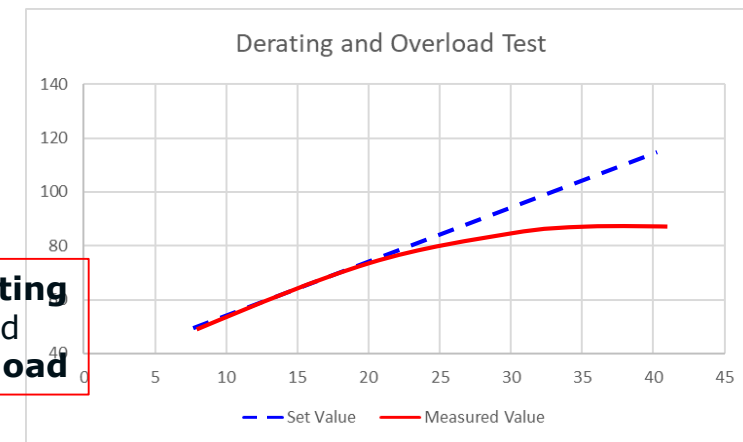
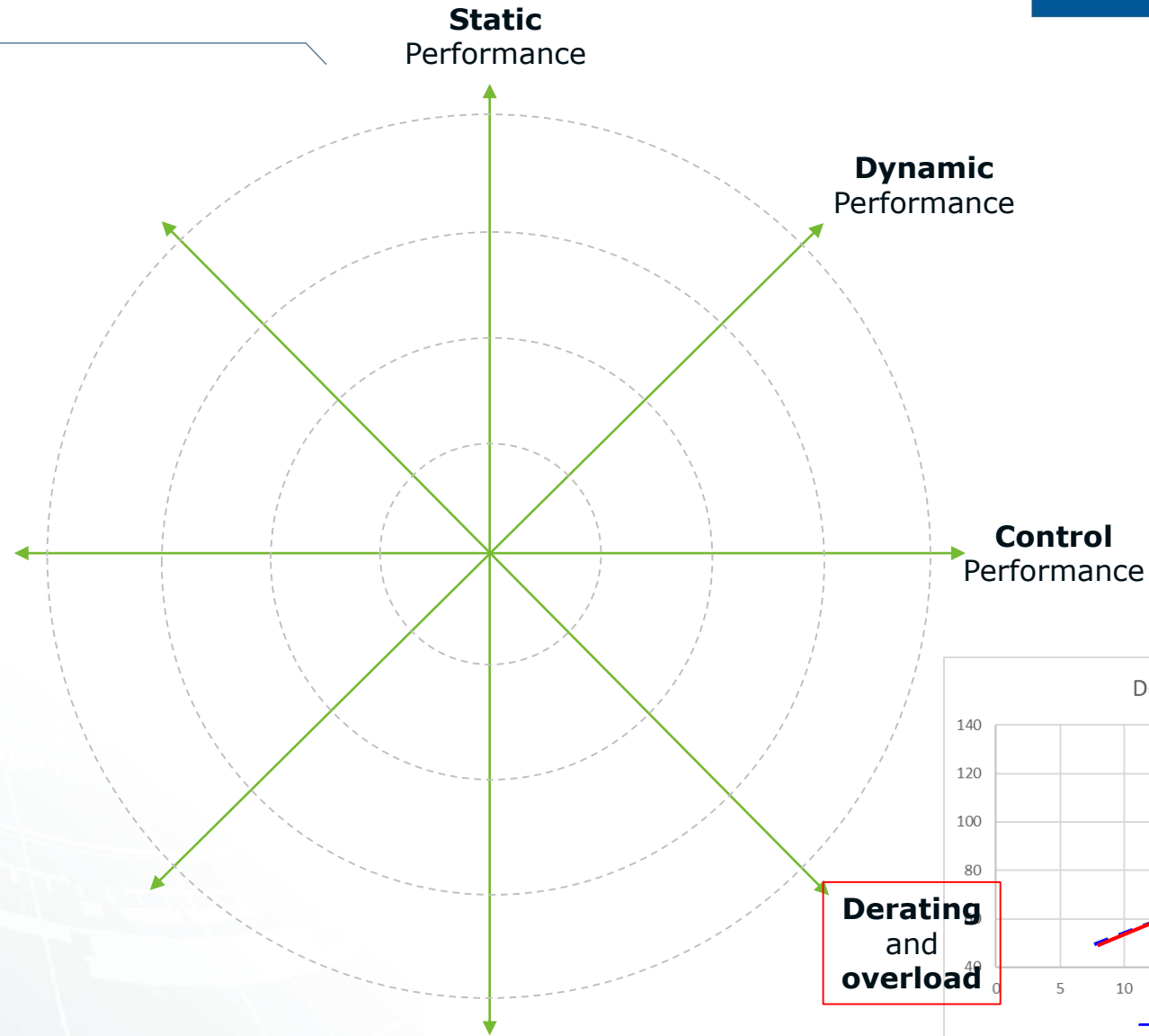
Control Performance Test: measure the stability and accuracy of the unit under test's control system



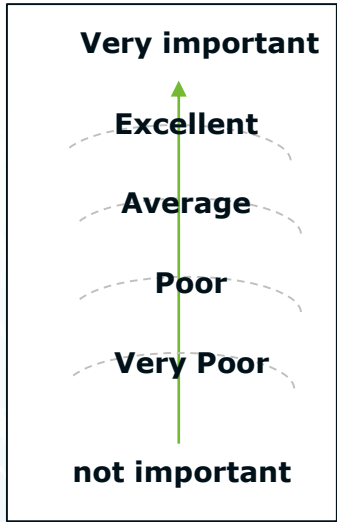
R&D Inverter Test Requirements



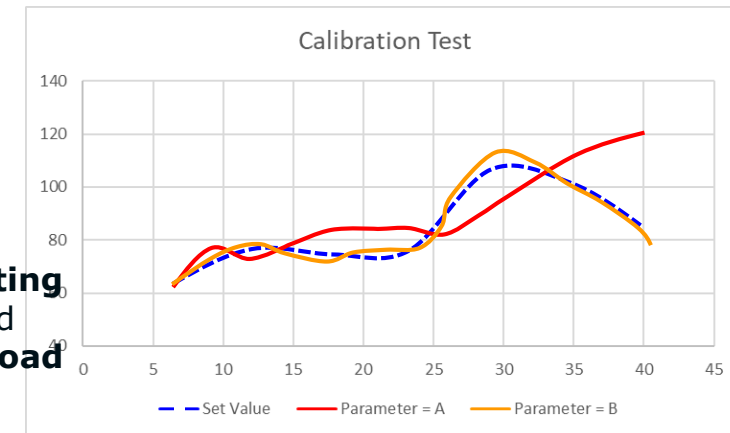
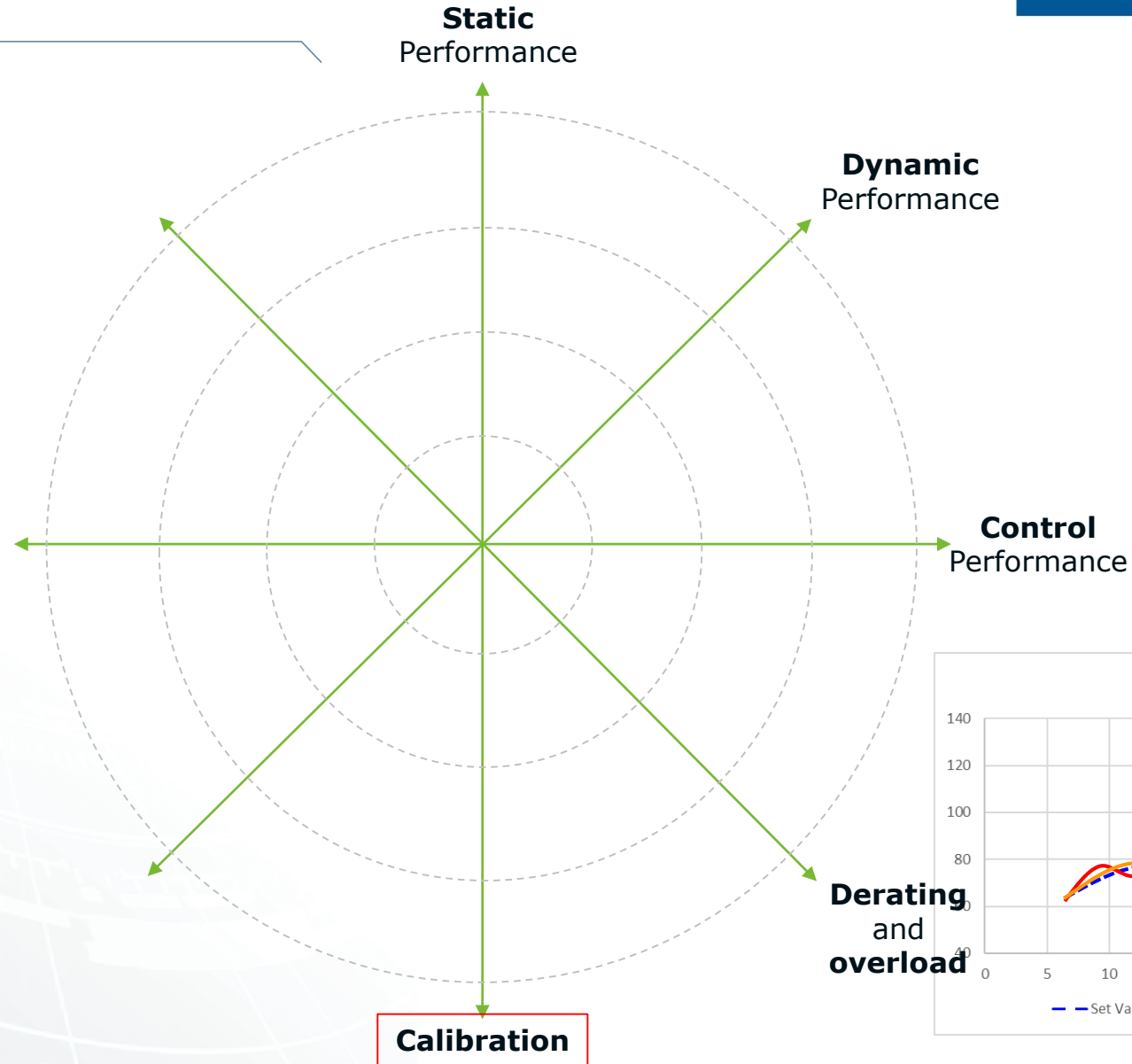
Derating and Overload Tests: verifies the behavior of the unit under test in case of overload or performance derating



R&D Inverter Test Requirements



Calibration Tests: perform the unit under test's calibration and/or measure the performances with different calibration sets.

