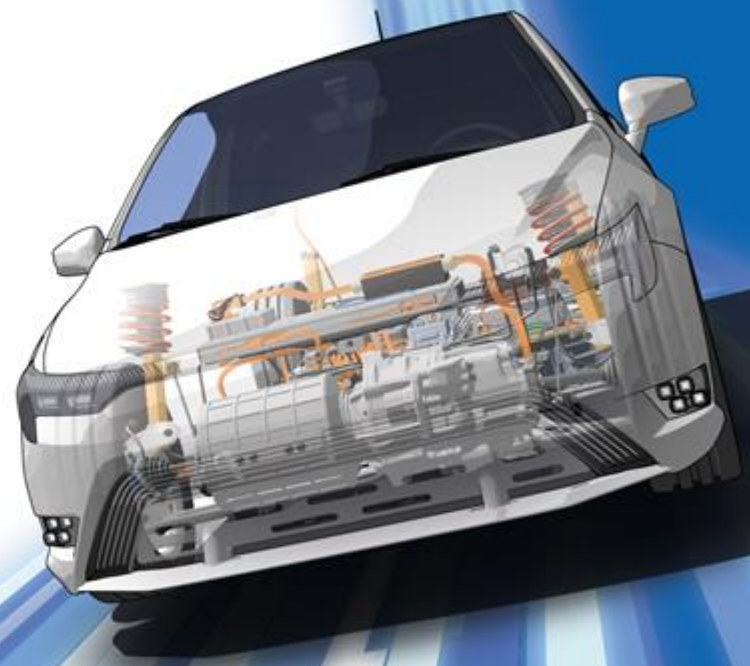
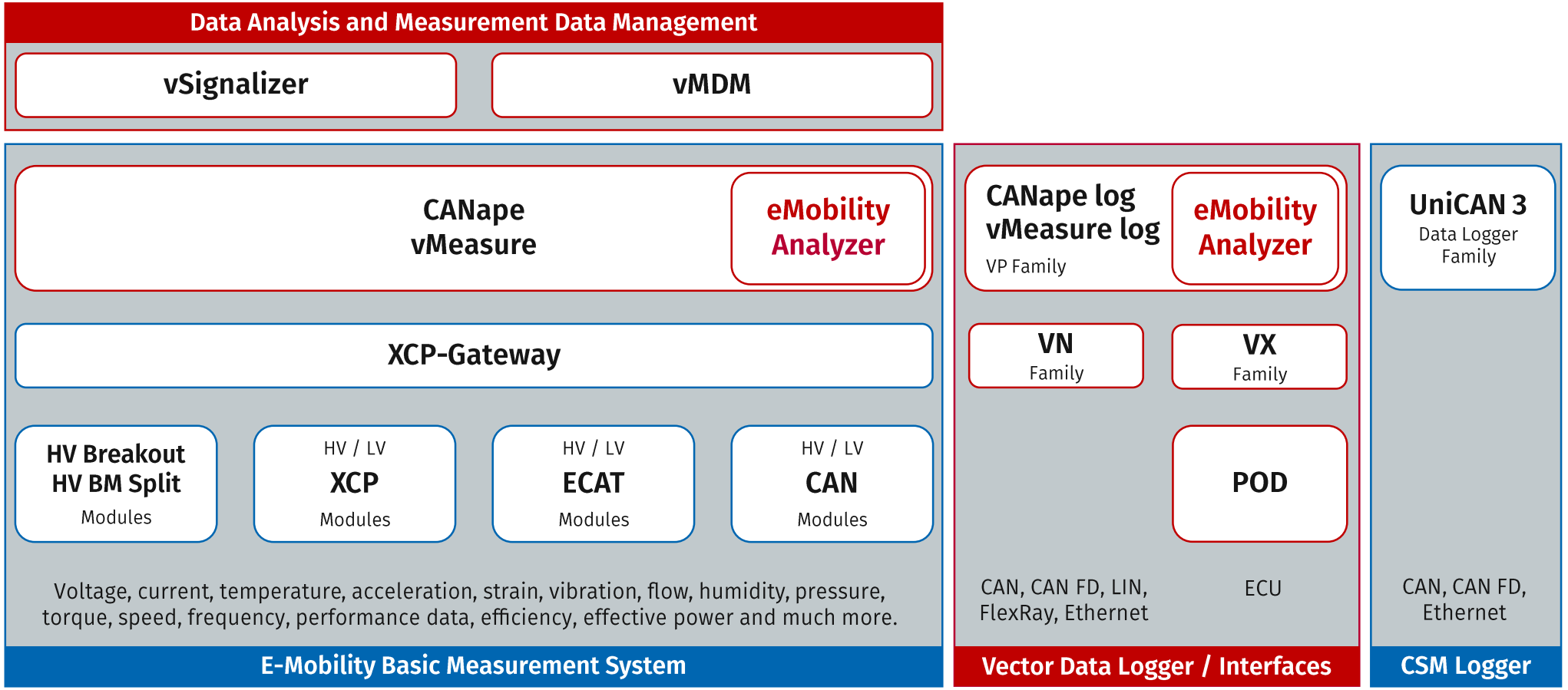
VECTOR CSM
TECHDAY
2023 MÜNCHEN DÜSSELDORF WOLFSBURG

Leistungsmessung mit CSM Messmodulen und dem Vector eMobilityAnalyzer



CSM VECTOR

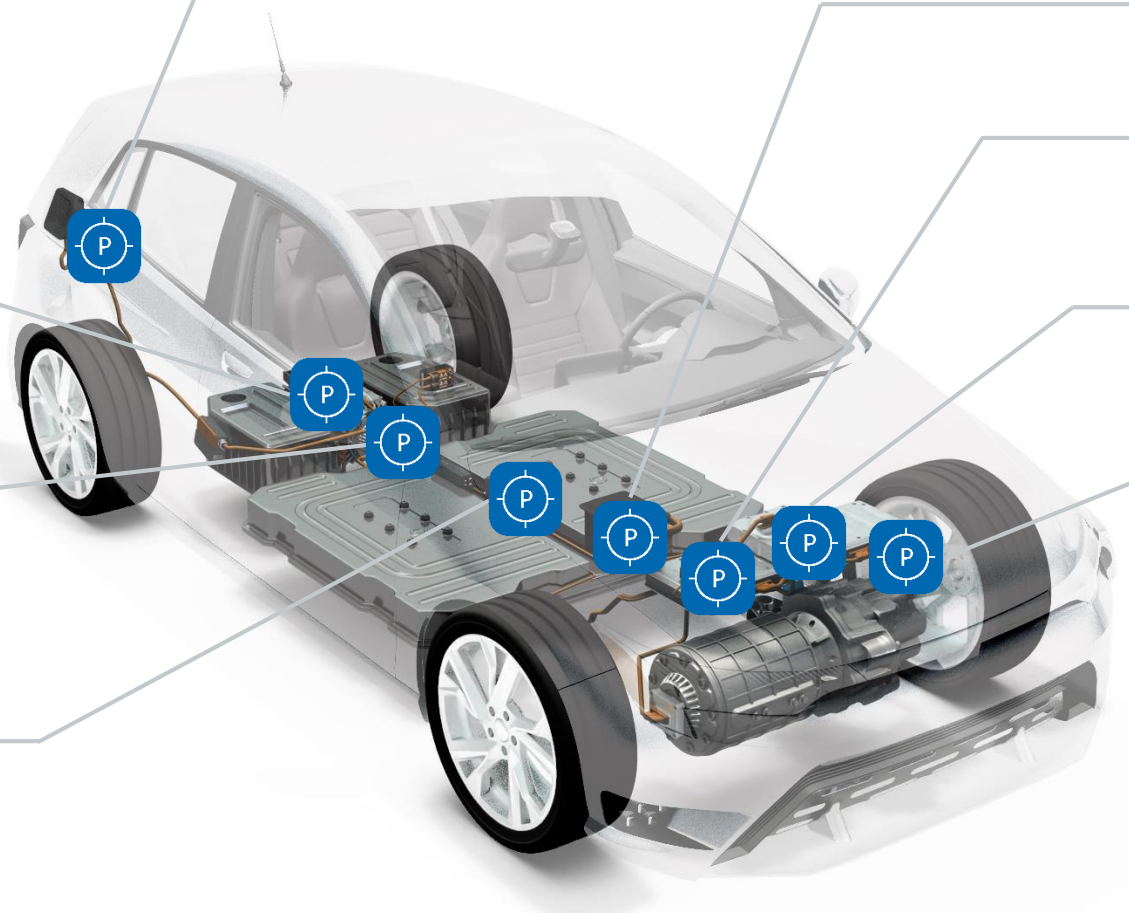
Vector CSM E-Mobility Measurement System



