

Accelerated Control and Calibration

Faster electric motor testing



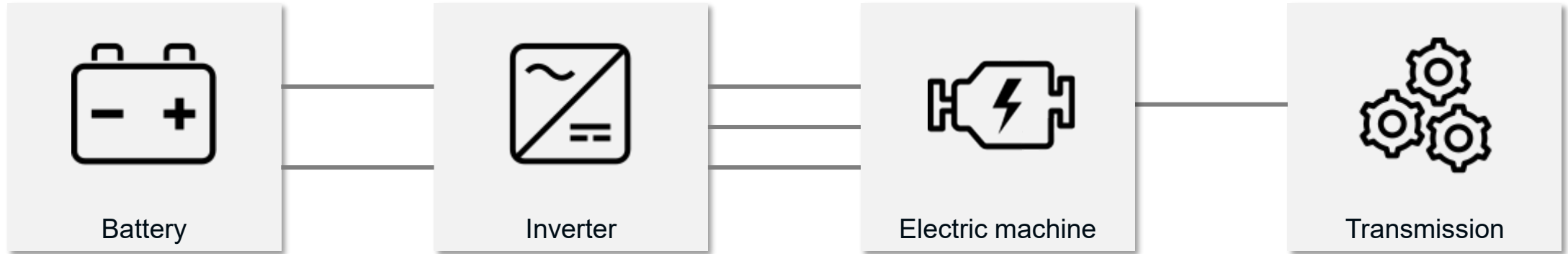
Mitch Marks
Business Development - Electrification
HBK

Agenda

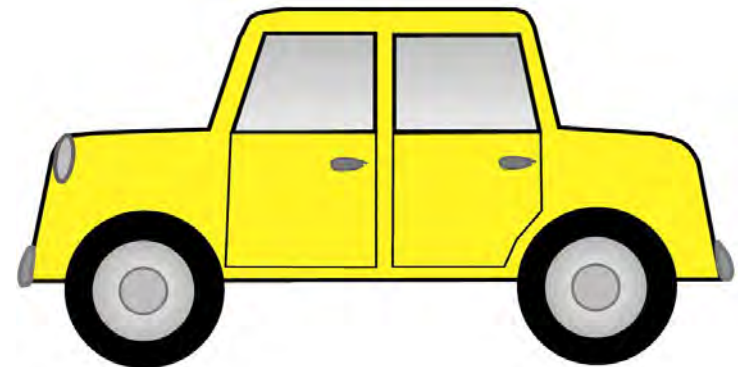
1. Powertrain Calibration – background
2. Motor Controller
3. Testing
4. Sources of delay in testing
5. Accelerated testing
6. Examples

Powertrain Calibration - Background

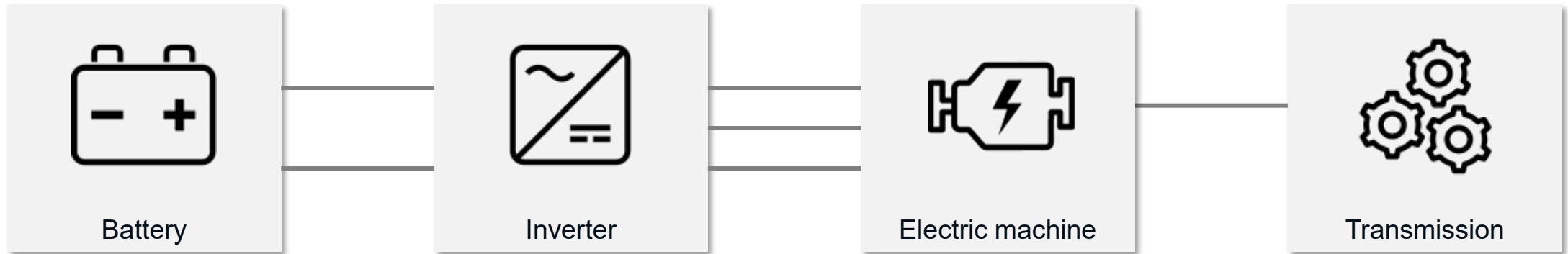
Electric Powertrain – Review & Function



Create Torque & Modulate Speed



Powertrain Variables & Control



Battery Variables

- ▲ Voltage level
- ▲ State of charge

Inverter Variables

- ▲ Control strategy
- ▲ Temperature

Motor Variables

- ▲ I_d , I_q , L_d , L_q , Flux
- ▲ Temperature

Mechanical Variables

- ▲ Gear state
- ▲ Temperature

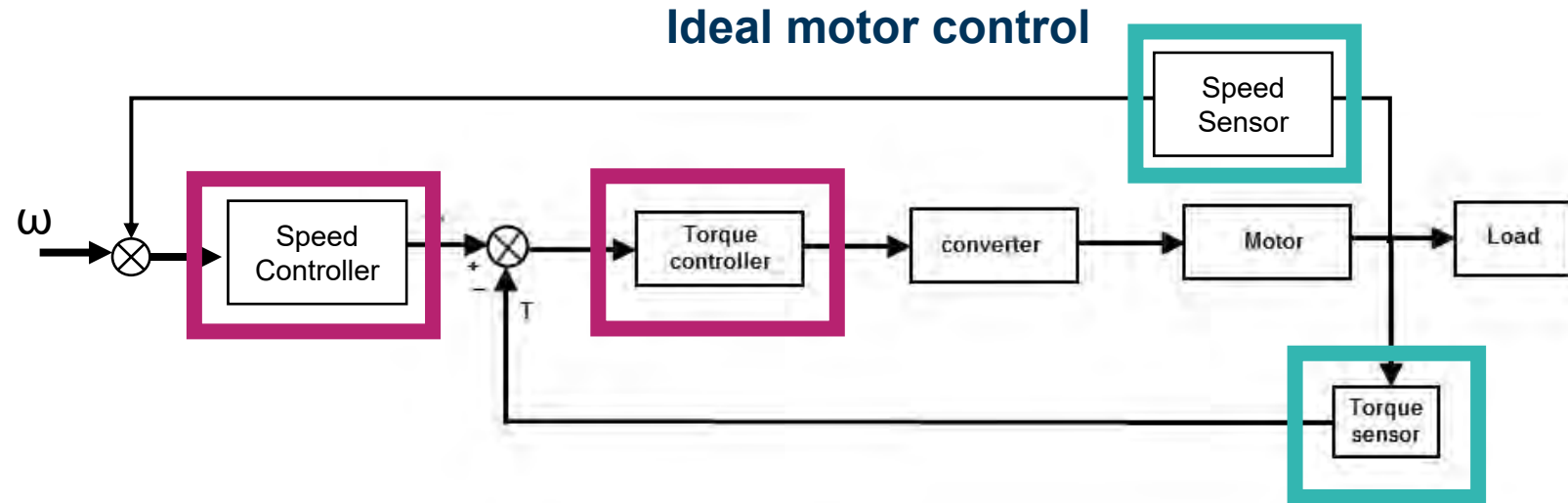
**Motor Controller Manages Transitions
In the Presence of Many Variables**

