Dynamic Real Time Power Measurements for Electric & Hybrid Drive Systems

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HBK
HOTTINGER BRÜEL & KJÆR

Presenter

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  „eDrive“ = testing of inverter driven electric machines
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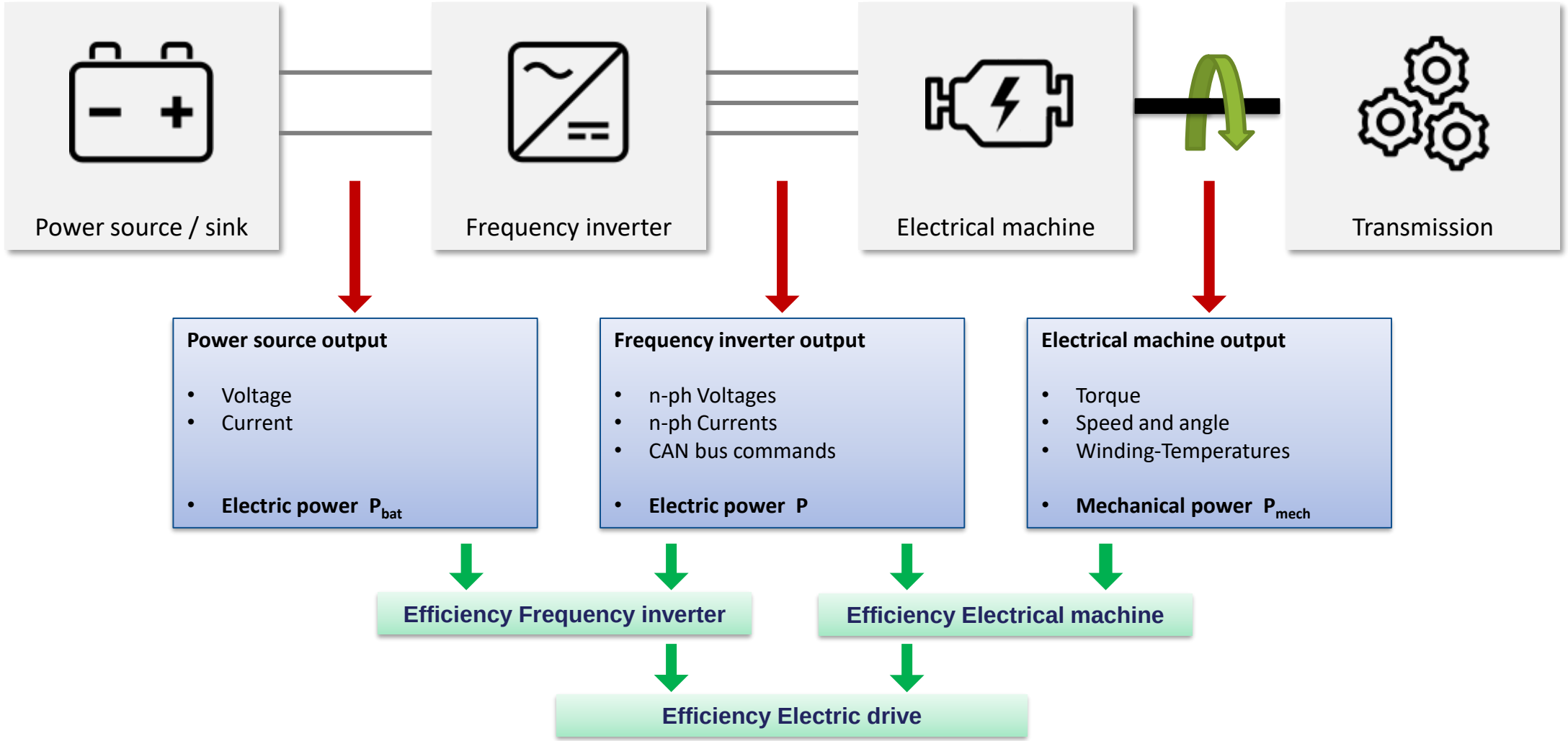
Klaus Lang

Introduction

In this webinar, a new power analyzer will be introduced. This PA is able to analyze complex systems and gives accurate results even in dynamic load changes

Current situation and problems

DAQ requirements on electric drive train



The traditional solution – a Power analyzer

Typical specifications of a mid range/high end PA

- 4 - 7 power channels
  - Voltage inputs up to 1000 V rms
  - Current inputs up to 20 A
- 1 - 2 torque / speed inputs
- Very high accuracy for 50/60 Hz signals
  - "Base accuracy 0.0n %"
- Analog PLL to track signal frequency
- Delivers ~ 5 to 50 results/s

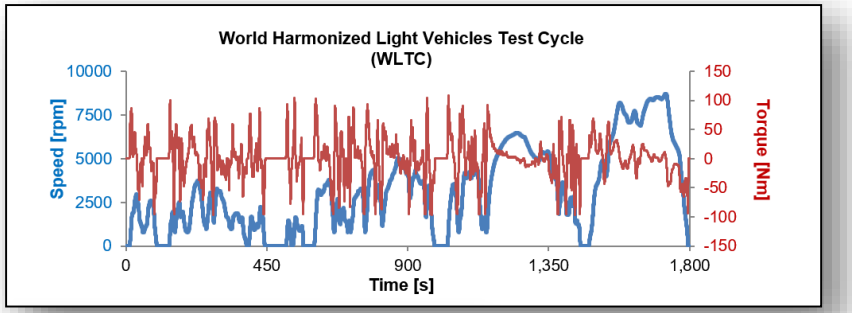
The traditional solution – a Power analyzer

Limitations and problems

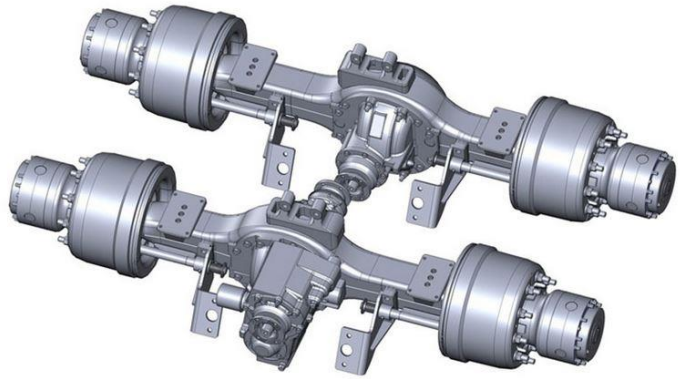
- Limited channel count
- Difficult to synchronize and to merge data
- Only voltage & current inputs
- Problems with rapidly changing fundamental frequency
- Not enough & unreliable results for dynamic load changes
- Raw data storage not possible or very time consuming

Overcoming two main limitations of conventional PAs

- **Problem 1**: Analog tracking is unreliable in dynamic load changes and gives questionable results
  - This is a problem für applications like dynamic testing, i.e. WLTP



- **Problem 2:** Limited channel count and only voltage / current inputs
  - This is a problem for complex system testing, i.e. double eAxle



Picture: Meritor

eDrive: The HBM Power analyzer components

Range of **mainframes**

2 to 17 slots for Power Analyzer cards

Up to **51 power channels** (U&I)

Up to **6 torque & 6 speed sensors**

Real time **Raw data storage**

3ch **Power analyzer card**

Typical **power accuracy 0.02%**

3 x voltage 1000 V, 3 x current for CT´s or clamps

Digital cycle detection for reliable results

HBM eDrive Power Analyzer

High accuracy **torque and current transducer**

T12HP with **accuracy class 0.02%**

Full range of CT´s 60A to 1200A
AC gain error 0.01%

Options and Accessories

EtherCAT/CAN FD for **real time data transfer**
Temperature inputs, isolated
CAN inputs
Vibration / Microphone inputs for NVH
HV inputs up to 20 kV

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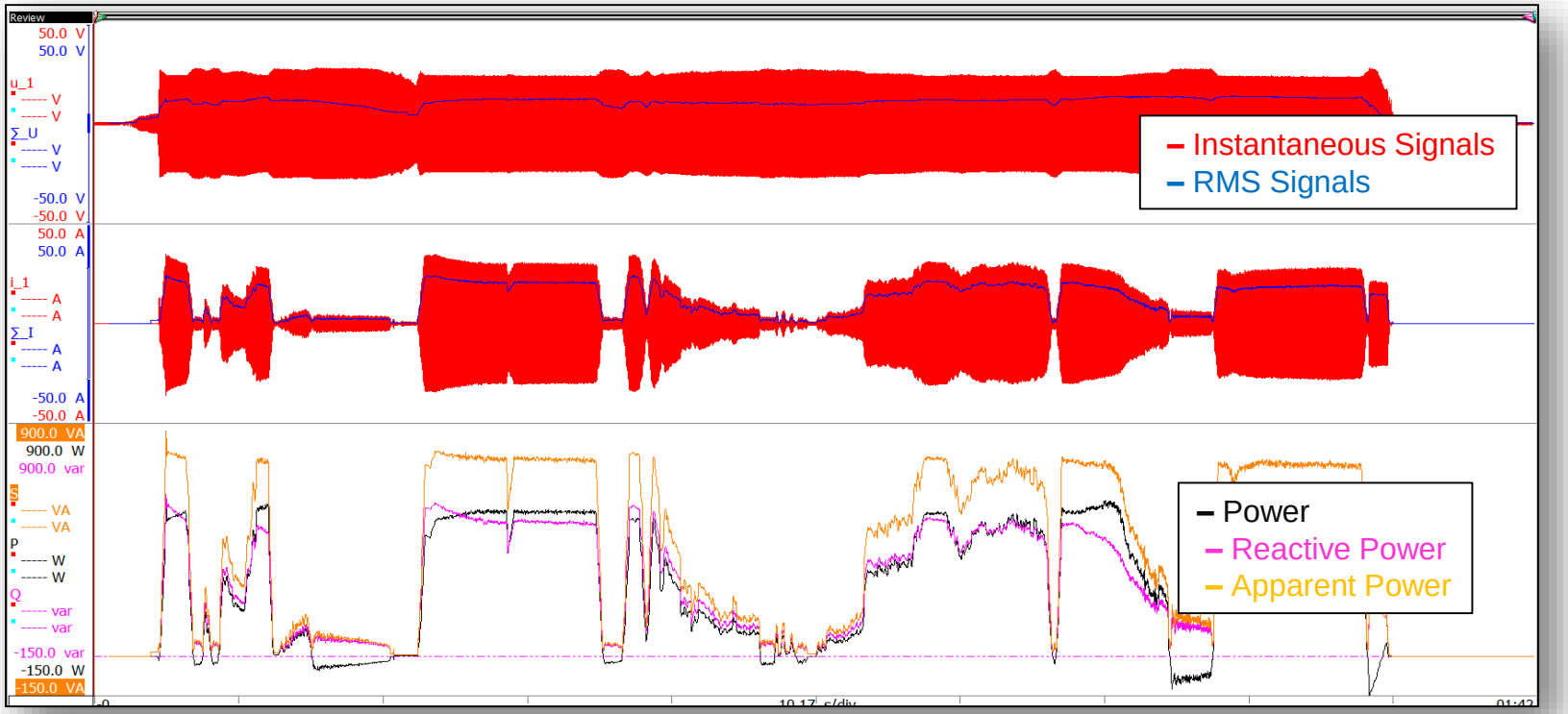
Dynamic testing

