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Current Measurement of Electric & Hybrid Vehicles – Influence of shielded HV motor & battery cable

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Executive Summary

Nowadays the determination of energy consumption and CO2 emissions is done at test benches by means of standardised driving cycles (NEFZ, WMTC etc.). For determining the energy consumption of electric vehicles this way doesn’t fit due to several reasons: no consideration of recuperation, no consideration of auxiliary loads, test is done at ideal testing conditions, etc. All-in-all the real energy consumption of vehicles can be up to 60% higher [2].

Therefore Real-Drive tests are getting more and more popular. The energy consumption is measured at different driving situations (highway, urban, uphill, downhill) and a couple of different parameters for the efficiency and energy analysis are determined.

To mount the sensors for voltage and current measurement represents a major tasks. The battery voltage can not be easily accessed as it needs to be protected due to the high voltage levels up to 1000V. And also the current measurement represents a major challenge as most of the High-Voltage (HV) cables are shielded. In this paper the influence of the measurement at shielded high-voltage (HV) battery and motor cables is analysed.

1 Introduction

The easiest way to measure power and energy consumption of electric & hybrid vehicles is reading out the data of the vehicles CAN bus signal. But this data can not be used for energy analysis due to several reasons. On the one site it is not allowed to use built-in sensors of the vehicle itself. Also the data are usually sampled with very low sampling rate (10Hz) and also not synchronized.

In Figure 1, a waveform segment of the battery current is shown both from the measurement with a high-sampling Power Analser (in green) as well as from the CAN bus (in black).

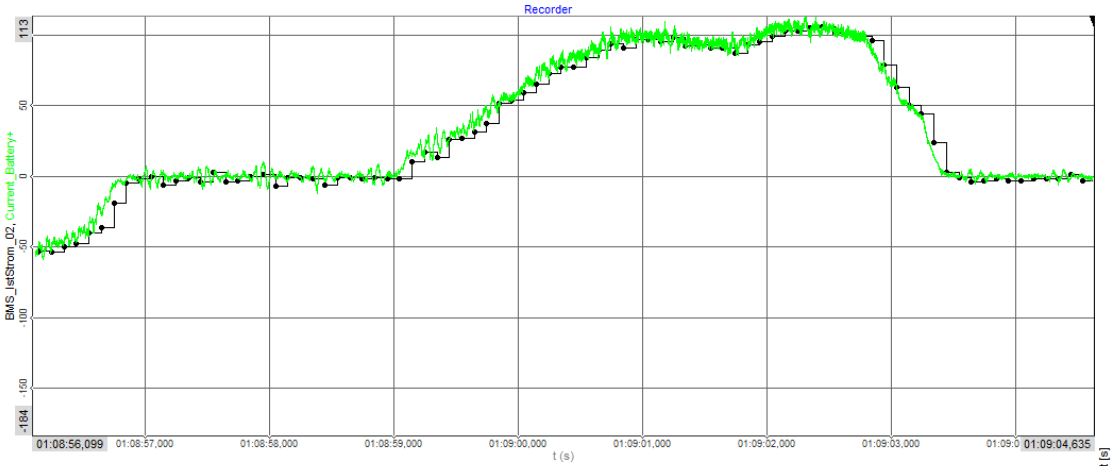

Figure 1. Battery current from measurement (light green) and CAN data (black)

In Figure 2, a waveform segment of the battery voltage is shown both from the measurement with a high-sampling Power Analser (in green) as well as from the CAN bus (in black).

