



Power and efficiency measurements

CSM Web Seminars

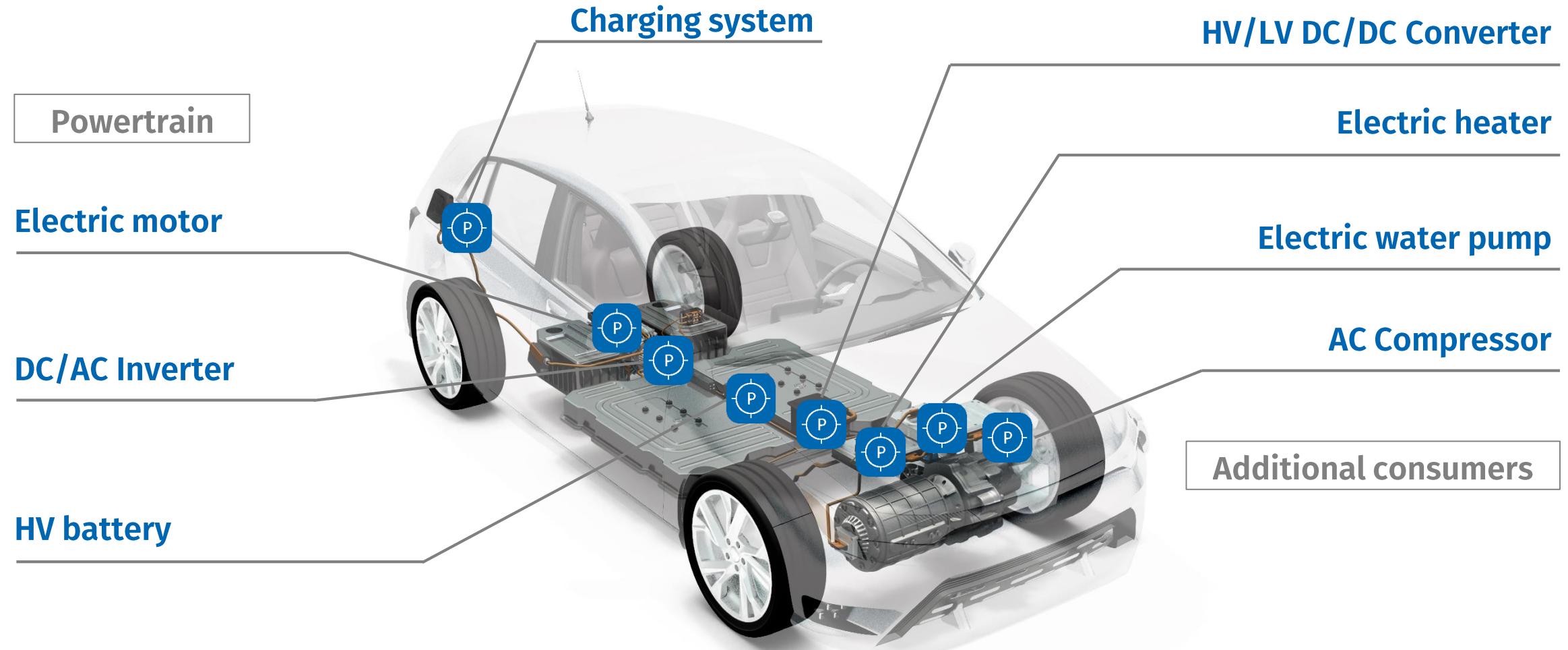


CSM Xplained
measurement technology

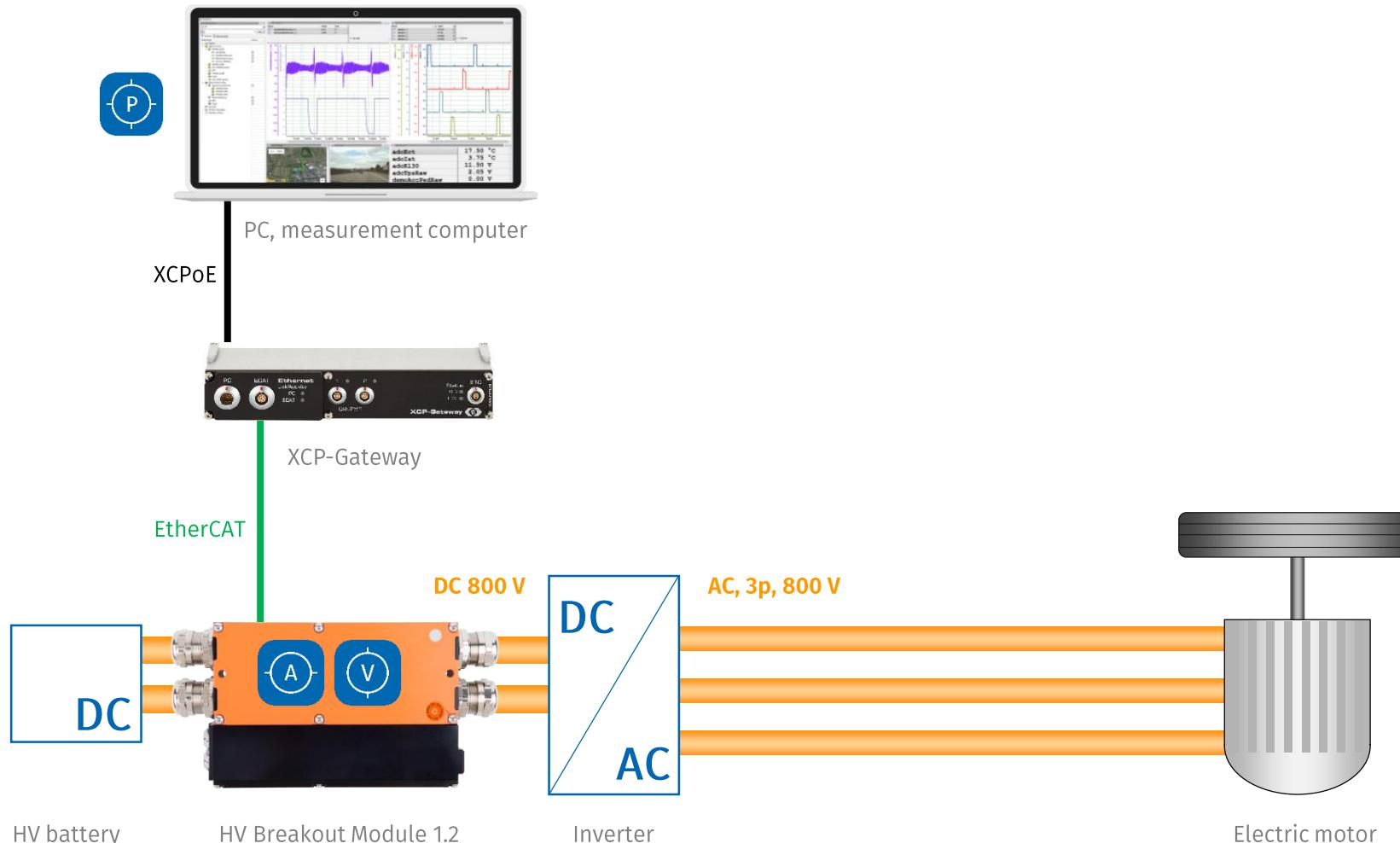
powered by **VECTOR** ➤

Innovative Measurement and Data Technology

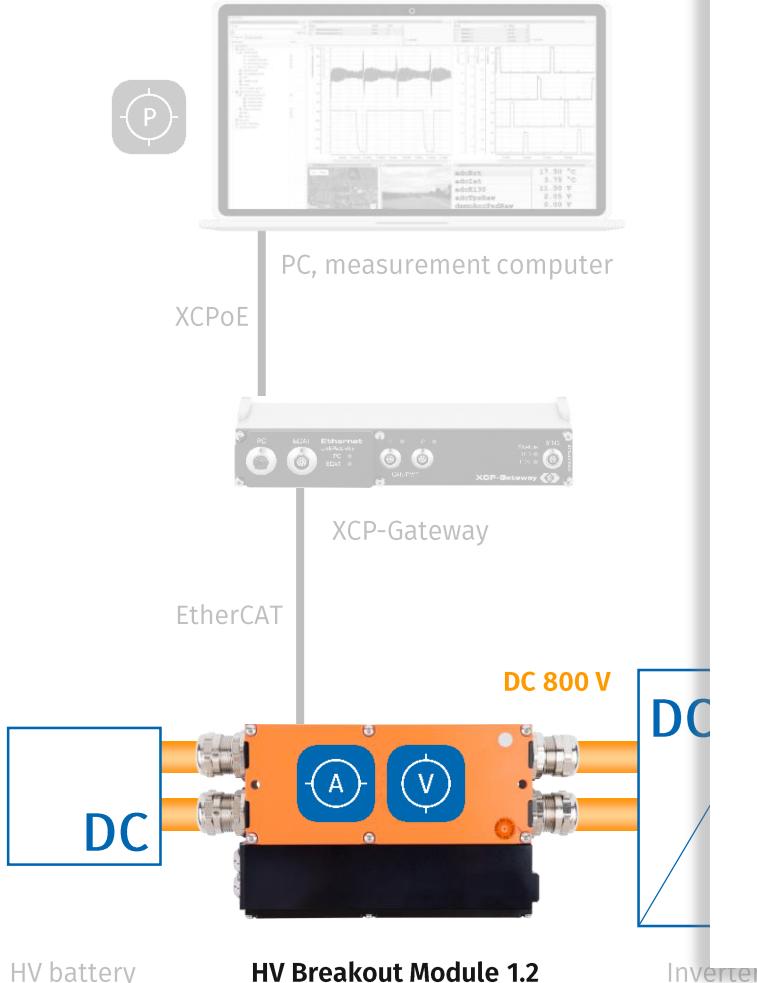
Power and efficiency measurements



Power measurement between HV battery and inverter



Power measurement between



HV Breakout Modules

HV Breakout Modules
on www.csm.de

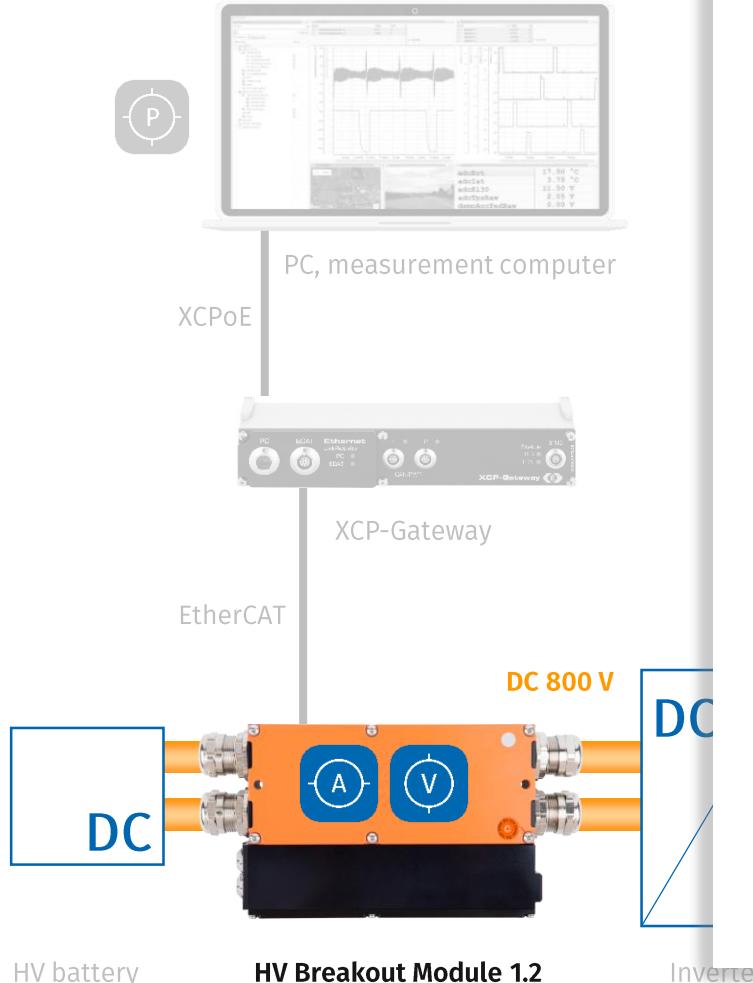


Measurement of high currents and voltages

- ▶ All in one compact solution
- ▶ Easy installation directly into the HV power cables
- ▶ Plug-in system for easy installation on test vehicles



