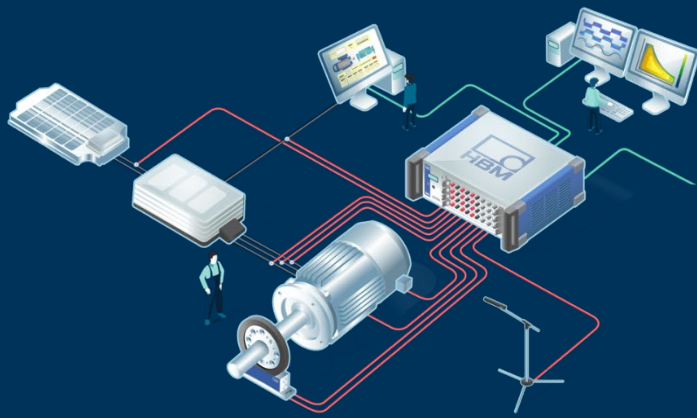




HBM Prenscia Technology Day

Virtual Seminar Series



Test and Measurement of Electric Powertrain – A Complex Electromechanical Problem

Presented by Mitch Marks
Electrification
HBK

Session #2: Electrical Power Testing & Analysis

Test and Measurement of Electric Powertrain – A Complex Electromechanical Problem

Abstract

Electrical powertrain is a complex system that has both electrical and mechanical elements. In the electric powertrain there are 5 main subsystems, batteries, inverters, motors, torque conversion, and control system. Each one of these systems has losses, dynamics, thermal limitations, and a control system. By simplifying a measurement chain to bring all these signals into one location and continuously recording the data there are many gains to the engineers. This streamlined system of testing allows for faster data collection, processing, and model correlation. This session will explore test and measurement of electric motors and inverters at a system level, including electrical power, mechanical power, temperature, NVH, and the dynamics of each of these systems. Some specific topics will include Torque ripple, NVH, efficiency, and Control system calibration.

About the presenter, Mitch Marks

Mitch has worked in electric motor developing and testing his entire career and specializes in test and measurement traction motors and drives. He has been with HBK since 2017 as a member of the electric power testing team. He has an undergraduate and a master's degree in electrical engineering from the University of Wisconsin – Madison WEMPEC program.

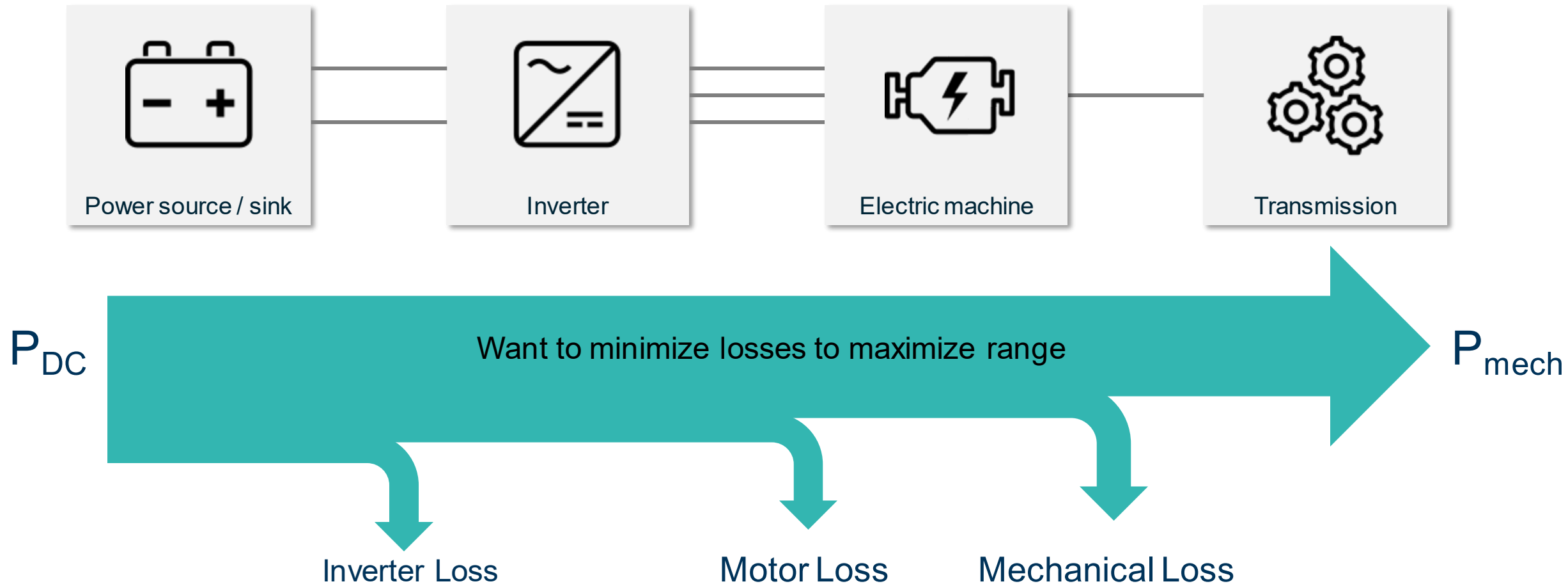
Test and Measurement of Electric Powertrain - a Complex Electromechanical Problem

Mitch Marks
Business Development Manager
Electric Power Testing

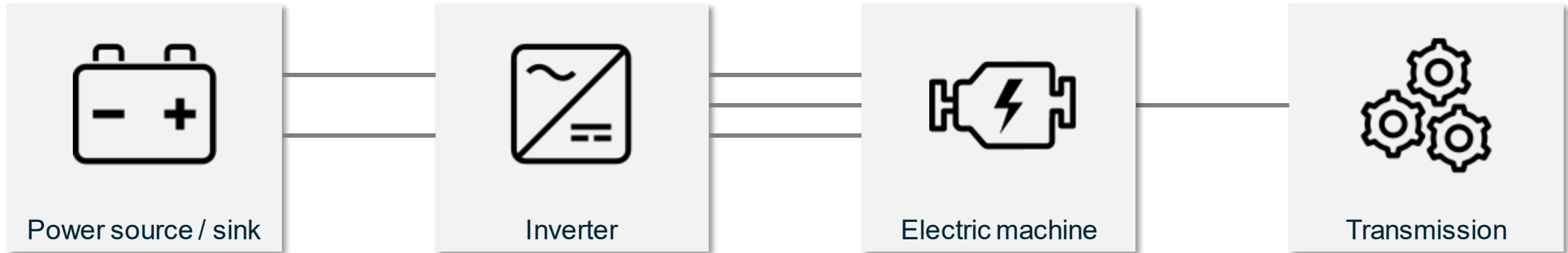
Agenda

1. Electric Powertrain
2. Electromechanical Testing Applications
3. Measurement Challenges
4. Application Example – Torque Ripple
5. Application Example - Drive Cycles Testing

