The HBM eDrive solution:
The next generation power analyser / DAQ for electric and hybrid test rigs

eDrive testing – presentation topics

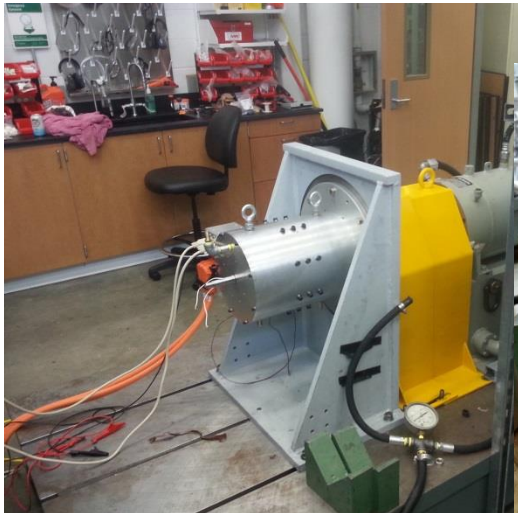
- Current motor testing limitations
- State of the art technical requirements
- Testing of an electromechanical system involving pressure, displacement, flow and temperature
- Acutator Testing
- Dynamic efficiency testing
- Dynamic control analysis
- Large system testing with many motors and converters
- Failure and fault analysis for motors
- Real time test system feedback
- Summary & Questions

Introduction

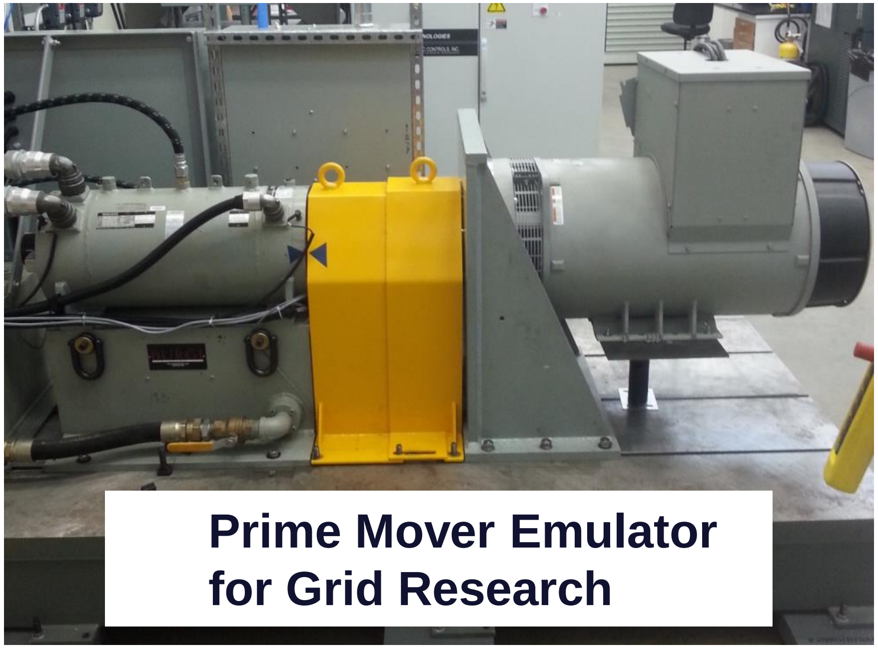
Mitch Marks

- BSEE, MSEE – Electrical Engineering
  University of Wisconsin – Madison WEMPEC
- Managed Power Lab
  - Traction motors
  - MicroGrids
  - Batteries
  - EV
- Previous positions in motor manufacturing, controls, and testing
- Current Motor Testing Specialist at HBM

Major Motor Projects



Wound Field Traction Machine



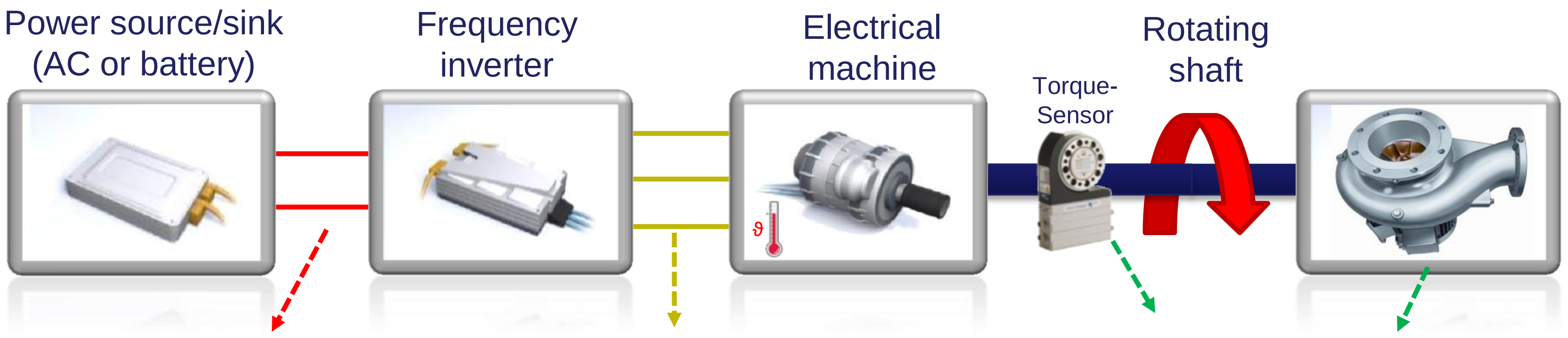
Prime Mover Emulator for Grid Research

Variable Magnetization State PM

Electric Truck

Limitations of Current Test Systems

DAQ requirements on electric drive train



Power source output

* Voltages

* Currents

* Temperatures

*** Electric power P_in**

Inverter output

* n-phase Voltages, modulated

* Currents

* Temperatures & CAN

*** Electric power P & PF**

Electric machine output

* Torque, Speed, and position

* Displacement & Acceleration

* Temperatures & Vibration

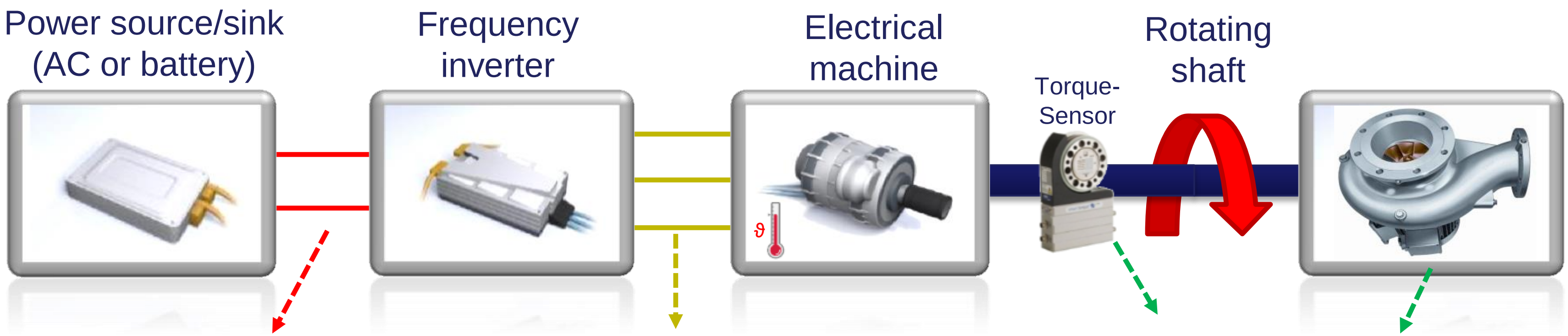
*** Mechanical power P_mech**

Inverter Efficiency

Motor Efficiency

Electric Drive Efficiency

Testing electric drives – the typical method



Battery voltage and current

Various slow speed measurement types,
i.e. just using DMM´s

Frequency inverter output

Power analyzer and scope

Electrical machine output

Torque transducer and DAQ system
for torque, angle and speed

Problems:

1. Limited understanding of the application -- Not designed for motor testing
2. No raw data available for verification or analysis – Disconnect of high and low sampling rates

1. Difficult time synchronization between different systems
2. Data storage (limited) in different systems & different formats
3. Power meters deliver few calculations only and are not reliable in dynamic load change situations
4. Limited or difficult system integration possibilities
5. Difficult for future expansion

User comment:

“Sometimes we measure efficiency larger than 1. We can´t believe that, but we can´t analyze further as we have no raw data.”

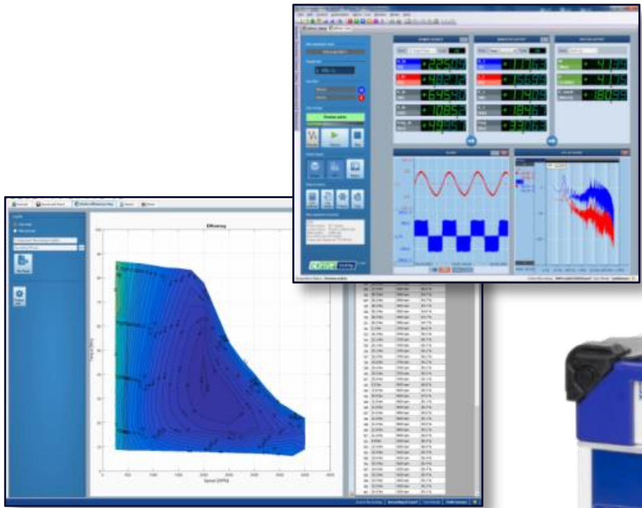
State of the Art Requirements

New Electric Motor Requriements

- Accurate power measurement in dynamic load changes
- Testing of machines with > 3 phases or multiple machines
- Noisy DC bus
- Torque Ripple
- Testing of complex systems like hybrids or actuators
- Acquisition of all signals with only one system
- Shortest possible test cycles per set point (~ms)

Introduction

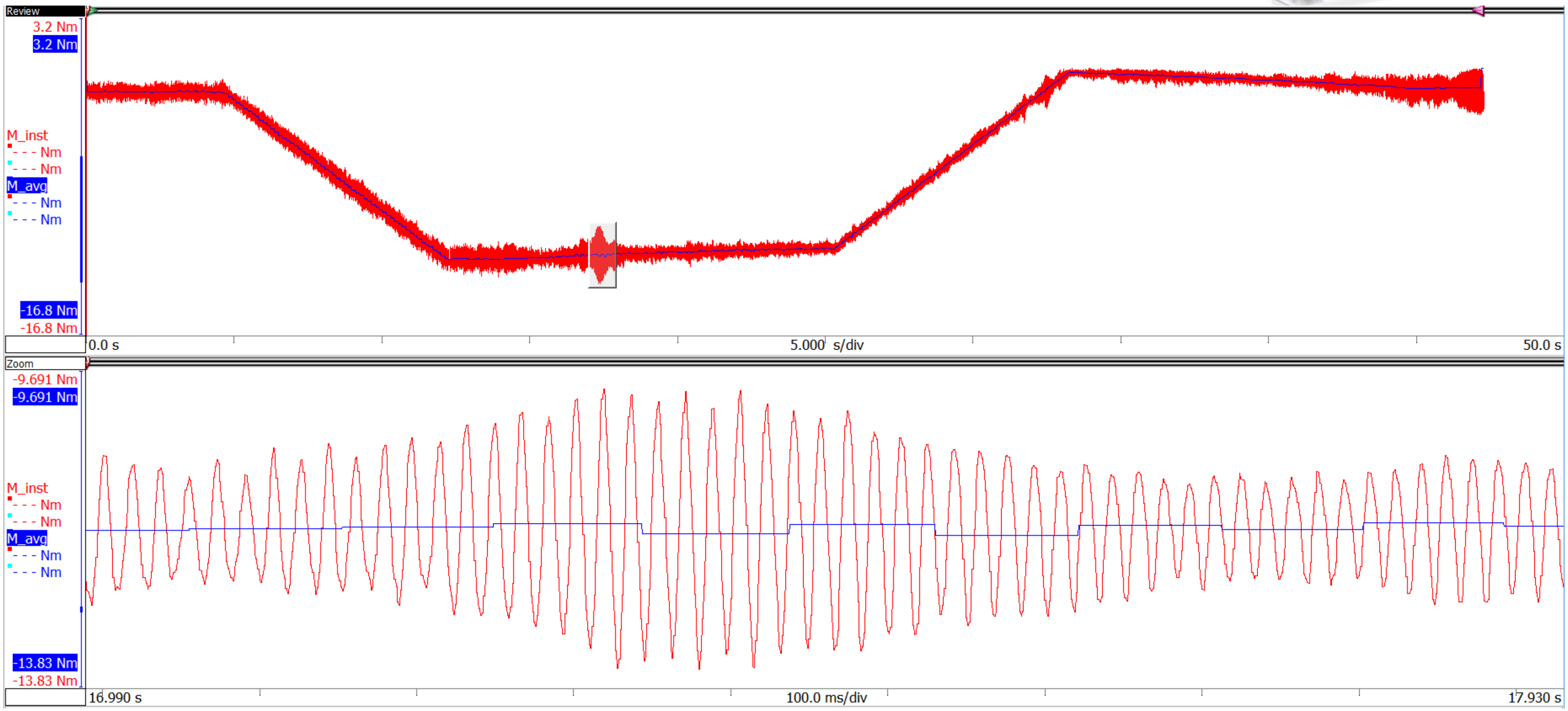
Designed for motor testing and analysis. eDrive has made the topics covered in this presentation possible.



