Current measurement in e-mobility

CSM Web Seminars

CSM Xplained
measurement technology

Current measurement in e-mobility

- Agenda
  - Basics
  - Measurement Technology
  - Application examples

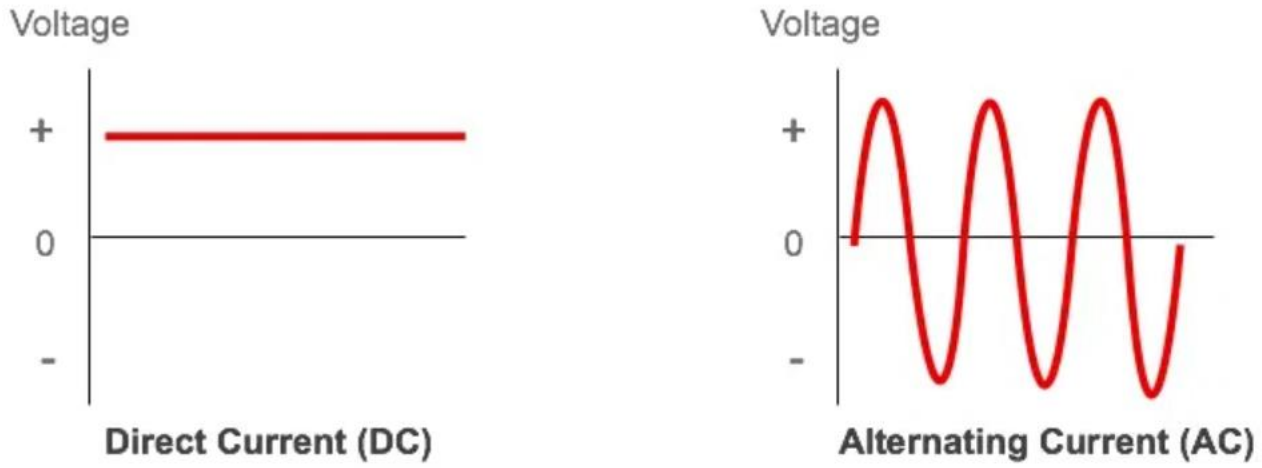
Current measurement in e-mobility

- Agenda
  - **Basics**

Measure electric current

Electric current, known from literature, study, internet, practice

- Direct current (DC)
- Alternating current (AC)
- Mixed or variable current



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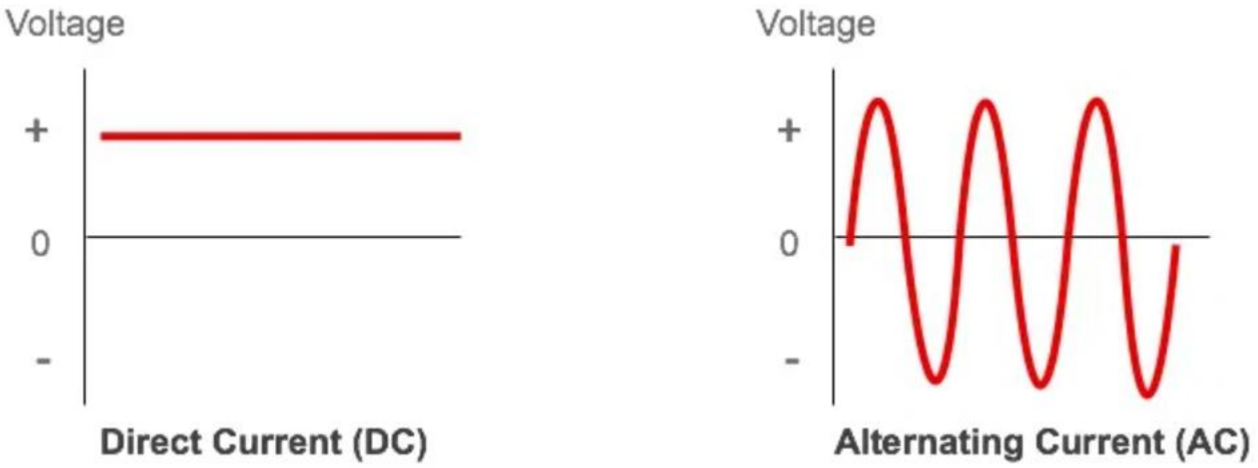

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Measuring transducer: Measure I, output I or U or …

Measuring converter: Measure I, output on digital bus

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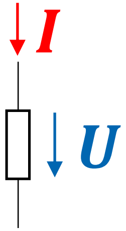
Popular Current Sensors:

- Current clamp, hinged transformer, closed ring
- Shunts, hall sensors, zero flux transducers, Rogowski coils
- Sampling Rate, bandwidth



$$I = \frac{U}{R_{shunt}}$$

Where do currents occur on the cables?

- Inner conductor
  - Large variable parts of the current?

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  - Usually between inverter and E-machine
  - Between inverter and braking resistor

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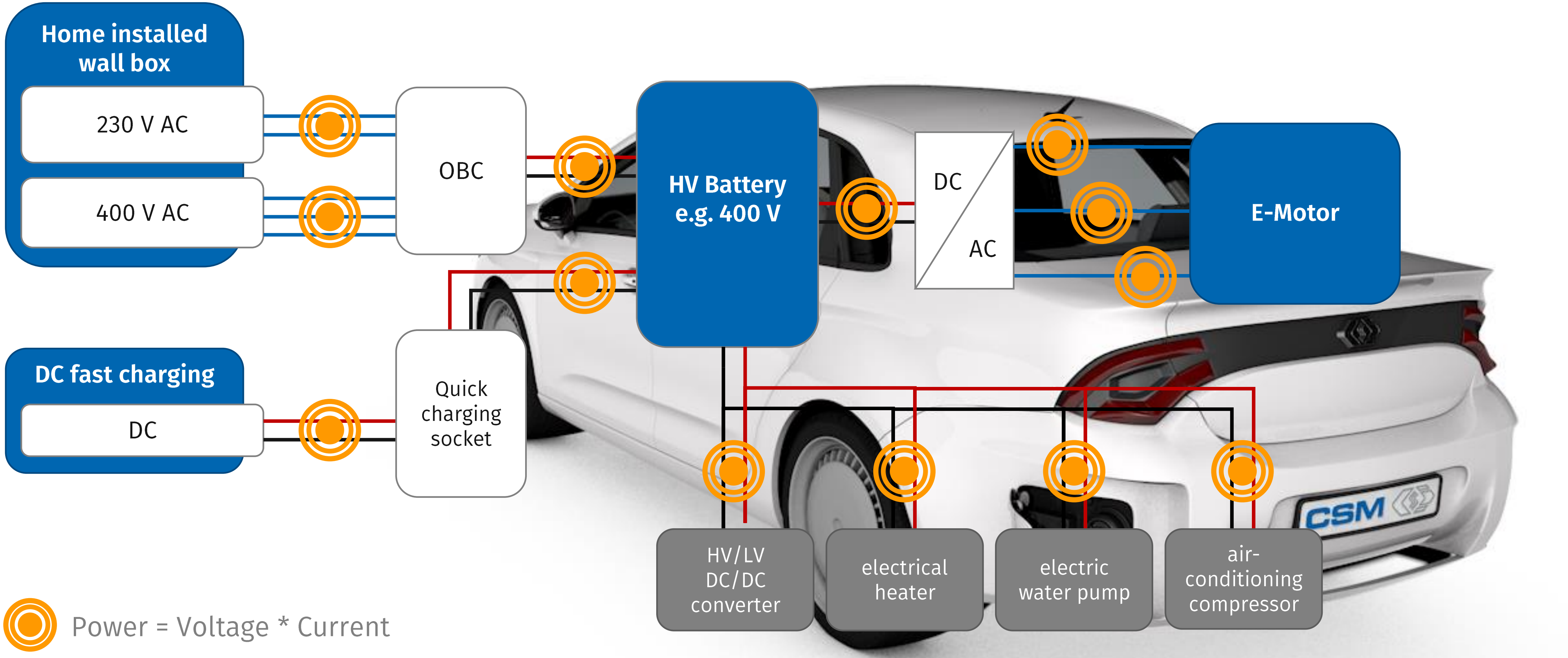
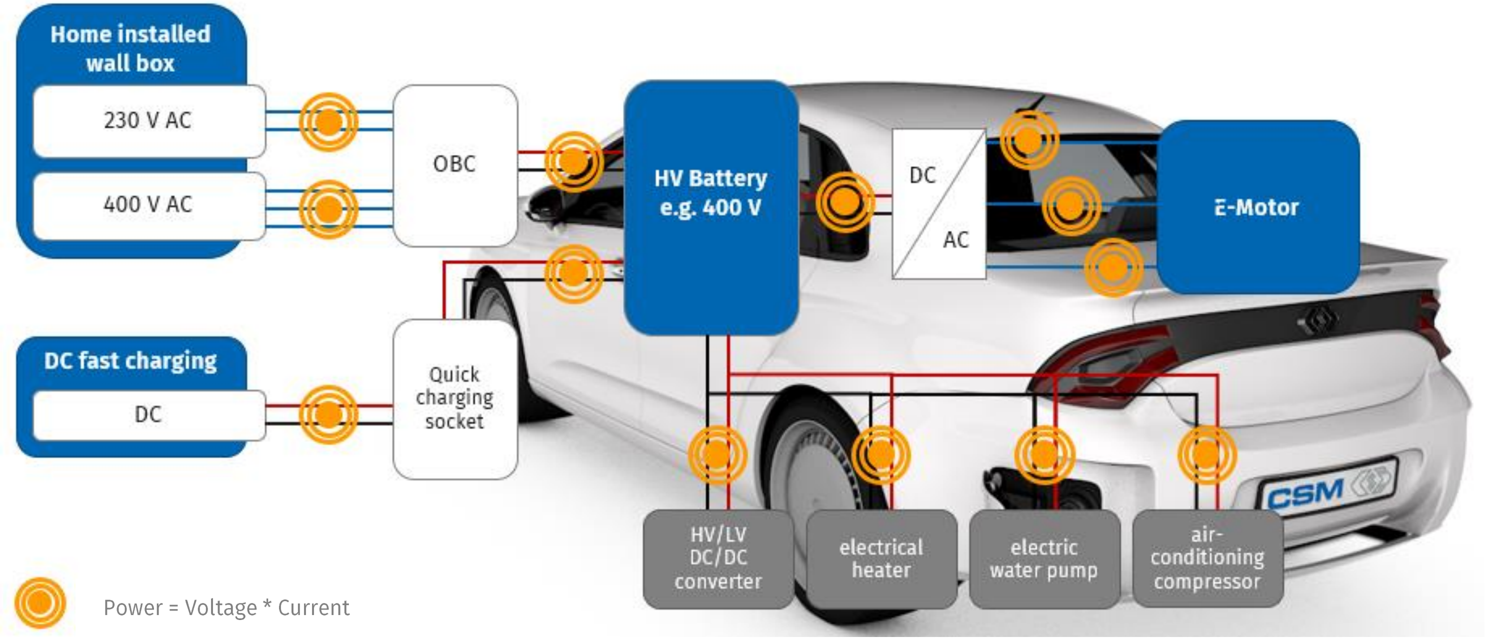
  - Between inverter and braking resistor