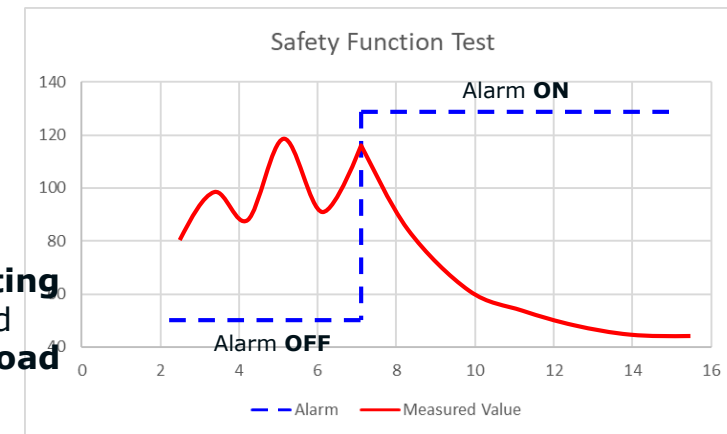
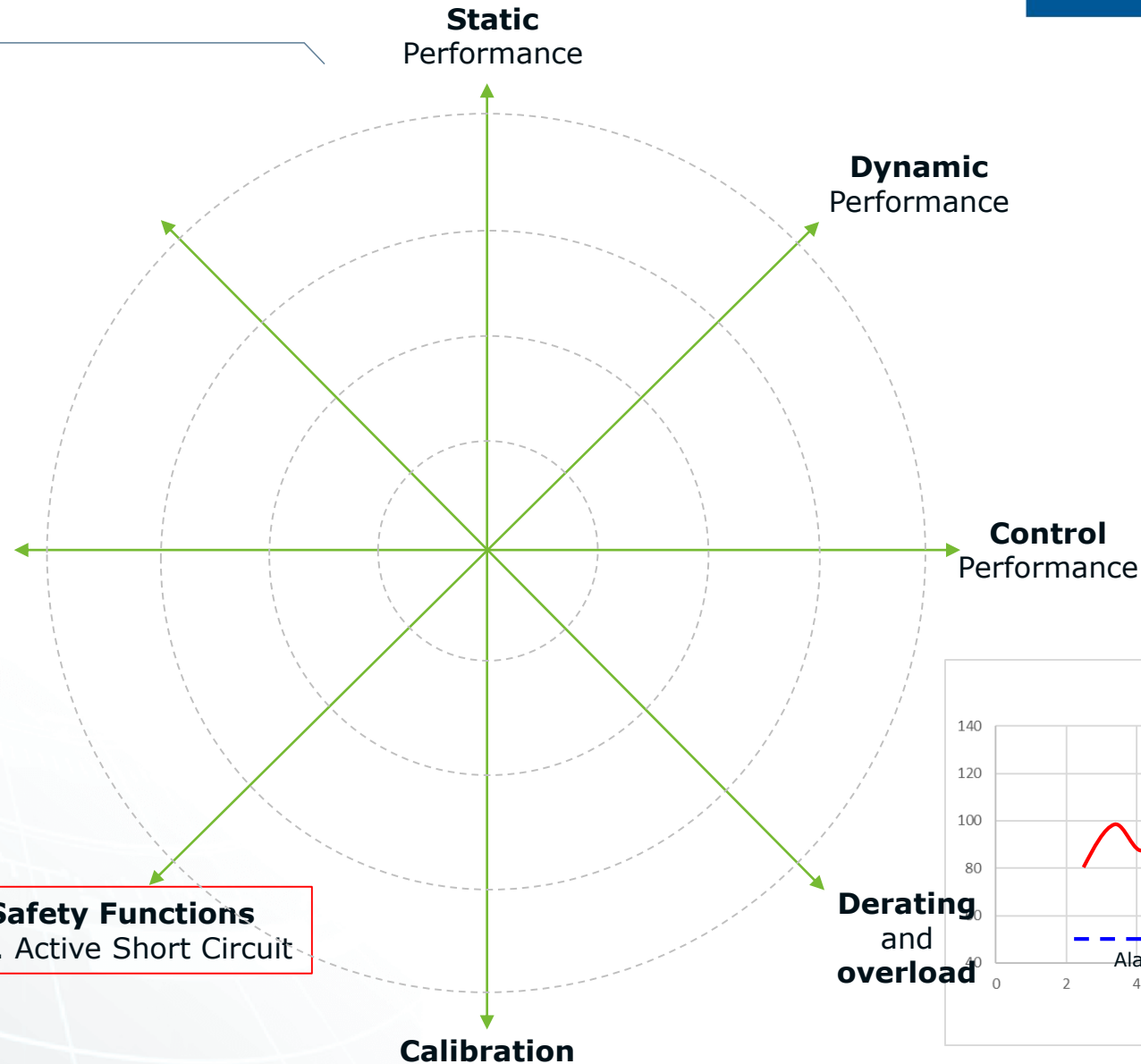


R&D Inverter Test Requirements



Safety Functions Tests: test the functionality and behavior of the unit under test's safety functions

Safety Functions
e.g. Active Short Circuit



R&D Inverter Test Requirements

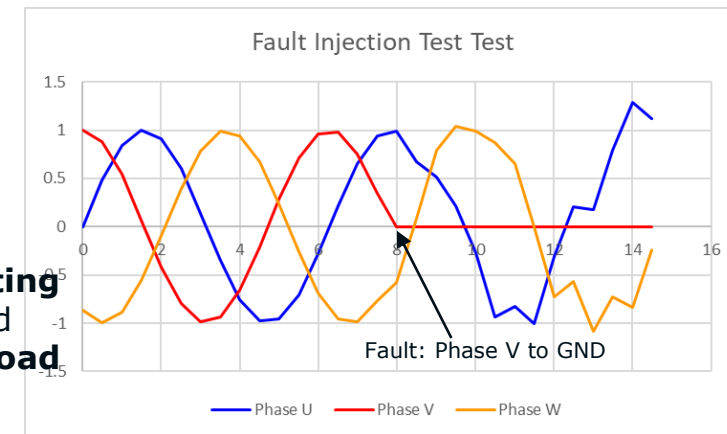
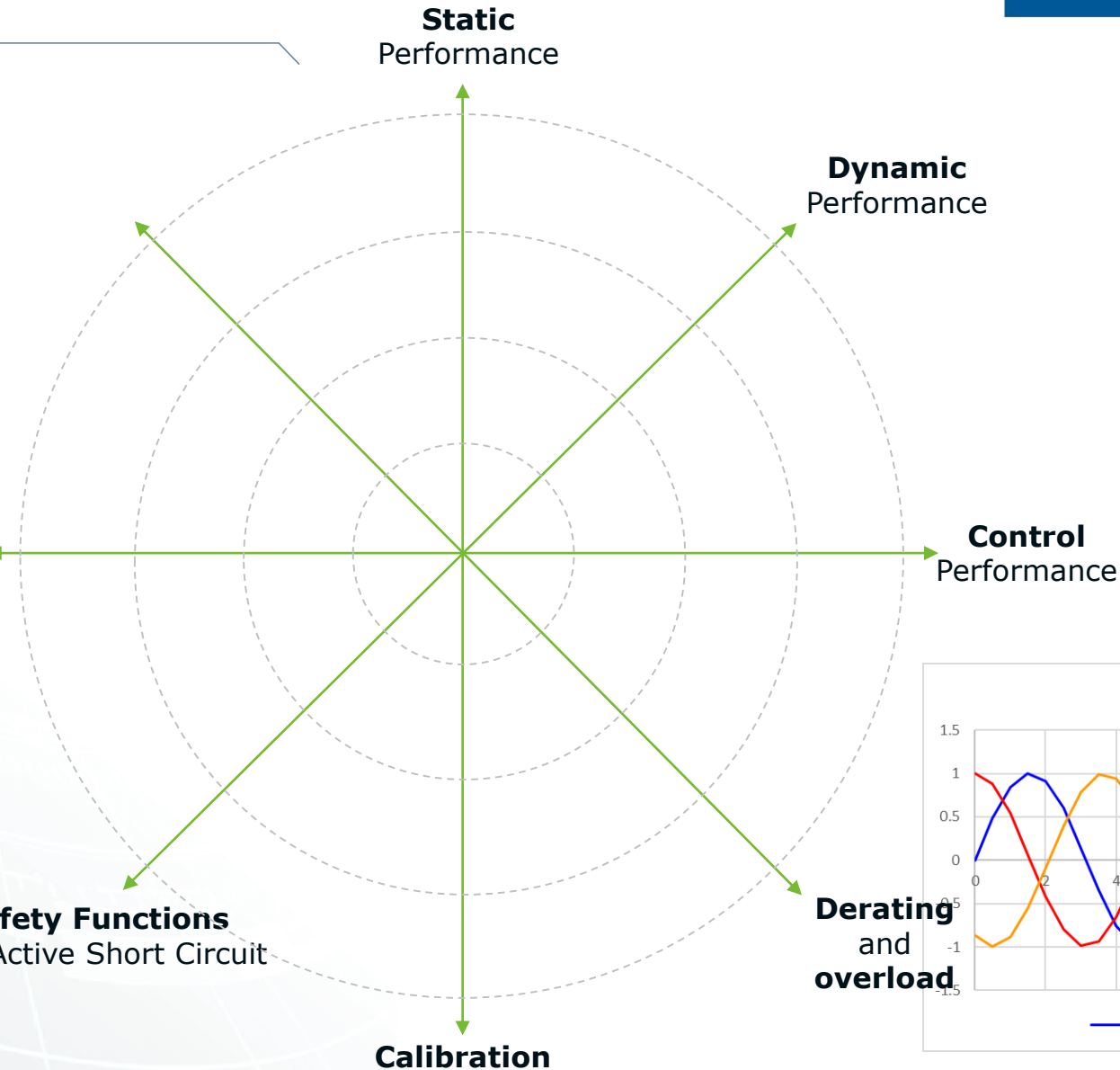


Fault Injection

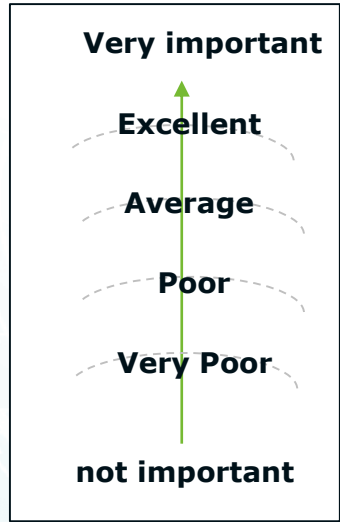
Fault Injection Tests: inject a fault in the system and observe the unit under test's behavior

Safety Functions
 e.g. Active Short Circuit

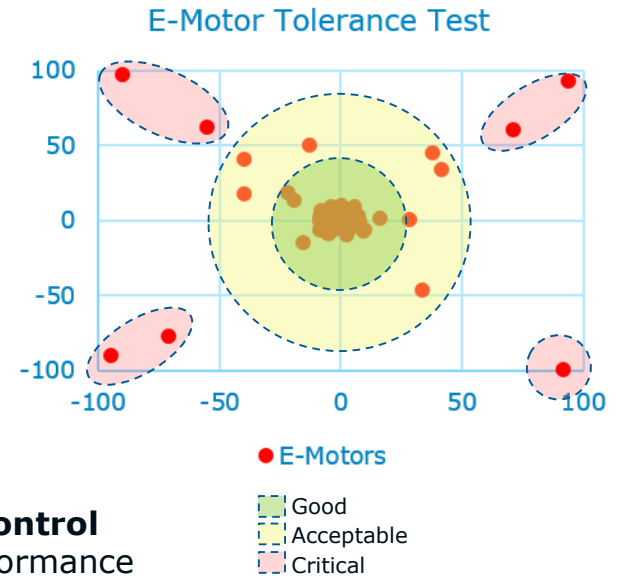
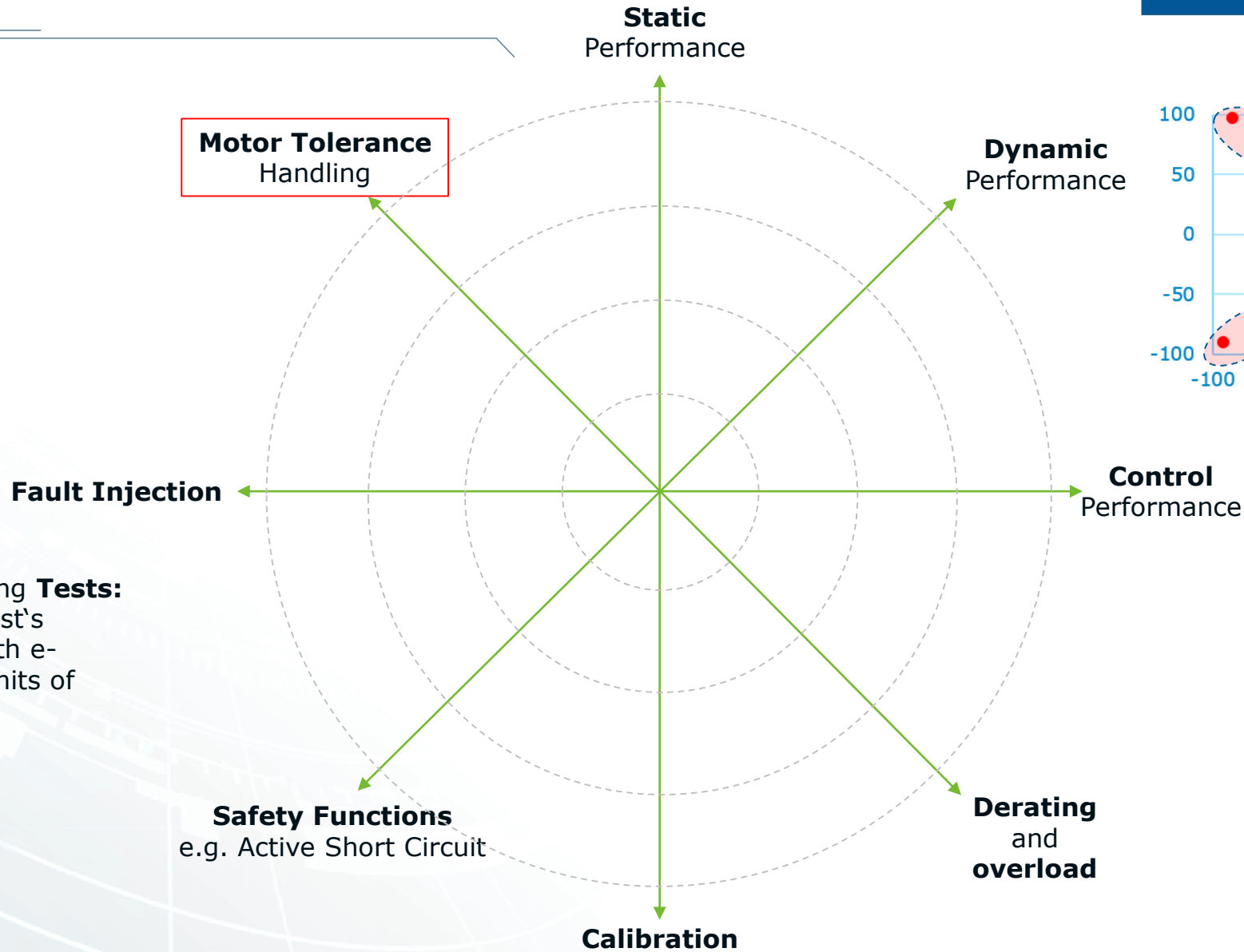
Derating and overload



