Measuring Shield Current of High-Voltage Cables in Electric Vehicles

HV Current and Voltage Measurement

Electric vehicles have a complex high-voltage (HV) electrical system including highly specialized power cables. For both safety and mitigation of electromagnetic interference, these cables have a braided shield between the inner and outer insulators. The large number of components with fast switching power circuits causes high current and voltage ripples in the entire high-voltage vehicle electrical system. This induces large currents in the cable shields. These effects increase with the length of the cable and the size of the inner conductor. In electric vehicles that have a high current draw, such as high-performance sports cars or heavy commercial vehicles, it is important to measure these effects in order to determine if the shield currents exceed the current capacity of the shield braids.

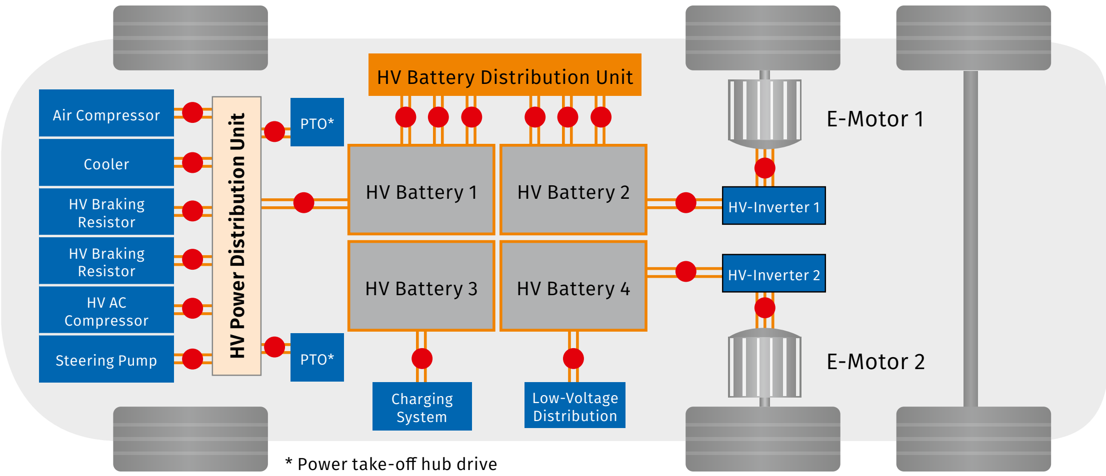

Fig. 1: Shield current measurement on an electric truck. The length of the cables causes different shield currents in the different areas of the high-voltage electrical system. At the measuring points marked in red, the shield current is measured in the individual HV power cables with CSM HV Breakout Modules.

Background

The high-voltage cables used in high-voltage vehicle electrical systems have, in addition to the HV inner conductor, a braided shield separated by insulation to avoid interference and radiation effects. An electric vehicle may have several batteries to power multiple electric motors that drive the axles and other components, plus pumps, brake resistors and cooling systems; all these systems must work in parallel. Since high voltages are switched in the high-voltage on-board power supply system during driving, high power and large currents are generated in the inner conductor. The current ripple in the inner conductor causes currents on the braided shield through inductive coupling. It is likely that these combined effects may exceed the shield's capacity. This may cause overheating, melting the cable insulator, and damaging the cable. Another side effect of sustained high shield currents is the premature aging of cable glands and the associated components in the harness connector.

Replacing parts damaged by excessive shield currents in the cables of a production vehicle is expensive and time consuming. Recalls of vehicles are even more expensive, and the news of a vehicle fire with this as the source can be most damaging to a brand's goodwill. Therefore, shield currents should be measured in all circuits of electric vehicles during their development. Every circuit must be measured simultaneously so that the mutual influence of adjacent components can be monitored under every load condition.