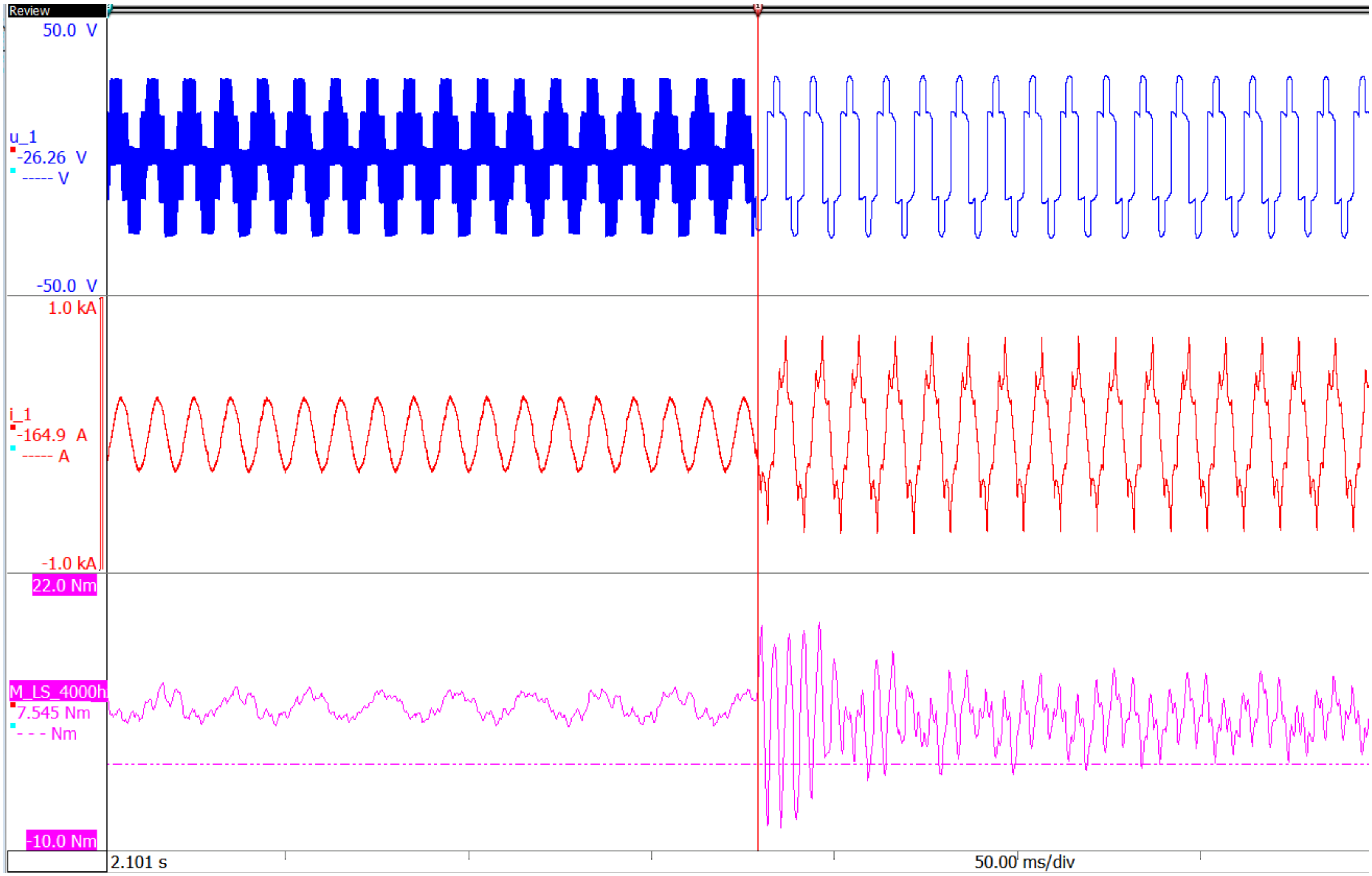
Testing of an Electromechanical System

Torque Ripple

- Instantaneous and averaged torque
- High sampling rate acquires full bandwidth of a torque cell
- Identify and analyze ripple

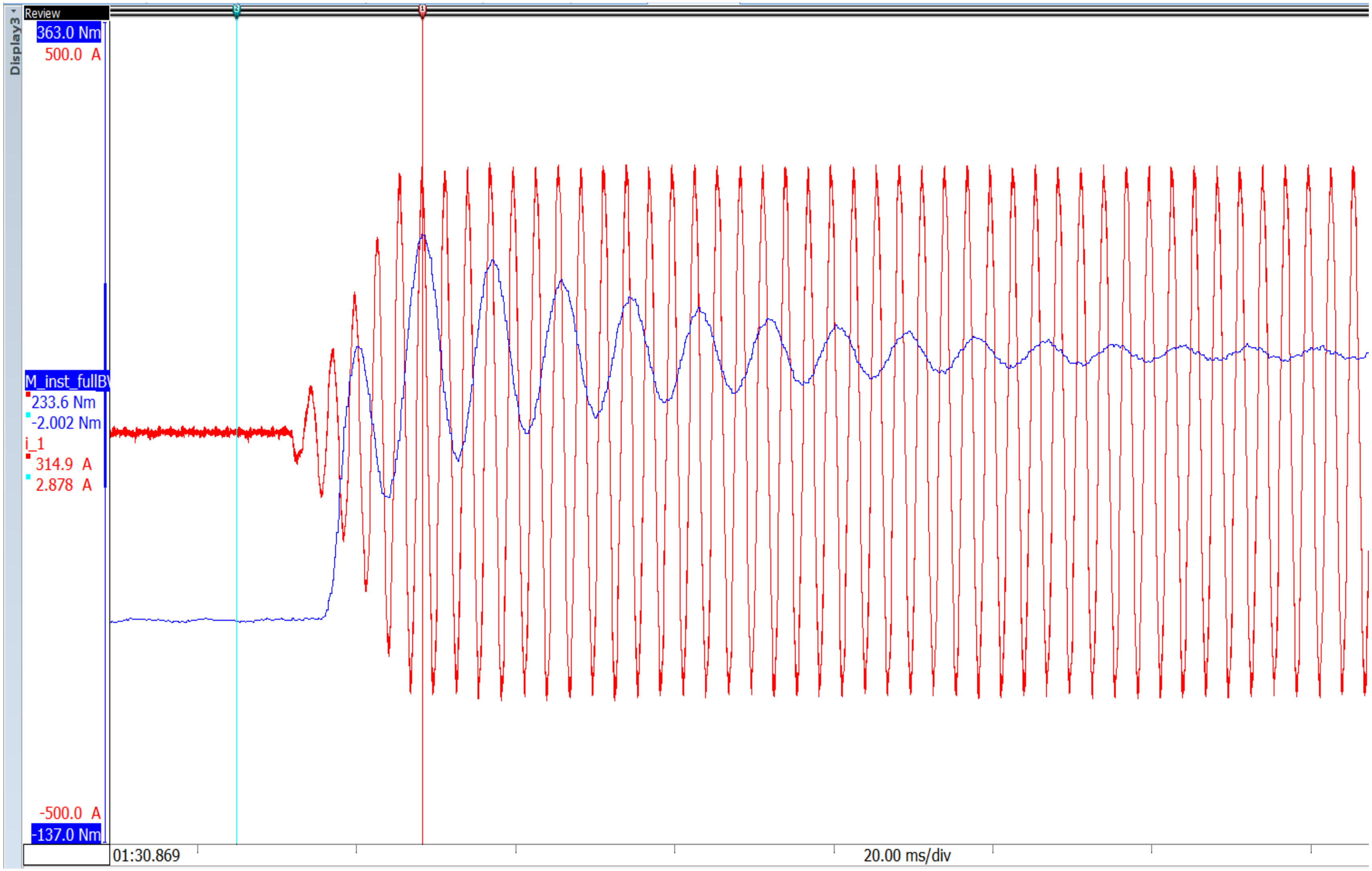


Torque Ripple from PM Motors → control change



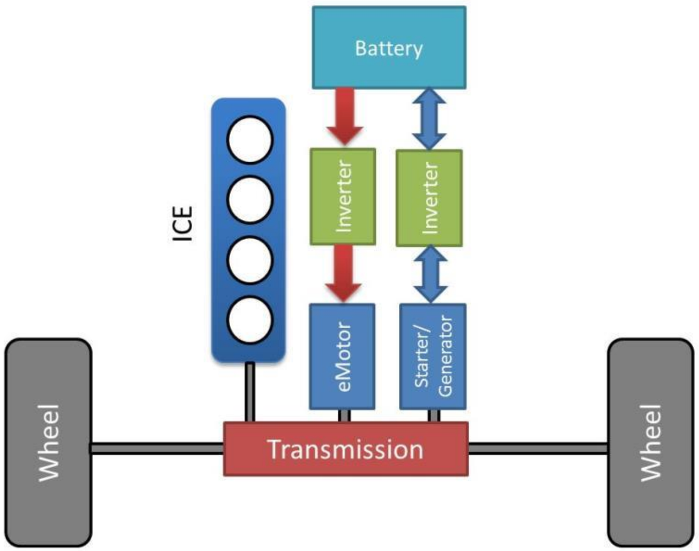
Dynamic Torque Measurement

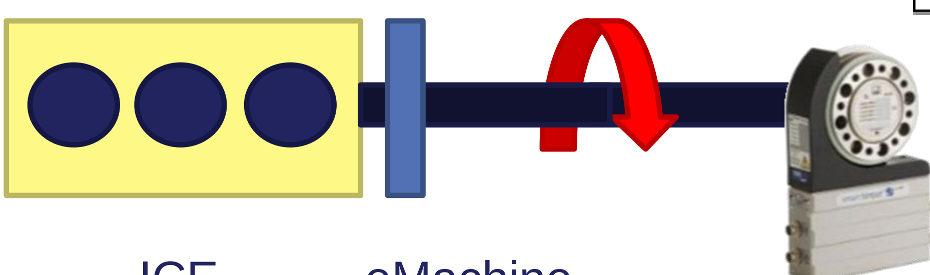
- 10000 RPM Test with 100kW Load Step



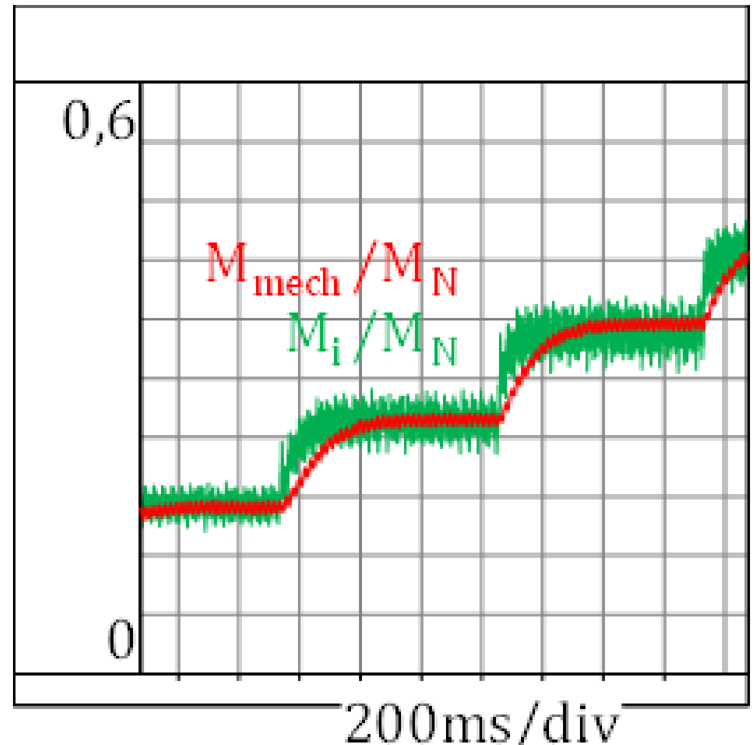
eDrive: Airgap torque estimation

- From the currents and with some formulas, you can compute the torque in the airgap of the machine.
- Thus you can estimate (1-3% accurate) the torque generated without measuring it





ICE eMachine

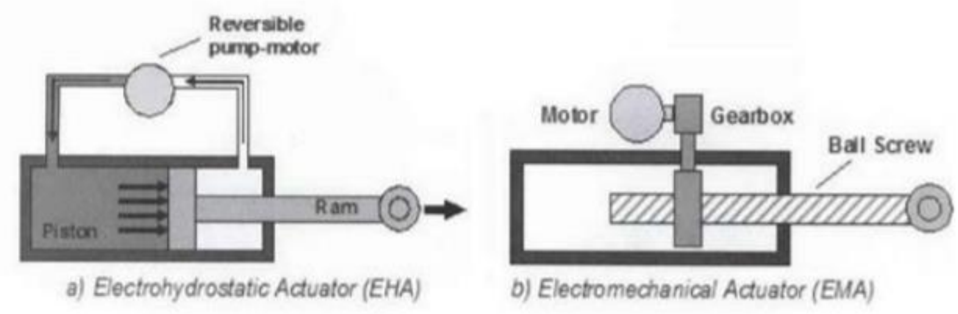


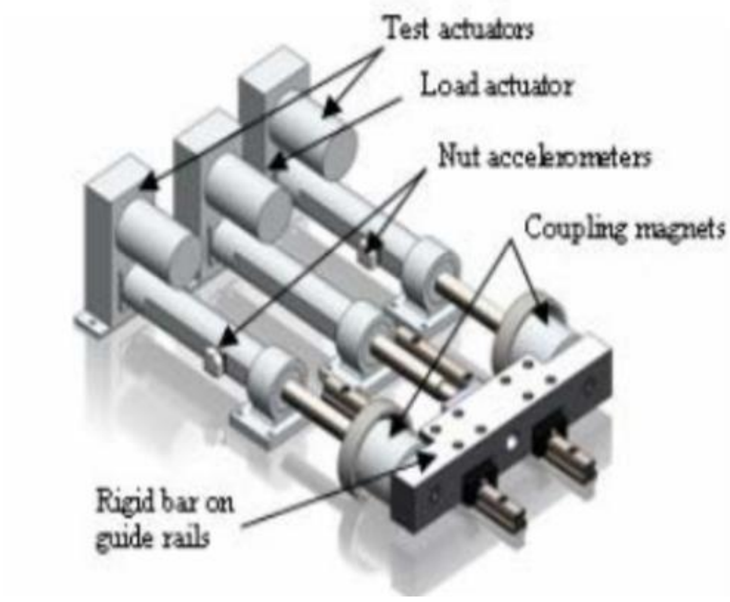
Comparison measured torque and airgap torque

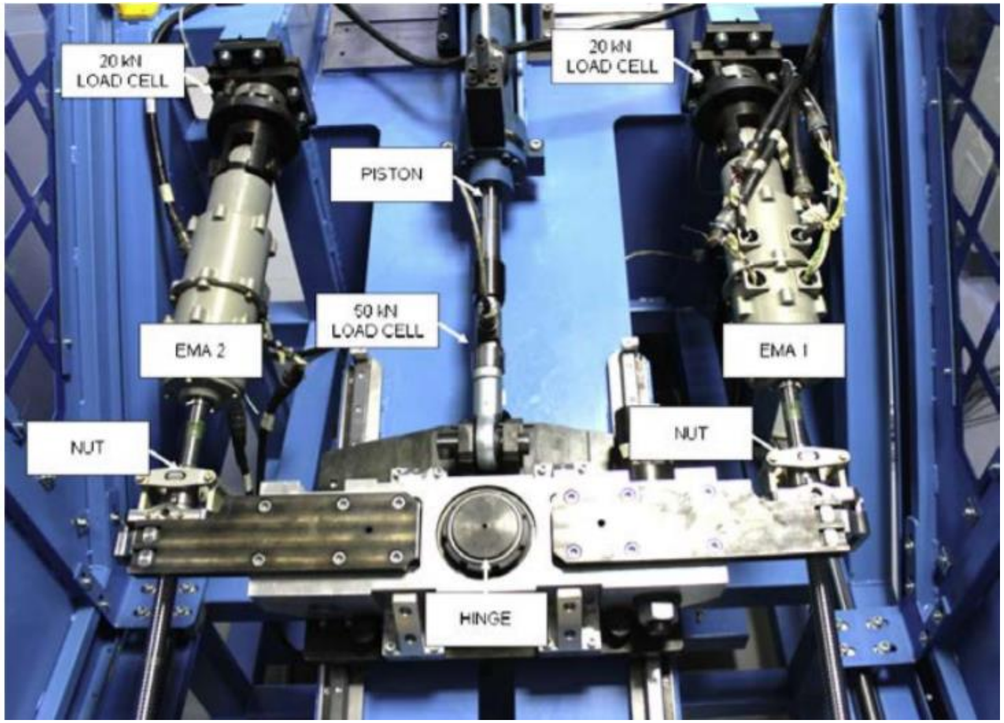
Actuator Testing

Research on Actuators

- Testing thermal characteristics
- Efficiency & Power Flow
- Comparing EHA & EMA
- Mechanical Behavior
- Control for best response







