An Axiometrix Solutions Brand

E-mobility

Challenges for data acquisition technology

Solutions and practical tips

Exactly what you are looking for.

Content

How will the energy storage of the future be measured?

Because of the need to provide solutions for testing e-vehicles, vehicle development and construction confront a variety of metrological challenges.

New components for electric vehicles or those in which the design and functionality have changed significantly – including high-voltage batteries, electric motors, transmissions, coupling or ancillary units – demand that test stand infrastructure is adapted, or requires completely new test procedures and new hardware for measurement data acquisition in development, certification or production.

These include, for example, high-voltage-capable, highly-isolated measurement technology and observing specific safety measures for those involved in the installation.

Due to the high electrical voltages that prevail in the vicinity of the battery and the electric motor, measurements and data acquisition on electric vehicles require not only high-voltage isolation, but also sufficient robustness in terms of electromagnetic interference.

The extensive sensor instrumentation used, for example, to acquire temperature and voltage on battery cells, also requires measurement technology to be networked.

Furthermore, different measurement hardware specifications are demanded for current measurement, power measurement, temperature measurement, for a large range of dynamics in current measurement, as well as for high voltage.

Sensor connection technology especially designed for the e-mobility environment – whether this is “classic” sensors with highly isolated cables, or fiber-optic sensors – allows measurement data to be acquired reliably and free of interference. Furthermore, high voltage (HV) connection boxes enable a safe contact and allow the clear separation of protected areas close to the sensors and areas exposed to the operator, that need to be highly isolated and in compliance with standards.

Measuring the performance of electric motors or vehicle components, running end-of-line tests to ensure the quality of electric motors, as well as testing driving dynamics and brakes on electric vehicles, demands innovative test procedures on the test stand or in road tests. These require highly isolated, robust and network-capable measurement systems and sensors that are immune to EMC interference.

This white paper presents measurement hardware, sensors and test stand solutions for reliable and safe measurements and data processing whenever tests are conducted on and around e-vehicles.

We present in this paper tried and trusted test solutions for development and certification, ranging from measurements conducted on energy storage devices, drives and components in the high-voltage range which are safe for personnel, through to power measurement and driving dynamics tests on e-vehicles and components.

These use-cases provide examples of standard problems and solutions to overcome the measurement challenges in the e-mobility environment.

01

Safe measurements on energy storage devices, drives and components

The further development of energy storage, i. e. of batteries or fuel cells, is one of the central challenges for the expansion of e-mobility. This requires measurement technology that efficiently supports new test scenarios for the development of storage media as well as for the charging infrastructure. Just some examples of new test tasks that accordingly demand measurement technology solutions are safety standards - such as protection against overheating or battery fire – the optimization of battery capacities for supplying powerful electric motors, and the development of alternative storage designs such as fuel cells or solid-state batteries. Intensive test activities are necessary in order to ensure that new developments reach production maturity in a short period of time. The demands placed on measurement technology are high. This is because it is not only important to conduct precise measurements in the e-mobility environment. Due to the high voltage levels, personal safety and robustness against electromagnetic interference are also important requirements.

E-vehicle in a charging station

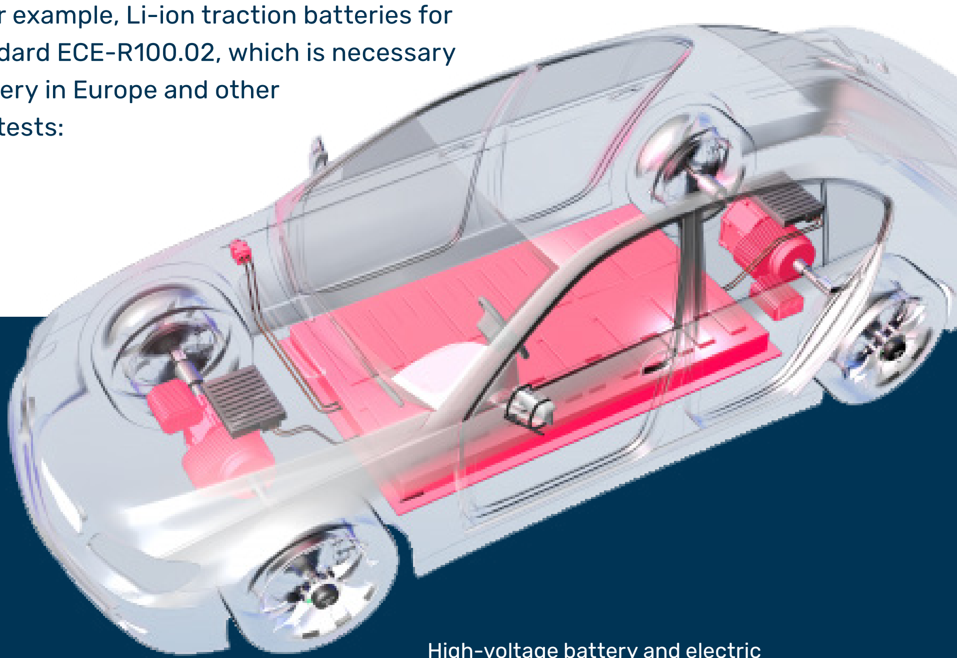
Harsh conditions in the test laboratory

Comprehensive approval and lifetime tests on high-voltage batteries

Extensive testing and validation are necessary in the development of traction batteries for e-cars or for electrically powered two-wheelers and small electric vehicles (so-called e-scooters). Against the background of safety and environmental standards, battery cells and modules as well as the complete battery pack and the battery management system are tested for their load limits. Other tests include performance tests, lifetime tests and measuring battery power.

Standards according to which, for example, Li-ion traction batteries for e-cars are tested - above all standard ECE-R100.02, which is necessary for the approval of a traction battery in Europe and other countries – include the following tests:

- **Cell overload**
- **Cell discharging**
- **Cyclical voltage limits**
- **Cell short circuiting**



High-voltage battery and electric drive in an e-vehicle

In this regard, the design of tests is very diverse, depending very much on the relevant standard and the energy storage device to be tested.

Combinations of test scenarios, such as the combination of climate chamber, humidity and simultaneous electrical operation, are also possible and common, for instance, in order to check environmental compatibility.

The development of the battery pack takes place after investigation of the individual cell. Li-ion battery packs have very high energy content. In electric vehicles, the energy content is usually between 50 and 100 kWh. This high amount of energy means that fire can scarcely be extinguished in the event of a battery fire and will result in the complete destruction of the vehicle. In order to prevent or minimize the risk of thermal runaway in the battery, the battery packs or - first of all - the individual cells are subjected to all possible mechanical, thermal and electrical stress and analyzed.

In so-called safety laboratories, the individual cell with a cell voltage of approx. 4.2 V and a capacity of up to 100 Ah is examined in various test series and in some cases destroyed in a targeted manner in order to optimize the behavior of the cell.

Electrical misuse tests that have been performed include those, for example, on high-voltage batteries for e-vehicles from a Stuttgart car manufacturer:

Overloading of the cell

This test involves examining the behaviour of a cell when overcharging occurs with a large direct current. In order to create conditions that are as identical as possible to those in the vehicle, the cell is fixed with clamping plates that are similar to the design of a battery pack and brought to a constant temperature of 60°C by way of example. The discharged cell is now charged and, from a certain cell voltage, overcharged with a constant overcurrent to double or triple the regular state of charge. The test parameters and charging currents are varied.

Discharging the cell

The “cell discharge” test is carried out in a similar way to overcharging, but with opposite current direction, in order to examine the deep discharge behavior.

Cyclical Voltage Limits

In this case, the voltage limits for overcharging and discharging the cell are cyclically exceeded with high charging or discharging current.

Shorting the cell

Under vehicle ambient conditions, the cell is short-circuited via an external switch with twice to three times the discharge time and its behavior is analyzed.

Thermal and mechanical misuse-tests

In the thermal misuse test, among other things, the ambient temperature is increased until the cell heats up by itself or the temperature in the cell changes faster than the ambient temperature. In a further test, the heat transfer behaviour of two neighboring cells is examined. One is specifically destroyed in order to examine behaviour or thermal propagation in the battery pack. In addition to this also come cyclical temperature profiles.




