

# Fuel Cell-Electric Drive Functional Test



## HV Current and Voltage Measurement

Fuel cell powered vehicles are an essential part of the electromobility transformation. The core component of the powertrain is the electrochemical reactor, known as the fuel cell stack. Commissioning is carried out on test benches and all essential functions are tested. Afterwards, the requirements for the entire fuel cell-electric drive are checked with a system validation. All basic data of the entire system are measured with high precision and the performance parameters are verified.

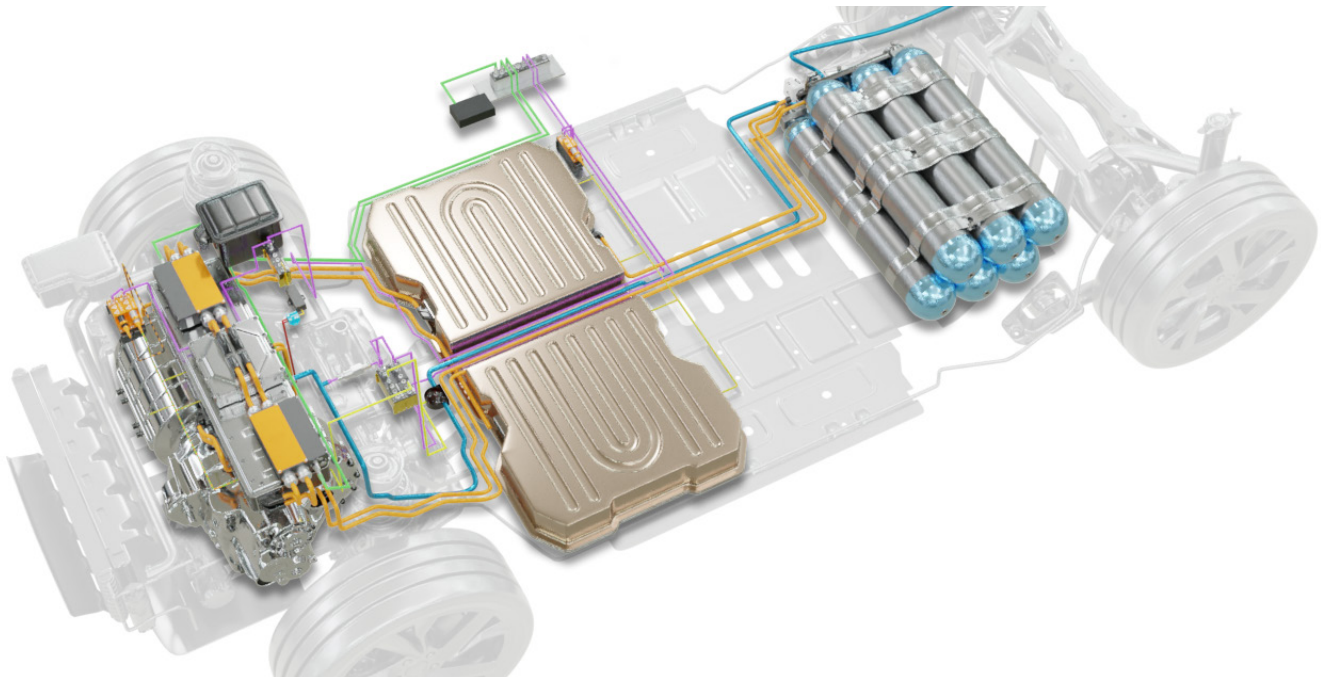


Fig. 1: Fuel cell vehicle equipped with CSM HV measurement technology and HV Breakout Modules