Basics Electrical Power

Electrical power	$P = U \times I$	Direct current (DC)
Instantaneous power	$p(t) = u(t) \times i(t)$	
Active power	$P = \frac{1}{T}\int_0^T u(t) \times i(t)dt$	
Active power	$P = \frac{1}{N}\sum_{n=0}^{N} u_n i_n \Delta t$	
Active power	$P = U_{rms} \times I_{rms} \times \lambda$	Alternating current (AC)
Apparent power	$S = U_{rms} \times I_{rms}$	Total apparent power
Power factor	$\lambda = \frac{\lvert P \rvert}{S}$	Any curve shape
Power factor = Displacement factor	$\cos\varphi = \frac{\lvert P \rvert}{S}$	Sinusoidal signal
Reactive power	$Q = \sqrt{S^2 - P^2}$	Total reactive power

Power measurements



Charging system

HV/LV DC/DC Converter

Powertrain

Electric heater

Electric motor

Electric water pump

DC/AC Inverter

AC Compressor

Additional consumers

HV battery

CSM's HV-safe Voltage measurements
Examples

HV AD4 XW1000

- To measure up to 4x U
- up to ±1000 V,
  ±2000 V for spike
- ECAT up to 1 MS/s

HV AD4 XW4000

- To measure up to 4x U
- up to ±1000 V,
  ±2000 V for spikes
- XCPoE up to 4 MS/s

CSM's Current Clamp

CSM Current Clamp

- To measure one current
- ±20 A .. ±1000 A
  - Analogue output ±2 V
  - DC-supply 10 V .. 30 V

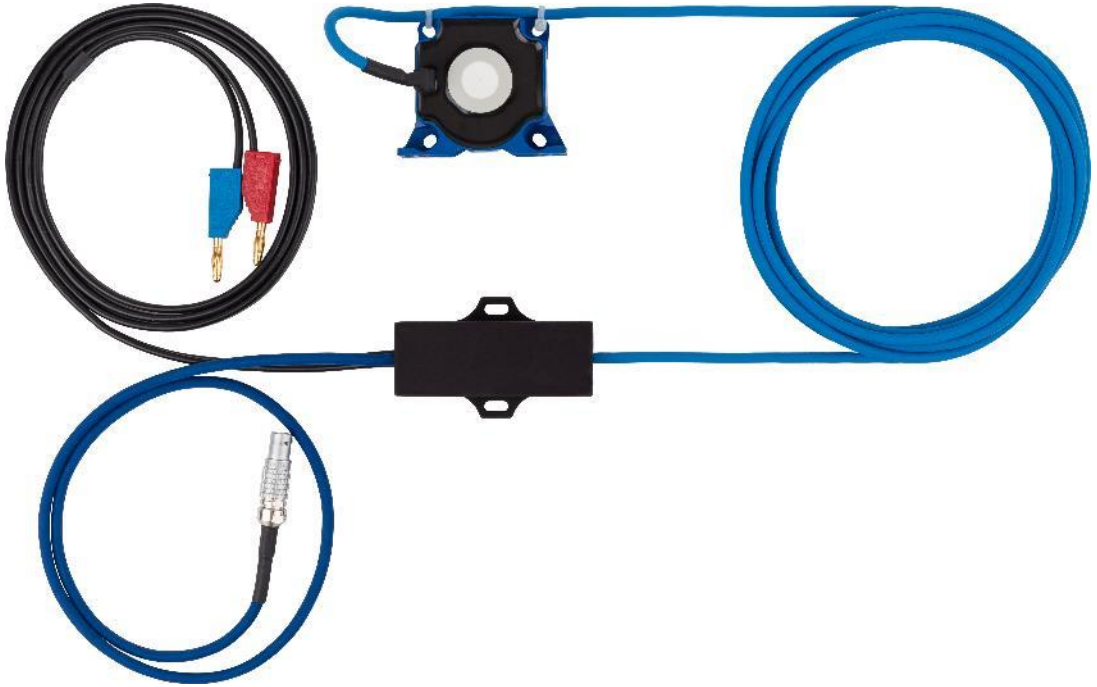
AD4 IG1000

- To measure 1 .. 4 voltages

CSM's LEM Sensor Package

LEM Sensor Package

- To measure one current
- ±5 A .. ±1250 A
  - Analogue output ±5 V
  - DC-supply 9 V .. 36 V
- Loop is potted



AD4 IG1000

- To measure 1 .. 4 voltages

CSM HV Measurement Modules - active Breakout Modules

HV Breakout Modules (BM) for in vehicle testing and dynamometer measurements

- Safe measurement of voltages up to ±2 kV
- Safe measurement of currents up to ±2 kA
- CAN and ECAT output, up to 1 MHz
- Comprising 1 or 3 shunts

HV BM 3.1

HV BM 1.1

HV BM 1.2

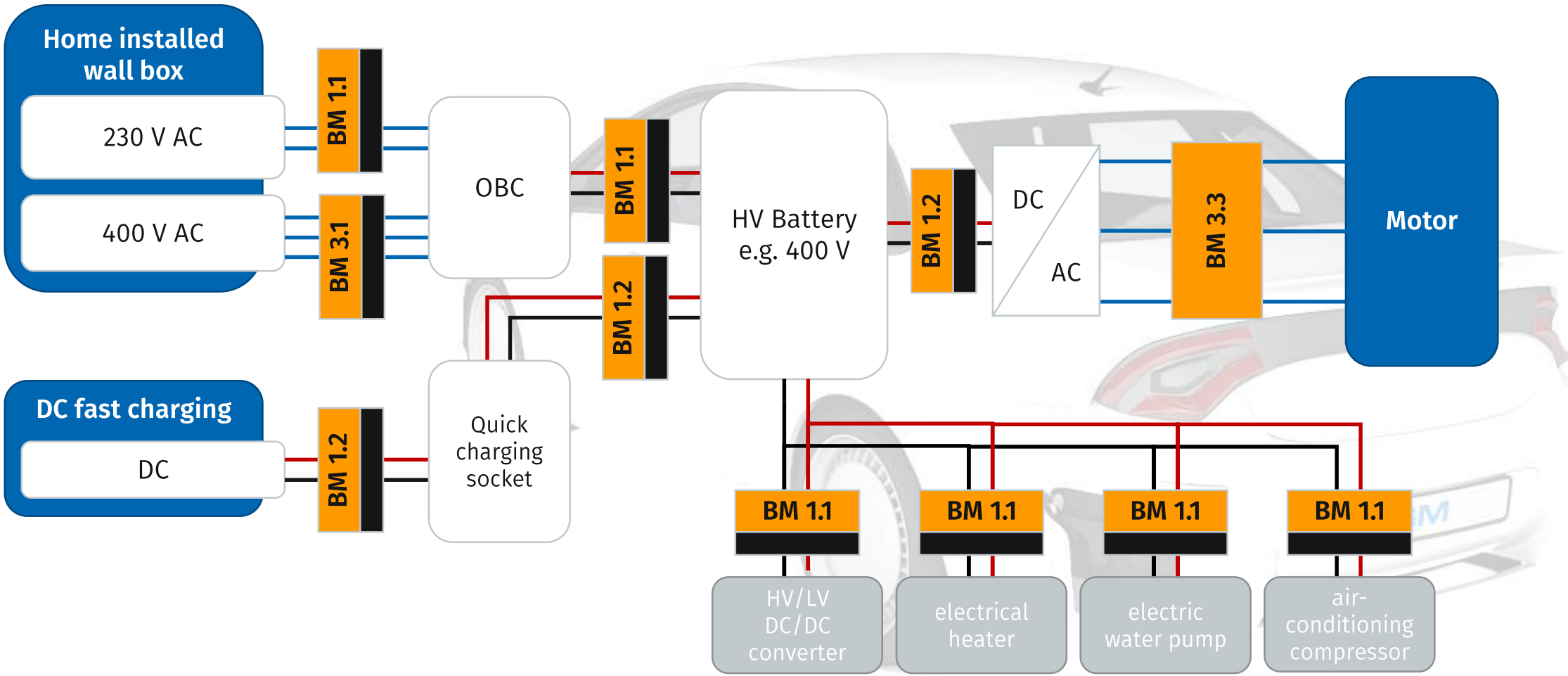
CSM HV Breakout Modules to Measure I and V and to Calculate P