- Potential effects
  - Burnt contacts
  - Scorched shields?

Power Measurements in EV High-Voltage Electrical Systems



Electric current in electromobility



Charging System(s) feed the HV Battery

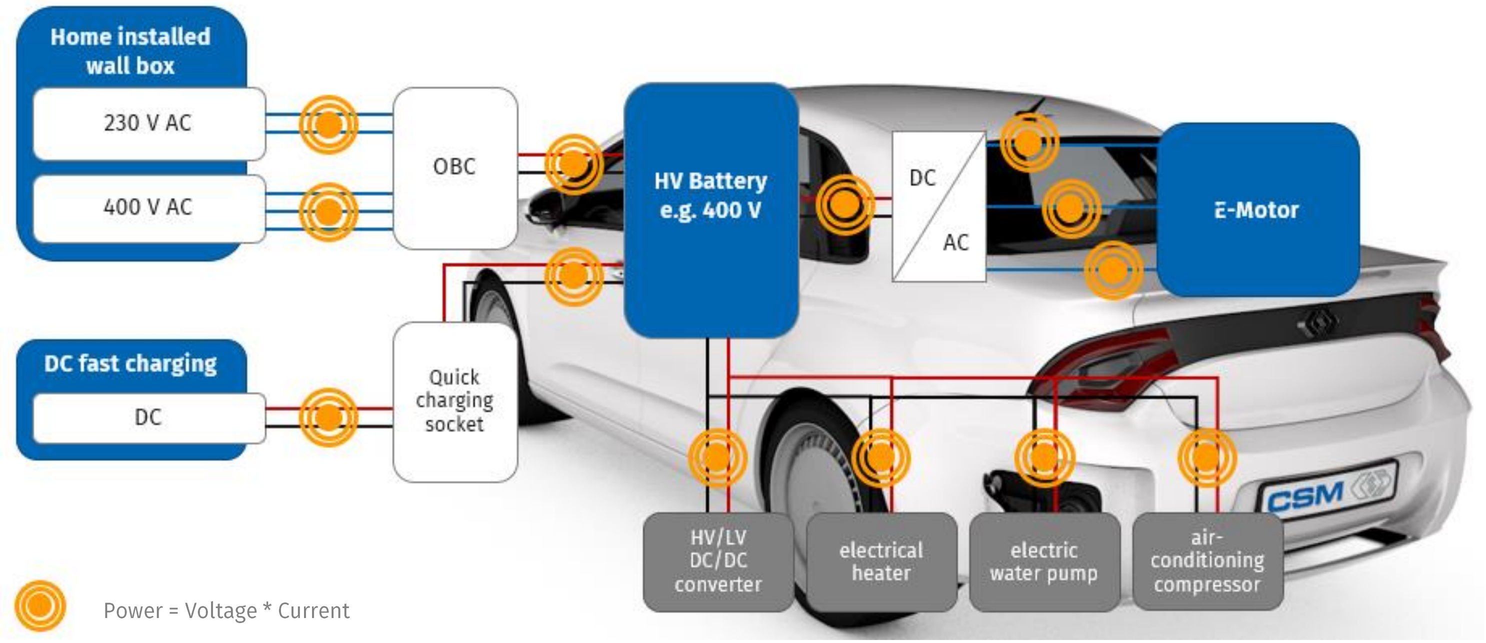
HV battery feeds consumers

- Inverter -> E-machine
- Small consumers

Current results from PWM-controlled voltage

Small consumers have built-in PWM control

Electric current in electromobility



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Current is never only direct current

Current has alternating components

Current measurement in e-mobility

- Agenda
  - Basics
  - **Measurement Technology**

WLTC – Worldwide harmonized Light-duty vehicles Test Cycles
EPA (Environmental Protection Agency) Drive Cycles

Fuel consumption in driving condition

- Diesel, carburetor fuel
- ...
- Electrical energy E [kWh]
- Electrical work W [kWh]
- Battery energy $E = Q * U$
- I(t) = dQ / dt
  - LV-Batterie ±2.5 A .. ±1,500 A

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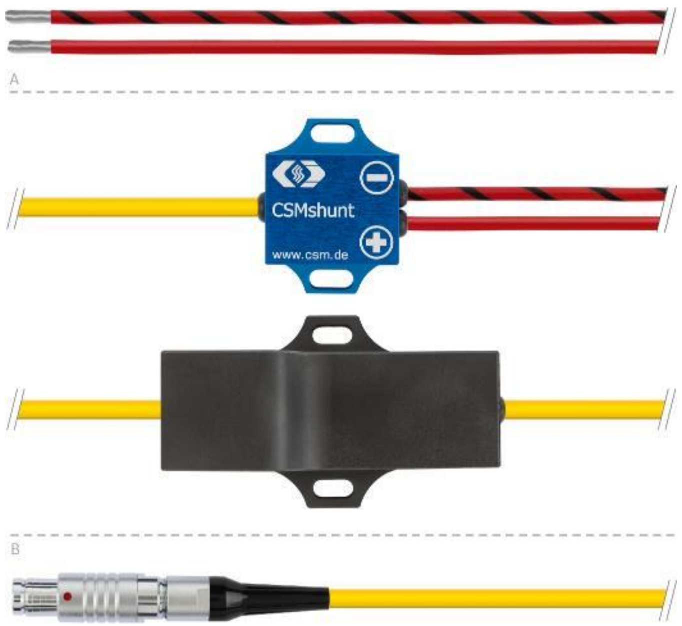

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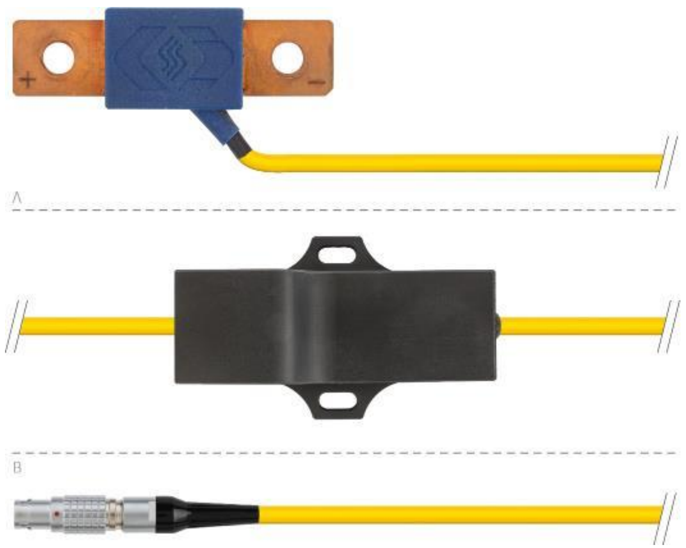