In the mechanical misuse tests, the cell is not fixed using clamping plates, but is mechanically loaded or bent in a targeted manner from all sides or penetrated by sharp objects in order to create an internal short circuit.

Examination of the individual cell serves the further development of the battery modules or the entire battery pack, which also includes the battery management and cooling systems. The behaviour of these high-voltage storage systems is then subjected to further tests.

USE CASE: **Measurement data acquisition on high-voltage storage**

When developing new batteries and battery management systems for e-vehicles, extensive testing and validation are the order of the day at SK Innovation. With these, the load limits of battery cells, modules and complete battery packs can be determined. Investigations include lifetime tests in a climate chamber, and the power of a battery is tested in charge and discharge cycles lasting several weeks. During the test, the cell voltage and cell temperature are measured and monitored on each battery cell. During crash loads, penetration, compression and bending as well as vibration tests, temperature, stress and other data from third-party devices are acquired with the test system and finally evaluated automatically.

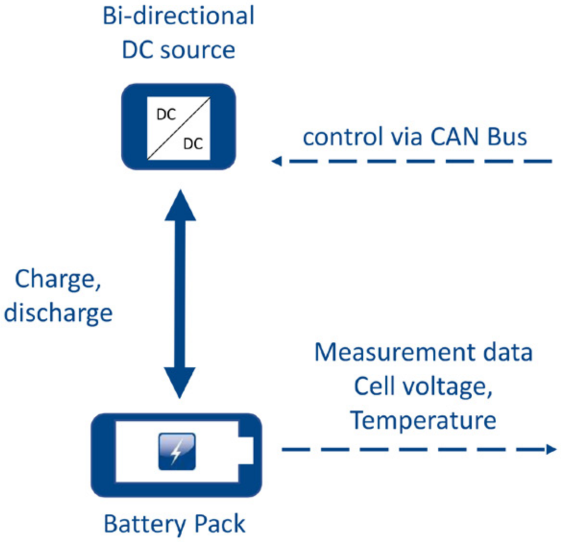
Battery pack

Design of a test system for Li-ion batteries

The design of test systems for Li-ion batteries requires an extensive "infrastructure" for the test environment, and this must also be controlled. Therefore, an integrated architecture of measurement hardware and software for automated testing and data analysis should be foreseen.

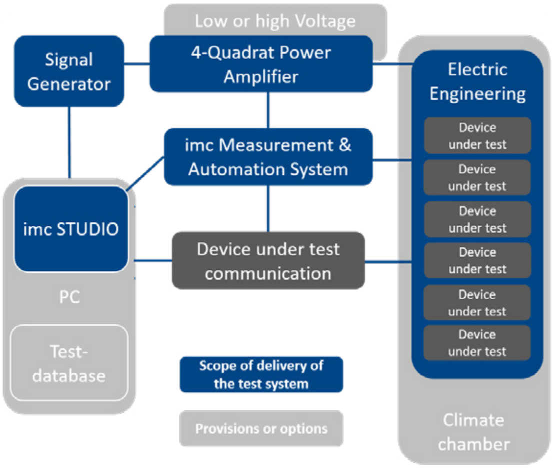
With real-time processing and monitoring of the measurement data, the test system can then be checked accordingly and – if necessary – a test can also be aborted. Since these are networked, multi-channel measurements, it makes sense to have a modular, networked and flexibly expandable measurement system that can be adapted to the different tests. It is necessary to have interfaces via which the control of third-party devices can be integrated. For example, data on status and the current temperature of the climate chamber can be acquired synchronously with the acquisition of temperature and voltage on the test object. Or video data can be acquired fully synchronous. This is necessary for downstream data analysis, especially in the case of prolonged lifetime tests with charging and discharging cycles.

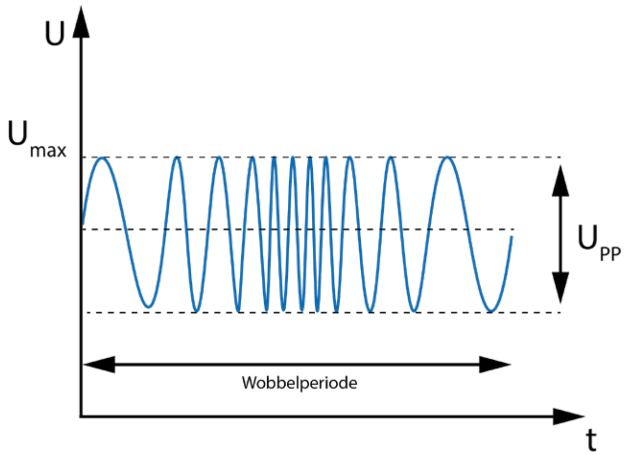
The following discusses the performance spectrum and the properties of measurement hardware for temperature and voltage acquisition in the high-voltage range.



imc CRONROS*flex* – a modular data acquisition system, measurement and control of test profiles

Test of automotive components for vehicle electrical systems conformity





USE CASE: **Testing components on the vehicle electrical systems, according to the standards for HV environments**

In order to guarantee smooth operation in the context of a complex system, electrical vehicle components must be tested conformity according to standards for such electrical systems. Certification measurements LV124, LV123, LV148 and so forth are carried out in HV-safe test machines. During the test, the components are exposed, among other things, to predefined profiles of the vehicle electrical system, including what is known as a “load dump” – the occurrence of a voltage peak. In order to be able to reliably measure the resulting voltages, the use of HV-suitable measuring modules is necessary.

Detail electrics of an electric drive

Measurement technology in HV environments

Optimize heat management with reliable temperature measurement

In addition to measuring the temperature and voltage on high-voltage batteries, temperature acquisition on electric vehicle drives is one of the new metrological tasks in the e-mobility environment. Various institutions - in Germany the ZVEI or the DGUV, and internationally the ILO (International Labour Organization) or ISSA (International Social Security Association) - define the high-voltage range in hybrid and fuel cell technology and in electric vehicles between voltages of >60 V and ≤1500 V Direct current (DC) or >30 V and ≤1000 V alternating current (AC).

In addition to the drive of an electric vehicle, there are a number of other temperature measuring points on components that need to be monitored and analysed. In a typical test vehicle, for example, there can be around 400 measuring points, which are typically located between the charging unit and the external charging infrastructure, and on the battery, between PTC elements that serve as interior heating and the e-air conditioning compressor. In addition to the battery systems already discussed and other energy storage systems such as fuel cells, testing is performed on supply circuits, drives, power electronics components, cable harnesses and connectors. This involves matters relating to durability and performance, efficiency, thermal management or overloading. For example, excessively high temperatures on the electric drive result in the winding isolation of the materials or the bearing lubrication becoming impaired, causing faster aging - thus reducing the robustness and lifetime of the motor.

The challenge of temperature measurement in a high-voltage environment is that, in addition to the question of metrological implementation, greater attention is paid to personal safety. The high voltages require measuring technology specially designed for this. Data acquisition systems for HV-environments ensure safe and reliable testing and - in accordance with occupational health and safety regulations - ensure the safety of the personnel deployed. There are two solution concepts that offer themselves for this purpose:

- Highly insulated data acquisition modules with classic electronic HV thermocouples.
- Data acquisition modules with fiber-optic sensors.

Temperature measurement in an HV environment with “classic” and fiber optic measurement technology - A comparison

Electrical highly isolated measurement technology

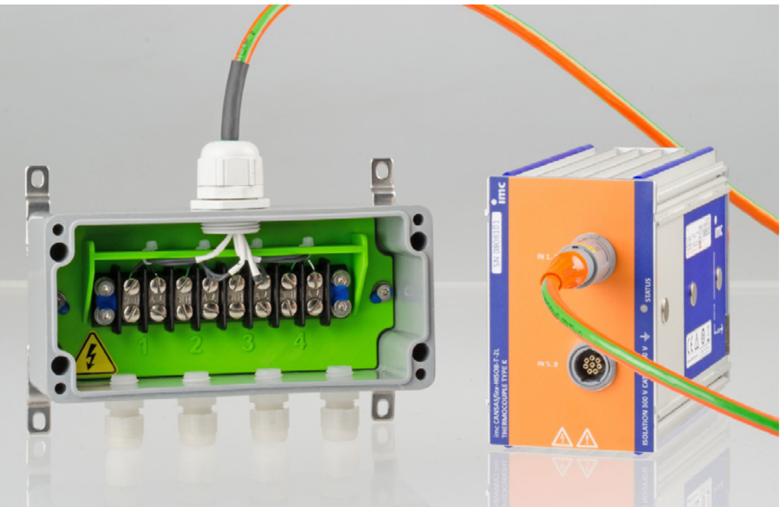
Classic HV measurement modules have highly galvanically isolating measurement electronics suited for sensors such as thermocouples, RTDs (PT100/1000) and NTCs, which are connected via specially isolated cables. The measurement hardware for high-voltage environments must comply with the device safety standard DIN EN 61010-1/2 and for applications in energy supply networks must be designed for the appropriate CAT class for the respective application environment. The connectors selected for the measuring inputs must also be suitable for high voltage.