Motor Controller

Intro to Controller

- Measurement
- Math & Estimation

- ▲ Need to regulate torque and speed
- ▲ Measures torque and speed
 - Commanded Torque from $\Delta\omega$
 - Commanded switching from ΔM
- ▲ Dictates V & I of the inverter
- ▲ Accounts for external states



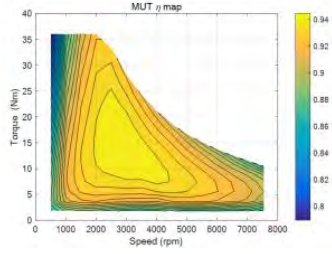
Challenges for in Vehicle Controller Measurements

- ▲ Torque, current, voltage, speed, temp
- ▲ Cost of sensors
- ▲ Accuracy of sensors
- ▲ Reliability of sensors
- ▲ Number of operation states
- ▲ Reliability of estimations for any given state

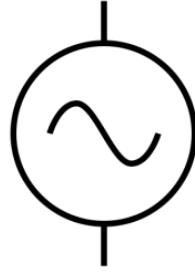


What Needs to be Tested?

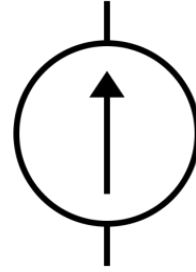
What do we Need to Measure for a Characterization?



Efficiency



Voltage



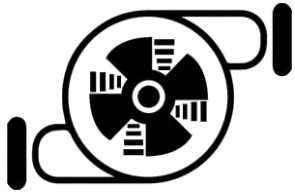
Current



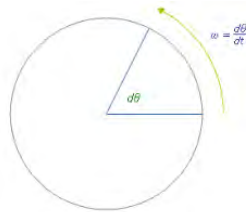
Torque

$$a = \frac{\Delta v}{\Delta t}$$

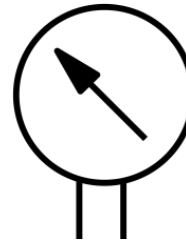
Vibration



Flow



Speed



Pressure



Temp

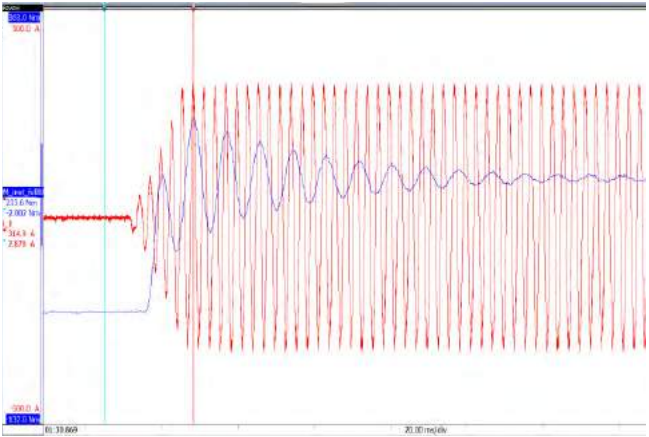


CAN

What do we Want to Understand?



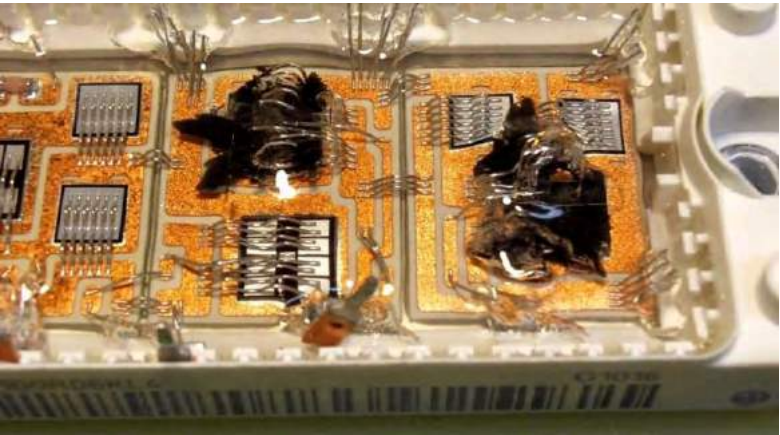
Range



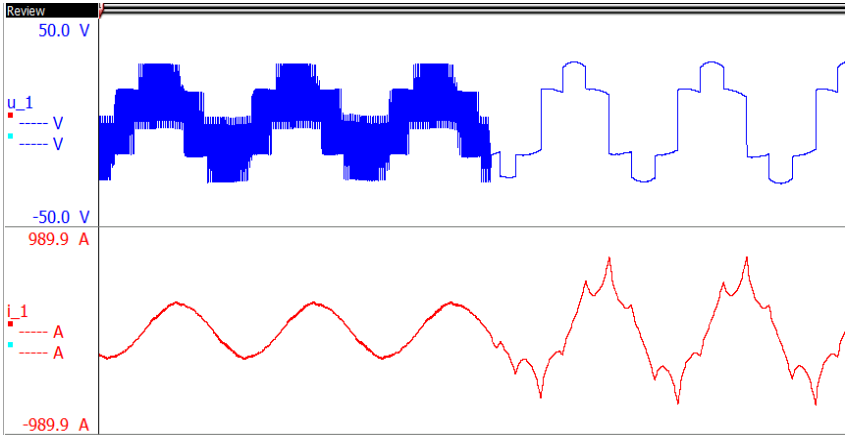
Transients



Estimated Torque Accuracy



Failures



Motor Control

What Conditions do we Need to Account For?



