Power measurements on electrified non-road mobile machines and construction equipment

CSM web seminars

CSM Xplained
measurement technology

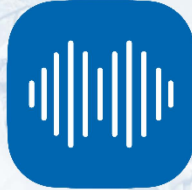# Benefits of electrified mobile machines and construction equipment

Compliance with regulations

Health of the users

Flexible use

Longer service life

Improved company image

by Stefan Redel / AdobeStock

by damark / AdobeStock

by onlyyouqj / AdobeStock

by EDAG Engineering

Electrification challenges

Mechanics, hydraulics

HV voltage, current

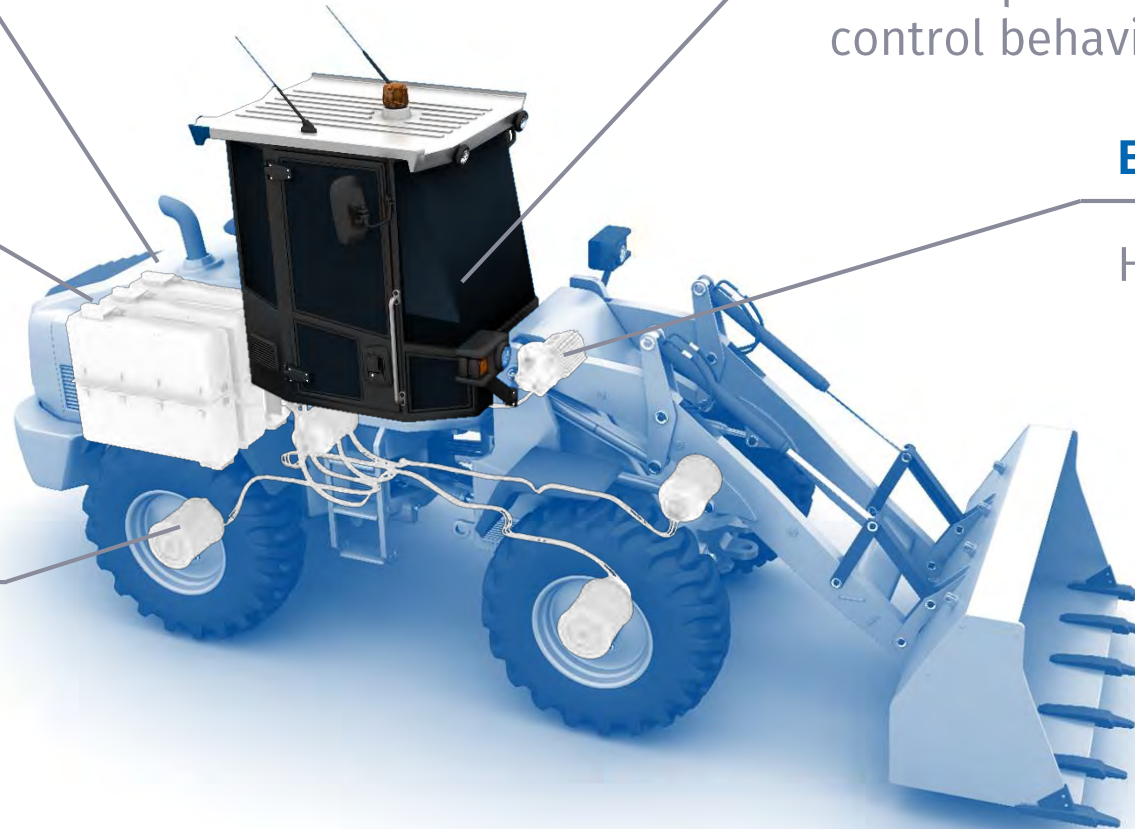**HV battery**

Fast power retrieval

Powertrain

High energy demand
over a long period

„Hydraulic Feeling"
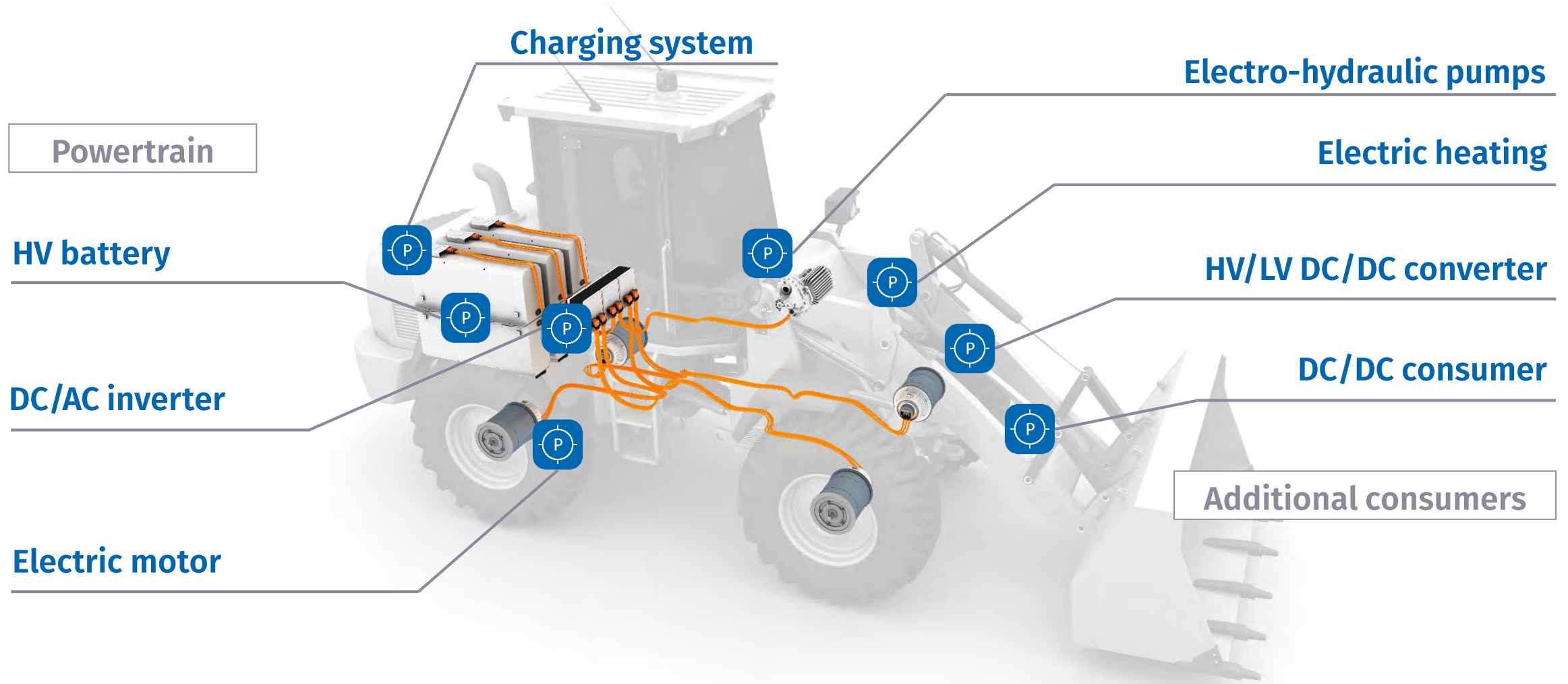
User requests for
control behavior

Electric motor control
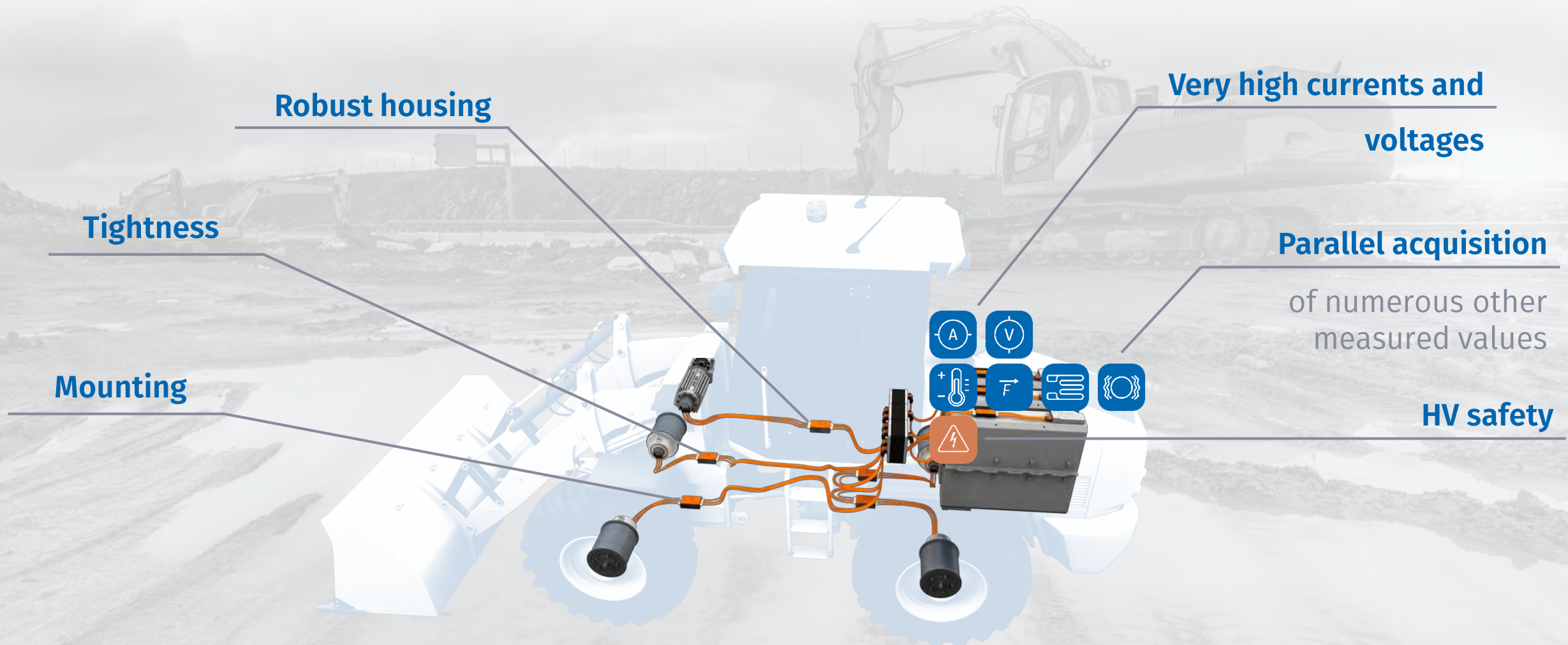
High precision required

Power measurement

Charging system

Electro-hydraulic pumps

Powertrain

Electric heating

HV battery

HV/LV DC/DC converter

DC/AC inverter

DC/DC consumer

Electric motor

Additional consumers

CSM Xplained: Power measurements on electrified non-road mobile machines and construction equipment
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Requirements for measurements

Robust housing

Very high currents and voltages

Tightness

Parallel acquisition

of numerous other measured values

Mounting

HV safety

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HV-safe measurement chain
Selection of suitable measurement equipment for high-voltage environments

