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Efficiency Analysis on electric & hybrid vehicles - Results out of Real-Drive tests

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Executive Summary

Battery Electric Vehicles (BEVs) have the potential to replace conventional fueled vehicles under the premise that the energy consumption, respectively the driving range, and the overall efficiency meet the consumer's expectations under real driving conditions. The determination of these parameters is central for evaluating the potential benefits of BEVs in comparison to conventional vehicles. As the transportation sector is a major polluter with high levels of greenhouse gas emissions, BEVs powered by low or zero emission energy sources are widely regarded as the next step to achieve a sustainable and energy-efficient mobility.

In this paper the grid-to-wheel efficiency of different electric vehicles is determined under real driving conditions. A mobile measurement system was mounted to the vehicles to give comprehensive statements about the energy consumption, the driving range as well as the efficiency of the individual drivetrain components. The routes for the road tests were chosen to consist of different representative characteristics (city, freeway, uphill, downhill, etc.) to further underline their influence on the energy consumption and the performance of BEVs under real driving conditions.

1 Introduction

As the transportation sector is a major polluter with high levels of greenhouse gas emissions, steps must be taken to reduce the emission rates. To achieve a significant reduction rate, a change from the use of fossil fuels to low or zero emission energy sources is required. Electric vehicles will play a leading role in achieving sustainable and energy-efficient mobility.

The electrification of vehicle drivetrains changes the requirements for testing vehicles. Beside the analysis of the combustion process it is also necessary to analyse the electrical drivetrain which can be realised in a number of different ways (motor, generator, in-wheel motors, fuel cell, 1 to 12 phase motors etc.). The following picture shows examples of how the drive-train for an electric car may be arranged with four in-wheel motors, a series and parallel hybrid car and a hydrogen car.

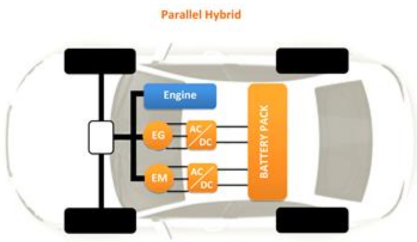

Figure 1 - Parallel hybrid vehicle [3]

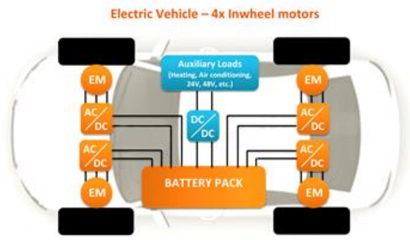

Figure 2 - Vehicle with 4x In-wheel motors[3]

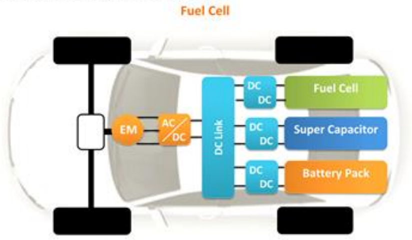

Figure 3 - Vehicle with Fuel cell[3]

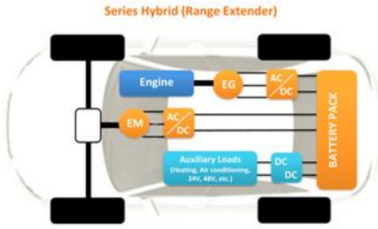

Figure 4 - Series hybrid vehicle[3]

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].

The aim of this paper is to determine the energy efficiency of electric vehicles under real driving conditions and to point out factors which have the highest influence on the energy consumption.

2 Measurement System

To analyse all necessary data online during measurement there are several requirements on the measurement system. The measurement system must be able to measure the power at different points inside the vehicle completely synchronous. To analyse the energy consumption for each driving situation it's needed to measure additional parameters like acceleration, velocity, position (all via GPS), speed, torque, temperature, video and signals of the vehicle bus (CAN).

Using conventional measurement equipment would require the use of a couple of instruments like several power analysers, data loggers, GPS loggers etc (see Figure). To supply all of this instruments independently of the vehicle battery would be quite challenging as well as feeding the instruments with the corresponding signals. Data merging of all the different measurement data would be a lot of work. The main disadvantage is that data can not be synchronized at all. This challenges makes it very difficult to get reliable measurement results.