User Driving Patterns Effect Efficiency

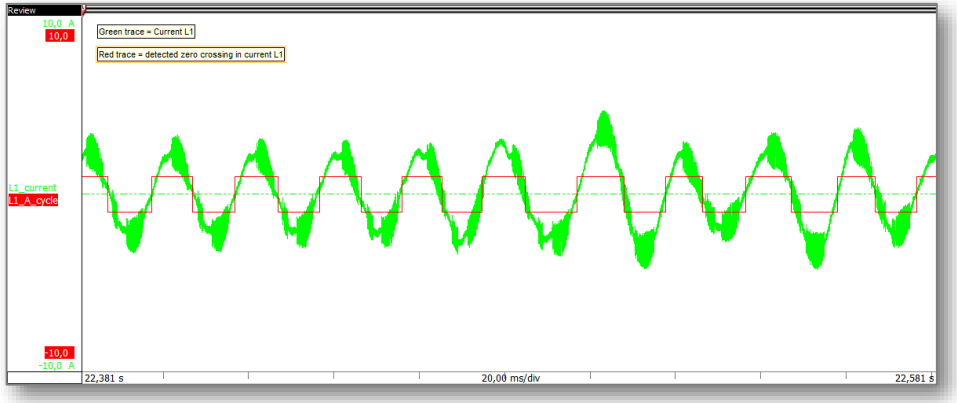
- Increased losses in dynamic situations makes drive cycle testing necessary
- Testing the system the way a user will do this; this gives accurate range estimations
- Cycle based power analyzer can accurately measure dynamic power
- Dynamic power is needed to optimize the machine controller



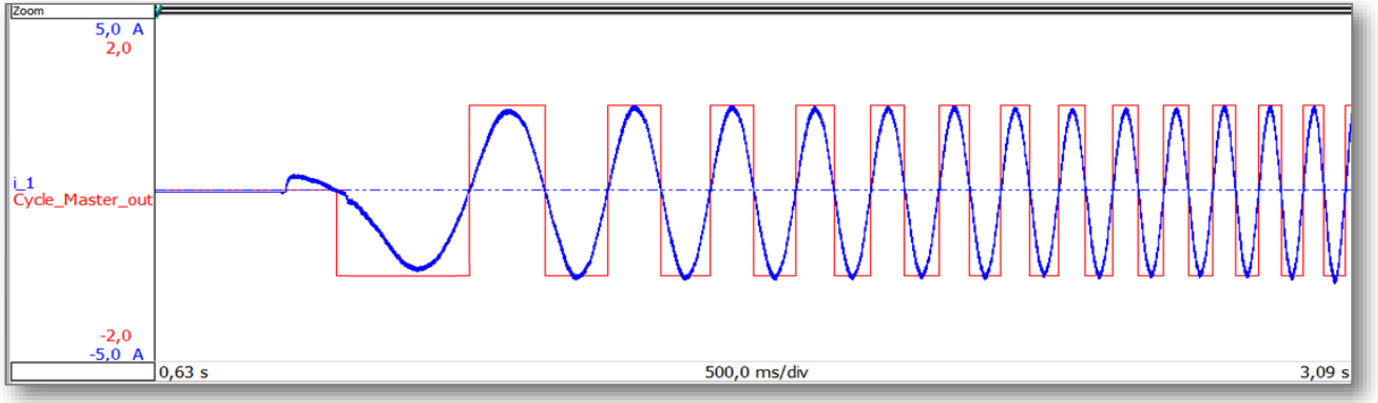
Dynamic signals from laps around a track on an electric scooter. Including: starts, stops, coasts, uphills and downhills

eDrive: Cycle detection – the key to correct power readings

- Conventional power analyzers use “Analog” PLL-based cycle detection
  - Problem: This only works in steady state load conditions
- The HBM eDrive system detects the cycles in real time using advanced digital algorithms
  - Then the power calculations are executed over a half cycle (or any multiple of this).
  - This delivers all cycle and thus accurate power results also in dynamic load changes



Current trace used for Cycle detection (green) and resulting “CycleMaster” trace (red)

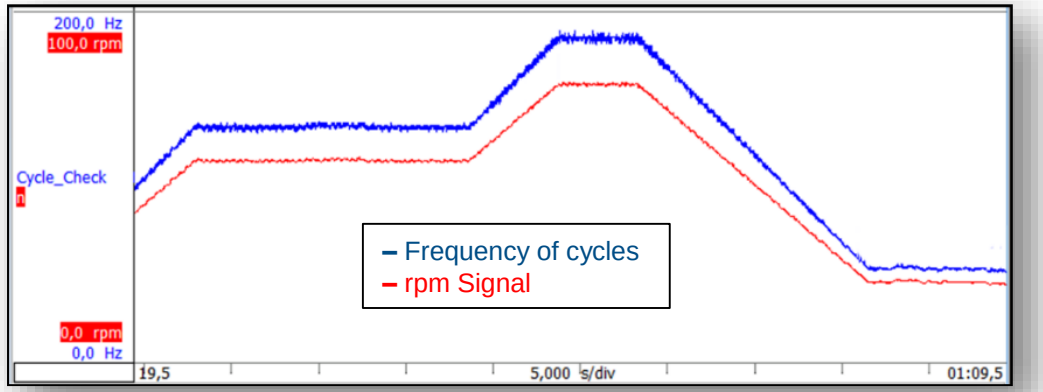


eDrive Cycle detection working during machine startup at rapidly changing fundamental frequencies

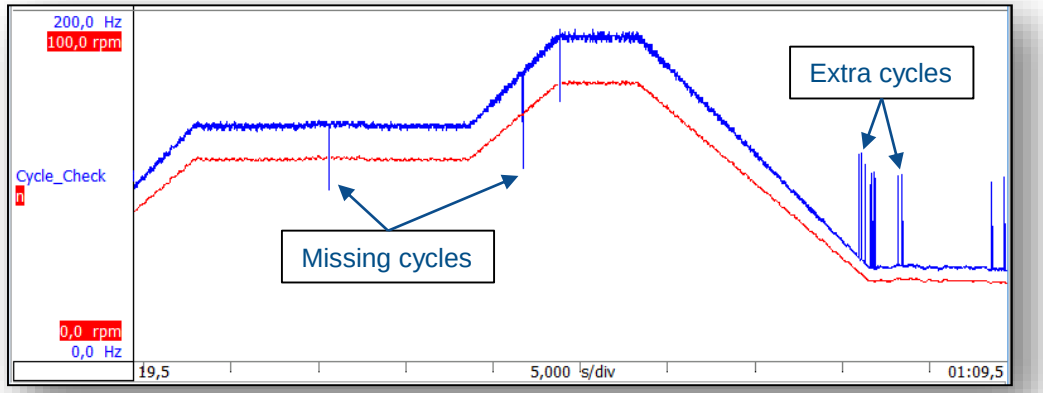
– *Side note: Each power analyzer card of the HBM eDrive system can be linked to others “cyles” or run on its own cycles.*

Cycle detect – Verification of proper results

- The eDrive application computes the frequency of the detected cycles
  - This frequency trace of the cycles needs to be the same “waveform” as the speed “n”
    - Differences are different scaling, pole pairs and slip (in case of an ASM)
    -
  - Wrong / missing cycles can have two effects:
    - Missing cycles will halven the frequency
    - Extra cycles will double the frequency
    - Easily seen as peaks in the frequency trace
- Using this method all cycles are checked
  - If these are correct, all power values are correct
  - And: Wrong cycles can be corrected post process