Taking into consideration:
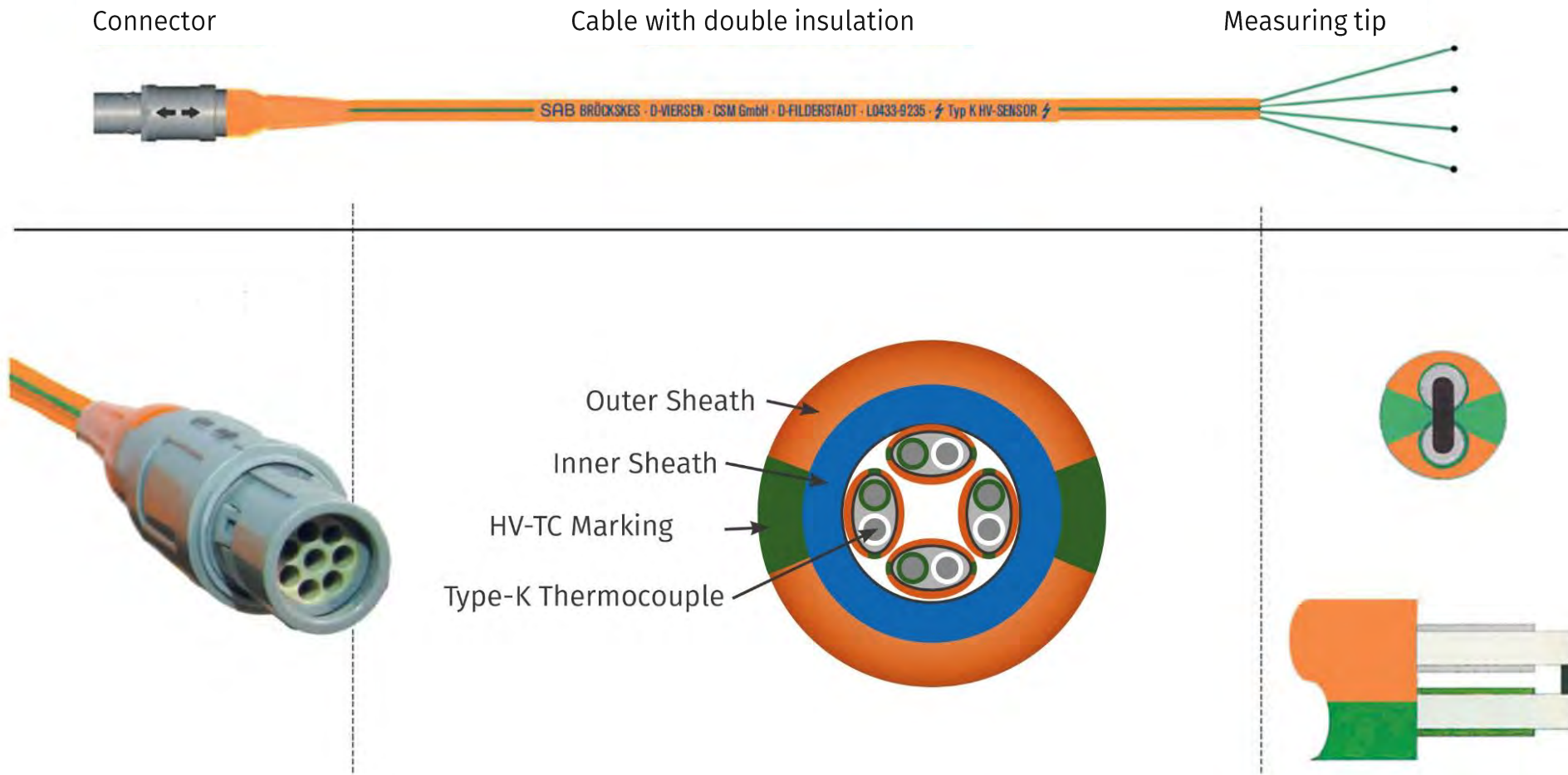
▶ Scenario   (Test bench? Laboratory? Mobile / field use?)

▶ Climatic conditions   (Ambient temperature, humidity)

▶ Pollution degree

▶ Signal frequencies to be acquired   (Usable bandwidth of the measurement channels)

▶ Operating voltage

Measurement equipment must be completely re-evaluated!

Danger
„High-voltage"!

HV-safe measurement chain
Sensor cables

Connector   Cable with double insulation   Measuring tip

SAB BRÖCKSKES · D-VIERSEN · CSM GmbH · D-FILDERSTADT · L0433-9235 · ⚡ Typ K HV-SENSOR ⚡

Outer Sheath

Inner Sheath

HV-TC Marking

Type-K Thermocouple

CSM

HV-safe measurement chain
HV-safe plug connection

HV-safe measurement chain
Isolation in the measurement device

Example: Temperature measurement module HV TH4 evo

High Voltage Part

broken sensor detection

Ref.

V_{in}^+

PT1000

V_{in}^-

analog low pass

ADC 16 bit

Low Voltage Part

K1

MC

K4

CAN controller

CAN transceiver

CAN BUS

functional isolation

power supply

Power +

Power GND
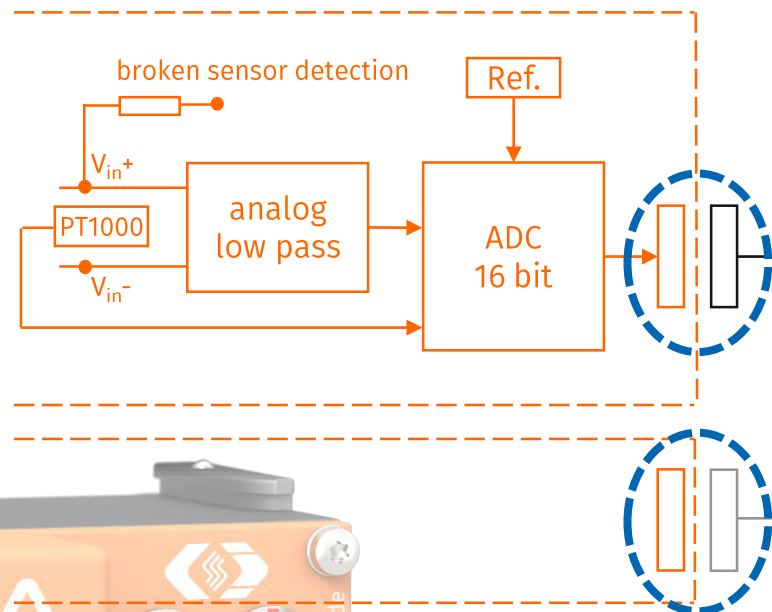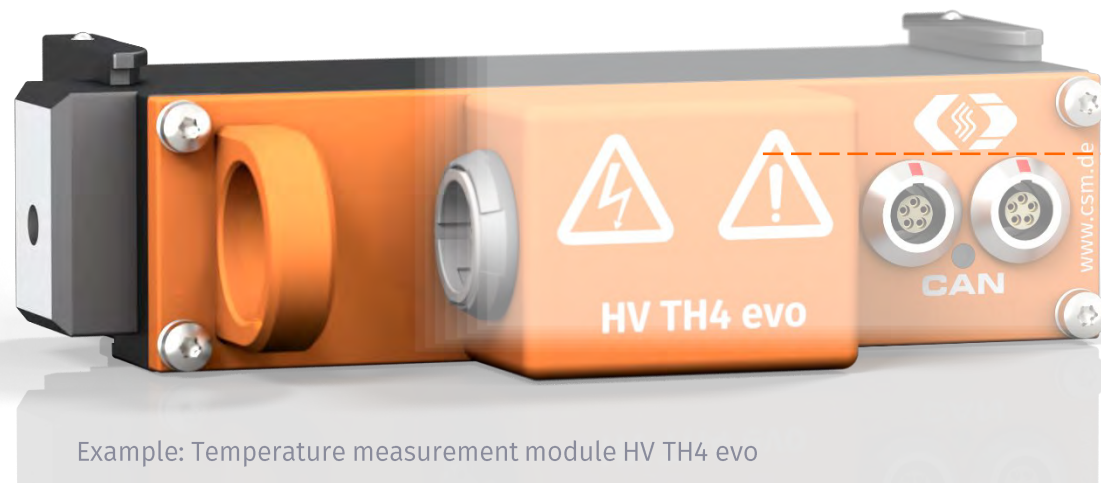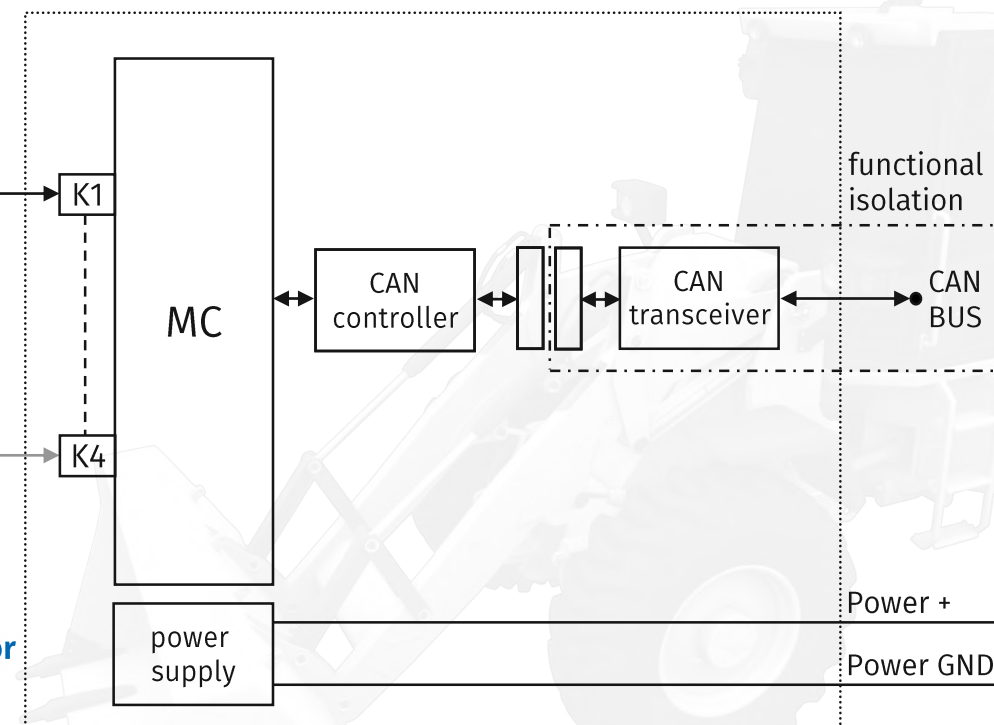
Isolation barrier with isolation up to 1000 V RMS for communication and power PER CHANNEL

Power measurement in the electric powertrain
Power measurement between HV battery and inverter

Smart Logger

PC

DC

DC

AC, 3p

DC

AC
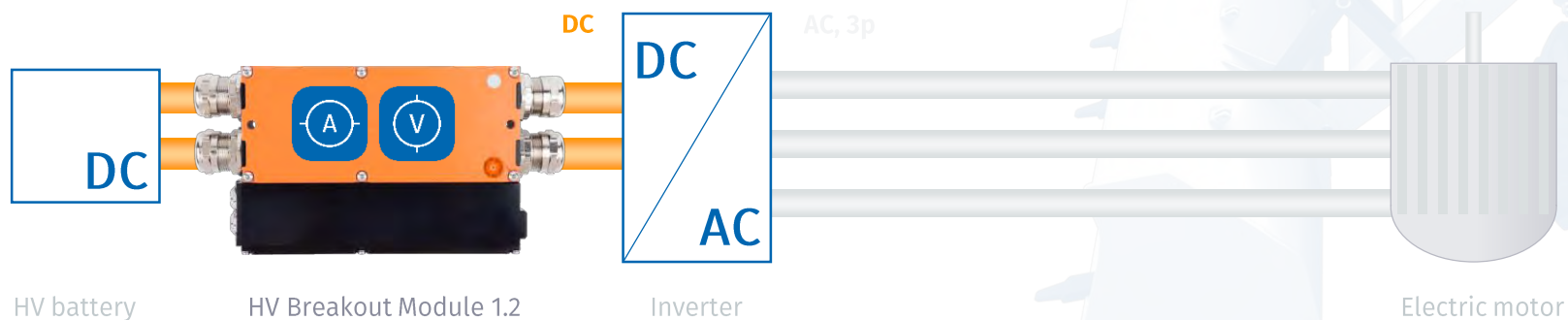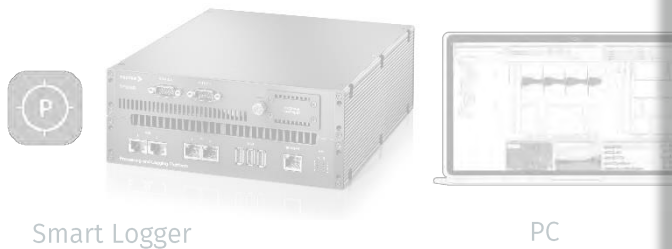
HV battery

HV Breakout Module 1.2

Inverter

Electric motor

HV Breakout Modules

Measurement of high currents and voltages

► All in one compact solution

► Measurement directly in the HV power cables
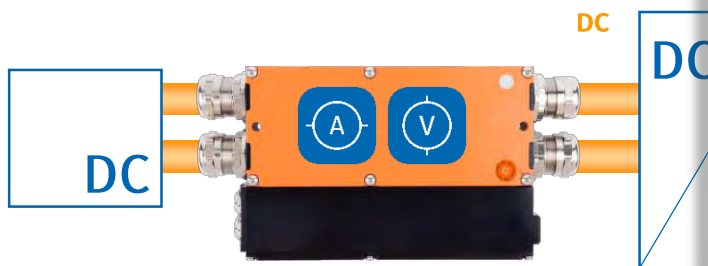
HV Breakout Modules on www.csm.de

Power measurement in the el...
Power measurement between...