HBM: public

Mechanical Velocity and Displacement

- Measurement using displacement sensors and commanded values
- Time alignment is necessary for knowing delay in controller
- Want to minimize overshoot and rise time
- Use feedback/feed forward in controls to accomplish acceptable response
- **There is no steady state**

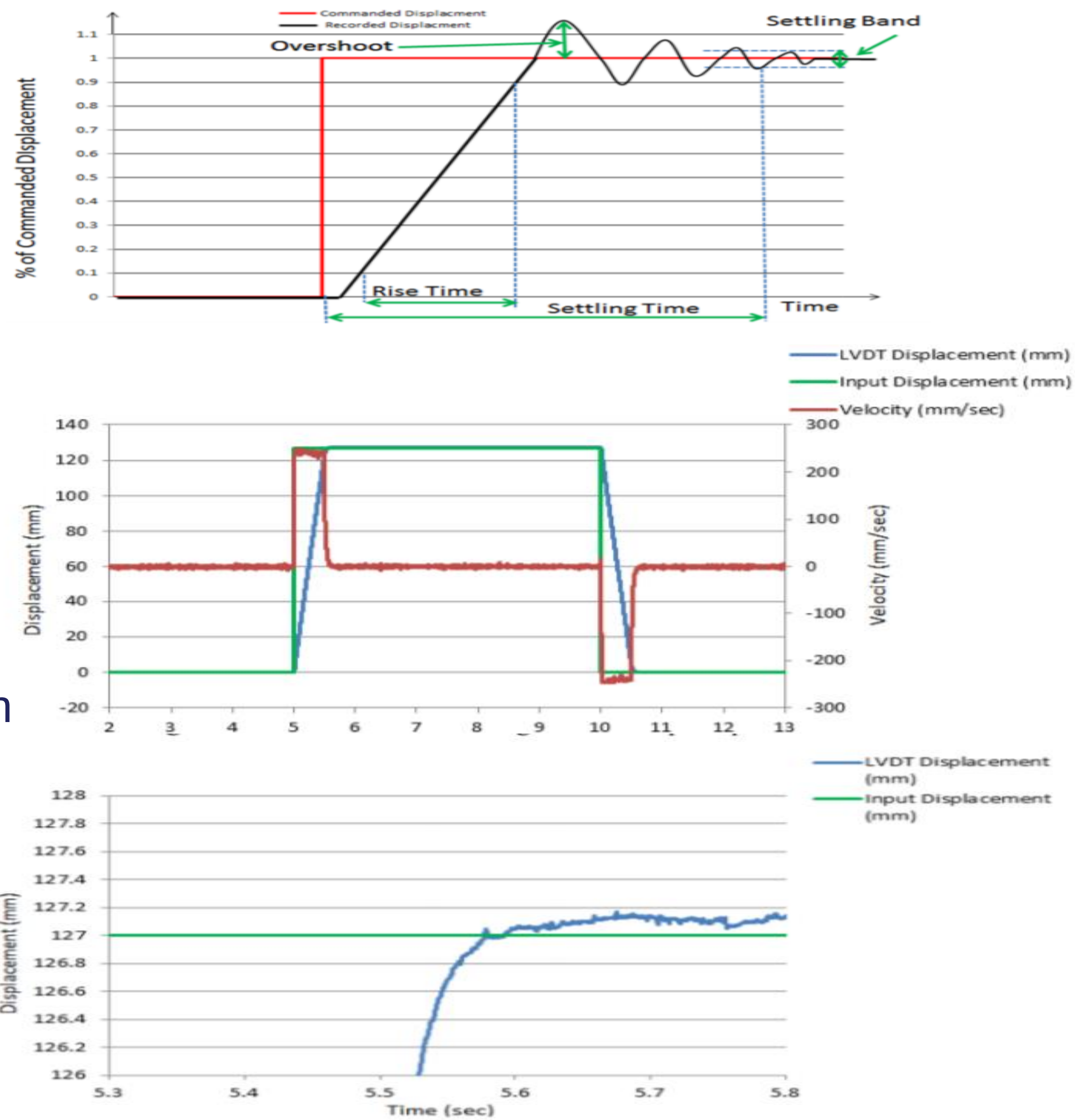
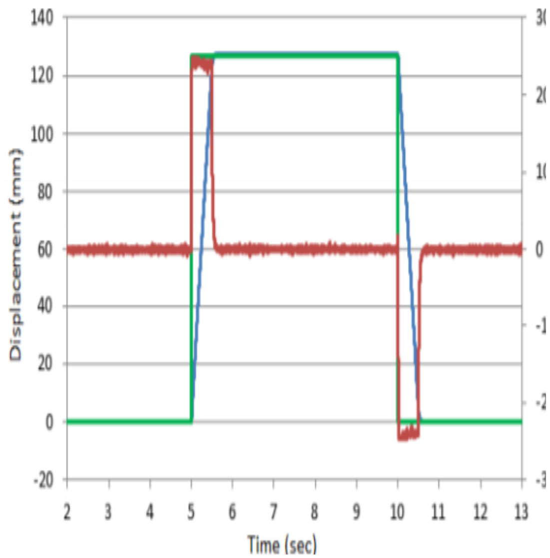
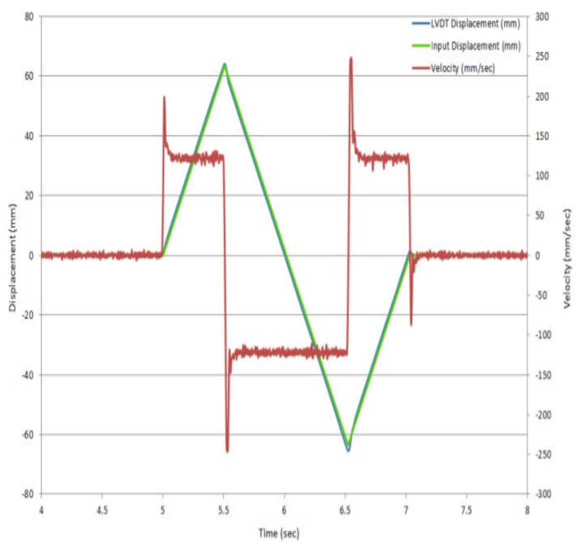


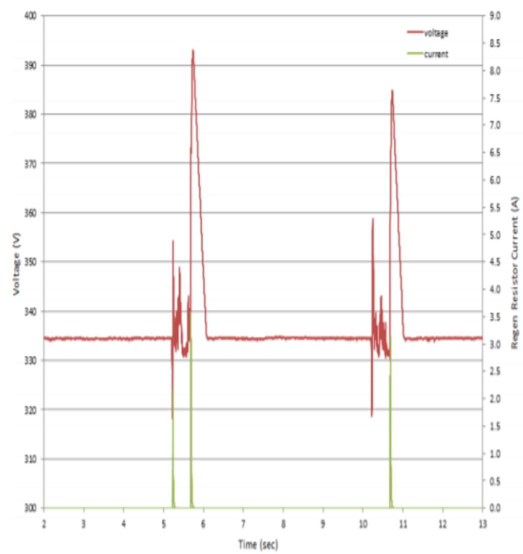
Figure 40 - Overshoot of Step Response

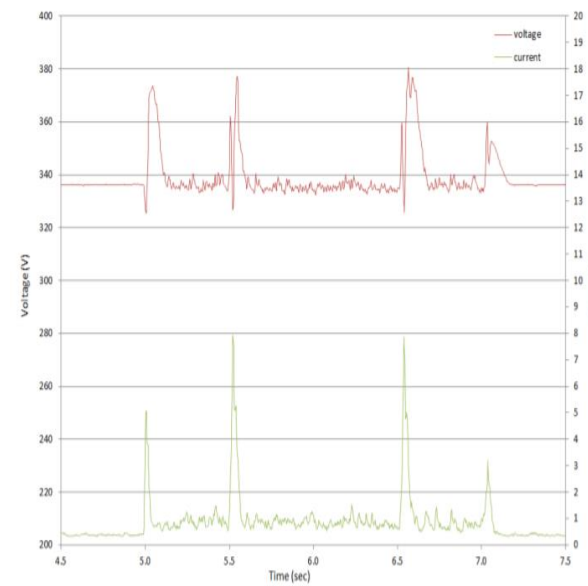
Regenerative DC Bus

- Power flow monitoring during step commands
- End up with Regen on the DC bus
- Current research into AC component of DC bus







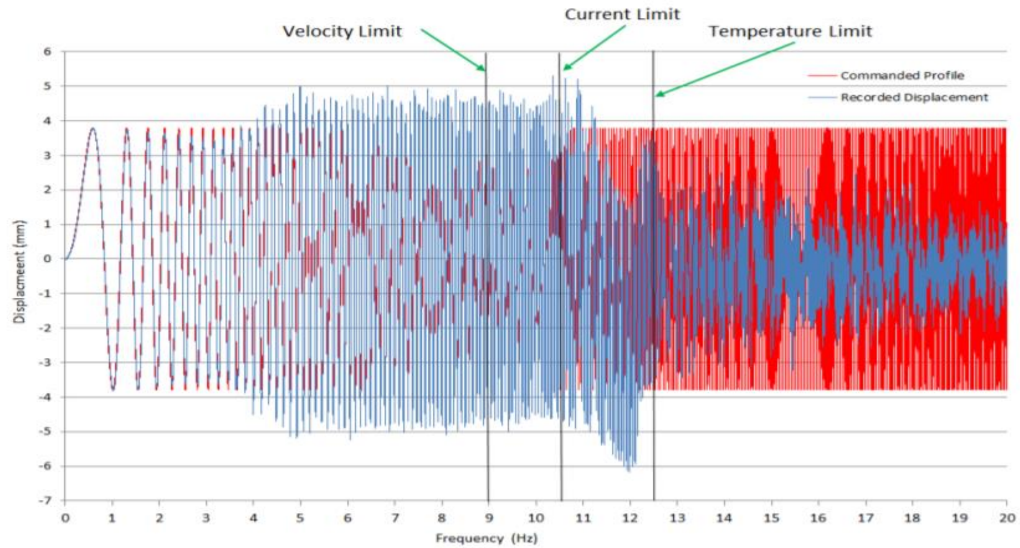


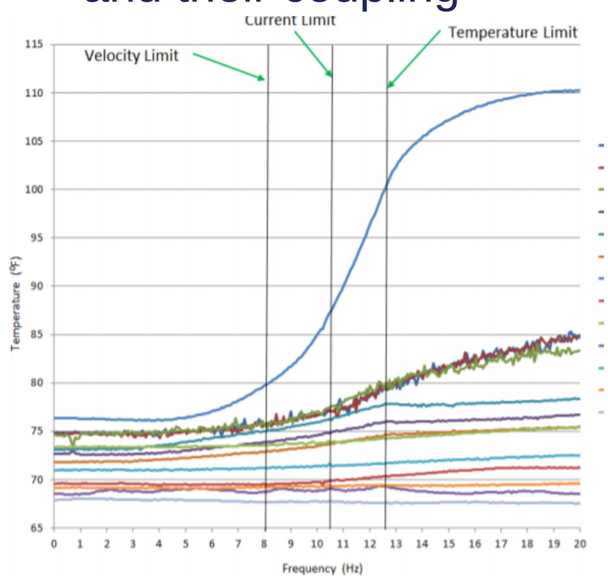
Frequency Response – Light Loaded Failure testing

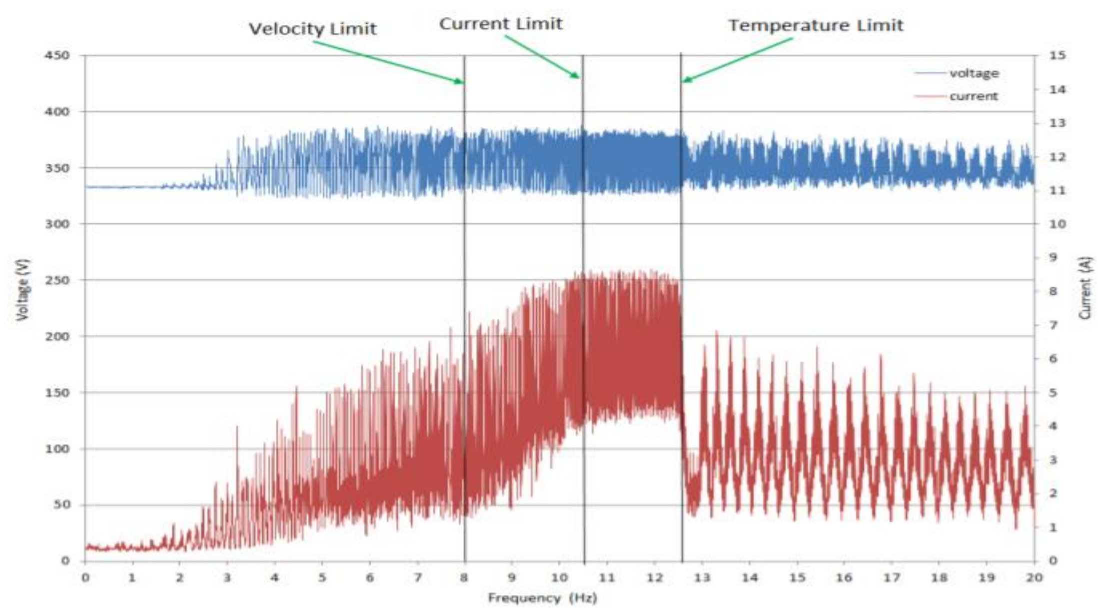
- Increase displacement command frequency and monitor current and temperature