Power measurement between



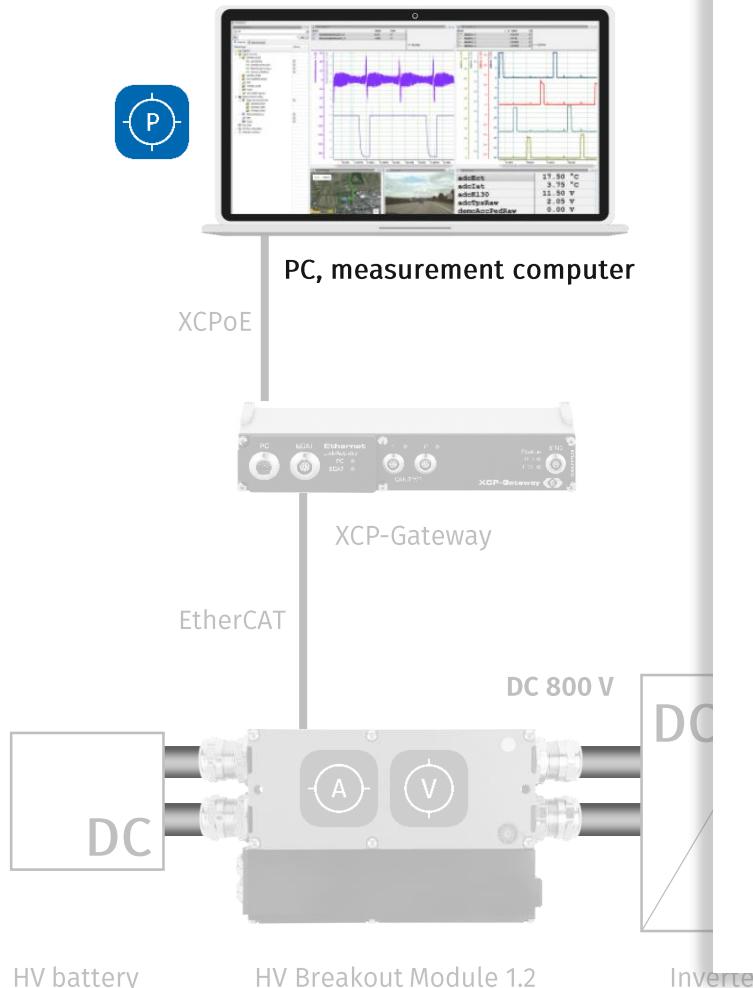
HV Breakout Modules

Measurement of high currents and voltages

- ▶ Current measurement with shunt modules
 - Inner conductor current I_{nom} : ± 50 A to $\pm 1,000$ A
 - Shield current
- ▶ Voltages up to 2,000 V
- ▶ Data rate up to 1 MHz per channel with EtherCAT, additional CAN interface
- ▶ For vehicle and test bench applications
 - IP67, operating temperature range: -40 °C up to +125 °C



Power measurement between



vMeasure exp – Data acquisition software

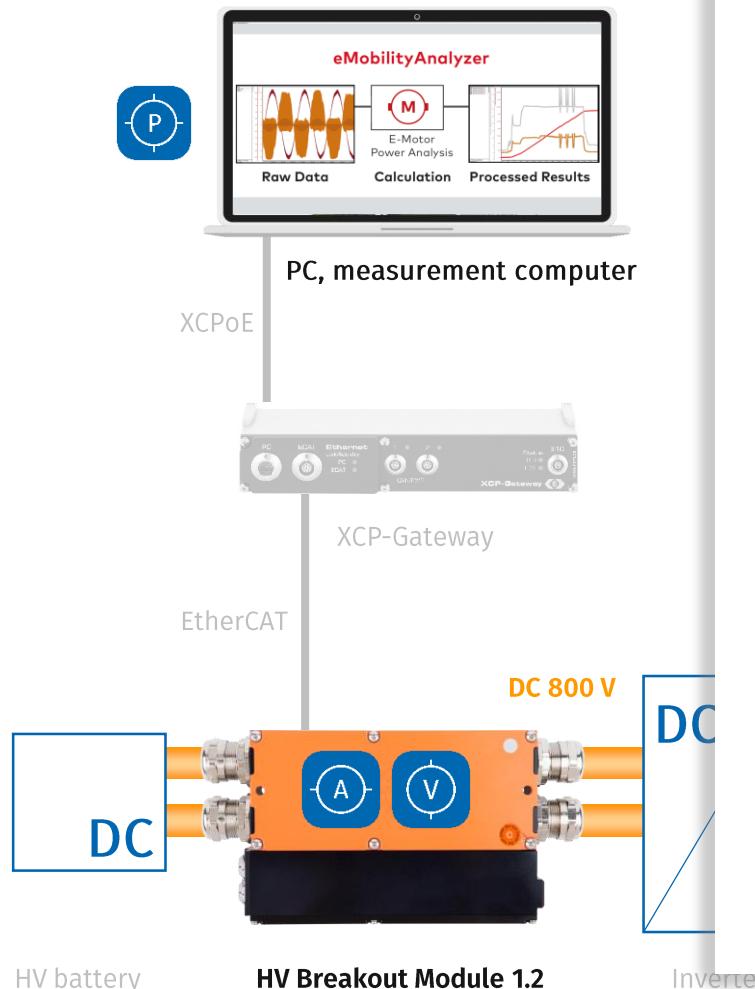
- ▶ **eMobilityAnalyzer** Power analysis harmonized with CSM measurement modules
- ▶ Multithreading functionality
- ▶ Time synchronized data acquisition from
 - CSM measurement modules (HV BM, ECAT, CAN)
 - Vehicle busses
 - Control units
 - Video, GPS
- ▶ Online calculations and scripting
- ▶ Multiple visualization



Basics Electrical Power

Electrical power	$P = U \times I$	Direct current (DC)
Instantaneous power	$p(t) = u(t) \times i(t)$	Non-sinusoidal signals
Active power	$P = \frac{1}{T} \int_0^T u(t) \times i(t) dt$	Non-sinusoidal signals
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	$\lambda = \frac{ P }{S}$	Any curve shape
Power factor = Displacement factor	$\cos \varphi = \frac{ P }{S}$	Sinusoidal signal
Reactive power	$Q = \sqrt{S^2 - P^2}$	Total reactive power
Efficiency	$\eta = \frac{P_{out}}{P_{in}}$	General
Efficiency	$\eta = \frac{P_{mech}}{P_{el}}$	Electric motor

Power measurement between



Power analysis with eMobilityAnalyzer and HV Breakout Module

Short measurement chain for power calculation

- ▶ **HV Breakout Module** supplies the digital instantaneous values (samples) of voltage u_n and current i_n
- ▶ **Real-time calculation** of interval-related quantities such as active power P in the **eMobilityAnalyzer**

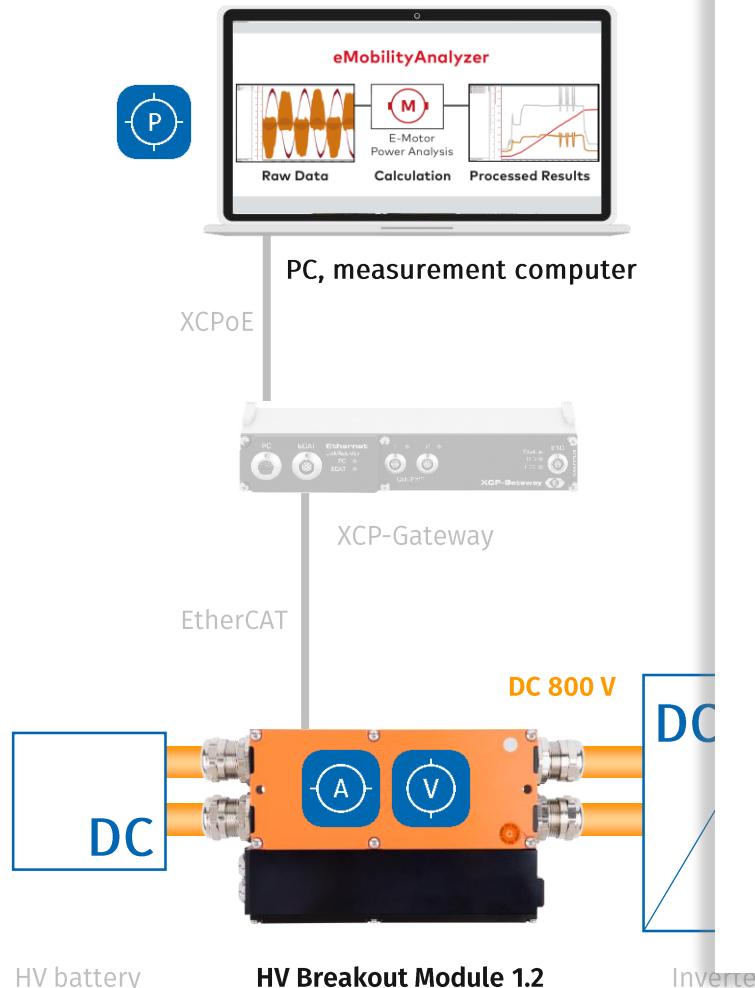
eMobilityAnalyzer
on www.csm.de



$$P = \frac{1}{T} \int_0^T u(t) \times i(t) dt$$

$$P = \frac{1}{N} \sum_{n=0}^N u_n i_n \Delta t$$

Power measurement between

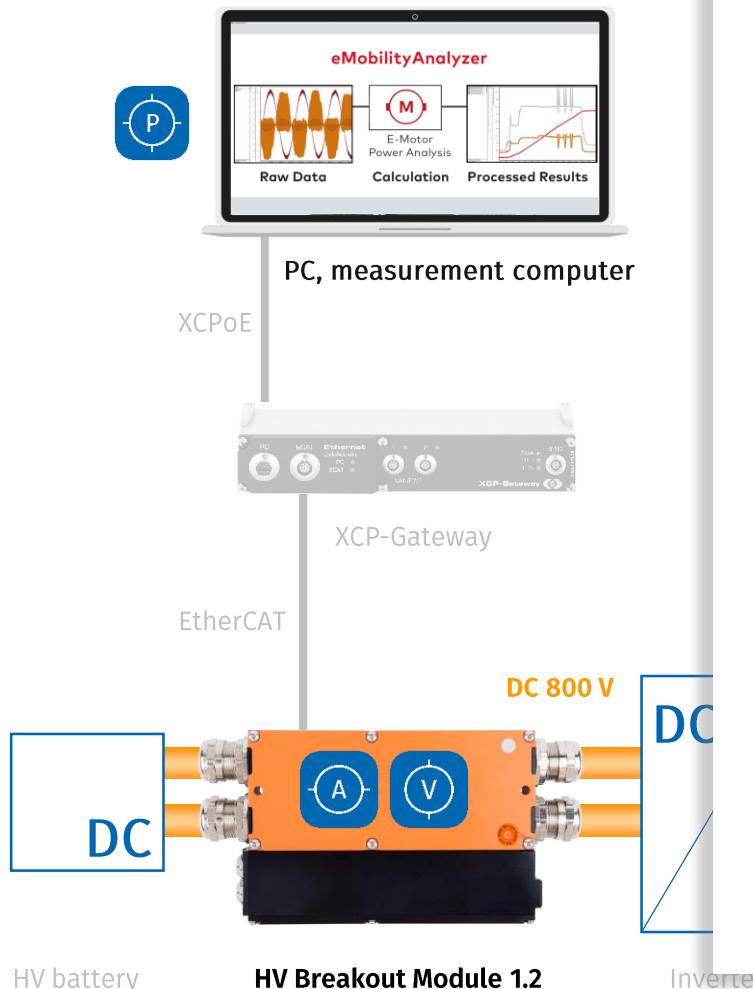


eMobilityAnalyzer - Function Library

The eMobilityAnalyzer enables a **real-time analysis** of

- ▶ **AxlePower** Mechanical power and work of an axle
- ▶ **ChargerEfficiency** Efficiency charging system
- ▶ **DCAanalysis** Analysis of a direct current signal
- ▶ **DCEfficiency** Efficiency of a converter
- ▶ **eMotorPowerAnalysis** Electric motor power analysis
- ▶ **eMotorYdelta** E-motor star delta transformation
- ▶ **Harmonics** Harmonic analysis (fundamental and harmonics)
- ▶ **InverterEfficiency** Inverter efficiency
- ▶ **PWMPowerAnalysis** Pulse width modulation Power analysis
- ▶ **Ripple** Ripple of a direct current signal
- ▶ **ShaftPower** Mech. Power from torque and speed