Highly insulating 6-channel CAN measurement module for voltage, temperature (RTD) and resistance (NTC), in combination with other CAN measurement modules.

Temperature measurement with electrical HV measurement technology

Advantages

- In addition to temperature measurement, electrical HV measurement modules can sometimes also support other sensors and measurement modes, such as for acquiring current, voltage or vibrations, and thus have a broader range of functionality.
- Classic HV measurement technology can also adapt to existing sensor instrumentation that is possibly not even explicitly suited for high isolation. If existing conventional sensor installations are limited to areas without personnel access, it may be sufficient to transfer this part of the instrumentation to a fully standard-compliant, HV-specified connection and measurement technology, thus defining a safety transfer interface in the form of a clearly separated connection box.



The HV box forms a defined safety transfer interface towards a fully HV-compliant wiring and measurement equipment

Challenges and potential problems:

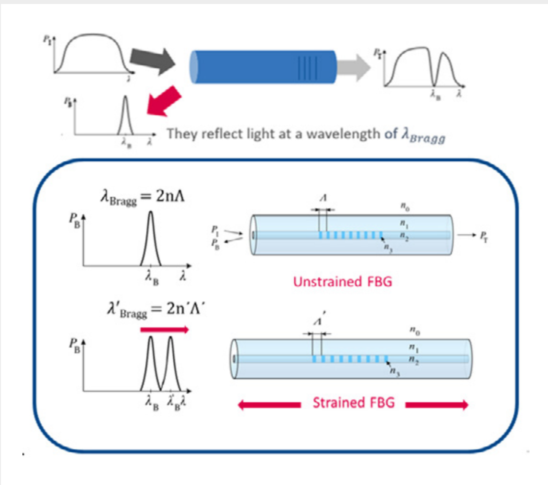
- Instrumentation and handling of the test vehicle may only be carried out by specially trained personnel (electricians).
- All elements of the measuring system must be designed to be safe for people (CAT specification)
- The thickness of the cable isolation and the dimensions of the sensors (e. g. PT100) can make assembly more difficult and even influence the properties of the test object, for example, if motor windings have to be moved.
- The metal content of cables and sensors can change the magnetic properties of the test object (magnetic fields in motor windings)
- The bulky isolation of the cables makes it difficult to route multi-channel applications through a vehicle.
- In the event of a defective sensor, a complete replacement of cable, sensor and connector must be considered, as these are one integrated and tested unit
- Loss of time in the test process due to unwieldy sensors.
- The signal quality of conventional sensors can be influenced by electromagnetic interference (EMC), electrostatic discharge (ESD) and high electrical potentials – and these will prevailsin the environ-ment of power electronics (converters).

Fiber optic measurement technology

Fiber-optic measurement technology with Fiber Bragg sensors is a measurement principle that is also suitable for an HV environment.

Fiber Bragg gratings (abbr. FBG) are optical interference filters in the core of a glass fiber. During measurement, “white” light from a broadband laser source fed into the fiber is selectively reflected at this interference grating. The narrow spectrum returned by the sensor with the characteristic Bragg wavelength represents the measurement quantity. This wavelength is proportional to the strain and temperature of the active region, as these determine the optical grating spacing.

In temperature sensors, the sensitive area may only react to the temperature self-expansion α (T) and the refraction behavior of quartz glass as a function f(T). The fiber is therefore embedded stress-free in order to avoid the influence of external expansion or mechanical stress. The fiber optic sensor consists of a glass capillary with a diameter of only 0.5 mm, which encases the fiber. There is also a variant with an additional ceramic and teflon coating, which is mechanically even more robust, thermally only slightly more sluggish and, having a diameter of 1.5 mm, is still sufficiently small. The Bragg wavelength of the acquired spectrum is evaluated in the evaluation unit, i.e. takes place in the measurement module, which is also referred to as an “interrogator” in FBG technology.



The Fiber Bragg principle

Fiber optic sensor

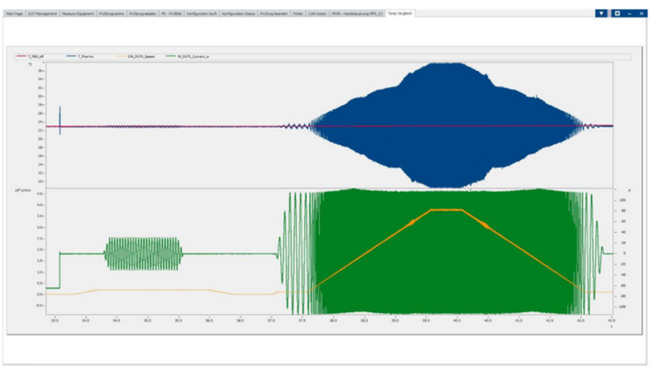
Fiber optic measurement module in a compact and portable design.

Advantages of temperature measurement with fiber optic measurement technology:

- The small diameter of the sensors enables easier handling and measurement at very narrow and demanding measuring points, e.g. in the winding of electric motors.
- Less time required for attaching the sensors.
- Extremely dynamic processes, such as those that occur during acceleration tests on electric motors, can be measured and optimized very easily for the first time: The compact design and correspondingly minimal thermal inertia allow the FBG sensor to respond quickly with time constants of 100 ms.
- Due to the purely optical measuring principle, the sensor is isolated by design and thus perfectly suited for high voltage and is completely immune to electromagnetic interference.

USE CASE: **Validation of temperature models for battery blocks with fiber optic sensors**

Studies show that measuring the temperature at the anode and cathode of a battery block and back-calculating it, using the geometric model, is not considered sufficient for thermal protection of the blocks. Depending on the material, the current state of charge, the thermal environment and the geometry of the battery block, in practice there are temperature differences of up to 25 °C between the real temperatures and the model results. In the test, a verification measurement was carried out with 64 FBG sensors in an intermediate foil between two battery blocks. FBG sensors were previously calibrated with the test item.



Comparison of the temperature of a fiber optic sensor (red) vs. thermocouple (blue), as a function of current (green) and speed (yellow).

Occupational health and safety when measuring in HV environments

A central aspect and advantage of fiber-optic FBG measurement technology is immediately evident:

If the entire technology does not involve any metallic conductors, but instead works purely optically - i. e. the user cannot have any contact with HV - then many complex and expensive aspects of personal protection, special training and safety-related measures are fundamentally mitigated and completely avoided already “at the source”.

Working on the vehicle electrics - in e-vehicles with HV batteries, high safety requirements and special staff training are necessary.