All cycles detected during 1 min test run

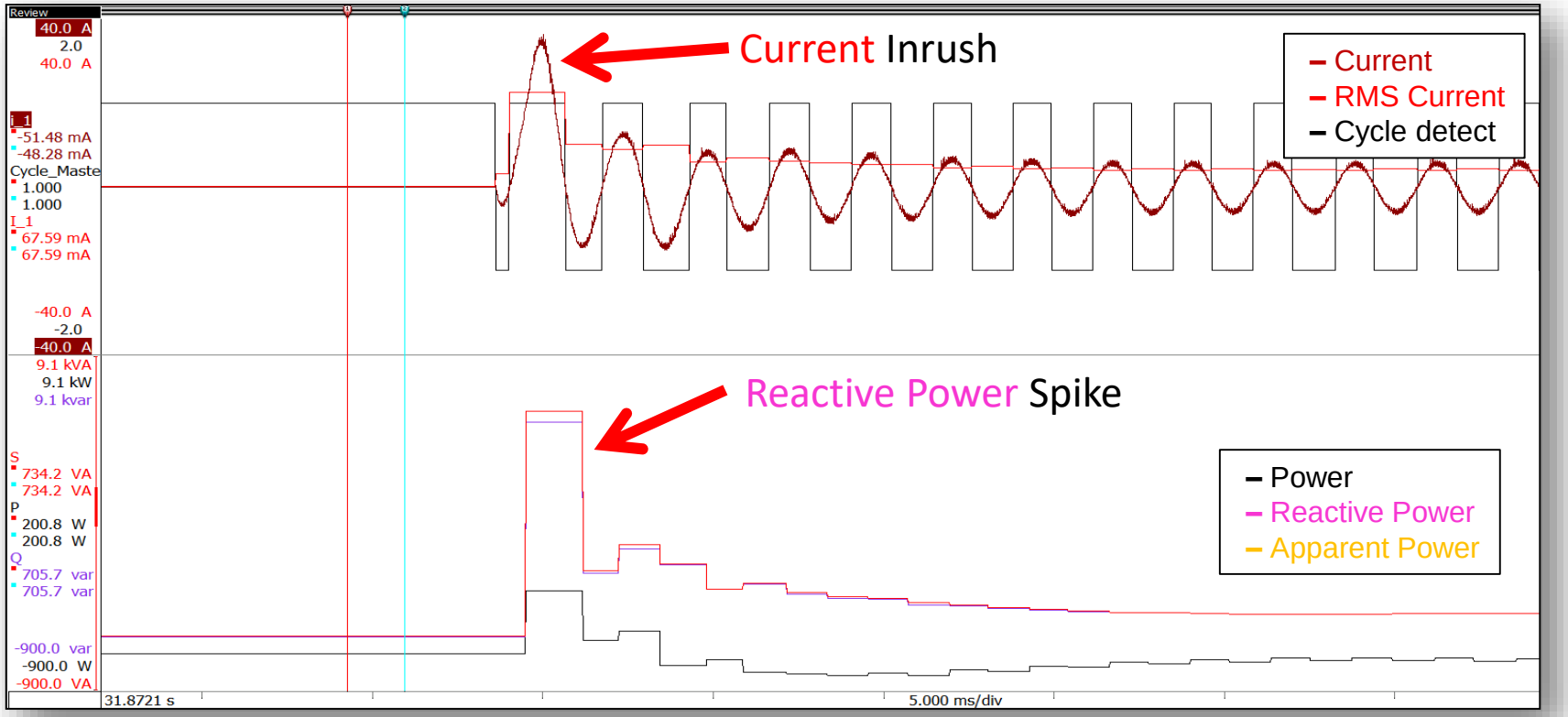


Some cycles incorrect during 1 min test run;

Note: cycle misfiring was caused by disabling AUTO mode and intentionally wrong manual settings

Importance of Dynamic Power Measurement

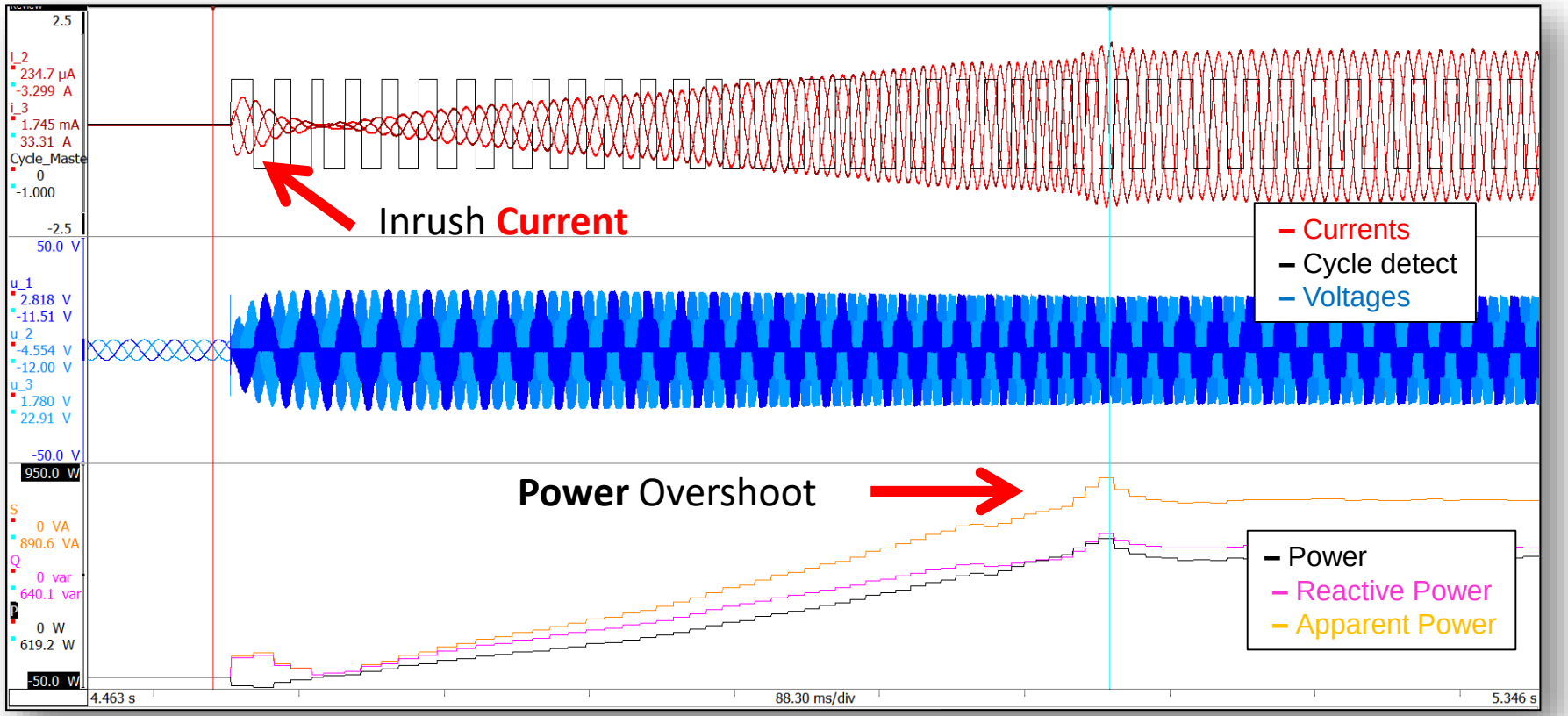
- At machine start, stop, or change of state there are losses associated with state change
- Example of an inverter started induction machine
- Large reactive power during the transient resulting in inefficiency
- Dynamic power measurements needed to understand actual efficiency during use



Current suddenly applied to an electric motor and associated power, reactive power, and apparent power for this dynamic load change

Dynamic Power Starting

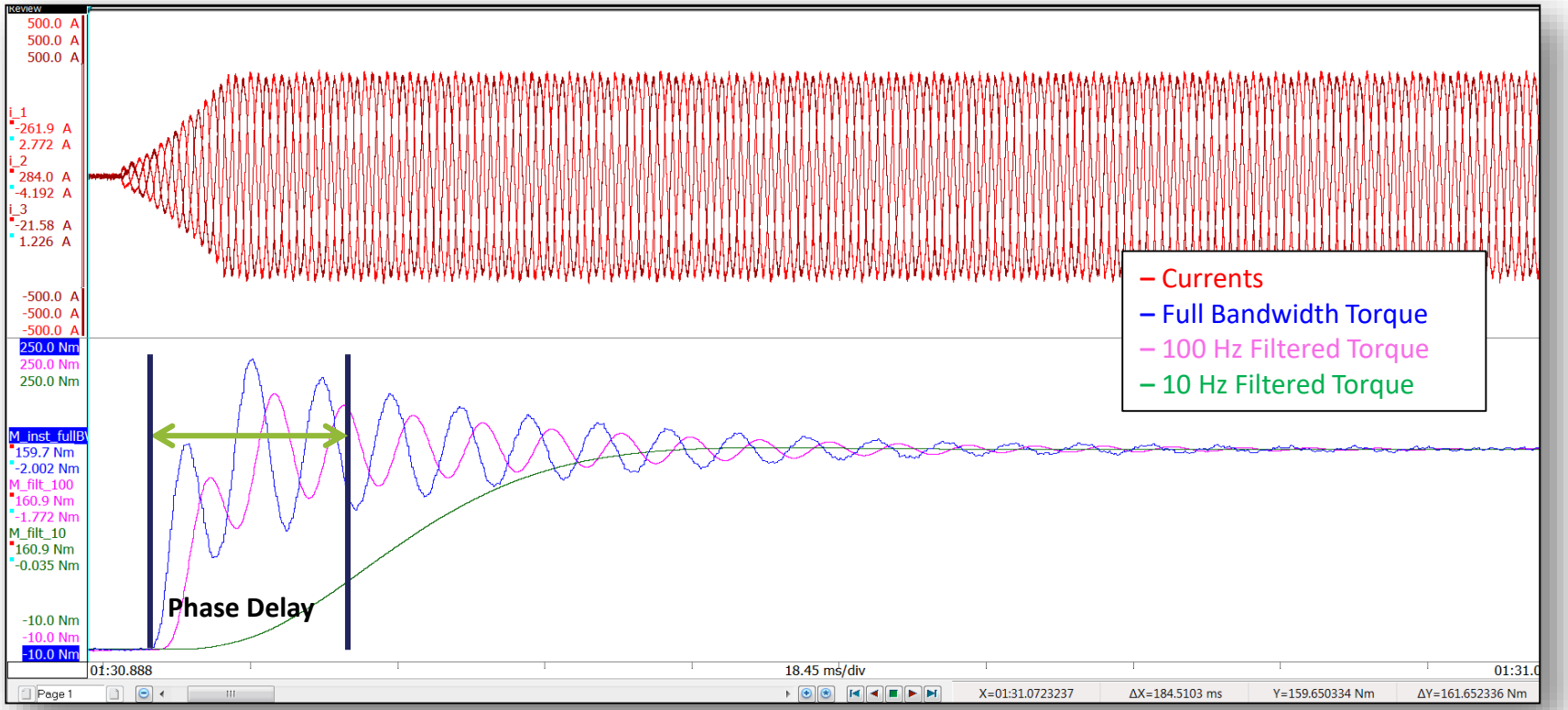
- Inrush of current when vehicle starts
- Voltage and current frequencies increase
- Extra power and reactive power needed to start the vehicle
- Overshoot of current, power, and reactive power at cursor



Scooter acceleration from 0 speed showing a ramp from 0 to full power.
Note back emf and PWM operation.