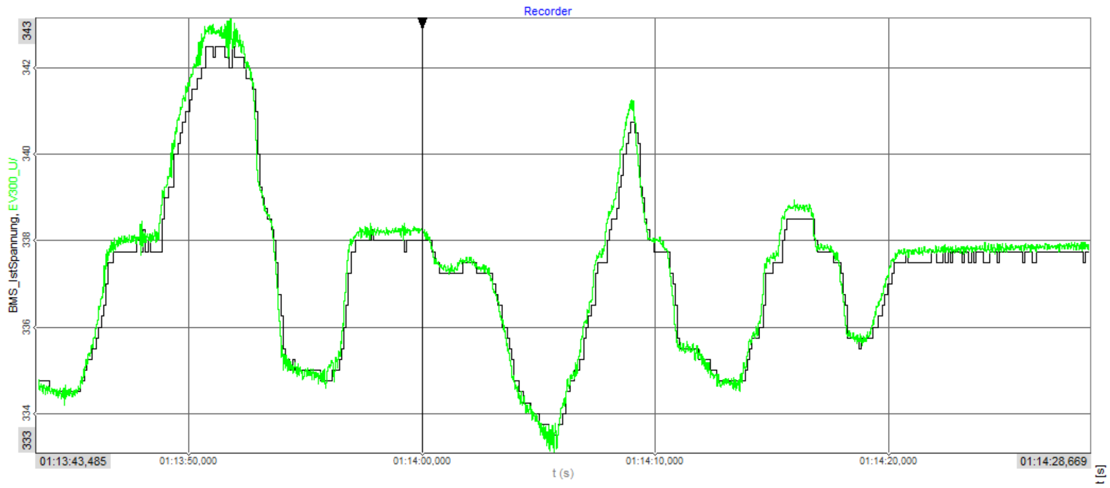

Figure 2. Battery Voltage from measurement (light green) and CAN data (black)

Based on the visualization it is already clear that the CAN data leads to significant deviations because of the low sampling rate of 10Hz. In the current signal (Figure 1) we see deviations at fast positive or negative signal changes. In voltage signal (Figure 2) we see that the voltage signal of vehicle CAN bus is following just very slowly the real signal, as well as offset to the real signal can be seen.

This means that by using CAN data, statements about the energy balance during test drives deviated up to 15% in comparison to the actual measurement data. Also for the voltage data displayed in Figure 1 and 2 the deviations are easy to see and question the energy flow analysis of hybrid and electric vehicles without using accurate measurement equipment.

The accurate acquisition of the electrical parameters is essential for giving expressive statements about the energy flow in hybrid and electric vehicles. Otherwise the deviation of the results is too high, even during shorter on-road tests that were also done for this paper.

2 MEASUREMENT SYSTEM

As measurement system the R2DB Power Analyser of DEWESoft was chosen. It is possible to measure up to 16 input channels for voltage or current simultaneously and fully isolated. In addition it is possible to measure GPS and Video data which gives valueable information for analysis of different driving situations. The following picture shows the measurement system and a current clamp mounted on the battery plus line of an electric vehicle.

Figure 3. Measurement system R2DB Power Analyser (left) and mounted current clamp (right)

For the measurement a high sampling rate of 1 MS/s were chosen to analyse also effects at higher frequency components of the signals. Voltage was measured directly at the isolated voltage inputs of the instrument. Current was measured via current clamps and zero-flux transducers. This type of current sensors were chosen because of high-bandwidth, high-accuracy and low phase error. For the individual measurements (test-bed or real-drive) always the same typ of sensors were used. The following table gives an overview of parameters:

Table 1: Measurement settings

Description	***Setting***
Sampling Rate	1 MS/s
Resolution	16 bit
Current sensor	1) Current Clamp DS-CLAMP-500DCS for Real-Drive tests Accuracy 0.3% / Bandwidth 200kHz 2) Current Sensor MCTS-1000 for Test-Bed tests Accuracy 0.03% / Bandwidth 500kHz

The measurement system combines functionalities of a Power Analyser, Scope, FFT Analyser, and Power Quality Analyser in just one instrument which allows easy and powerful analysis for this kind of measurements. In the next screenshot (Figure 4) you will see a screenshot of the measurement software DEWESoft of the tests.