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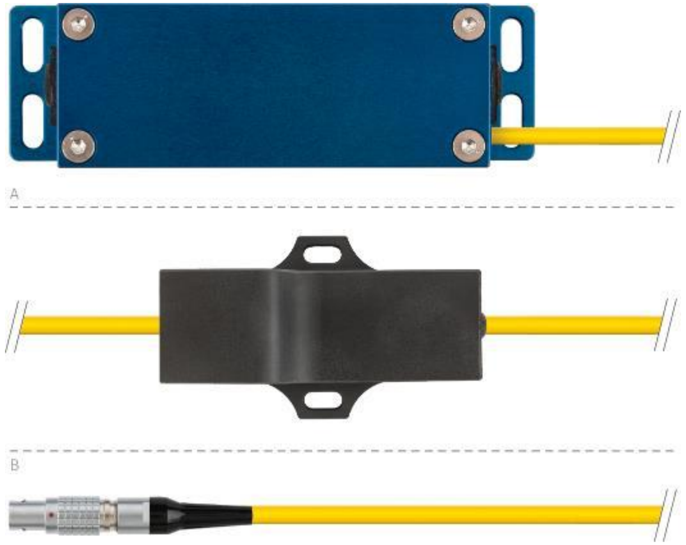
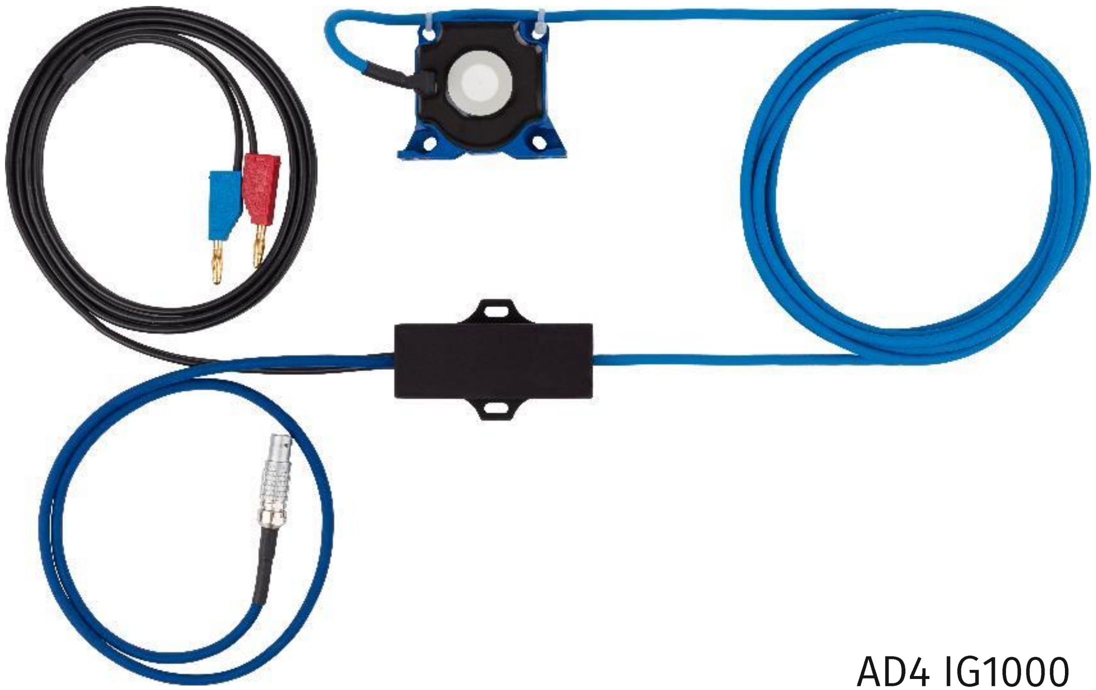


LEM sensor packages by CSM ≥ 100 kHz

Current measurements

- Wide variety of measuring ranges
  - ±5 A .. >> ±1000 A
- Integrated DC supply
  - 9 V .. 36 V
- Measurement of U_{out} with fast AD converter
- Parameterization and calibration data in TEDS chip



AD4 IG1000

LEM sensor packages by CSM ≥ 100 kHz

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  - ±5 A .. >> ±1000 A
- Integrated DC supply
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- Measurement of U_{out} with fast AD converter
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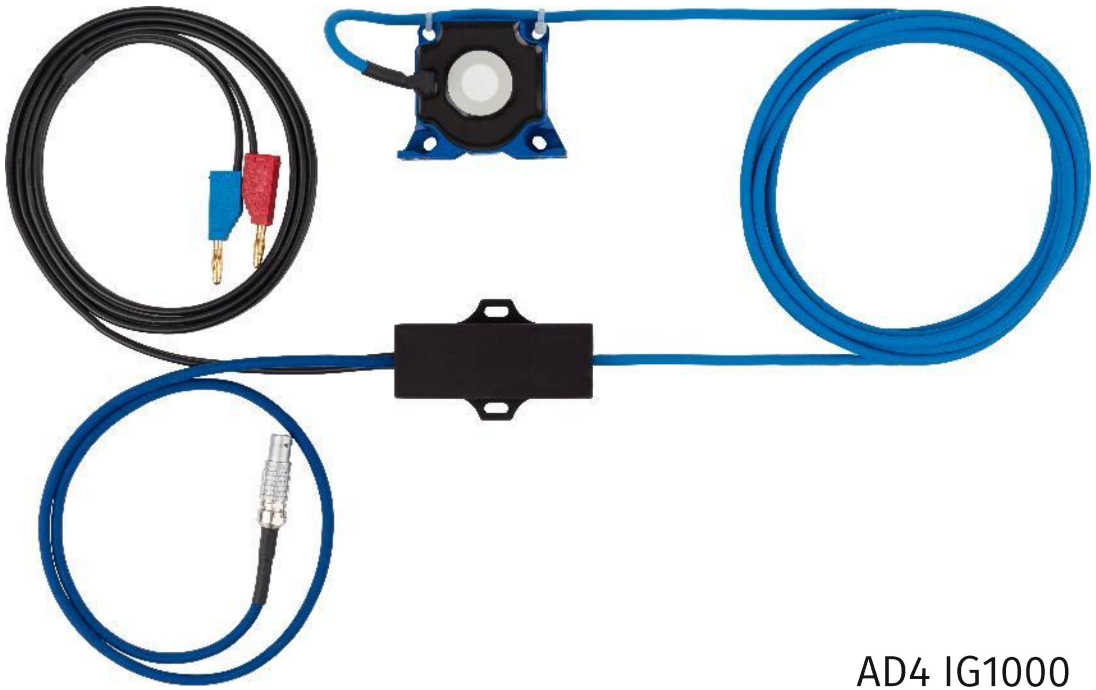
- (HV) connector does not fit through LEM
- I_mess = shield current + inner conductor
- Latency



AD4 IG1000

CSM AD converter and transducer from HIOKI, DC ... ≥100 kHz

Current measurements with clamp

- Various measuring ranges
- Measurement of U_{out} with fast AD converter
- Limited temperature range
- Suitable for use in vehicle?
  - Test bench
  - Road test

- I_mess = shield current + inner conductor

AD4 IG1000

CSM HV Breakout Modules (HV BM) for measuring I and U, calculating P

There are different HV safe modules

- For single phase measurements of Current
  - Shunt inserts, I_{nom} :
    ±50 A, ±125 A, ±250 A, ±500 A, ±800 A
  - I_{Peak} up to ±1,400 A
  - Voltage :
    Up to 1000 V (working) and 2000 V (peaks)
- 1 MHz Sampling per channel
- Outputs I, U, P
  - EtherCAT and CAN

HV BM 1.2
=
1 Phase
2 PG's

CSM HV Breakout Modules (HV BM) for measuring I and U, calculating P

Current measured via **Shunts**

- Calibration data stored in the chip
- Temperature compensated
- Adjustment to the measuring range
- IP67 Enclosure and EN61010 safe

HV BM 1.1
=
1 Phase
1 PG

PA (Potential equalization)

CSM HV Breakout Modules – Flexible Variants

5 Module Options

- **HV BM 1.1** = 1 Phase, 1 HV Cable (V+, V- common insulation)