Various breakout modules available

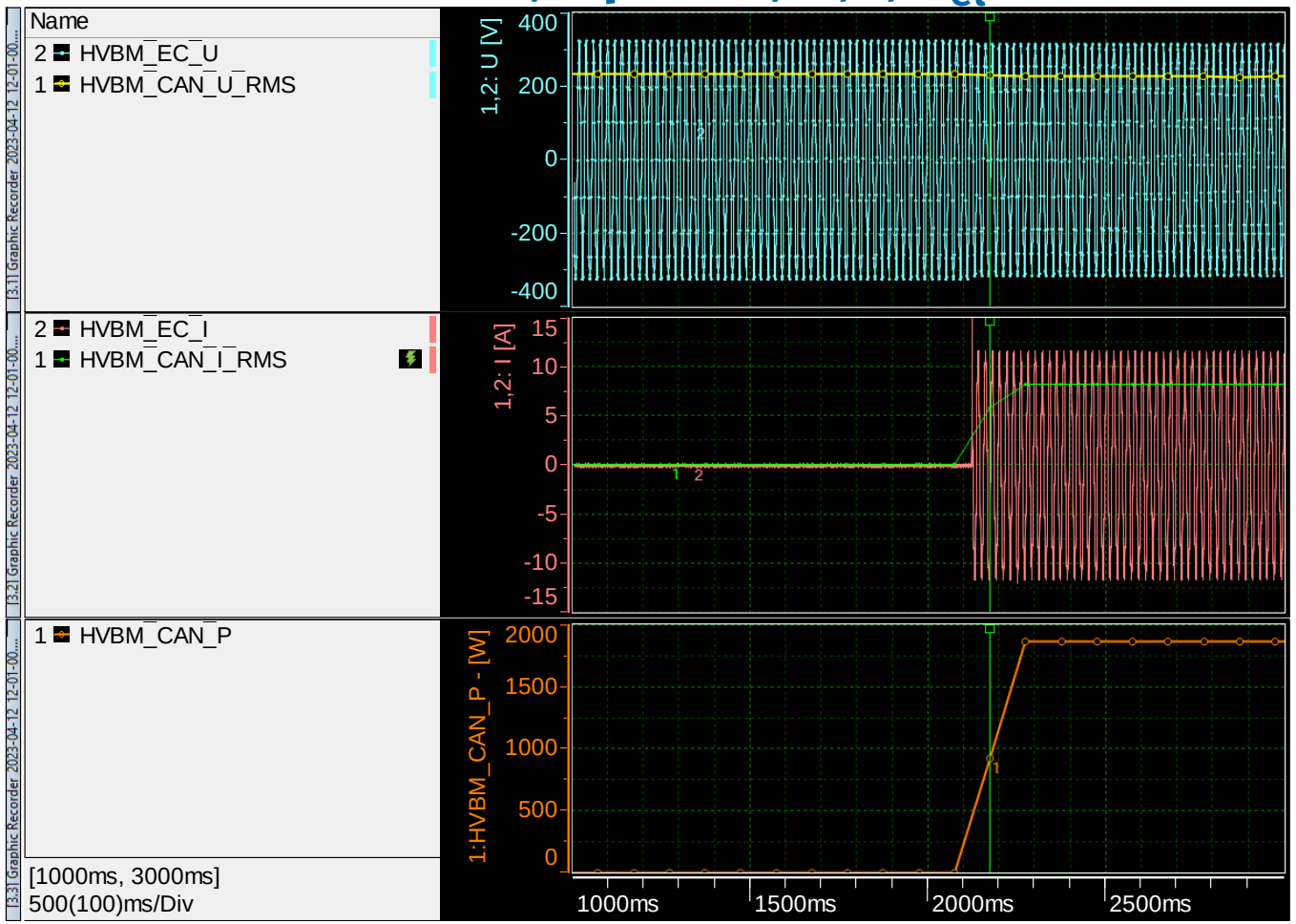
- Single phase measurements of
  - V up to 1 kV working voltage and 2 kV of spikes
  - Inserts, I_{nom} : ±1000 A, ±500 A, ±250 A, ±125 A
  - I_{spike} with shunts up to ±2000 A
- EtherCAT output up to 1 MHz per channel
- Optional CAN output for data loggers
- **Calculation of RMS-values and power**

HV BM 1.2
=
1 phase
2 glands

Power Measurements in HV Electrical Systems with HV BM's (Breakout Modules)



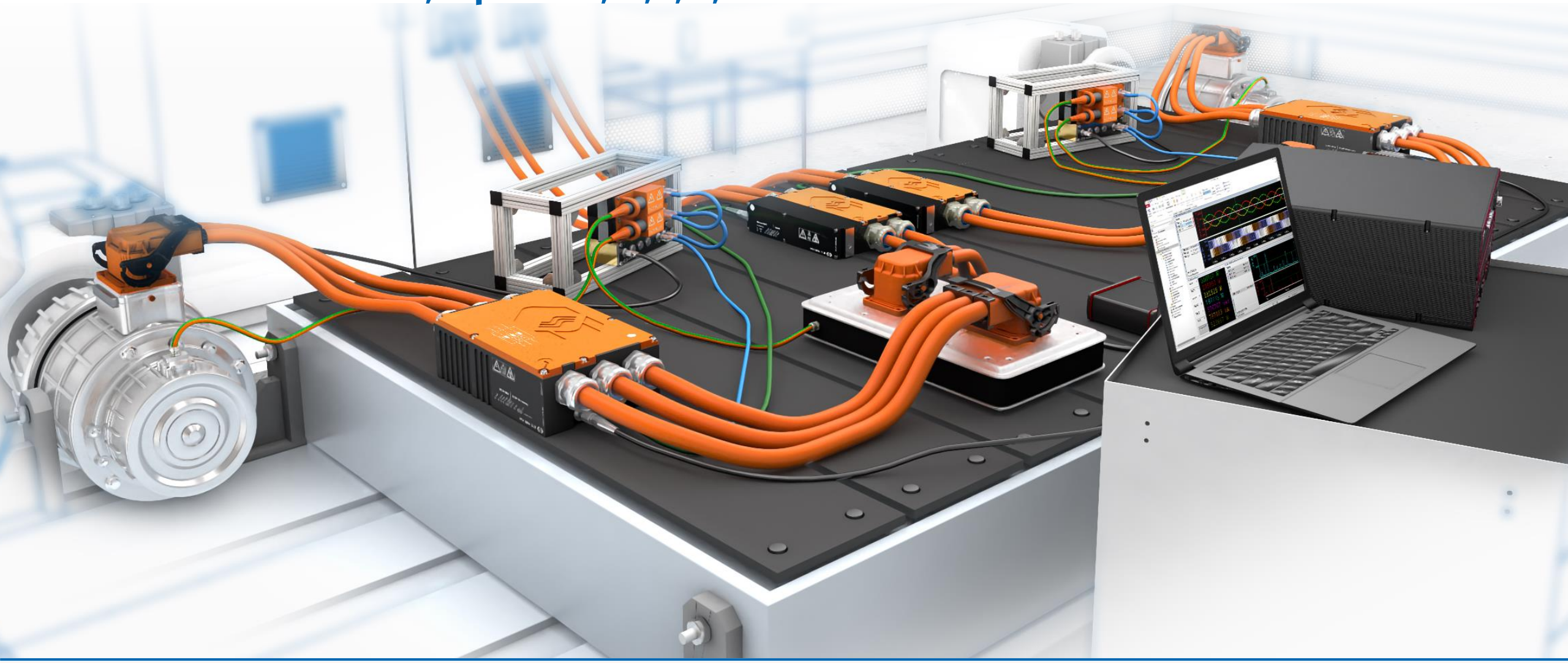
DUT: Electric kettle, 1 phase, U, I, P_{el}