- Eventually things break down

- Monitor limits of system and their coupling





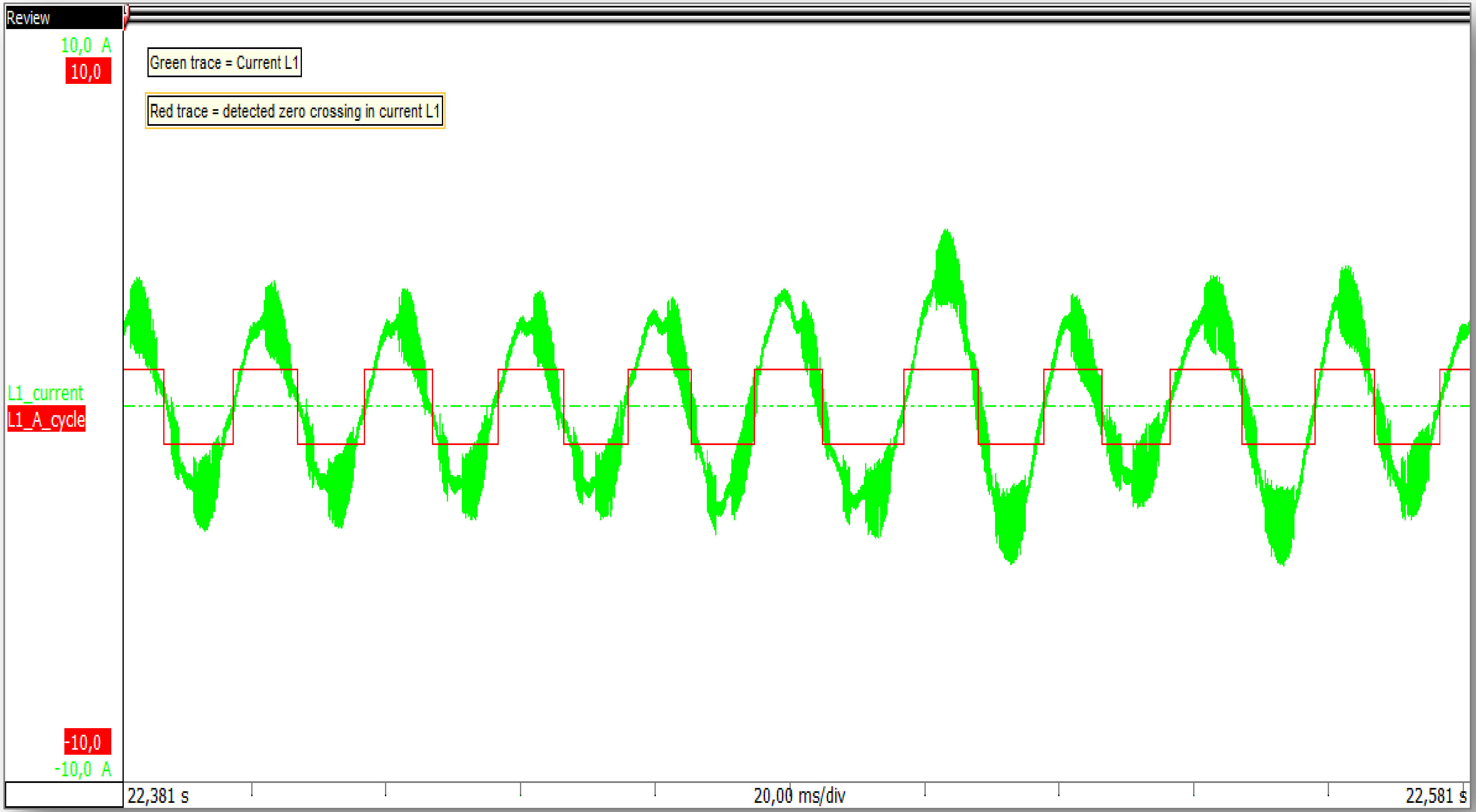


Cycle Detect

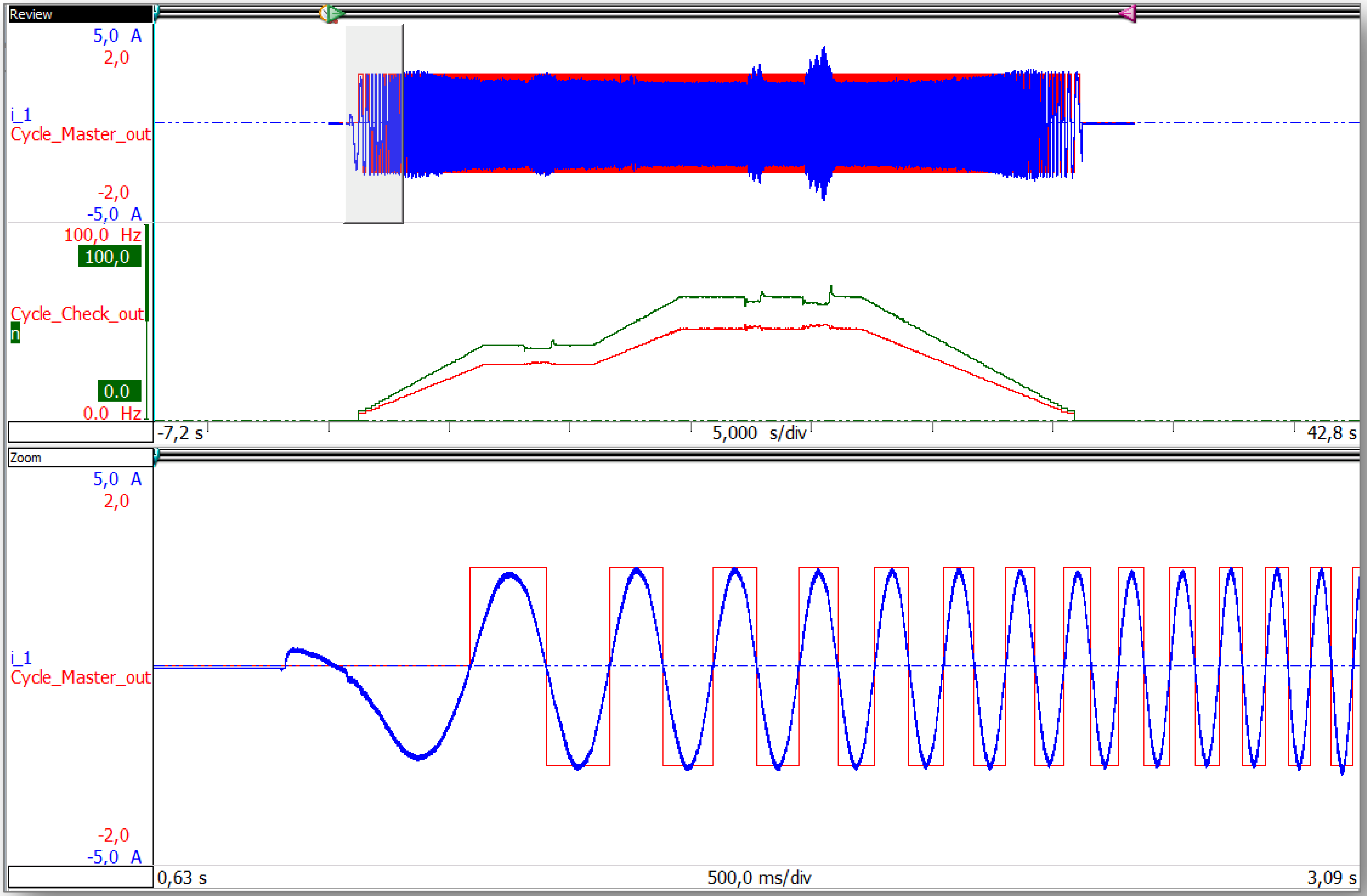
Making dynamic testing possible

Dynamic Testing →Cycle detection

- To compute any power result the “cycles” of the signals are needed
- Detecting the cycles via zero crossings is difficult due to noise
- Allows for dynamic power measurements



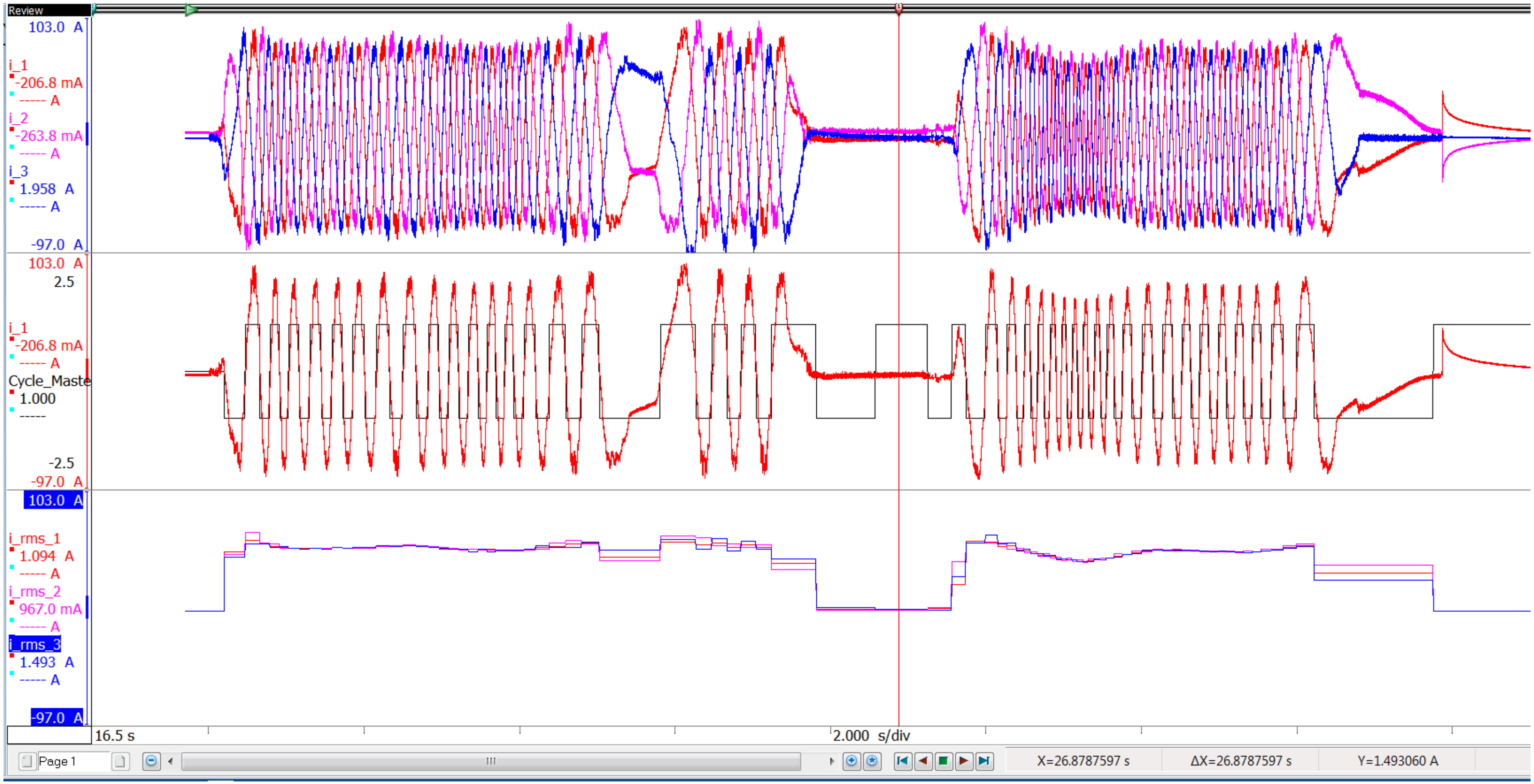
eDrive: Cycle detect verification



In Vehicle Testing

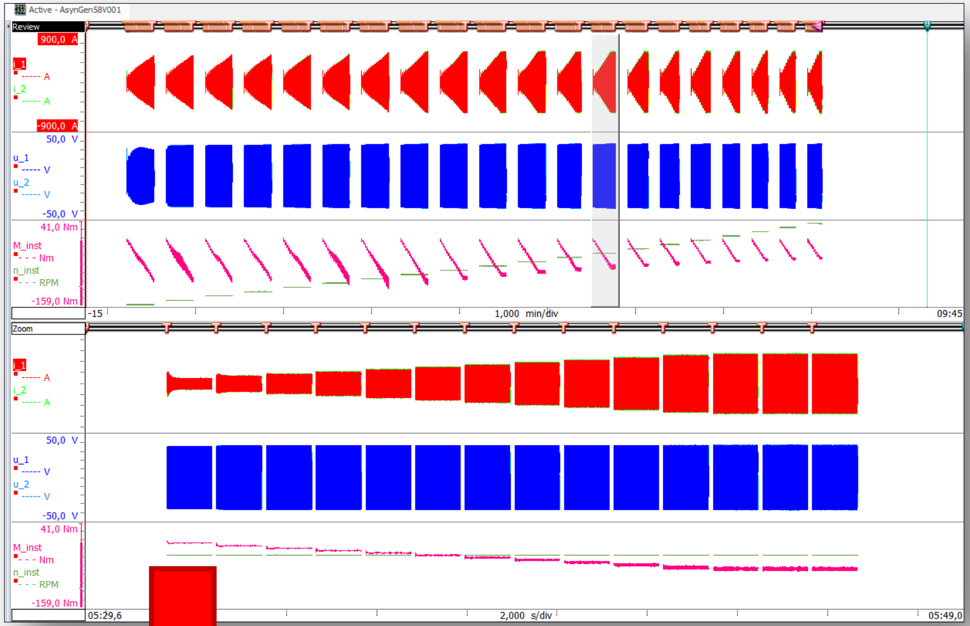
Cycle Detect

- Currents for a Chevy Bolt
- Driving around parking lot
- Cycle detect functioning with changing frequency and amplitude



Dynamic Efficiency Testing

Accelerated efficiency mapping

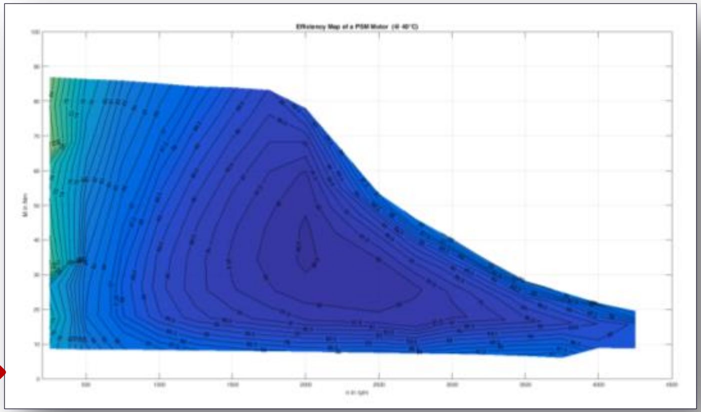


❶ Raw data is stored per set point in real time

- 293 set points
  - 20 different speed values
  - 17 different torque values
- Each set point:
  - 100 ms recording
    400 ms pause,
    then next torque step
  - After full torque ramp,
    a few seconds
    pause before next speed step

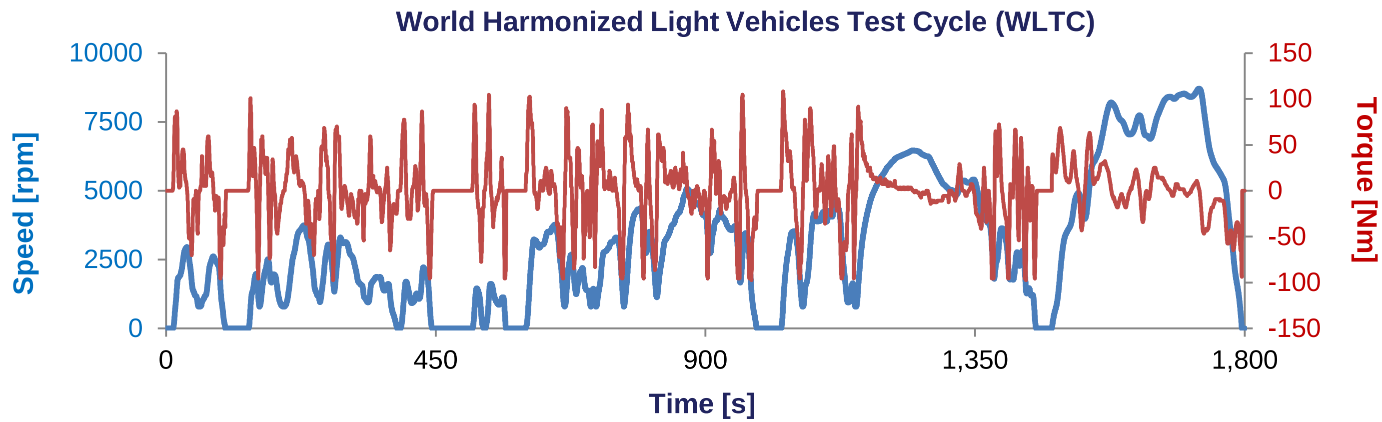
❷ During test result table with P, P_mech, M, n, η… is created in real time