HV BM 1.1

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- **HV BM 1.2** = 1 Phase, 2 HV Cables (V+, V- Separate insulation)

HV BM 1.1

HV BM 1.2

CSM HV Breakout Modules – Flexible Variants

5 Module Options

- **HV BM 1.1** = 1 Phase, 1 HV Cable (V+, V- common insulation)
- **HV BM 1.2** = 1 Phase, 2 HV Cables (V+, V- Separate insulation)
- **HV BM 1.2 +S** = HV BM 1.2 + measuring HV Cable Shield currents

NEW

HV BM 1.1

HV BM 1.2

HV BM 1.2 +S

CSM HV Breakout Modules – Flexible Variants

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- **HV BM 3.1** = 3 Phases, 1 Cable (V+, V- common insulation)
- **HV BM 3.3** = 3 Phase, 3 Cables (3 * Separate Insulation)
  + Integrated XCP-Gateway SOON


HV BM 1.1


HV BM 1.2


HV BM 3.1


HV BM 1.2 +S

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HV BM 1.1


HV BM 1.2

Test-bench

- Easy integration into test automation system

In-Vehicle

- IP67, -40°C to +125°C


HV BM 3.1


HV BM 1.2 +S

Simplified and Consistent tool-chain (hw and sw) throughout development process

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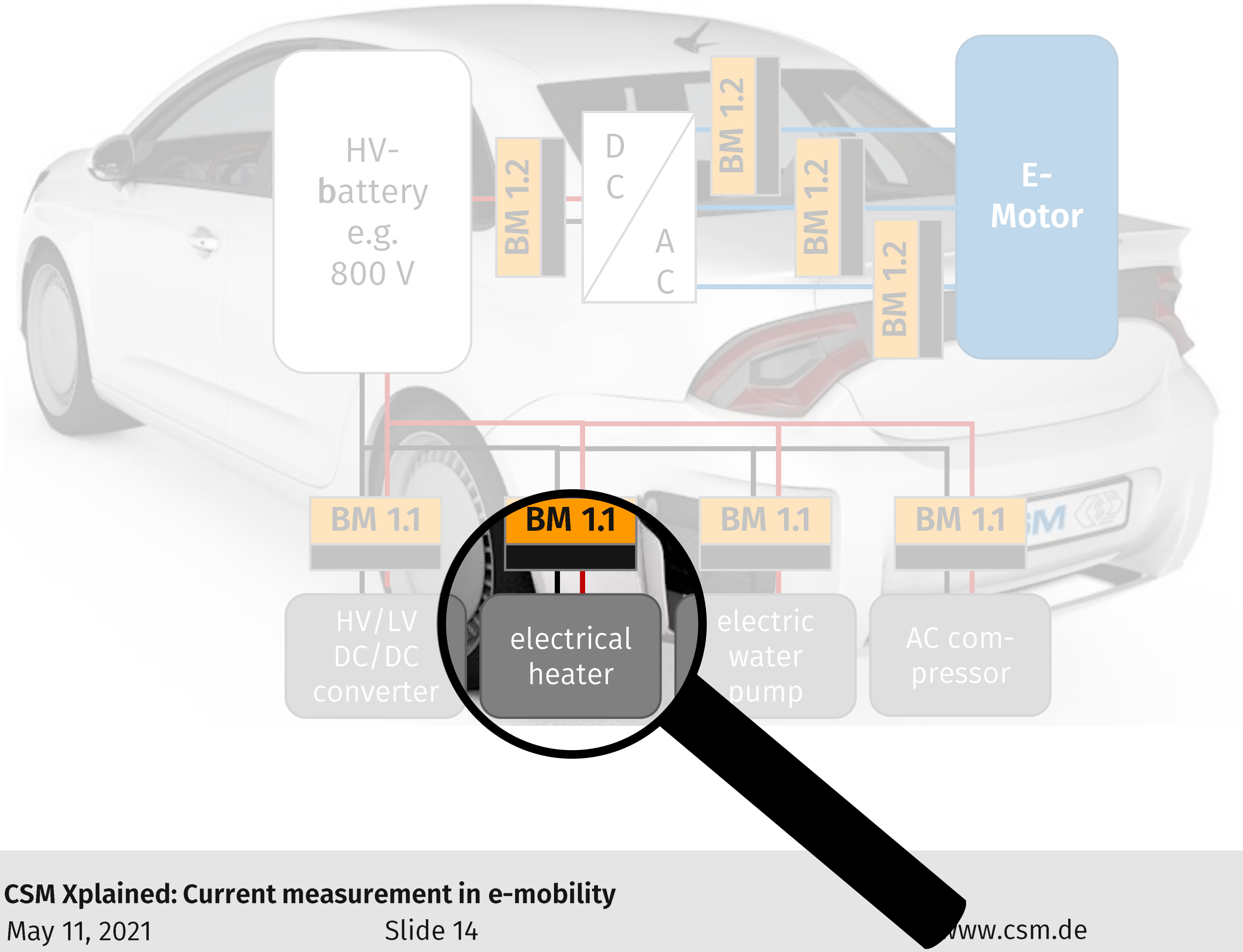
Electric current in electromobility



HV battery feeds consumer

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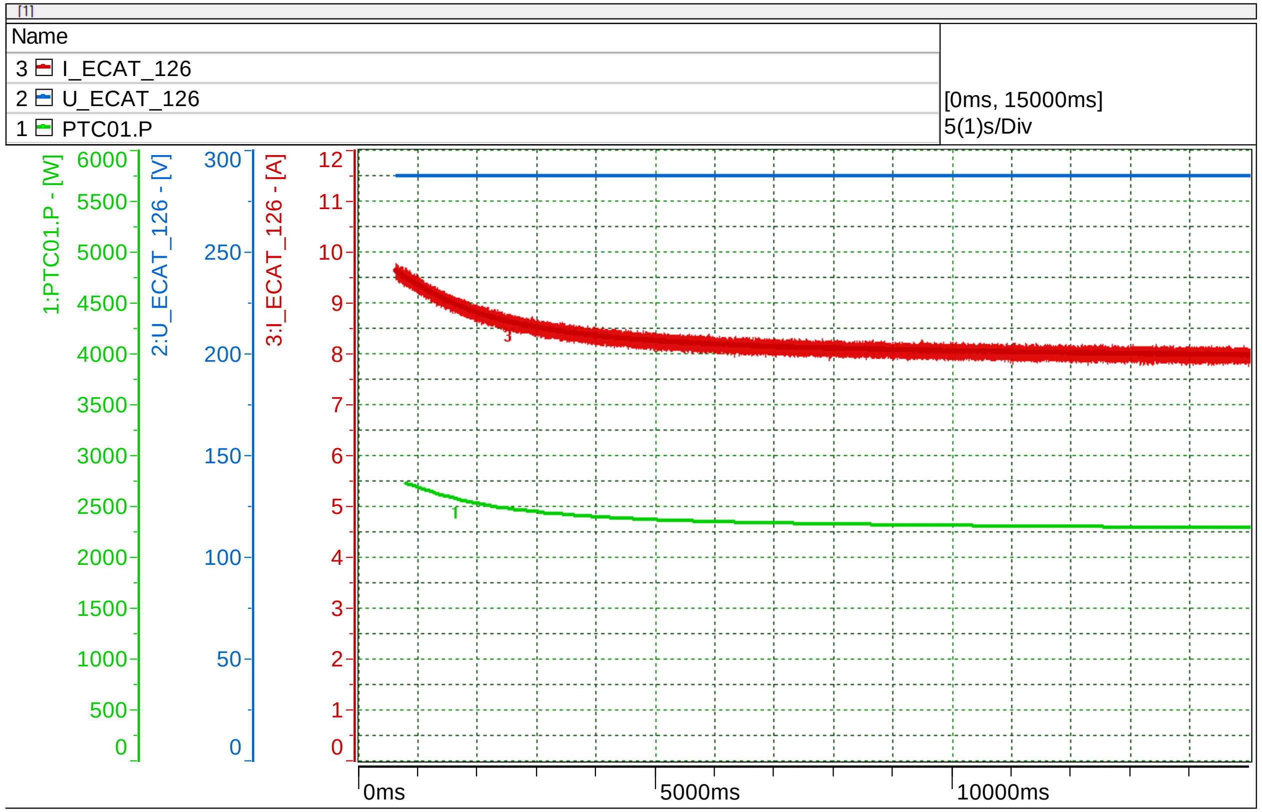
Current results from PWM-controlled voltage