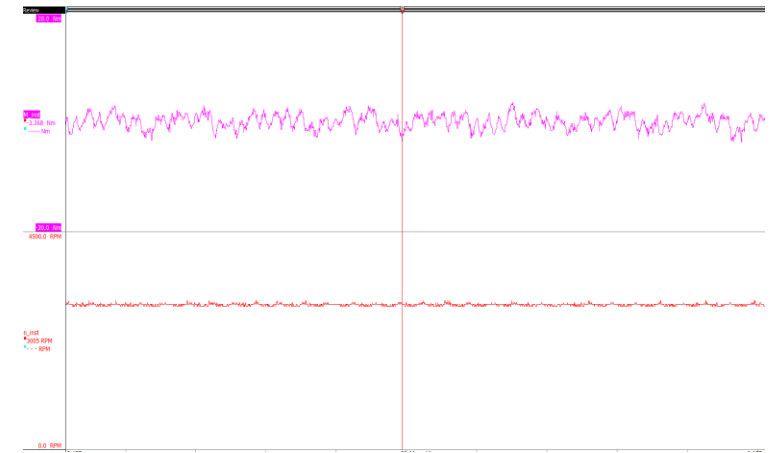
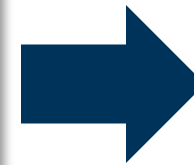
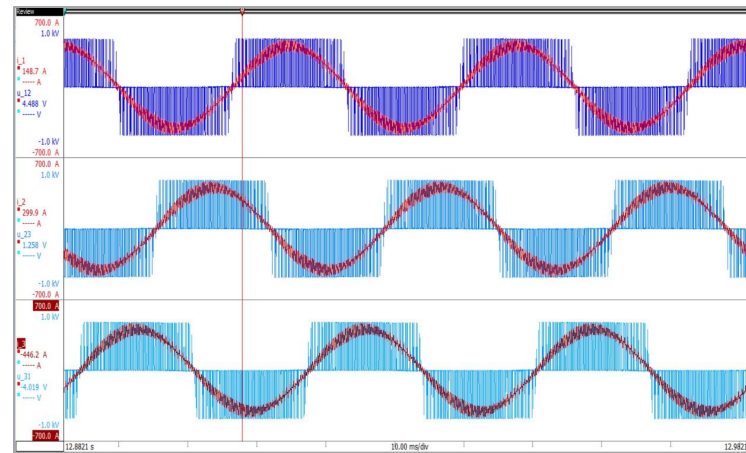
Electrical Powertrain



Other Electrical Powertrain Considerations



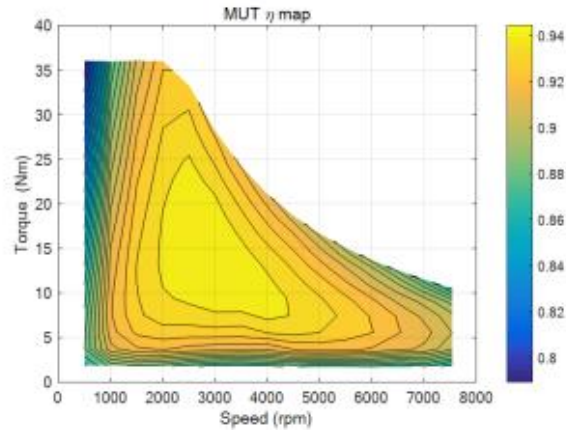
- Product Experience
- Durability
- Noise and Vibration
- Thermal
- System performance