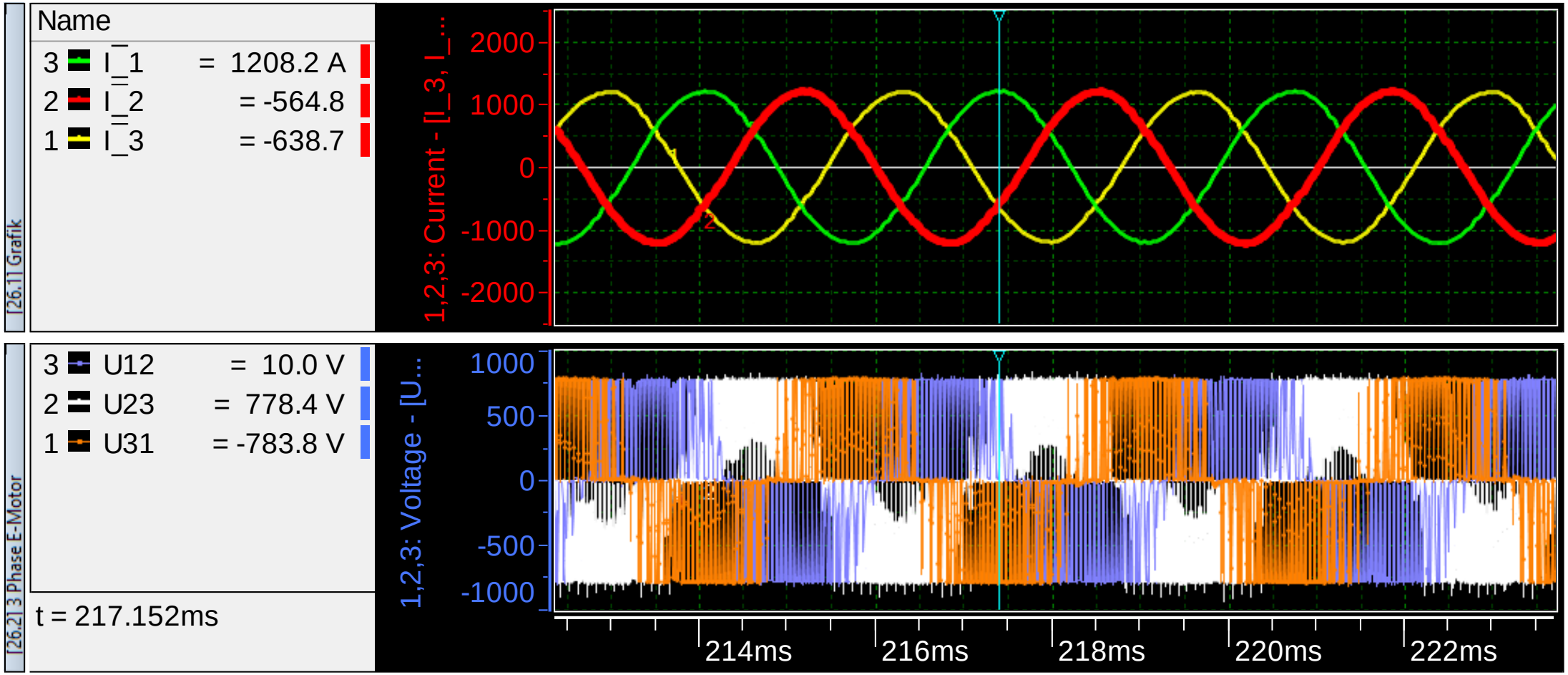
HV BM 1.2 with option Calc.

- To measure U, I
- To calculate P, U_rms, I_rms
- To save CPU load on PC
- To save SSD on PC

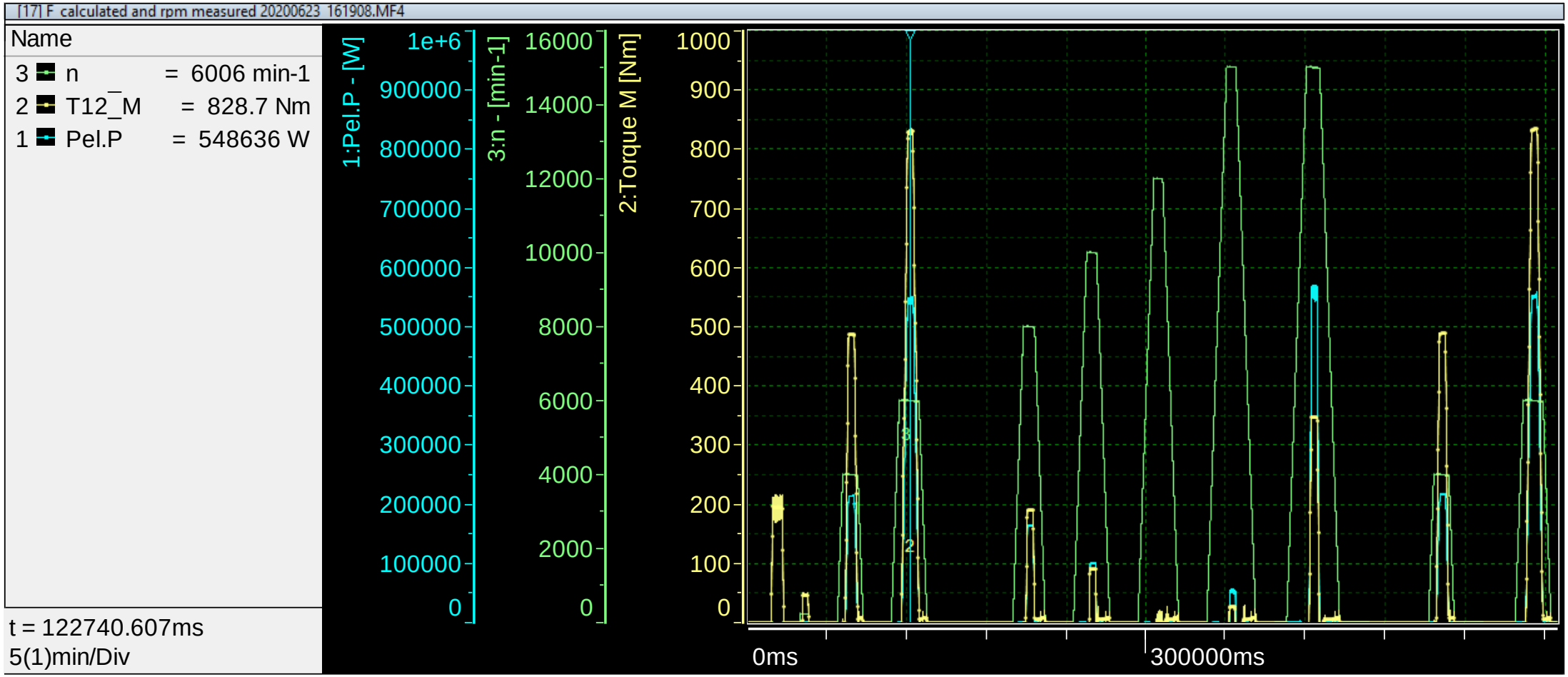
DUT: Electric Motor, 3 phases, U, I, P, ...