Small consumers have built-in PWM control

Current is never only direct current

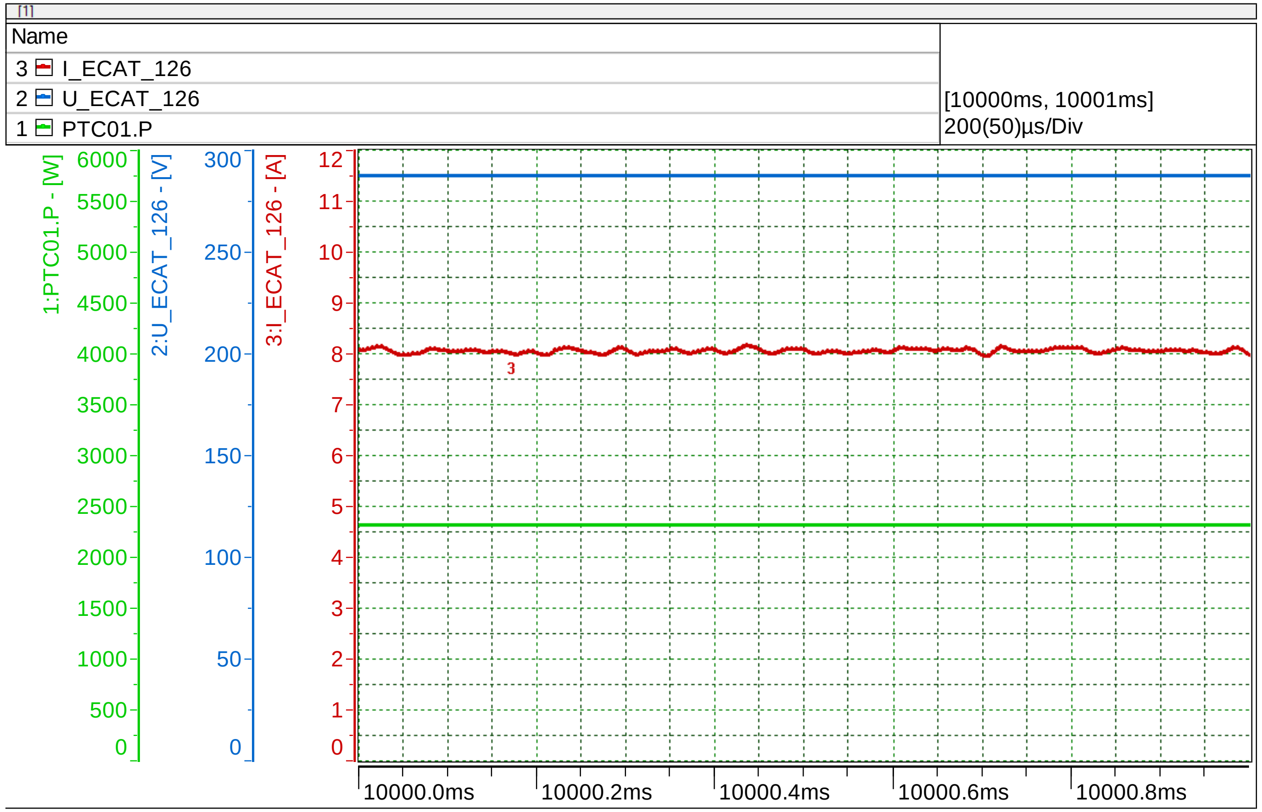
Current has alternating components

PTC-Electrical Heater



- Stable supply voltage
- Heating element heats up
- Current and power decrease at the beginning

PTC-Electrical Heater

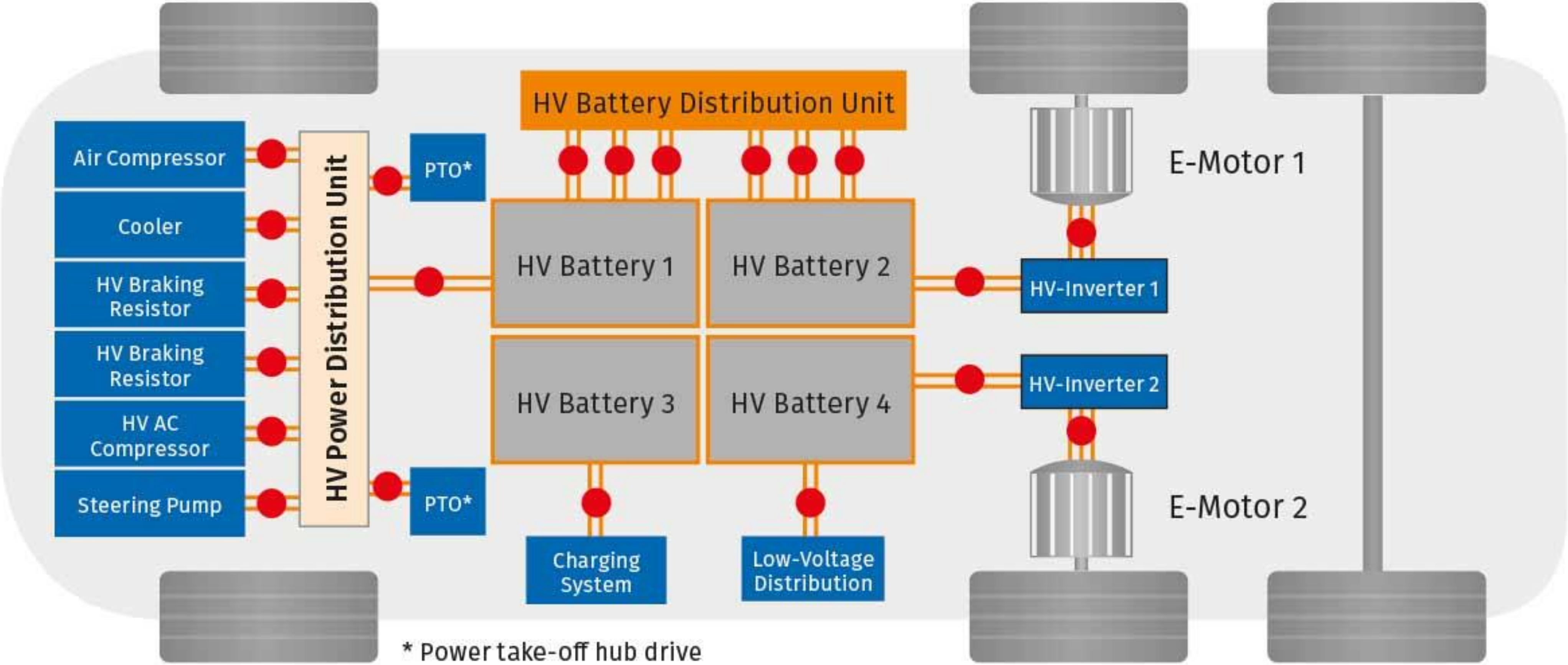


Heating power is PWM controlled

Well designed buffer capacitor

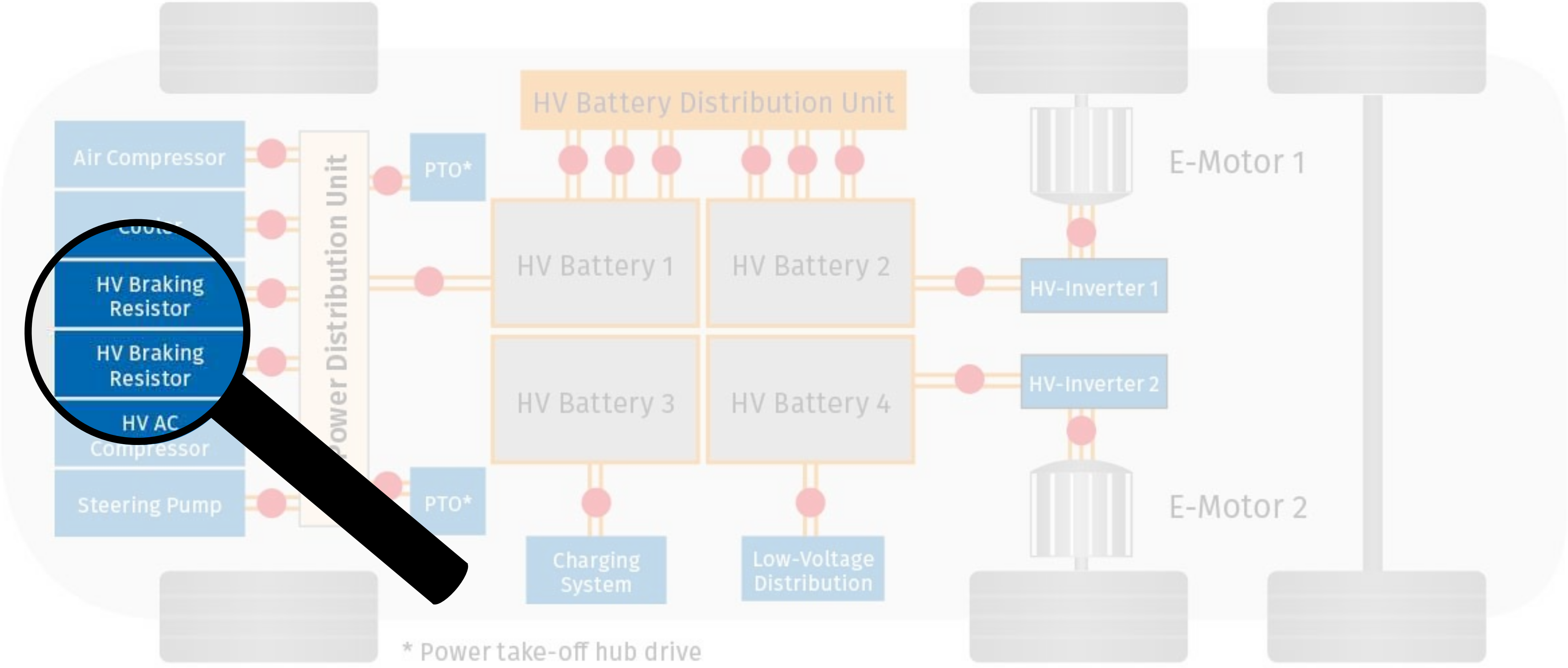
- Little feedback on the supply voltage
- Little ripple in current consumption