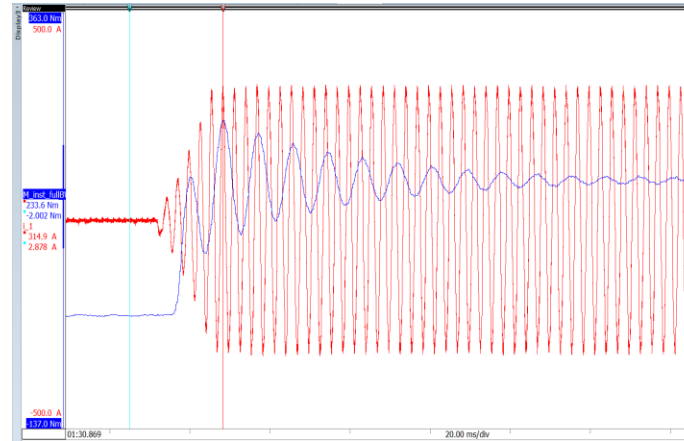
Electromechanical Testing Applications

What Tests are Being Run

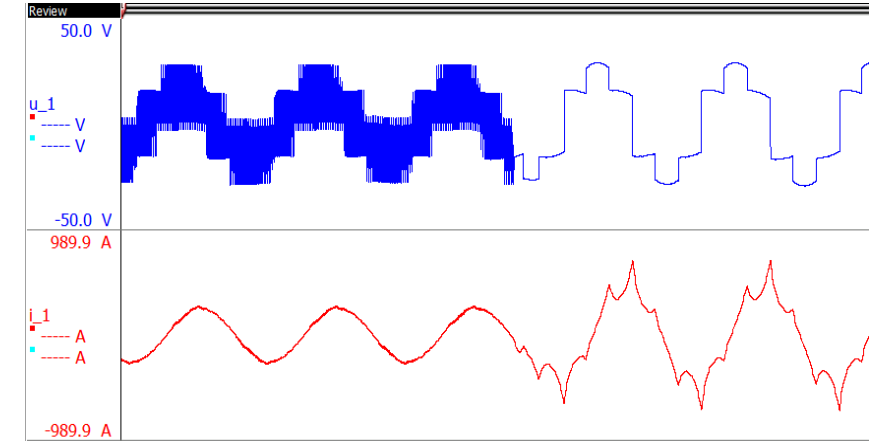
Efficiency



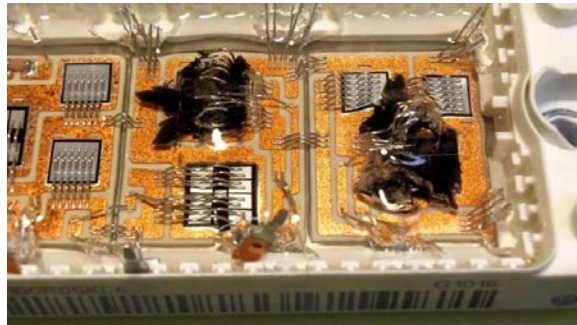
Transients



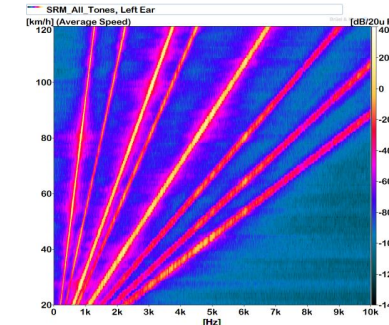
Controls



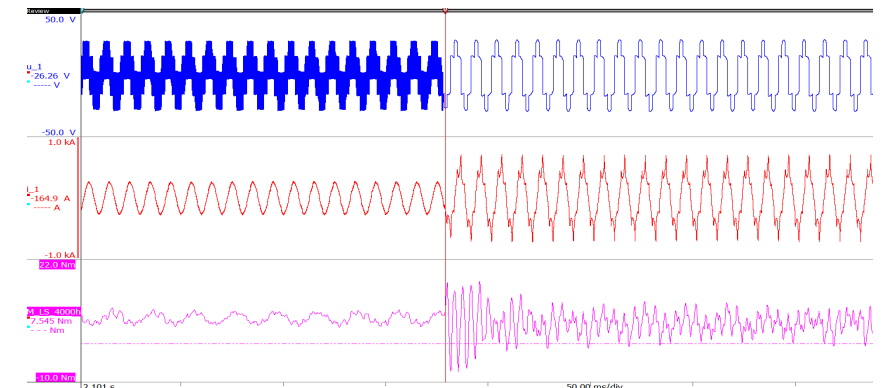
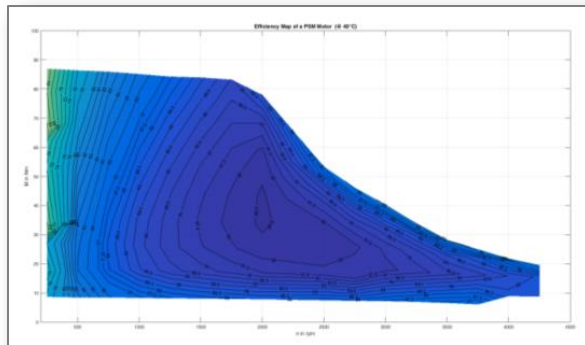
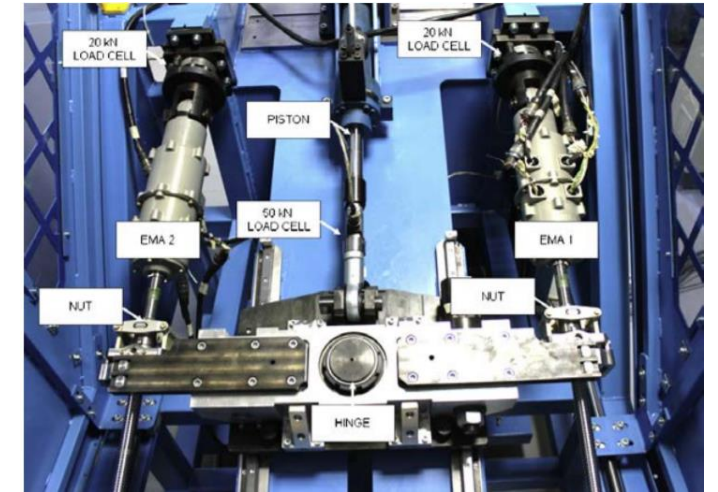
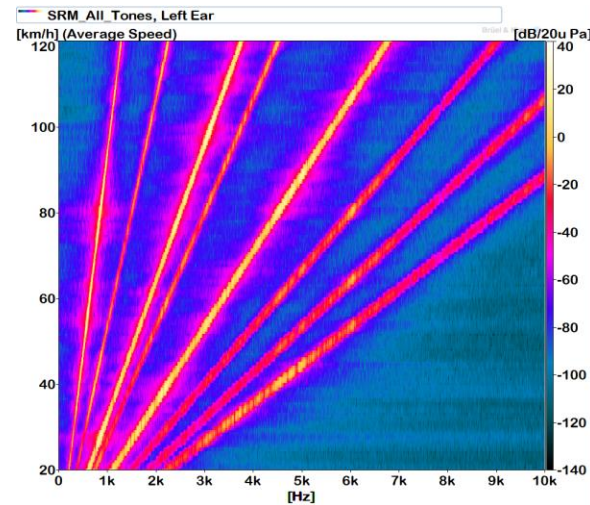
Durability & Failures