DUT: Electric Motor, 3 phases, U, I, I_rms up to 860 A



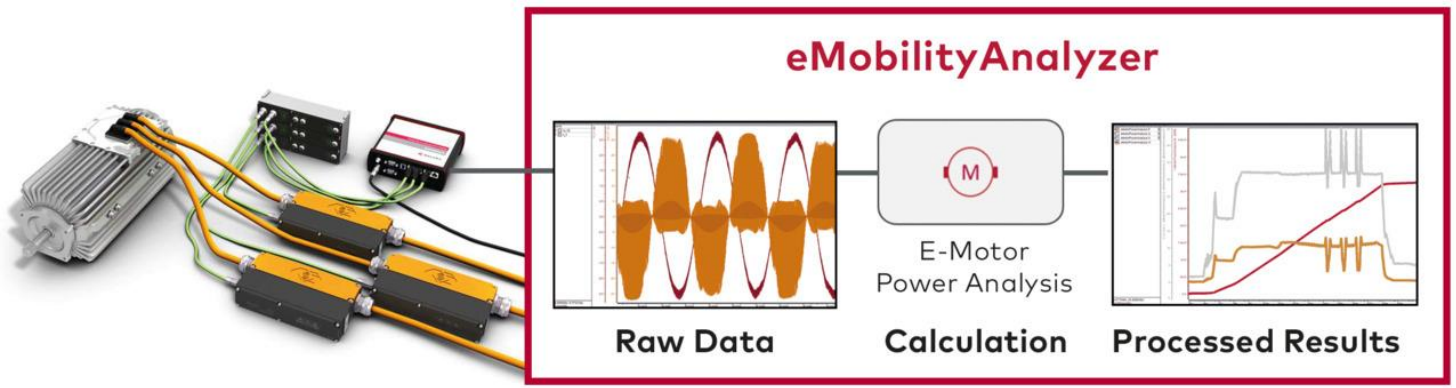
DUT: Electric Motor, 3 phases, P_{el} and mechanical data

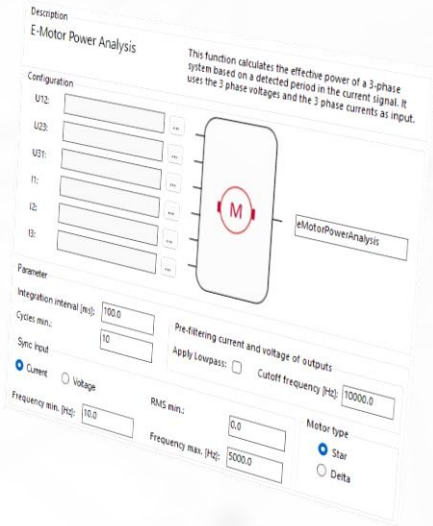


Power Analysis with Vector-CSM eMobility Measurement System

Vector completes the measurement system with data acquisition systems providing the

- **eMobilityAnalyzer** fast function library **with Power Analyzer functionality**

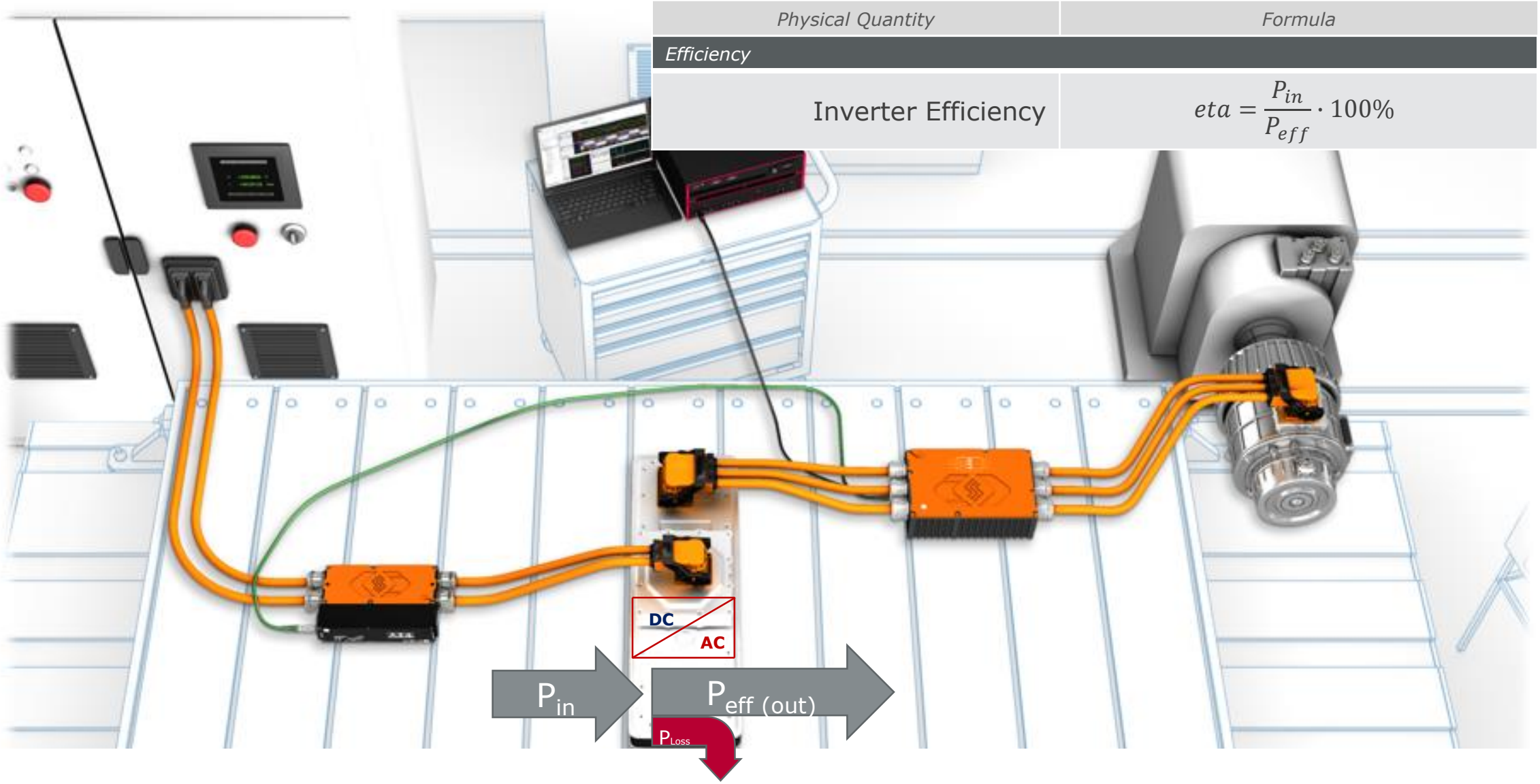




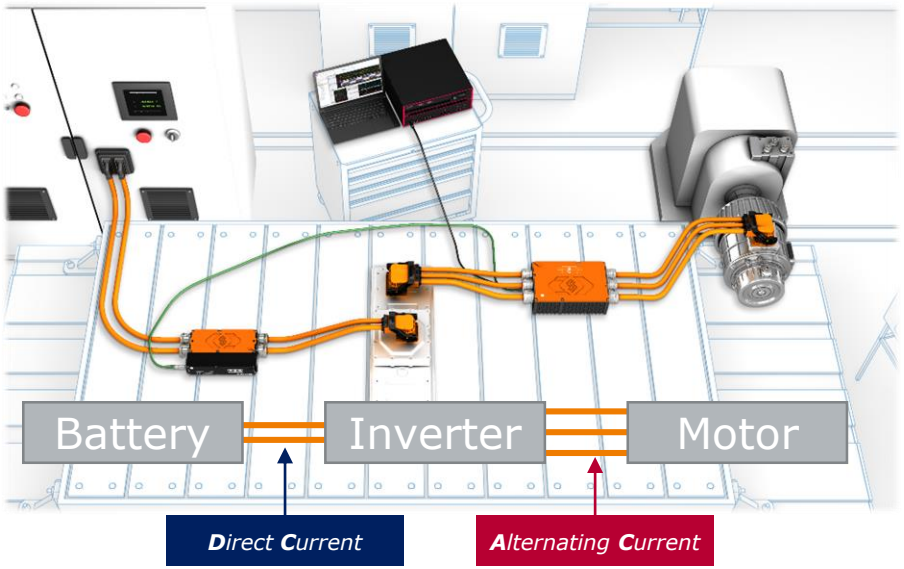
- Available in **CANape**, **vMeasure**, **vSignalyzer**
  - Measure power along with
    - Signals from ECUs, vehicle bus, all kinds of further analog sensors
    - Context information like GPS, video
- All precisely synchronized and stored to the same measurement file