Commercial vehicle, HV electrical system

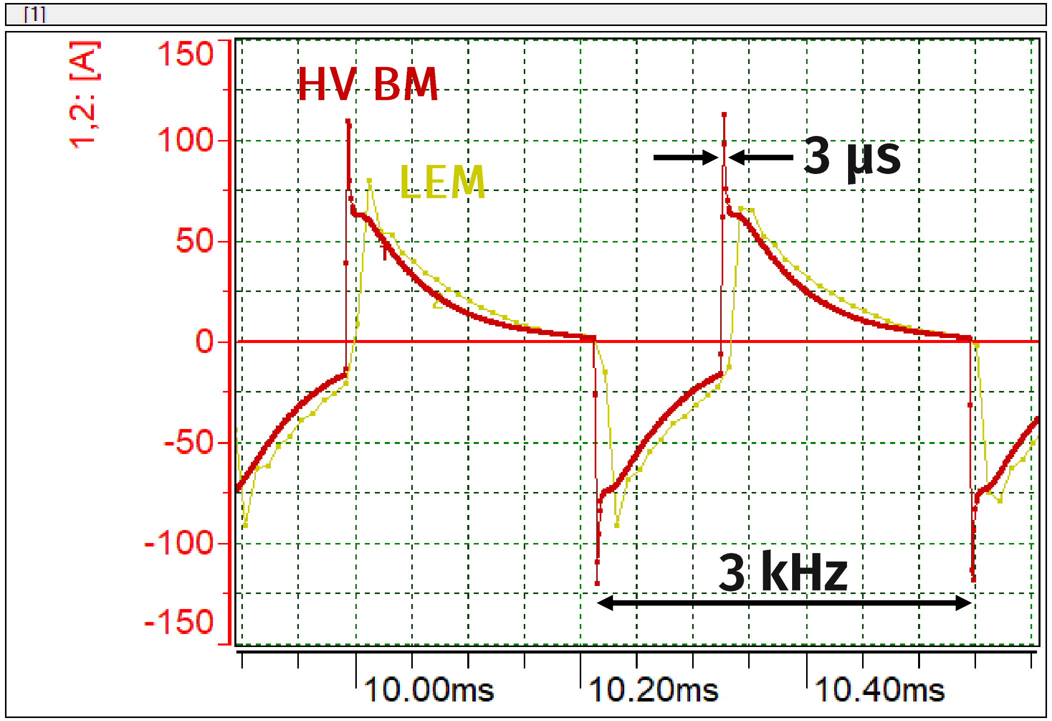


* Power take-off hub drive

Commercial vehicle, HV electrical system



Braking resistor, measurement of shield current



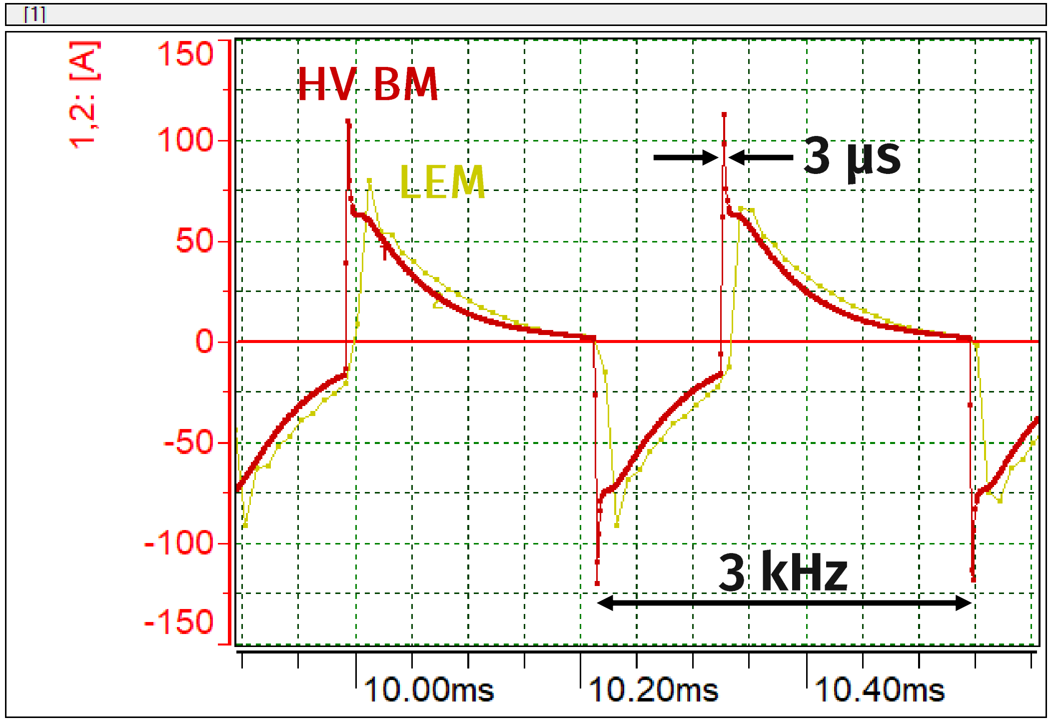
PWM controlled braking power

3 kHz basic system frequency

HV BM

- Captures Spikes of 3 µs

Braking resistor, measurement of shield current



Measured, maximum shield currents :