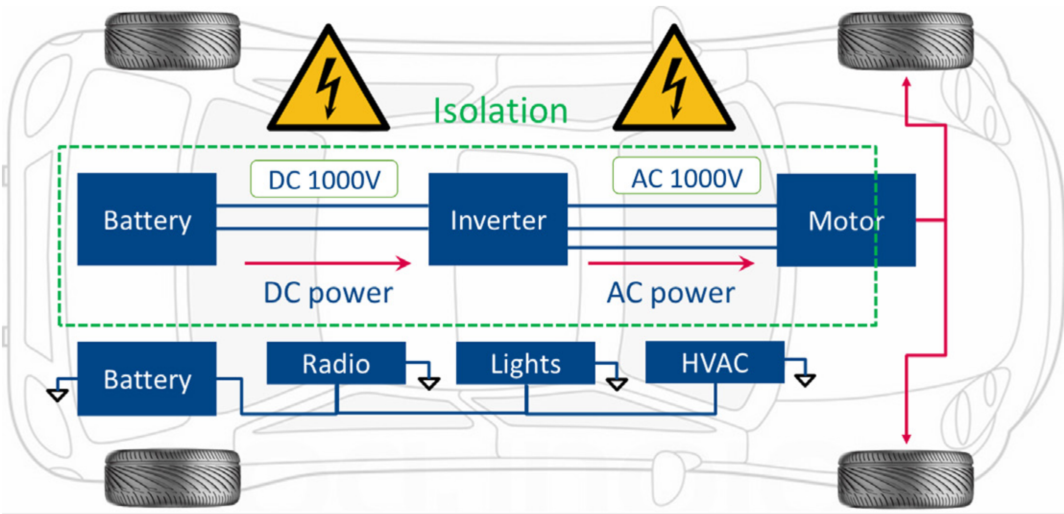
02

Measuring the power of an electric vehicle

In the constant optimization, further development and design of the electric drive and vehicle components, the focus is on power and improving energy efficiency. Furthermore, temperature management plays a role, which is ultimately relevant to safety. In order to achieve high power density, a motor must have a high torque density and must always be kept at a temperature within safety limits using cooling systems and suitable materials. Optimizing the efficiency of the drive machine also involves interaction with converter technology. For the operation of the ancillary units such as air conditioning and heating in e-vehicles, the power of their own actuators - which are independent of the drive motor - is of relevance.

Other aspects of power measurement relate to the interaction between battery life, efficient charging and the possibility of recuperation. The latter provides additional source of energy, improves efficiency and has influence on the design of brake systems. Compared to classic combustion engines, e-vehicles therefore result in fundamentally different brake system designs that need to be systematically analyzed and tested. Finally, in addition to analyzing the electric drive, another metrological task is to measure the mechanical power of individual components in order to be able to evaluate and optimize efficiency in a manner that is well-founded.

For systematic development and testing, it is important to simulate these different situations in order to determine optimal power and lifetime of the vehicle battery and components.



Electric drive and vehicle electrical system

Efficiency and power measurement

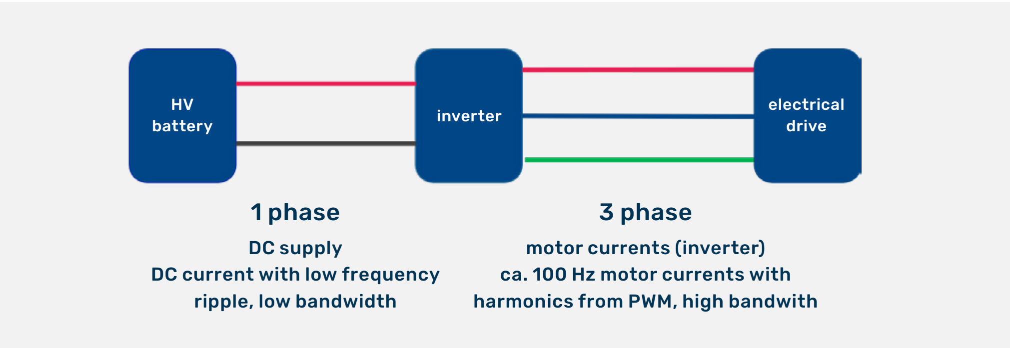
When evaluating technical systems, the distribution of energy at any instant is of crucial importance. If one relates the energy to a unit of time, one obtains, by definition, power as a characteristic quantity of the system state. In the following section, based on physical principles, we will show how power in electrical systems can be measured. In order to determine the efficiency, for example, of an electric motor, mechanical power must also be recorded.

$$\eta = \frac{P_{mech}}{P_{el}}$$

Efficiency factor: mechanical output power delivered P_{mech} and effective electrical power consumed P_{el}

The efficiency of an electric motor is one of the decisive quantities when optimizing the yielded range of an electric vehicle to be delivered by a given battery systems capacity. The efficiency factor results from the ratio of the mechanical output power to the effective electrical input power.

One of the typical measurement tasks in the development of electric vehicles is to determine the power of the electric drive train -- i. e. the battery, converter and electric motor. Among other things, it is about how the effective power can be measured in a three-phase system between the converter and the electric motor, which measurement hardware is used, and what we should pay attention to with regard to the measurement setup, the sampling rate and data evaluation.



Points of power measurement on the electric drive

On the one hand, the figure shows the DC supply of the battery system as a single-phase DC link with superimposed ripple and, on the other hand, the three-phase system between converter and motor with motor currents determined by the rpm speed and with harmonics resulting from the PWM (abbr. pulse width modulation)

The calculation of electrical power

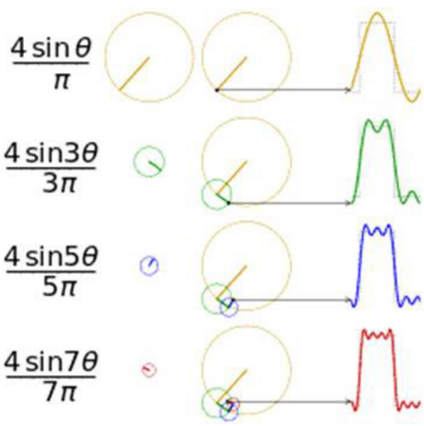
Instant power Note: In the case that both voltage and current consist in stationary periodic quantities of a common frequency, the power is also periodic. So the mean value of this momentary power over a period represents the power that is taken from a source on average over time.	$p\,(t) = u\,(t)\,i\,(t)$
Effective power frequency f= $2\pi\omega$ period $T = \frac{1}{f}$ Phase shift between current and voltage φ	$\overline{P(t)} = \frac{1}{T}\int_{(N-1)T}^{NT} u(t)i(t)\,dt$ $\overline{P(t)} = \frac{1}{T}\int_{(N-1)T}^{NT} \hat{u}\sin(\omega t)\,\hat{\imath}\sin(\omega t+\varphi)\,dt$ $= \frac{\hat{u}}{\sqrt{2}}\frac{\hat{\imath}}{\sqrt{2}}\cos\varphi = U_{RMS}\cdot I_{RMS}\cos\varphi$
Apparent power	$S = U_{RMS}\cdot I_{RMS}$
Reactive power	$Q = \sqrt{(S)^2-(P)^2}$

Effective power can be converted into other forms of power (mechanical, thermal, etc.). Reactive power imposes additional stress upon the circuit and apparent power is the geometric/vector sum of the two.

Normally, current and voltage contain higher frequency harmonics: In the case of non-sinusoidal periodic quantities of current and voltage, it is helpful to represent periodic signals according to Fourier. This can be used to show which frequencies in current and voltage contribute to the effective power and thus determine the required bandwidth or sampling rate of the measuring system.

Fourier series

According to Fourier, any periodic signal can be composed of the sum of sine and cosine signals. For the square-wave signal shown in the figure it can be clearly seen that with an increasing number of harmonics taken into account (odd multiples of the fundamental) it increasingly shows the form of a rectangle.



Fourier series

Non-sinusoidal quantities, as mostly occurring in electrical networks, can be represented as an infinite sum of sinusoidal signals (fundamental wave and harmonics).

$$u = \sum_{k=1}^{\infty} U_k \cdot \sqrt{2} \cdot \cos(k\omega t + \phi_{uk}) \qquad i = \sum_{l=1}^{\infty} I_l \cdot \sqrt{2} \cdot \cos(l\omega t + \phi_{il})$$

Non-sinusoidal quantities of current and voltage as a Fourier series

$$\int_{-\pi}^{\pi} \cos(nx) \cdot \cos(kx)\, dx = 0 \text{ für } n \neq k \text{ und } \pi \text{ für } n = k$$

Orthogonality theorem

The orthogonality theorem states that an integral over a period is zero when harmonic sine wave components of unequal frequencies are multiplied. Only frequencies that occur in both current and voltage contribute to the effective power. These are non-zero when multiplied over a period.