Noise & vibration

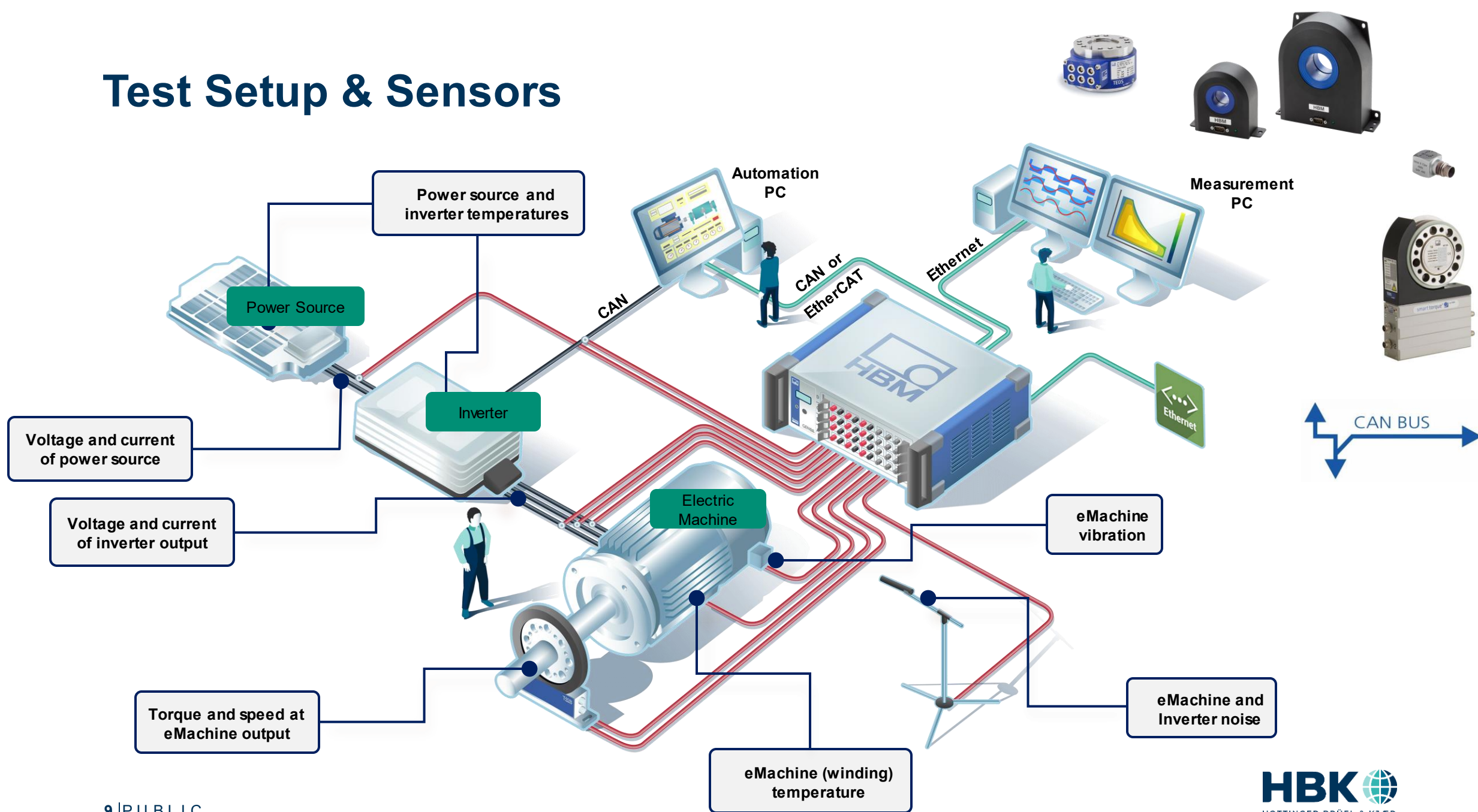


Test Applications



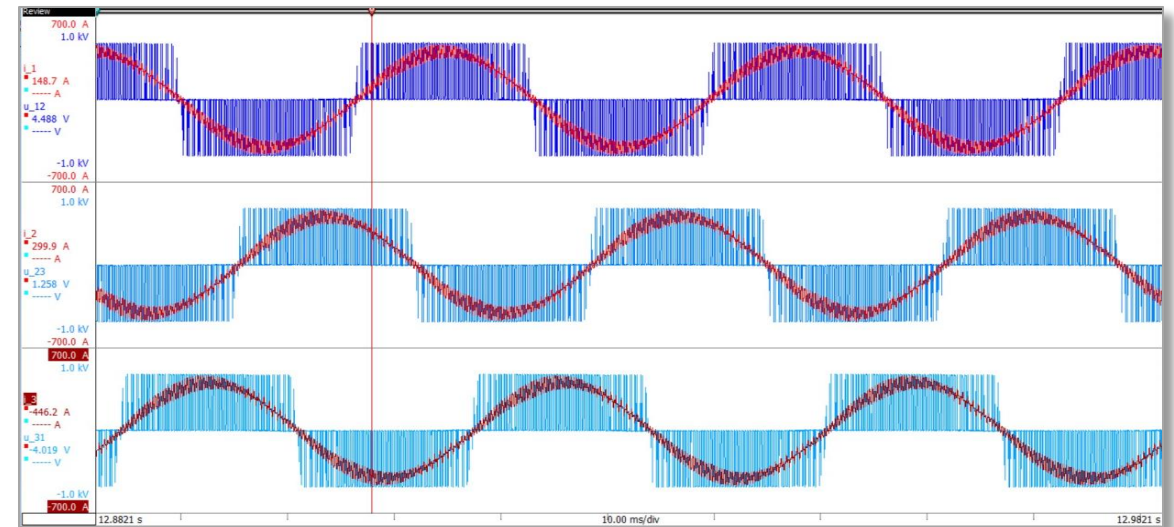
Measurement Challenges

Test Setup & Sensors



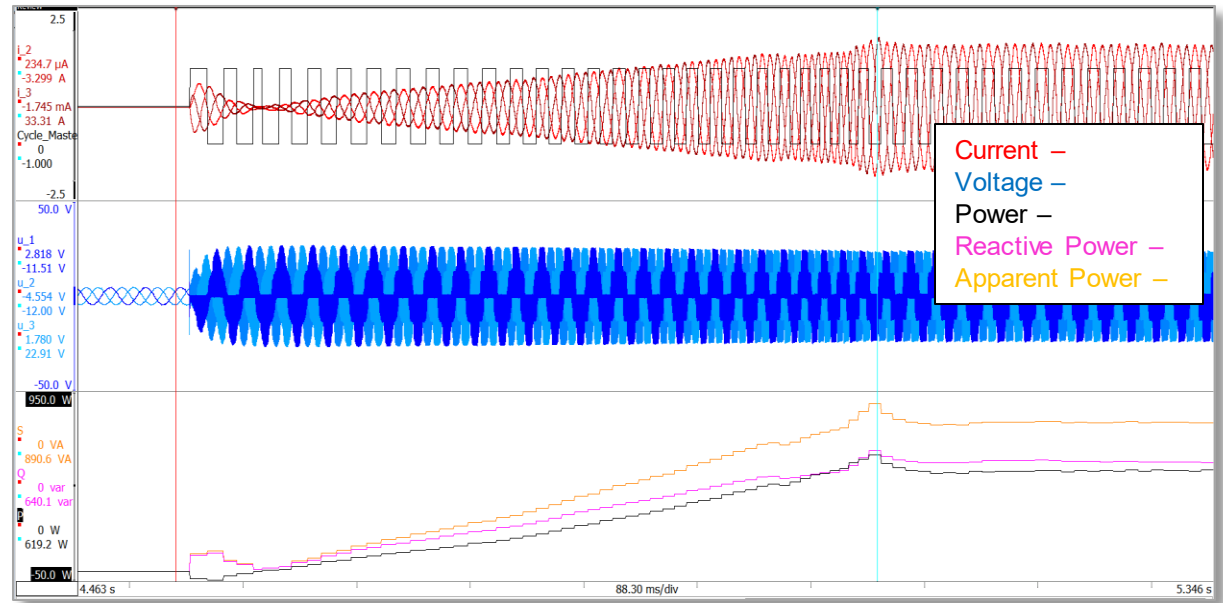
Measurement Challenges

- Diverse set of signals
 - Electrical and mechanical
- Dynamic signals
 - Transient conditions by nature (inverter)
 - Dynamics of vehicle
- High frequencies
- Accuracy
- Data correlation
- Data volume



Dynamic Testing with Cycle Detect

- Transient power measurements allows to dynamically measure efficiency
- Cycle detect allows measurement of signals as frequency is changing
- Dynamic testing allows to characterize real world scenarios
- Measure power accurately during frequency changes

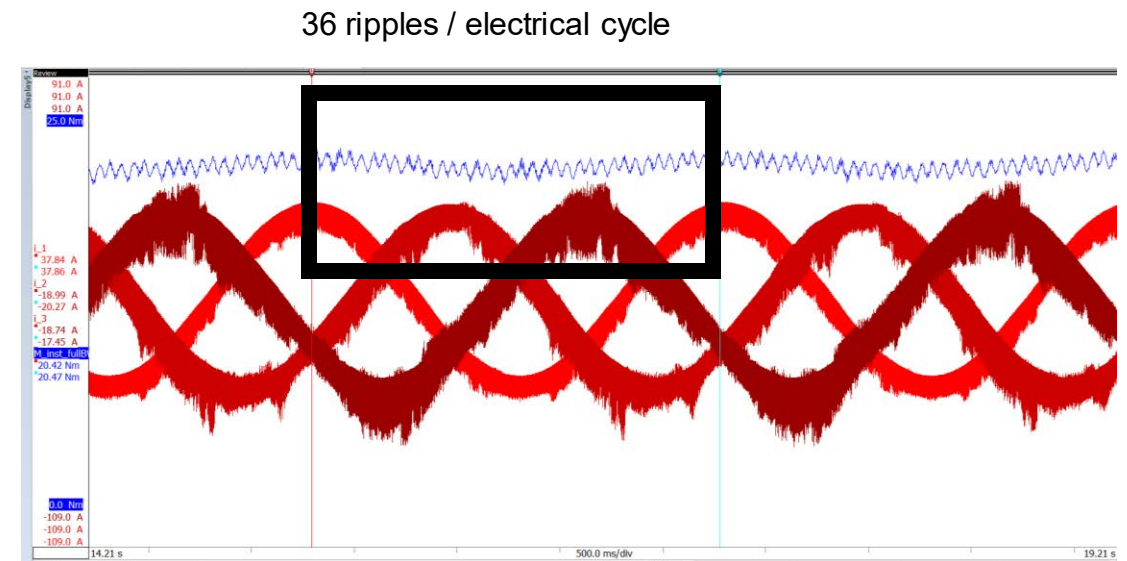


Vehicle acceleration from 0 to full speed showing a ramp from 0 to full power.