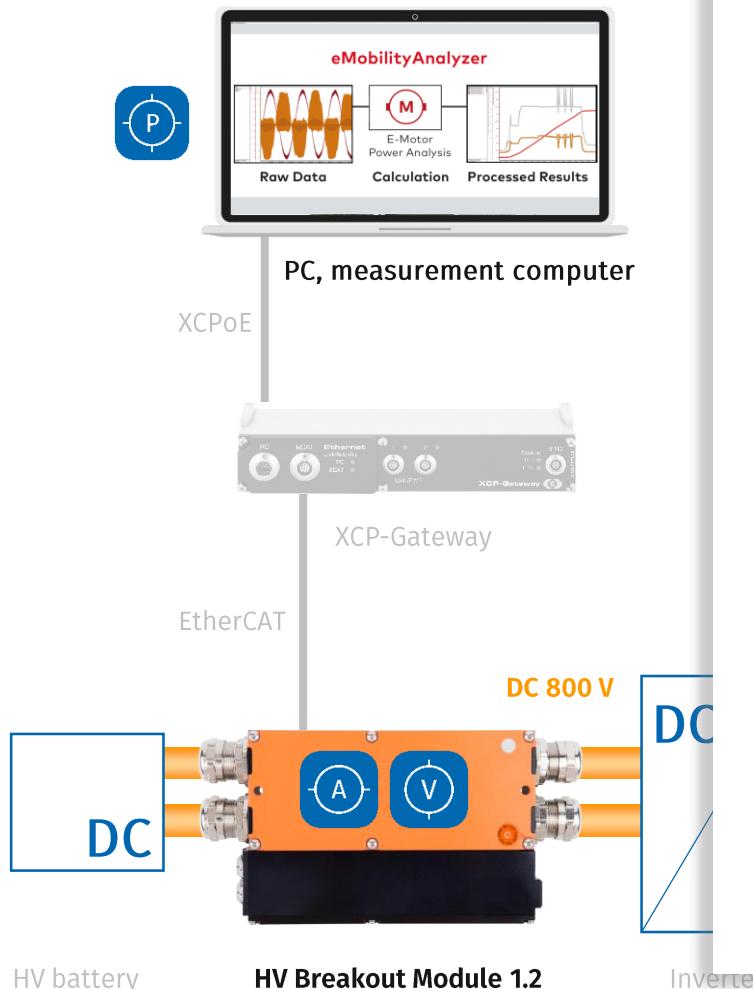
Power measurement between



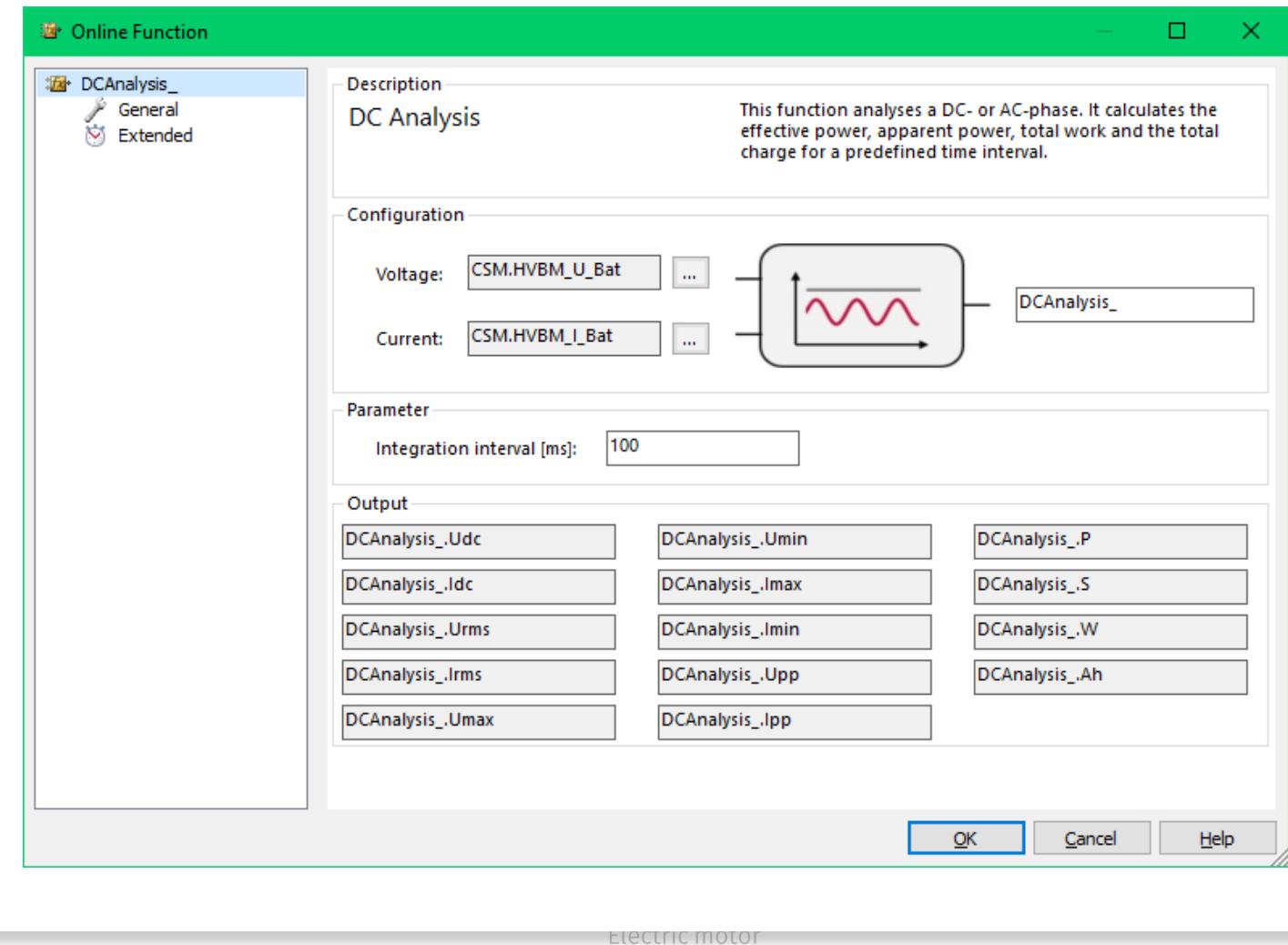
Power analysis on a DC signal

Name	Comment	Base data type
DCAnalysis		STRUCT(112)
DCAnalysis.Ah	Total charge [Ah]	DOUBLE
DCAnalysis.Idc	Average current [A]	DOUBLE
DCAnalysis.Imax	Maximal current [A]	DOUBLE
DCAnalysis.Imin	Minimal current [A]	DOUBLE
DCAnalysis.Ipp	Peak-to-peak current [A]	DOUBLE
DCAnalysis.Irms	Root mean square current [A]	DOUBLE
DCAnalysis.P	Active power [W]	DOUBLE
DCAnalysis.S	Apparent power [VA]	DOUBLE
DCAnalysis.Udc	Average voltage [V]	DOUBLE
DCAnalysis.Umax	Maximal voltage [V]	DOUBLE
DCAnalysis.Umin	Minimal voltage [V]	DOUBLE
DCAnalysis.Upp	Peak-to-peak voltage [V]	DOUBLE
DCAnalysis.Urms	Root mean square voltage [V]	DOUBLE
DCAnalysis.W	Total energy [kWh]	DOUBLE

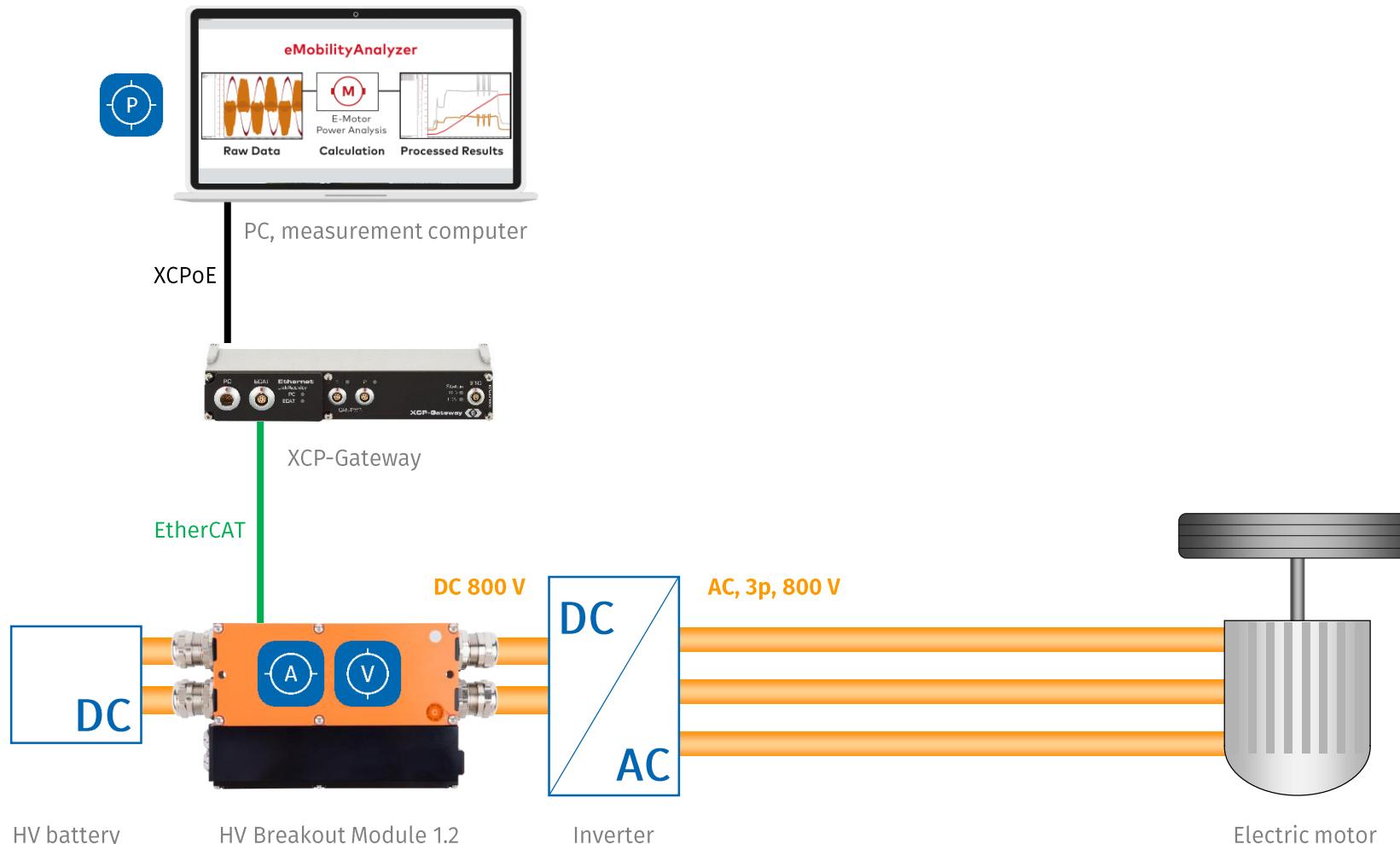
Power measurement between



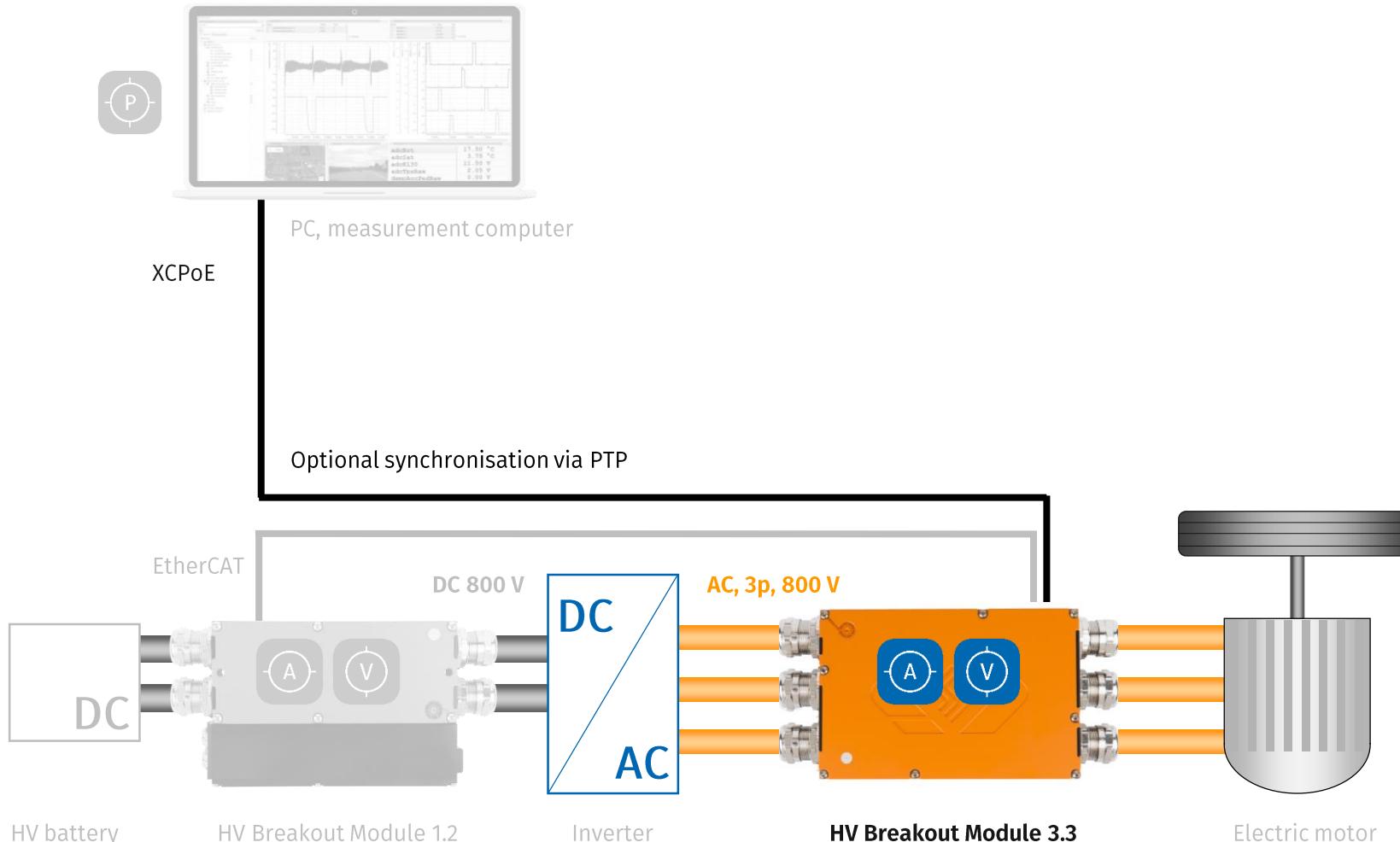
Power analysis on a DC signal



Power measurement on a powertrain (in real time)



Power measurement between inverter and electric motor (in real time)