Smart Logger
PC

DC

DC

DC

HV battery
HV Breakout Module 1.2
Inverter
Electric motor

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CSM

Smart Logger

PC

DC

DC

DC

DC

HV battery   HV Breakout Module 1.2   Inverter   Electric motor

HV Breakout Modules

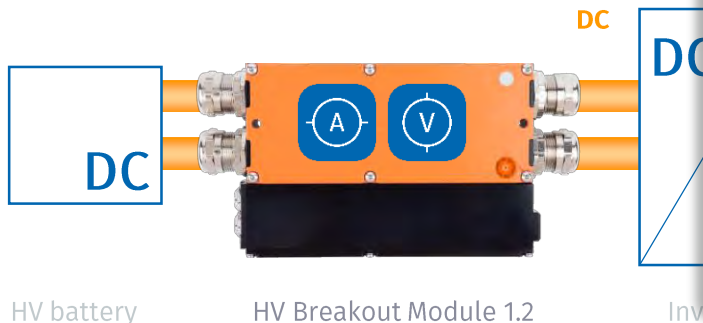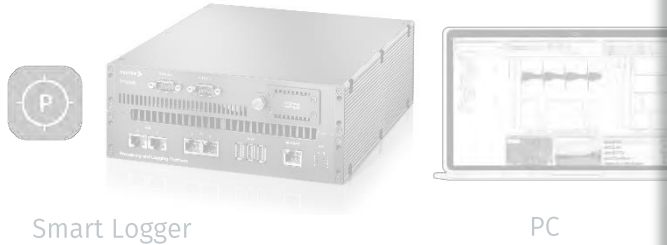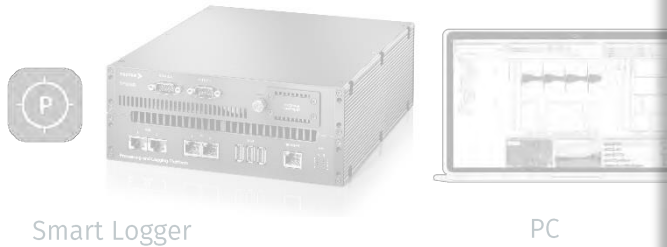## Measurement of high currents and voltages

► Current measurement with shunt modules

  ▪ Inner conductor current I_{nom} : ±50 A to ±1,000 A

  ▪ Shield current

► Voltages up to ±2,000 V

► Calculation of active power, apparent power, reactive power, power factor and RMS values U and I directly in the module

► Data rate up to 2 MHz per channel (XCP-on-Ethernet),1 MHz per channel with EtherCAT®

► Additional CAN interface

► For in-vehicle and test bench applications

  ▪ IP67, operating temperature range: -40 °C to +125 °C

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HV Breakout Modules

Measurement of high currents and voltages

► Cable connection via

- PowerLok connectors

- Ring terminals (cable glands)

    • Optional plug & play with customized adapters

HV Breakout Module 1.2 with pre-assembled customer-specific adapters

Smart Logger

PC

DC

DC

DC

HV battery   HV Breakout Module 1.2   Inverter   Electric motor

Power measurement in the electric powertrain
Power measurement between HV battery and inverter

Smart Logger

PC

XCP-on-Ethernet

XCP-Gateway

EtherCAT

DC

DC

AC, 3p

DC

AC

HV battery

HV Breakout Module 1.2

Inverter

Electric motor

Smart Logger

PC

XCP-on-Ethernet

XCP-Gateway

EtherCAT

DC

DC

DC

DC

HV battery   HV Breakout Module 1.2   Inverter   Electric motor
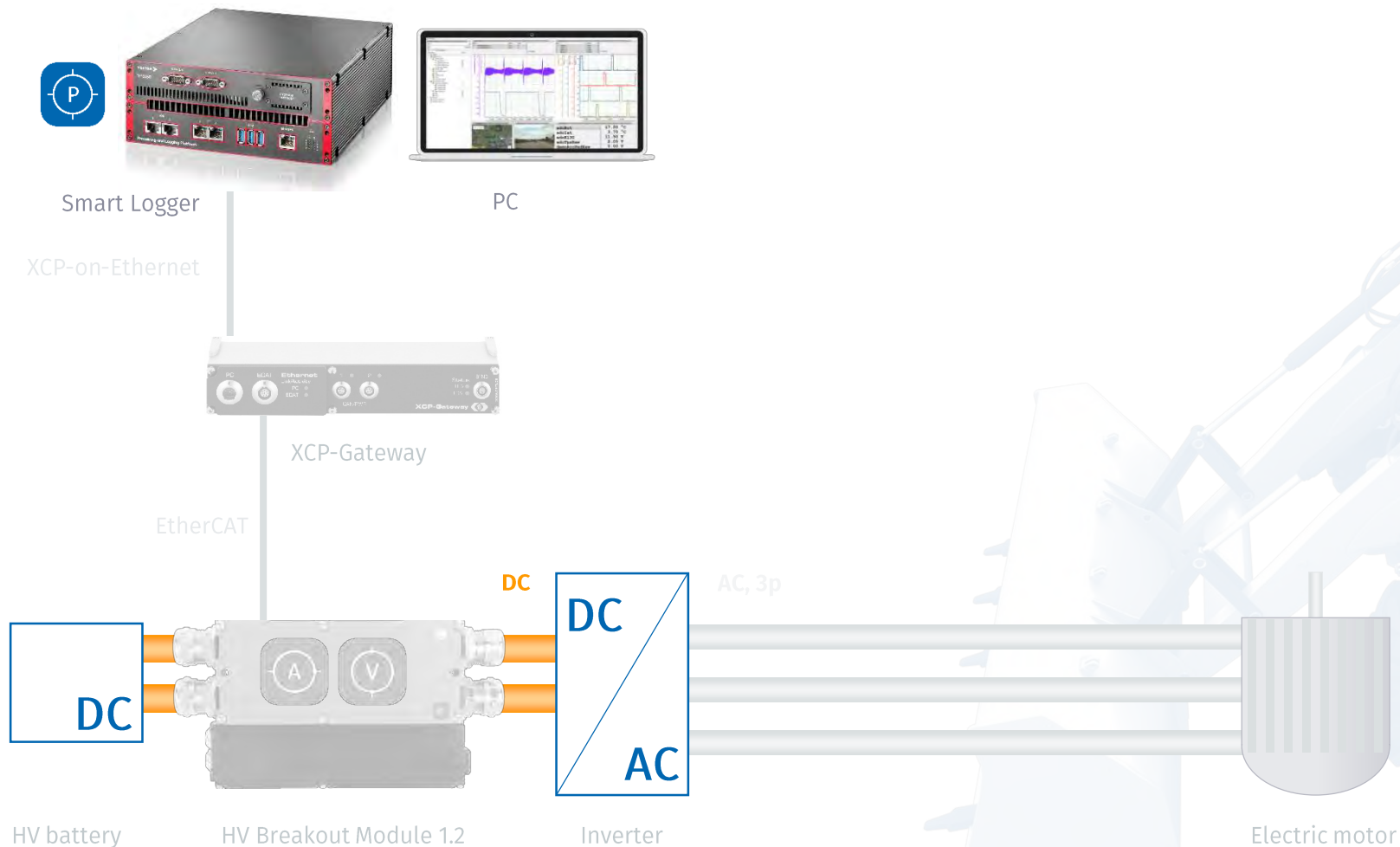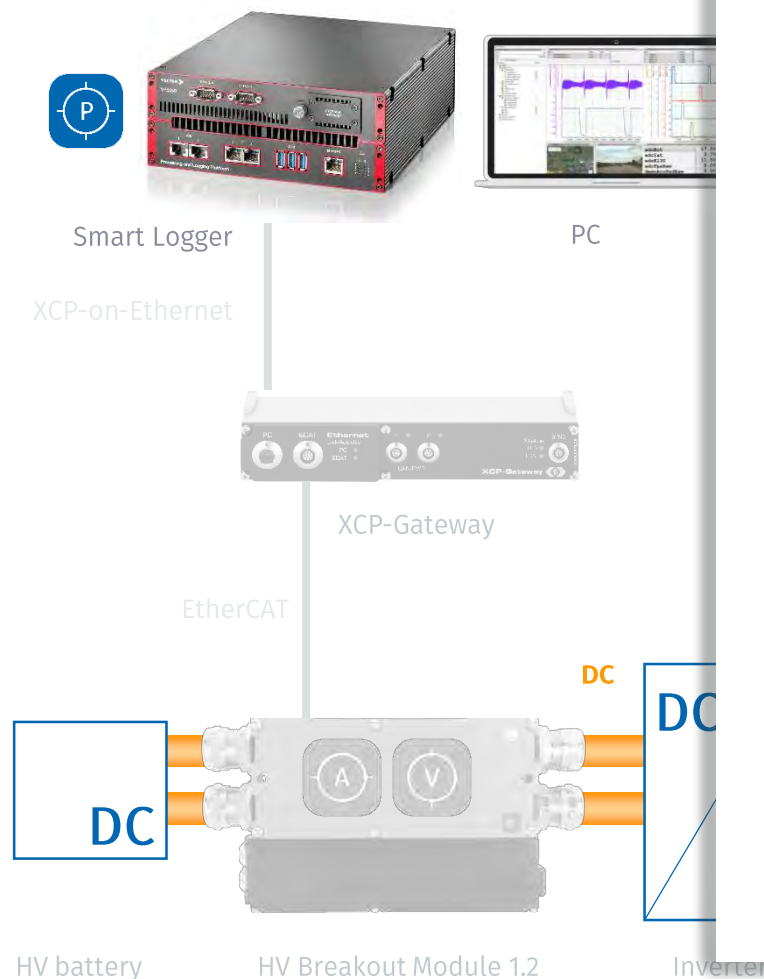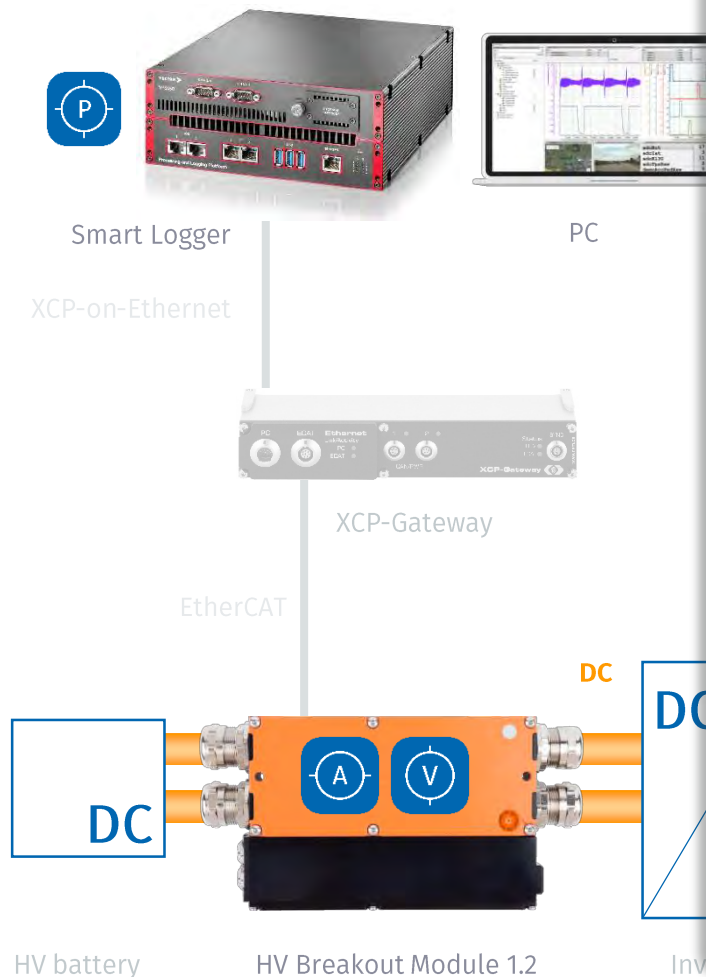
vMeasure – Data acquisition software