Application Example – Torque Ripple

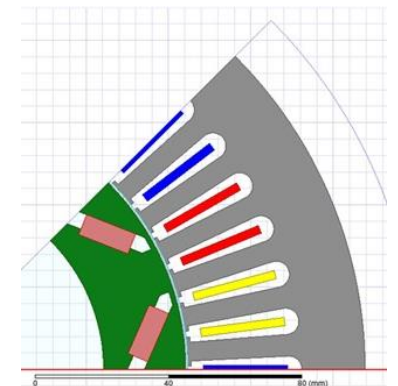
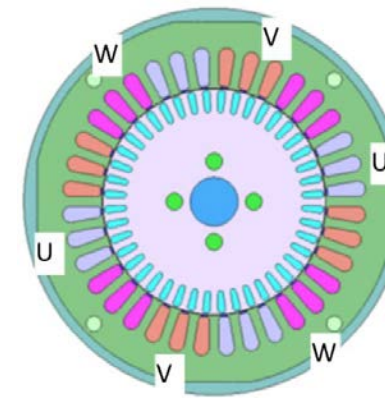
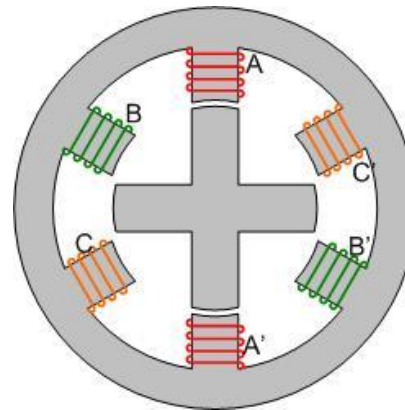
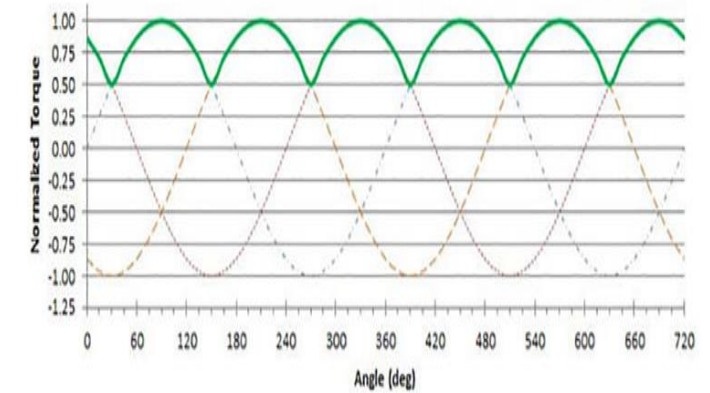
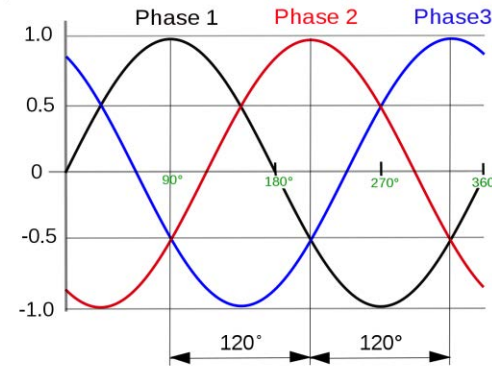
Torque Ripple is a Periodic Disturbance in Torque

- Torque is not a static
- Torque ripple has a frequency and amplitude
- Ripple is proportional to frequency
- Torque ripple has several potential sources
- Many test stands show heavily filtered torque



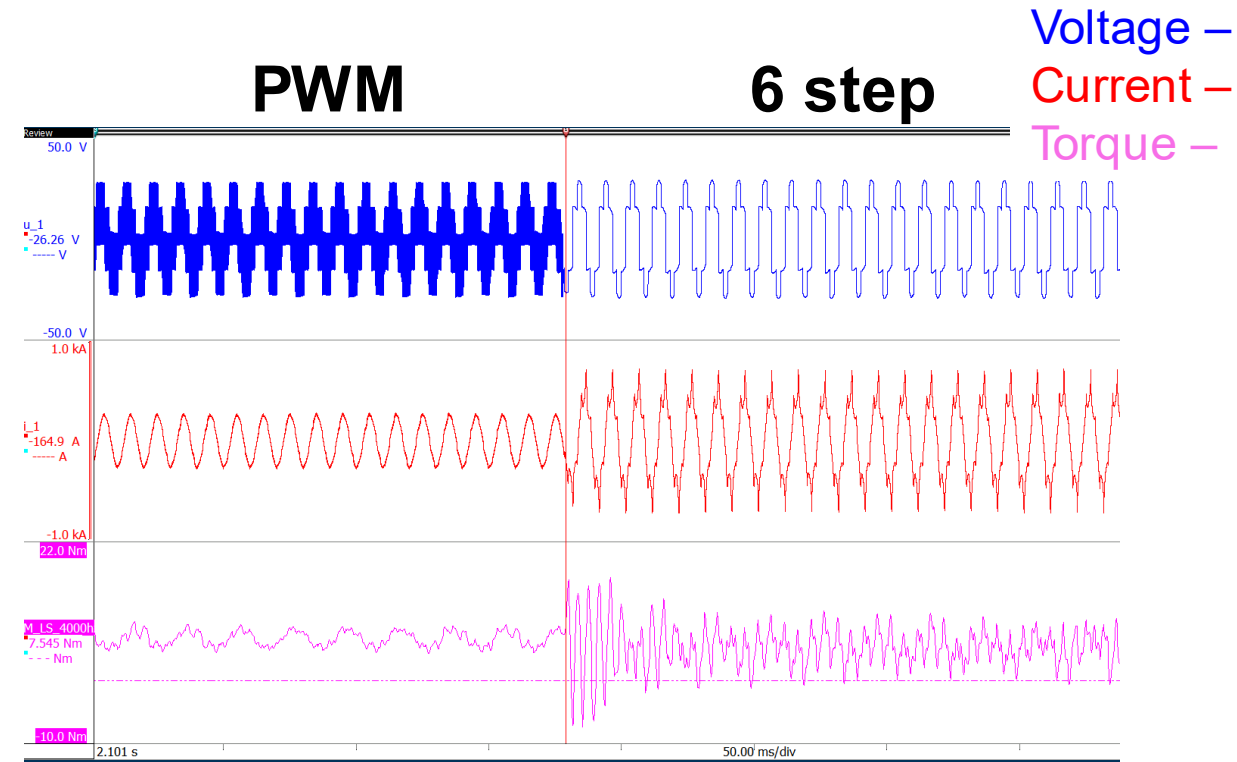
Torque Ripple Sources

- Electrical excitation
 - 3, 6, n phase excitation
 - Inverter switching
 - Harmonics
- Machine construction
 - Magnets
 - Slots
- Mechanical resonances
- Machine alignment
- Loading