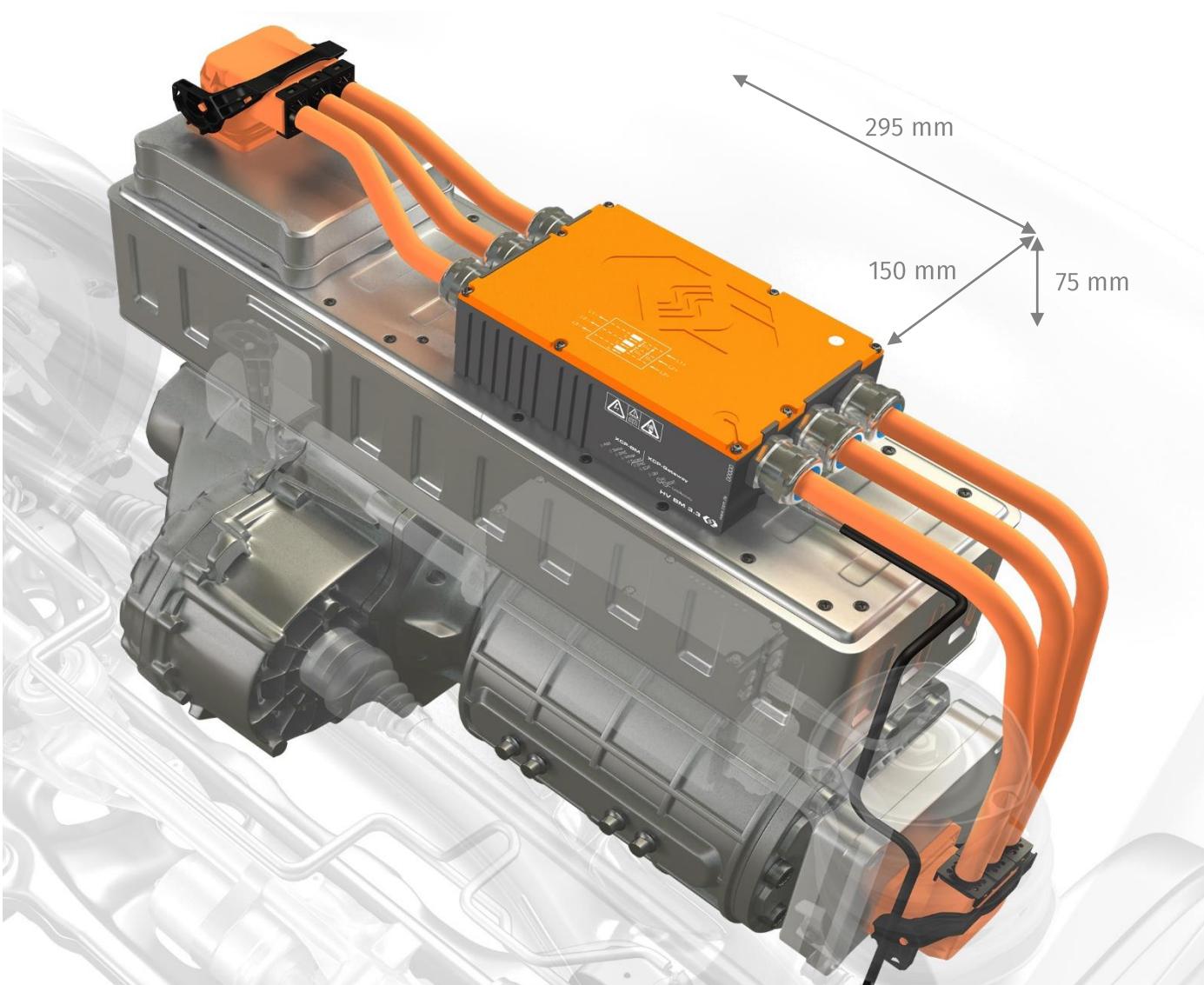
HV Breakout Module 3.3

- ▶ Measurement of 3-phase currents and voltages
- ▶ Performance analysis with the eMobilityAnalyzer
- ▶ Output of measurement data
at a rate of up to 2 MHz
per measured variable
via XCP-on-Ethernet



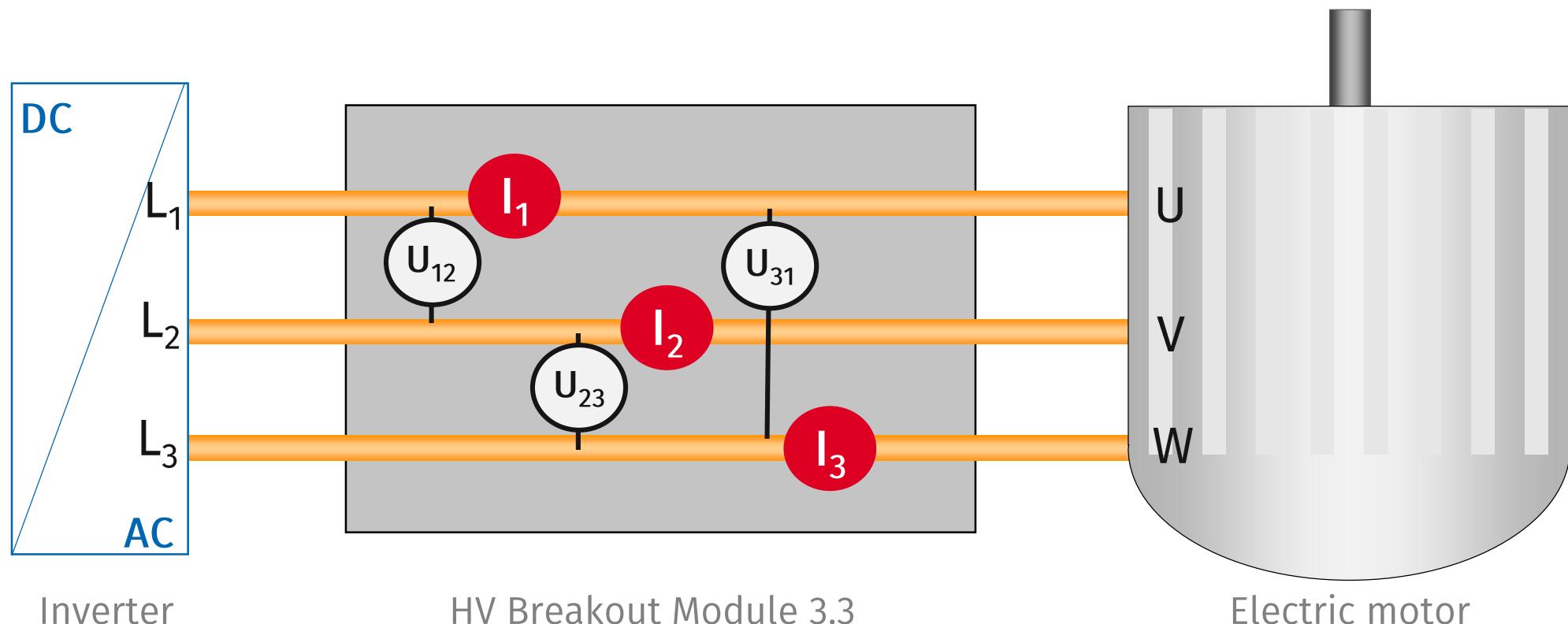
HV Breakout Module 3.3

- ▶ Voltages up to $\pm 1,000$ V
Measurement range for transients up to $\pm 2,000$ V
- ▶ Currents up to 800 A
(nominal value shunt module)
Measurement range for peaks up to $\pm 1,400$ A
- ▶ Optional PTP Sync (IEEE 1588)
- ▶ Optional "XCP Gateway" function for connecting additional CSM CAN and EtherCAT® measurement modules



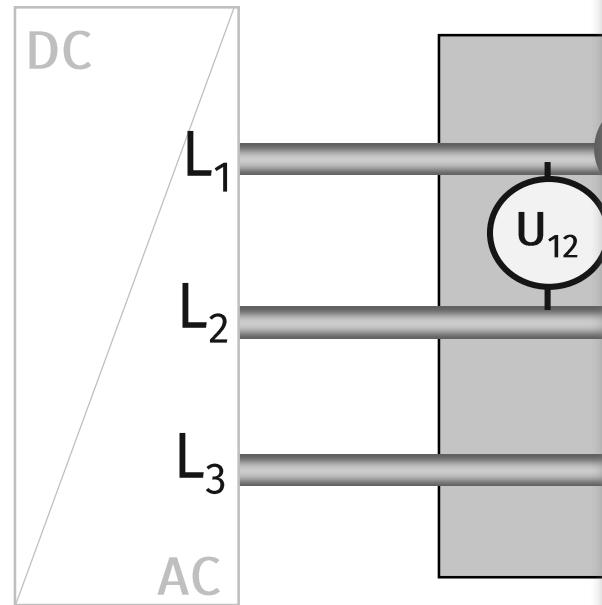
3-phase power measurement (3φ3L, 3V3A)

- Phase-synchronous measurement of current and voltage



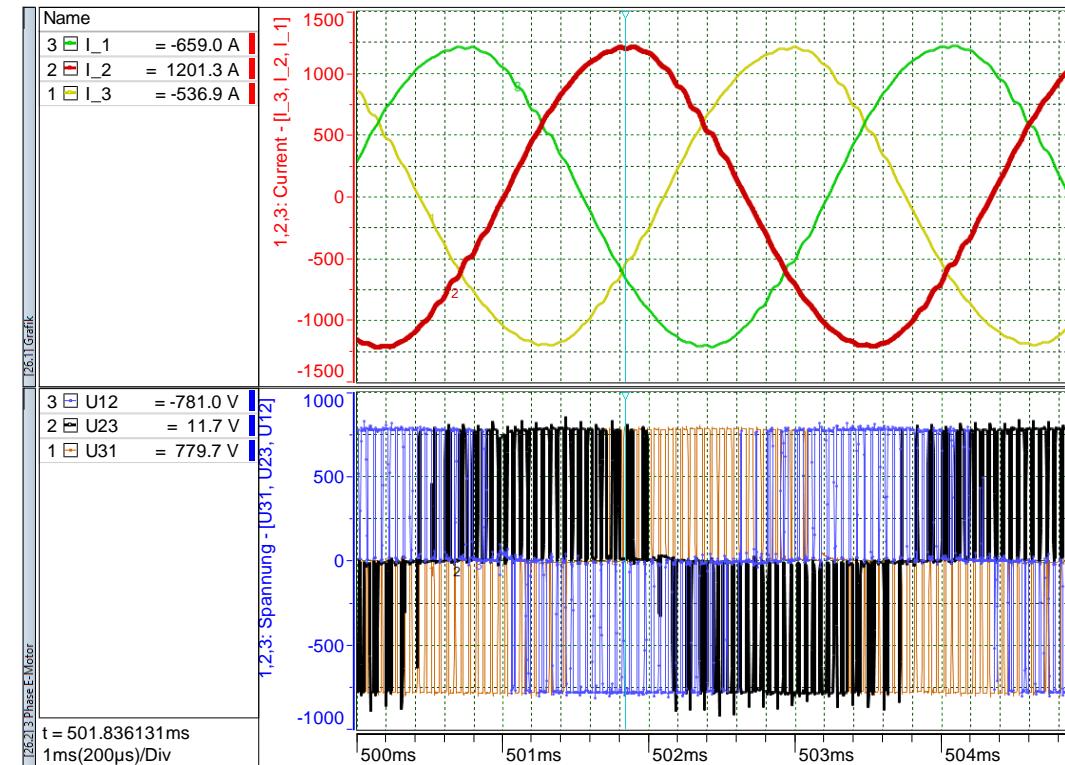
3-phase power measurement

- Phase-synchronous measurement



Calculation in the eMobilityAnalyzer

For the 3-phase power analysis, the eMobilityAnalyzer calculates the **period length** and **frequency in real time** from the sampled values to the phase-synchronous currents and voltages of the HV breakout module.



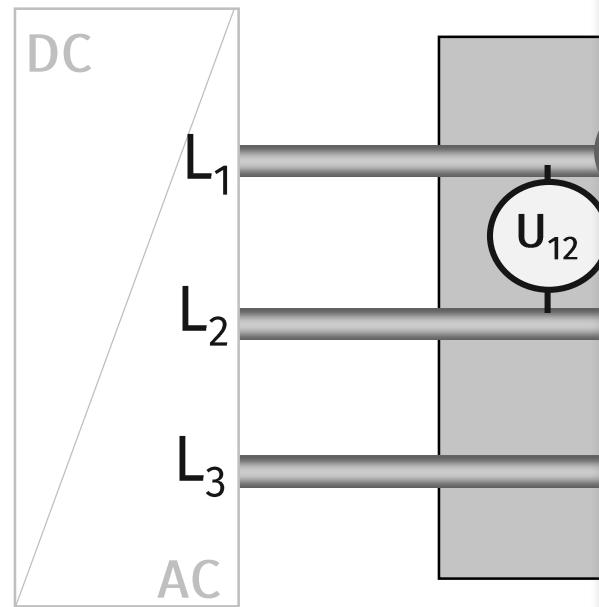
Measurement on
3-phase electrical motor
@ $P_{el} \sim 550$ kW

HV Breakout Module 5.5

Electric motor

3-phase power measurement

- Phase-synchronous measurement



Inverter

HV Breakout Module 5.5

Electric motor

Easy configuration in the eMobilityAnalyzer

Online Function

eMotorPowerAnalysis

General
Extended

Description

E-Motor Power Analysis

This function calculates the effective power of a 3-phase system based on a detected period in the current signal. It uses the 3 phase voltages and the 3 phase currents as input.

Configuration

U12: CSM.HVBM_3_3_U12 ...
U23: CSM.HVBM_3_3_U23 ...
U31: CSM.HVBM_3_3_U31 ...
I1: CSM.HVBM_3_3_I1 ...
I2: CSM.HVBM_3_3_I2 ...
I3: CSM.HVBM_3_3_I3 ...