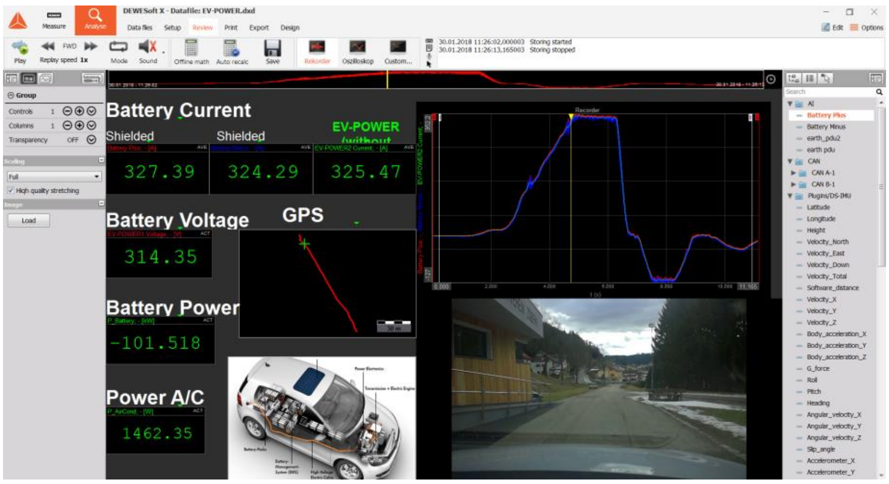

Figure 4. Screenshot of measurement software [1]

3 THE INFLUENCE OF SHIELDED MOTOR CABLES

As the data of the vehicle itself are not sufficient for energy analysis, current and voltage sensors have to be mounted.

First, the influence of shielded and unshielded motor cables was determined, as the switching frequencies of inverters lead to leakage currents over the cable shield. For this purpose, battery and auxiliary loads currents were measured both with and without shielding.

The following figure (Figure 5) shows the measurement configuration for analysis of the influence of the shielded motor cable. One current sensor was mounted at the cable incl. the shield and one without the shield.

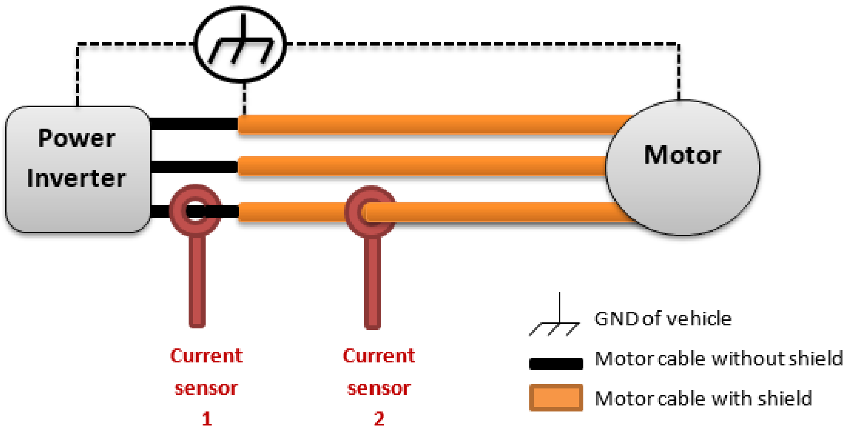

Figure 5. Measurement configuration

At the car we did this analysis the following behaviour was worked out:

The current signal of the shielded motor cable was smoothed compared to the current signal without shield (see Figure 6).