Efficiency is the Ratio of Input vs. Output Power

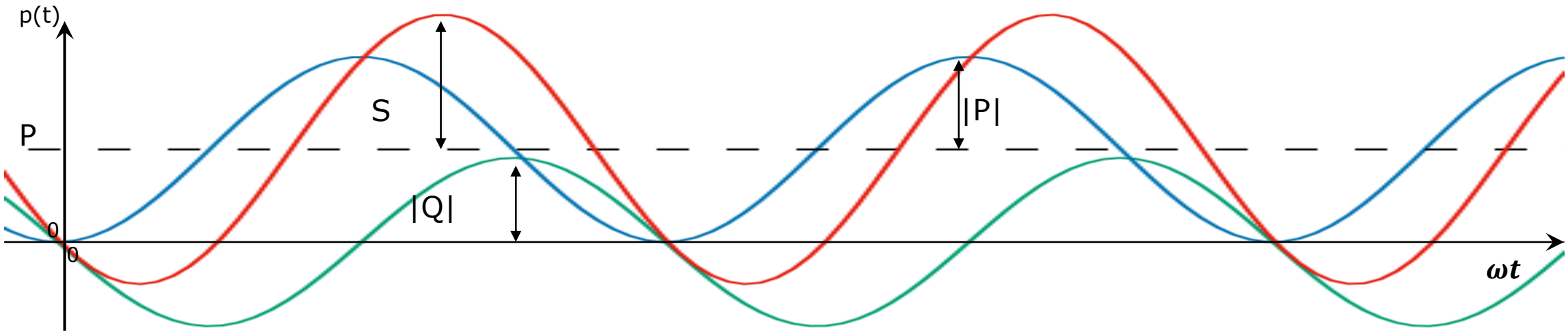
Physical Quantity	Formula
Efficiency	
Inverter Efficiency	$eta = \frac{P_{in}}{P_{eff}} \cdot 100\%$



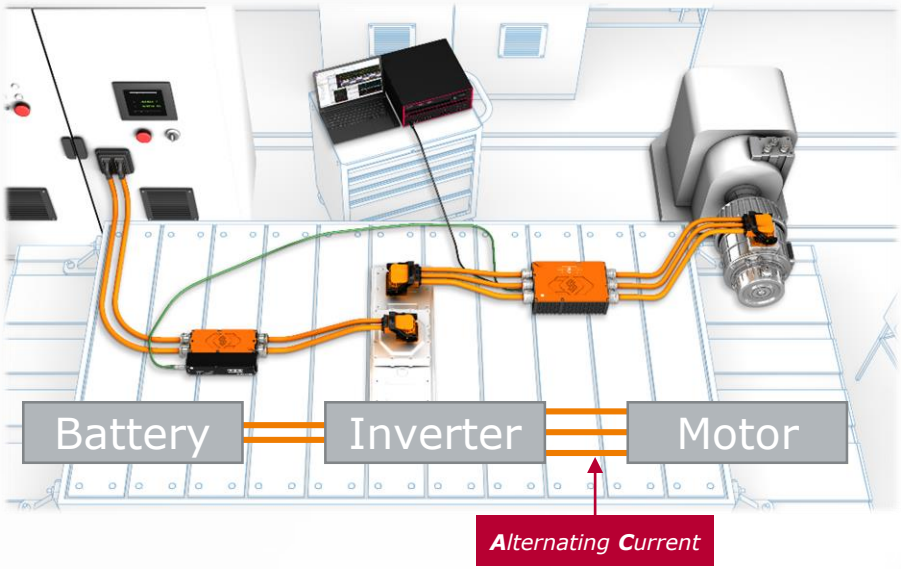
Indirect Power Measurement by Current and Voltage Measurement

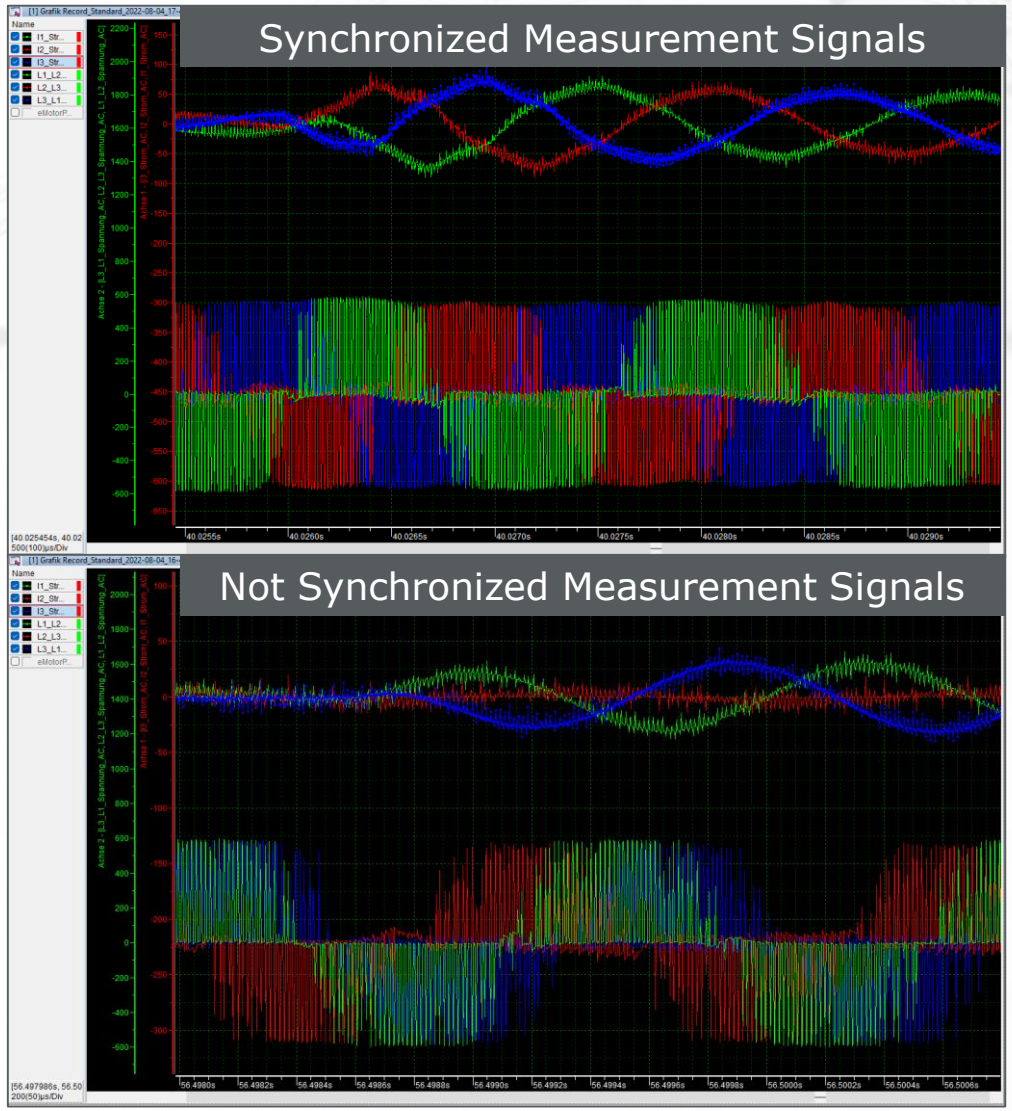


Physical Quantity	Formula
Direct Current	
Power	$\boldsymbol{P = \mathbf{V} \cdot I}$
Alternating Current	
Complex Power	$\boldsymbol{S = \sqrt{P^2 + Q^2}}$
Active Power	$\boldsymbol{P = \hat{V} \cdot \hat{I} \cdot cos(\varphi) = \frac{1}{T} \int_{t_0}^{t_0+T} v_{(t)} \times i_{(t)}\, dt}$
Reactive Power	$\boldsymbol{Q = \mathbf{V} \cdot I \cdot \lvert \sin \varphi \rvert}$
3-Phase Effective Power	$\boldsymbol{P_{eff} = P_1 + P_2 + P_3}$