Properly Measuring Dynamic Torque

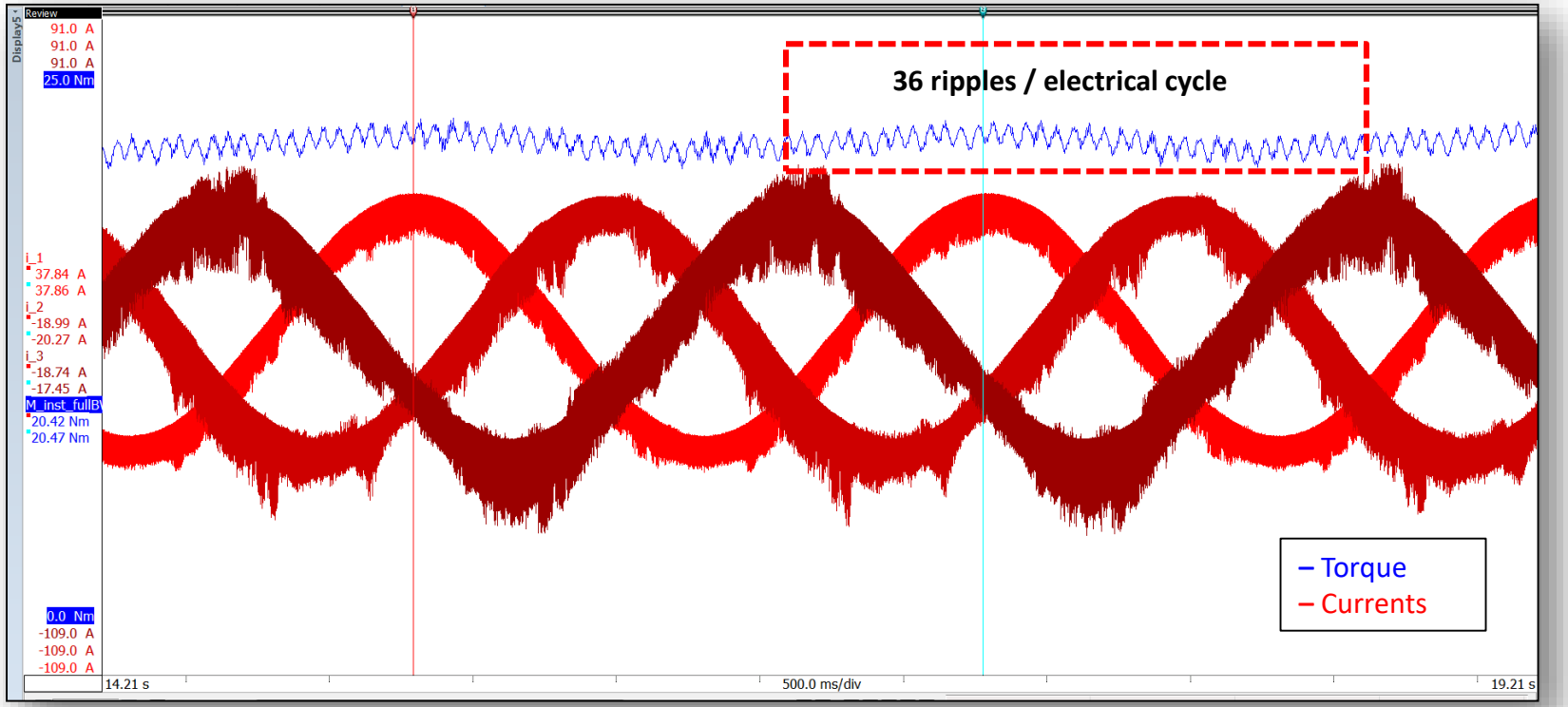
- Torque from load steps has dynamic content
- Torque responses often have overshoots and settling time
  - Overshoots can harm the system
- Filtered torque has phase delay and looses some amplitude info
- Highly filtered torque has large phase delay and looses all amplitude and frequency info



Load step for an electric machine and cyclical torque with different filter rates

Torque ripple → Dynamic torque in a steady state

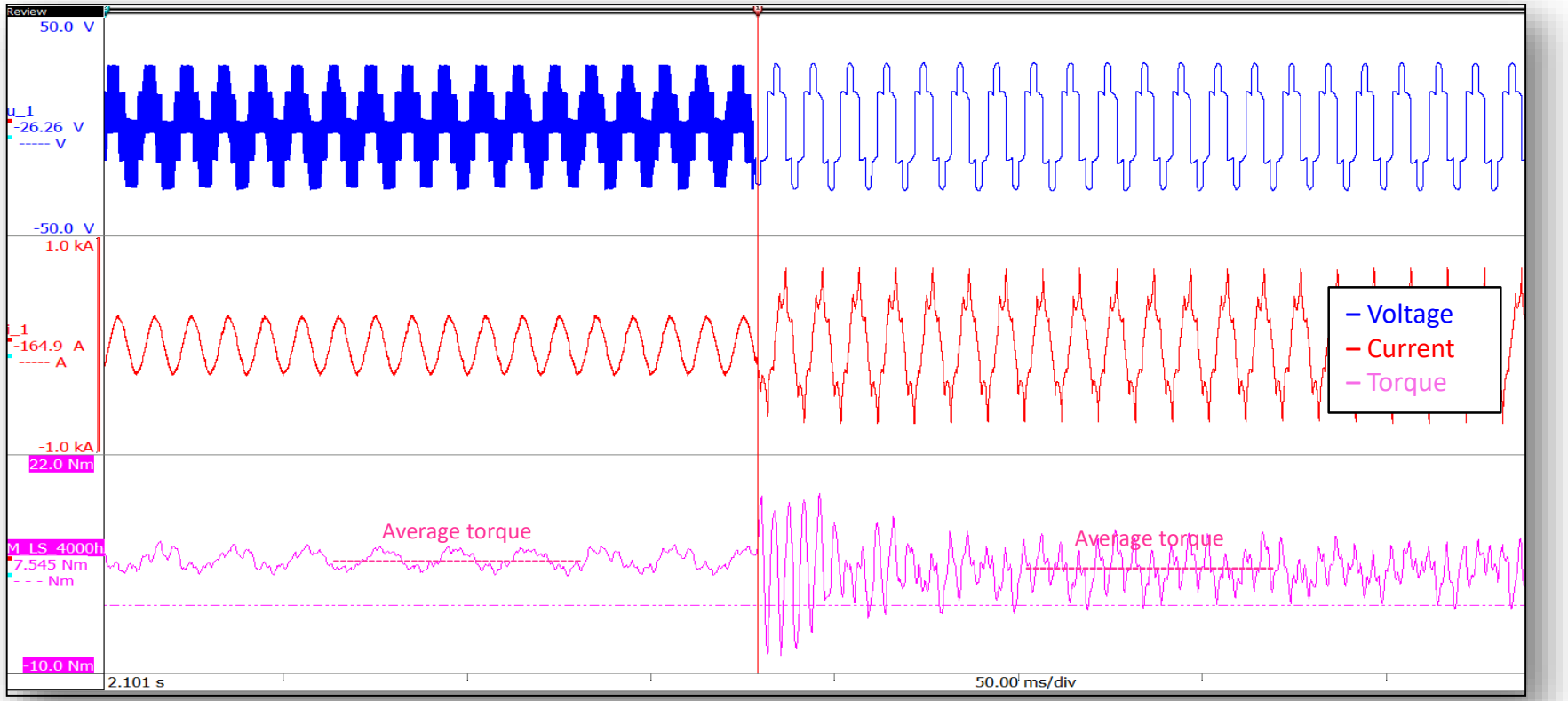
- Torque is not constant
  - It always is a DC with an AC ripple
  - Ripple has a cyclical nature
- The ripple is a function of motor construction and excitation
  - Slots
  - Magnets
- Ripple frequency is proportional to speed



Three phase motor excitation currents (red) and resultant torque ripple (blue)