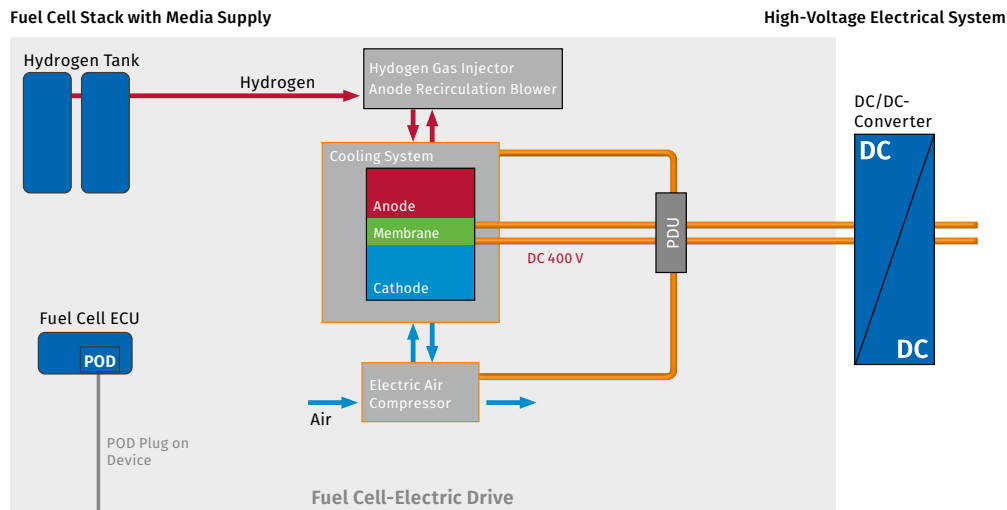


## Background

The fuel cell stack is a series of individual fuel cells, where the energy from the chemical reaction of continuously supplied hydrogen and atmospheric oxygen is converted into electrical energy in a so-called "cold combustion". This requires a precise operating system that feeds hydrogen,

atmospheric oxygen and moisture in a finely controlled manner. The stack is temperature controlled by a cooling system.



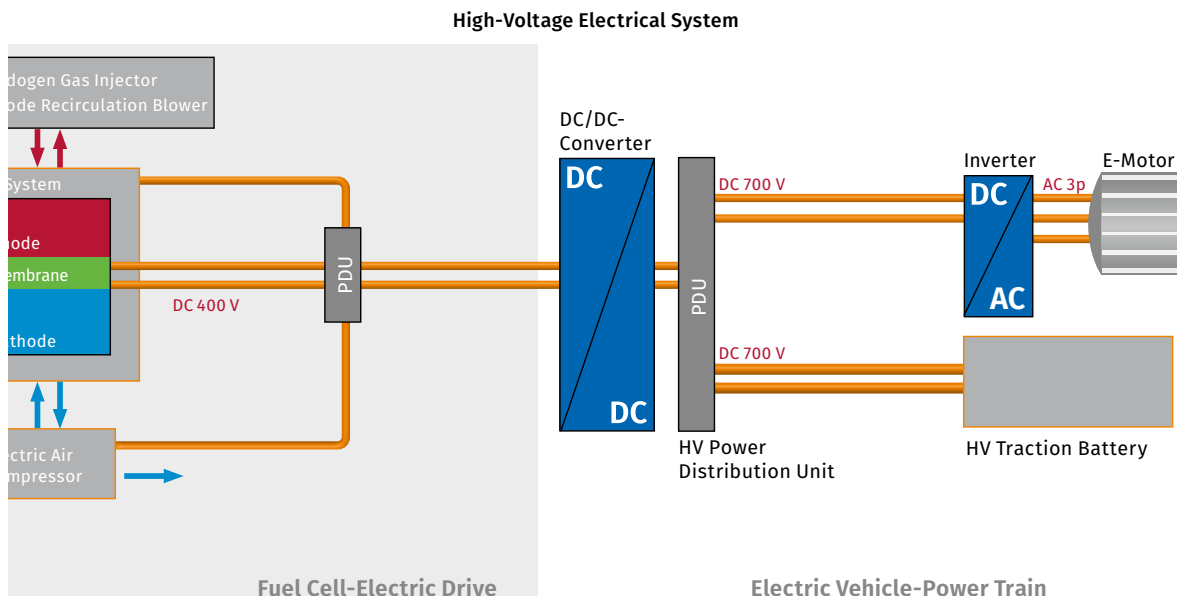


The fuel cell current is a measure of the current density occurring in the stack. Depending on the characteristics of the fuel cell, the output current leads to an actual fuel cell stack voltage, which must be measured synchronously. This stack voltage is composed of the number of fuel cells in the stack. Without power output, the fuel cell stack has a certain open circuit voltage which is also controlled in all test runs.

The fuel cell-electric drive is usually a complete subsystem of a vehicle provided by a supplier. In combination with the other components of the vehicle powertrain, the result is the overall vehicle performance and dynamics. The characteristics, functions and properties of the fuel cell-electric drive are verified on test benches up to production release with various tests. The energy from the fuel cell stack is

delivered to the DC/DC converter, which serves all other high-voltage units and components of a vehicle. They are interconnected via the high-voltage vehicle electrical system. The power electronics of the DC/DC converter also contain important functions, such as setting the stack set-point current for the respective operating mode. The DC/DC converter also contains a boost converter, for example to 700 V for the motor drivetrain (inverter and e-motor) and the traction battery.

Fuel cell electric vehicles usually have diverse operating modes, depending on the selected operating strategy and desired driving dynamics. The fuel cell stack provides the necessary electrical energy for both the traction drive and battery charging.