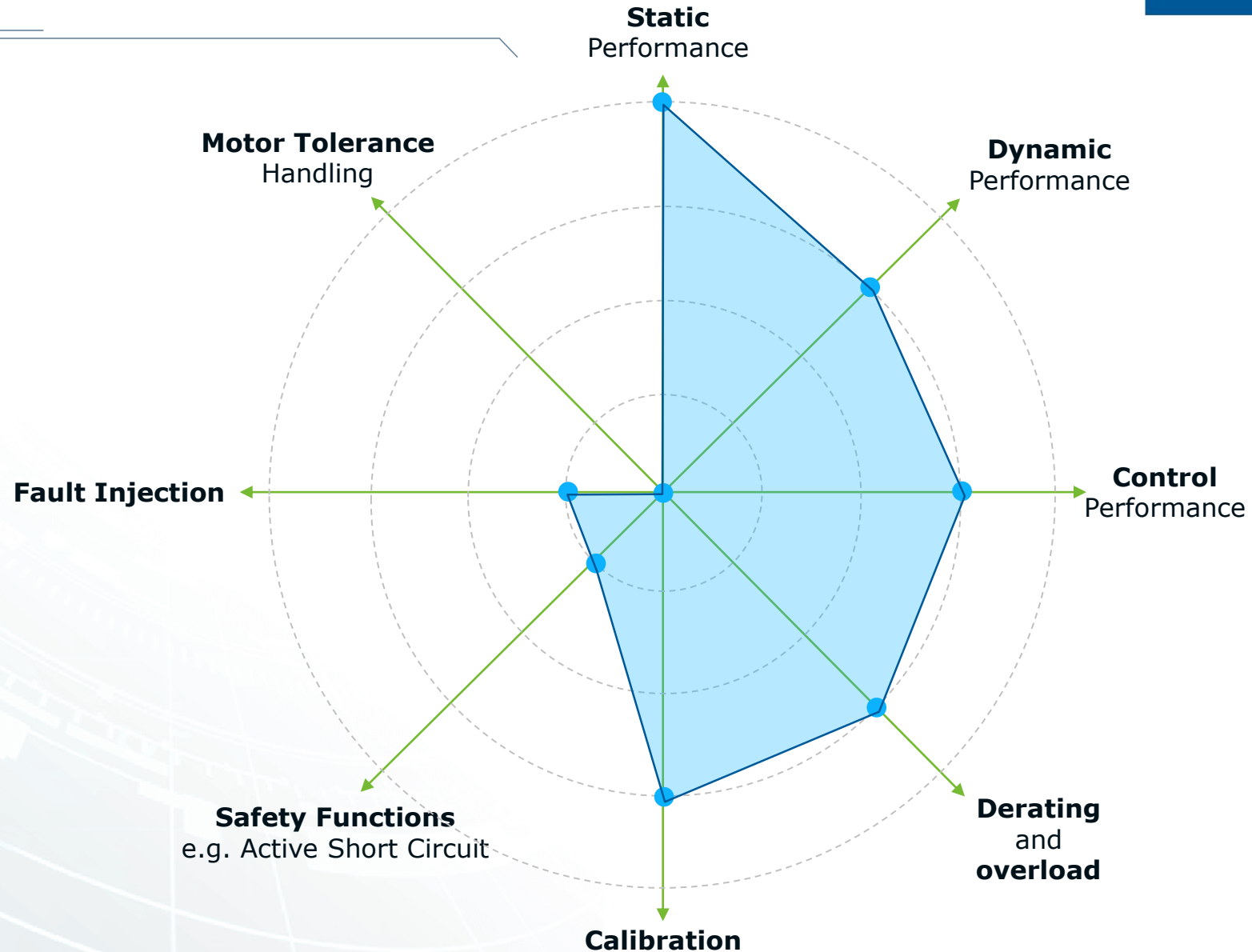
R&D Inverter Test Requirements



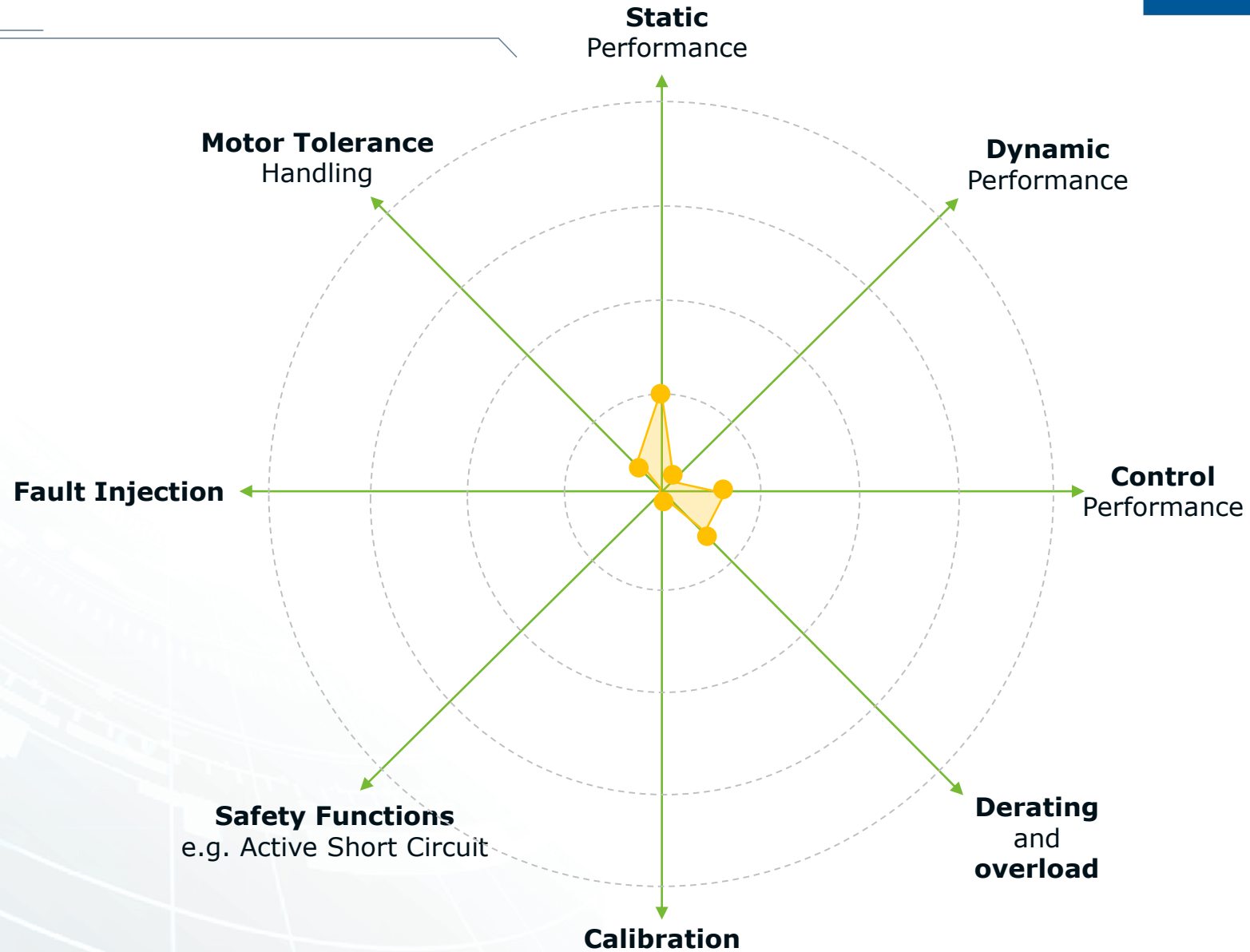
Motor Tolerance Handling Tests: observe the unit under test's behavior when testing with e-motors at the extreme limits of tolerance ranges



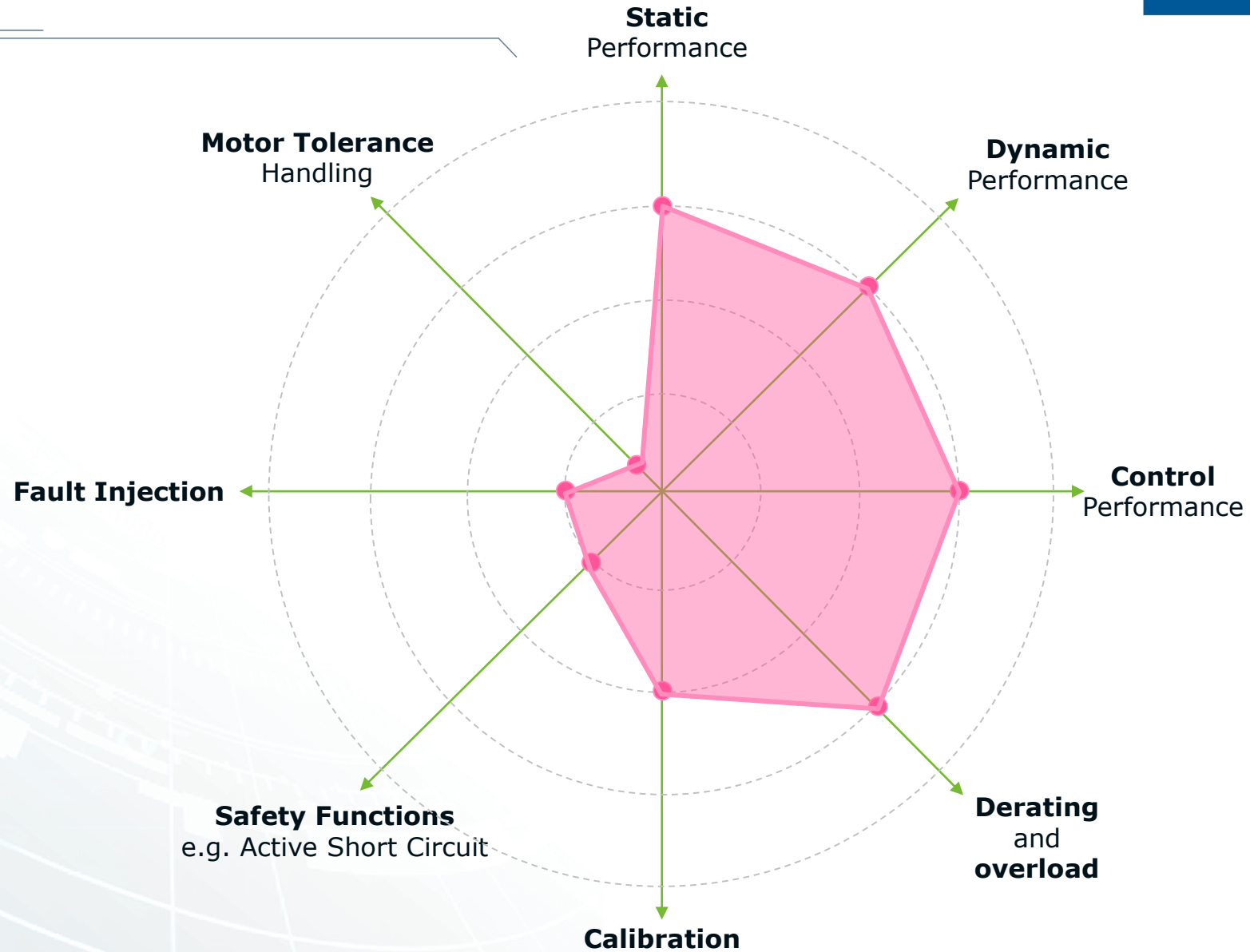
Inverter test with e-motor & dynamometer