Torque ripple → Effects of the Inverter

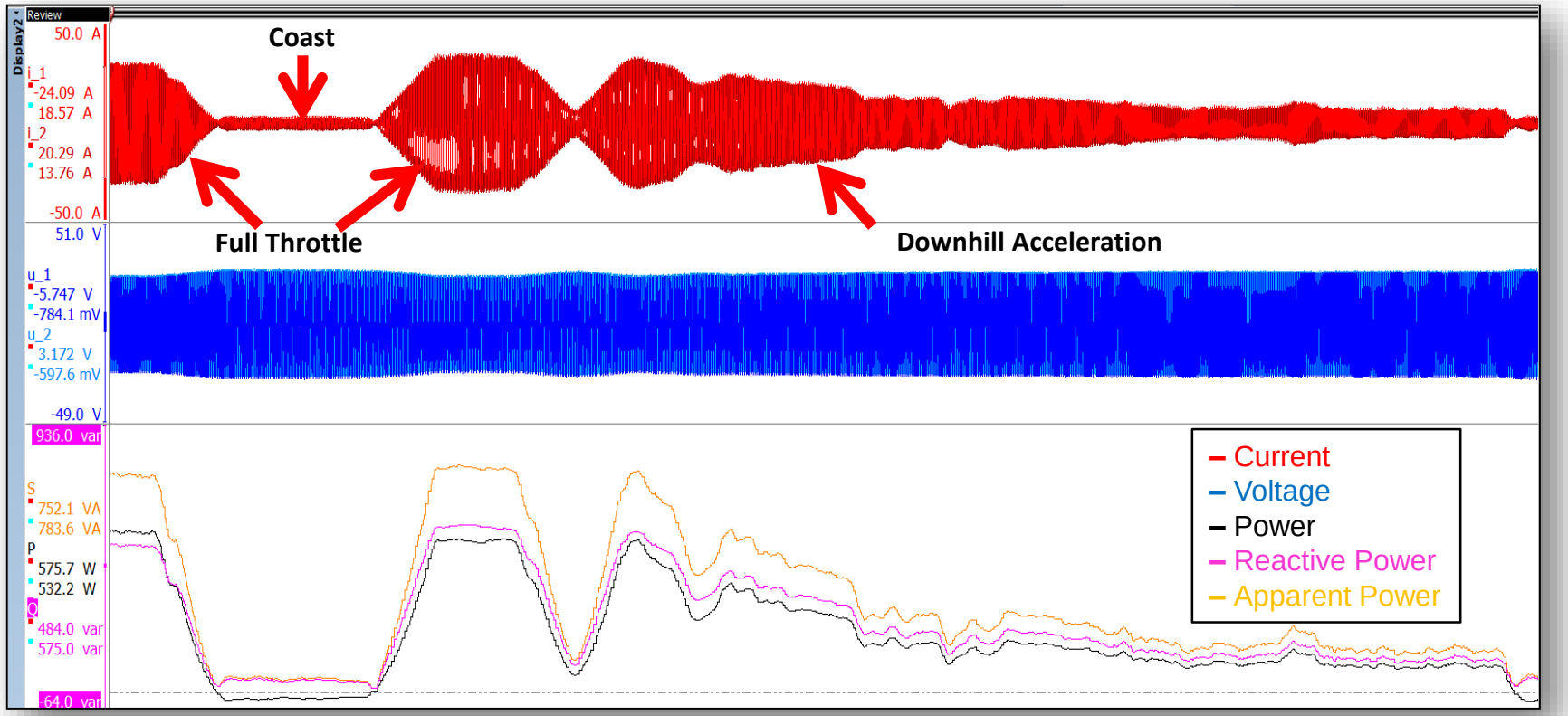
- Control changes are a good opportunity to look at torque transients
- Example: Control change from PWM to six step (smooth sine wave to jagged)
  - Ripple frequency increases with control change
  - Negative torque swings



Control change from PWM to 6 step

Real World Road Load Test Dynamics

- Driving in different scenarios results in different current profiles
- Power changing with environment or driver habits
- Power fluctuations influence system efficiency
- Understand control behavior to disturbances



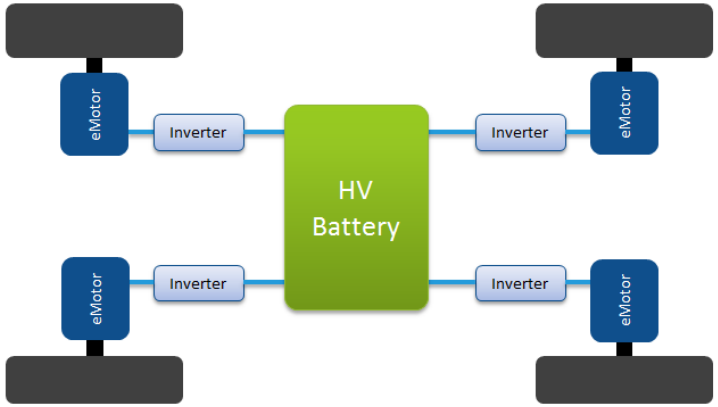
Scooter dynamics for full throttle, a coast, and downhill acceleration

Testing complex systems

New hybrid and electric drive concepts – examples: system level

All wheel drive

- Superior driving performance

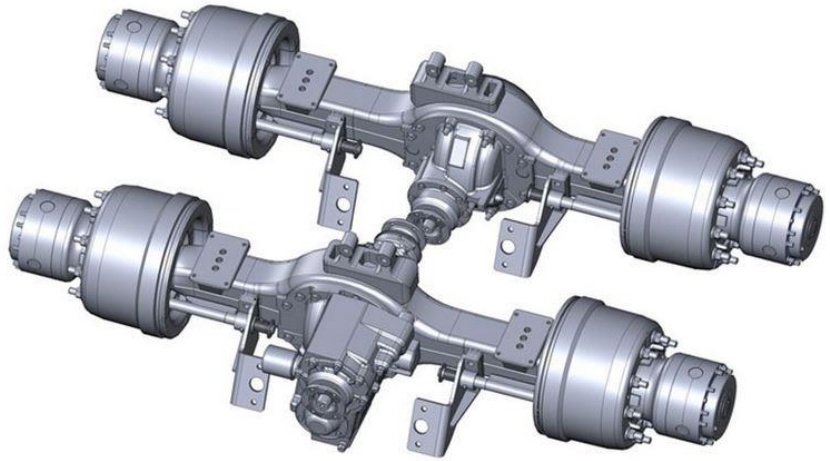


Picture: qs motors

- Needs high ch count of power channels, 4 x torque/speed and advanced analysis to understand system behavior

Dual eAxle drive

- Good compromise between costs and driving performance



Picture: Meritor

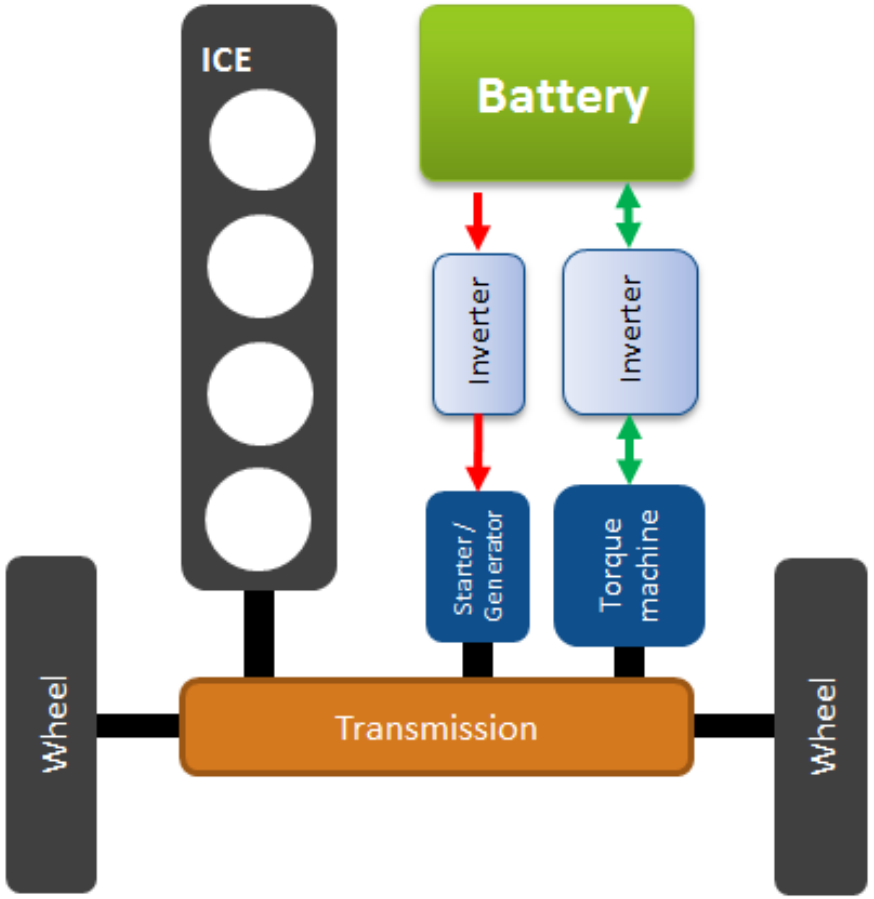
- Needs 2 x DC power, 4 x torque /speed, and advanced analysis to understand system behavior

New hybrid and electric drive concepts – examples: system level

Complex Hybrid drive with eCVT

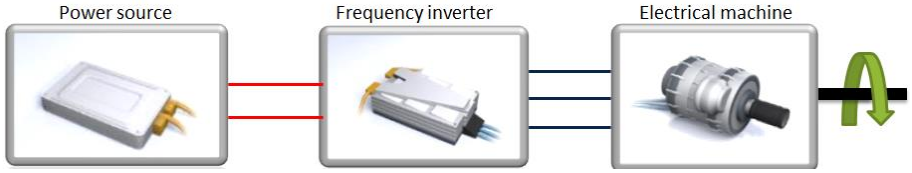
- Advanced hybrid concept with ICE, dual e-machines, dual inverters
- Very complex drive strategies
  - Seven different energy flow conditions

- Needs lots of electrical and mechanical inputs
- Needs multiple torque/speed inputs
- Often TM / SG torque cannot be measured
  - Airgap torque computation needed