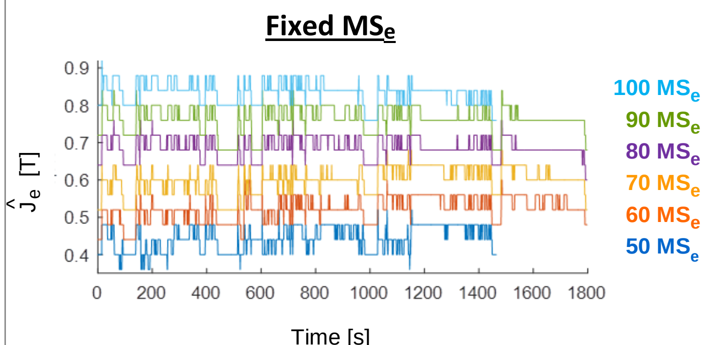
❸ Finally: Post run map creation (in MATLAB or other drawing sw)

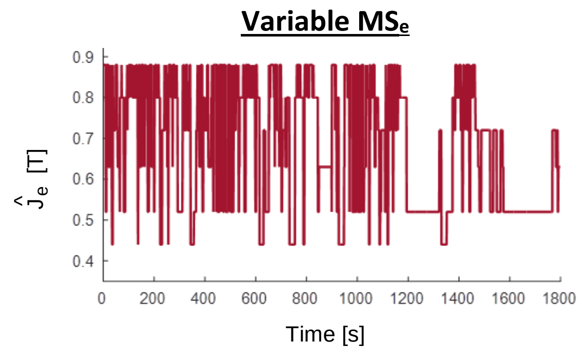


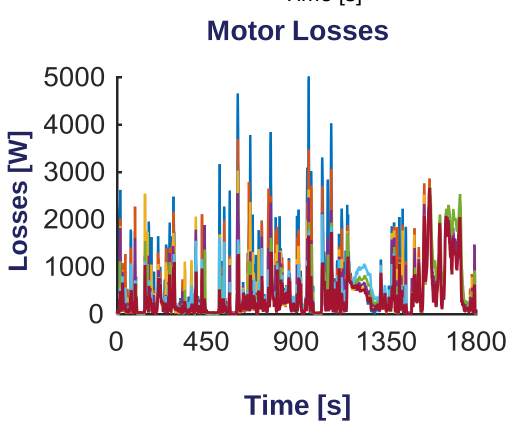
➲ Complete mapping can be done in a few minutes

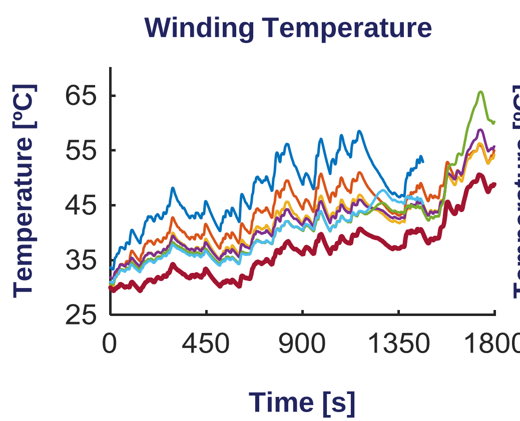
Drive Cycle Testing

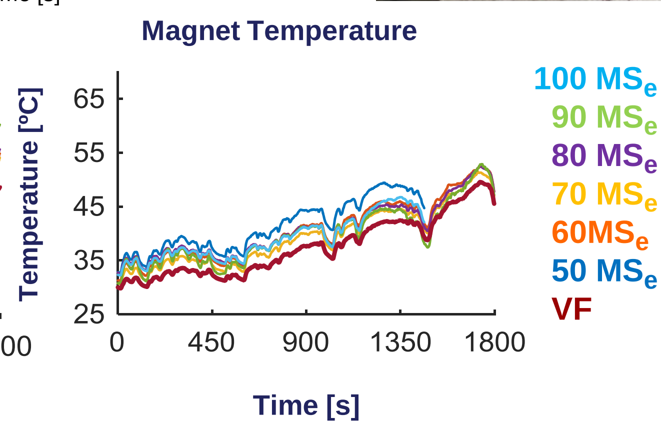






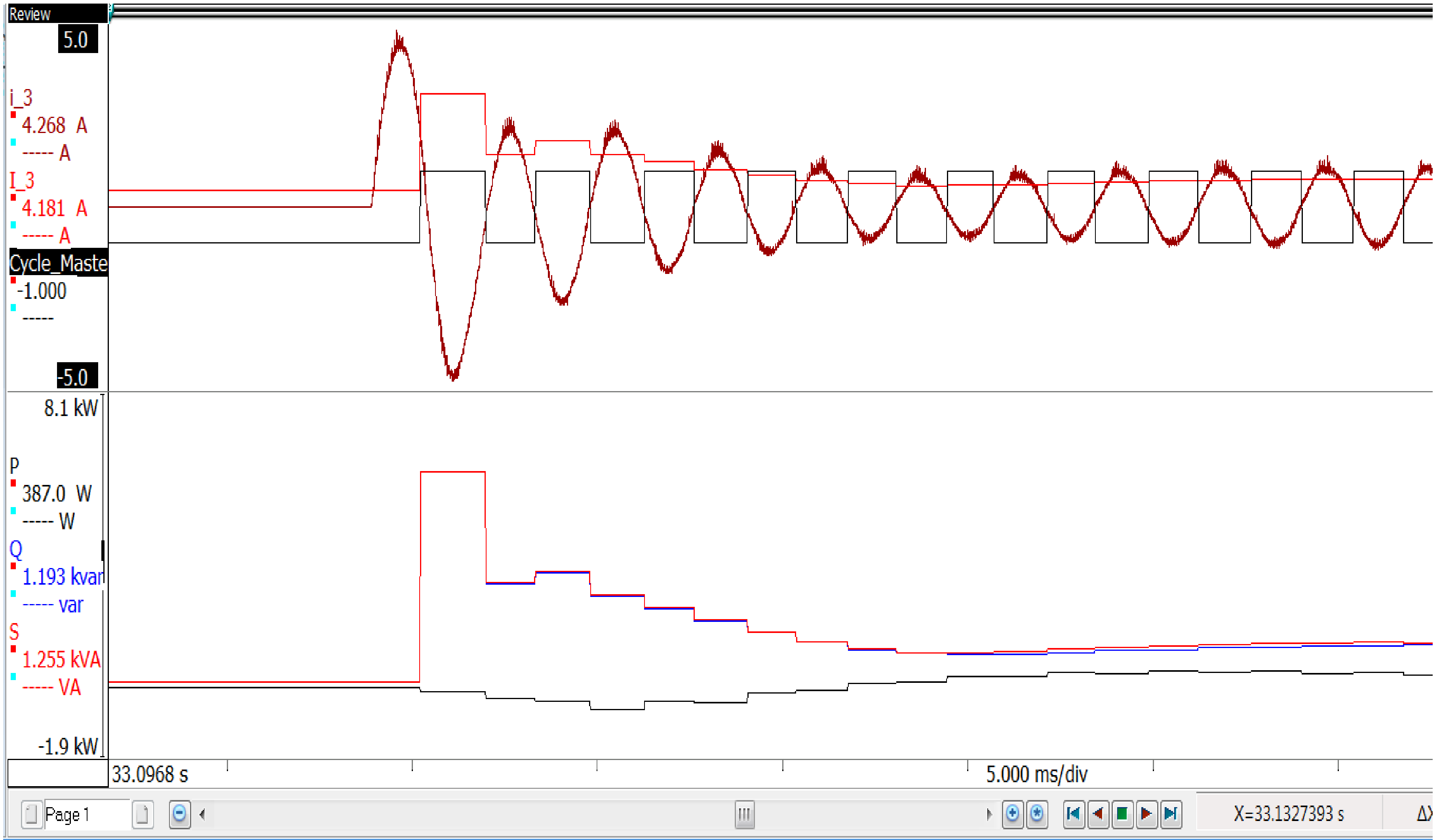






Power, Efficiency, Current, and Cycle Detect zoomed

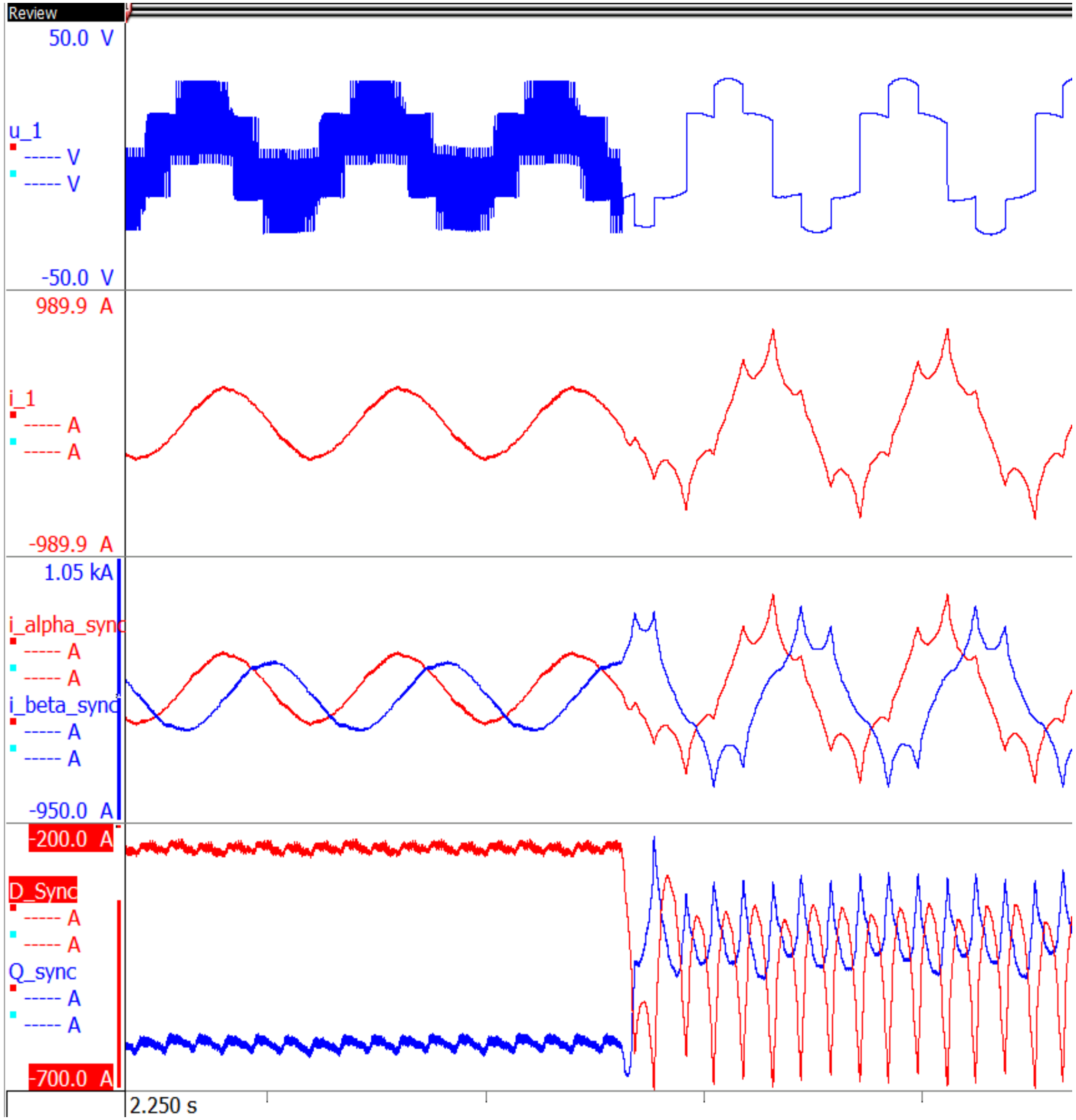
- Calculations are done on a per cycle basis



Dynamic Control Analysis

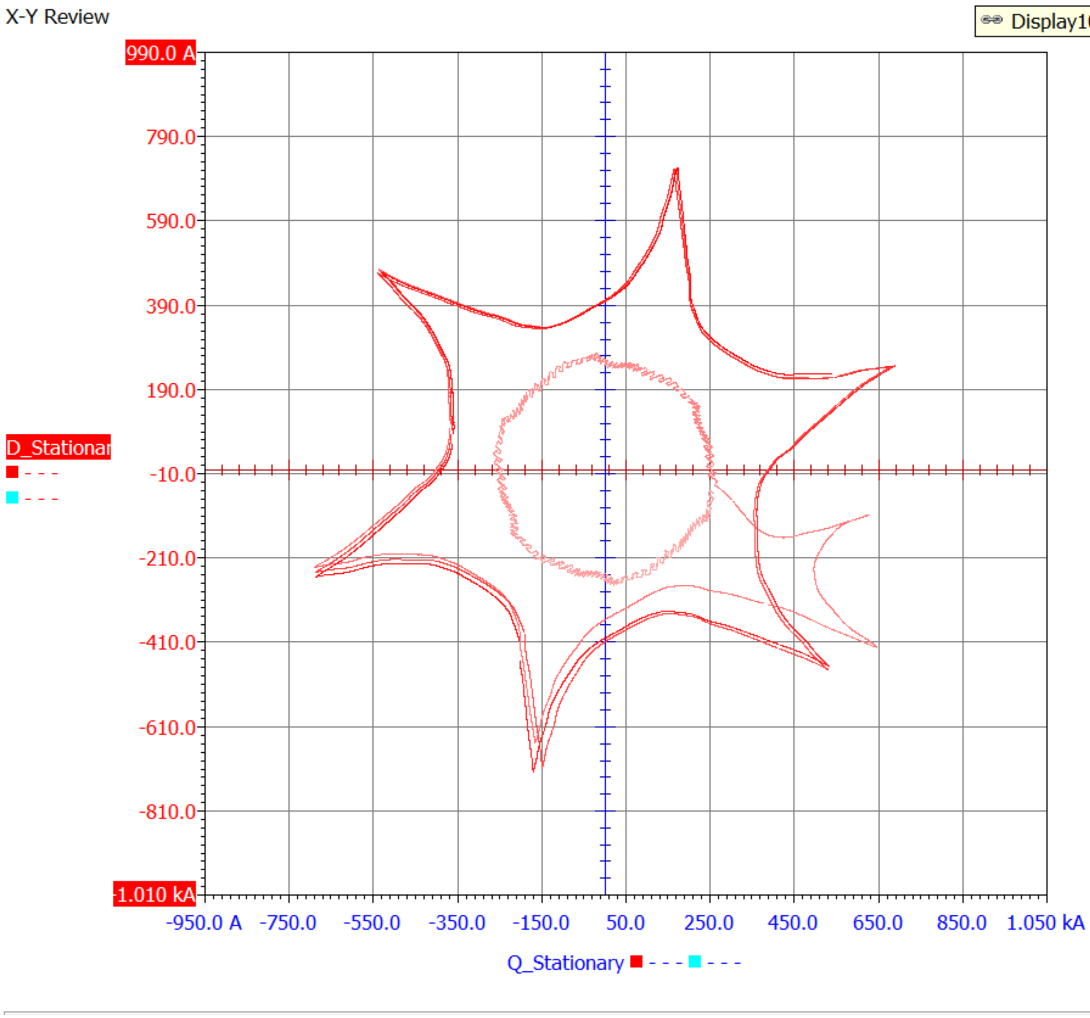
Monitor Control Changes

- Voltage and Current from Customer
- Voltage Transition from PWM to 6-Step to increase speed
- Current changes from Pure Sinusoid to jagged
- Control Changes highlighted in Space vector and DQ0
- DQ0 shown in different reference frames