Motor type

Star
 Delta

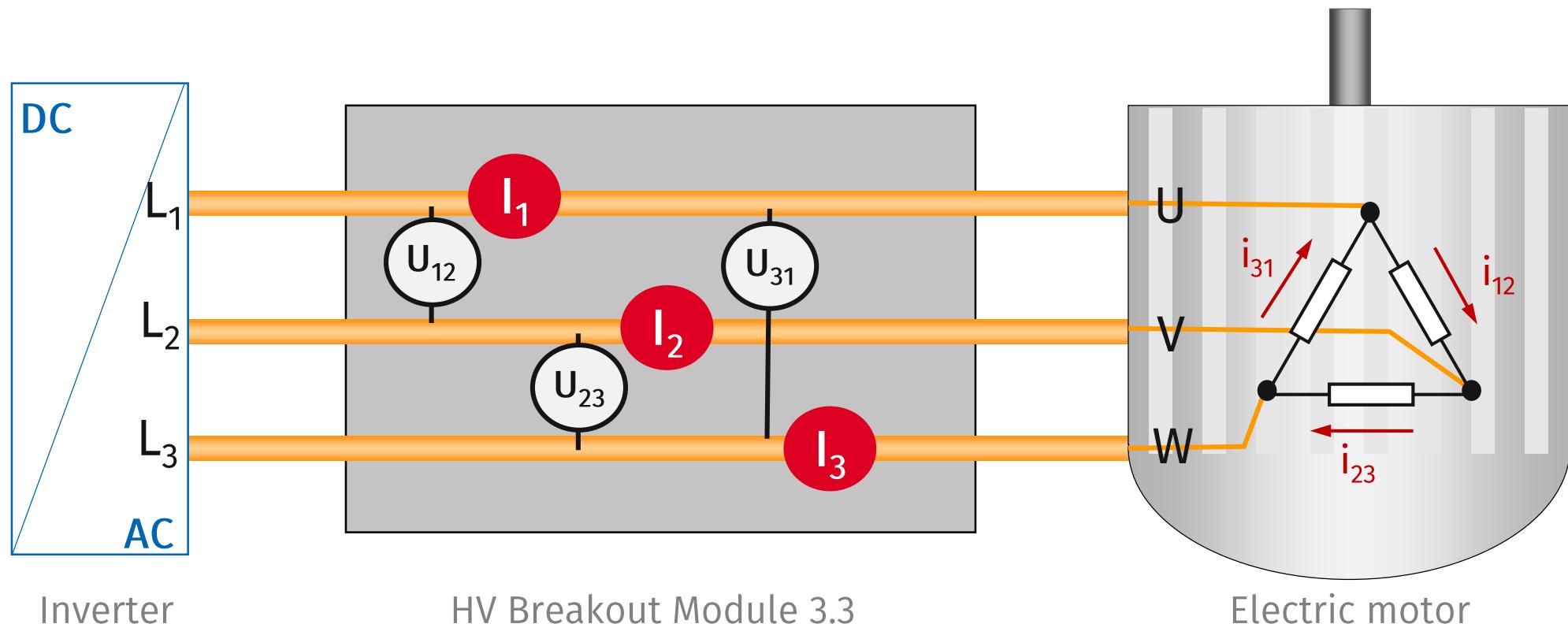
Parameter Output

Cycle: 1 ▾ Period min. [ms]: 2.0 Nu: 0.5
Smooth: 5 Period max. [ms]: 100.0 Irms min. [A]: 0.00

OK Cancel Help

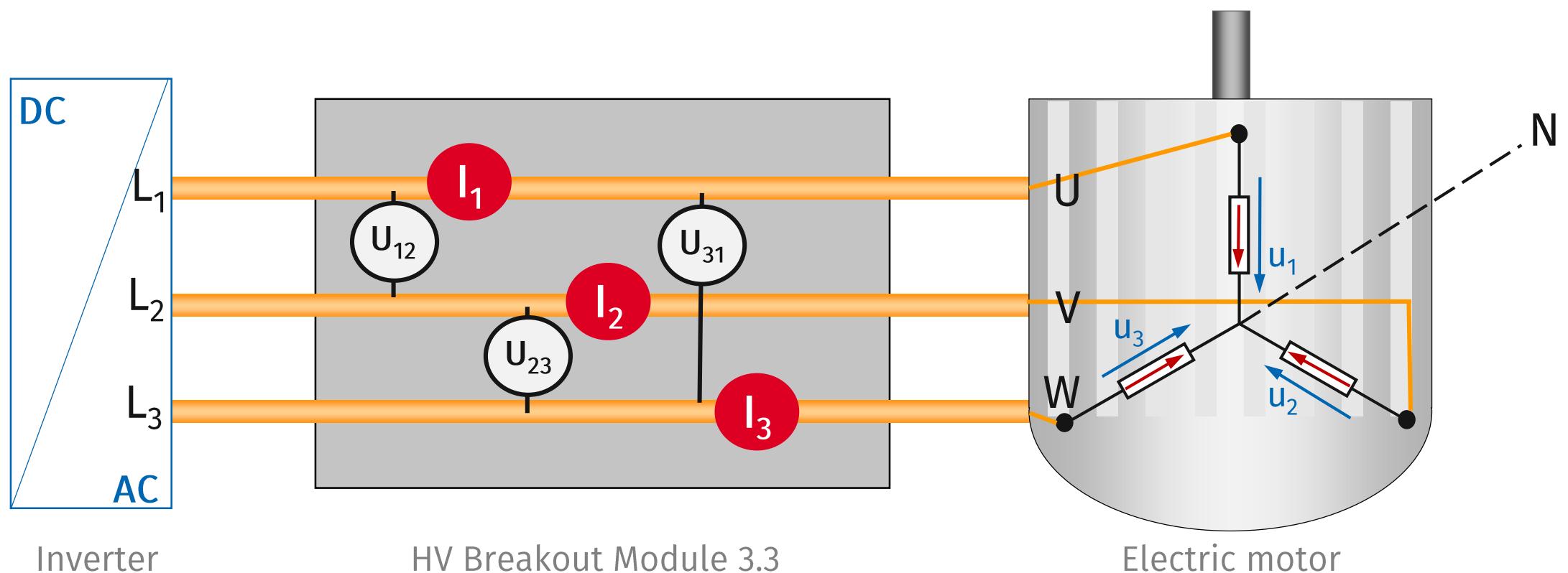
3-phase power measurement (3φ3L, 3V3A)

- ▶ with Y-Δ transformation
- ▶ Active power motor = sum of active powers of the individual motor windings
- ▶ $P = P1 + P2 + P3$



3-phase power measurement (3φ3L, 3V3A)

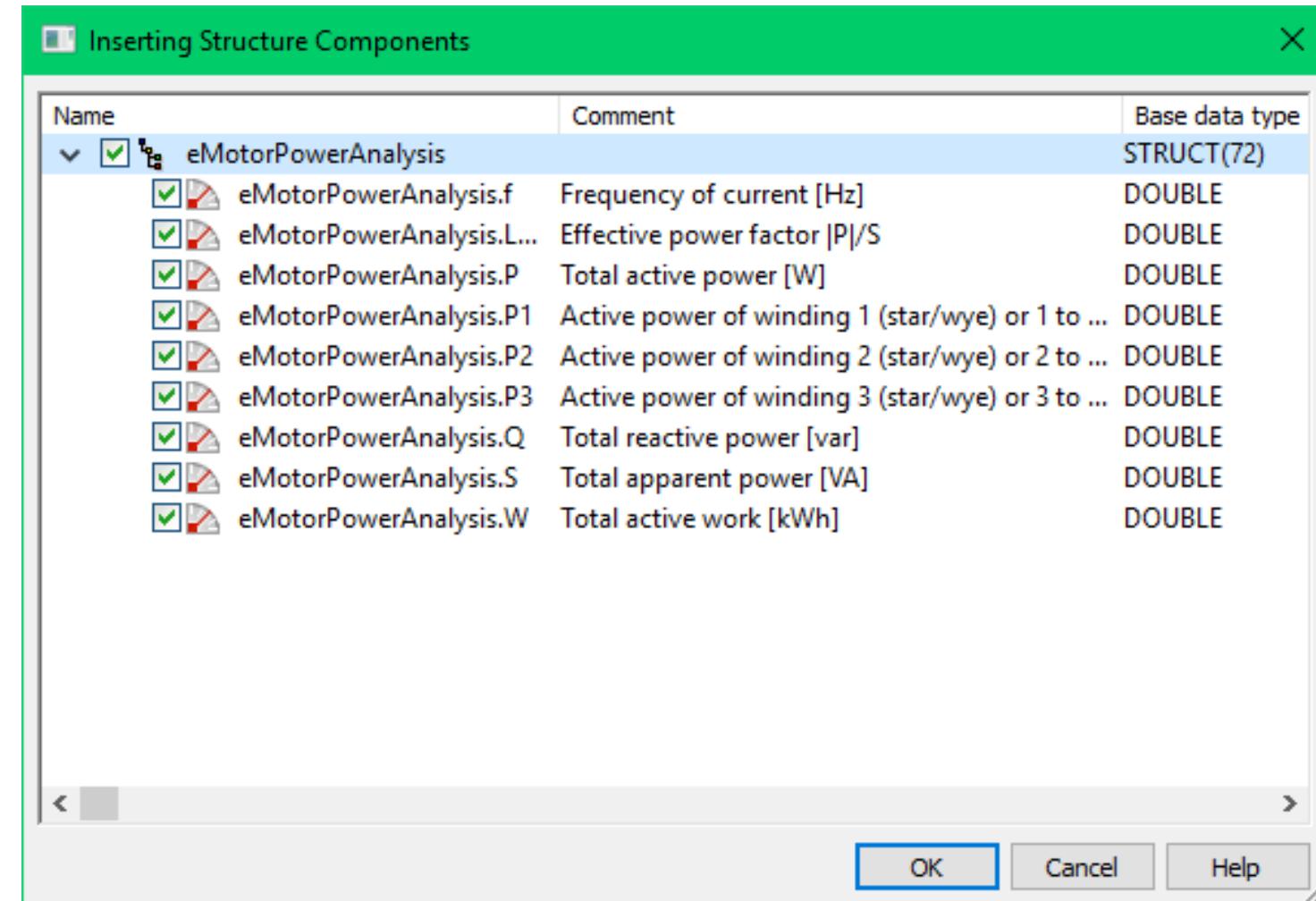
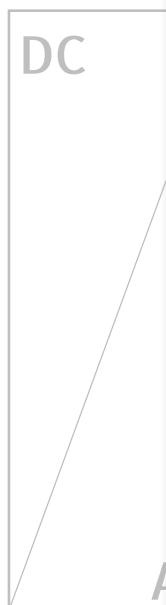
- ▶ with Y-Δ transformation
- ▶ Active power motor = sum of active powers of the individual motor windings
- ▶ $P = P1 + P2 + P3$



Power calculation in the eMobilityAnalyzer

3-phase power

- ▶ with Y-Δ transformation
- ▶ Active power
- ▶ $P = P_1 + P_2 + P_3$



Inverter

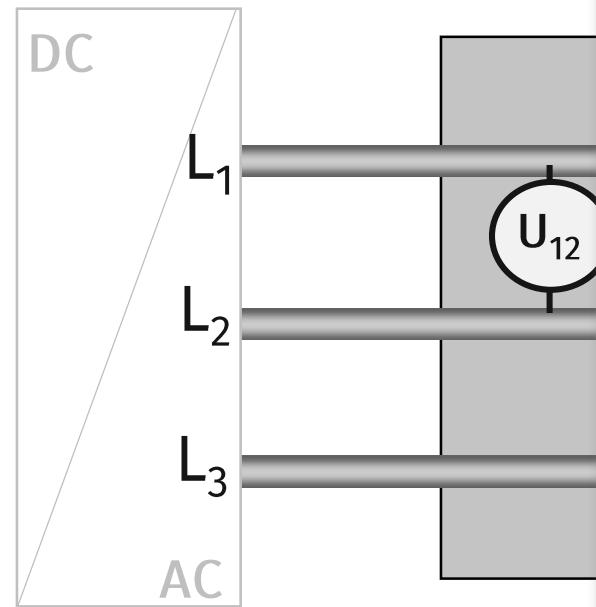
HV Breakout Module 3.3

Electric motor

Star-Delta Transformation in eMobilityAnalyzer

3-phase power measurement

- ▶ with Y-Δ transformation
- ▶ Active power motor = sum of active powers
- ▶ $P = P_1 + P_2 + P_3$



Inverter

HV Breakout Module 3.3

Electric motor

Online Function

eMotorYdelta_

General Extended

Description

E-Motor Y- Δ -Transformation

This function calculates the phase currents I_{12} , I_{23} , I_{31} and voltages U_1 , U_2 , U_3 through the star-delta transformation. It uses the three phase voltages U_{12} , U_{23} , U_{31} and currents I_1 , I_2 , I_3 .

Configuration

U12: CSM.HVBM_3_3_U12 ...
U23: CSM.HVBM_3_3_U23 ...
U31: CSM.HVBM_3_3_U31 ...
I1: CSM.HVBM_3_3_I1 ...
I2: CSM.HVBM_3_3_I2 ...
I3: CSM.HVBM_3_3_I3 ...