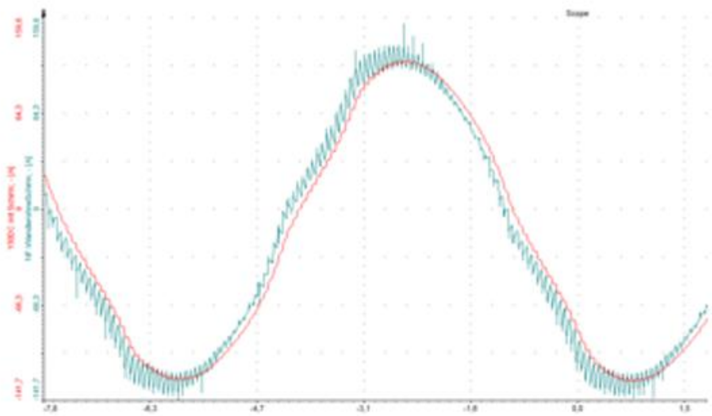

Figure 6. Waveform of measurd current with shield (red) and without shield (turquoise)

The signal with shielded motor cable is smoothed heavily compared to the signal without shielded motor cable. In addition also a phase shift between the signals can be seen.

In addition the current signal with shielded motor cable is damped at higher frequencies, see Figure 7.

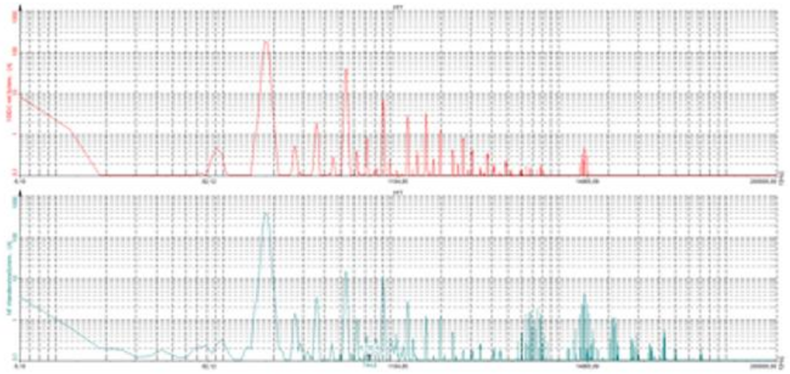

Figure 7. FFT-Spectra of current signal with (turquoise) and without (red) shielded motor cable

In the FFT spectra dampings of the signal already can be seen at frequencies >1kHz. In Figure 7 this can be seen especially at the right part of the picture. In addition a DC part of the signal with shielded motor cable can be seen (very left on Figure 7).

Finally the phase shift, seen in figure 8, is also frequency dependent. The following picture shows the phase shift between the signals with and without shielded cable (green) and the frequency (red).

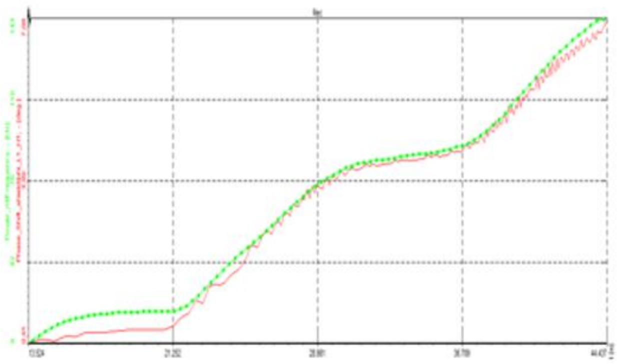

Figure 8. Phase shift between shielded and not-shielded motor cable (green) and frequency.

This findings of damping at higher frequencies and the frequency dependent phase shift clearly point a Low-Pass behavior when measuring at shielded motor cables.

3 THE INFLUENCE OF SHIELDED BATTERY CABLES

Not only measurement at shielded motor cables have a heavy impact on measurement results, also at battery cables there is huge impact. The following figure shows the measurement configuration for evaluation of shielded battery cables to measurement results.