For instantaneous power, this results in three summands, of which only the first is not equal to zero over a period, and only this summand is effective power.

$$p(t) = \sum_{l=k=1}^{\infty} U_k I_l \cdot \cos(\phi_{uk} - \phi_{il}) + \sum_{k=1}^{\infty} \sum_{l=1}^{\infty} U_k I_l \cdot \cos[(k+l)\omega t + \phi_{uk} + \phi_{il}]$$
$$+ \underbrace{\sum_{k=1}^{\infty} \sum_{l=1}^{\infty}}_{k \neq l} U_k I_l \cdot \cos[(k-l)\omega t + \phi_{uk} - \phi_{il}]$$

Instantaneous power

$$\overline{P(t)} = \frac{1}{T} \int_{(N-1)T}^{NT} p(t)\, dt \qquad = \sum_{k=1}^{\infty} U_k I_k \cdot \cos(\phi_{uk} - \phi_{ik})$$

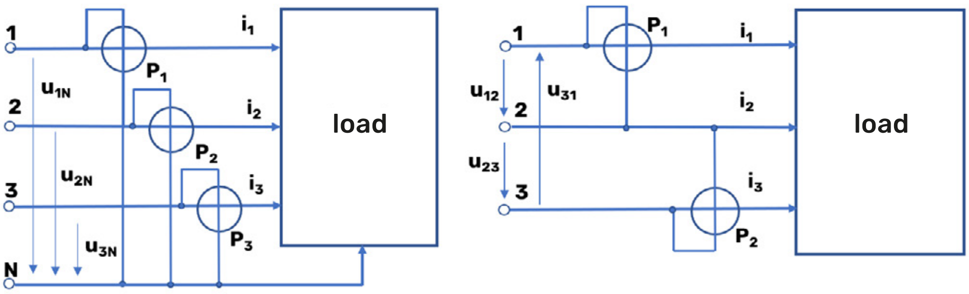
Effective power

Calculating effective power in a three-phase system

When transferring to a three-phase system, the following calculations result. The effective power can be calculated or measured in two ways.

Power calculation in the multiphase system

In the 3-phase system, depending on whether the neutral conductor carries current, the 3 wattmeter or the two-wattmeter method (ARON circuit)



Three-wattmeter or two-wattmeter method (ARON circuit) in a three-phase system

Firstly, the three-wattmeter-method:

$$P_\Sigma(t) = u_{1N}i_1 + u_{2N}i_2 + +u_{3N}i_3$$

Here, the three star voltages are multiplied by their currents.

u_{1N}; u_{2N}; u_{3N} Voltages between phase conductor and star point (neutral point)

Secondly, the two-wattmeter-method (Aaron):

$$P_\Sigma(t) = -u_{31}i_1 + u_{23}i_2$$

Here, two phase conductor voltages are multiplied by two currents.

u_{23}; $-u_{31}$ Voltages between two phase conductors

Or generally

Effective power: $P_\Sigma(t) = \sum_{\mu=1}^{n-1} u_{\mu n} i_\mu$

The fundamental wave of the voltage signals at the motor is determined by the speed in conjunction with the number of pole pairs and is in the order of ≤ 2 kHz for a traction motor.

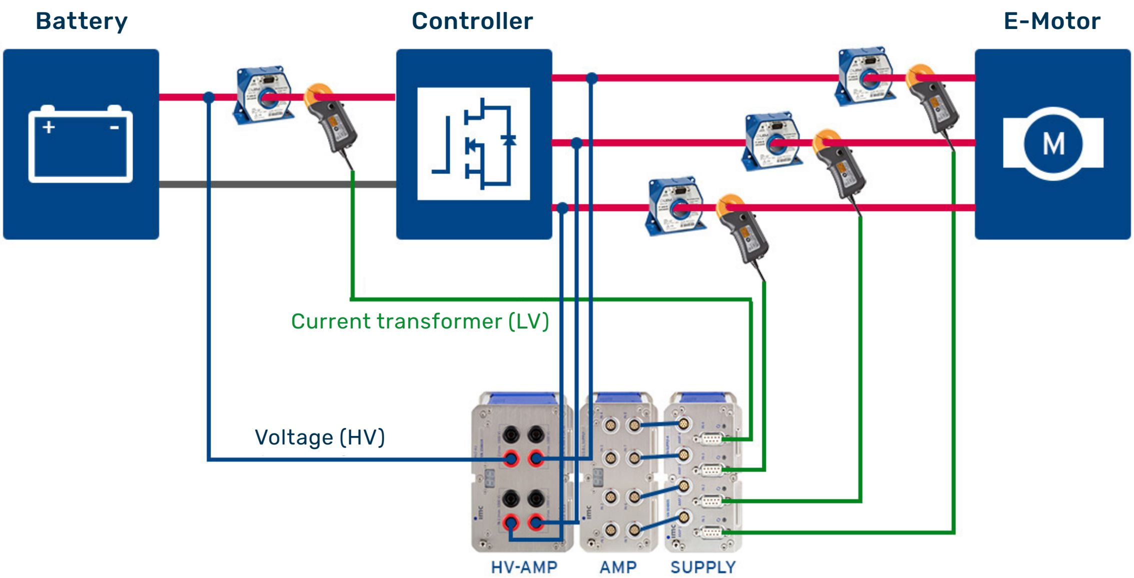
The sinus waves that are effectively aimed for, are actually implemented by switched pulses, whereby the bandwidth of the voltage is significantly higher due to the high-frequency harmonics of this PWM. The fundamental wave of the PWM pulse is typically above 10 kHz and the harmonic content can extend into very high-frequency ranges due to the steep square wave slopes. The bandwidth of the current, on the other hand, is significantly smaller because the current is smoothed by motor inductance. The lower of the two bandwidths of current or voltage is decisive for acquiring instant power. The dynamics of the current are relevant here and thus determine the necessary bandwidth and sampling rate for power measurement.

The situation is reversed for single-phase power measurement on the intermediate circuit between the battery and the converter. Here the battery acts like a large capacitor. The voltage here is the quantity with the low harmonic content and the current has a higher harmonic content. Recuperation, DC-DC converters and power converters from various ancillary units will typically contribute to the harmonic content of the current.

The correct selection of the sampling rate or bandwidth which is required for the acquisition of electrical power cannot be stated in general, but always depends on the individual application. However, one should always be aware that between the involved measurement quantities of current and voltage, the one with the lower bandwidth determines the necessary bandwidth of the effective power.

Measurement hardware for determining the performance of the electric drive train

The following measurement components are used in our model structure for the measurement task described earlier: You can see fluxgate ring converters for current measurement and a multi-channel measurement system, such as an imc CRONOS*flex* with HV2-2U2I measurement modules for direct acquisition of voltages up to 1000Vrms AC and measurement of current transducer signals. Each module has two high-voltage and two low-voltage inputs. The fluxgate transducers also need a supply, which in our case is provided by the imc CRONOS*flex* SEN-SUPPLY-4.



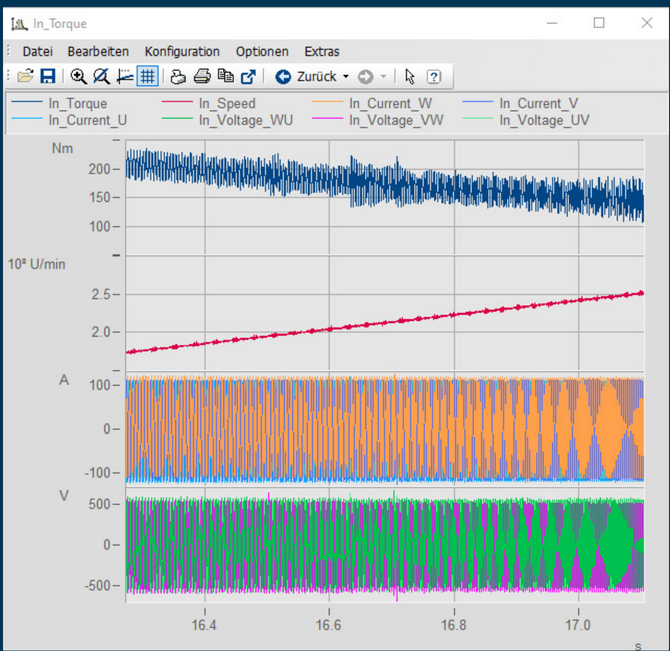
Measurement hardware for power measurement on the electric drive