Challenge

Until now, measuring shield current has been complex and difficult to accomplish. Traditional instrumentation was not optimized for in-vehicle packaging or the working environment. Furthermore, obtaining accurate shield current measurementssynchronized with working current in a single cable was challenging; attempting to measure shield currents simultaneously in all circuits throughout the vehicle was even more cumbersome and time consuming.

As is typical with the successful introduction of innovations, users will identify applications for the technology beyond the scope of the original design. Such is the case with the CSM High-Voltage Breakout Module. This module was originally intended to simultaneously measure voltage and current of the inner conducter of high voltage cables for eMobility, but one customer identified the ability to measure shield current with only minor modifications to the original HV BM design. This usecase introduces HV BM 1.2+S for a simplified and synchronized measurement of shield currents on high-voltage cables throughout an electric vehicle.

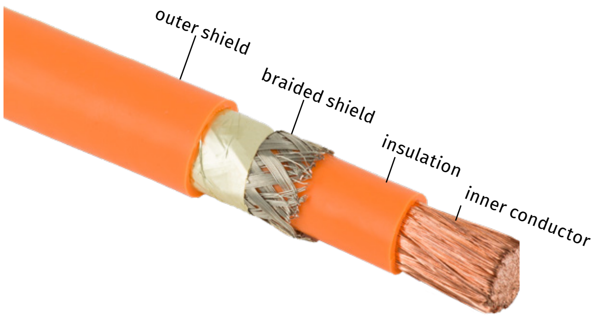

Fig. 2: Construction of high-voltage cables. The braided shield is separated by an insulation from the inner conductor. The shield consists of parallel, interlaced strands and a film screen. AC components in the inner conductor induce currents in the shielding braid.

The CSM Measurement Solution

The solution is the Vector CSM E-Mobility Measurement System.

Shield currents are measured via an additional internal shunt in the **HV BM**. In order to achieve accurate measurement of the shield current, a well-constructed, low impedance connection of the shield braid to the measuring shunt is required. For this purpose, the braided shielding is separated above the insulated inner conductor and connected to the shunt.

The inner conductor of the cable is applied to a separate measuring shunt to simultaneously measure the inner conductor current.

In addition to the shield currents, the inner conductor current and the voltage in the HV cable can also be measured synchronously with the **HV Breakout Module 1.2+S**. The sampling rate must be at 1 MHz to detect all the high-frequency shield current peaks.

Fig. 1 shows a dynamometer measurement setup for shield currents in the HV cable network of an electric commercial truck being developed by a major OEM. Every auxiliary unit is powered by several HV batteries, and switched on simultaneously during operation. Multiple HV Breakout Modules 1.2+S are securely installed on the vehicle frame at all the necessary points in the on-board high-voltage electrical system, as indicated by red dots. The shield current measurements are performed synchronously in all circuits during a specified dynamometer driving cycle to obtain an accurate picture of the maximum shield currents.

Due to the simultaneous shield current measurement in all relevant high voltage lines, the verification on the vehicle dynamometer need only be performed once.

For the measurement of shield currents on high-voltage cables, CSM specially developed the HV Breakout Module types HV BM 1.2+S (current, voltage, power and shield current). Like all our HV BM products, they are designed for safe measurement applications in high-voltage cables for rough, mobile use. Using proprietary isolation barriers, measurement technicians and downstream equipment are protected from high-voltage short circuits. The HV BM housing is IP67 rated, protecting the cable connections, shunts, and measurement electronics inside the unit. The HV BM modules are highly configurable with various cable gland sizing options, and shunt amperages ranging from 50-800 A (1400 A peak).

The HV BM transmits the measured data (U, I, calculated P) to the analysis converter at a data rate of up to 1 MHz (and synchronized within 1 µs) per channel via an EtherCAT® interface. Currents and voltages are sampled with high precision and synchronicity. Lower transmis¬sion rates can also be output via the CAN bus interface.