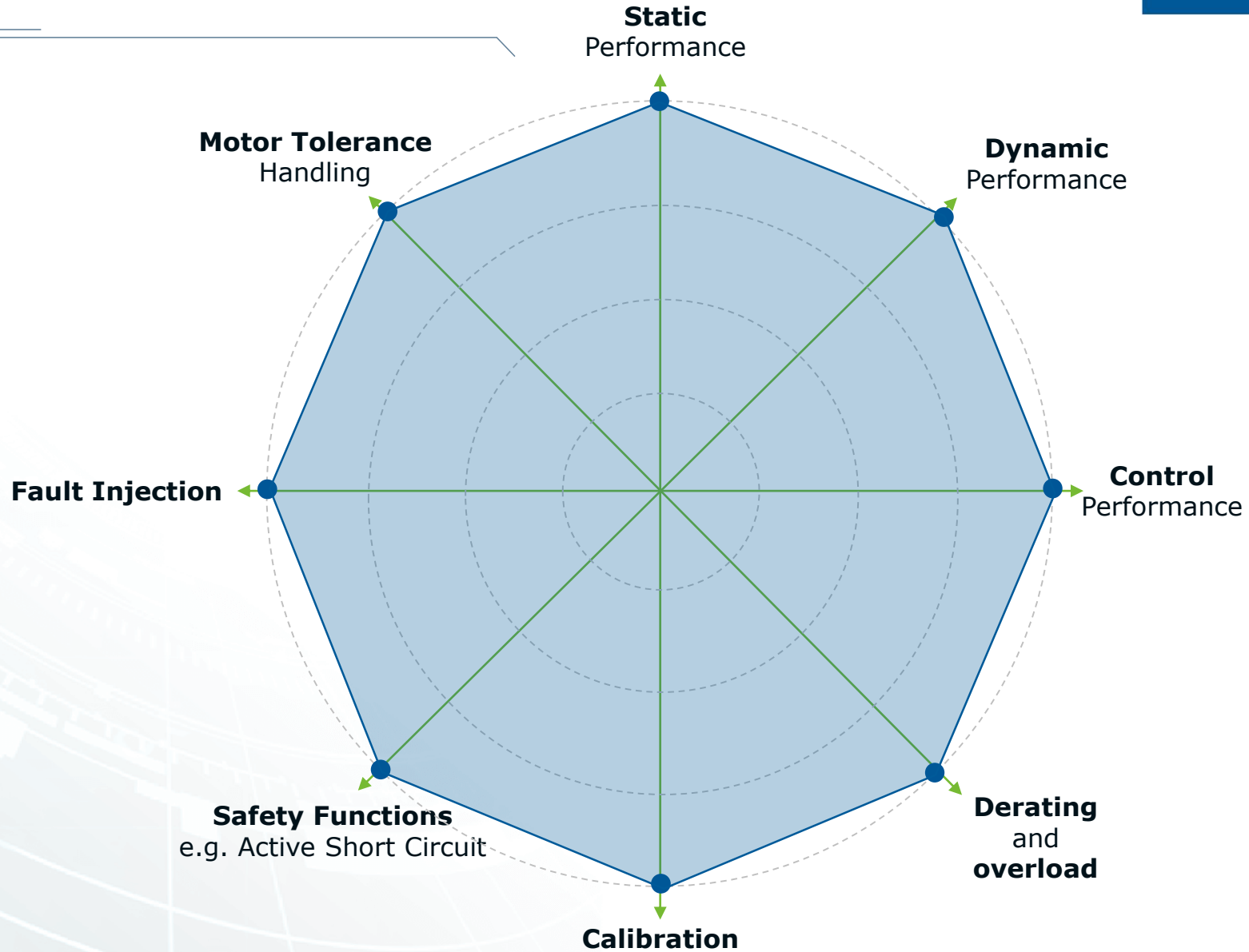
Passive loads test coverage



Vehicle Road Test Coverage



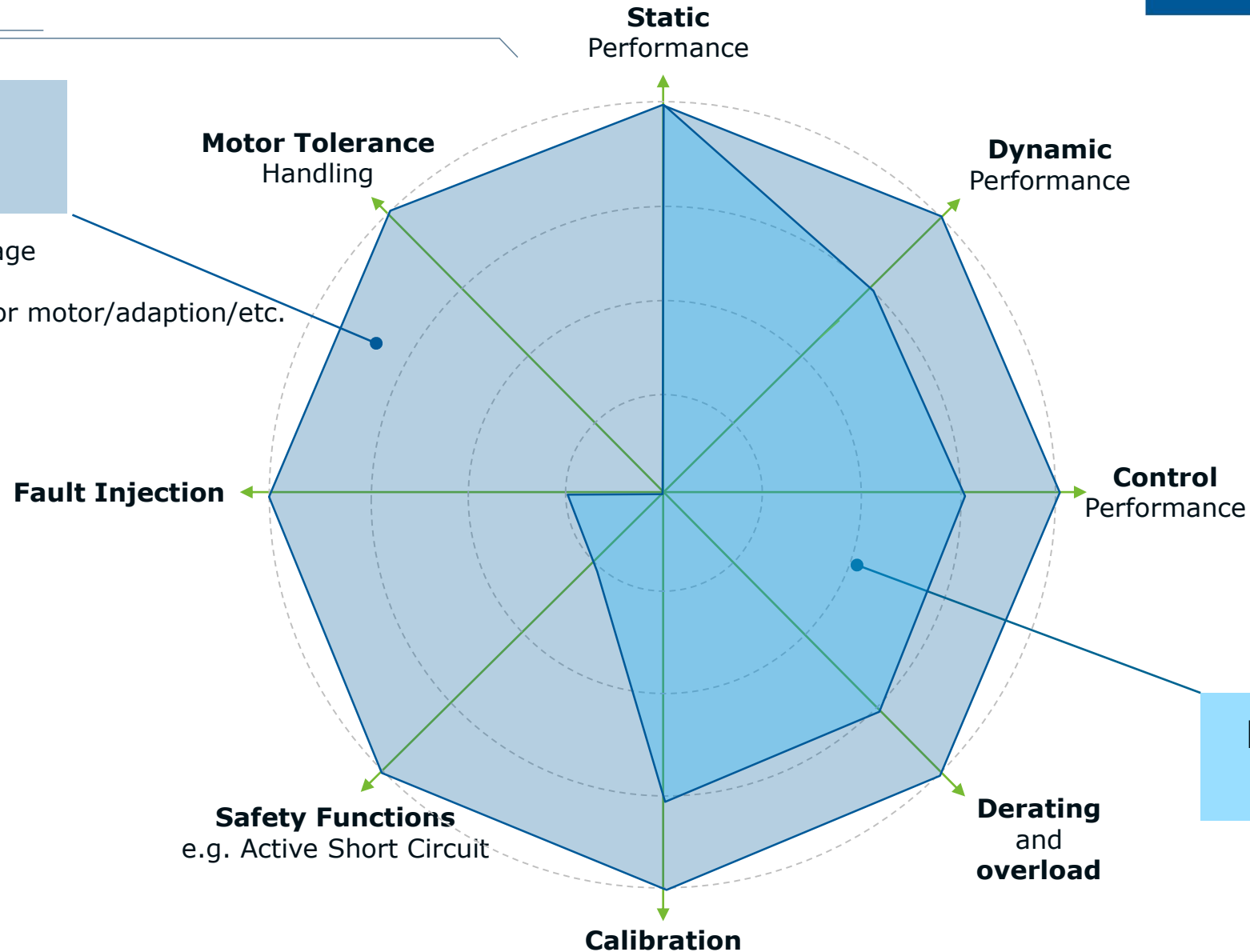
AVL Inverter Testbed Capabilities



Inverter test coverage comparison

AVL Inverter Test System

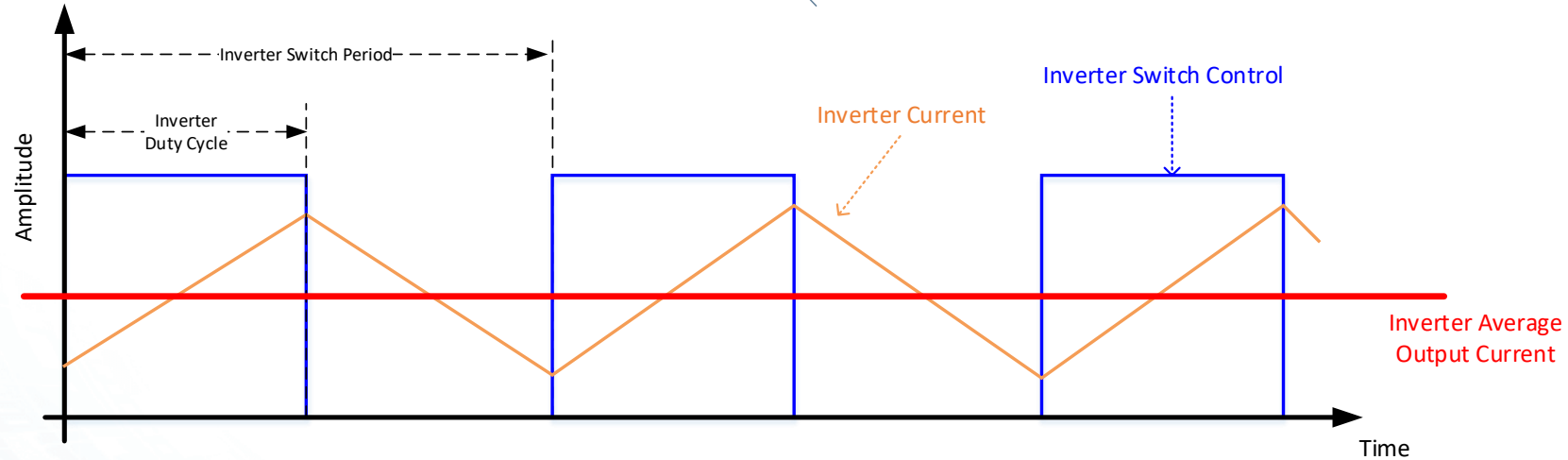
- Very highest coverage
- min. 10x faster
- „zero“ costs/delay for motor/adaption/etc.