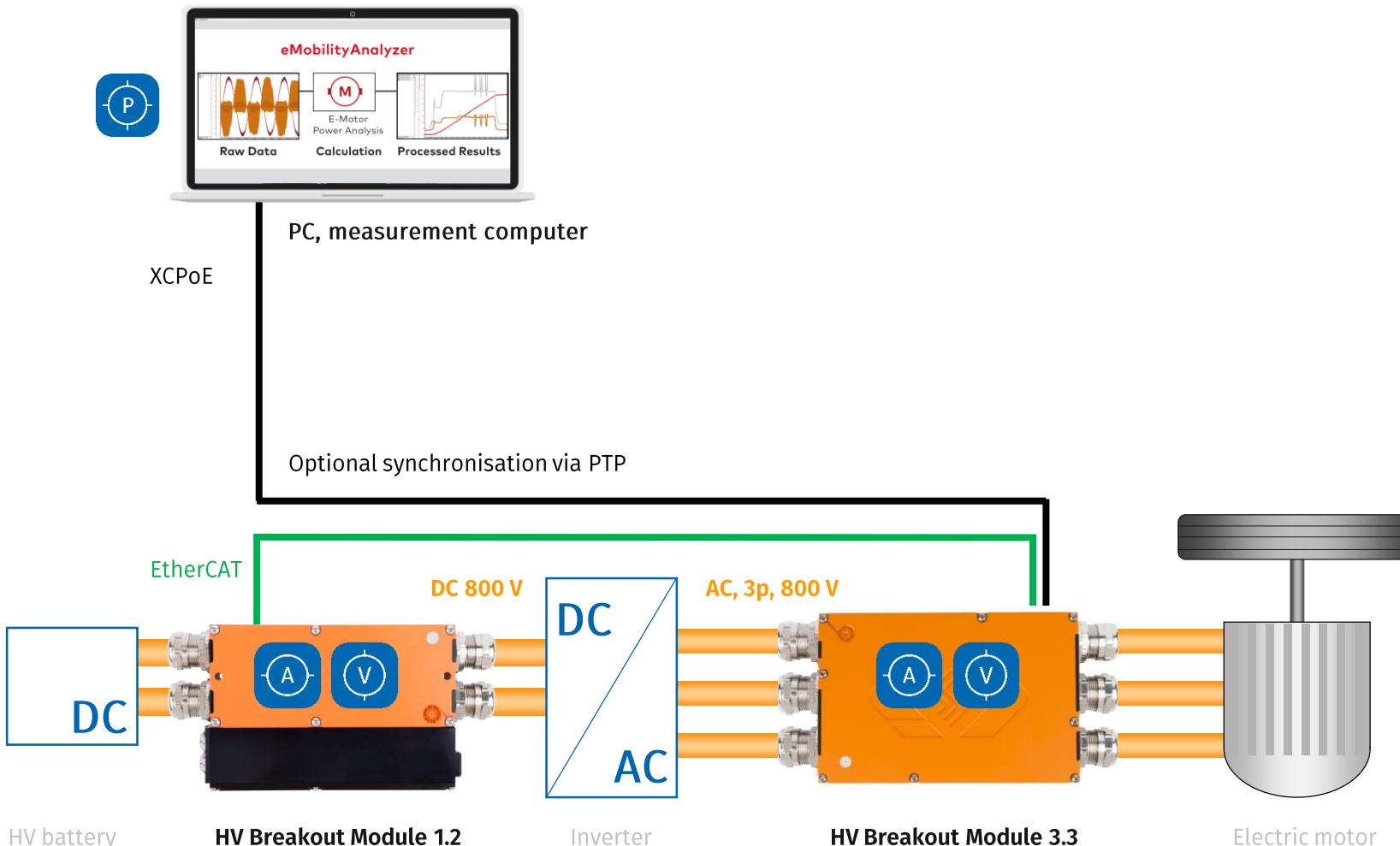
Output

eMotorYdelta_.U_1 eMotorYdelta_.U_3 eMotorYdelta_.I_23
eMotorYdelta_.U_2 eMotorYdelta_.I_12 eMotorYdelta_.I_31

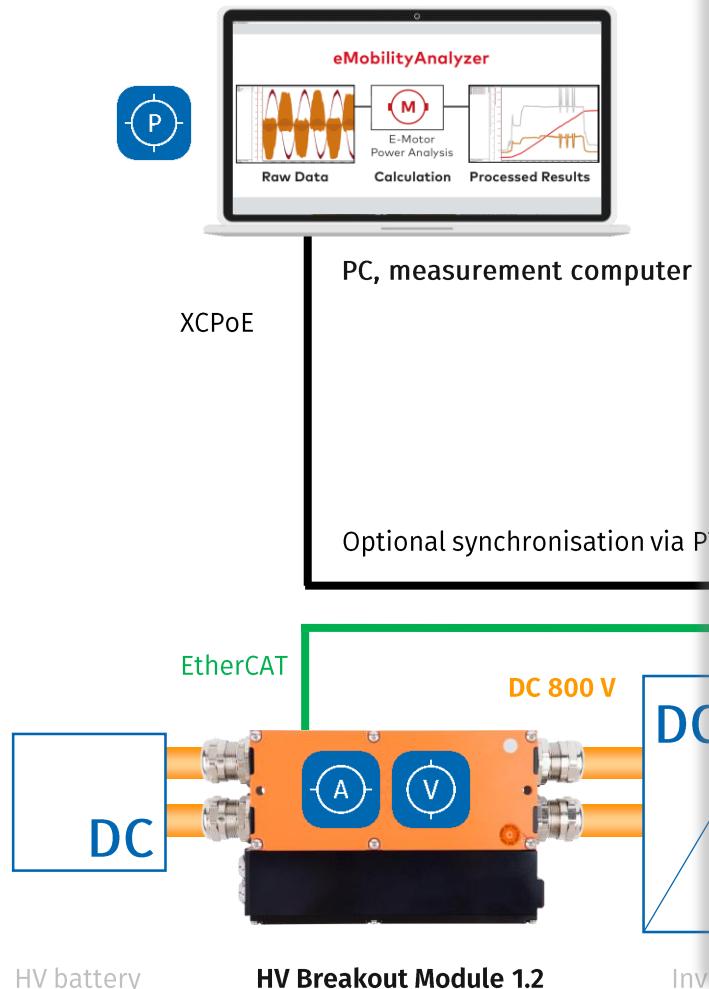
OK Cancel Help

The screenshot shows the configuration dialog for the 'eMotorYdelta_' function. The function is described as calculating the star-delta transformation for an electric motor. It takes three phase voltages (U12, U23, U31) and three phase currents (I1, I2, I3) as inputs and provides six outputs: three phase voltages (U1, U2, U3) and three phase currents (I12, I23, I31). The configuration panel includes dropdown menus for each input and output, and a help button at the bottom right.

Efficiency measurement at the inverter



Efficiency measurement



Calculation in the eMobilityAnalyzer

Online Function

InverterEfficiency_

- General
- Extended

Description

Inverter Efficiency

This function integrates the active power of three power line AC inputs and one DC output. It also calculates the overall efficiency of an inverter.

Configuration

Uin:	CSM.HVBM_U_Bat	...	InverterEfficiency_.Pin
Iin:	CSM.HVBM_I_Bat	...	InverterEfficiency_.Win
U12:	CSM.HVBM_3_3_U12	...	InverterEfficiency_.Pout
U23:	CSM.HVBM_3_3_U23	...	InverterEfficiency_.Wout
U31:	CSM.HVBM_3_3_U31	...	InverterEfficiency_.eta
I1:	CSM.HVBM_3_3_I1	...	InverterEfficiency_.etaW
I2:	CSM.HVBM_3_3_I2	...	InverterEfficiency_.Pd
I3:	CSM.HVBM_3_3_I3	...	InverterEfficiency_.Wd

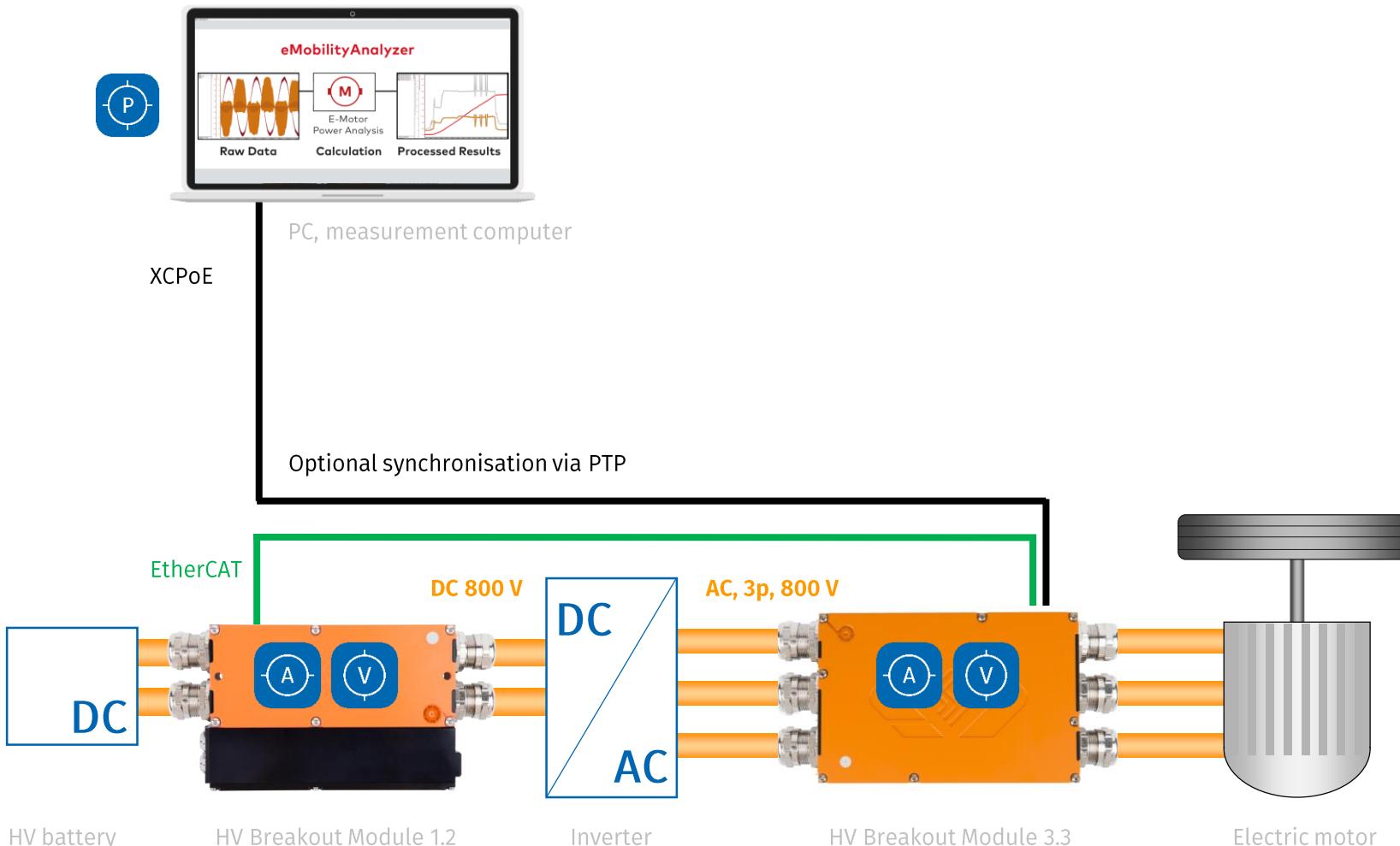
InverterEfficiency_

Parameter

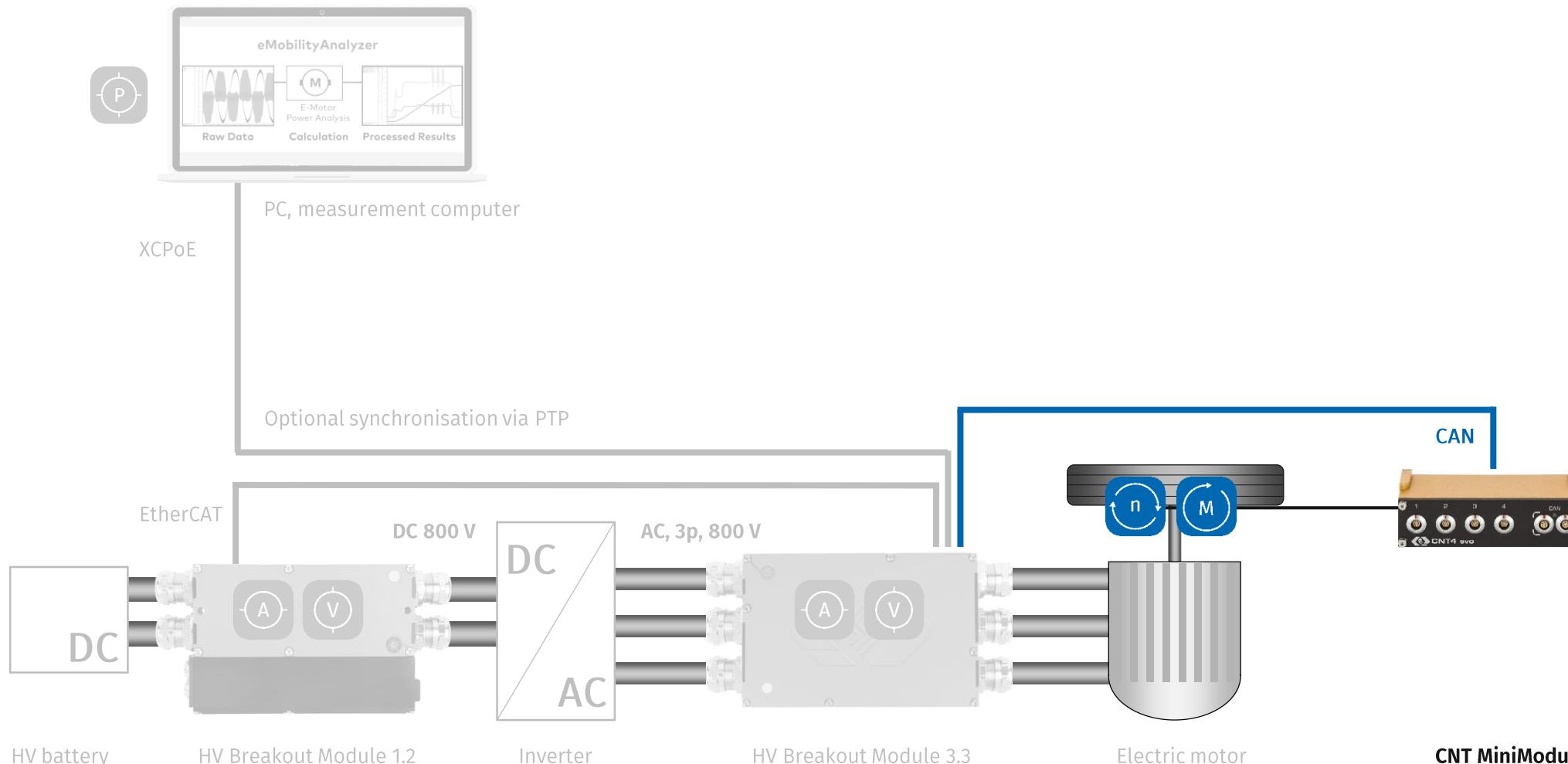
Integration Interval [ms]:	100	Cycles min.:	10	Irms min.:	0
Frequency min.:	500	Frequency max.:	5000	Sync Source:	0