▶ **eMobilityAnalyzer** power analysis

  optimized for CSM measurement modules

▶ Multithreading functionality

▶ Time synchronized data acquisition from

  ▪ CSM measurement modules (HV BM, ECAT, CAN)

  ▪ Vehicle buses (Ethernet, Flexray, CAN FD, …)

  ▪ ECUs

  ▪ Video, GPS

▶ Online calculations

  and scripting

▶ Multiple visualization

  options

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Power analysis with eMobilityAnalyzer and HV Breakout Module

Short measurement chain for power calculation

▶ **HV Breakout Module** provides 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**.
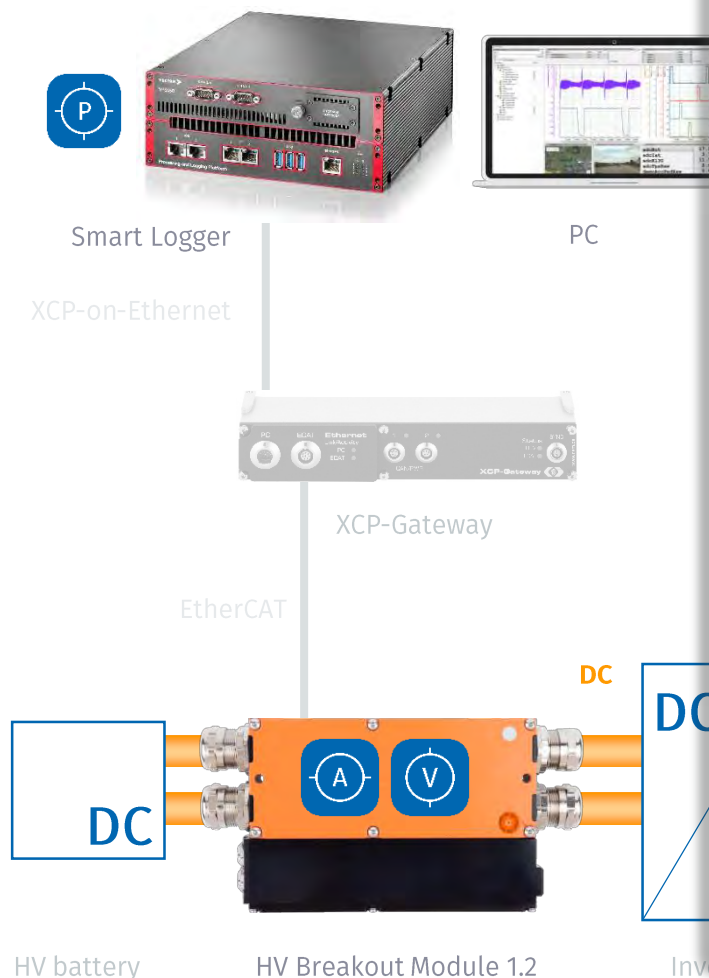
$$P = \frac{1}{T}\int_0^T u(t) \times i(t)dt \qquad P = \frac{1}{N}\sum_{n=0}^{N} u_n i_n \Delta t$$

Smart Logger

PC

XCP-on-Ethernet

XCP-Gateway

EtherCAT

DC

DC

DC

DC

HV battery

HV Breakout Module 1.2

Inverter

Electric motor

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eMobilityAnalyzer – Function library

The eMobilityAnalyzer enables a **real-time analysis** of
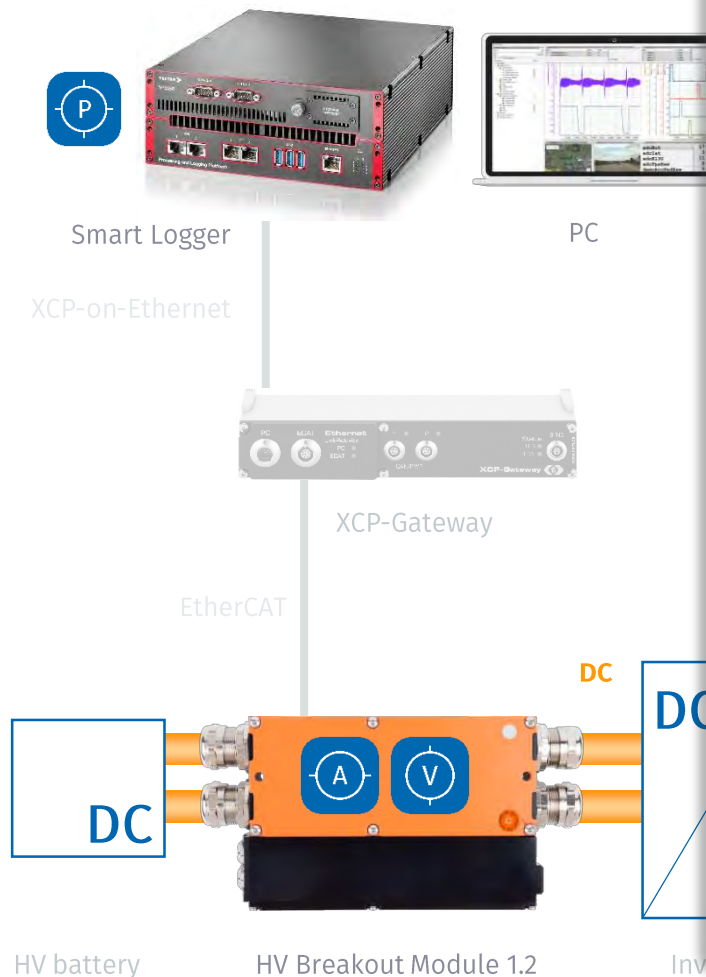
▶	AxlePower	Mechanical power and work of an axle
▶	ChargerEfficency	Efficiency charging system
▶	DCAnalysis	Analysis of a direct current signal
▶	DCEfficency	Efficiency of a converter
▶	eMotorPowerAnalysis	E-motor power analysis
▶	eMotorYdelta	E-motor star delta transformation
▶	Harmonics	Harmonic analysis
▶	InverterEfficency	Inverter efficiency
▶	PWMPowerAnalysis	Pulse width modulation power analysis
▶	Ripple	Ripple of a direct current signal
▶	ShaftPower	Mech. power from torque and speed

Power measurement in the el
Power measurement between

Smart Logger

PC

XCP-on-Ethernet

XCP-Gateway

EtherCAT

DC

DC

DC

DC

HV battery   HV Breakout Module 1.2   Inverter   Electric motor

CSM

Power measurement in the electrified non-road mobile machines

Power measurement between

Smart Logger

XCP-on-Ethernet

XCP-Gateway

EtherCAT

DC

DC

HV battery   **HV Breakout Module 1.2**   Inverter   Electric motor

PC

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

OK   Cancel   Help

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CSM
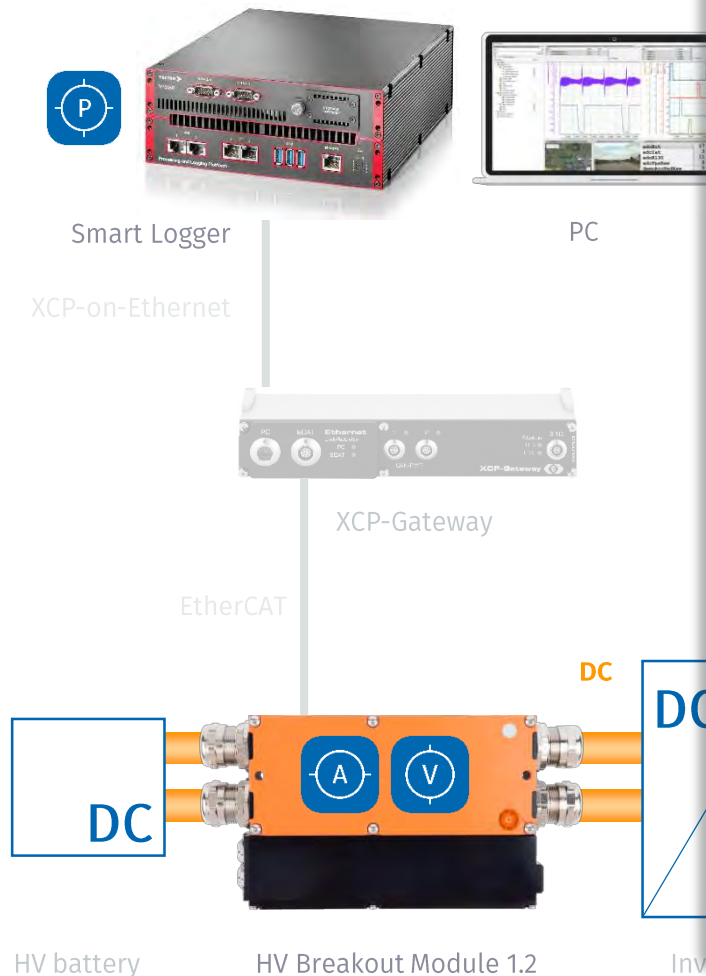
Power analysis of a DC signal

Smart Logger

XCP-on-Ethernet

XCP-Gateway

EtherCAT

DC

DC

DC

DC

HV battery

HV Breakout Module 1.2

Inverter

Electric motor

PC

DCAnalysis_
- General
- Extended

Description
DC Analysis

This function analyses a DC- or AC-phase. It calculates the effective power, apparent power, total work and the total charge for a predefined time interval.

Configuration

Voltage: CSM.HVBM_U_Bat ... DCAnalysis_

Current: CSM.HVBM_I_Bat ...

Parameter

Integration interval [ms]: 100

Output

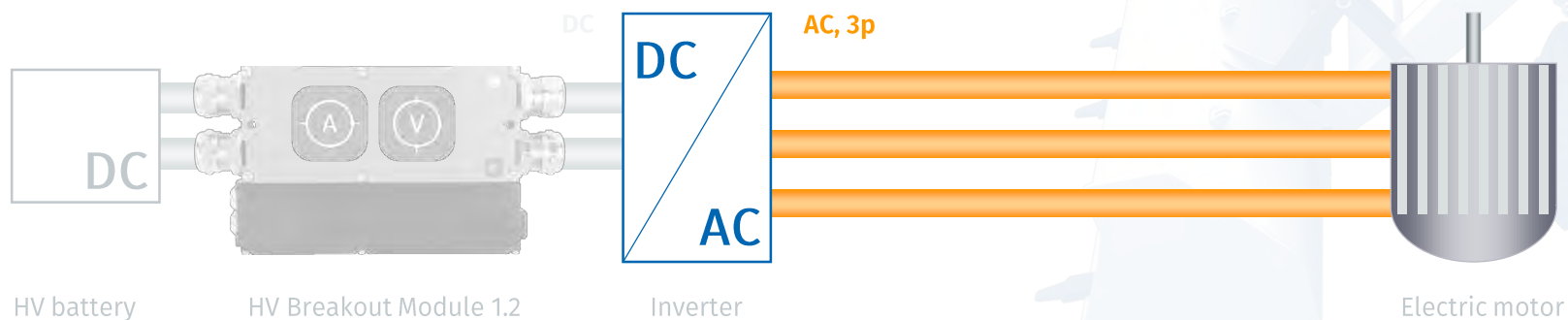|		
DCAnalysis_.Udc	DCAnalysis_.Umin	DCAnalysis_.P
DCAnalysis_.Idc	DCAnalysis_.Imax	DCAnalysis_.S
DCAnalysis_.Urms	DCAnalysis_.Imin	DCAnalysis_.W
DCAnalysis_.Irms	DCAnalysis_.Upp	DCAnalysis_.Ah
DCAnalysis_.Umax	DCAnalysis_.Ipp	