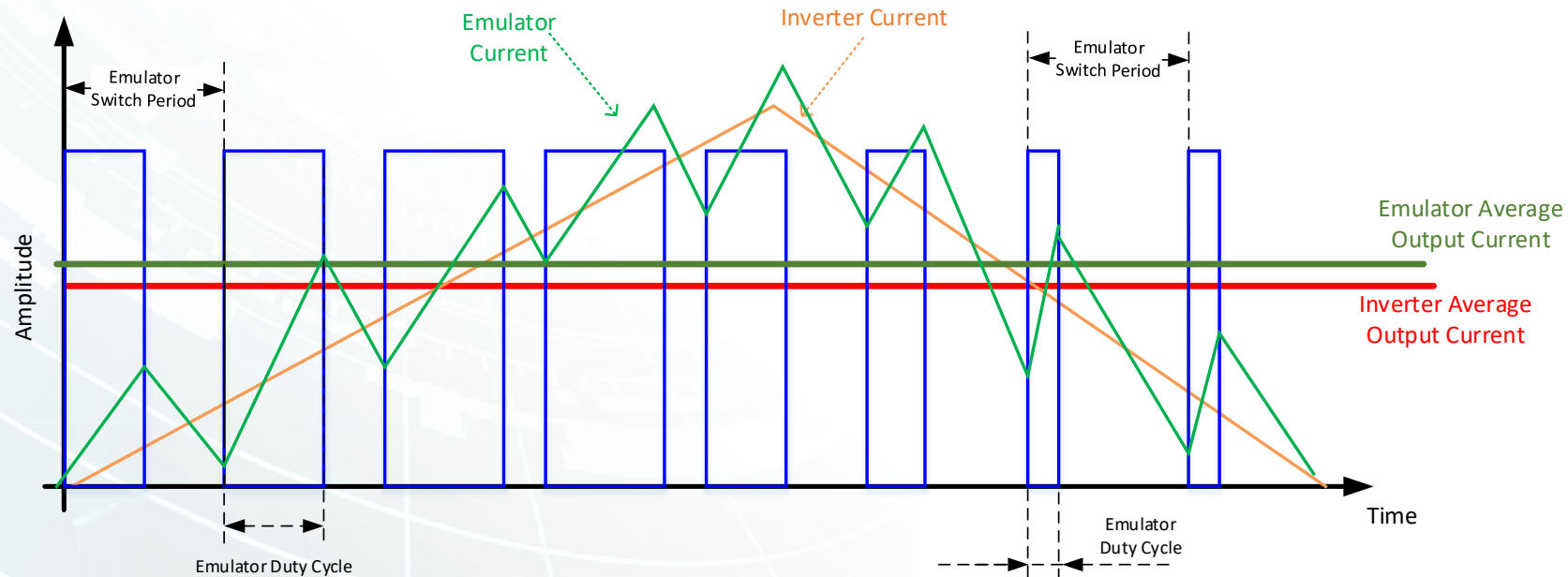
E-Motor Based Test System

HIGH PERFORMANCE VS.
LOW PERFORMANCE
E-MOTOR EMULATOR

Poor Performance System E-Motor Emulator with Low Switch Frequency

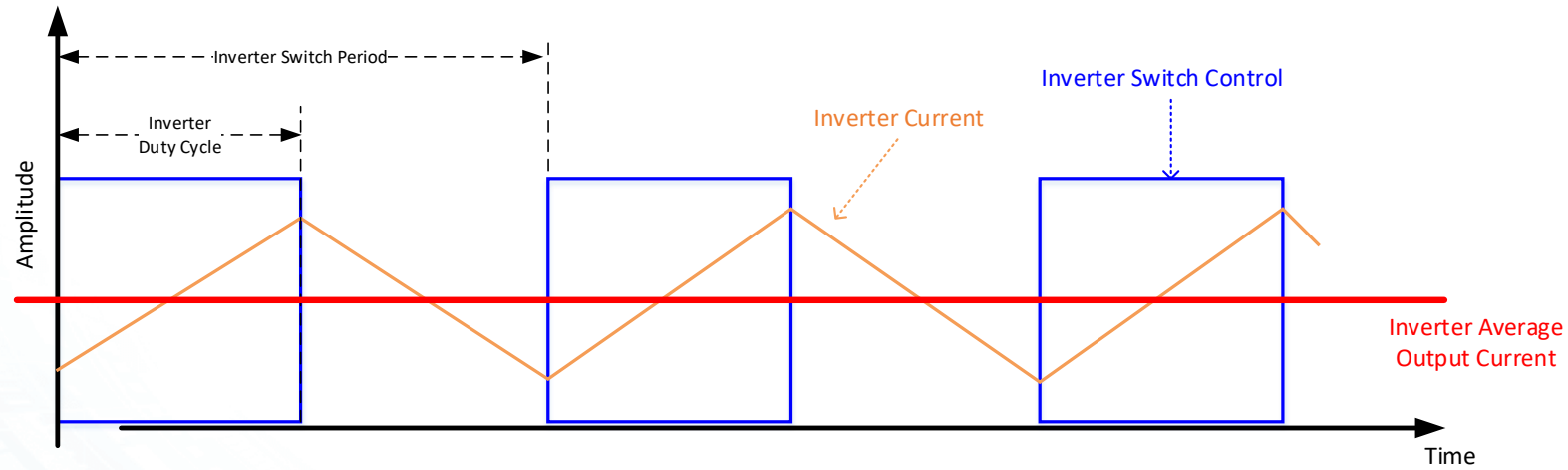


Inverter Behavior

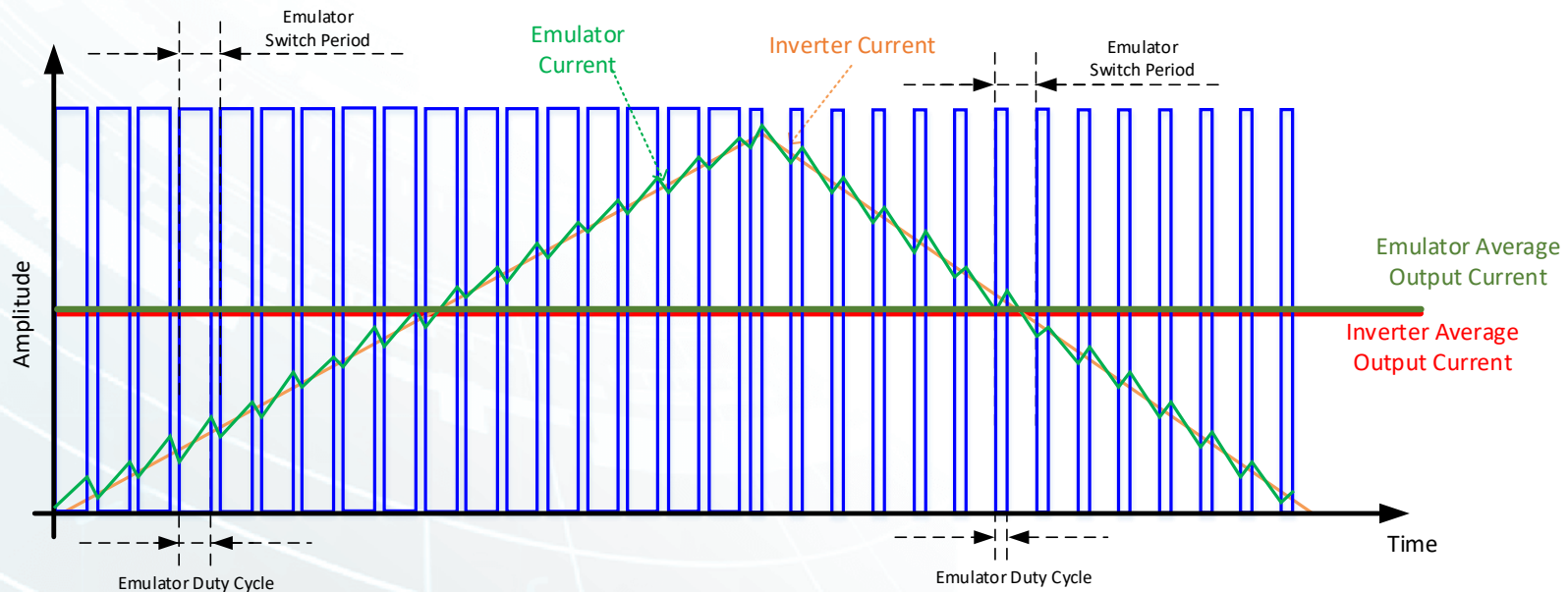


E-Motor Emulator Behavior

High Performance System E-Motor Emulator with High Switch Frequency

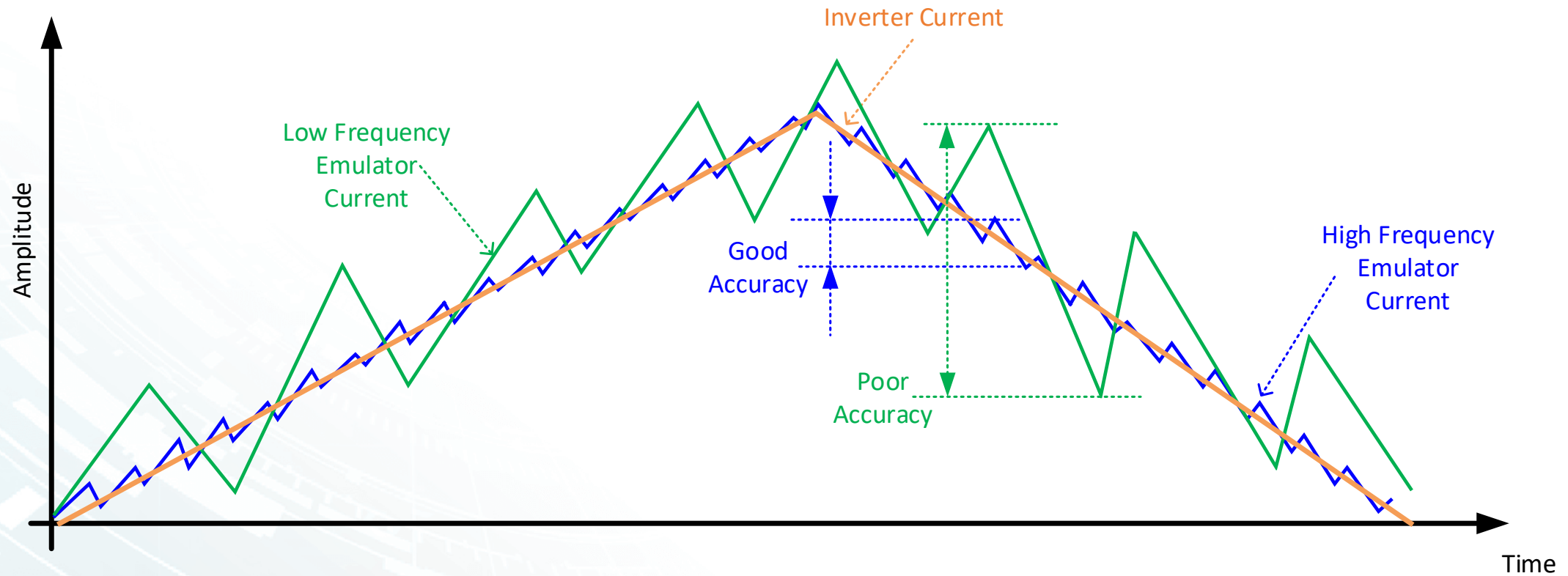


Inverter Behavior

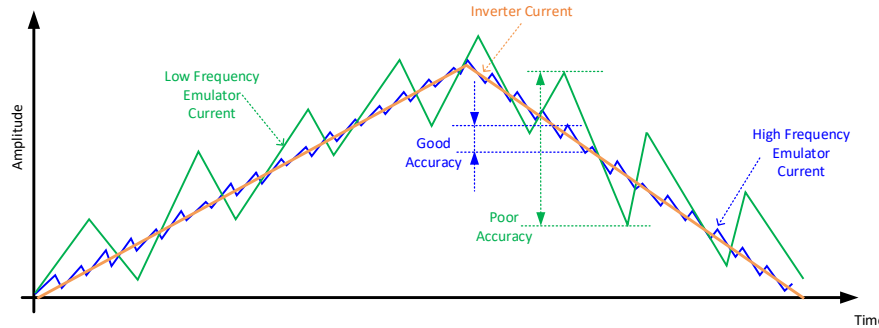


E-Motor Emulator Behavior

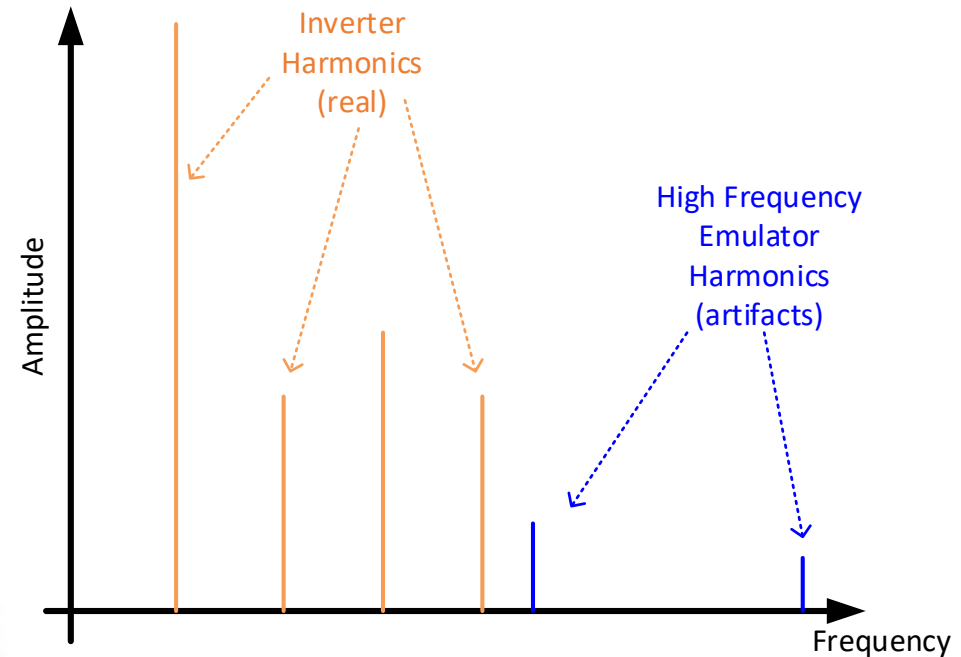
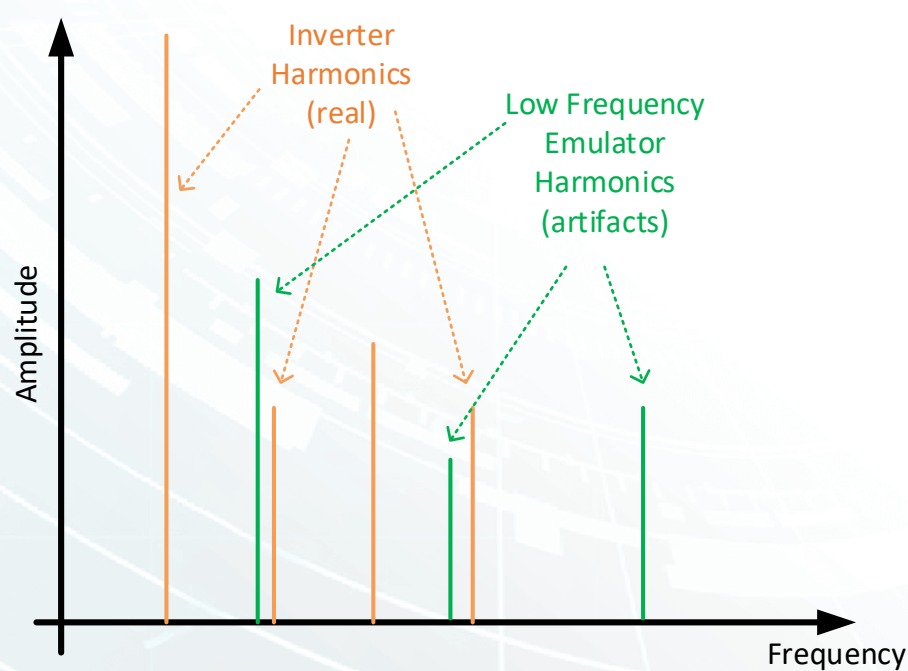
Low-High Switch Frequency Comparison Time Domain



Low-High Switch Frequency Comparison Frequency Domain



When using a low frequency emulator to develop and calibrate the control strategy, we risk to waste efforts to compensate for harmonic behavior that has been introduced by the emulator switch frequency and is therefore not real

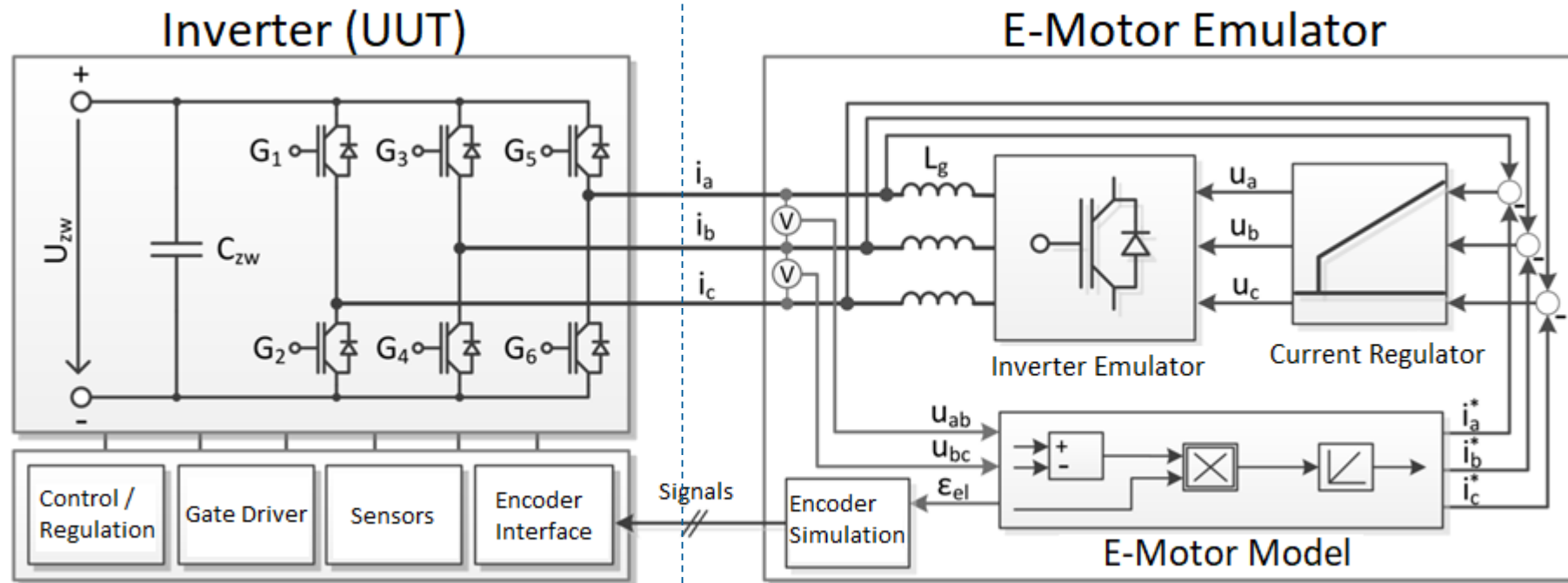