Measurement data evaluation:

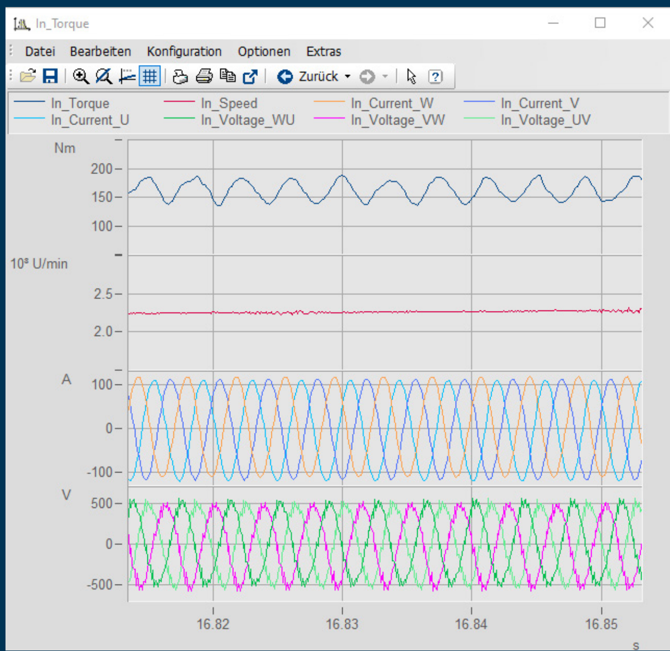
From raw data to efficiency factor of the electric motor

With the comprehensive functions of powerful data analysis software such as imc FAMOS, it is possible to further process the acquired measurement data and calculate the efficiency.

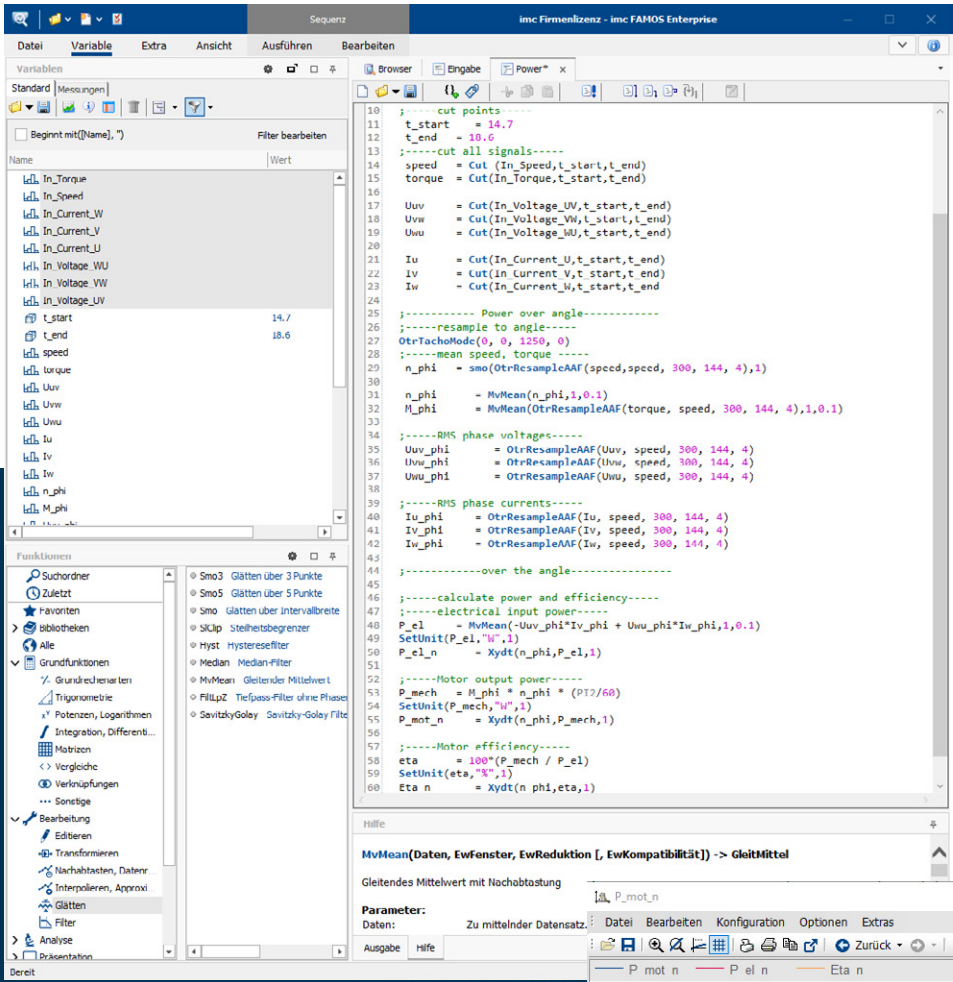
When calculating the efficiency, the speed signal is converted into rotational angle, after which all data sets are transformed from time domain to angle domain. The electrical power is averaged with a window width of one mechanical revolution. This corresponds to the integral over a period for motors with one pole pair, i.e. the electrical and mechanical revolutions are identical.



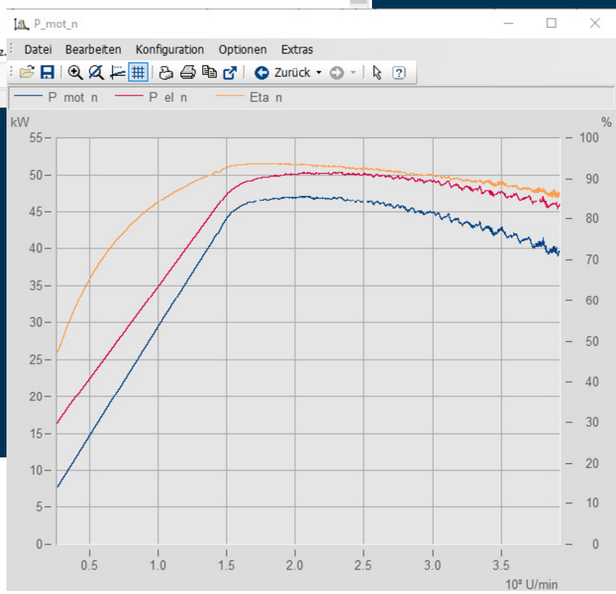
Curve window with the acquired raw data for torque, speed, current and voltage. In our model test, the 3-phase permanently excited synchronous motor is loaded with a load machine that accelerates from 0 to 4000 RPM.



Curve window with details, covering a period of 40 ms. Clearly visible are the three phase currents and voltages and their ripple. Due to the PWM scheme, voltage has significantly higher harmonic content than the current. The voltage curve, which actually consists of PWM pulse patterns with constant square-wave amplitudes, can already be seen here as a resulting sinusoidal curve through analog filtering. The current, on the other hand, is actually physically present as a low-distortion sine wave curve due to the smoothing magnetic properties of the motor. Its frequency is essentially determined by the rotational speed.



Evaluation of the power data of the data analysis software imc FAMOS



The calculated electrical and mechanical power and the efficiency are plotted against speed.

Metrological requirements for testing electric motors

Electric motors play an important role in drive design for electric, hybrid and light hybrid vehicles, as well as in safety systems and vehicle comfort components. A distinction is made here between electrically commutated motors (EC), permanent or separately excited motors (PSM or FSM), or asynchronous motors (ASM). The selected motor should be optimally utilized, especially in terms of the highest possible efficiency at the required torque curve. In development and production, there are a number of metrological challenges to be mastered. Furthermore, by precisely determining the relationship between the magnetic flux and the current, the power electronics (ECU) is optimized.