- I_{max}: LEM = 90 A | HV BM = 120 A

PWM controlled braking power

3 kHz basic system frequency

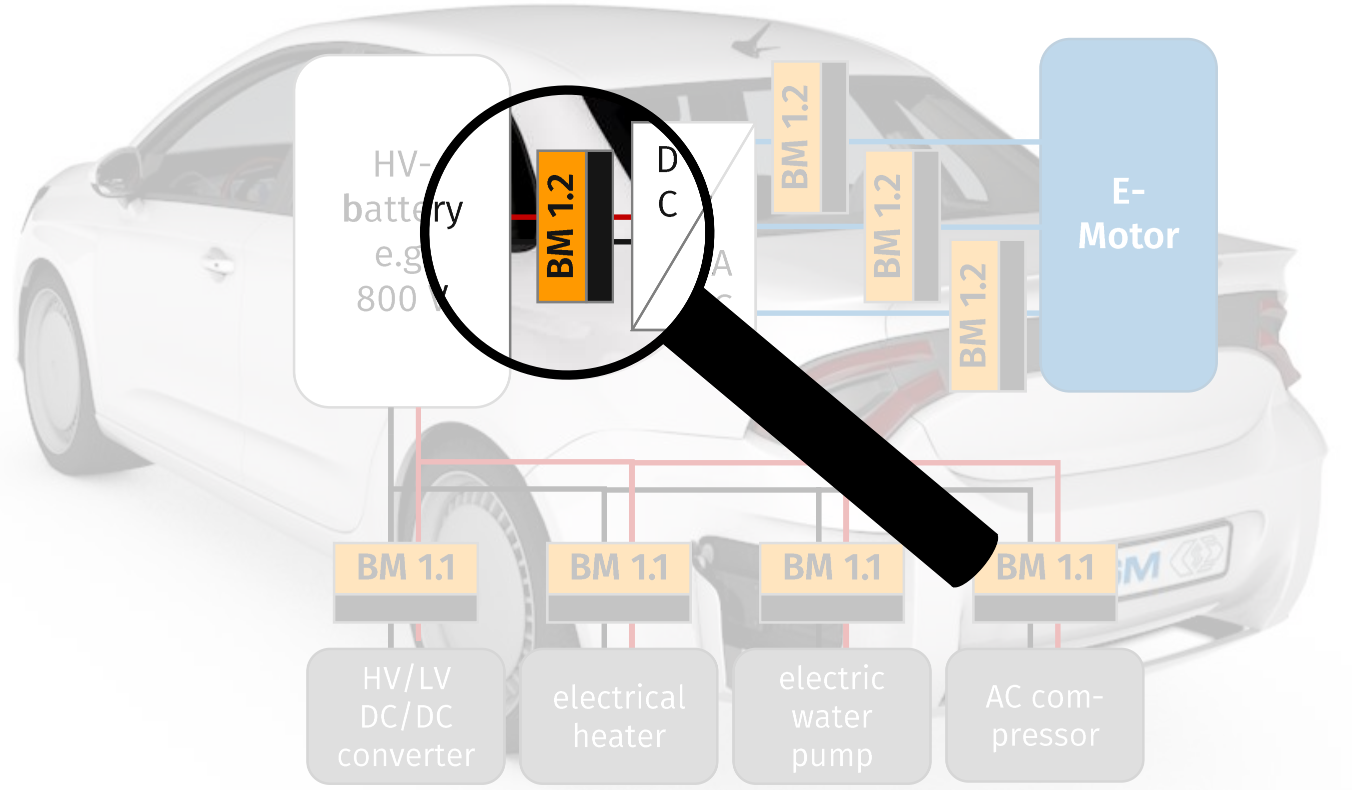
HV BM

- Captures Spikes of 3 µs

LEM Sensor Package + AD4 IG1000

- measurement bandwidth too small to resolve peaks
- Spike latency of ~20 µs
- Measures only 75% of peak current

Electric current in electromobility



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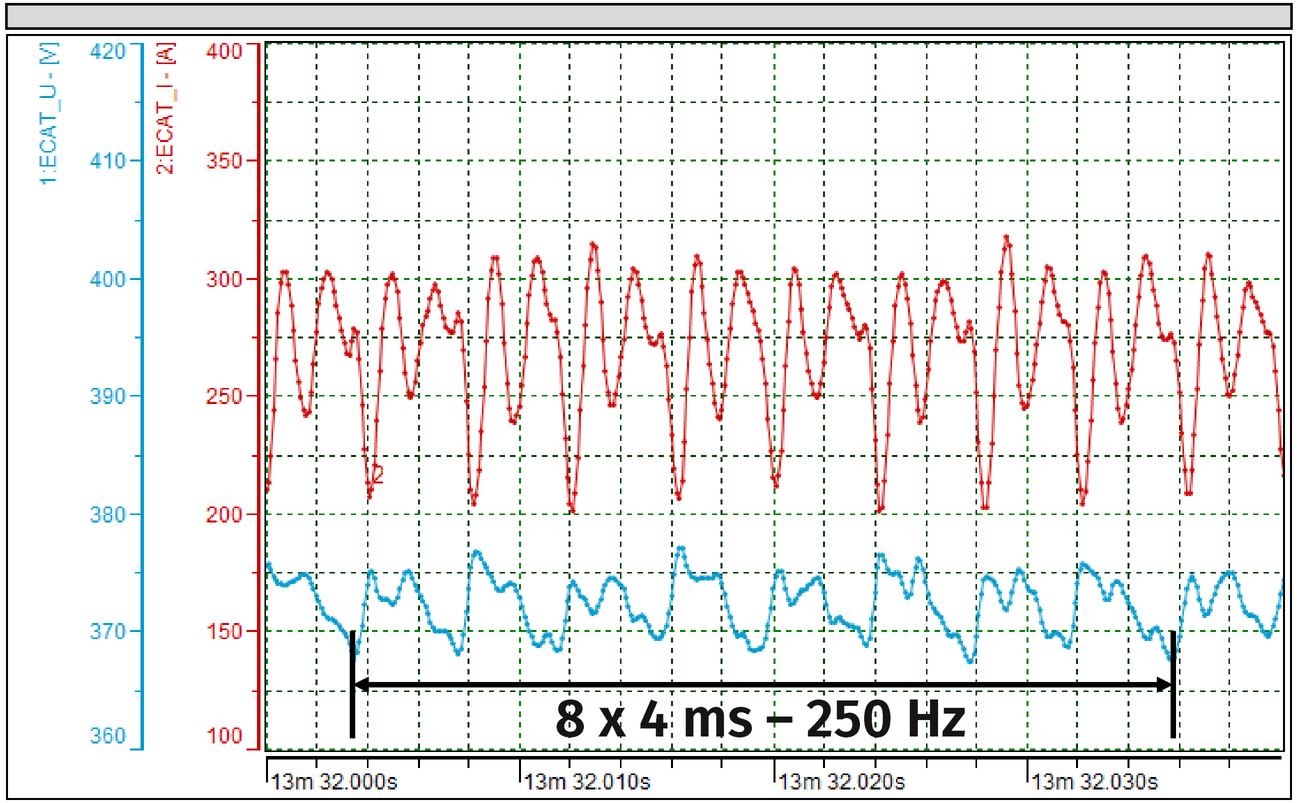
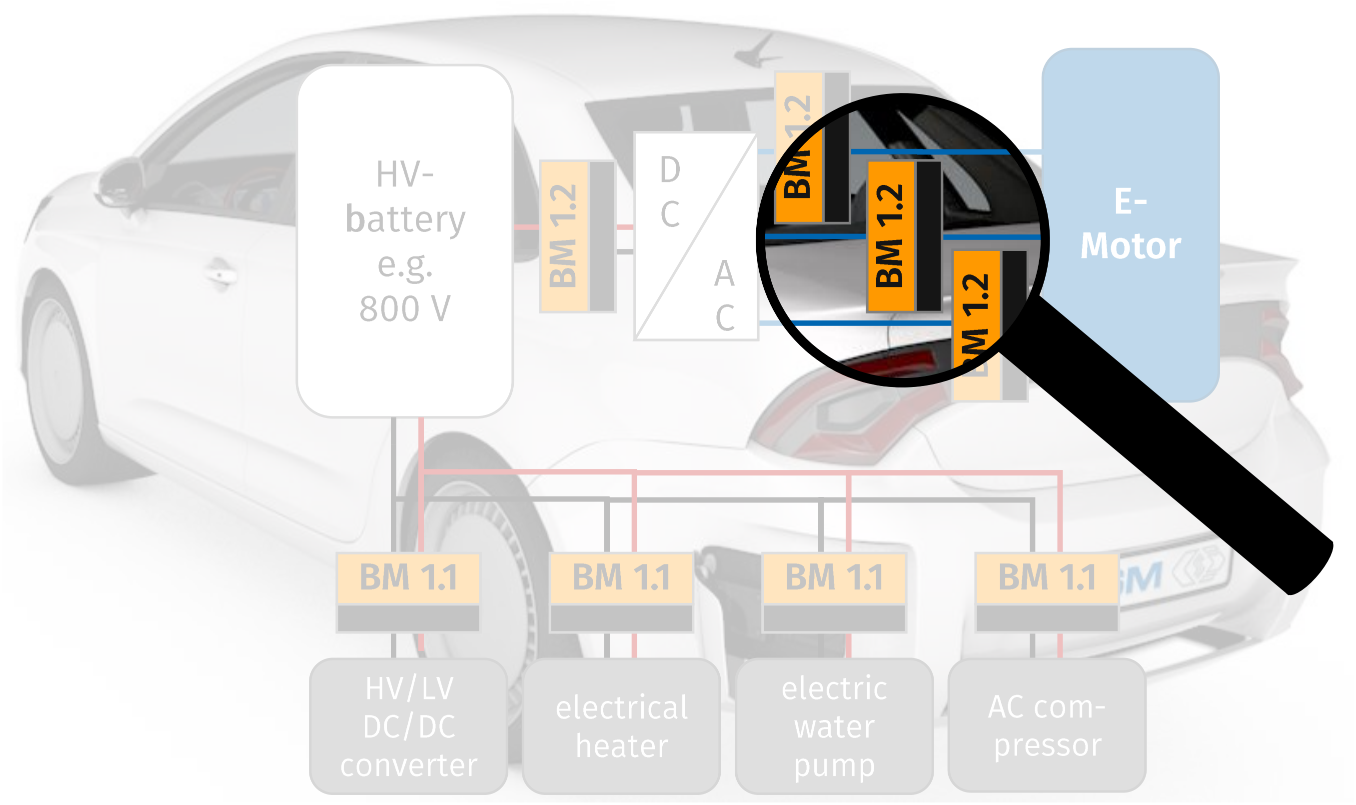
Battery to Inverter, HV BM 1.2, measurement of current and voltage