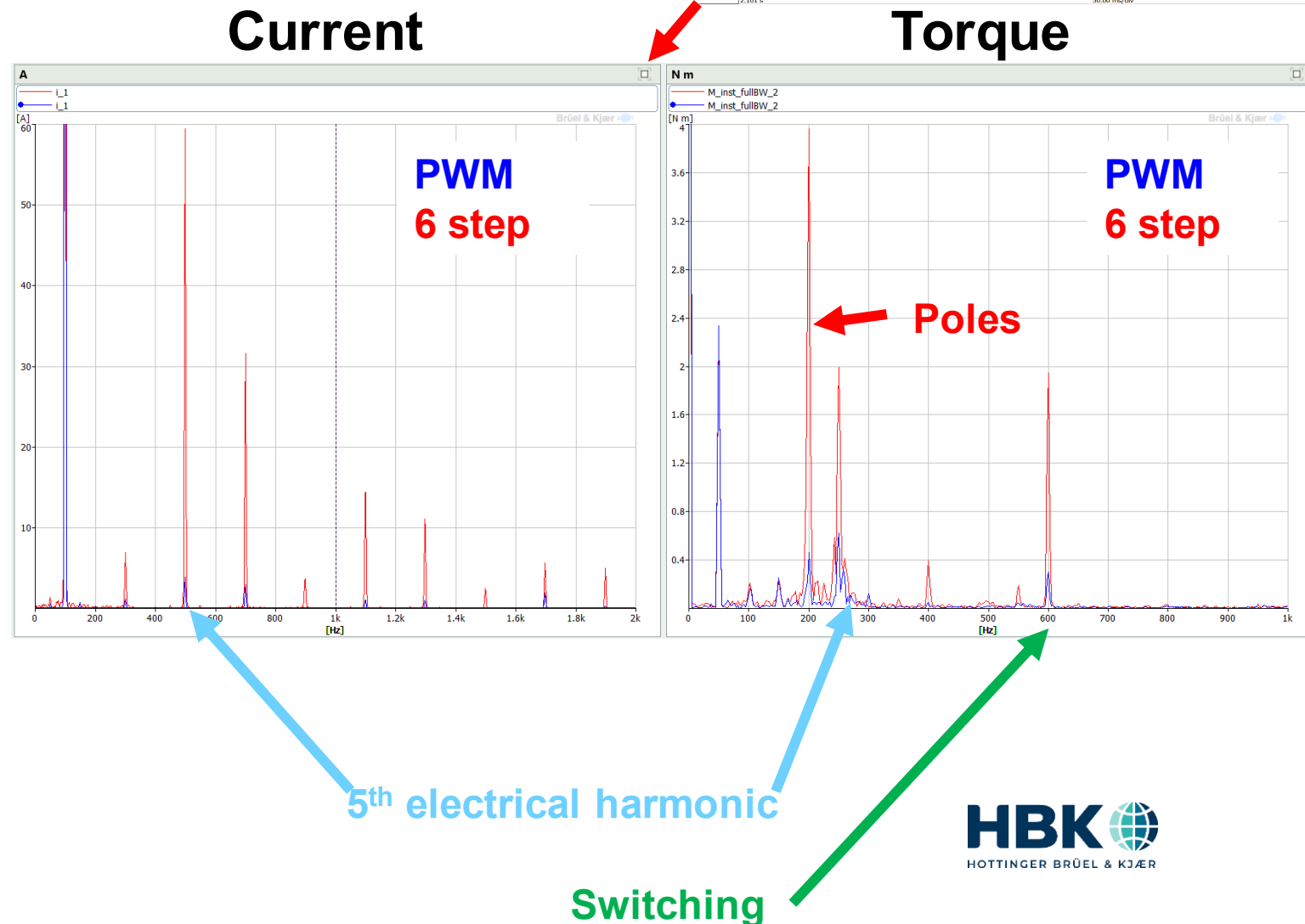
Inverter Voltage Influence on Mechanical Torque

- Torque has frequency component
- Inverter control type effects torque
 - PWM excitation on the left
 - 6 step excitation on the right
- These effects will result in NV at the machine and down stream

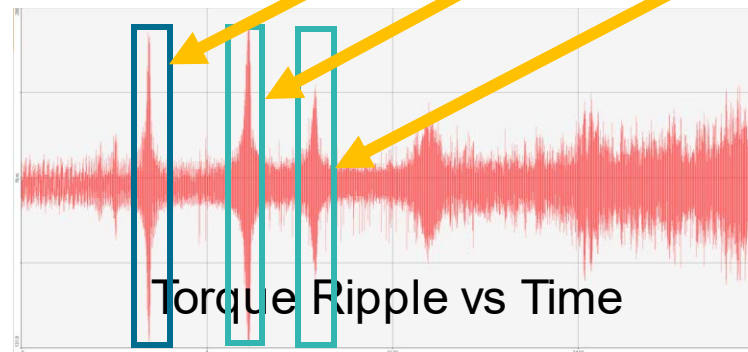
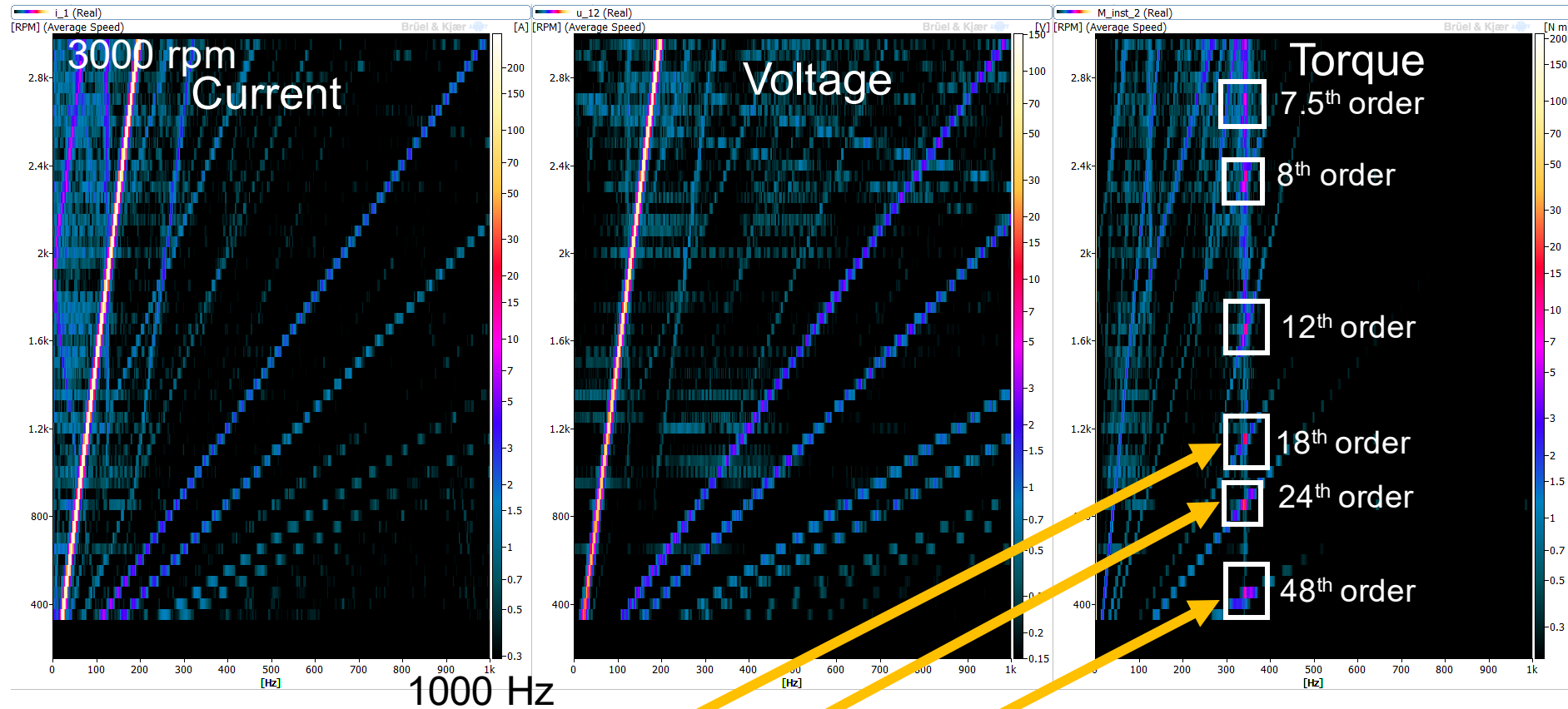


Voltage, Current, and Torque Frequency

- Electrical and mechanical fundamentals are related by pole count
- One control technique has significantly more harmonic content than the other
 - Electrical harmonics effect torque harmonics
- Frequency analysis of torque ripple can be used for correlation