The heart of an inverter test system

**E-Motor Emulator ... see how it
functions**

E-Motor Emulator ... basic operation principle

E-Motor replaced with a power electronic device



E-Motor Emulator ... testbed integration

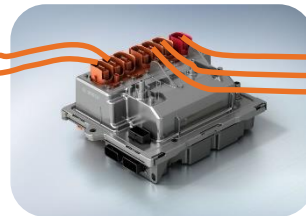
The e-motor emulator replaces both, e-motor and dynamometer

Battery Emulator

- ✓ HV Batterie Replacement (Virtual Battery with Correct Characteristics)
- ✓ Standard Unit Today



Inverter under Test

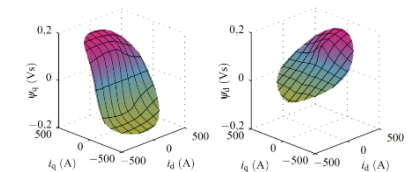


E-Motor Emulator

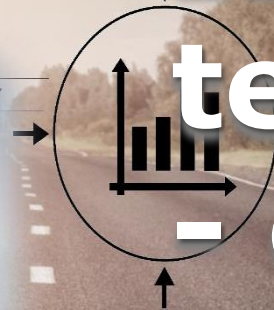
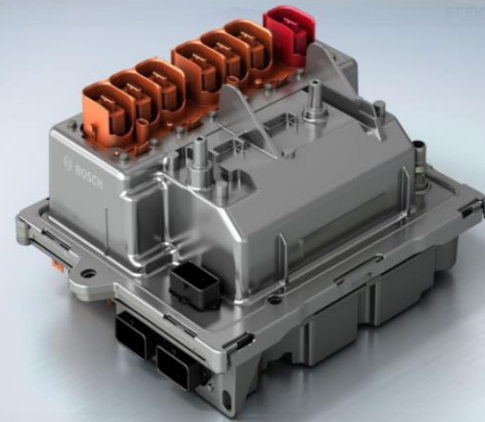
- ✓ E-Motor Replacement (Virtual E-Motor with Correct Characteristics)
- ✓ Dyno Replacement (No Mechanics)

- ✓ Control of rotor position
- ✓ Control of torque
- ✓ Control of speed

E-Motor Data



E-Motor Emulator ... making it happen



**Is your inverter
test concept
- efficient ?
- realistic ?
- fast ?**

Calling the inverter test system into
existence ...