The eDrive Creator: Allow user to „draw“ his system

- Customer maps his systems by redrawing it in the eDrive software

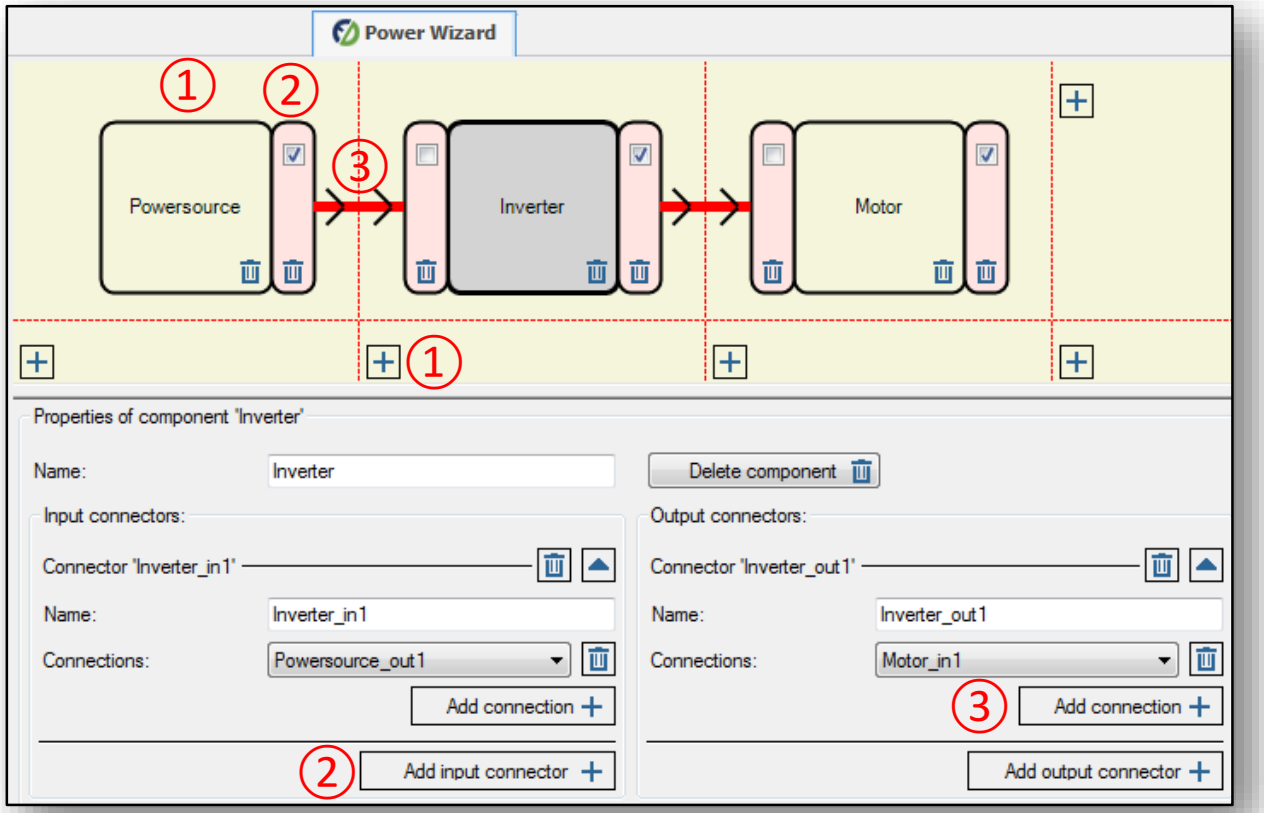


Example application „simple drive line“

- First step is to create a „System view“
  - Add **Components** ① as needed
  - Add **Connectors** ② to components
    - Components auto size if needed
  - Add **Connections** ③ between connectors

- In a second step (not shown)
  - Link cycle results between **connectors** if needed
  - Create **Efficiency blocks** as needed

- **With the given “system view”, all formulas and displays are automatically created**



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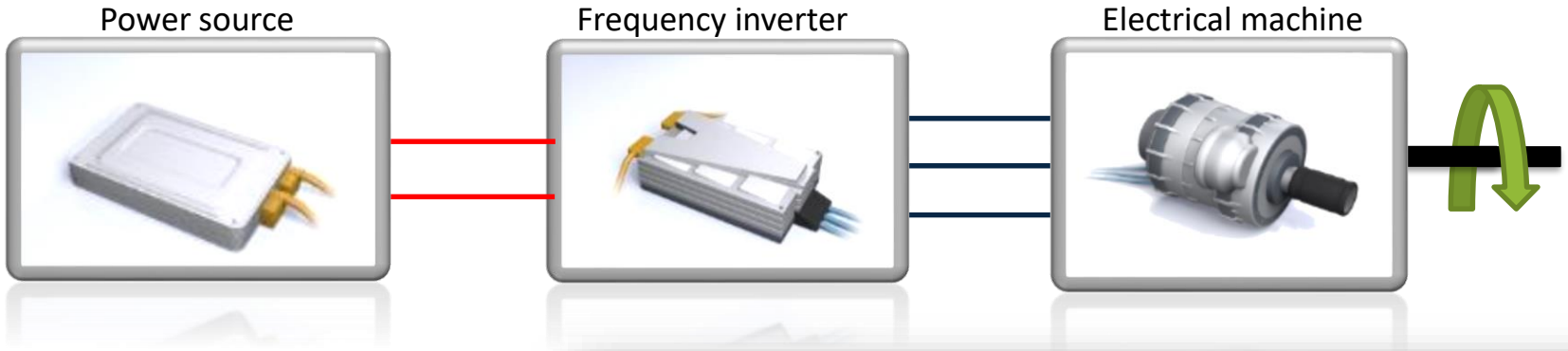
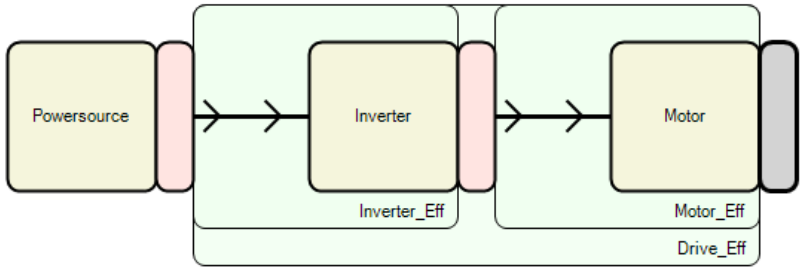
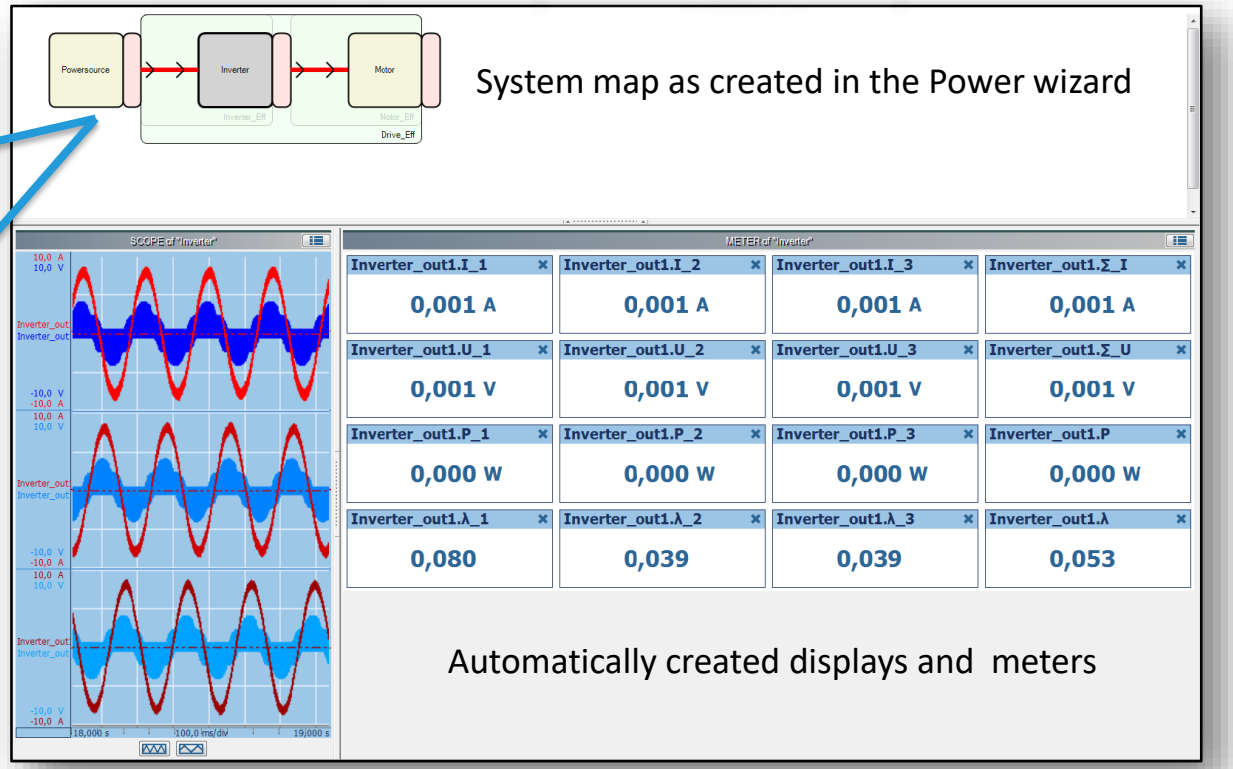
eDrive Creator example: Simple drive line