OK Cancel Help

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Power measurement in the electric powertrain
Power measurement between inverter and electric motor

Smart Logger

PC

DC

AC, 3p

DC

AC

DC

HV battery

HV Breakout Module 1.2

Inverter

Electric motor

Power measurement in the electric powertrain
Power measurement between inverter and electric motor

Smart Logger

PC

DC

AC, 3p

DC

DC

AC

A V

A V

DC

HV battery

HV Breakout Module 1.2

Inverter

HV Breakout Module 3.3

Electric motor

CSM Xplained: Power measurements on electrified non-road mobile machines and construction equipment
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CSM
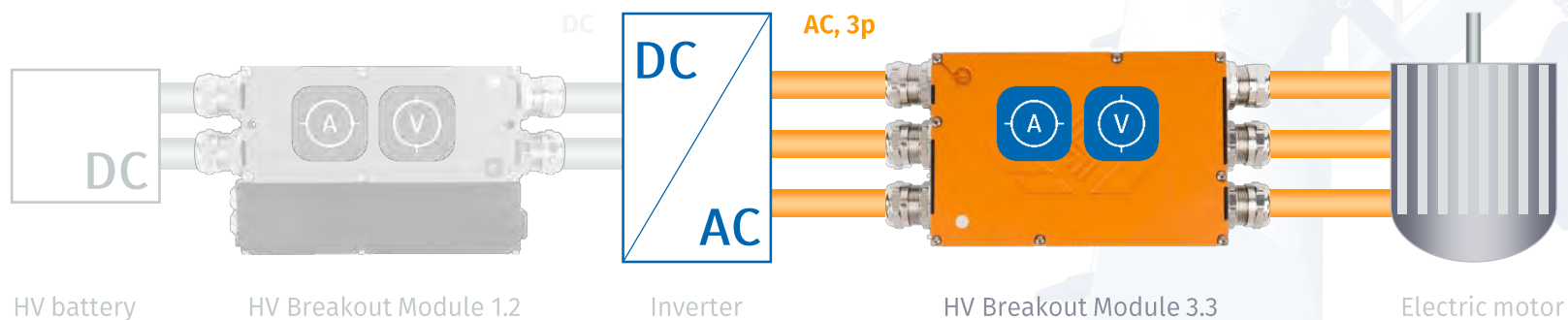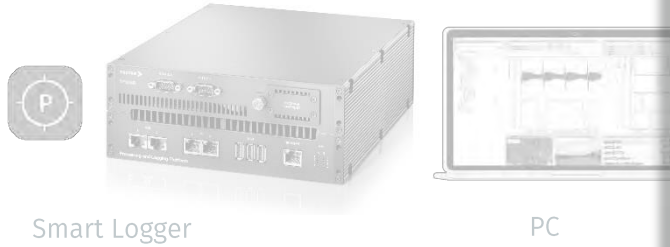
HV Breakout Module 3.3

HV BM 3.3 on www.csm.de

- ▶ Measurement of 3-phase currents and voltages

- ▶ Power analysis with the eMobilityAnalyzer

- ▶ Output of measurement data at a rate of up to 2 MHz per measured value via XCP-on-Ethernet

HV BM 3.3 variants: Cable connection via ring terminals (cable glands) or PowerLok-connector system

Power measurement in the el...
Power measurement between...

Smart Logger   PC

DC

DC   DC

HV battery   HV Breakout Module 1.2   Inverter   HV Breakout Module 3.3   Electric motor

CSM Xplained: Power measurements on electrified non-road mobile machines and construction equipment
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CSM

Power measurement in the electric powertrain
Power measurement between inverter and electric motor
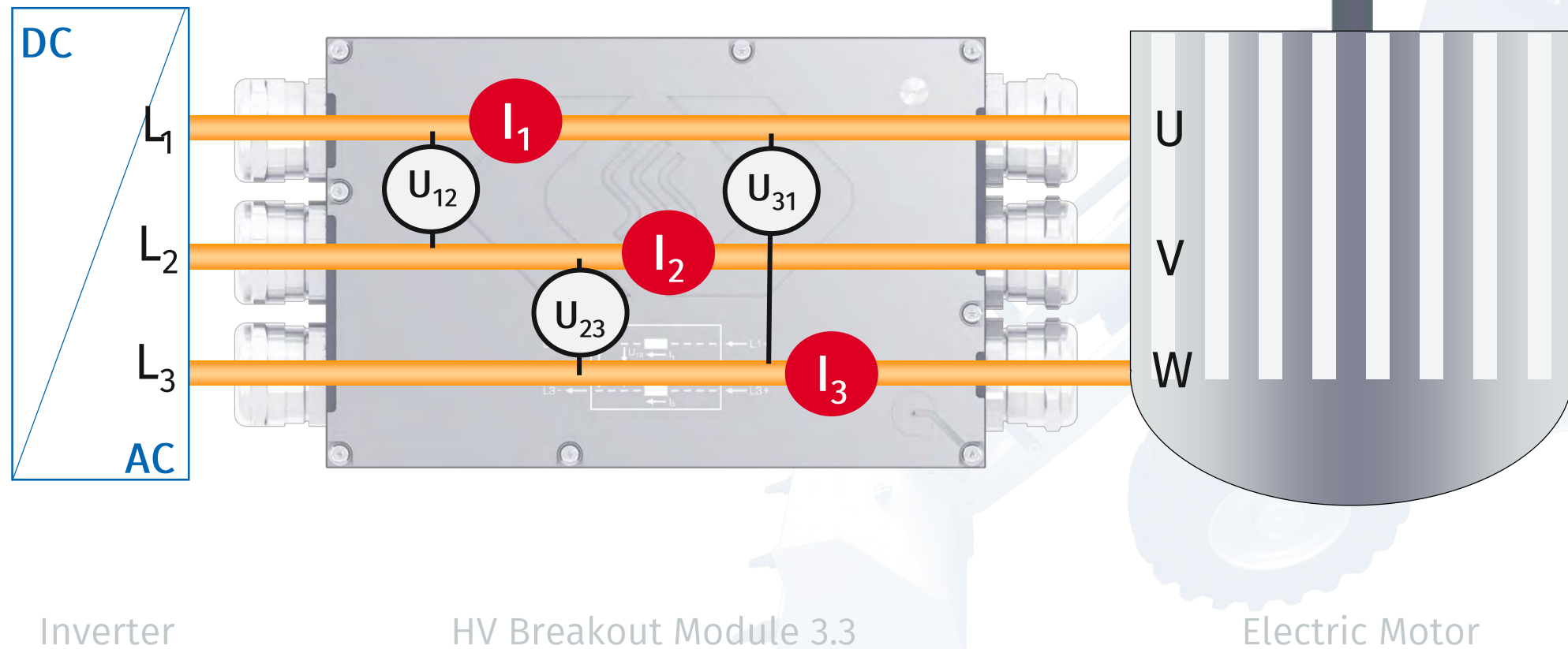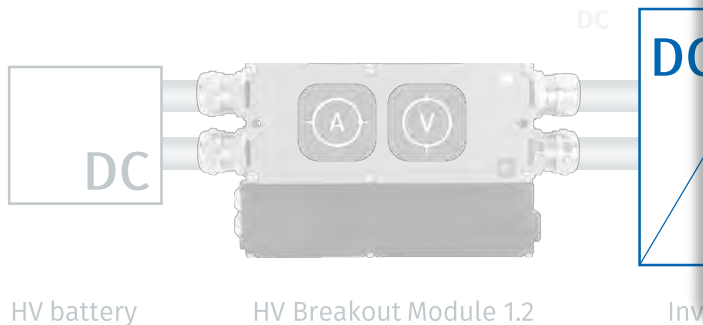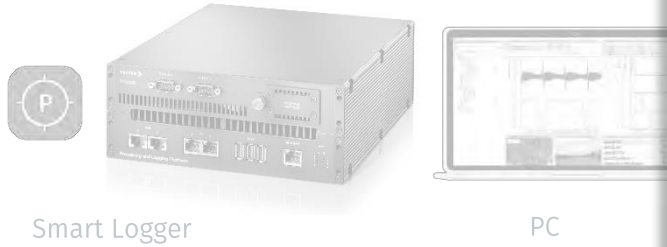
HV Breakout Module 3.3
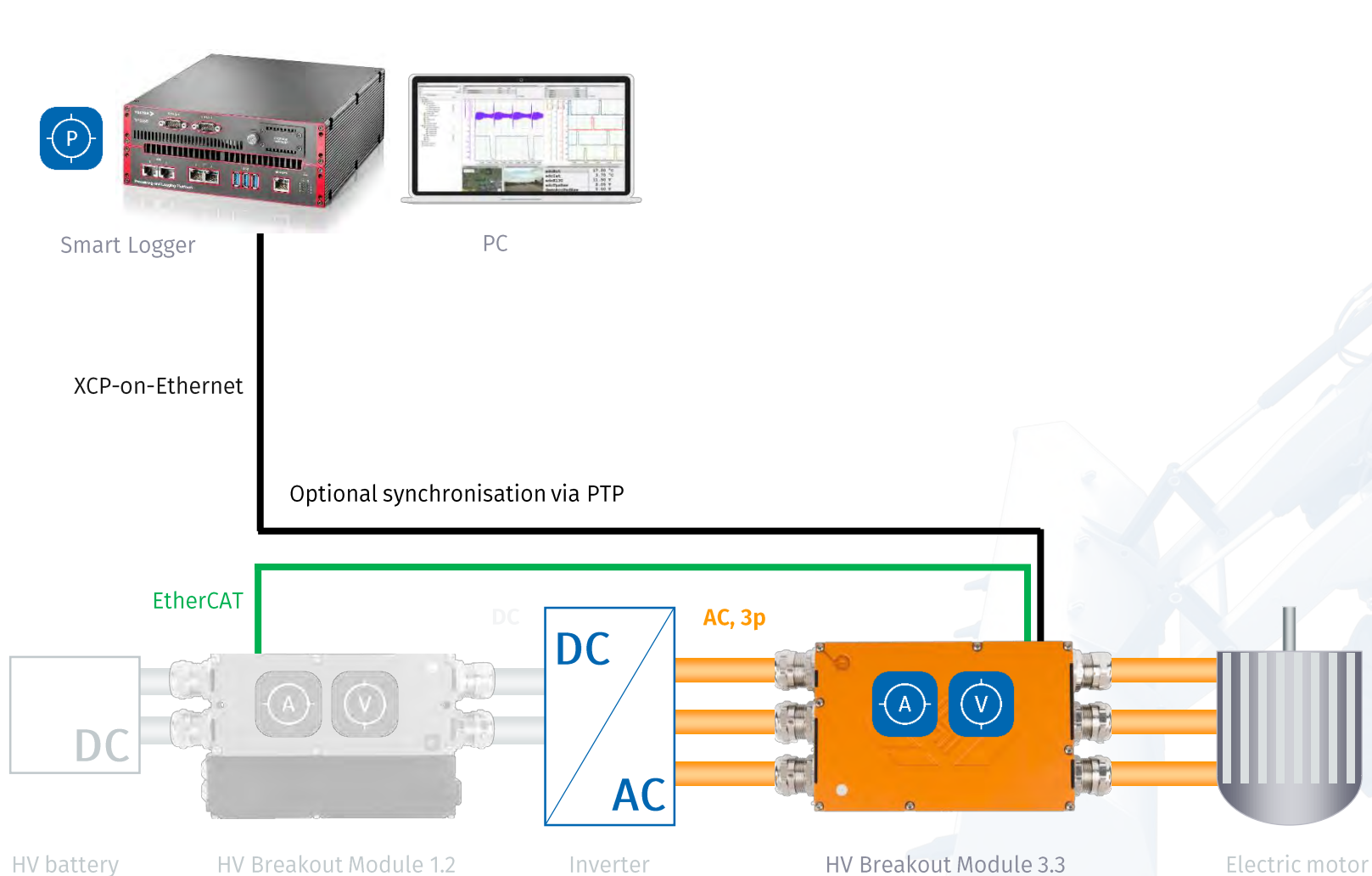
▸ Voltages up to ±1,000 V (measuring range for transients up to ±2,000 V)