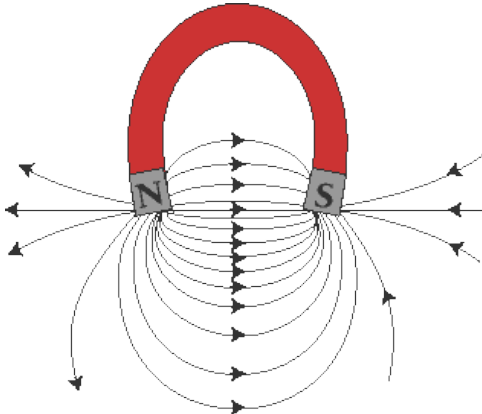
Voltage



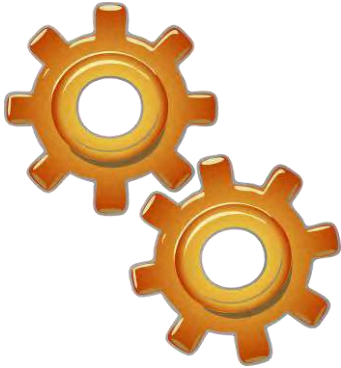
State of Charge



Temperature



Magnetic Flux



Gear

Dynamometer Test Stand

▲ Load Machine

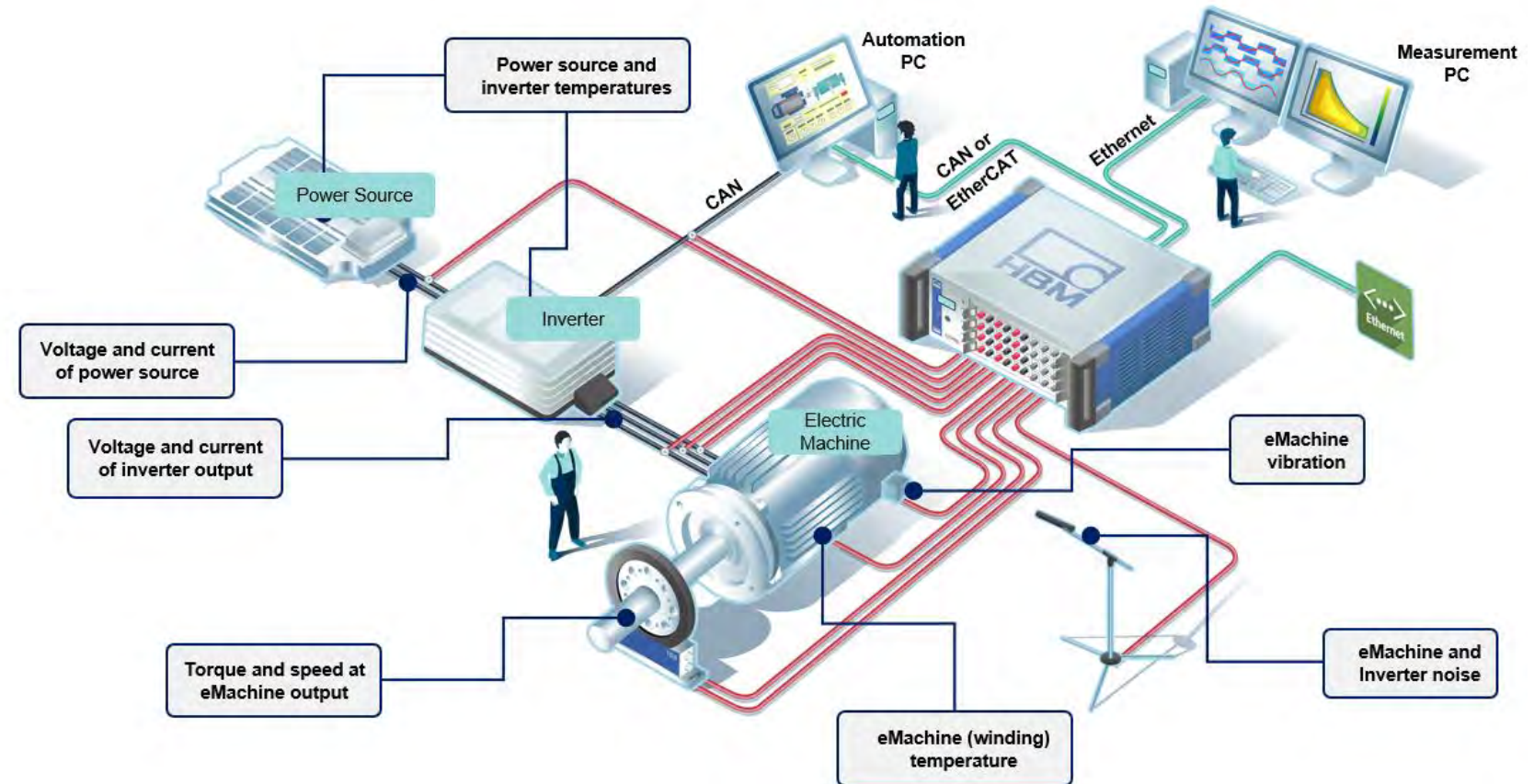
- Simulate test conditions
- Hold stable points

▲ Sensors

- Measure relevant quantities
- Accuracy to fit needs

▲ Measurement

- Accuracy to fit needs
- Sampling and bandwidth
- Time align relevant quantities