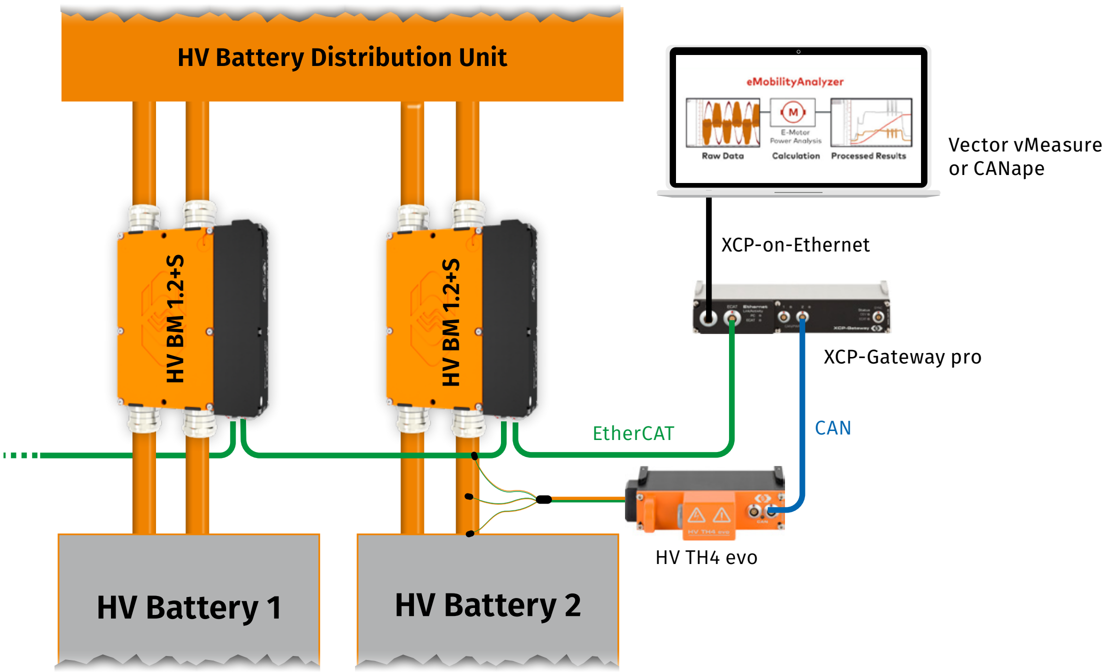

Fig. 3: Schematic test setup with HV breakout modules for shield current measurement. The temperature of cables and glands are measured with a thermal measuring module HV TH4 evo.

Fig. 3 shows a subset of the entire measurement system where the shield current data and temperature data are transmitted to the analysis software via CSM XCP-Gateway. For applications requiring high sampling rates, such as shield current measurement, CSM HV BMs are networked via EtherCAT®.

Other measurements that do not require high sampling rates, such as thermal data, are taken with CSM's CAN-based HV miniModules.

The high-speed data via EtherCAT® and the lowspeed data via CAN are both channelled through the XCP-Gateway. This gateway is a converter from EtherCAT® protocol to the popular XCP-on-Ethernet protocol for use in data analysis software. In this example the software used is vMeasure or CANape from Vector, allowing for real time analysis with the eMobilityAnalyzer function library while the data is recorded on the analysis computer. The user can define certain events, such as current peaks, to trigger the recording of data.

The Vector CSM E-Mobility Measurement System can detect up to 40 measuring channels. Each channel can have up to 1 MHz per second sampling rate and can be synchronized to within 1 µs.

The measuring system can be extended with a Vector interface if the vehicle is to be calibrated via the serial POD (Plug on Device) interface with the analysis computer. The advantage here is that variables from the electronic control unit (ECU) are recorded simultaneously with the measured values of the CSM modules.

In conclusion, CSM's measurement modules for High-voltage applications provide the speed, accuracy, and performance required for optimizing electrified vehicles. Being rugged and durable, they are ideal for on-vehicle use and well suited for test bench applications.