▸ Currents up to ±800 A (nominal value shunt module)
(measuring range for peaks up to ±1,400 A)

▸ Optional **"XCP Gateway" function** for connecting additional CSM CAN and EtherCAT® measurement modules
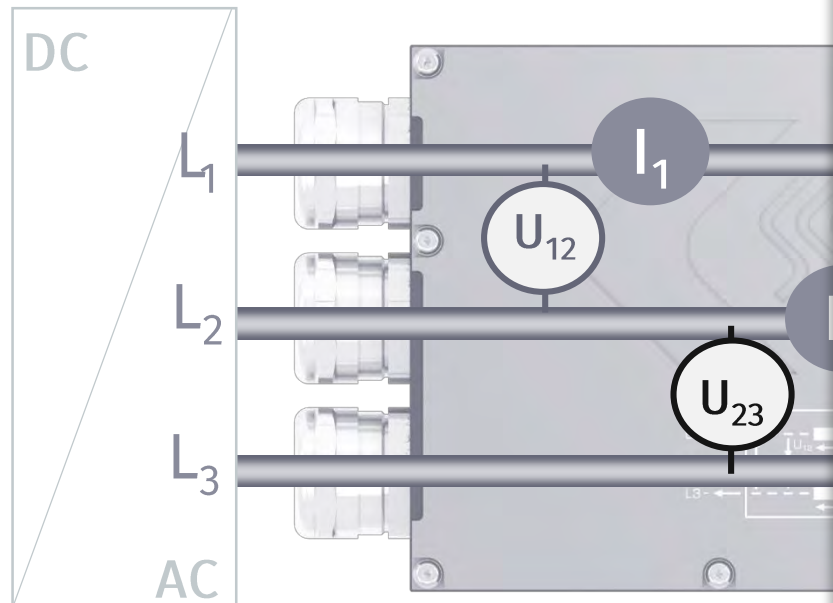
▸ Optional PTP Sync (IEEE 1588)
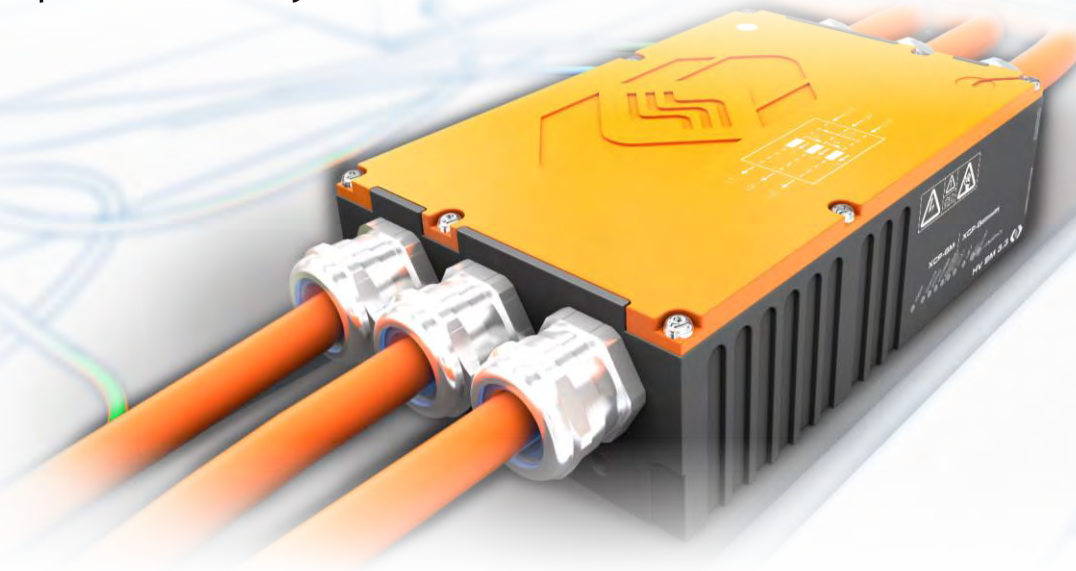
Smart Logger   PC

DC   DC

HV battery   HV Breakout Module 1.2   Inverter   HV Breakout Module 3.3   Electric motor

Power measurement in the electric powertrain
Power measurement between inverter and electric motor

Smart Logger

PC

XCP-on-Ethernet

Optional synchronisation via PTP

EtherCAT

DC

DC

AC

AC, 3p

A V

A V

DC

HV battery

HV Breakout Module 1.2

Inverter

HV Breakout Module 3.3

Electric motor

Power measurement in the electric powertrain
Efficiency measurement at the inverter

Smart Logger

PC

XCP-on-Ethernet

Optional synchronisation via PTP

EtherCAT

DC

DC / AC

AC, 3p

DC

HV battery

HV Breakout Module 1.2

Inverter

HV Breakout Module 3.3

Electric motor

Power measurement in the elec...
Efficiency measurement at the i...

Smart Logger

PC

XCP-on-Ethernet

Optional synchronisation via PTP

EtherCAT

DC

DC

DC

AC

HV battery   HV Breakout Module 1.2   Inverter

Calculation in the eMobilityAnalyzer

- InverterEfficiency_
  - General
  - Parameter
  - 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_Batt	...
Iin:	CSM.HVBM_I_Batt	...
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	...

InverterEfficiency_.Pin
InverterEfficiency_.Win
InverterEfficiency_.Pout
InverterEfficiency_.Wout
InverterEfficiency_.eta
InverterEfficiency_.etaW
InverterEfficiency_.Pd
InverterEfficiency_.Wd
InverterEfficiency_.f

DC / AC

InverterEfficiency_

Parameter

Integration interval [ms]: 100.0
Cycles min.: 10

Pre-filtering current and voltage of outputs
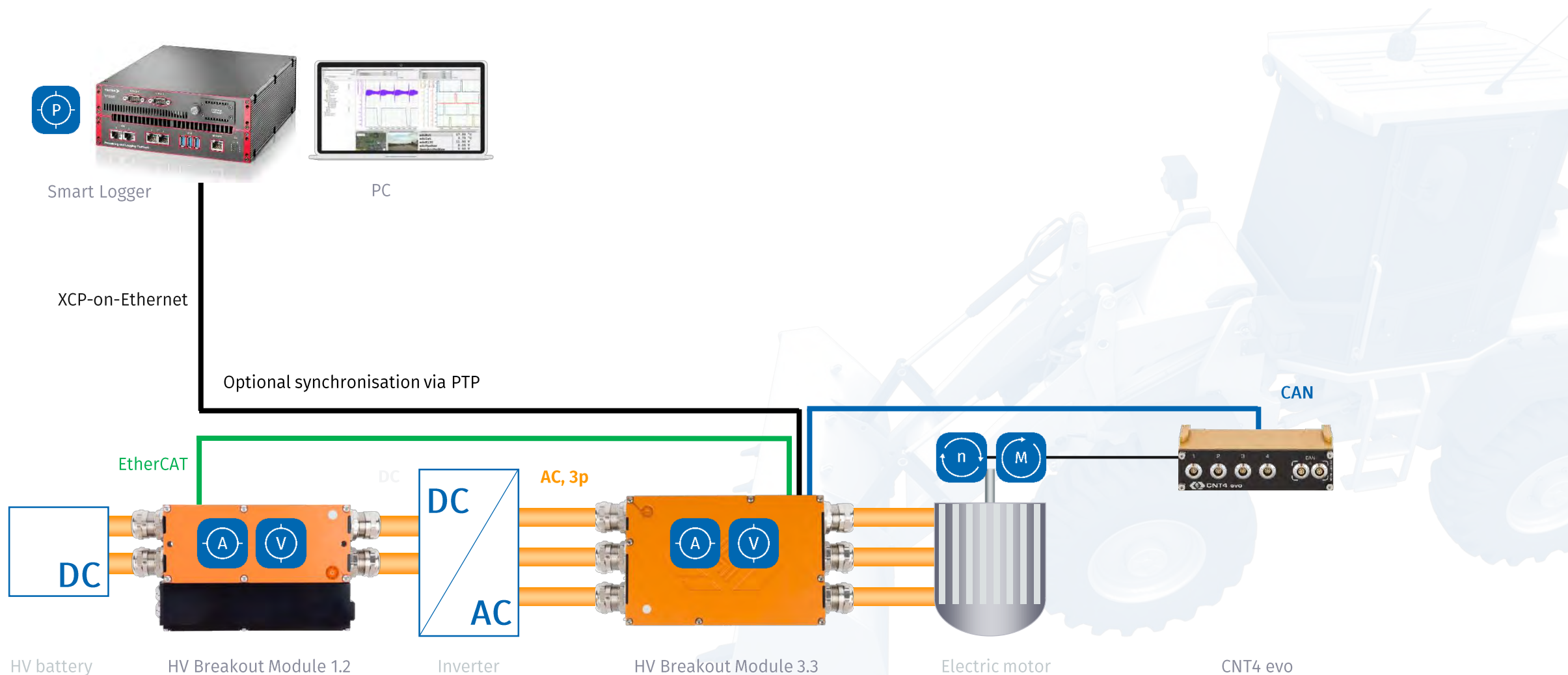Apply Lowpass: ☐   Cutoff frequency [Hz]: 10000.0

Sync Input
○ Current   ● Voltage
Frequency min. [Hz]: 10.0

RMS min.: 10.0
Frequency max. [Hz]: 5000.0

OK   Cancel   Help

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CSM

Power measurement in the electric powertrain
Calculation of the overall efficiency

Smart Logger

PC

XCP-on-Ethernet

Optional synchronisation via PTP

CAN

EtherCAT

DC

AC, 3p

DC

DC

AC

A   V

A   V

HV battery

HV Breakout Module 1.2
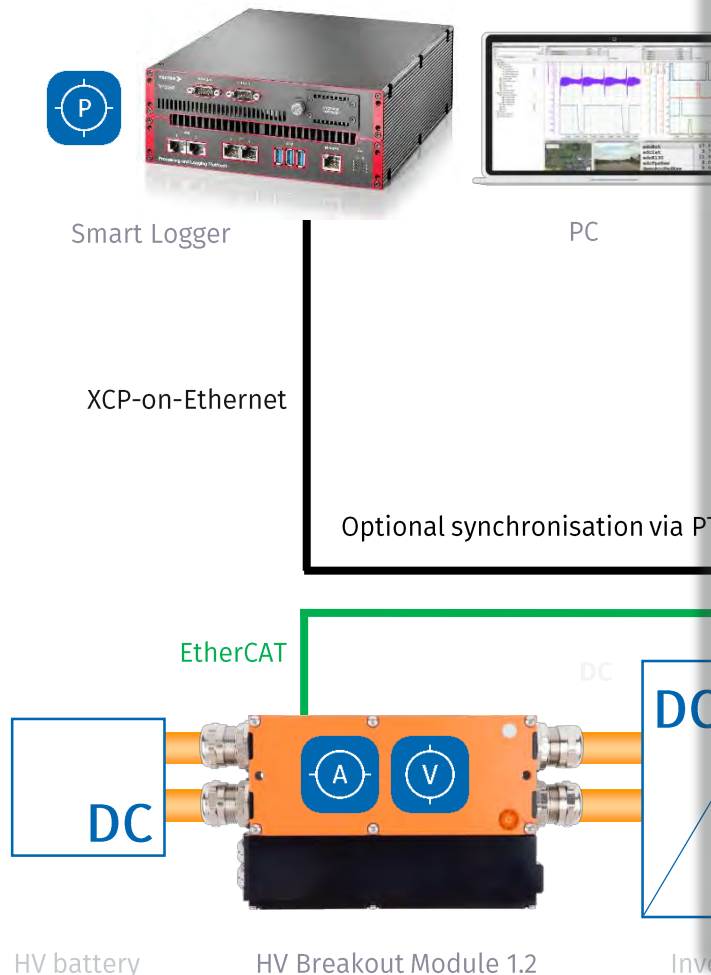
Inverter

HV Breakout Module 3.3

Electric motor

CNT4 evo

Power measurement in the el...
Calculation of the overall effic...