Challenges at AC Power Measurement – Synchronization



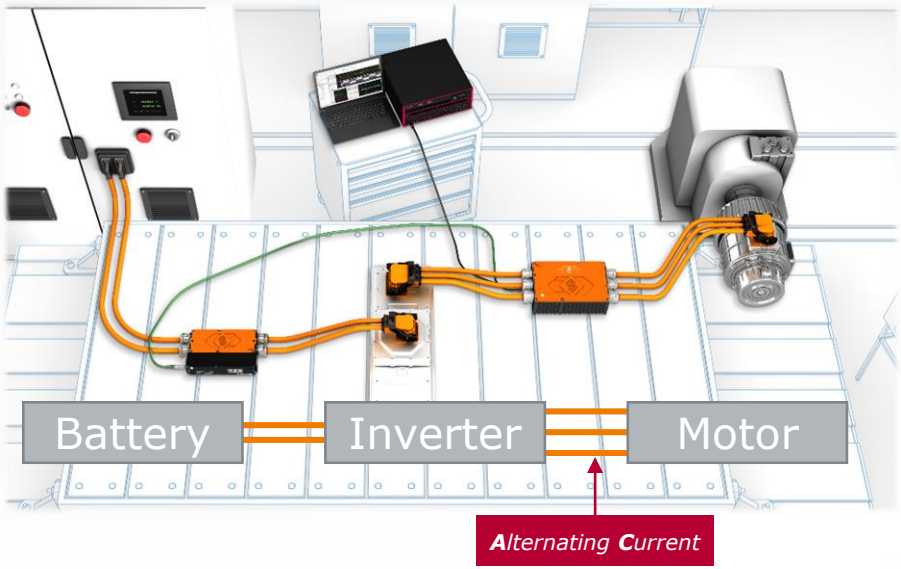


The phase angle φ must be accurately measured so requirements to time synchronous acquisition are very high to avoid

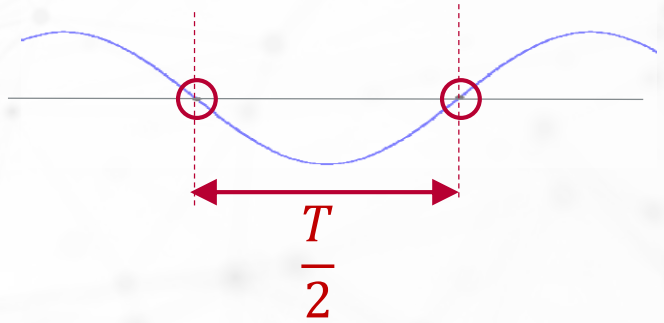
- shifts by time inaccuracy
- any variation in system latency on the different signals acquisition path's

- Precise Synchronization of current and voltage measurement is a MUST for power calculations

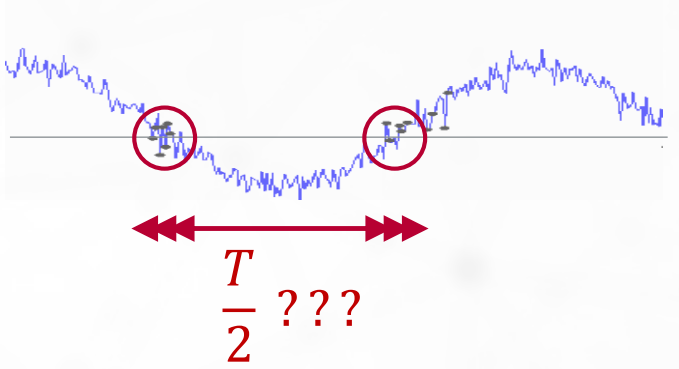
Challenges at AC Power Measurement – Frequency Detection



Ideal Sinusoidal Signal

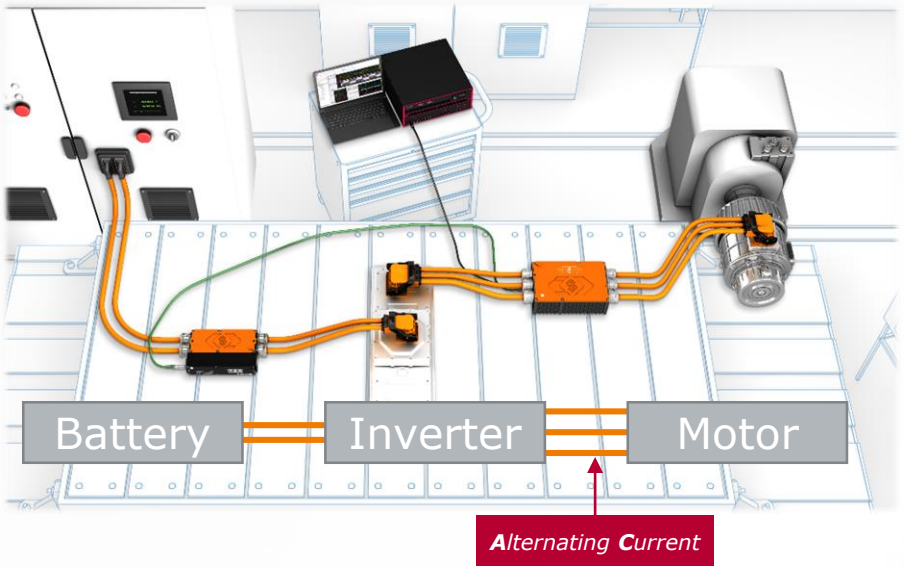


Real Noisy Measurement Signal

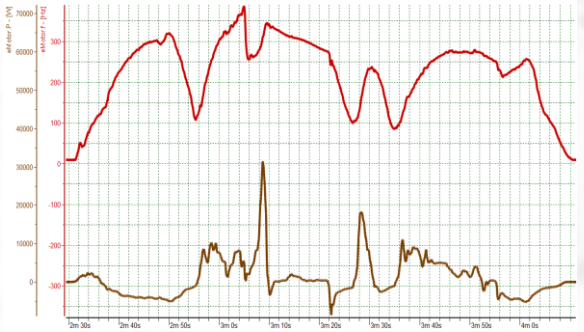


- The frequency f by period time T detection ($f = \frac{1}{T}$)
- Detection of T in noisy signals is a challenge
  - Zero crossing difficult to determine
- Sophisticated statistical algorithms are required to determine period time / frequency

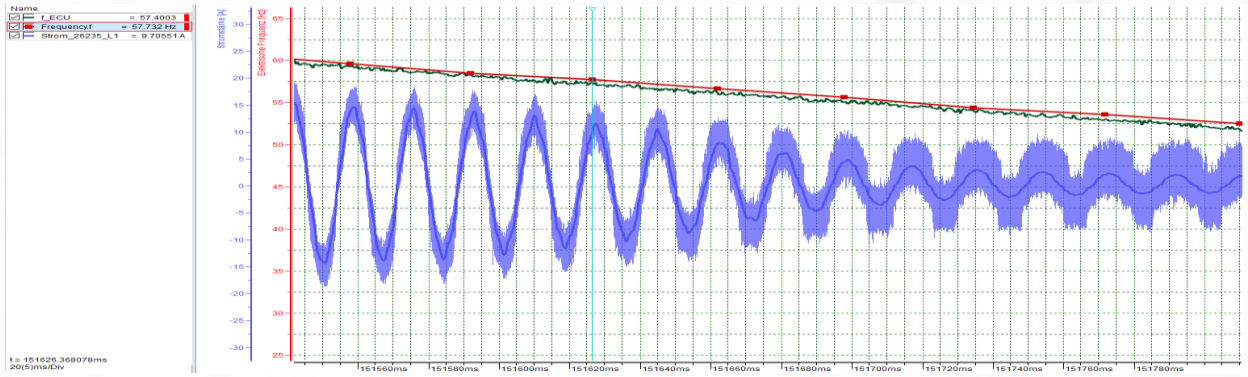
Challenges at AC Power Measurement – Highly Dynamic Frequency Changes