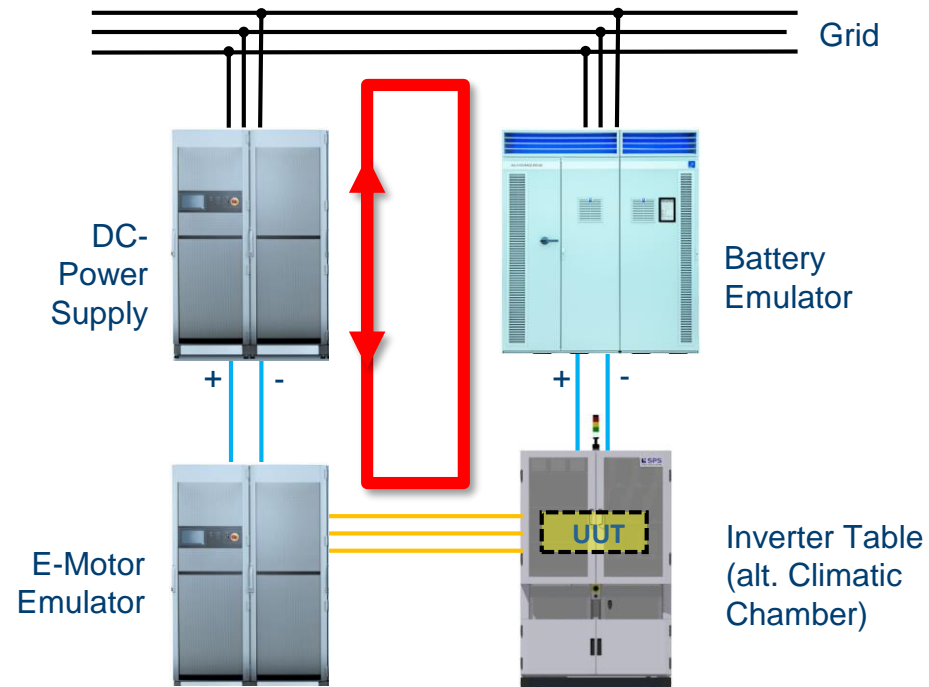
A modular test bed architecture

Basic inverter test system layout with e-motor emulator



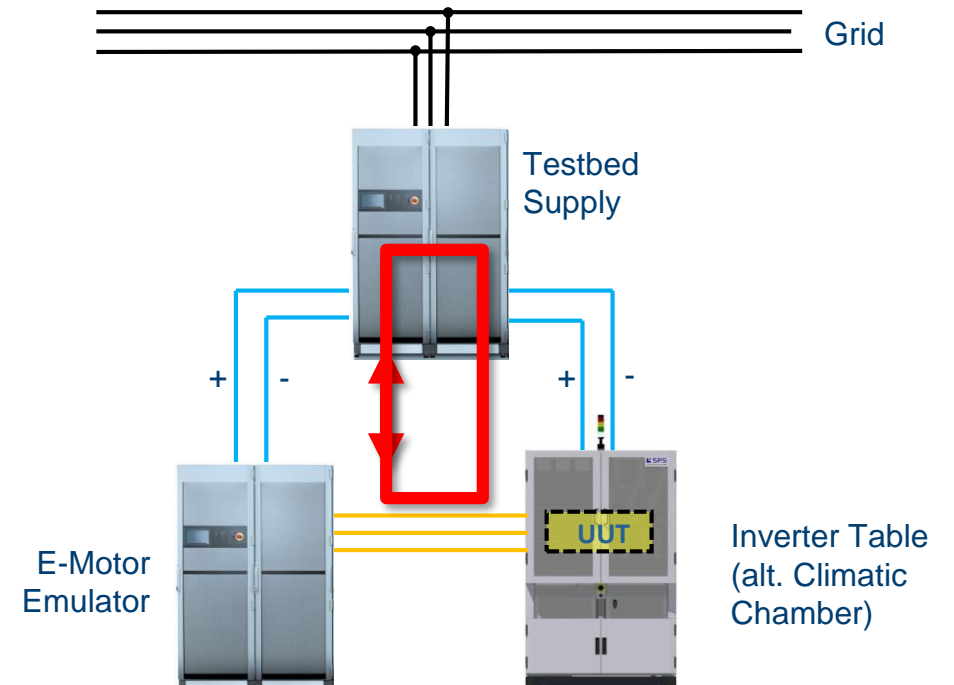
AC Power Cycle Topology

- + Allows integration of a real battery
- Weight and physical dimensions

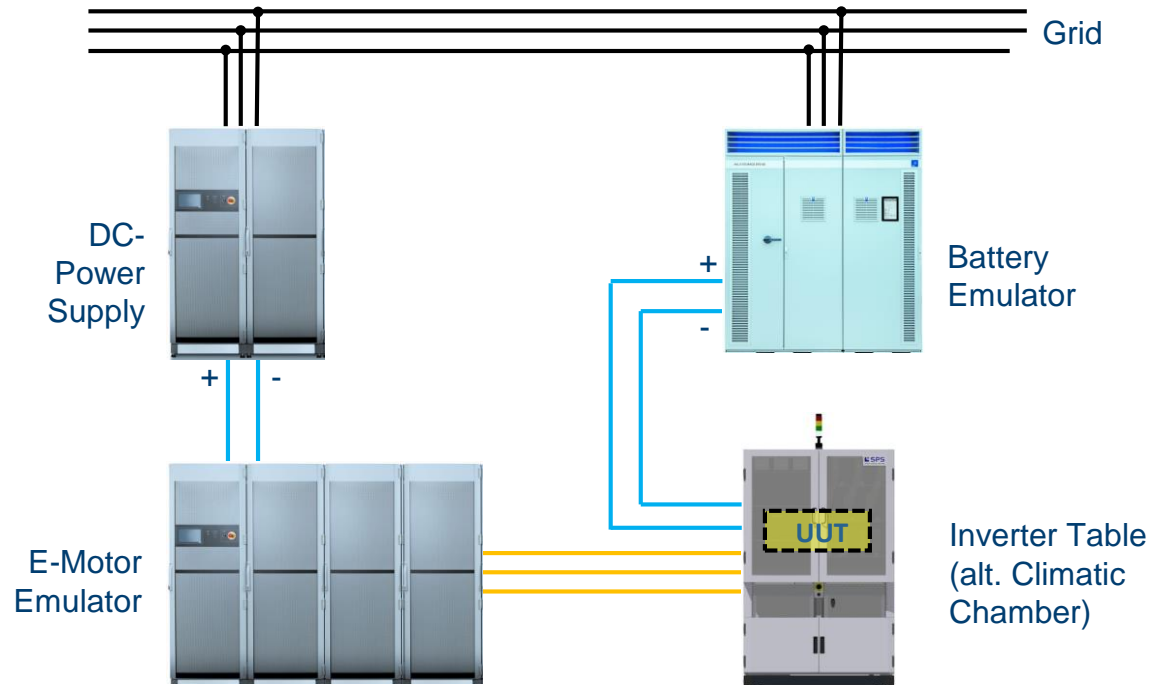


DC Power Cycle Topology

- + Compact
- Later integration of a real battery not possible



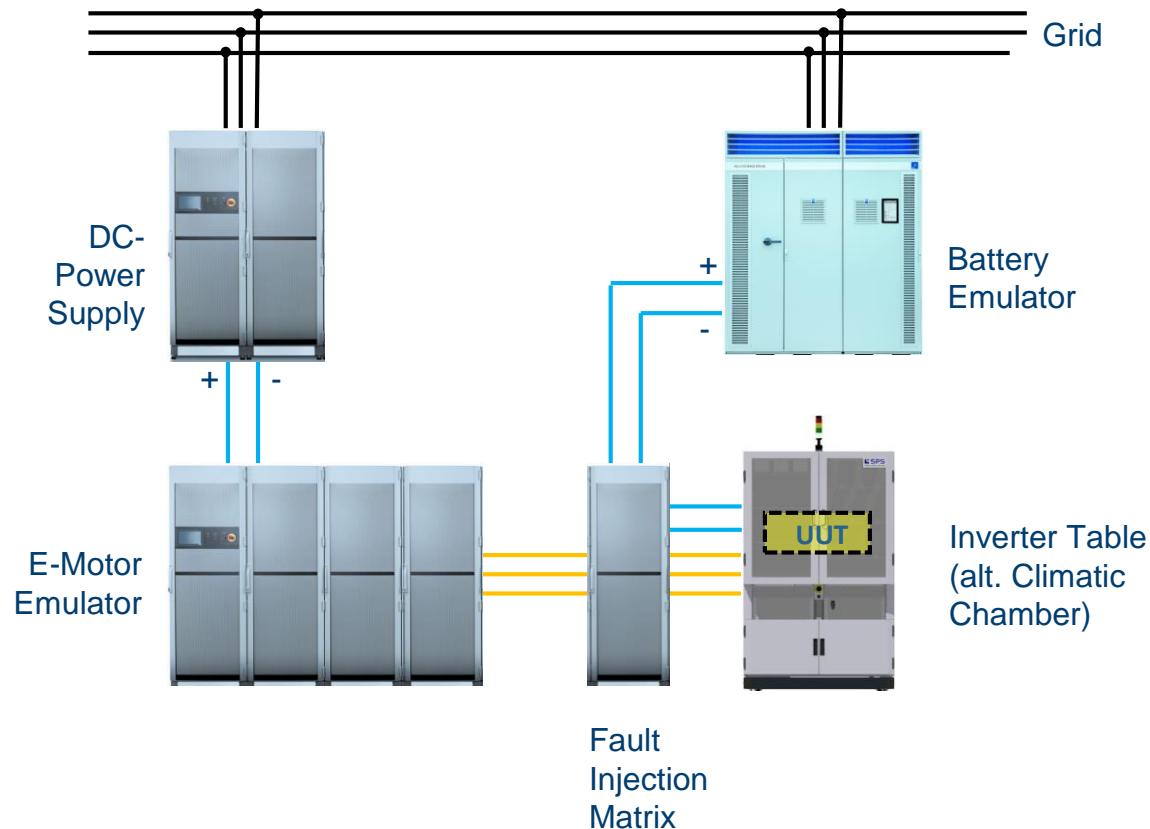
E-Motor Emulator Phase Current Scalability



The E-Motor Emulator phase current capability can be selected in $400A_{RMS}$ steps:

- $400A_{RMS}$
- $800A_{RMS}$
- $1,200A_{RMS}$

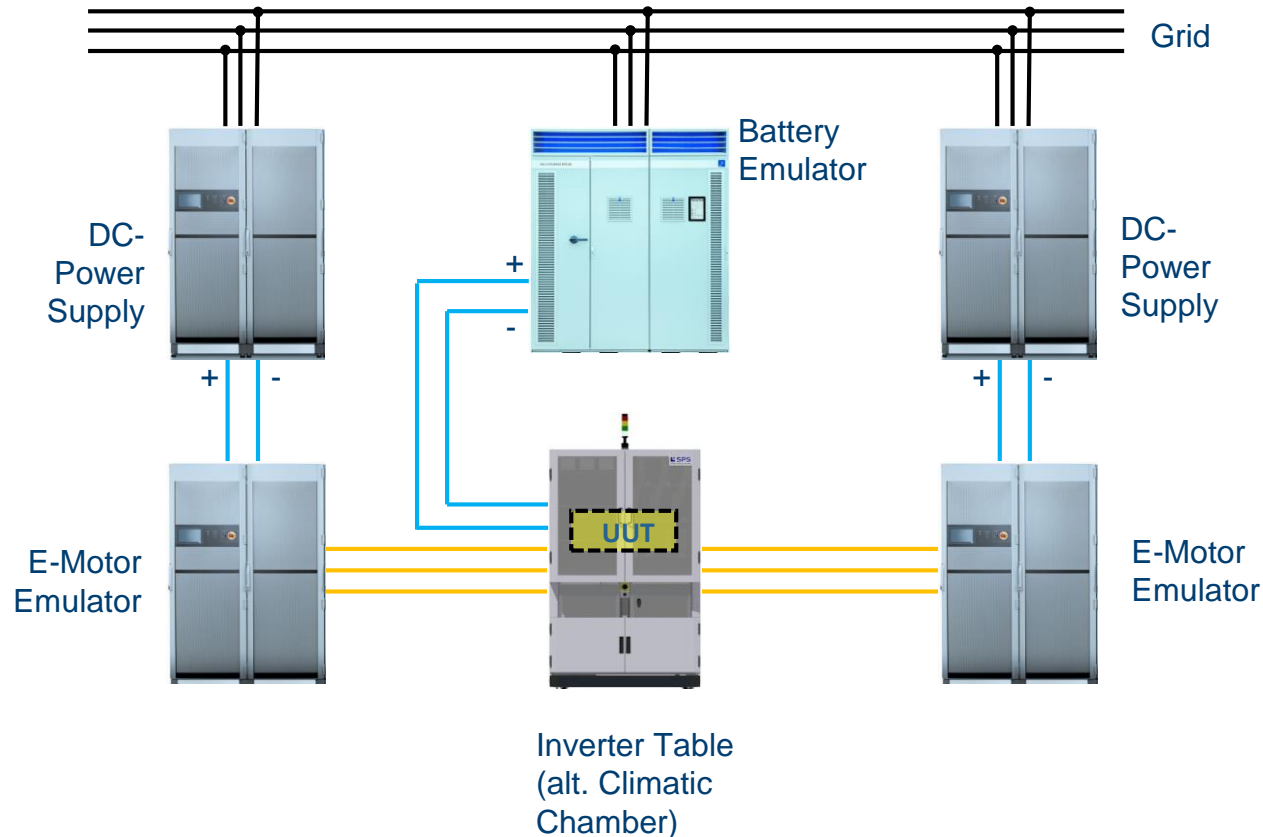
E-Motor Emulator Phase Fault Injection



A fault injection matrix simulates phase faults with high current / voltage ratings:

- **Phase break**
- **Phase-to-phase short**
- **Phase short to battery +**
- **Phase short to battery -**
- **Phase short to chassis**

Extension to Emulate 6-Phase E-Motors



Implementation of a second E-Motor Emulator provides several testbed variants:

- Test of two channel inverters
- Test of 6-phase inverters
- Doubling the phase current
- Parallel test of two 3-phase inverters (requires another battery emulator)

Other options are:

- 6-phase fault injection testing
- Emulation of Externally Excited Motors

INVERTER TESTING ...

PICK THE RIGHT TEST EQUIPMENT!

Why is the AVL inverter test system unique in the market?