Windings of an electric motor

USE CASE: **Test stand for the entire electric drive train**

This universal traction motor test stand was realized for a research institute. The test stand for testing the entire electric powertrain, including lithium-ion batteries, has two load machines with a maximum motor torque of 500 Nm (continuous) and 600 Nm (intermittent). The maximum drive speed is 8000 rpm (gearless). The battery simulator for supplying the power converter under test has an output of 120 kW with a current of max. ±600 ADC and a voltage of up to 1,000 VDC. There are also interfaces for vehicle buses CAN, CANopen and FLEXRay, real-time data acquisition for HiL control simulation, control of the drive and the energy supply. The battery test takes place in a separate fire protection container that is equipped for testing high-voltage batteries according to EUCAR Hazard Level 7. Temperature conditioning is performed in the range from -40 °C to +140 °C in order to simulate defined load and aging conditions.

imc Test & Measurement, Berlin

imc Test & Measurement – Model-based test methods as the founding idea

In 1988, imc Test & Measurement GmbH was founded based on research into model-based test methods at the Technical University (TU) Berlin. As a manufacturer and solution provider of productive measurement and testing systems, imc Test & Measurement has since then been implementing measurement technology solutions for users in vehicle technology, mechanical engineering, railways, aviation and energy.

IFAM test stand for electric motors and batteries

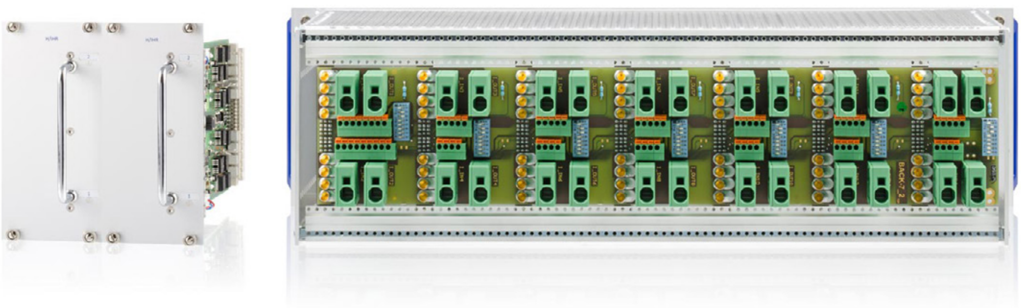
Wide-range current measurement for energy management

In order to increase the range of electric vehicles, not only the main traction power train and the units in the high-voltage circuit are the only relevant factors. The dramatically increased number of “secondary” components and control units in the 12V or 48V vehicle power systems (as in conventional combustion vehicles) now also makes a significant contribution to energy consumption.

Therefore, the interaction of these systems is also important, and especially the implementation, testing and optimization of energy saving and sleep modes. This requires precise knowledge of the energy consumption profiles of the involved device, in particular ECUs (abbr. Electronic Control Units). Complex interactions and sophisticated standby strategies are involved in modern vehicles, and in electric vehicles in particular, in order to minimize the quiescent currents and thus the overall energy consumption.

Such measurement tasks become challenging when, in addition to the quiescent current in the range of a few nanoamperes, power-up startup surge and full load phases with currents rising up to 50 A must also be measured which might follow up within a few milliseconds.

This is why complex interactions and sequences must be recorded in complete, uninterrupted measurements. It is therefore important to carry out a comprehensive energy assessment of the vehicle electrical system during the development of a vehicle in order to optimize its range. Quiescent and operating currents must be measured and analyzed in extremely wide measuring ranges, and the energy profiles in shut down procedures must be acquired. Such extreme range dynamics represent a serious technical challenge, especially in current measurement, if this is to be done with automatic range adjustment (“auto-ranging”) during an uninterrupted, ongoing measurement.



imc CANSAS IHR modules

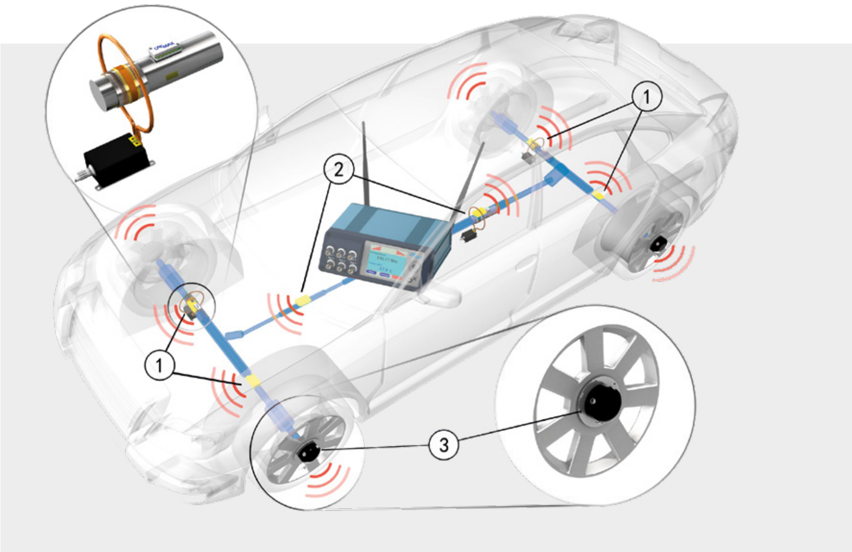
CAN-based wide-range current measurement module from imc

With a high-precision, uninterrupted measurement of current profiles from 50 nA to 50 A, it is possible, for example, to seamlessly record and analyze transitions between idle (“sleep mode”) and operating states in automotive components, control units and subsystems in one continuous measurement.

Wireless mechanical power measurement

The efficiency of an electric motor, which determines the range of an electric vehicle, is calculated from the electrical power supplied and the mechanical power output.

In order to record the mechanical power on the test stand or in road tests, it is necessary to measure the speed and the corresponding torque applied and acting on a shaft. However, it is often not feasible, especially with mobile measurements and in the context of a complete vehicle, to use conventional, stationary torque measuring shafts or corresponding speed sensors. This is because access and installation options are not available for flanging or “looping” such stator-based sensor systems into the drive train.



Measuring points for mechanical power measurement

With an innovative system for non-contact power measurement on vehicles - one that does not require an additional mechanical connection for detecting the angle of rotation - these parameters can be acquired and processed very precisely in real time and without changing the test object.

The imc Dx telemetry consists of a sensor and transmitter unit (Dx-SCT) that is mounted directly on the vehicle axle using a half-shell housing. It acquires the torque (via DMS) and the speed via an integrated MEMS-based sensor. The measured data is telemetrically transmitted to a receiver unit (RCI) inside the vehicle.

This universal transmitter module can be used flexibly and enables wireless measurements with different numbers of channels and sensor assignments. The possibility of operating up to four transmitters synchronously with one receiver allows all four output shafts on a vehicle to be recorded simultaneously - and this without an additional stator or reference point.

Power P = 2ϖ • n • M
with RPM n and torque M

03

Driving dynamics tests on e-vehicles

New driving dynamics and braking behavior – increased demands on test systems

The extreme acceleration capability of the electric drive gives electric cars a more dynamic driving performance. Furthermore, the use of battery storage changes the vehicle mass and its distribution, resulting in a lower vehicle center of gravity and thus greater lateral dynamics with increased forces on the wheels. Furthermore, it is possible to highly dynamically control torque and speed on each wheel, individually. The braking behavior also changes due to the recuperation of braking energy. Furthermore, concepts for autonomous driving place further demands on the chassis, the drive train and the brakes of an electric car. The development process therefore also includes the evaluation of these new and in some cases increased mechanical loads.

The new driving characteristics of electric vehicles also raise new questions in the investigation of vehicle dynamics

Measuring wheels for highly dynamic electric vehicles

The higher mechanical loads that occur on e-vehicles compared to conventional vehicles are usually due to batteries being much heavier and the lower center of gravity.

In addition to a higher vertical wheel force, the lateral forces that occur on the wheels during driving manoeuvres are greater, resulting in higher lateral dynamics. This leads to significantly higher loads, especially in the case of larger diameter tires with optimized rolling resistance.

On top of simulation, comprehensive test driving is necessary in order to determine the forces acting on a vehicle. Measuring wheels are used that deliver reliable results even under harsh environmental conditions. Whether it be handling tests with full braking at high thermal loads or test driving at low temperature, in snow, rain and ice -- a measuring wheel records highly dynamic measurement data during the drive, including all forces and torques, with a very high level of accuracy. The subjective driving experience, the famous “seat-of-the-pants feel” of a test driver, can be objectively backed up with precise measurement data. It is important that the measurement wheel records both very low and very high mechanical loads with high precision.

Measuring wheels specially designed for electric vehicles record the fast changes in control interventions on the wheels dynamically and in high temporal resolution.