Space Vector Transformation During a Control Transition

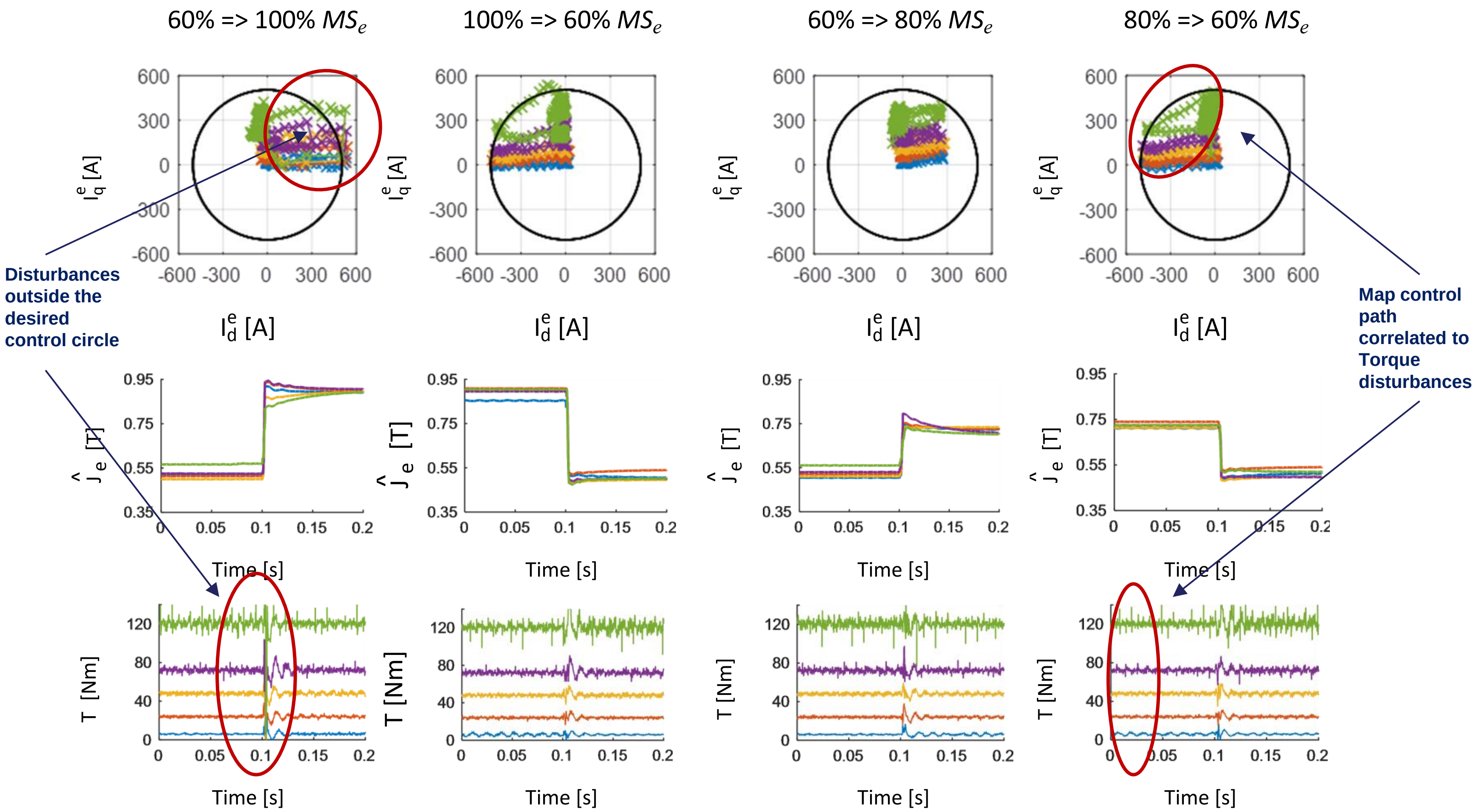
- Space Vector α and β
- Confirm control behavior
- Visualize control path during transitions



Watching Id and Iq during a Magnetization change

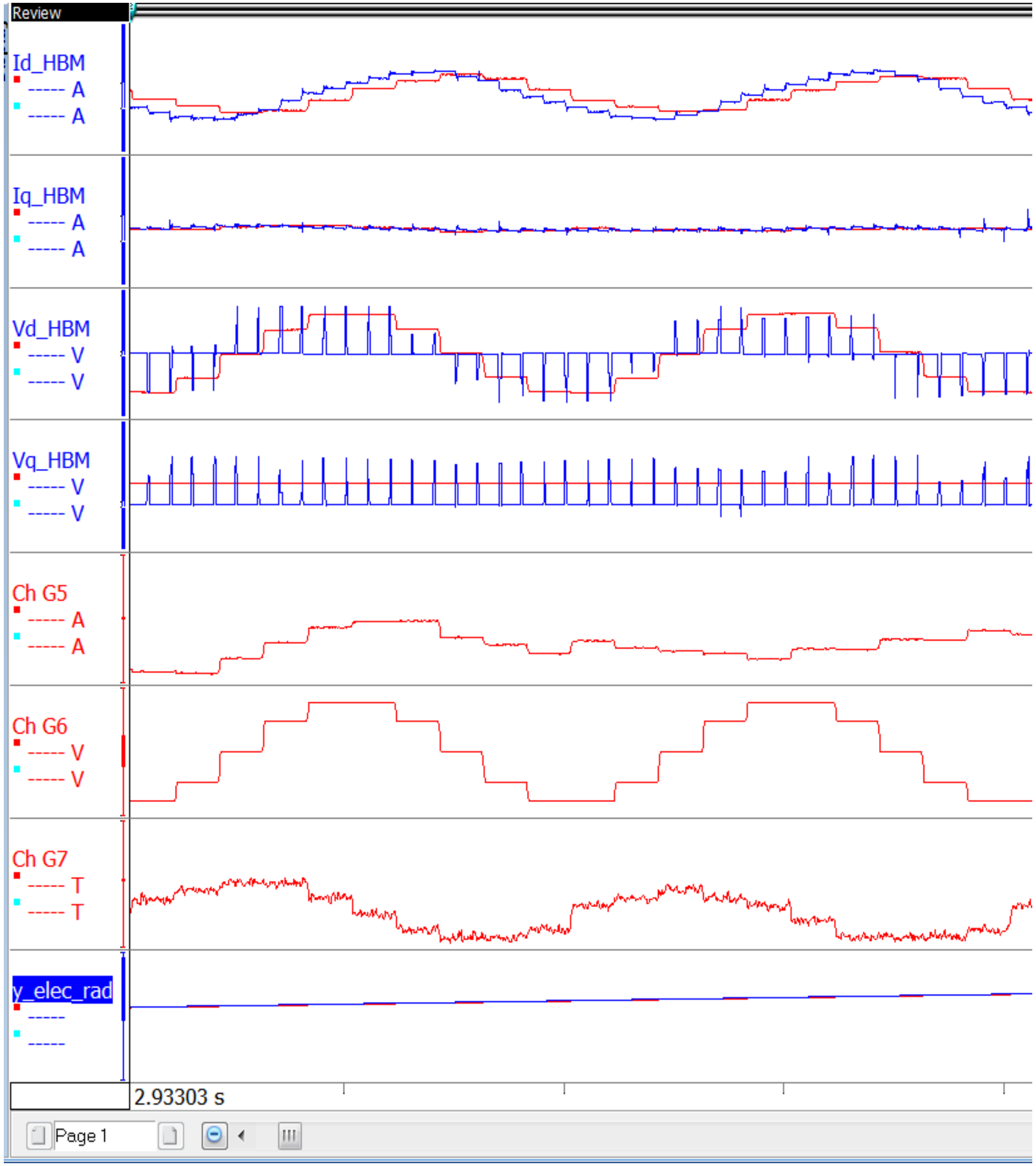
Transitions:

MS change for increasing and decreasing MS_e level combinations at 2000 rpm, over a range of torque conditions



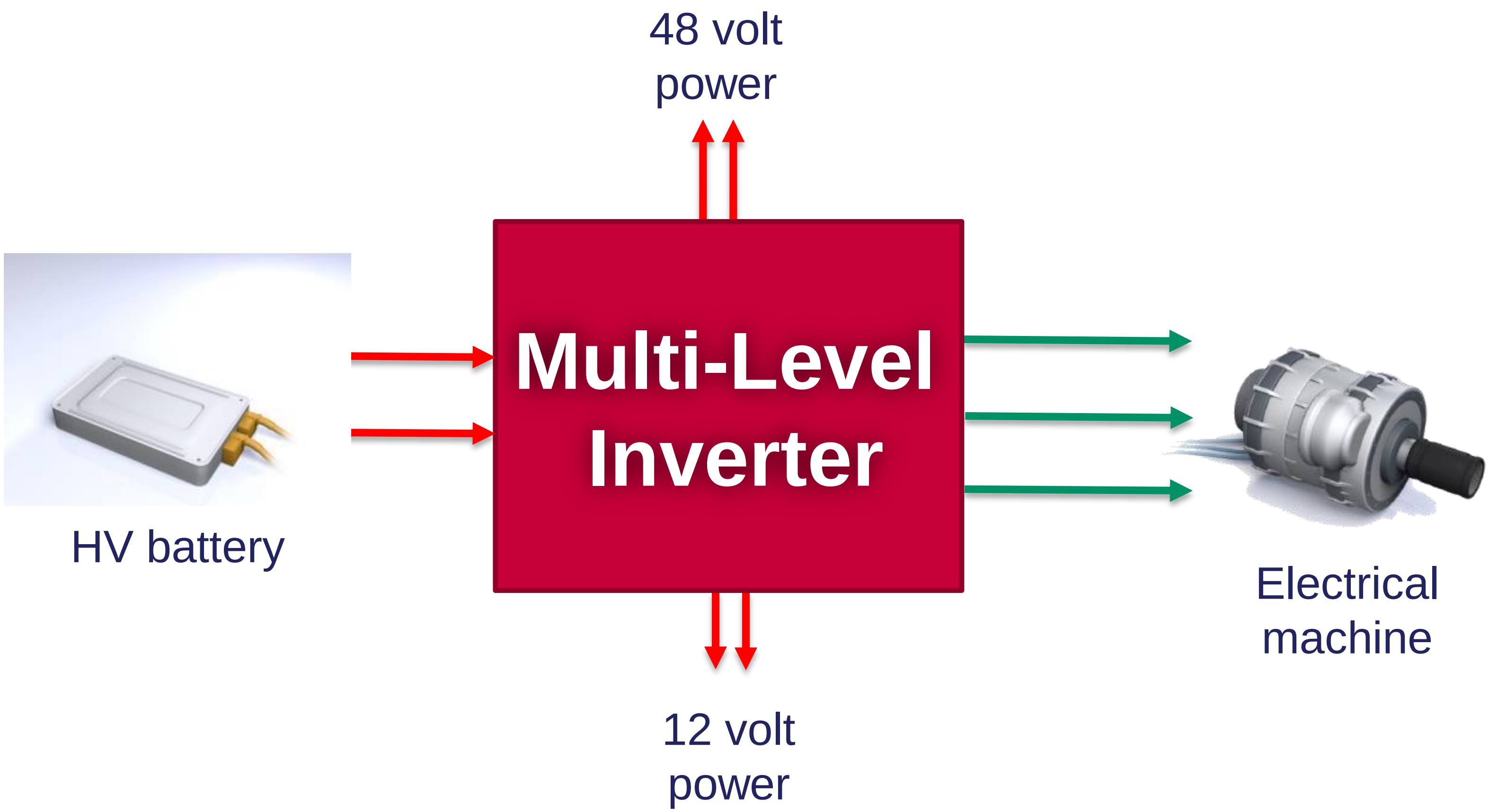
Having controller and physical signals in one location

- Id – Direct Axis (field)
- Iq – Quad Axis (Torque)
- Vd
- Vq
- Iq* - Estimated
- Id* - Estimated
- J – Magnetization State
- Angle of Rotor



Large System Testing

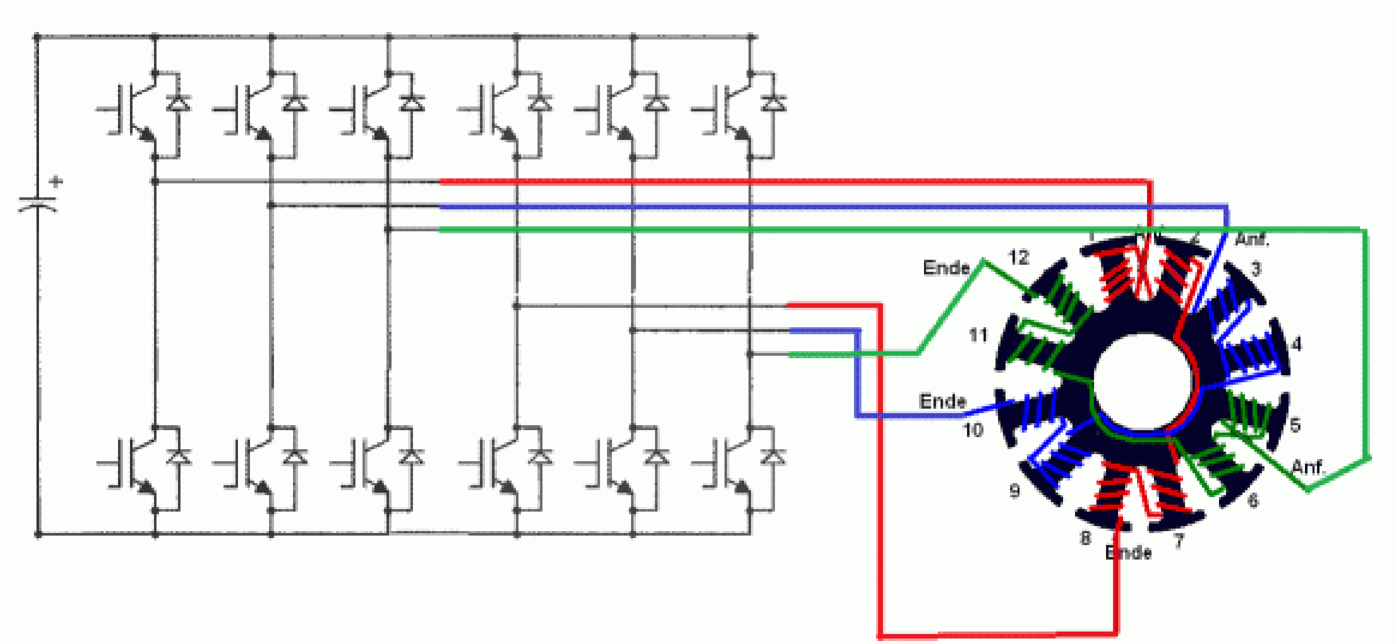
Efficiency testing on multi level inverter