OK Cancel Help

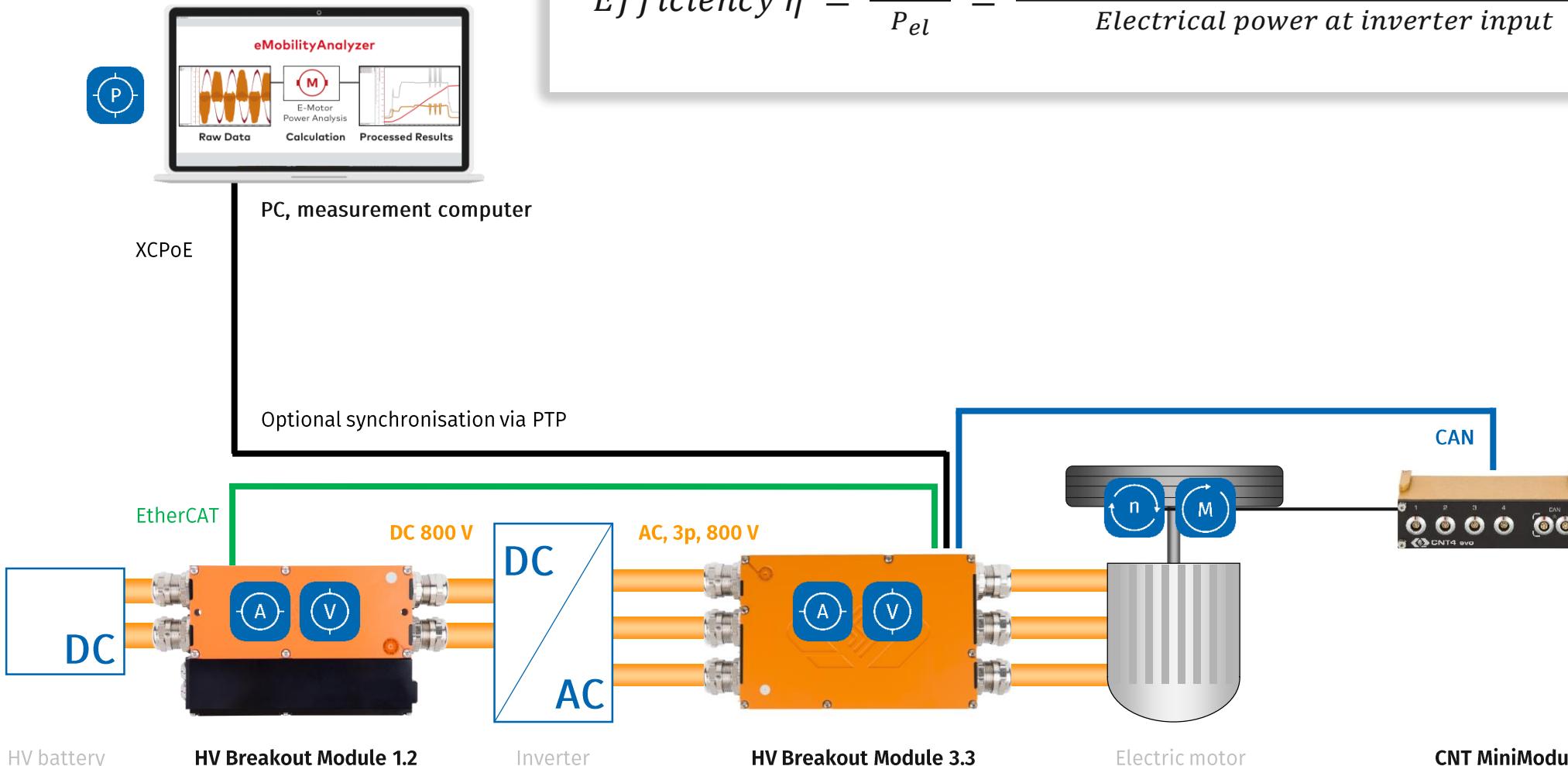
Calculation of the overall efficiency



Calculation of the overall efficiency



Overall efficiency



Calculation in the eMobilityAnalyzer

$$\text{Efficiency } \eta = \frac{P_{\text{mech}}}{P_{\text{el}}} = \frac{\text{Mechanical shaft power on the electric motor}}{\text{Electrical power at inverter input}}$$

ShaftPower_

General
Extended

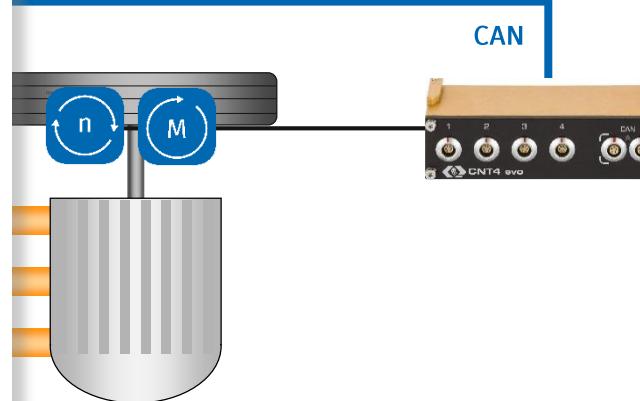
Description
Shaft Power
This function calculates the current mechanical power based on torque and rotational speed of a shaft. It also outputs the total work from start of the measurement.

Configuration
Torque M: T12.HP_MSG0.M ... ShaftPower_
Revolution n: T12.HP_MSG0.n ...

Parameter
Integration interval [ms]: 100

Output
ShaftPower_.P ShaftPower_.W

OK Cancel Help



HV battery

HV Breakout Module 1.2

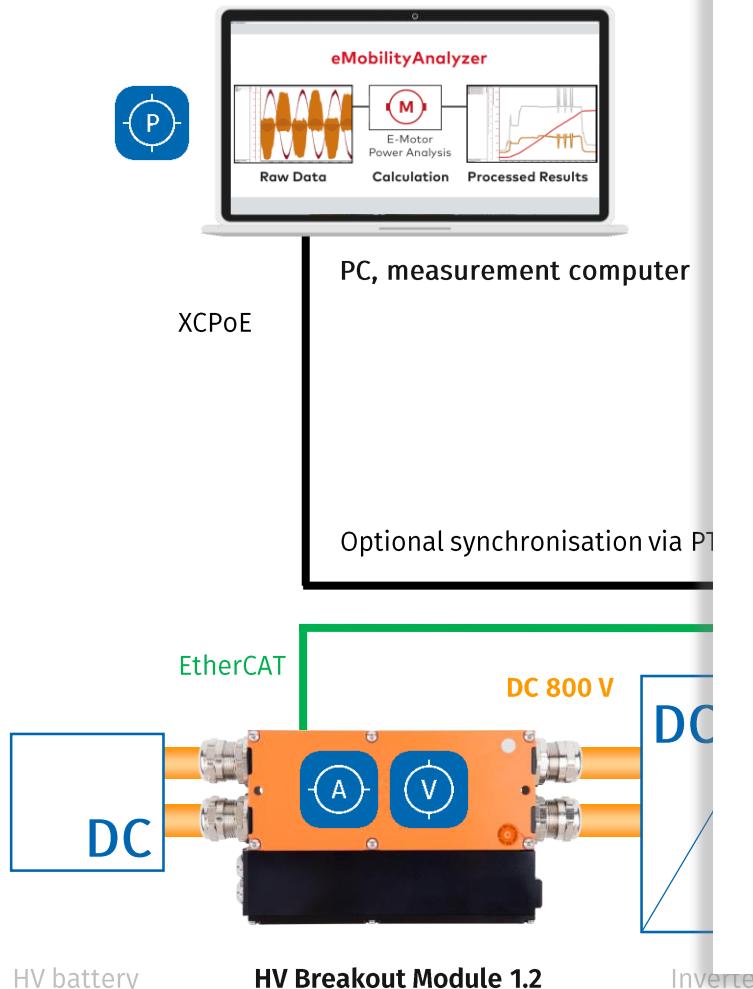
Inverter

HV Breakout Module 3.3

Electric motor

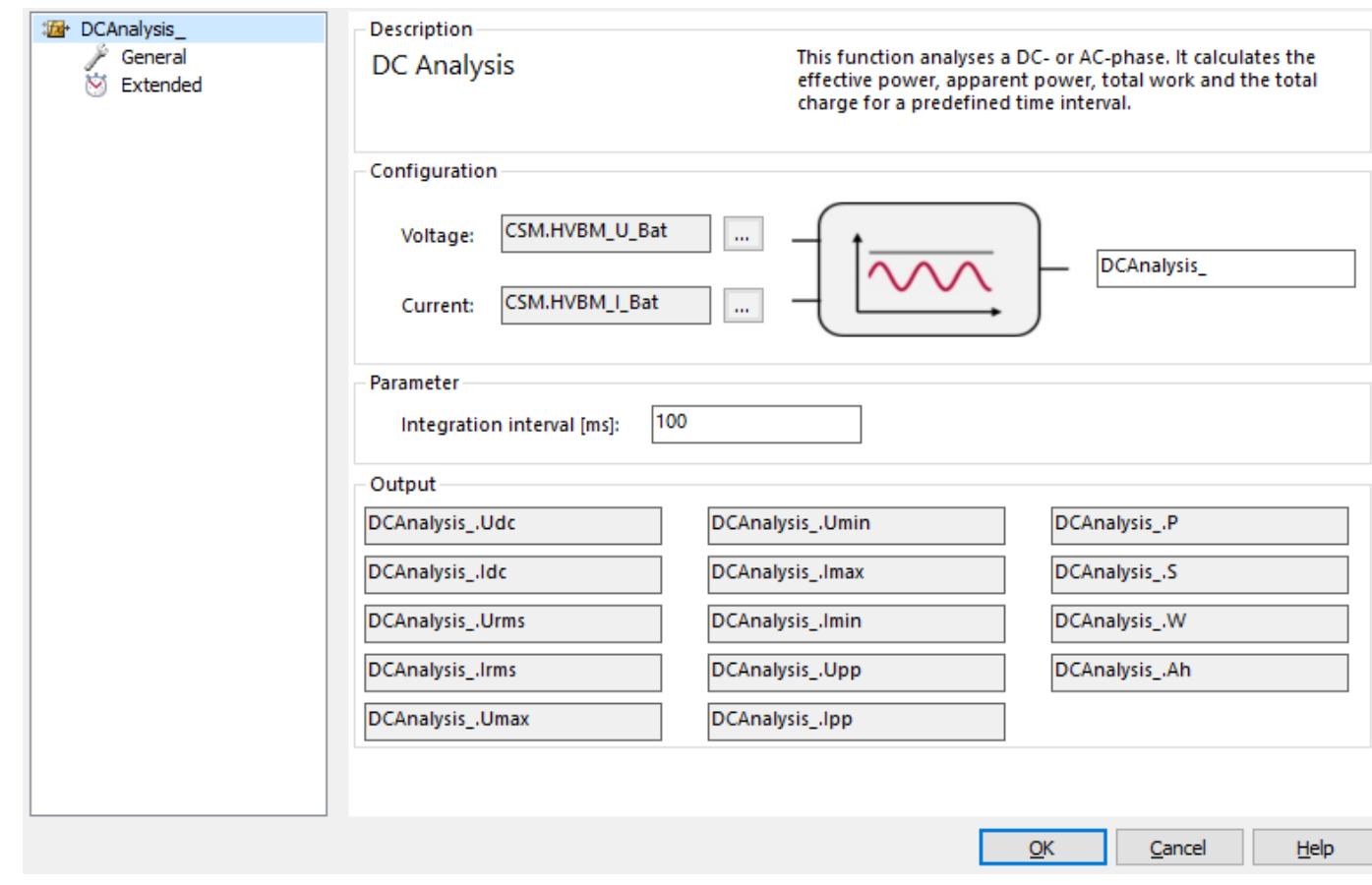
CNT MiniModul

Overall efficiency

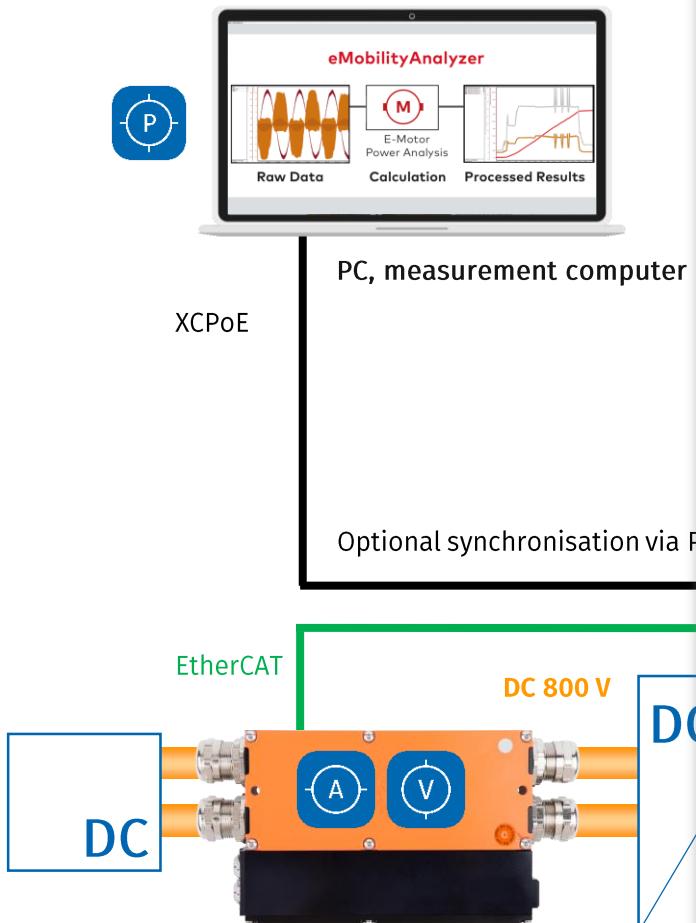


Calculation in the eMobilityAnalyzer

$$\text{Efficiency } \eta = \frac{P_{\text{mech}}}{P_{\text{el}}} = \frac{\text{Mechanical shaft power on the electric motor}}{\text{Electrical power at inverter input}}$$