Protection against EMC interference during data acquisition and transmission

Furthermore, special attention is paid to optimal shielding of the measurement wheel against electromagnetic interference. For tests with traction motors in the prototype stage, it is therefore necessary to have a robust measuring wheel design with high electromagnetic compatibility. Both the signal quality and the digital data transmission from the measuring wheel to the receiving device must not interfered by the influence of strong electromagnetic fields.

Fine tuning the drive architecture: mastering control loops

With modern drive architectures, the wheels are often no longer directly mechanically connected in the vehicle. As a result, the control loops are only coupled via the roadway and it becomes necessary to coordinate the interaction of the wheels with one another.

The investigation of this interaction during very fast control interventions is essential for the safety of both the driver and vehicle. This is because an electric motor reacts much more directly than a combustion engine and the time between the triggering of the control intervention and the change of the values is therefore very short.

Measuring wheels must provide synchronous data acquisition from all wheels with a very high temporal resolution. Measurement solutions specially designed for e-vehicles are available. These consist of four measuring wheels and a data acquisition system that synchronously captures data in high resolution.

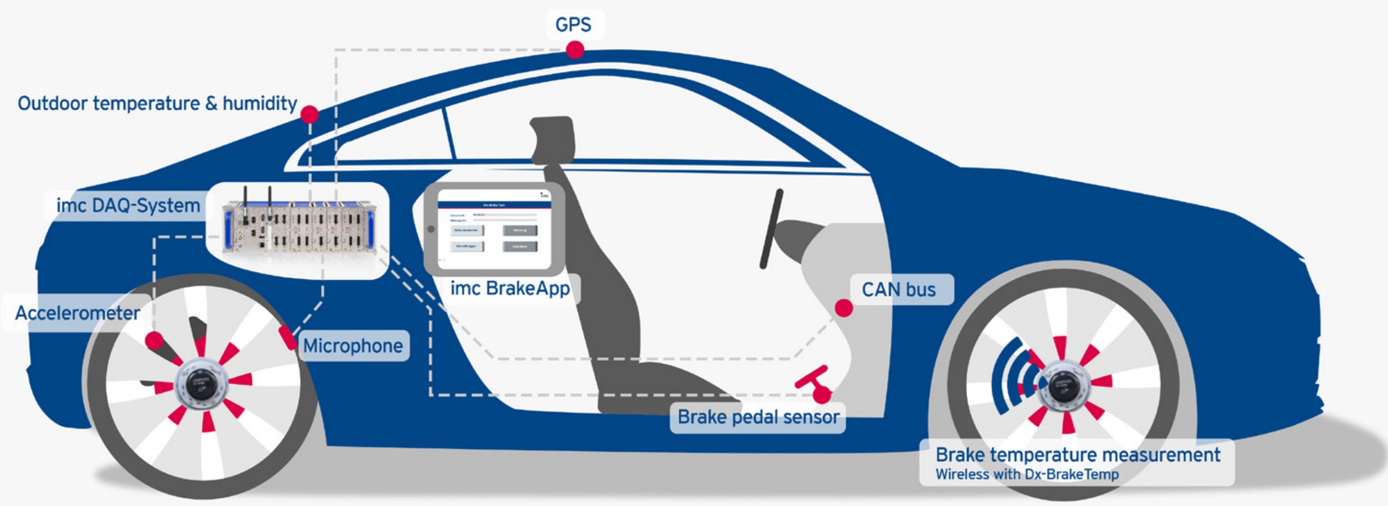
The use of measuring wheels provides information about wheel contact and lateral forces on the e-car

WFT measuring wheel and imc CRONOS*flex* data acquisition system

Wheel brake development for electric vehicles

Recuperation in electric vehicle means that a large part of the braking energy is fed back into the drive battery via the electric motor. During normal operation of an e-vehicle, wheel brakes are therefore only used for comparatively strong manoeuvres or as a redundant safety system. Brake systems adapted to electric vehicles therefore have novel properties that demand extensive testing. In this regard, the task at hand includes coordinating all systems that affect braking.

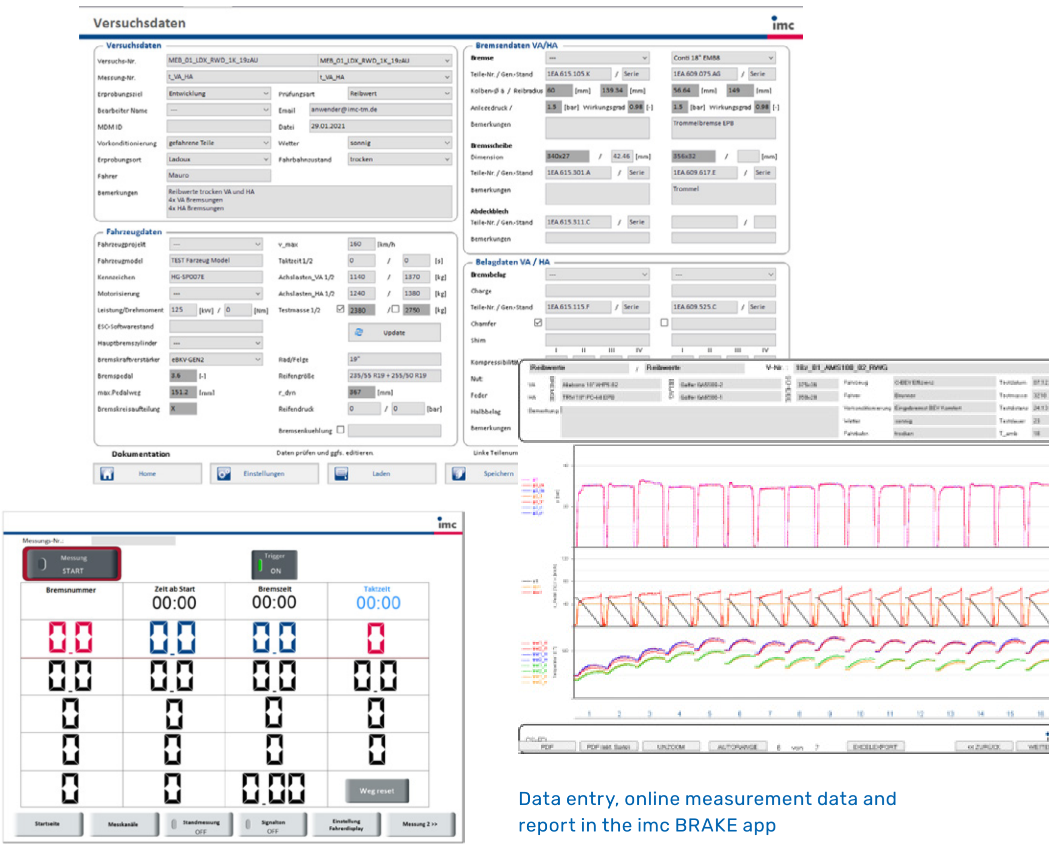
A wide variety of parameters must be acquired in brake tests, including brake pressure, brake disc temperature, vibration in the brake calliper and brake noise. Measurement technology must be flexible and capable of being adapted to the respective measurement quantities.



Schematic structure of the brake test system imc BRAKE app

With a data acquisition system that includes sensors and wheel telemetry, all relevant parameters can be acquired and processed, including braking distance, braking force, pedal travel, temperature sensor readings, interior and external noise (microphones) and vibration. International standards such as ECE, ISO, FMSSV and SAE act as the guidelines for testing procedures. These are also the basis of test procedures used by automobile manufacturers. Typical vehicle brake tests are performance tests such as emergency braking with cold and hot brake discs, comfort tests in the event of sudden temperature changes on the brake disc due to, for example, standing water, and thermal tests such as cooling tests and downhill driving tests. Furthermore, tests cover different road surface, stationary tests for pedal travel measurement and the incorporation of noise and vibration aspects (NVH analyses).

Brake test measurement



Data entry, online measurement data and report in the imc BRAKE app

Imprint

imc Test & Measurement GmbH
Voltastraße 5
13355 Berlin

phone: +49 (0)30 467090-0
e-mail: marketing@imc-tm.de
www.imc-tm.de

version 1.0 – June 2022