- More power channels needed
- Special formulas needed for efficiency

New challenges: > 3 ph motors

- More power channels needed
- Formulas for total power are different from „standard“ 3 ph



Example formulas:

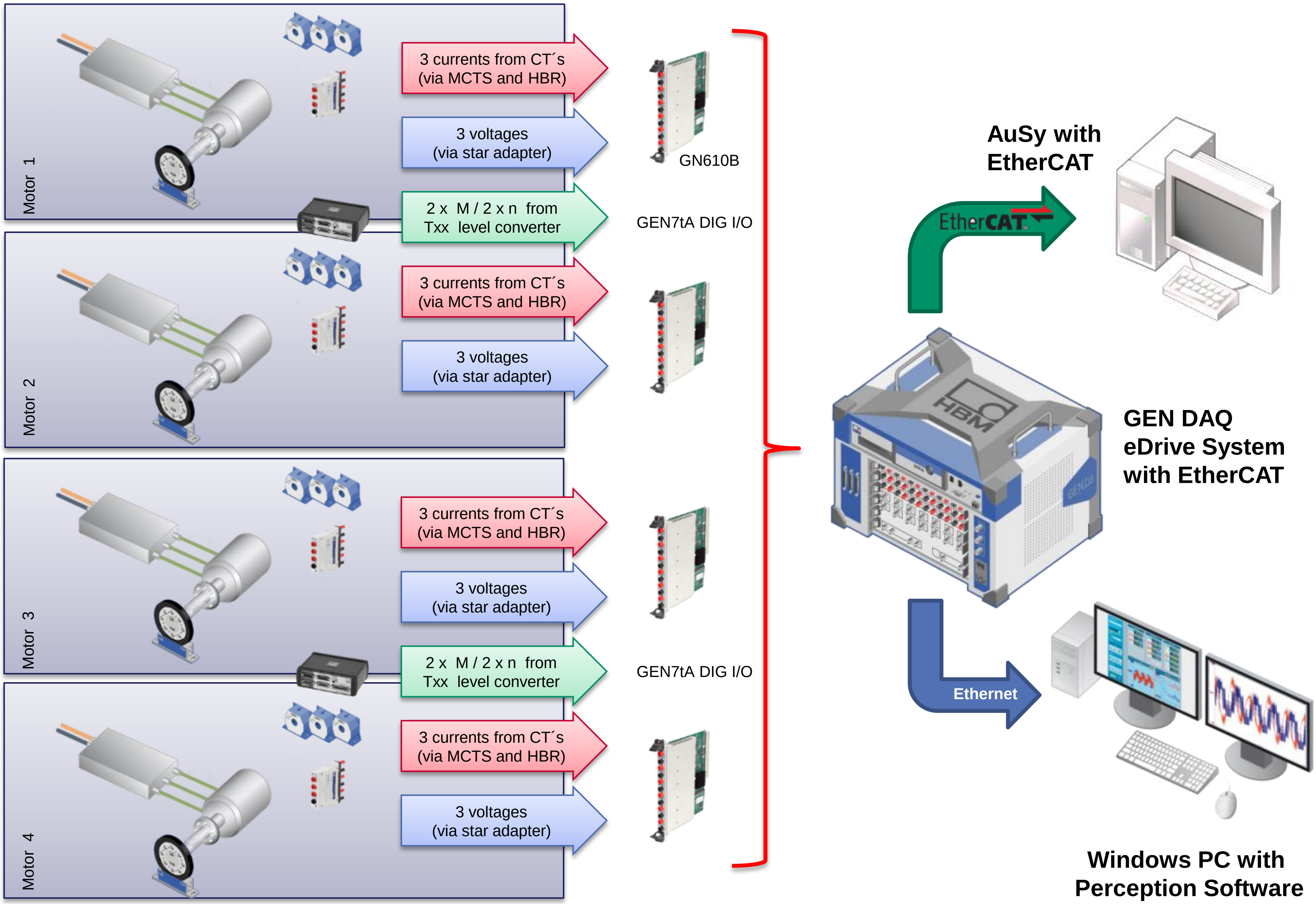
P_L1	@CycleMean (RTFormulas.p_1 ; RTFormulas.Cycle_Master)
P_L2	@CycleMean (RTFormulas.p_2 ; RTFormulas.Cycle_Master)
P_L3	@CycleMean (RTFormulas.p_3 ; RTFormulas.Cycle_Master)
	The sum of the active power per phase gives the total active power
P_tot	RTFormulas.P_L1 + RTFormulas.P_L2 + RTFormulas.P_L3

Standard formulas for 3ph real power

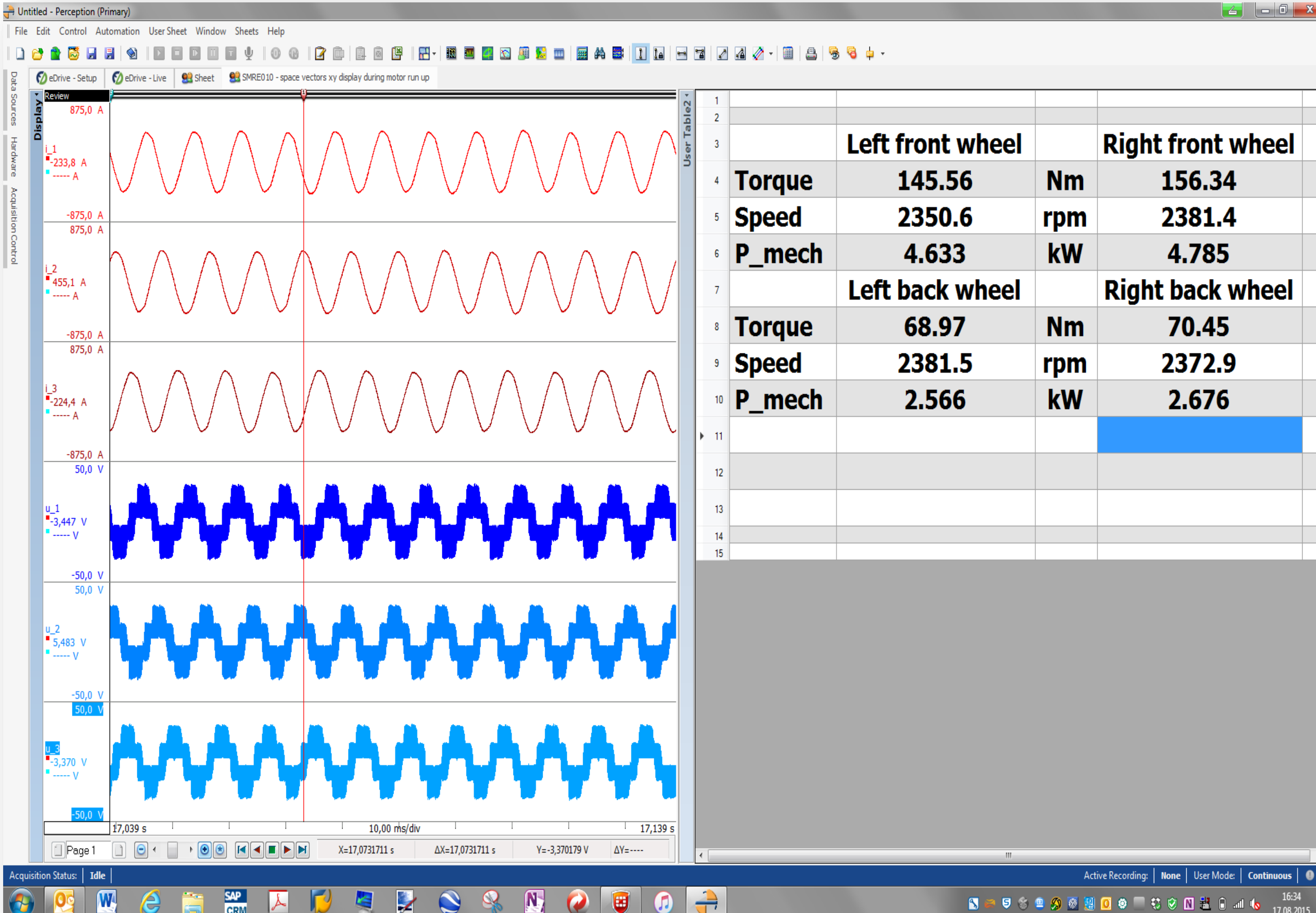
P_L1	@CycleMean (RTFormulas.p_1 ; RTFormulas.Cycle_Master)
P_L2	@CycleMean (RTFormulas.p_2 ; RTFormulas.Cycle_Master)
P_L3	@CycleMean (RTFormulas.p_3 ; RTFormulas.Cycle_Master)
P_L4	@CycleMean (RTFormulas.p_4 ; RTFormulas.Cycle_Master)
P_L5	@CycleMean (RTFormulas.p_5 ; RTFormulas.Cycle_Master)
	The sum of the active power per phase gives the total active power
P_tot	RTFormulas.P_L1 + RTFormulas.P_L2 + RTFormulas.P_L3 + RTFormulas.P_L4 + RTFormulas.P_L5

User entered formulas for 5ph real power

Electrical four wheel drive tested with a single eDrive system



Electrical four wheel drive tested with a single eDrive system



	Left front wheel		Right front wheel
Torque	145.56	Nm	156.34
Speed	2350.6	rpm	2381.4
P_mech	4.633	kW	4.785
	Left back wheel		Right back wheel
Torque	68.97	Nm	70.45
Speed	2381.5	rpm	2372.9
P_mech	2.566	kW	2.676

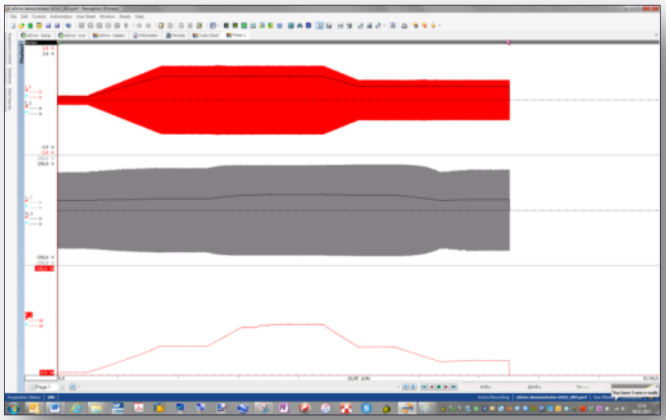
Failure and Fault Analysis

eDrive: Durability testing

- Tests according to Chinese standards
  GB/T 29307-2012, GB/T 18488.1-2015 and 18488.2-2015
- Defines at least 400 h of continuous testing, 1000 h recommended
- Last 30 minutes should be kept in circular buffer to analyse failures
  - This sums up to about 10-25 GB of data
- GEN DAQ offers unique „Circular recording“ option with full disc pretrigger

Graphical setup of circular recording in Perception

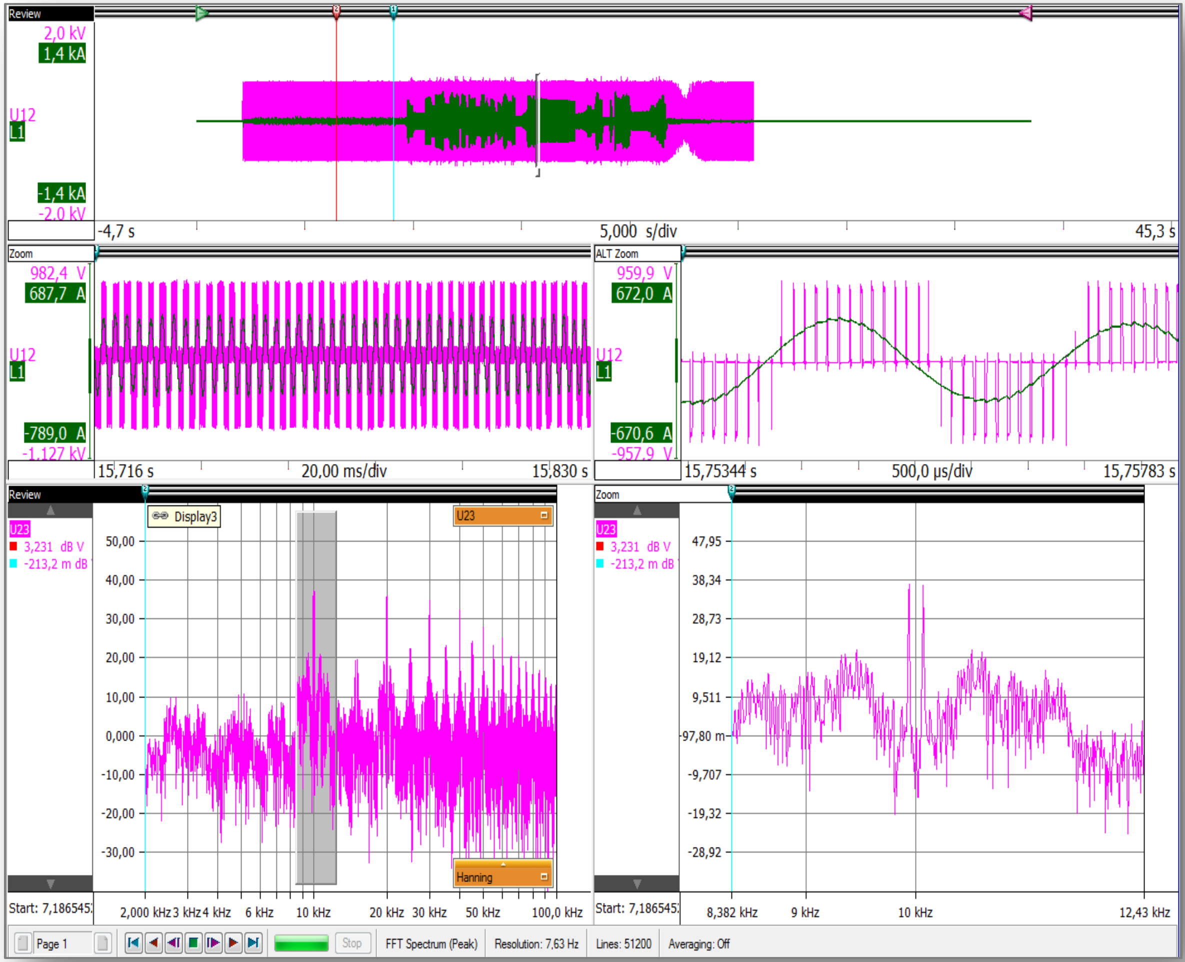
- Powerful trigger capabilities on all input signals incl temp & vibration
  - Side note: HBM patent on fast display used in Perception:
    10 GB are shown in review in 4 s
- So power values are streamed to ECU (using EtherCAT to CAN gateway) while raw data is kept in circular buffer