- Very **dynamic** vehicle **operation conditions** continuously changes
  - Acceleration
  - Breaking
  - Recuperation
  - Load changes
  - Direction changes
  - Force feed back from road, …

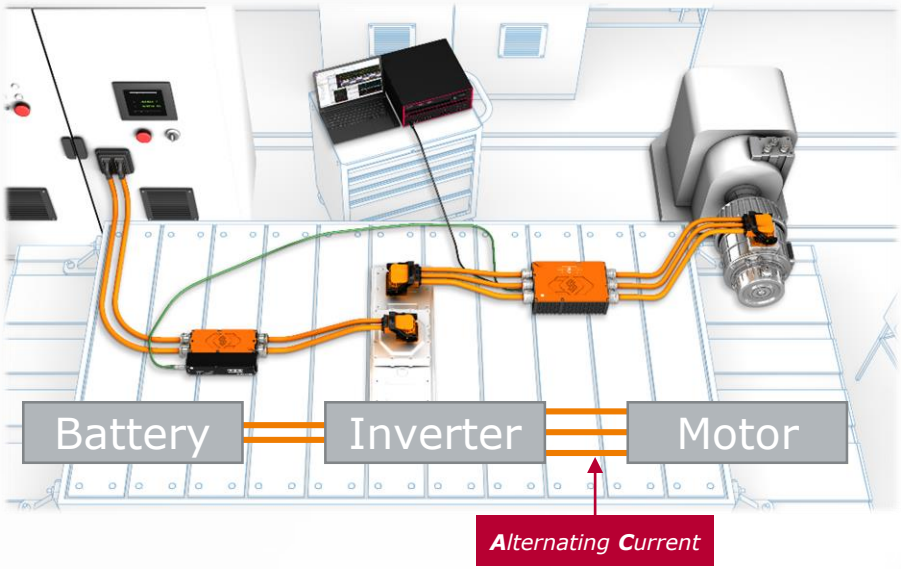


- **Frequency and Amplitudes** are not steady state, they are **changing** very **dynamically** by load and speed

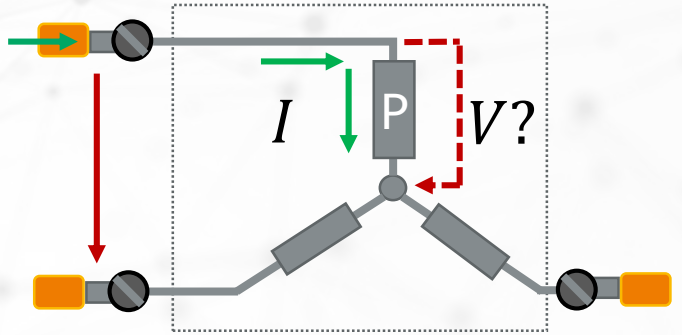


- Frequency detection must be stable/fast enough to follow highly dynamic changes

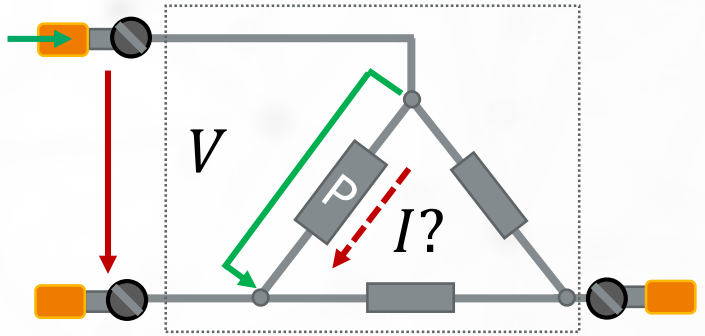
Challenge eMotor Power Analysis



Star Motor



Delta Motor



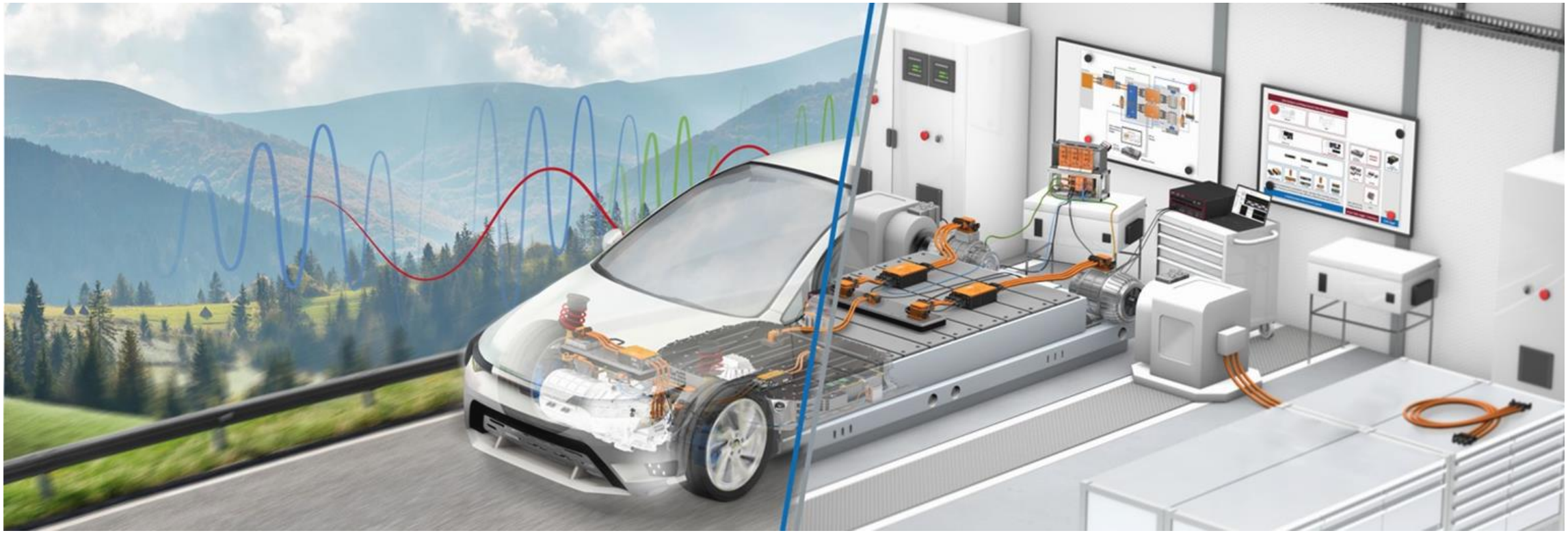
Accessible measurement points for current and voltage measurement cannot be used directly for power calculation.

- The Y-delta transformation or its inverse required to calculate the respective currents and voltages of windings

Conventional Tools for Power Analysis

- Power analyzer are typically
  - Very precise
  - Made for In-lab usage
  - Limited synchronization to further signal sources
    - ECUs
    - Vehicle Bus Signals
    - …
  - Missing context information
  - Challenging offline analysis

Power Analysis with Vector-CSM eMobility Measurement System



- All equipment is capable for On-Road Vehicle Trials and Laboratory use cases
- **Vector Smart Logger** can run the measurements fully automated in On-Road Tests
- And automated Data Analysis and Reporting can be realized with Vectors Measurement Data Management Tool **vMDM**