Sources of Delay in Motor Calibration

Delays in Testing

Many measurements

- Data alignment
- Data types
- Every department needs to test

Errors during testing

- Re-run tests
- Nonsense results

Thermal stability

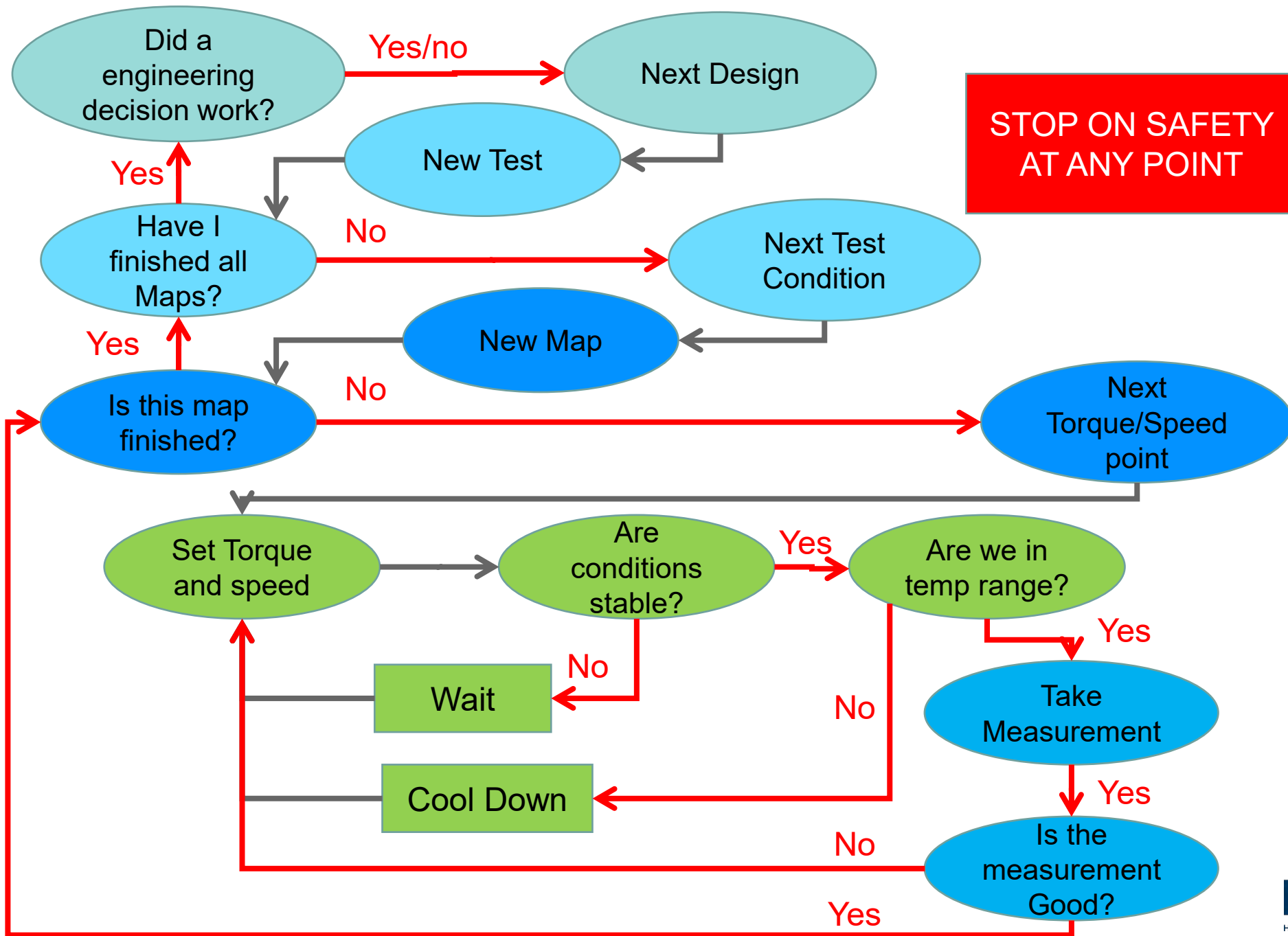
- Time heating up
- Time cooling down

Measurement points

- How long does each point take
- Thousands of points

Troubleshooting

- Black box equations
- Complex equation setup



Measurement Points → Time Consumption

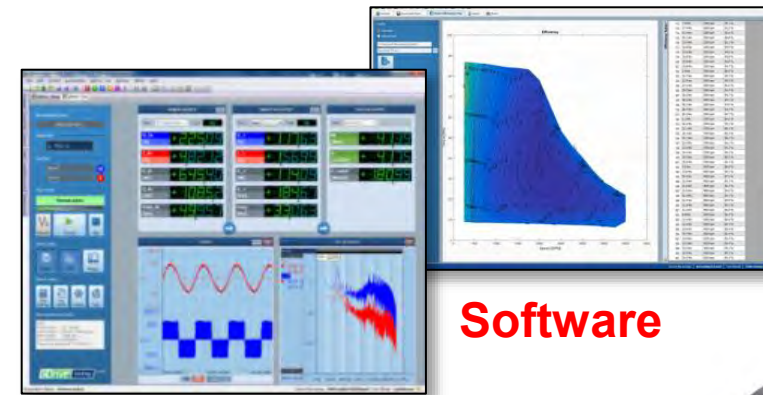
- ▲ Efficiency Map is 200 points
 - 10 temperatures
 - 5 gear states
 - 5 states of charge
 - $200 \times 10 \times 5 \times 5 = 50,000$ Points
- ▲ Transitions
- ▲ Heating up & cooling down
- ▲ Other tests – control, transient, calibration
- ▲ Plus Re-running tests

Points	10 second Measurement	1 second Measurement	.1 second Measurement
50k	139 hours	13.9 hours	1.39 hours
20k	55.5 hours	5.6 hours	.56 hours
5k	13.9 hours	1.39 hours	.139 hours