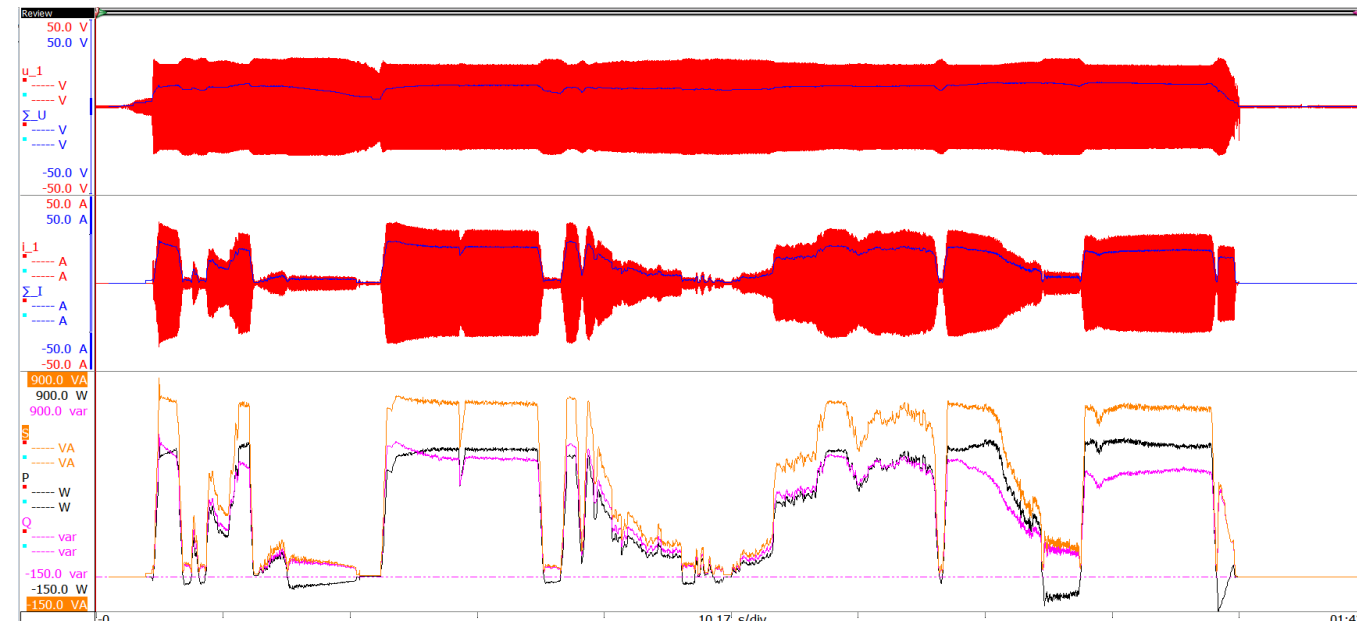
Torque Ripple Colormaps



Application Example - Drive Cycles Testing

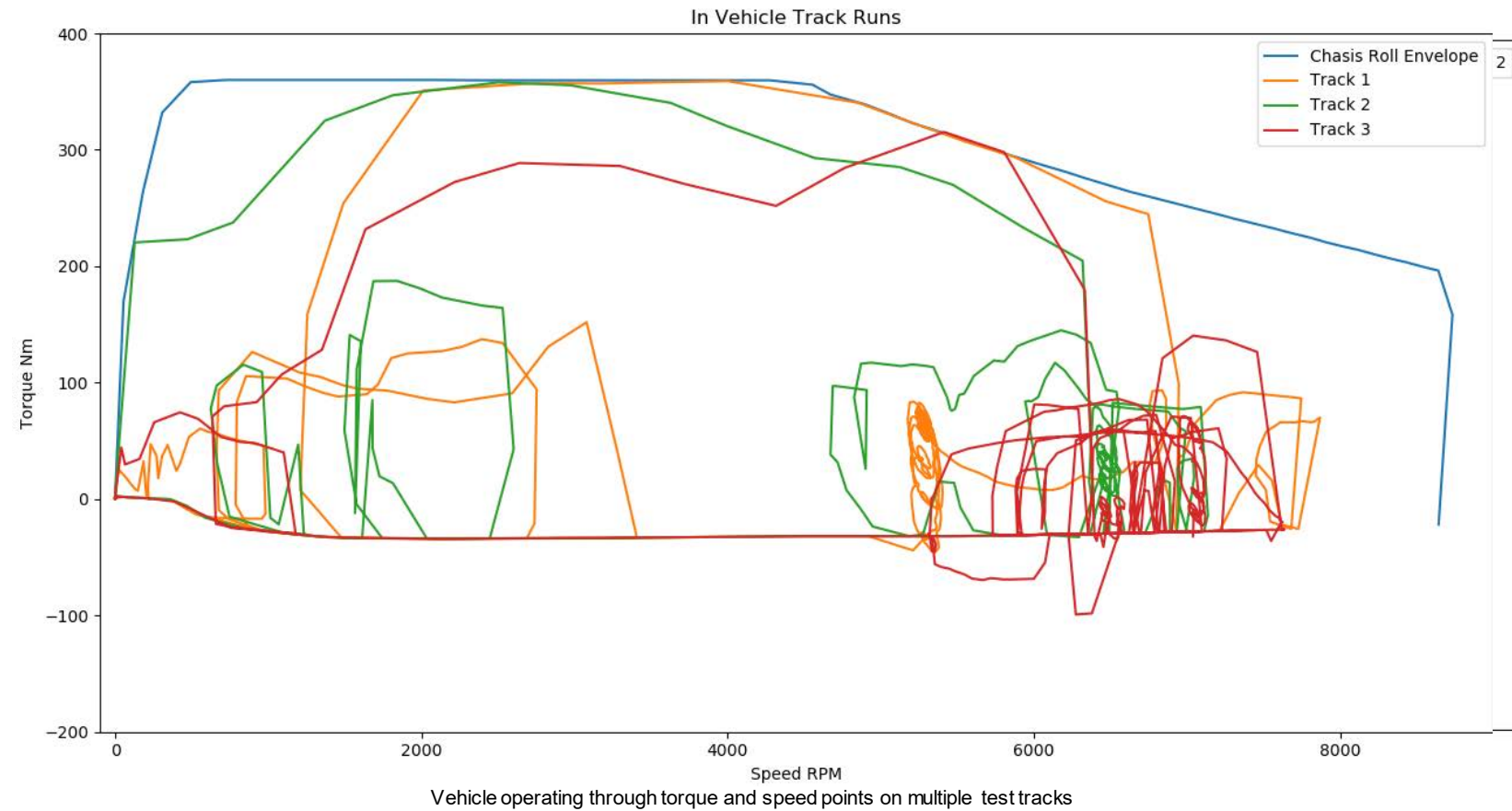
Range Determination Testing

- Vehicle range numbers require certification at a vehicle level
- Testing is done DC → Wheels for certification
- Testing is done DC → AC → Torque → Wheels for R&D to maximize range
- All require extreme accuracy and integration
- Also done in vehicle