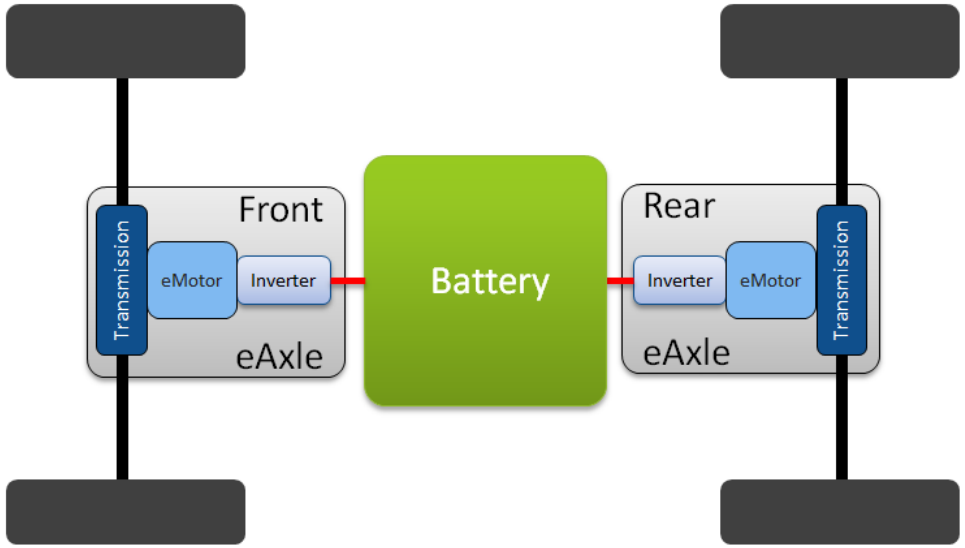


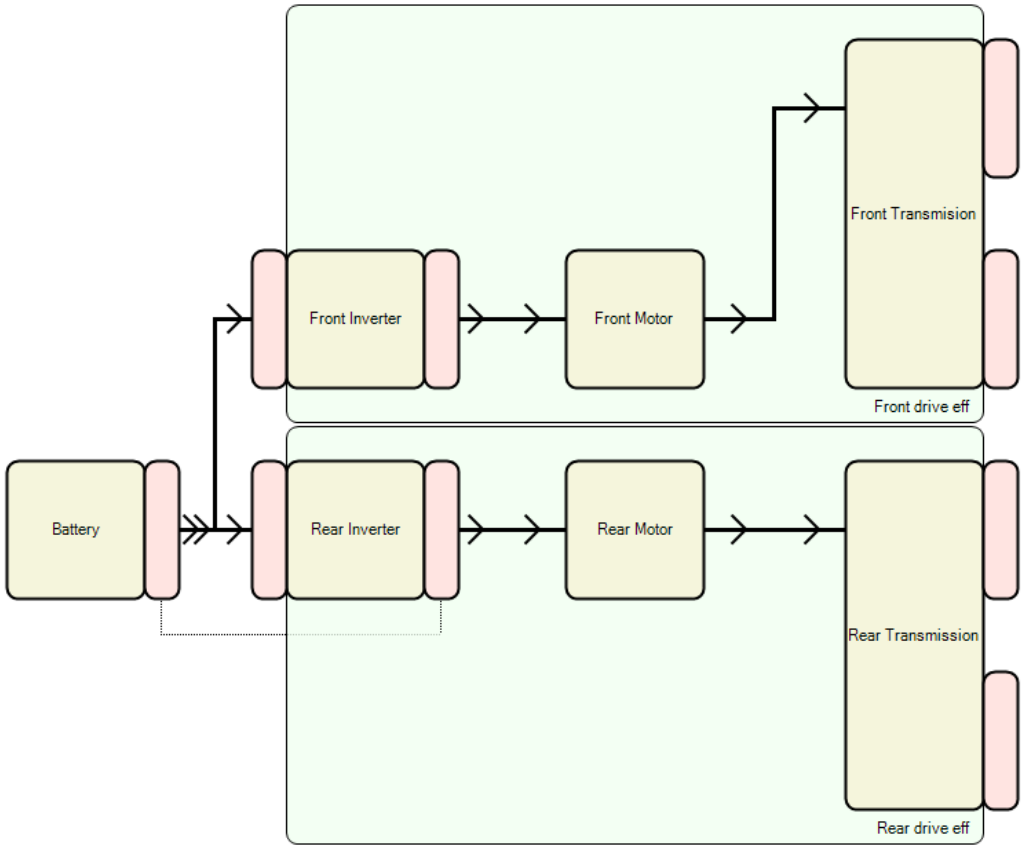
System map as created in the Power wizard



Power Wizard example: Dual eAxle

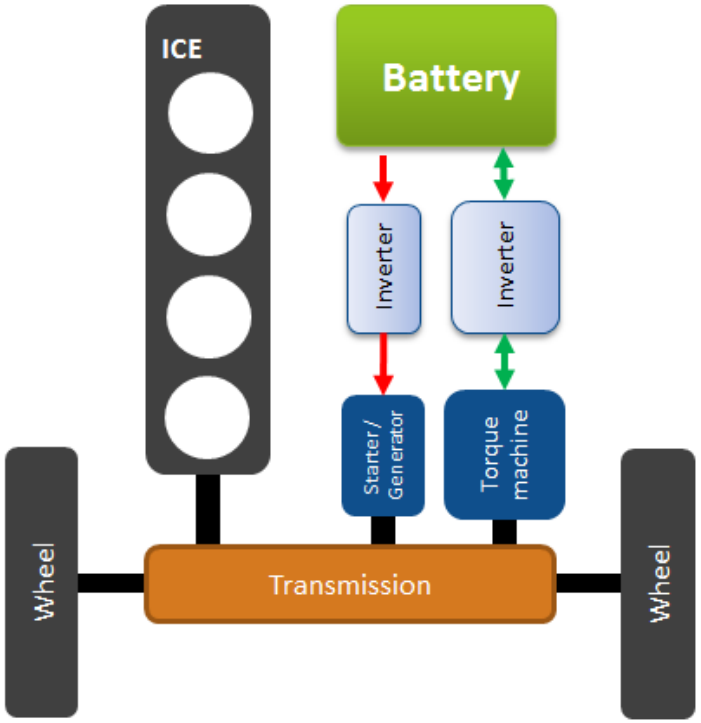
- Needs a total of
  2 x DC power channels and
  4 x Torque/ speed mechanical power channels