Accelerated Testing

Simplification Methods

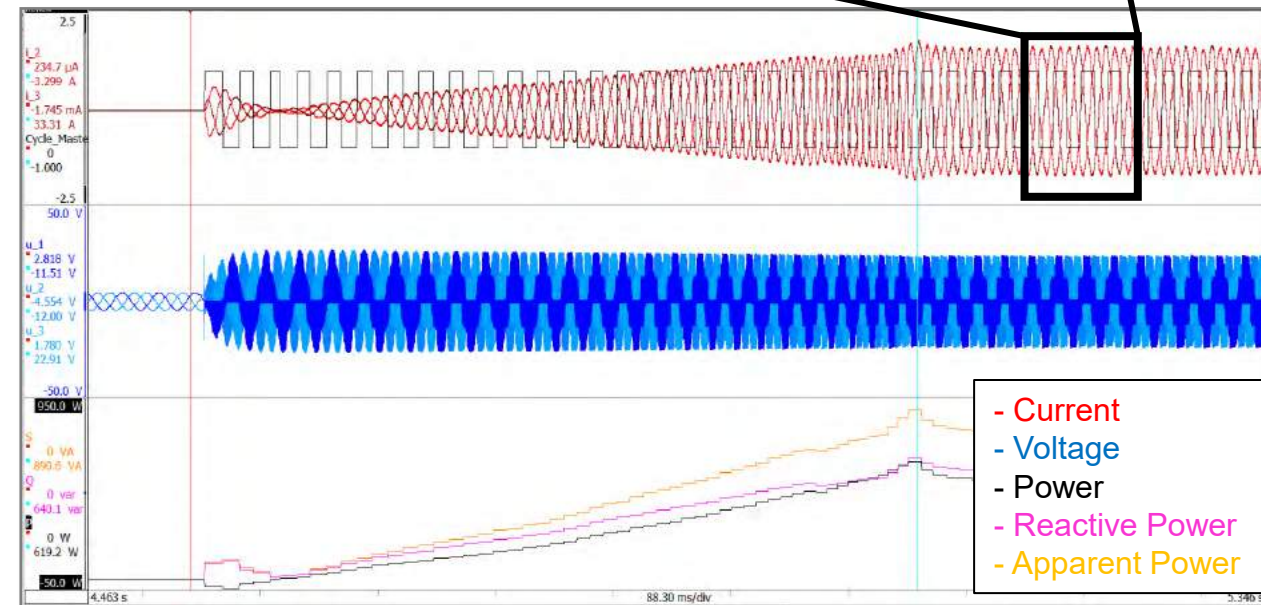
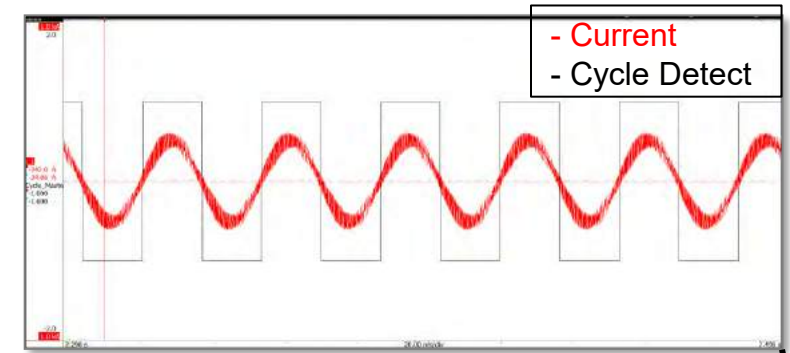
- ▲ Reduced number of measurement devices
 - Simplified setup
- ▲ Decreased measurement time
 - Less time measuring
 - Less time waiting for thermal
- ▲ Recorded data
 - No need to re-run tests
- ▲ Real time feedback
 - Faster test transitions
- ▲ Transparent / editable equations
 - Simplified troubleshooting
 - Advanced equations – DQ0



Examples

Fast and Accurate - Power is Calculated on a 1/2 Cycle Basis

- ▲ To compute any power result the “cycles” of the signals are needed
- ▲ The eDrive **hardware** detects the cycles using advanced digital algorithms in a DSP
- ▲ RMS values, power, efficiency, and advanced calculations are done on the cycle basis
- ▲ Allows for dynamic testing
- ▲ Accuracy 0.015% + 0.02% with Auto-Range



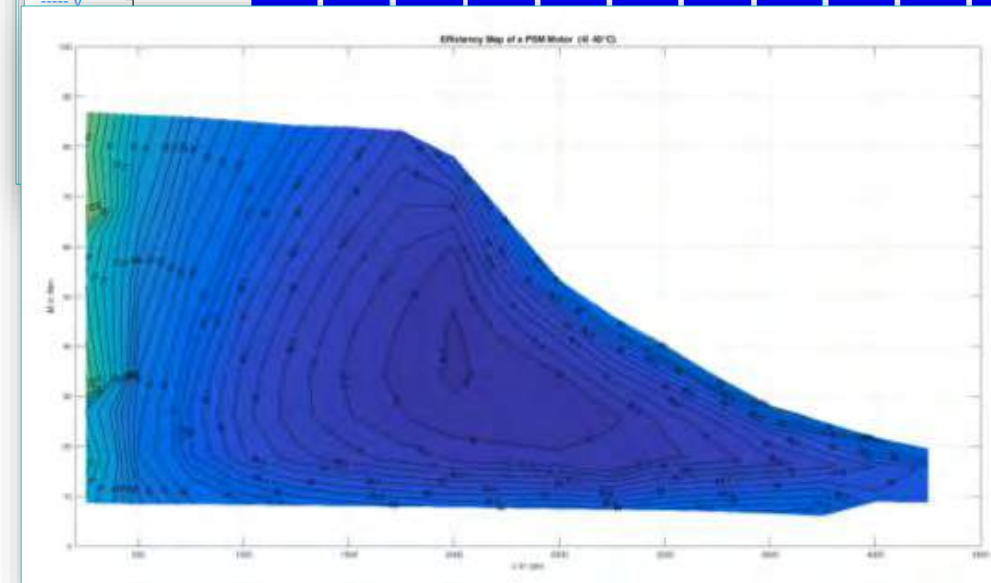
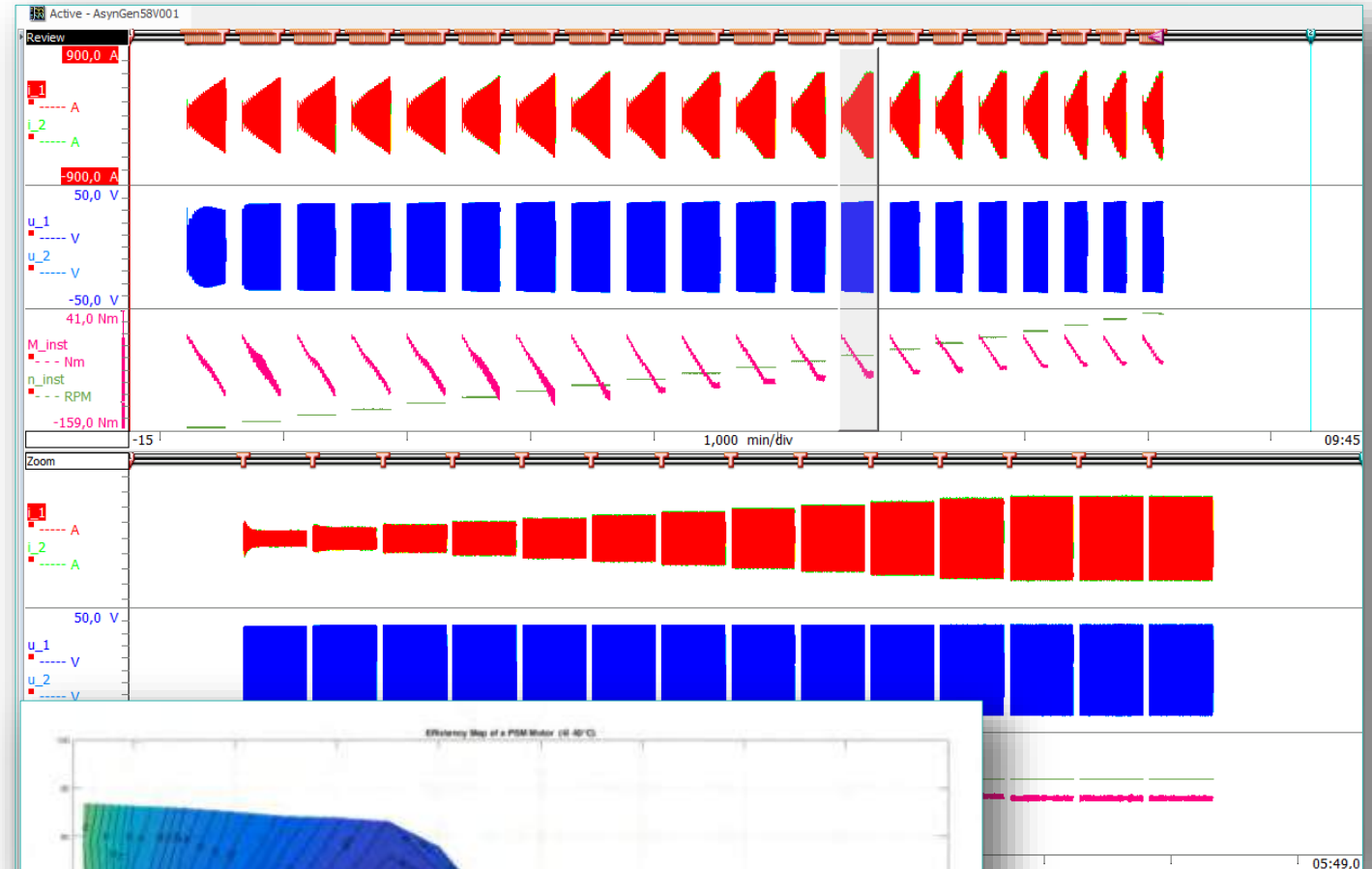
Accelerated mapping