Long data recording reviewed in Perception

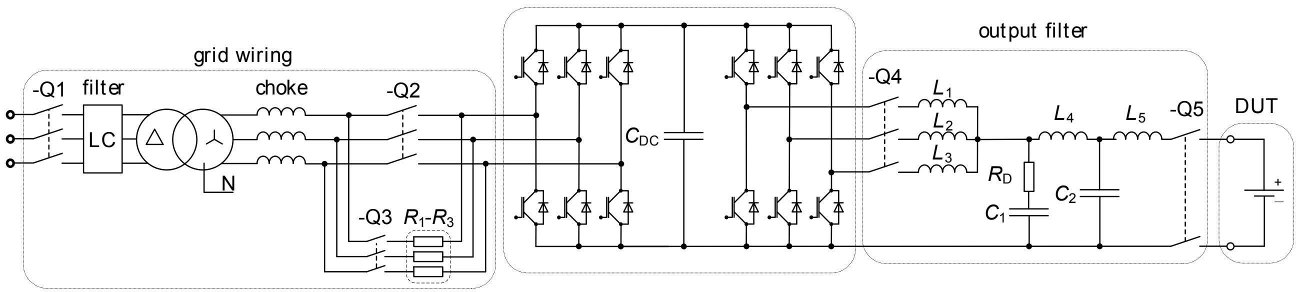
FFT of the voltage

- FFT can show information on test
- Unexpected FFT can indicate issues
- Increase of certain harmonics over time can indicate issues
- Use FFT to see torque ripple beyond resolution of sensors
- High Sample rate and Raw data necessary for long term failure testing



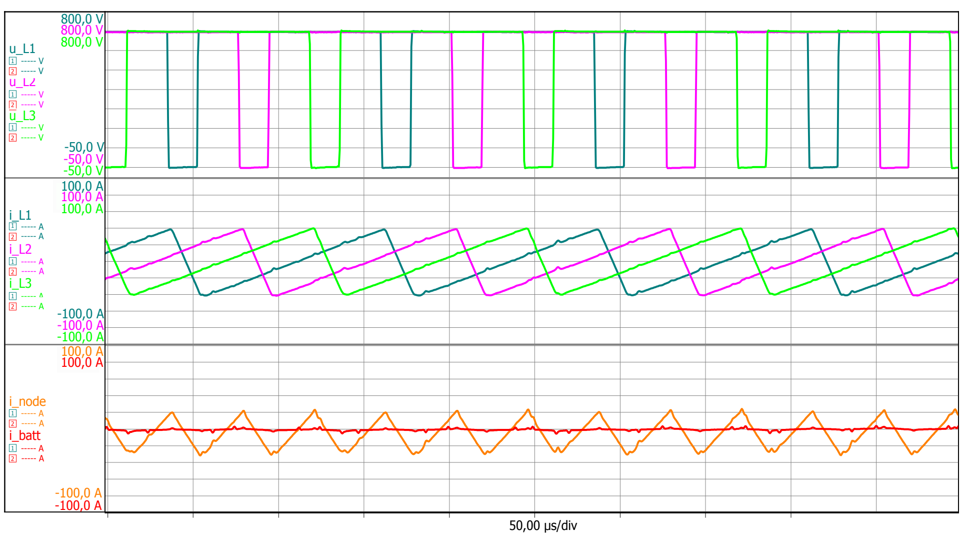
Battery Control & Lifetime Testing

- Batteries used in automotive need to be verified and tested



Schematic of battery test rig

- As they are charged and discharged using inverters with (small) DC link capacitors, high frequency components in the charging currrents need to be detected and minimized

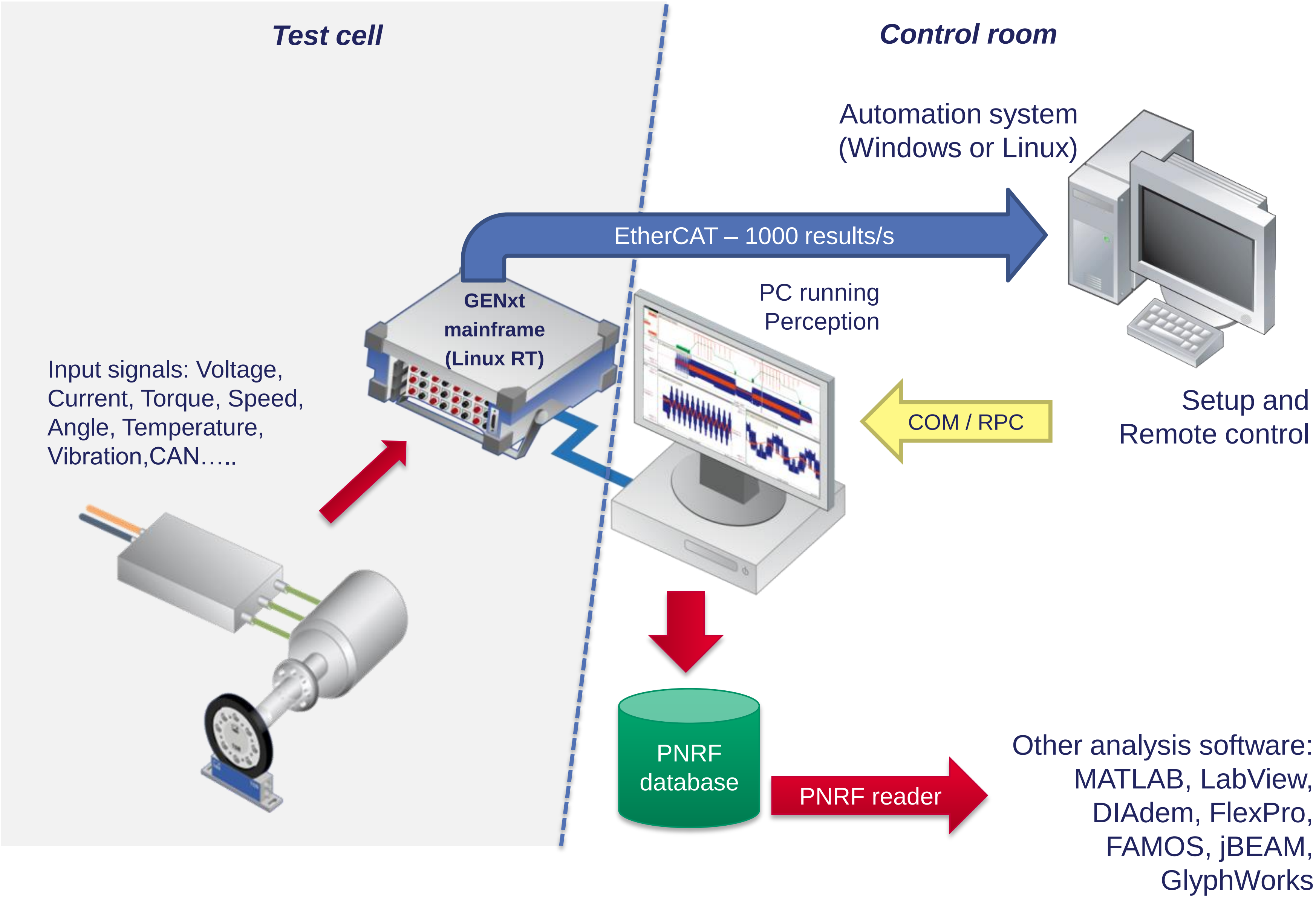


Charging currents before (yellow) and after optimization (red)

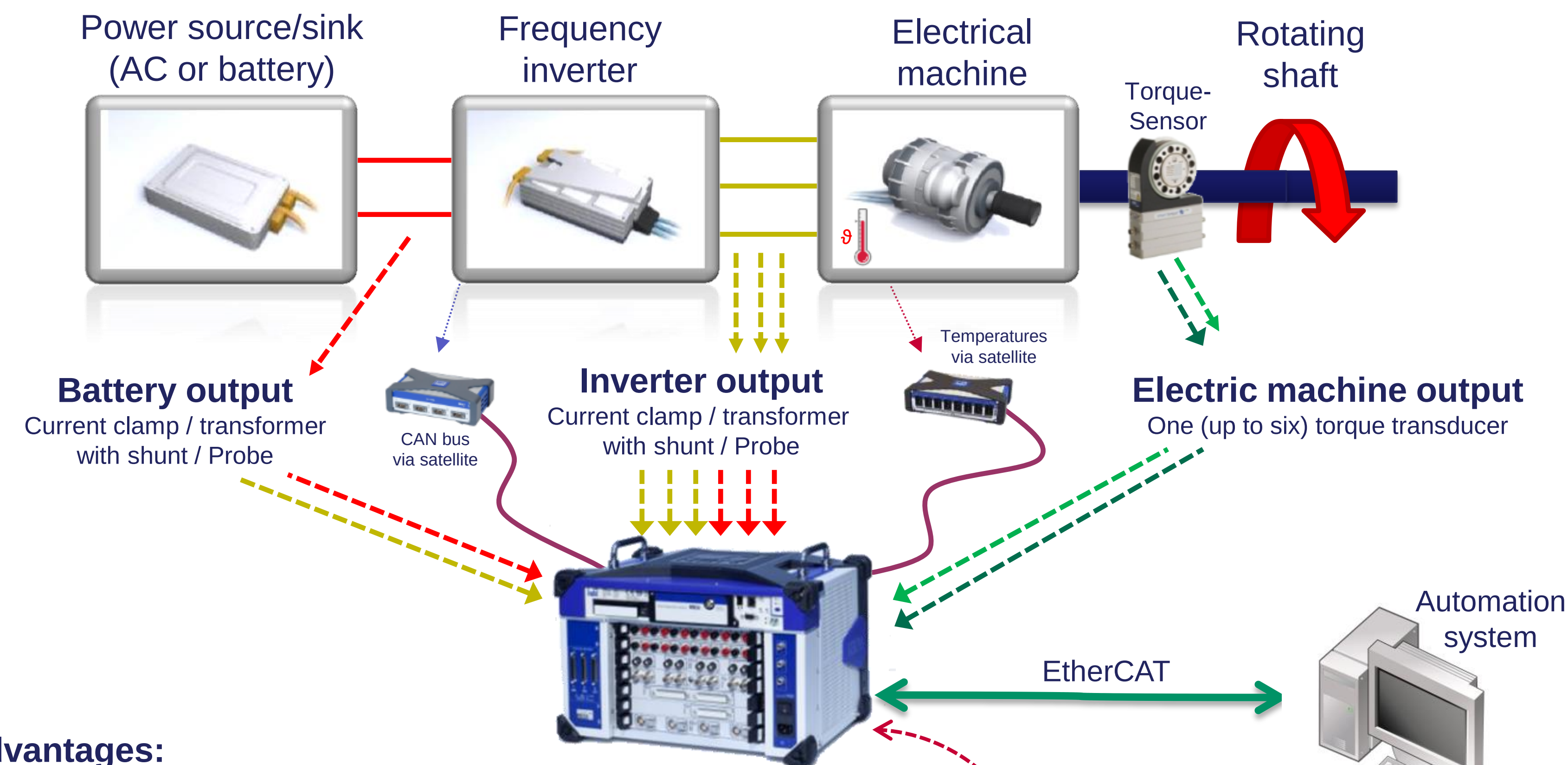
Automotive battery test rig using GEN DAQ

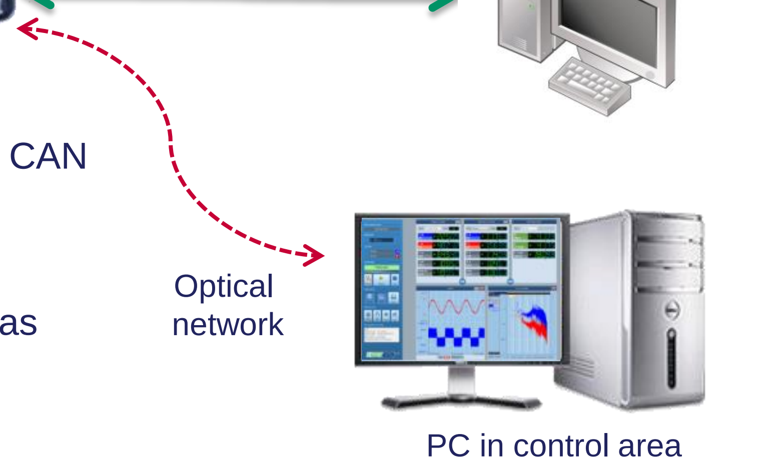
Real Time Feedback In a Test system

eDrive: Interfacing with the GENxt products – RPC & EtherCAT



eDrive: HBM´s testing concept – a single system does all the jobs





Advantages:

1. Synchronous acquisition of all data in one file & format, with higher channel count and temperatures / vibration / CAN
2. Continuous recording or snapshots per set point for verification, analysis and motor mapping
3. Real time power calculations per cycle, plus user formulas
4. Advanced analysis capabilities like space vector, dq0 transformation or airgap torque
5. Real time data transfer to automation system

HBM: public

eDrive: The HBM components for advanced power analysis

- GEN DAQ configurable, expandable mainframes
  - Up to **51 channels for power measurements (102 U&I)**
  - Continuous streaming or **storage per set point in real time**
  - Support for up to **6 torque transducers** (12 as special)

- 6 channel input card (= 3 power channels)
  - Voltage up to +/- 1000 V, current via CT´s or clamps
  - Sample rate 1 MS/s @ 18 bit, typ. power accuracy 0.02%
  - Option: 5 kV_{rms} differential probe, 0.1% accurate
  - Plug-in artificial star adapter, cascadable
  - Burden resistors for CT usage
  - On board **user programmable math**

- High accuracy HBM torque transducer (with speed)
  - Accuracy 0.02%

- Options
  - EtherCAT interface for **real time data transfer** to automation
  - **Temperature** satellite, 1 kV isolated, 8 channels
  - **CAN** input
  - Various inputs for **strain, vibration, temp**....
    …and also “scope cards” up to 250 MS/s

eDrive testing – Mission statement

Like other power analyzers, the HBM eDrive computes power values and efficiency and displays these in real time.

Unlike other power analyzers, the HBM eDrive can store a variety of signals & raw data - like a high end DAQ - for review, verification and advanced analysis such as efficiency mapping or dq0 transformation.

Thus it does not only give you "efficiency" ,
but it also <u>helps you to improve the efficiency</u>.

It also offers a complete solution acquiring more than 3 phases, complex setups, temperatures, CAN and vibration as well.

For system integration, it offers modern integration tools including real time result transfer and accelerated motor mapping capabilities to save test time.

Note: eDrive is a strategic target market area for HBM.

Thanks for your time – Any Questions?

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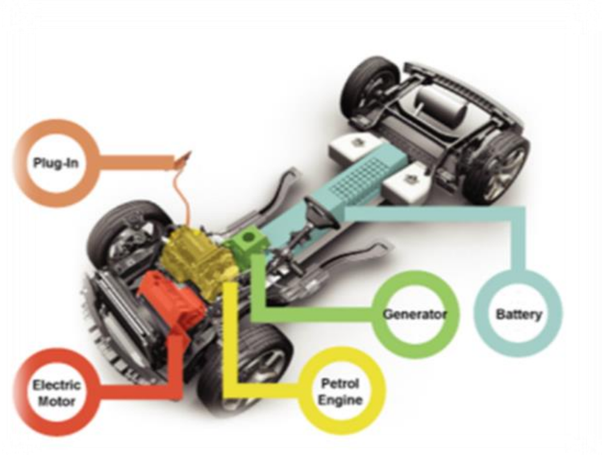

HBM: public