## Challenge

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The functional tests cover all operating functions such as cooling circuit, cooling control, heating, hydrogen paths (anode path), air paths (cathode path), high-voltage electrical circuits, sensor technology and fuel cell control unit. High-precision measurement of a wide range of physical parameters is required for functional testing and validation of the fuel cell drive system. In addition to temperatures, volumetric flows, humidity and pressures, measurements of currents and voltages in the high-voltage circuits are necessary. From these, the delivered energy, power and efficiency are calculated.

The individual sub-systems for hydrogen, air and cooling circuits are individually applied and commissioned. A defined start-up process is carried out to start the fuel cell system. After that, the specific system functions are tested: Cold start behavior, warm-up phase duration, operating points, thermal management or the cooling circuits. A functional test proves whether the system behaves as it should, for example whether all control parameters are set correctly.

With validation, the system requirements such as performance parameters, reaction speed to load changes or service life are proven with tests and endurance runs.

Current, voltage and power measurements are used to check correct operation in the various operating phases. For example, the characteristic curve of the power during the warm-up phase, for start-up, load changes, partial load and peak load as well as various other distinctive operating points.

The voltage ripple occurring in the HV-DC circuit must be checked, because limits are defined for magnitude and slope. The allowed ripple current load, for example, in peak load operation must also be verified.

With the measurement of currents, voltages and powers in the high-voltage paths, all transient processes are also checked. For example, when the fuel cell stack is switched on or when units such as the air compressor or the cooling system heater are switched on. Here, the current and voltage curves must be viewed at a high sampling rate of 1 MS/s in order to evaluate voltage dips, amplitude slopes, ripple magnitudes and interfering subharmonic frequency components.

Ultimately, the specified efficiency curves of the fuel cell-electric drive are demonstrated. The efficiency is the energy delivered in relation to the hydrogen consumed. It depends on the load point and the optimal supply of the different media: hydrogen, atmospheric oxygen, humidity and cooling. A non-optimal supply, for example of stack humidification, leads to a drop in stack voltage.

Accurate measurement and analysis of current, voltage, power and efficiency verify and prove all system-relevant performance parameters of the fuel cell electric drive.

## The CSM Measurement Solution

For direct current, voltage and power measurement, a **HV BM 1.2** is inserted in the HV+ and HV- cables to the DC/DC converter and the battery. Further Breakout Modules (HV BM 1.1) measure the currents of the air compressor and the cooling system. Simple current measurement can be performed via CAN at sample rates of, 1 kHz, for example. For fast measurements of current, voltage and power up to sampling rates of 1000 kHz can be used, via EtherCAT® (ECAT) bus. For current measurements inside auxiliaries, **CSM LEM sensor packages** can be used, to be connected via analog-to-digital modules (**AD4 Mini-Modules**) also on the ECAT bus (not shown in Figure 3).



Fig. 3: HV Breakout Module 1.2 for measuring current, voltage and power in the separate HV+ and HV- lines between fuel cell stack and DC/DC converter.



Fig. 2: An XCP Gateway 4S pro is used to synchronize and acquire the EtherCAT data and to bundle the CAN data.

The measured values from the HV Breakout Modules and the LEM sensor packages are sent to an **XCP-Gateway**, which converts the data into the XCP protocol and transmitted to the test bench software via XCP-on-Ethernet (XCPoE).

The AD4 ECAT MiniModules are used to time-synchronize the measurement of all other voltages required for verification. At the stack supply all important physical parameters of the supply are measured with additional CSM low and high voltage modules. The sensors for measuring volume flows, pressure and humidity are connected to conventional AD4 and HV AD CAN Mini modules. Temperatures are measured at high-voltage critical points via **HV TH8 evo** modules. THMM 16 MiniModules are used at non-critical high-voltage points.