Calculation in the eMobilityAnalyzer

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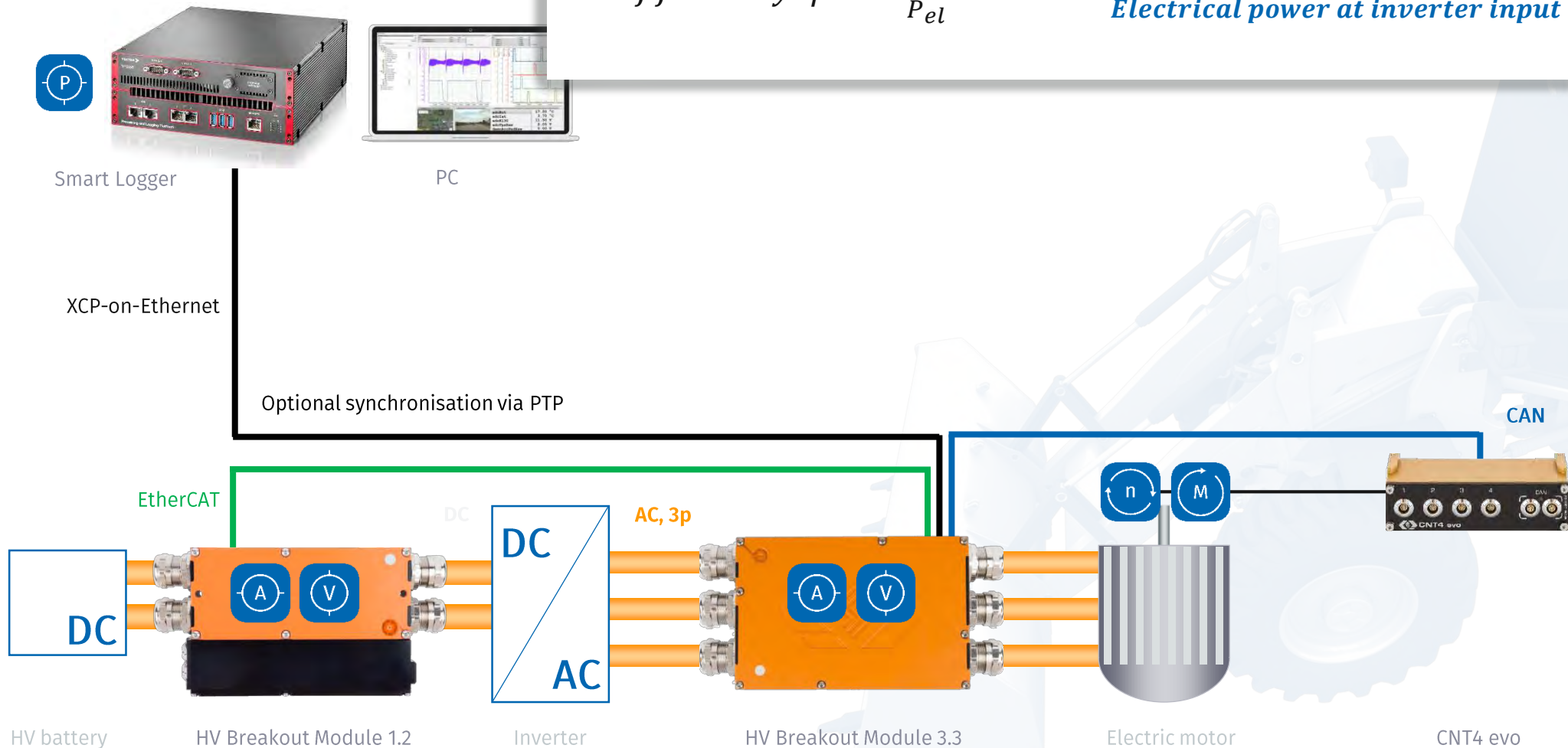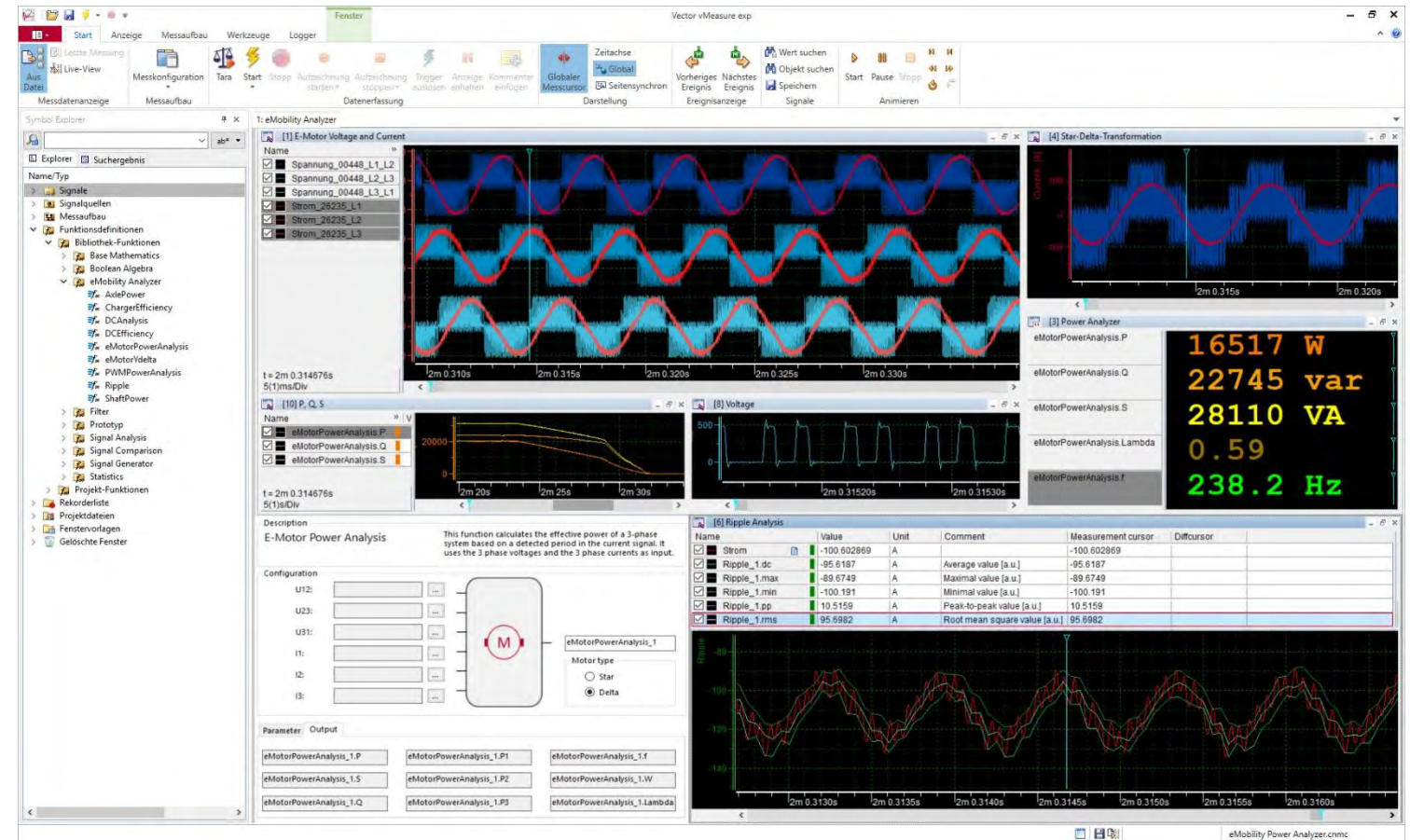
Smart Logger   PC

XCP-on-Ethernet

Optional synchronisation via PTP

CAN

EtherCAT

DC   DC   AC, 3p

DC   A   V   DC   AC   A   V   n   M

HV battery   HV Breakout Module 1.2   Inverter   HV Breakout Module 3.3   Electric motor   CNT4 evo

CSM Xplained: Power measurements on electrified non-road mobile machines and construction equipment
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CSM
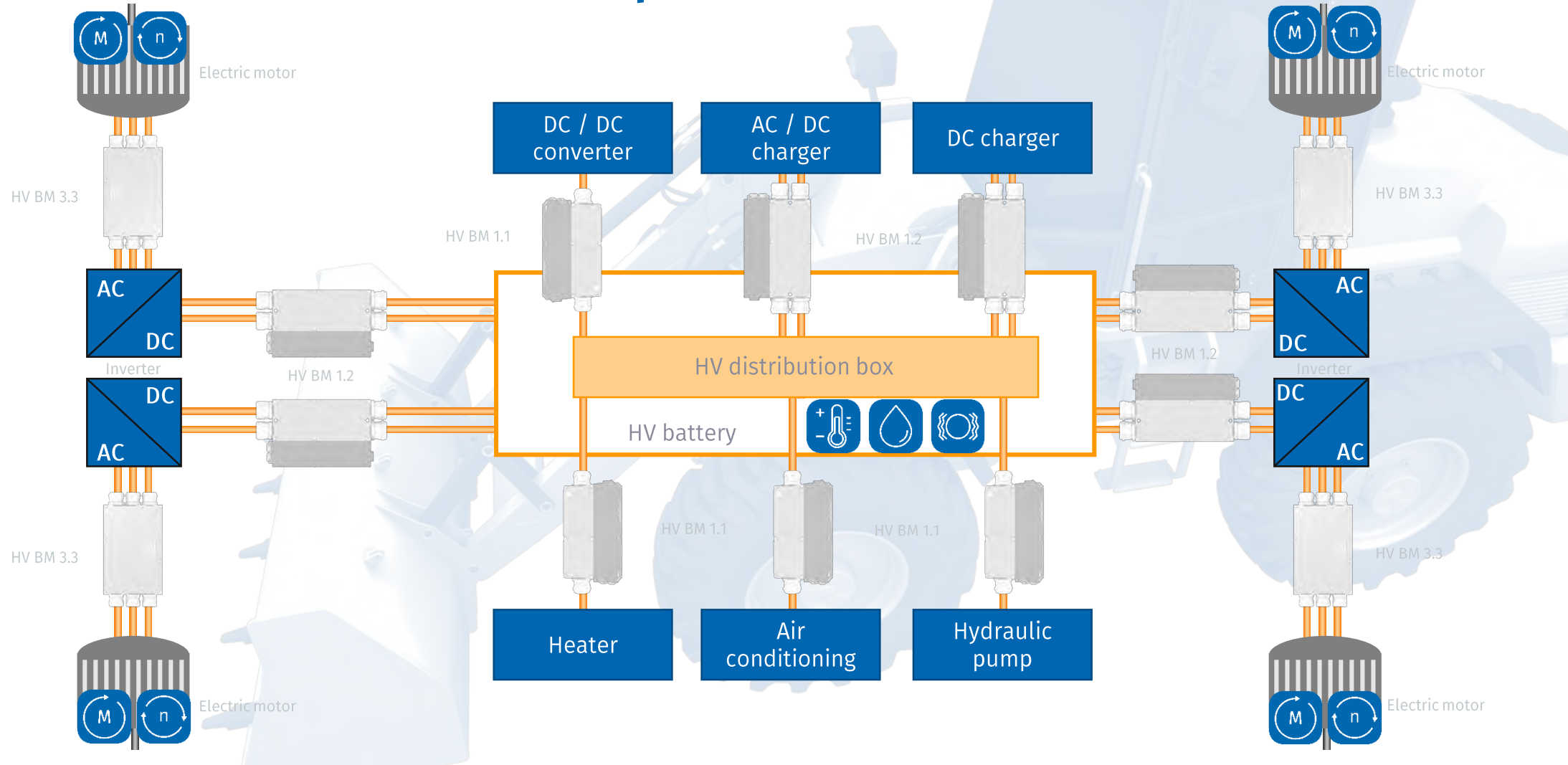
Power measurement in the electric powertrain
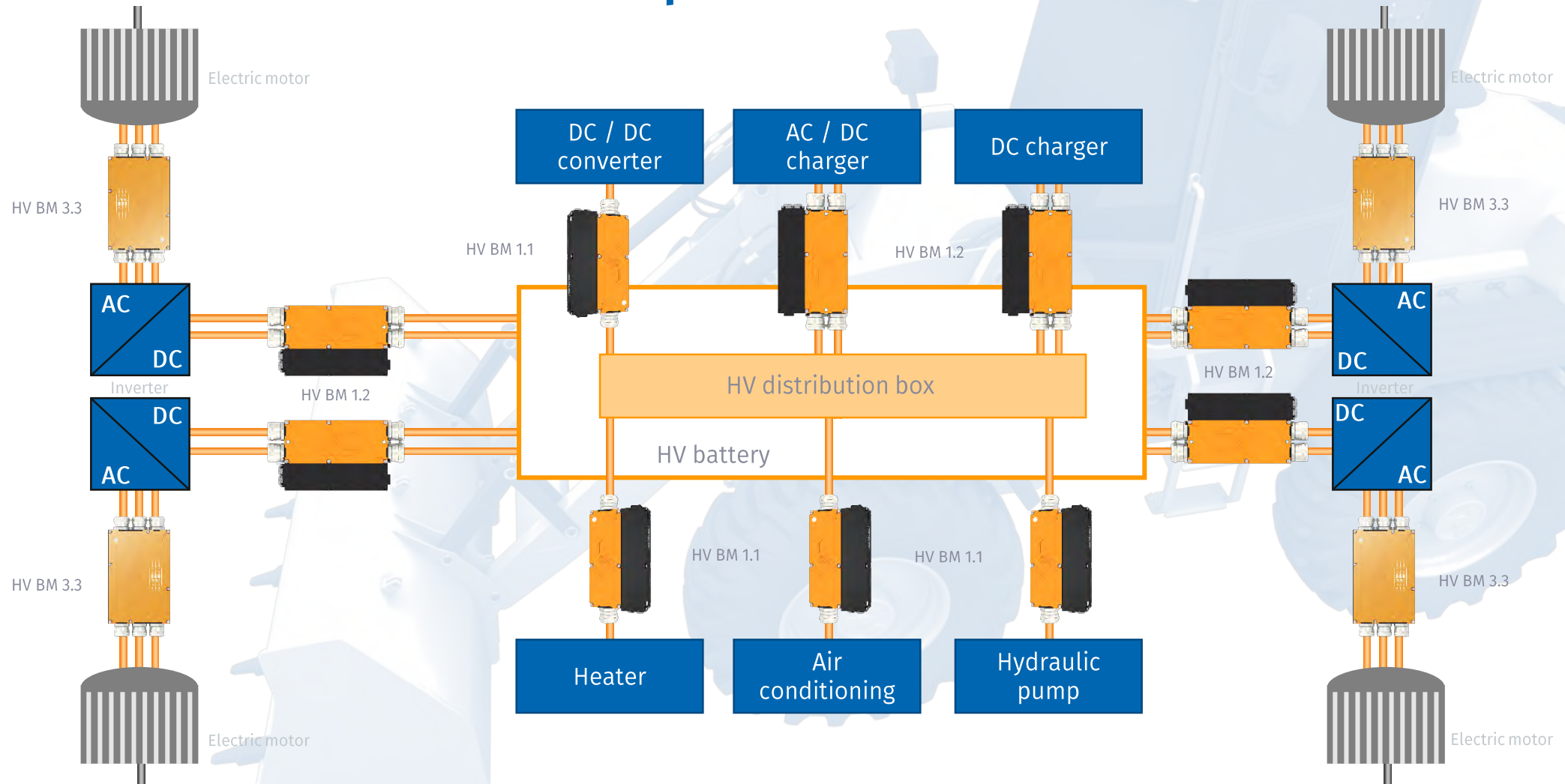
Power measurement in the electric powertrain