With the measurement software vMeasure, the numerous 1 MS/s signals are acquired, visualized and analyzed in real-time. The **eMobilityAnalyzer** library developed for vMeasure and CANape calculates the effective current; apparent, active, and reactive power; as well as indirectly the heat generation in the shield from the recorded currents and voltages in real time.

Fig. 4: Current on the inner conductor (orange) and on the shield (blue) as well as calculated signals of the eMobilityAnalyzer

From the measurement in Figure 4 it can be deduced that the inner conductor current is opposed by a large shield current of up to 75 A. vMeasure calculates the DC portion of the shield current with the eMobilityAnalyzer, but also the RMS value and the minima and maxima of the shield current. It is shown that although the average shield current is 0 A, regular peak-to-peak values of up to 140 A are measured. The effective current is calculated at 32 A.

The resistive losses in the shield, and thus the heat generation, are proportional to the square of the calculated effective current (P ~ I_{rms}^2). The decisive factor here is the resistance coating of the shield, which usually has a small wire cross-section and a correspondingly high resistance coating. This can lead to a significant heating of the shield and thus of the cable.

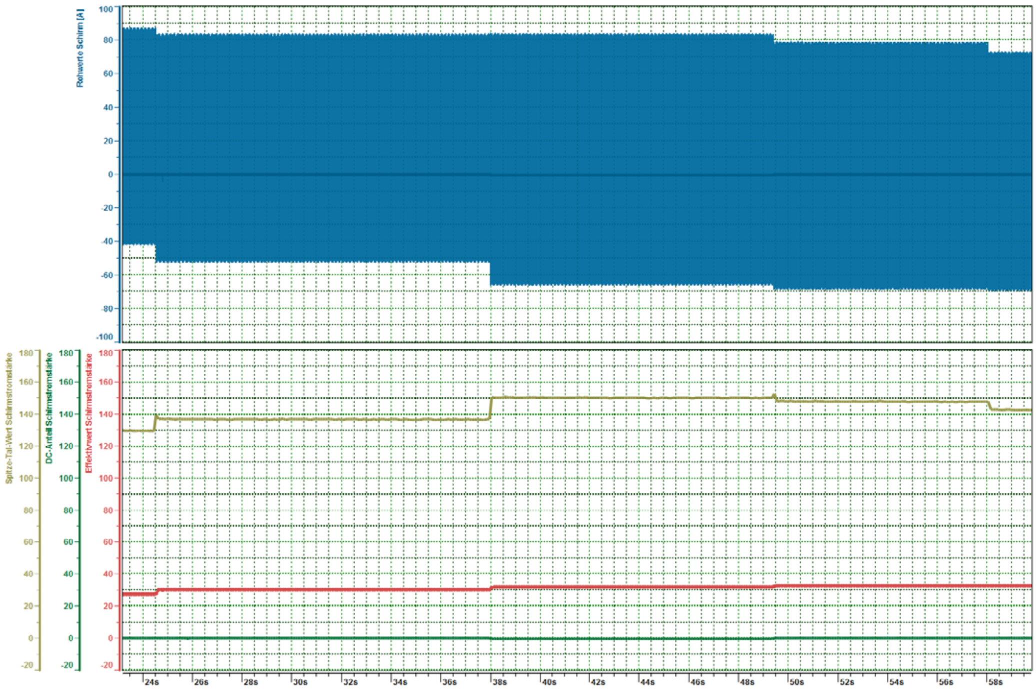

Fig. 5: The same measurement as in Figure 4, here the view over several seconds

Figure 5 shows the course of the measured shield current as well as the calculated signals and the gain of information from the calculated signals vMeasure generates new measurement signals online from the calculated values, which can be further processed with all functions of vMeasure.

The recording of the signals can be triggered. vMeasure allows the recording of selected signals or the online calculated signals to limit the amount of stored data. The sample rate of the recording is flexible.