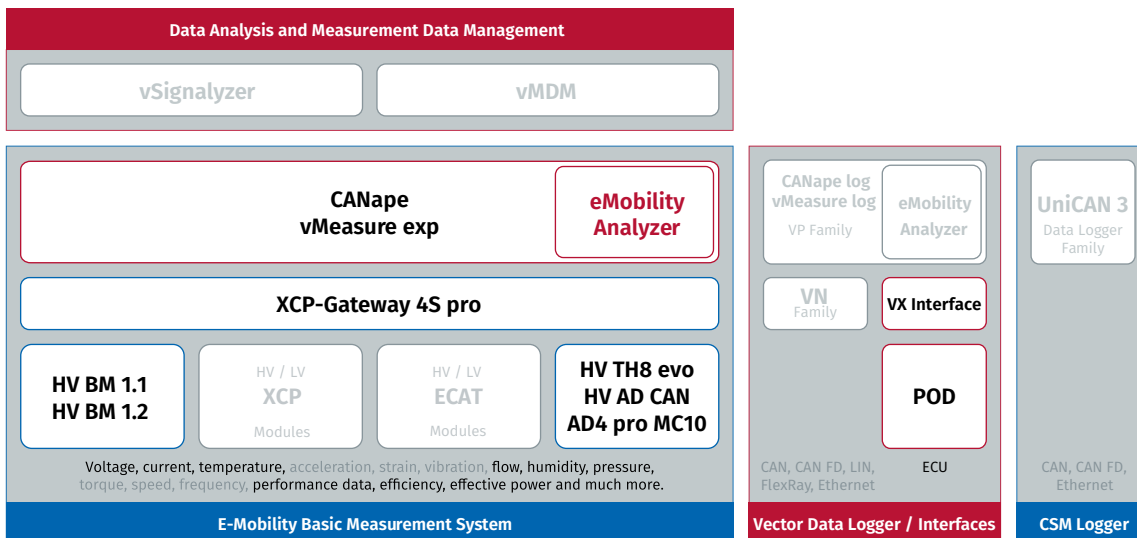


Fig. 4: The fuel cell-electric drive functional test in the systematics of the Vector CSM E-Mobility Measurement System