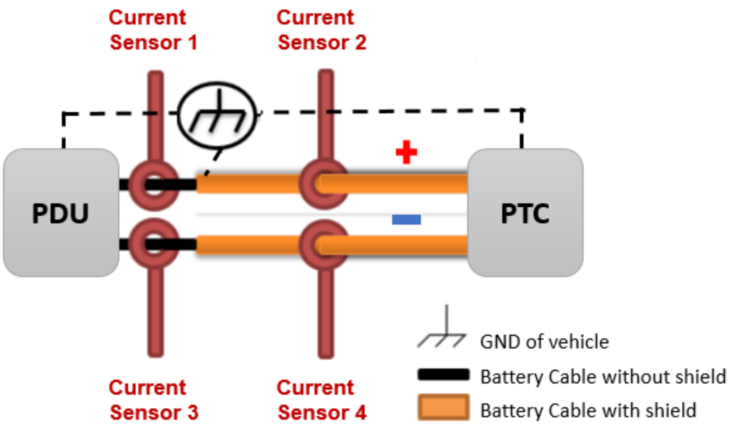

Figure 8. Measurement configuration for evaluation of shielded Battery Cable

Exemplary the impact of shielded battery cable is shown in Figure 9, where the current over a Auxiliary (PTC) was recorded while starting the electric vehicle.

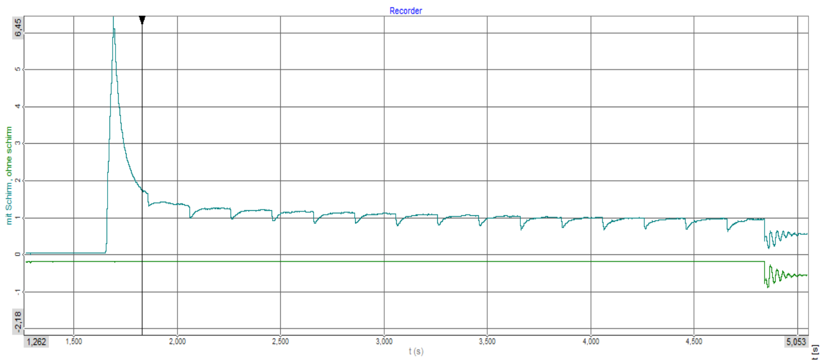

Figure 9. Current measurement with (turquoise) and without shielded cables (green)

The green waveform shows the measured current signal without shielded cable, while the turquoise cable shows the measurement signal including the shield. Whilst starting significant shield currents are measured, being 5 times higher in comparison to the measurement without shield. At the black marker, a deviation of 35% was calculated.

Further measurements demonstrating the shield influence can be seen in Figure 10. The green signal is the measured signal without shielded battery cable. The red current shows the measurement on Battery Plus while the blue signal shows the measurement on Battery Minus

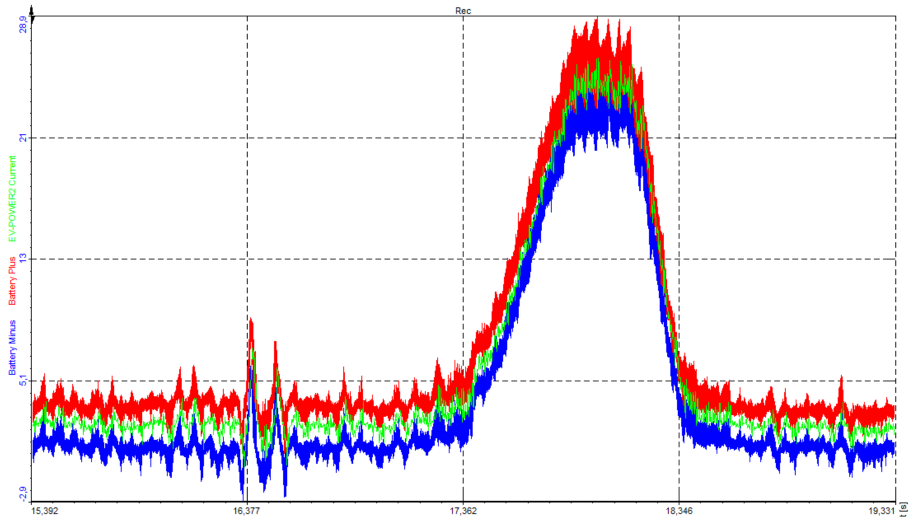

Figure 10. Influence of shielded battery cable
Green = Measurement without shield,
Blue = Measurement on Battery Minus,
Red = Measurement on Battery Plus