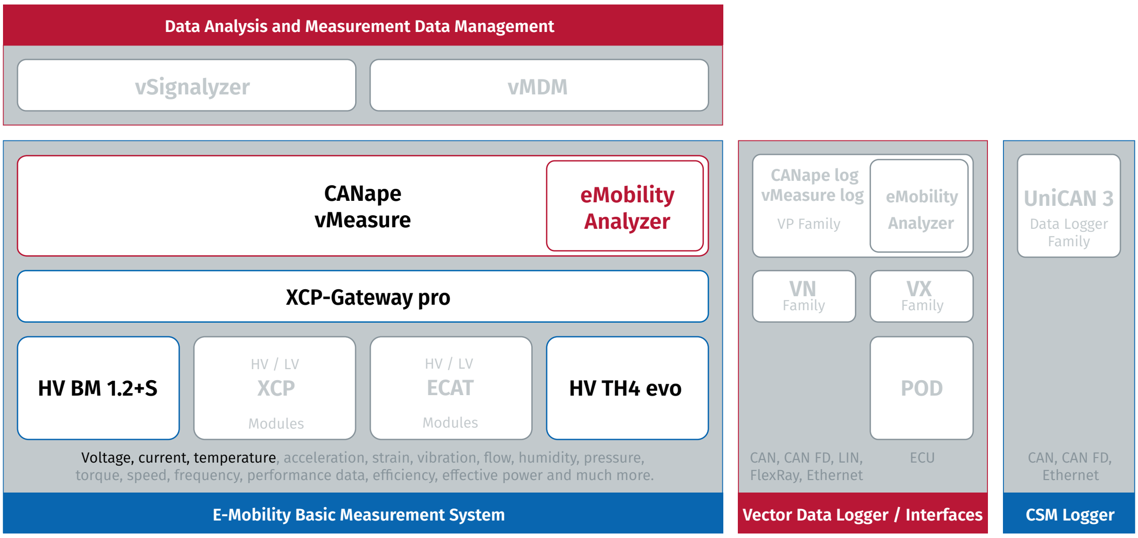

Fig. 6: The measurement of shield currents of HV cables in electric vehicles in the systematics of the Vector CSM E-Mobility Measurement System

Benefits

- Innovative, fast, precise and flexible measurement for the validation and verification of the HV electrical system in the laboratory and in road tests
- CSM's HV Breakout Modules (HV BM) have been specially designed for safe measurement on high-voltage cables. Current and voltage are recorded synchronously in the HV BM.
- The HV BM outputs the measured data (U, I) with a maximum data rate of up to 1 MS/s (1 µs), so that the requirement for the temporal resolution in the microsecond range is satisfied.
- Synchronous recording includes not only all signals, but also signals from control units or the vehicle bus systems
- The power of the vMeasure measurement software makes it easy to perform complex mathematical operations on measurement channels during measurement. Thus, in addition to the recording of the measured signals, complex calculations such as the calculation of efficiency or the blind- and reactive powers can be done simultaneously and integrated into the recordings or visualized at the same time
- The user can measure the current and voltage dynamics in the electric drive and receives immediate feedback during the driving test.
- Seamless, automated analysis and professional representation of the measurement data is possible with the Vector vSignalyzer software tool
- Direct transmission and secure storage of measured data can be done with the cloud-based Vector measurement data management system vMDM

Featured Products

HV Breakout Module 1.2+S

The HV Breakout Module 1.2+S allows single-phase measurement of current, voltage and power in separate HV+ and HV- cables. In addition, currents in the braided shield can be measured.

HV TH evo

CSM's HV TH4 evo measurement module allows safe temperature measurements with thermocouples on high-voltage components. Thanks to its compact design and reinforced insulation up to 1,000 V RMS, it is particularly suitable for decentralised use in road tests.

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®.

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 or via e-mail sales@csm.de.

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