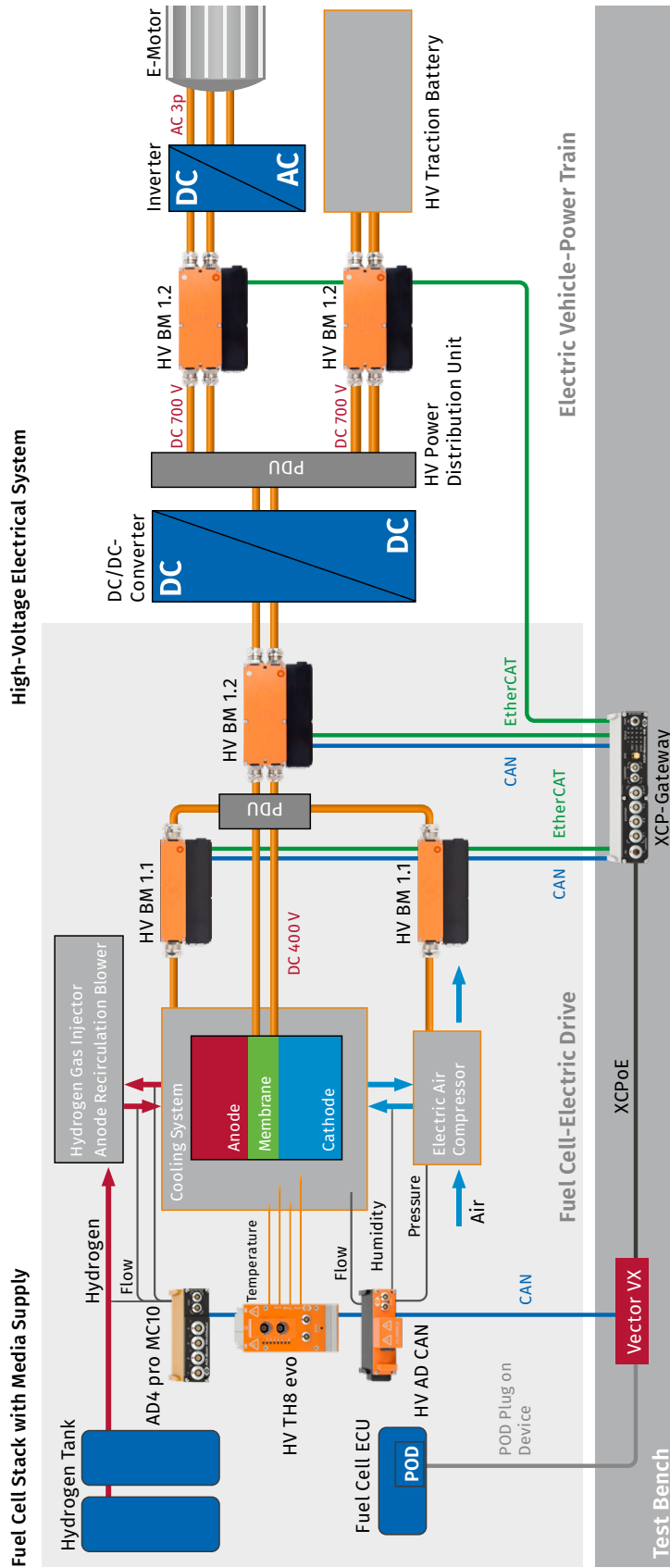


Fig. 5: Fuel cell-electric drive on the test bench. The fuel cell stack supplies the necessary power via a HV power distribution unit (PDU) for all other components. Energy consumers are the HV aggregates for the media supply of the stack: HV cooling system, HV air compressor and other components connected for tests. CSM's CAN-based Mini Modules measure volume flows, pressures and temperatures of the different media paths: Hydrogen path, air path, coolant path. The HV consumer currents of the coolant pump, heater and air compressor are measured with HV breakout modules. A HV breakout module measures current and voltage to the DC/DC converter, which is used to calculate the delivered energy.

Both the DC/DC converter, the traction battery and the electric motors (E-Axle) are connected to the fuel cell-electric drive system in the vehicle. It supplies the respective HV components with energy according to the operating mode. In the figure above on the right side, the entire vehicle powertrain is connected for testing. Further breakout modules are used to measure the respective HV paths currents and voltages.



## Benefits

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With the conventional and high-voltage measurement modules from CSM, the test bench can be equipped exactly according to the measurement requirements. High-voltage measurement modules are used where measurements are made in high-voltage environment. Fast EtherCAT measurement modules allow a high sampling rate to assure that high-speed transient data is not missed.

High voltage Breakout Modules allow direct measurement of high currents and voltages with calculation of instantaneous power in the HV cables. Measurement data are sent to the test bench via CAN or for fast measurements with a sampling rate up to 1 MS/s via EtherCAT.

CSM LEM sensor packages are used for current measurements at installation space constraints. These current transformers are connected via a CSM ADMM4 measuring module, which also performs the simultaneous voltage measurement.

The integration into a test bench software like ETAS INCA for fast measurement is very easy: The software add-ons “CSM INCA AddOn ETH” allows an easy integration of the CSM measurement modules into the INCA measurement and analysis software from ETAS. The configuration is easily done via a customized user interface.

For accurate power analysis, the Vector software vMeasure with the eMobility Analyzer is ideal.



## Featured Products

### HV Breakout Module - Type 1.2

CSM's HV Breakout Module (BM) Type 1.2 was designed for single-phase measurements of current, voltage and power. It is ideal for measurement on large consumers such as electric motors equipped with separate HV+ and HV- cables. The HV Breakout Module 1.2 is available in two versions for connection via cable glands or PL500 plug-in system (HV BM 1.2C).



### AD4 ECAT MM Series - Type IE1000

CSM's AD4 ECAT IE1000 measurement module is ideally suited for the most accurate analysis of high-frequency signals with measurement data rates of up to 1 MHz per channel. It offers a high-precision and unipolar sensor excitation from 5 to 24 V DC for a variety of sensors, that is adjustable per channel.



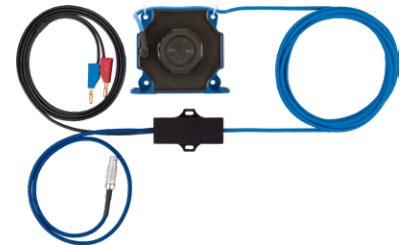
### XCP-Gateway Series

CSM's XCP-Gateway Series protocol converters were specially developed for CSM EtherCAT® measurement modules and for measurement tasks with multiple measurement channels and high measurement data rates. The XCP-Gateway is available in "Basic" and "pro" versions. The "pro" version has two CAN interfaces via which CAN-based CSM measurement modules can be connected and integrated into the XCP-on-Ethernet measurement data protocol. In the "pro" version, temperature data from the HV Breakout Modules can also be transferred directly via EtherCAT®.



### LEM Sensor Packages

CSM's LEM Sensor Packages allow fast and synchronous current measurements. Highly dynamic current measurements (e.g., on all three phases on the inverter, as well) with a threshold frequency of up to 200 kHz in a measurement range of up to  $\pm 1,250$  A can be carried out with this Sensor Package along with the EtherCAT®-based measurement modules of the AD4 ECAT Series.



### HV TH8 evo

The HV TH8 evo thermal measurement module allows high-voltage safe temperature measurements with thermocouples on high-voltage components. With its 19-inch slide-in housing and reinforced insulation up to 1,000V RMS, it is particularly suitable for use in test benches.



Complete solutions from a single source:

CSM provides you with comprehensive complete packages consisting of measurement modules, sensors, connecting cables and software - customized to your individual needs.

Further information on our products are available on our website at [www.csm.de](http://www.csm.de) or via e-mail [sales@csm.de](mailto:sales@csm.de).



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