Both, measurement on Battery Plus and Battery Minus with shielded cable will lead to a significant measurement error of 1.5% at 340A, in both directions. A total difference of 3% between the battery-plus and battery-minus signal leads to further deviations when calculating the energy during on-road tests.

Shielded motor cables lead to damped signals, a fact which amplifies for higher frequencies. In addition, higher current values were measured on those input channels with shielded cables. Due to all the points the capacitive leakage can have low-pass characteristics and significantly affect measurement results and in further consequence the validity of reports and analyses.

In Figure 11, the FFT of both the battery-plus and battery-minus signals is illustrated including the fundamental frequency of the motor (1), the multiples of the fundamental frequency of the motor (2) and of the switching frequency (3).

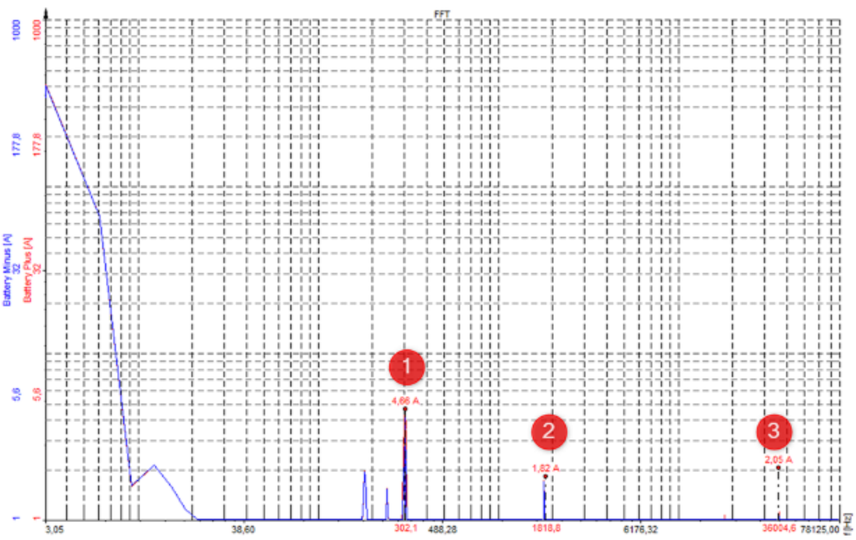

Figure 11. FFT analysis of the battery current signals

6 SUMMARY

This paper explored the main challenges for measuring the energy consumption of electric and hybrid vehicles. The results shows that just reading out the data of the vehicles CAN bus are sufficient for energy determination. Using current sensors represents a major challenge as the currents have to be measured without shielded battery & motor cable. The influence of the shielded cables are huge. At auxiliaries the deviation can be up to 50%. For battery and motor lines the deviation can be up to 5%.

References

[1] Grasel B. (2013), Efficiency Determination of Electric Two-Wheelers under realdriving, master thesis, university of applied sciences Pinkafeld

[2] UNFCCC (2015), „Adoption of the Paris Agreement“, United Nations Framework Convention on Climate Change, Paris, https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Authors

Bernhard Grasel obtained a DI (Diplomingenieur) degree in energy and environmental engineering from the university of applied science of Pinkafeld in 2012, and a B.Sc. in Business Engineering from the university of applied science of Wr. Neustadt in 2010.

In his current position he is in charge of the business unit for Power & E-Mobility at DEWESoft GmbH. One major application field is measurement & testing on electric & hybrid vehicles.