@ P_{el} ~ 100 kW

- PWM controlled drive power
- Great dynamics of the current
- I_{eff} = 271 A
- I_{min} = 203 A
- I_{max} = 312 A
- σ_I = 27.6 A
- U_{eff} = 372 V
- Requires measurement rate much faster than 250 Hz to capture mixed current signal

Electric current in electromobility



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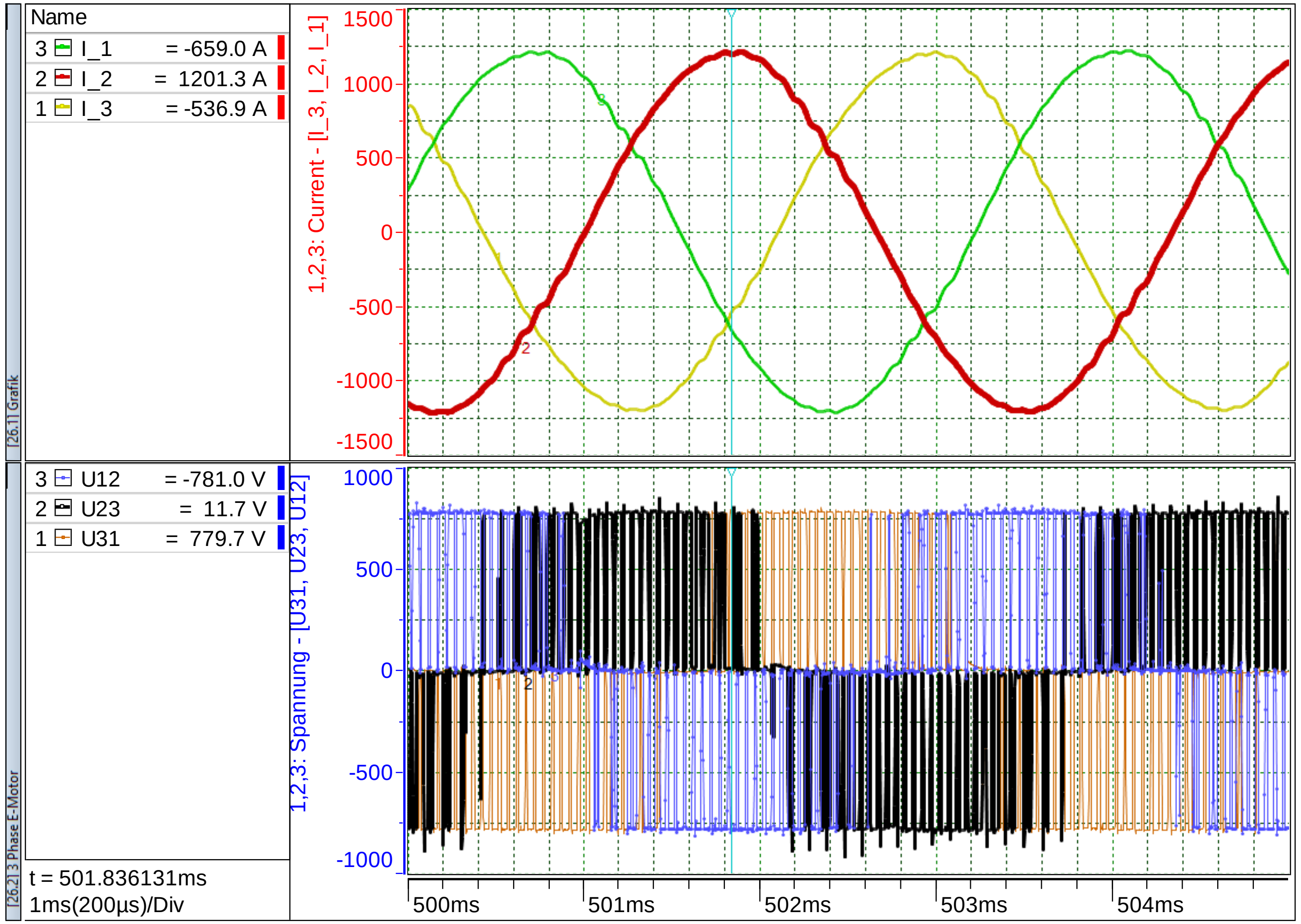
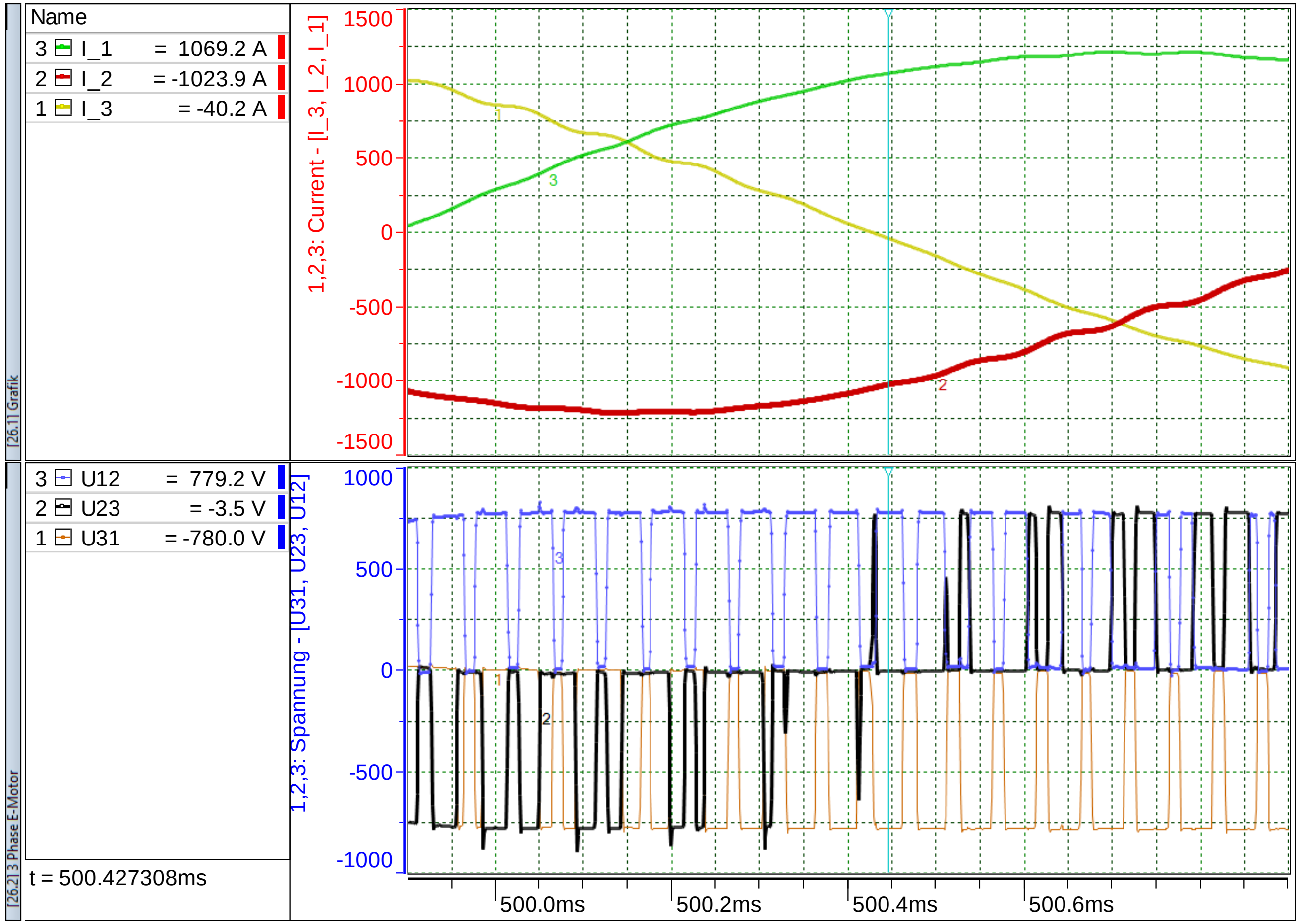
E-machine, three-phase, HV BM 1.2, measurement of current and voltage



@ P_{el} ~ 550 kW

- Motor currents @ 300 Hz (3.3 ms)
- Synchronous machine
- 3 pole pairs
- 6000 rpm
- 1,200 A
- PWM and inverter visible

E-machine, three-phase, HV BM 1.2, measurement of current and voltage



- PWM @ 20 kHz (50 µs)
- U_{23} is inverted in the image

@ P_{el} ~ 550 kW

Current measurement in e-mobility with CSM measurement technology

- CSM offers several solutions for the proper application
  - Shunts, LEM, Hioki, Breakout Modules
    - Easy connection to and configuration with CSM Modules
  - Low Voltage (<60 V) and High Voltage (>60 V) Applications
- Robust, HV-safe, on-vehicle uses
- Test bench, road test