The e-motor is precisely emulated according to the real physics via:

- 320ns model iteration
- 800kHz switching frequency
- Power amplifiers THD 0.09%
- Use of real motor data

Modular and scalable:

- Up to 1,000V
- Up to 2,400Arms in 400A steps
- Power from 160kW to >1MW
- Any rotor sensor on the market
- 3-phase / 6-phase motors / dual

Fault injection on power level with correct e-motor characteristics:

- Phase shorts
- Phase breaks
- Active short

All e-motor models relevant for the automotive industry are available & approved:

- PMSM 3-phase, 6-phase
- IM 3-phase, 6-phase
- EESM 3-phase, 6-phase

All required functionality available:

- Tool chain for motor-copy functionality
- Synthetic motor data
- Inverter protection
- Exciter coil emulation
- Rotor sensor fault injection
- Built-in scope
- Automation system
-

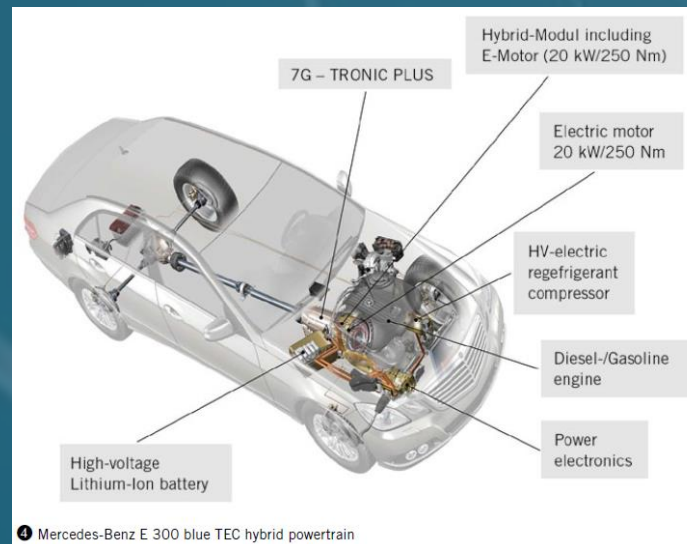
INVERTER TESTING WITH EME ...
A **GAME CHANGER** – GLOBALLY!

Daimler: Full road-to-lab for complex inverter controls testing

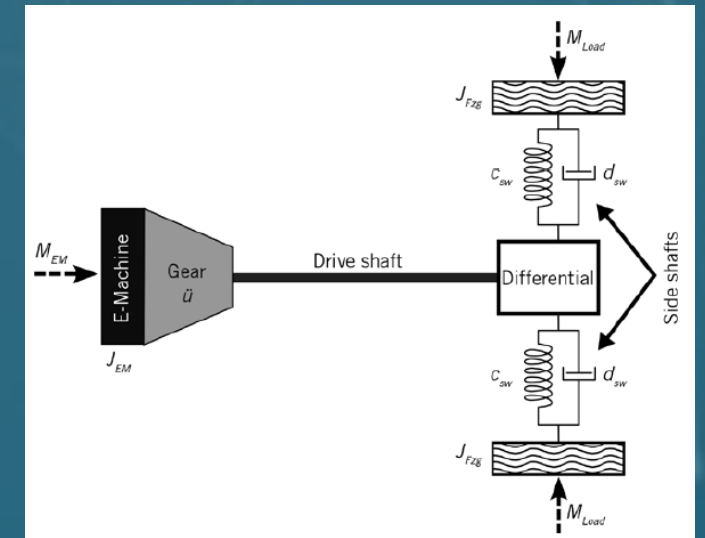


VIRTUAL E-MOTOR
AS A TOOL FOR THE DEVELOPMENT
OF POWERTRAIN CONTROLLERS

Further information: ATZElectronic 2013-031



E-motor emulator is part of the „virtual car“

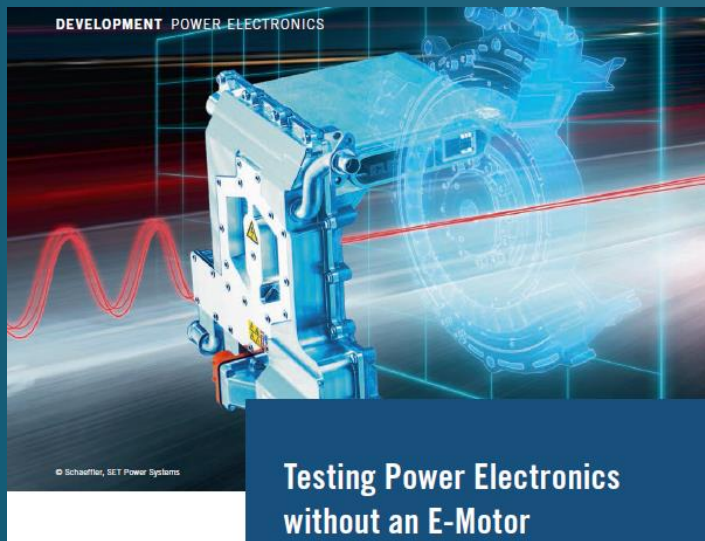


Inverter control loop test for smooth traction ... in office area @ full power!

„This approach also opens up new possibilities. Engineers working in the field of drive inverter development now have the possibility of running system tests in a laboratory environment, reproducibly and under power, thus enabling them to systematically optimise control algorithms. [...]

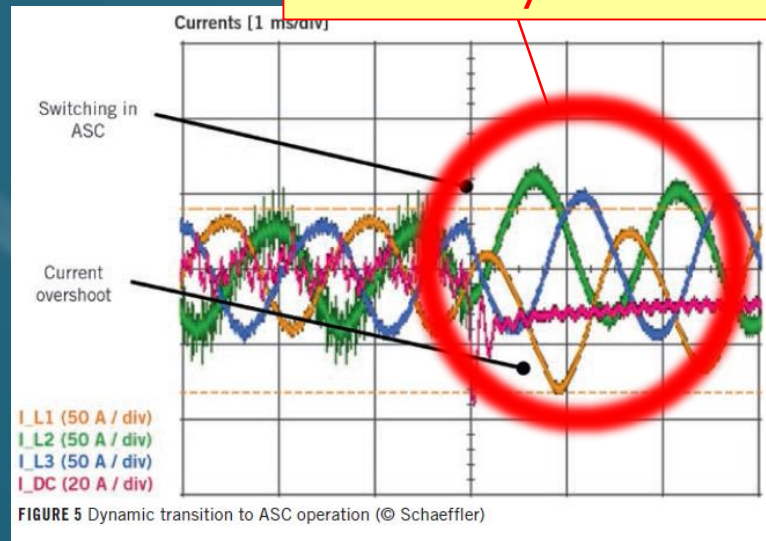
The number of **vehicle tests** required have been drastically reduced, which **reduces costs and development times**“

LuK Schaeffler: Torque Vectoring Inverter Test (ASIL-D)



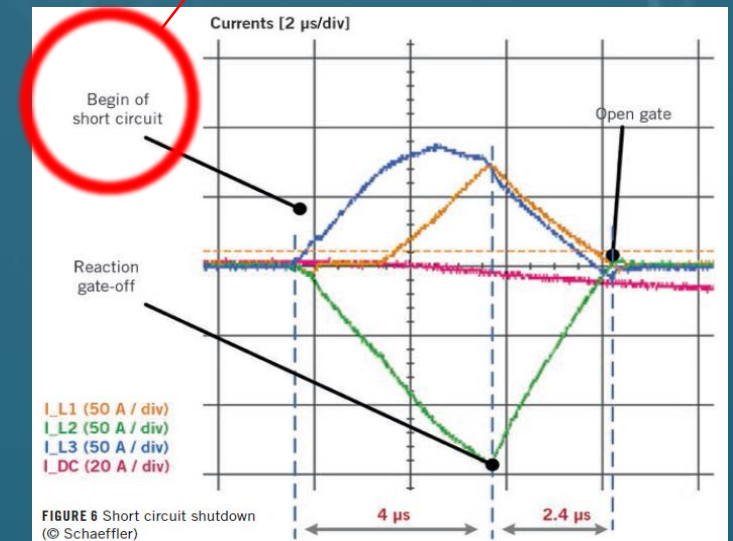
Further information: ATZelectronic 2015-06

correct dynamics...!



... active short circuit test

... phase short injection



...short circuit shutdown

„The AVL Inverter Testsystem has proven itself as an ideal test tool. **Within two weeks** we could run a testprogram which used to take **half a year!** “

How Mercedes India challenges Silicon Valley

AVL Inverter Testsystem

"We make sure that new cars drive longer and longer in the virtual world, before we need actual prototypes. That increases the flexibility in development, accelerates the processes and reduces costs on top of that." (Manu Saale, Die Welt, 27.11.2016)

"Not for nothing have we set up a testbed in the cellar, which can simulate any electric motor [AVL's Inverter Testsystem], long before it is available at all as a prototype." (Thomas Weber, Die Welt, 27.11.2016)



<https://www.welt.de/motor/article159733767/Wie-Indien-dem-Silicon-Valley-den-Rang-ablauft.html> (27.11.2016)

Global & shared testing with same data base

Virtual E-Motor shared worldwide via Email allows...

- sharing test resources
- concurrent engineering
- testing free from tolerance issues and mechanics (no real motor)
- easy test result comparison between different locations due to numerically correct results



Customer which know us...



2019

USA

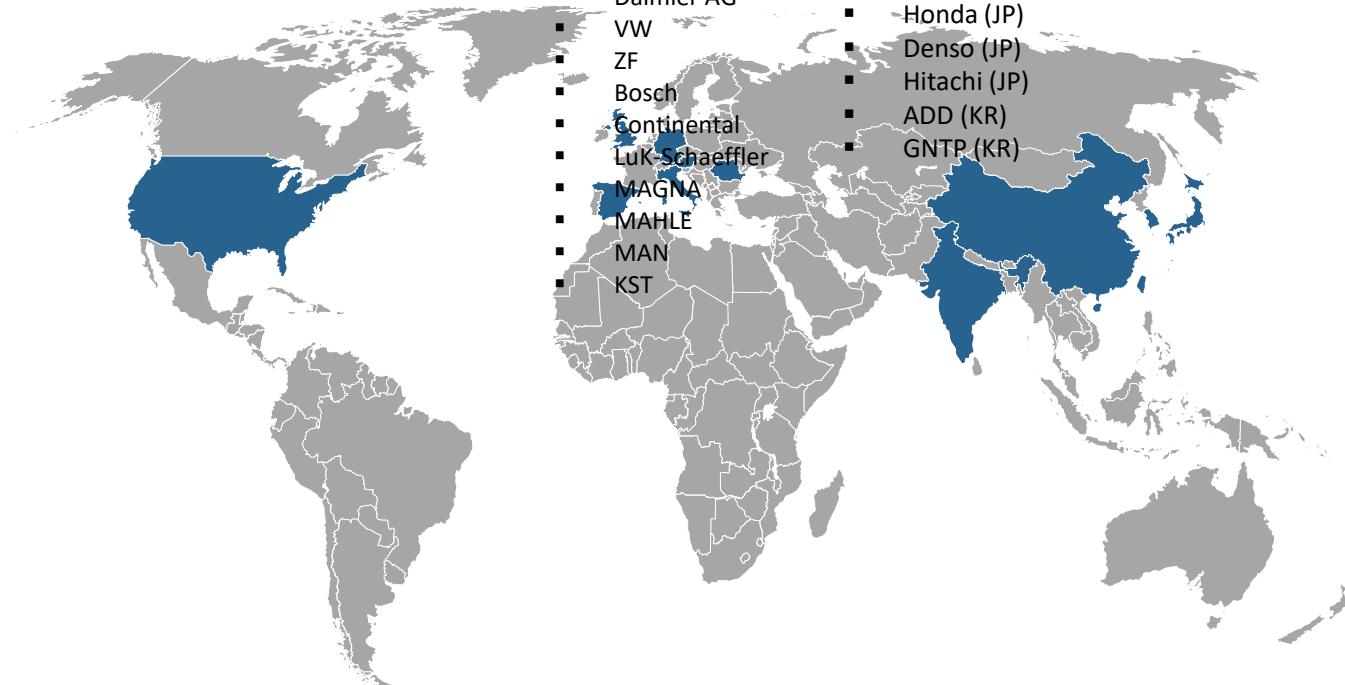
- Mercedes R&D
- Cummins
- Delphi
- Ford

Europe

- Honda
- DYNEX
- APRL
- JLR
- Dyson
- Valeo / Siemens
- BMW AG
- Daimler AG
- VW
- ZF
- Bosch
- Continental
- LuK-Schaeffler
- MAGNA
- MAHLE
- MAN
- KST

Asia

- CRRG (CN)
- FAW (CN)
- SAIC (CN)
- ITRI (TW)
- Mercedes (IN)
- Catarc (CN)
- Delphi (CN)
- Honda (JP)
- Denso (JP)
- Hitachi (JP)
- ADD (KR)
- GNTG (KR)



Thank You



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