Raw data is stored per set point in real time

- 293 set points
- 20 different speed values
- 17 different torque values

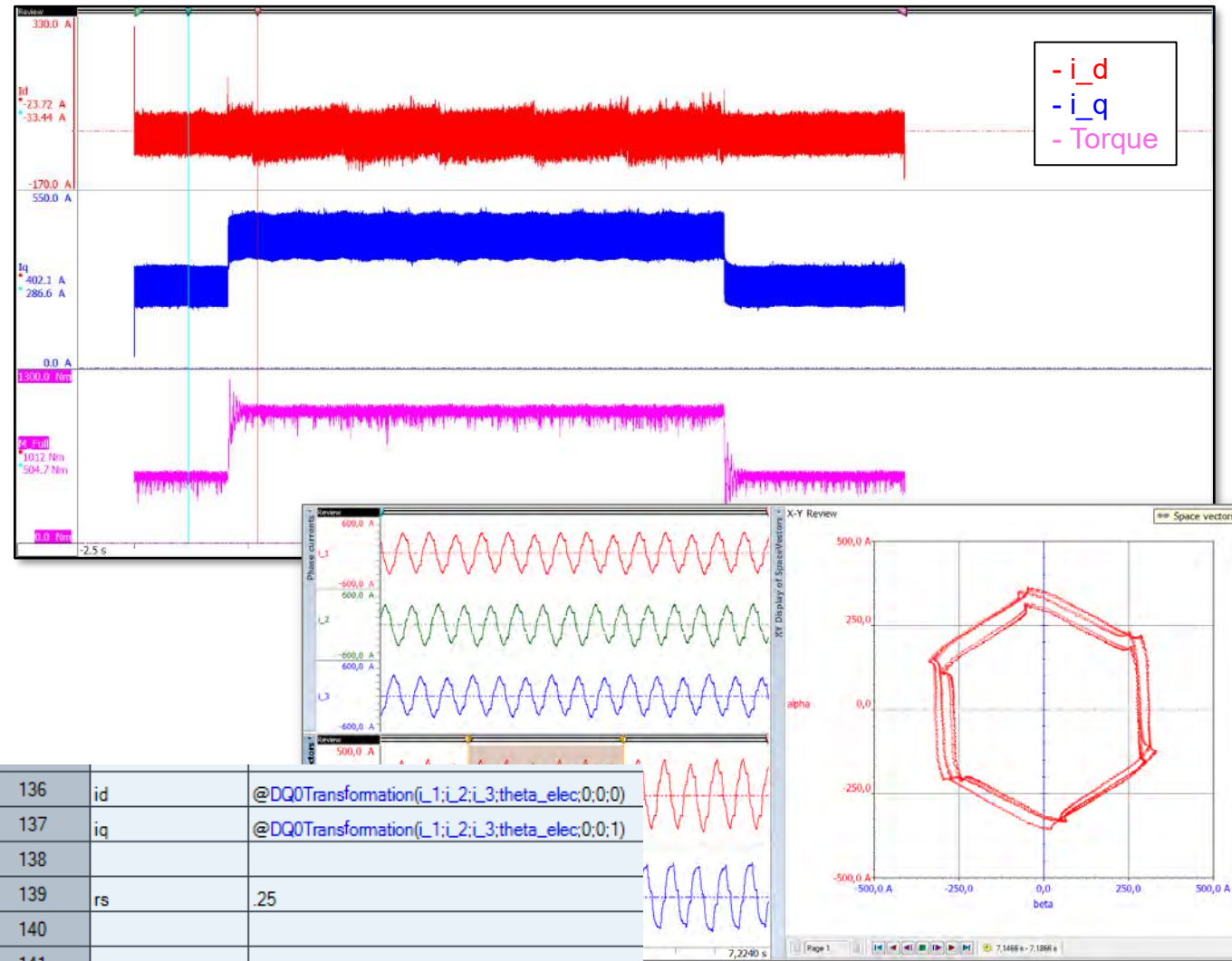
Each set point:

- 100 ms recording
- 400 ms pause,



Live Advanced & Custom Equations

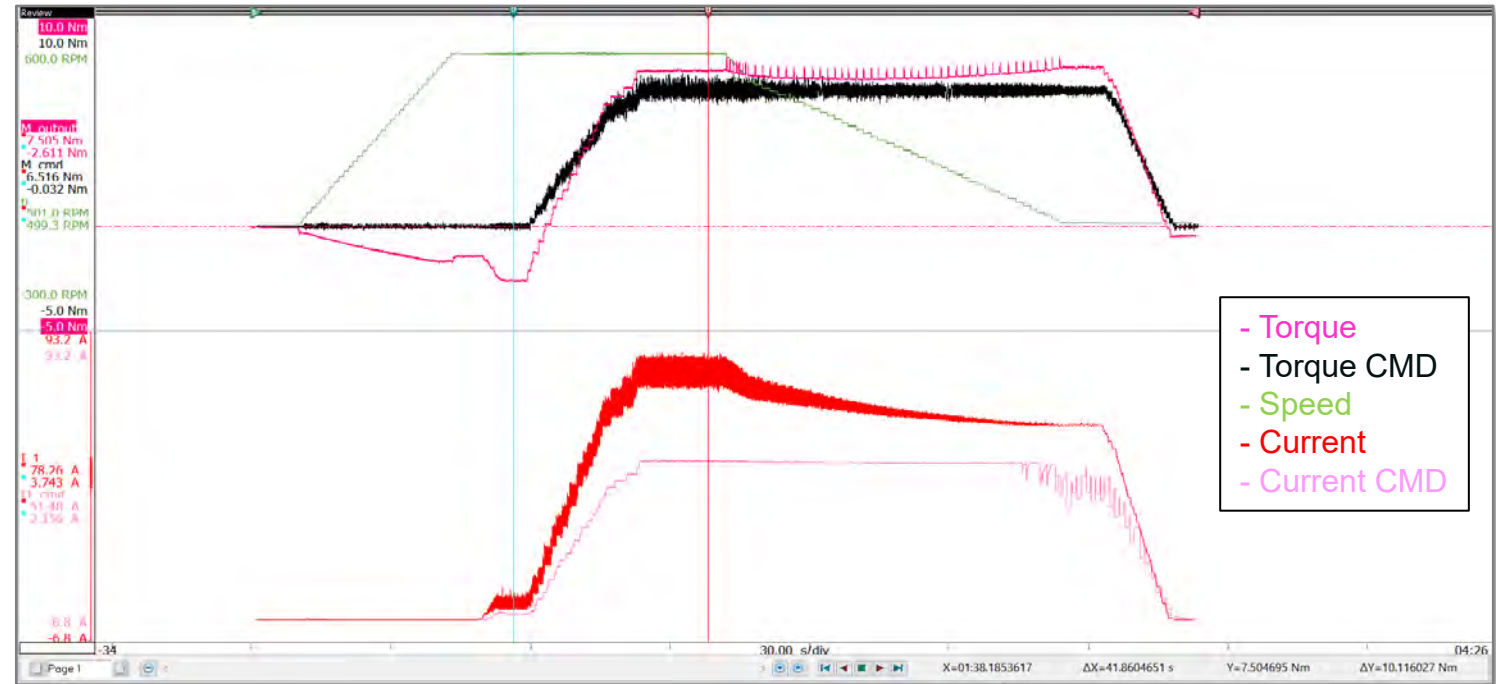
- ▶ DQ0 or space vector transform for a load step
- ▶ Time domain display of DQ or space vector transformations
- ▶ Insights on what is happening in the machine
- ▶ Time synchronized to other signals



136	id	@DQ0Transformation(L_1;i_2;i_3;theta_elec;0;0;0)
137	iq	@DQ0Transformation(L_1;i_2;i_3;theta_elec;0;0;1)
138		
139	rs	.25
140		
141	flux_d_1	@Integrate(vd-rs*id)
142	flux_d_avg	@CycleMean(flux_d_1;2;Cycle_Master)
143	flux_d	-(flux_d_avg-flux_d_1)
144		

Advanced Analysis - CAN Bus Measurement

- ▲ Acquisition and display of CAN signals and their measured counterparts
- ▲ Evaluate internal controller and sensors calculations
- ▲ Tune the system and make engineering decisions
- ▲ Understand failures



Re-Run a Faulty Test

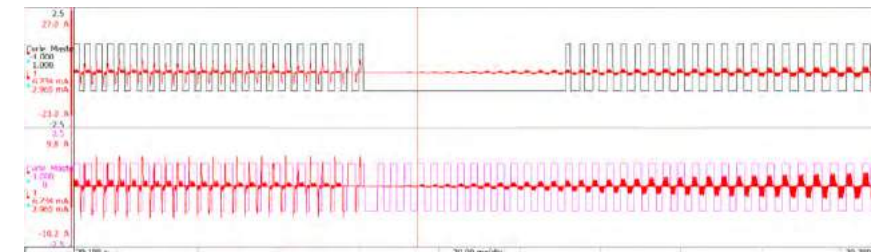
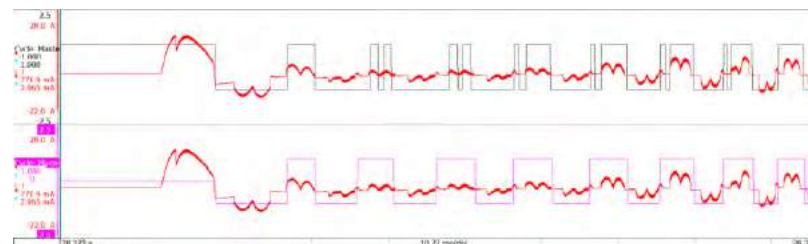
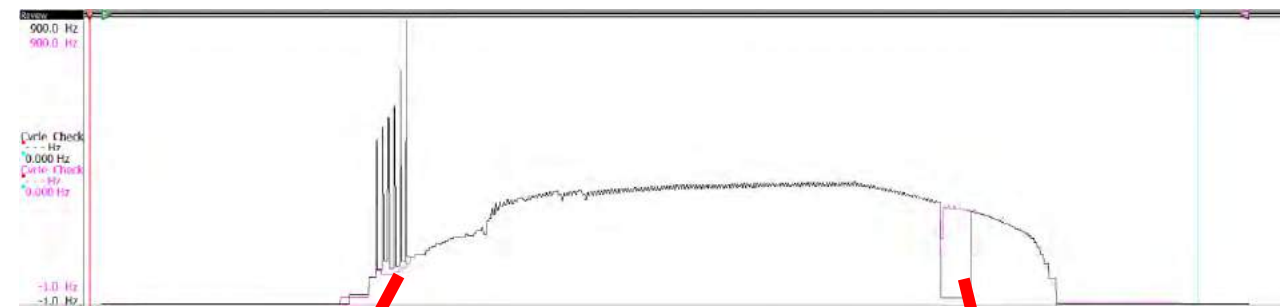
- Calculation errors happen with all systems
- Understand errors with raw data and editable equations
- Rerun tests without physically redoing them
- Example of changing the cycle detect algorithm