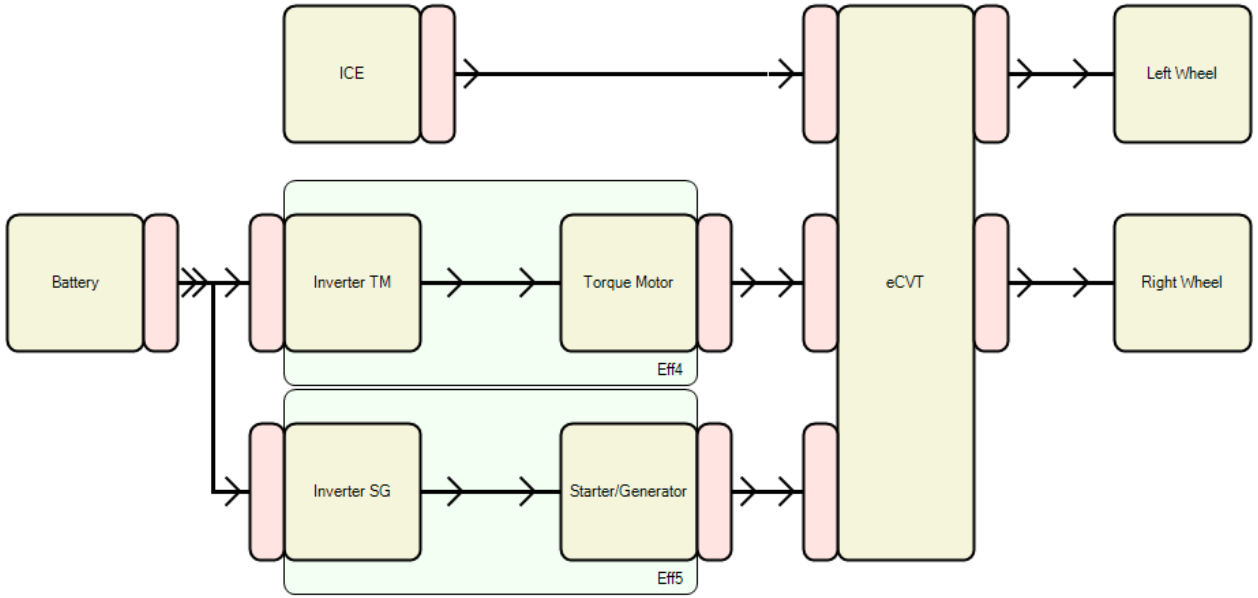




Power Wizard example: Hybrid drive with eCVT

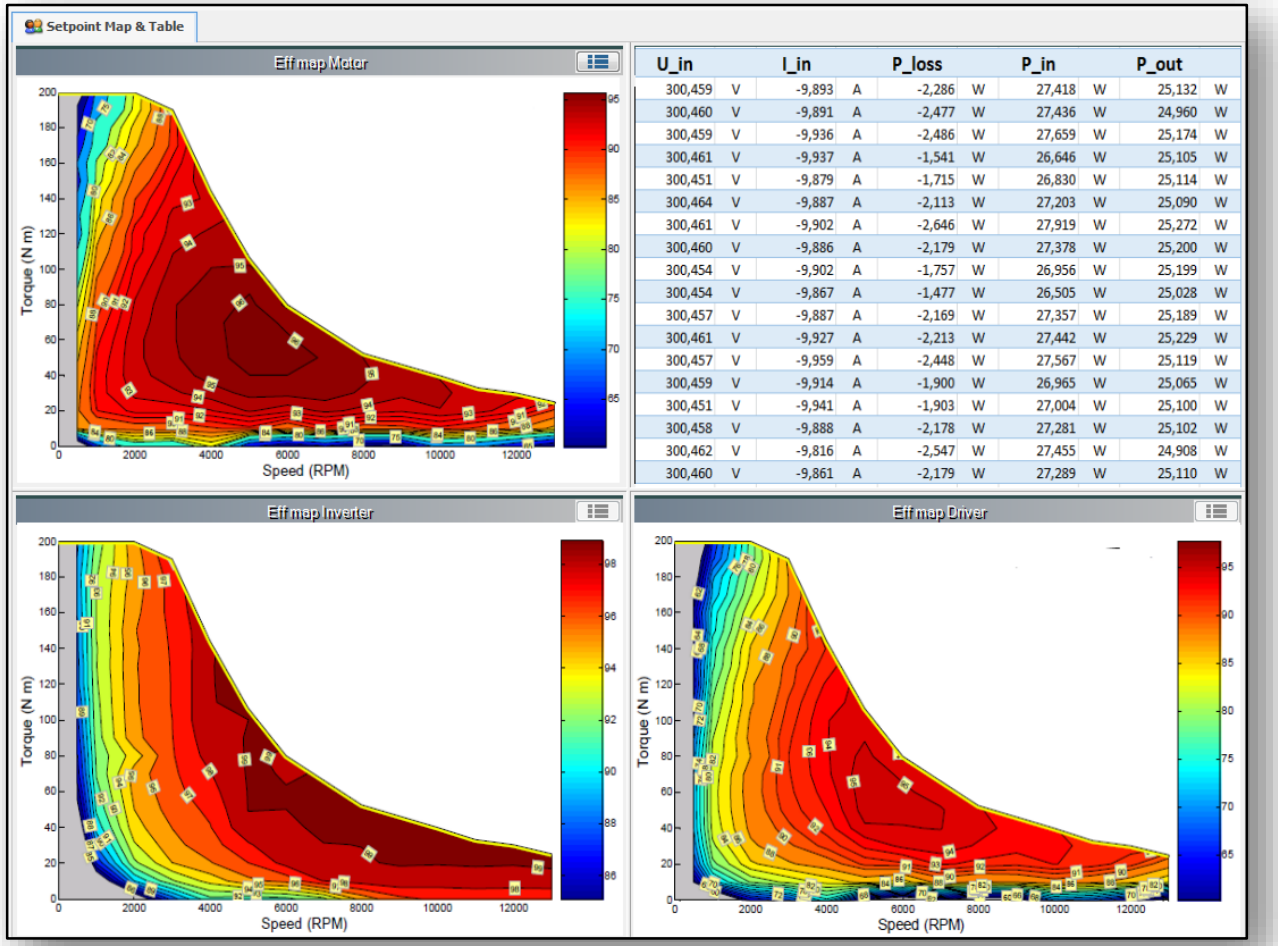
- Needs a total of
  6 x AC Power channels and 3 x DC power channels and
  5 x torque/speed mechanical power channels





The „Power Wizard“: Enable multiple Efficiency maps

- Third step is to set up the desired maps
  - User just needs to select x, y, z from available power results
- Multiple efficiency maps can be drawn
  - Done live as new set point results come in
  - Applications:
    - Motor map, inverter map and drive map can be done simultaneously
    - Maps for multiple machines at the same time
  - Gives live feedback about test
- The software also creates a CSV file
  - This can be used for further analysis



Note:
Raw data is stored as well and can be analyzed with MATLAB or DIADEM, for example

Summary

Comparison conventional PA with HBM eDrive solution

	Power Analyser	HBM eDrive
		
Power channels	3 to 7	Up to 51
Torque/Speed channels	1 to 2	Up to 6
Accuracy	Very high for static signals	High for all signals
Power and efficiency measurement	Yes	Yes
Synchronization	Difficult	Not needed as all in one system
Motor maps (Efficiency, vibration, modulation…)	No	Yes
Raw data storage	Difficult and slow	Yes, real time
Dynamic testing	**No**	**Yes**
Multiple fundamental frequencies	**No**	**Yes**
Temperatures	No	Yes
NVH tests	No	Yes
CAN in, out, remote	Yes, some	Yes
Drive analysis (i.e. space vectors, dq currents)	Yes, some	Yes
System analysis (i.e. energy flow, symmetrical components)	No	Yes

HBM eDrive summary

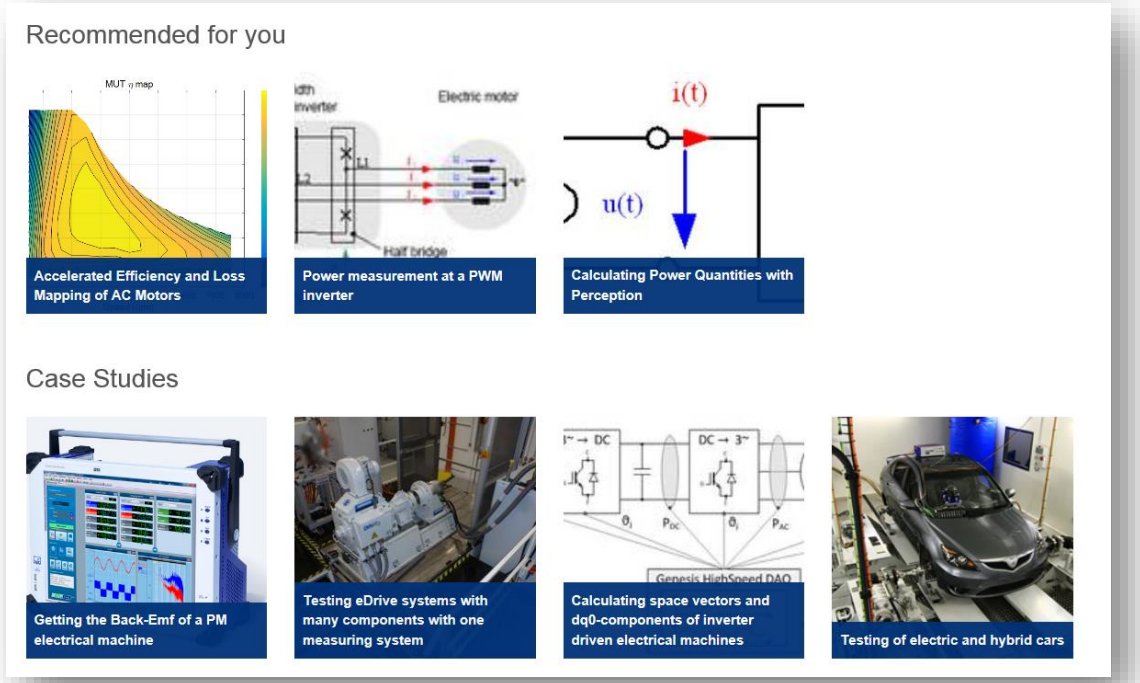
- Scalable power analyzer
  with up to **<u>51 x power channels</u>**
  - Also 6 x torque/speed, temps, CAN, NVH….
- Real time power calculation per half cycle
  deliver **<u>reliable results in dynamic changes</u>**
- Scalable concept and eDrive Creator user
  interface enables **<u>analysis of complex systems</u>**
- Raw data is **<u>stored in real time</u>**
  for advanced analysis and verification

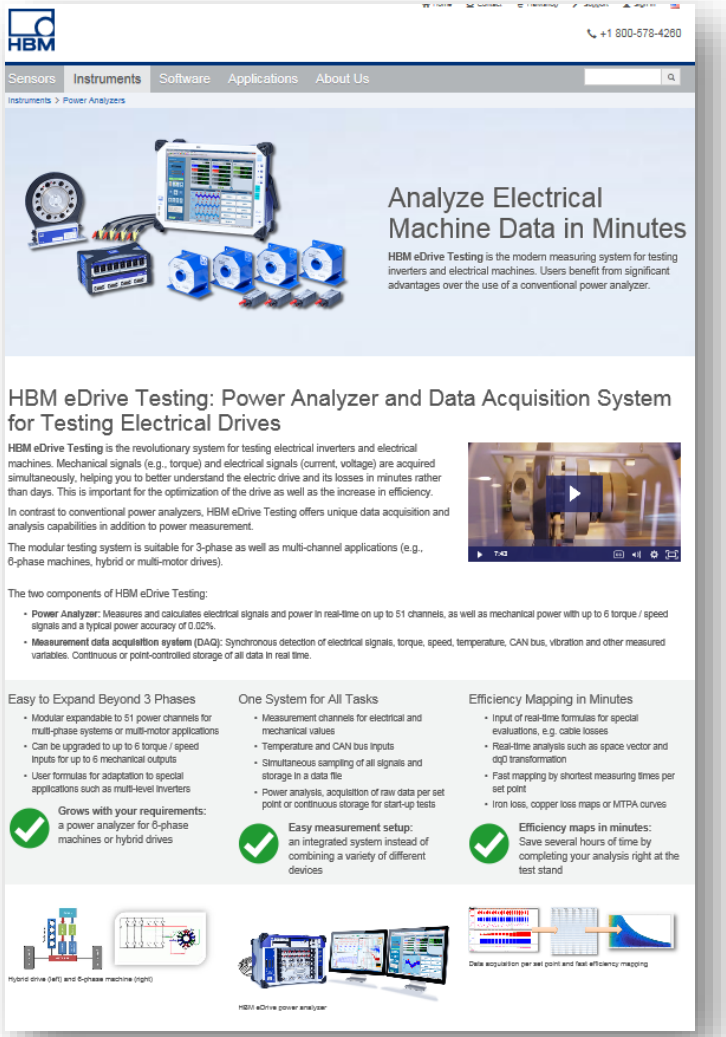
Additional informationen

More information can be found on our website:

- https://www.hbm.com/en/3153/edrive-testing/

On the same page there are
more interesting links to the same topic:





Any questions?

- If you have any questions, please do not hesitate to contact us: webinar@hbm.com
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