The Vector CSM E-Mobility Measurement System

**Data Analysis and Measurement Data Management**

vSignalizer	vMDM

E-Mobility Basic Measurement System

CANape
vMeasure exp

eMobility Analyzer

XCP-Gateway

HV Breakout HV BM Split Modules	HV / LV XCP Modules	HV / LV ECAT Modules	HV / LV CAN Modules

Voltage, current, temperature, acceleration, strain, vibration, flow, humidity, pressure, torque, speed, frequency, performance data, efficiency, effective power and much more.

Vector Datenlogger / Interfaces

CANape log
vMeasure log
VP Family

eMobility Analyzer

VN Family	VX Family

POD

CAN, CAN FD, LIN, FlexRay, Ethernet   ECU

CSM Logger

UniCAN 3
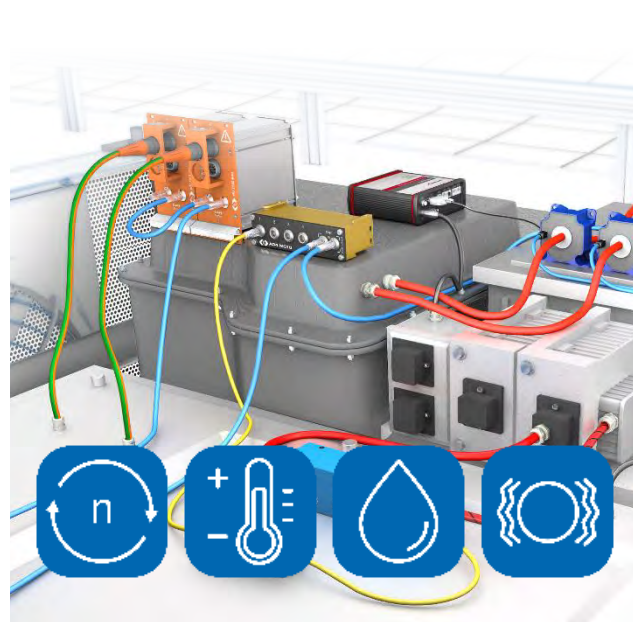Data Logger Family

CAN, CAN FD, Ethernet

Power measurements on electrified non-road mobile machines and construction equipment

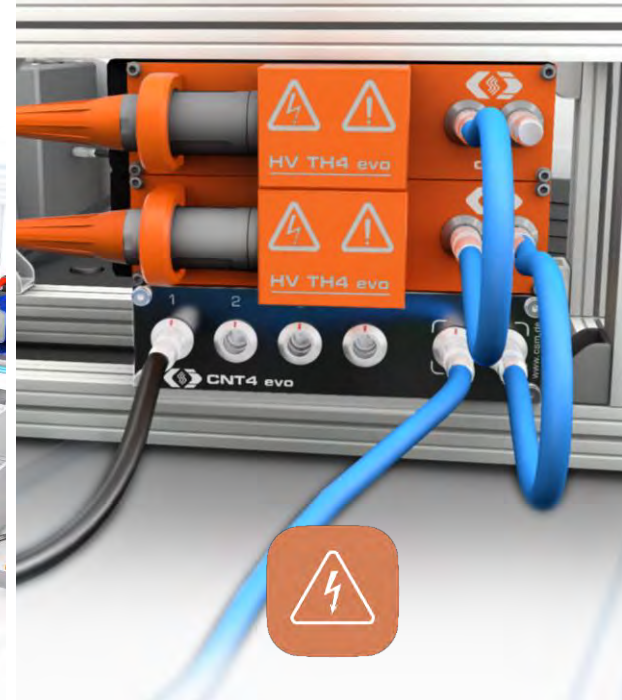The Vector CSM E-Mobility Measurement System allows simple and precise

electrical power measurements
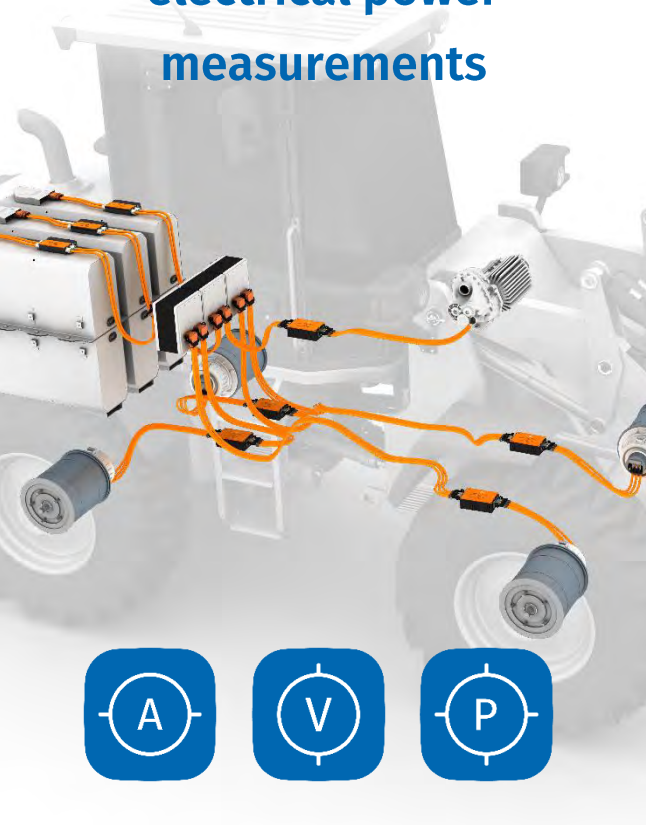
acquisition of additional thermal and mechanical values

measurements in HV and LV environments

use in road tests or on the test bench

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.**

CSM GmbH (Germany, International)
Raiffeisenstraße 36
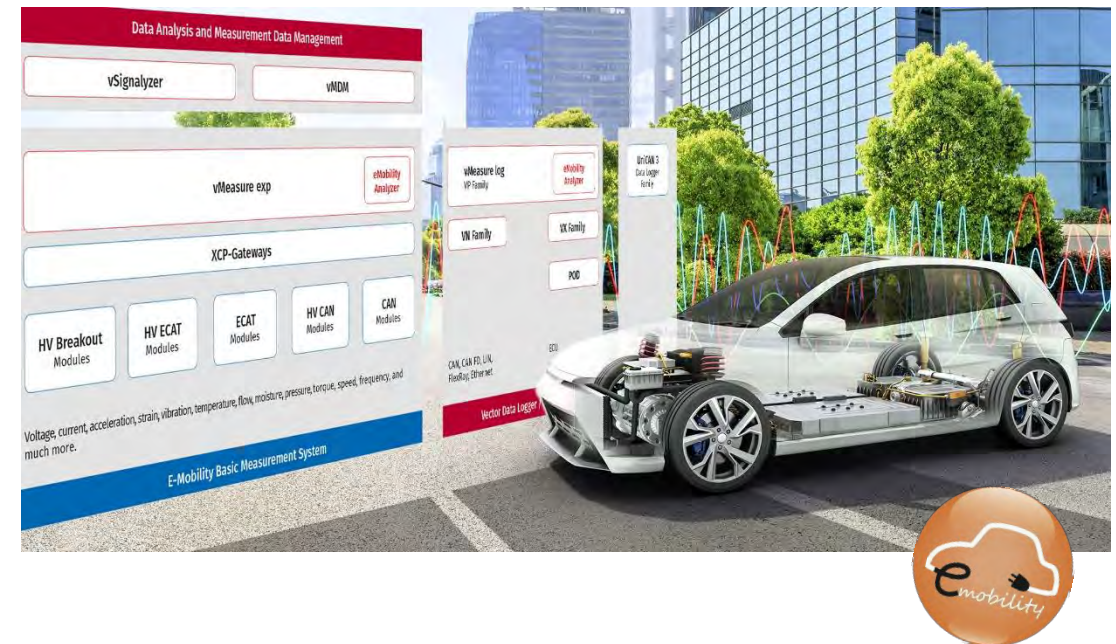70794 Filderstadt
Phone: +49 711 – 77 96 40
email: sales@csm.de

CSM Products, Inc. USA (USA, Canada, Mexico)
1920 Opdyke Court, Suite 200
Auburn Hills, MI 48326
Phone: +1 248 836-49 95
email: sales@csmproductsinc.com

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of CSM Xplained, please visit

www.csm.de/webseminars