Bad Cycles

Cycle_source_2	i_1
Cycle_count_2	1
Cycle_level_2	.1
Cycle_hyst_2	.1
Cycle_holdoff_2	.0001
Cycle_cutoff_frequency	2750
Cycle_source_filt_2	@FilterBesselLP (i_1 ; 2 ; Cycle_cutoff_frequency; 0)

Corrected Cycles

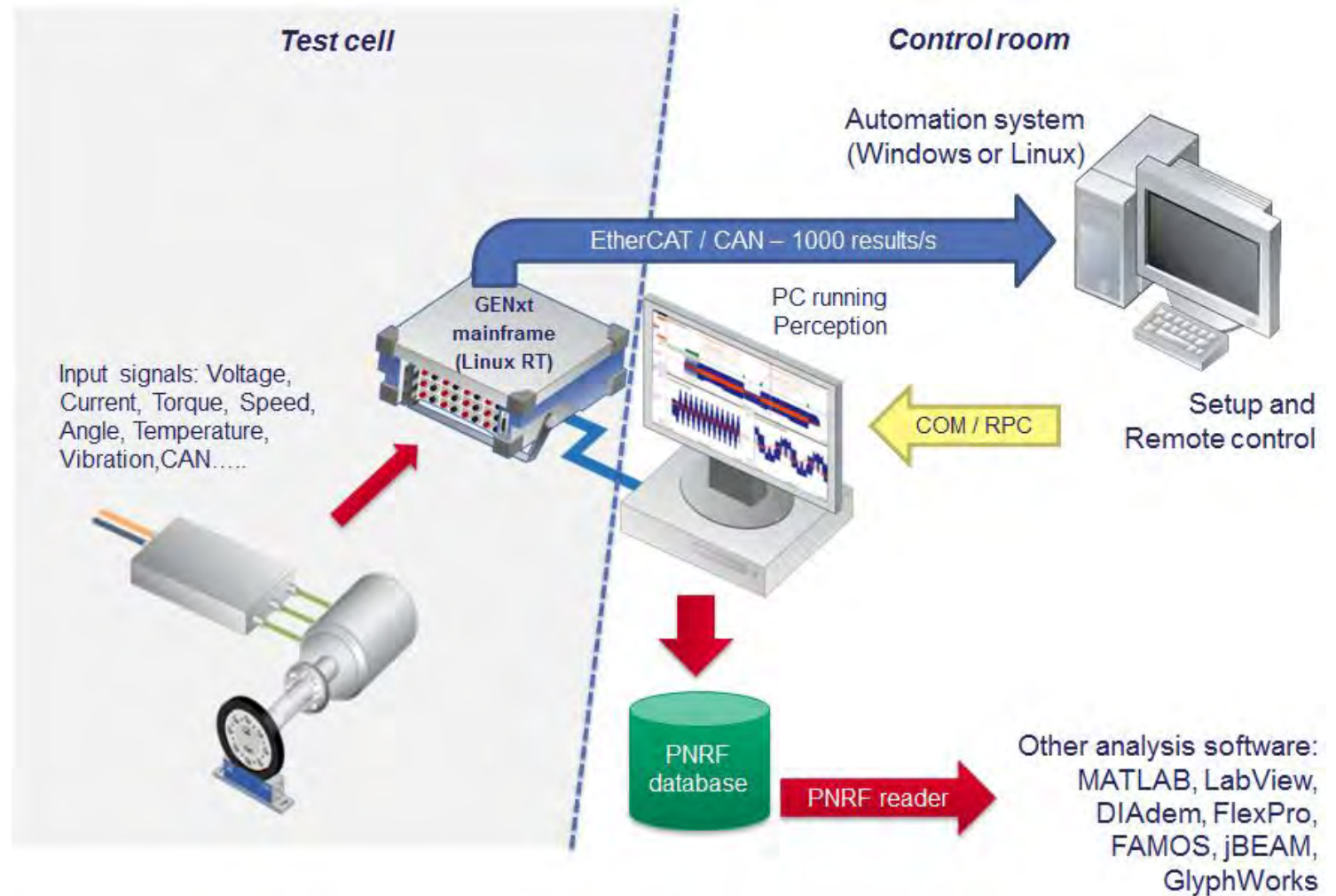
Cycle_source	i_1
Cycle_count	1
Cycle_level	0
Cycle_hyst	.005
Cycle_holdoff	0.0008
Cycle_cutoff_frequency	750
Cycle_source_filt	@FilterBesselLP (i_1 ; 2 ; Cycle_cutoff_frequency; 0)



Feedback to Automation Systems - Integration Tools



- Real Time Feedback:
 - CAN 2.0 or FD
 - EtherCAT
 - API
- System Control:
 - LabVIEW
 - C+
 - Python
 - TTL signals



Conclusion

- ▲ Motor control & calibration is a demanding task
- ▲ Measured data is important for internal controller estimations
- ▲ Estimations are determined by extensive test and measurement
- ▲ HBK can accelerate the calibration process



Mitch Marks

Mitchell.marks@hbkworld.com

Hbm.com/eDrive