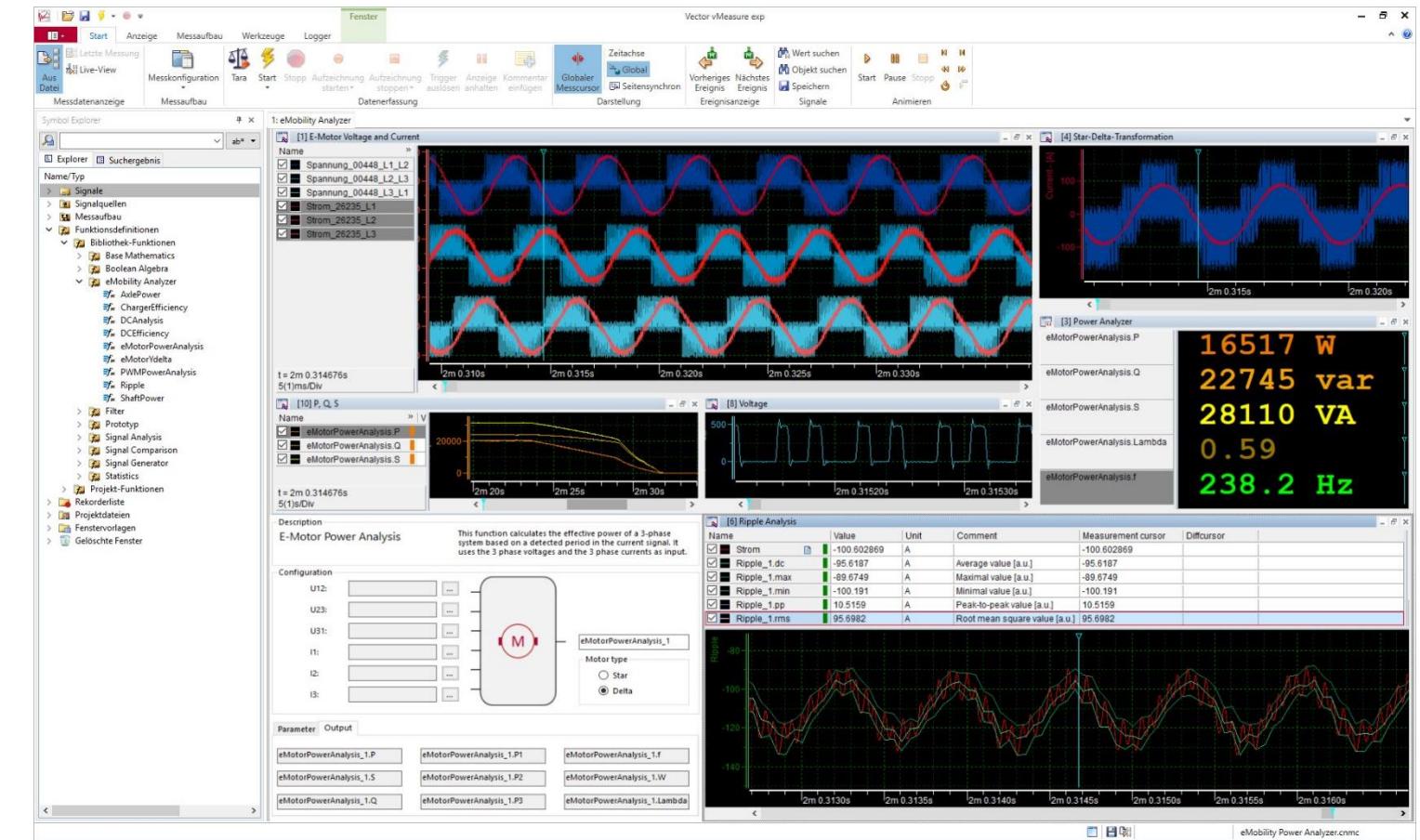


Performance analysis



Online display in vMeasure exp

- ▶ Multiple visualization of different simultaneous eMobility analyses



Vector CSM E-Mobility Basic Measurement System - Power Analysis

vMeasure exp

eMobility
Analyzer

XCP-Gateways

HV Breakout
Modules

HV ECAT
Modules

ECAT
Modules

HV CAN
Modules

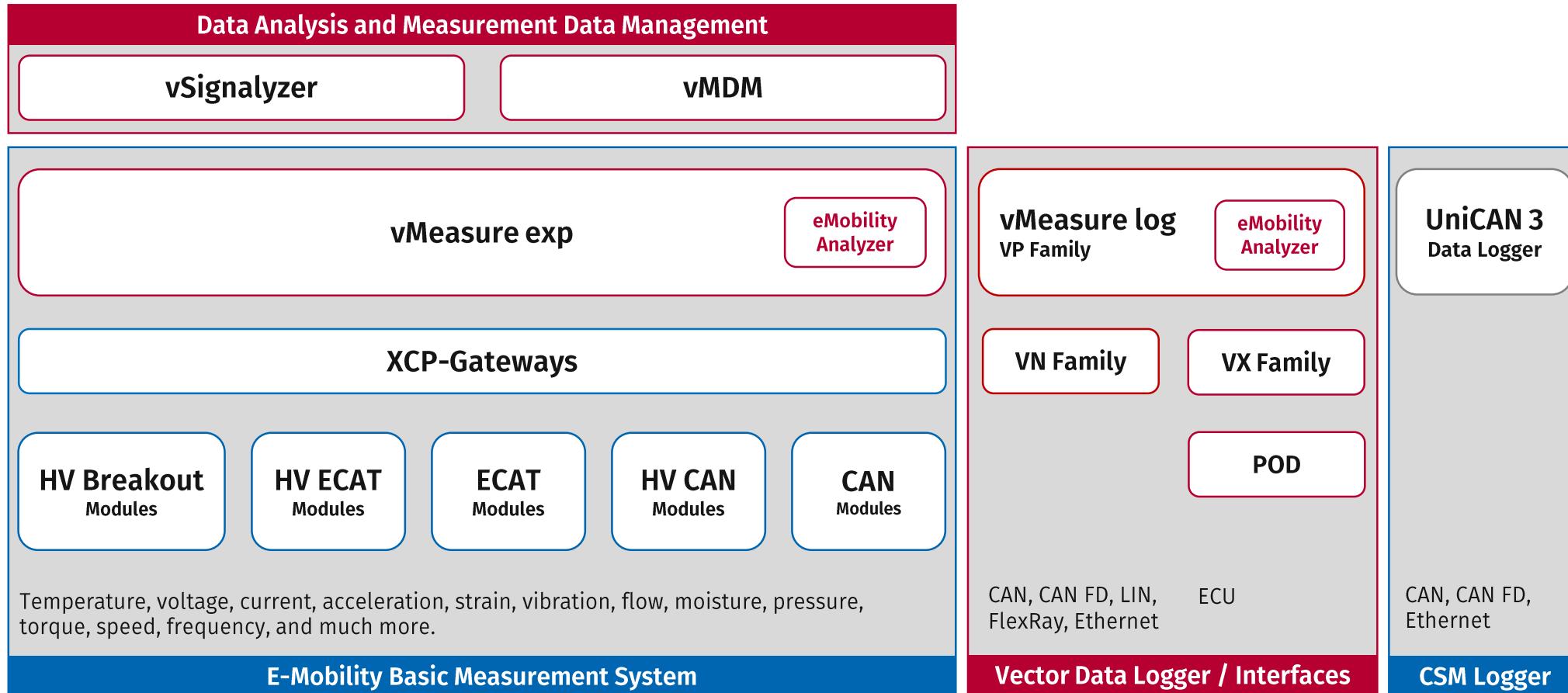
CAN
Modules

Voltage, current, acceleration, strain, vibration, temperature, flow, humidity, pressure, torque, speed, frequency, and much more.

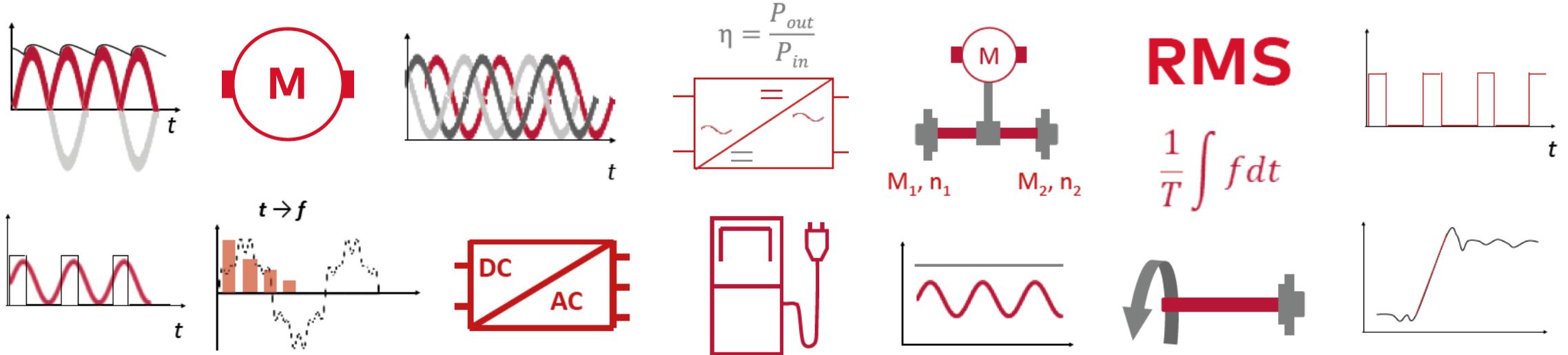
E-Mobility Basic Measurement System



The Vector CSM E-Mobility Measurement System



Features and benefits of the Measurement System



The E-Mobility Measurement System is constantly being expanded with customer applications. You will receive new analysis tools free of charge with each Vector software release. New measurement modules from CSM open up applications for all areas of electromobility.

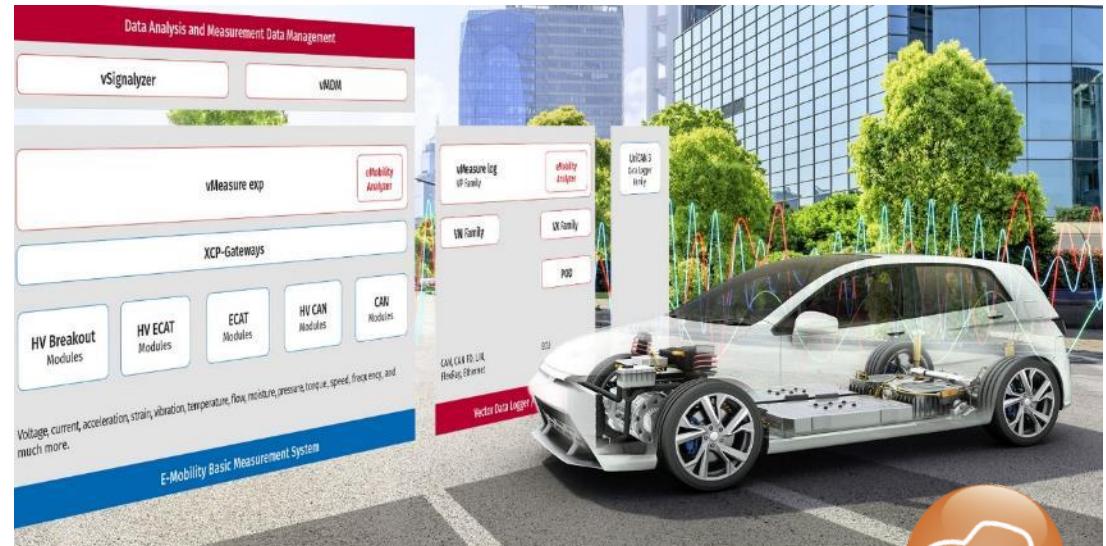
About CSM

CSM has been setting technological standards for decentralized measurement technology in vehicle development for over 35 years. Our CAN bus and EtherCAT® measurement devices support worldwide renowned vehicle manufacturers, suppliers and service providers in their developments.

Continuous innovation and long-term satisfied customers are our guarantee for success. Together with our partner Vector Informatik, we have developed an easily scalable and powerful E-Mobility Measurement System for hybrid and electric vehicles and are constantly expanding the areas of application. With our high-voltage safe measurement systems designed for fast and synchronous measurements and power analyses, we actively accompany the change to **E-Mobility**.

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CSM Xplained
measurement technology