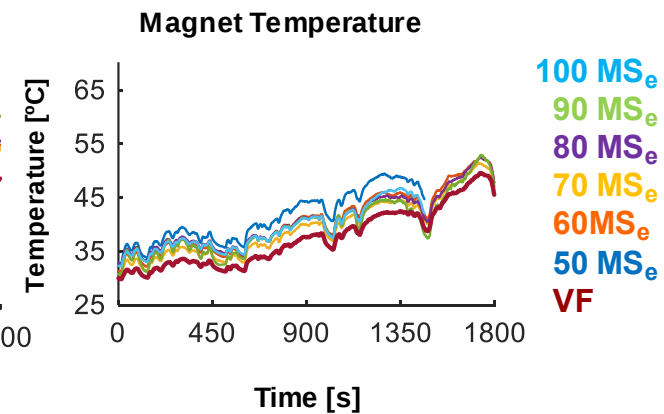
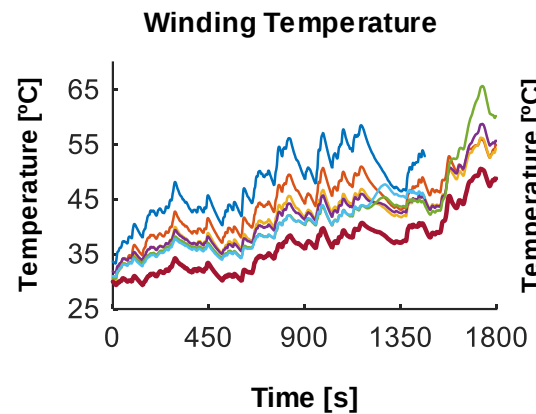
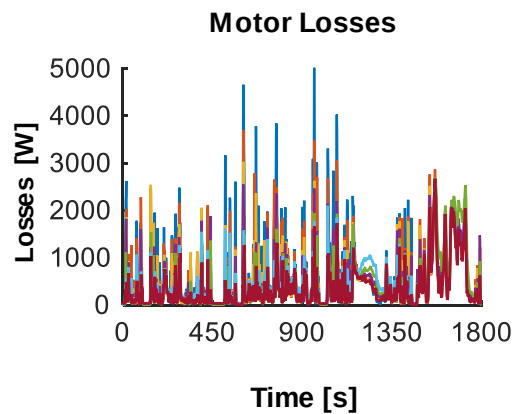
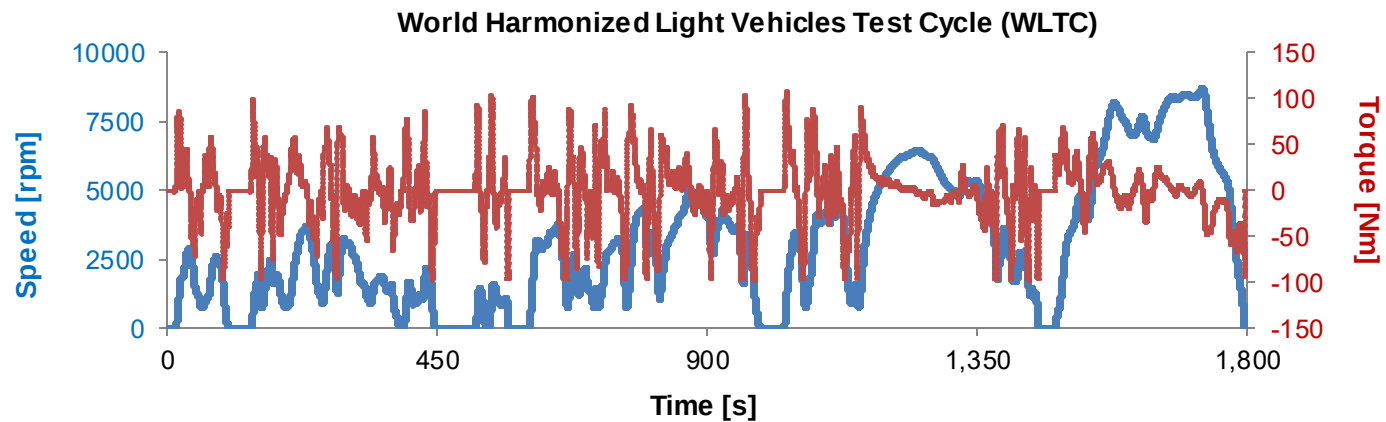


In Vehicle Testing

- Road data can be used to determine the operation range
- Data taken from CAN bus & measurements
- Determine where main operation points are
- Validate real world operation



Drive Cycle Testing

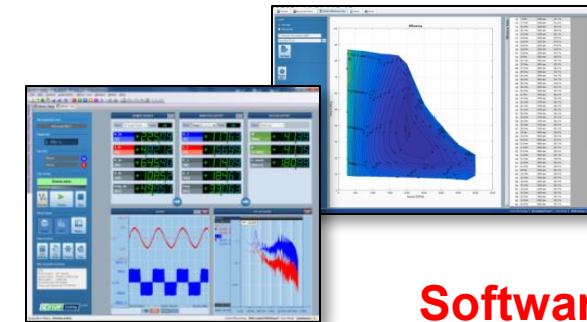


Measurement Solutions

eDrive Value

- Simple data collection of electro-mechanical signals
- Fast and accurate efficiency measurements
- Future proof testing capabilities
- Auditable testing
 - Stored data
 - Public equations
- Feedback to control systems

Acquisition



Software



Sensors

Conclusions

- Electric Powertrain is a difficult measurement task
 - Electromechanical
 - High frequency
 - Minimal steady state conditions
- Measurement of these signals is not simple
 - Correlation
 - Data volume
 - Data diversity
- Electromechanical & dynamic testing is possible with the appropriate equipment
- HBK can be a strong partner for a variety of tests

Links to Other Applications

- HBK Electric Power Testing Knowledge Base
 - <https://www.hbm.com/en/7381/electric-power-knowledge-base/>
- HBK Electric Power Testing Lunch and Learn Series
 - <https://www.hbm.com/en/9033/lunch-and-learn-electric-power-testing/>
- Other Webinars
 - Torque ripple
 - NVH in electric machines
 - Sensors for Electric Power
 - Back EMF measurements
 - Electric aircraft
 - Dynamic & In vehicle testing
 - And more!

Knowledge Base



Lunch & Learn



eDrive Product



Thank You



Mitch Marks

Business Development at HBK -
Hottinger, Brüel & Kjær



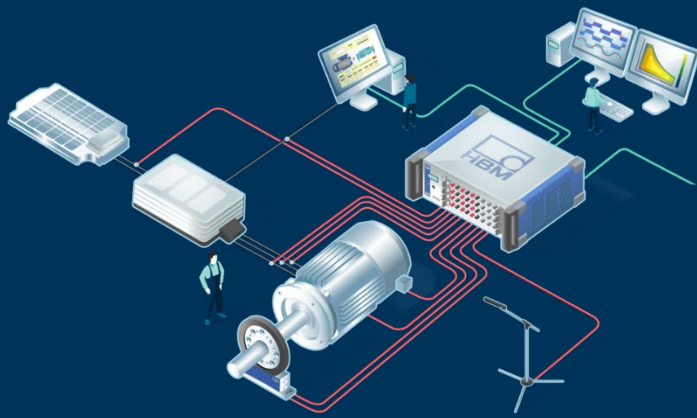
▲ Anonymous

- Does inverter control type effect torque ripple and noise and vibration?
 - *Control type dictates at what position and frequency, energy is transferred to the rotor by the inverter. These interactions will often cause additional harmonics, which can be reflected in torque. Two common examples of controls that effect torque are six step control and PMSM field weakening.*
 - *Manufacturers are increasingly using special inverter control algorithms to improve NVH. One of the advantages of using an HBK solution, is that it allows direct measurement of the high voltage signal to the motor synchronously with the noise and vibration signals, which provides you with a powerful troubleshooting and benchmarking tool.*
- Industry standards for range only call for DC power and range traveled for certification. What is the value of measuring the 3 phases for drive cycle tests?
 - *By accurately measuring the AC power from the inverter, engineers are able to identify at which parts of the drive cycle their losses are the worst. While some scenarios like acceleration may demand high losses, there are other that could be improved to optimize overall range.*
 - *Performing in vehicle measurements on the AC signals can also lead engineers to a better understanding of user interface issues. Recording the inverter and controller while there is an interface issue can accelerate troubleshooting times. The measurement of real world AC signals will help control and calibration engineers troubleshoot and develop their vehicles more quickly.*



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