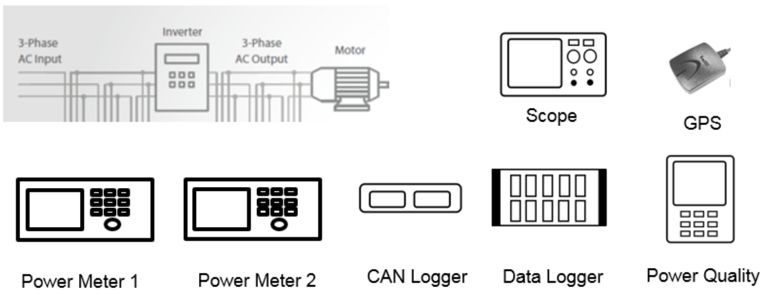

Figure 5: Needed measurement systems

So for this measurements the R8DB Power Analyser of DEWESoft was used as it is possible to measure up to 64 signals and with the measurement software it's possible to acquire all the different signals (analoge, digitial, video, vehicle bus) completely synchronous. The system has a build-in battery pack and supplies also power for all the different sensors. The vehicles battery pack is therefore not affected by the measurement system. This advantages allows detailed energy consumption analysis for any driving situation. The following Figure shows the measurement system:

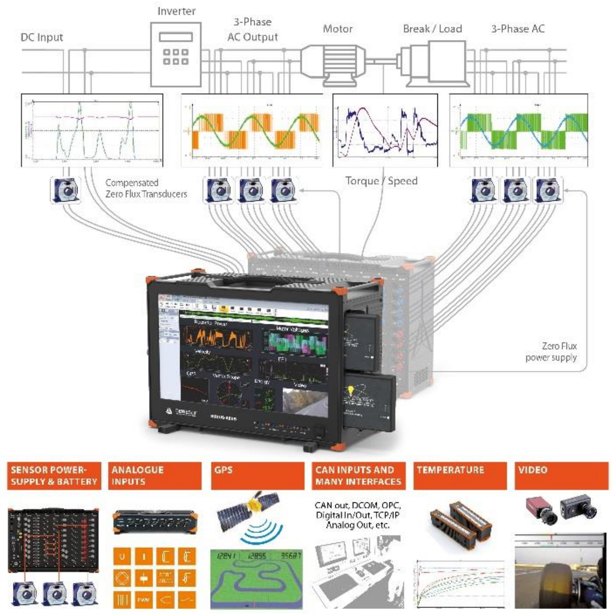

Figure 6: DEWESoft All-In-One measurement system

3 Efficiency Analysis

The real energy consumption of (electric) vehicles can deviate up to 60 % [2] of the manufacturers' specifications. To understand how such deviations can occur, we first analysed the factors which have the highest influence on the energy consumption. Therefore different test drives (uphill, city, highway, different test drivers, etc.) were done. The following table shows how much the individual factors can influence the energy consumption.

Table 1: Factors which influence energy consumption of electric vehicles mainly

Description	***Energy Consumption***
Reference Energy consumption	***20 kWh/100km [4]***
Driving cycle on testbench	± 60 % [2]
Temperature-depended capacity of HEV-battery	± 10 % [4]
Behaviour of test driver	± 10 % [1]
Drive train technology (Hybrid Vehicles)	+ 20 % [4]
Hot weather (Cooling)	+ 20 %
Cold weather (Heating)	+ 100 %
Uphill	+ 800 % [1]
Auxiliary loads (e.g. light, fans, radio etc.)	± 10 %
Summer/Winter Tires	± 7 %
Speed 130 km/h	+ 100 %

As you can see there are a lot of factors which can influence the energy consumption substantially. As reference for this comparison, the averaged energy consumption of the tested electric vehicle was used.
Notably weather conditions can have a high impact. For example the difference of doing efficiency analysis at very cold weather (-40°C) compared to ambient temperatures of about 20°C can influence the energy consumption of up to 100%. This means that the range of the electric vehicle is halved at this temperature. Also hot weather (e.g. +30°C) influences the energy consumption significantly as cooling is necessary. This can lead to about 15% more energy consumption.

Different test drivers, auxiliary loads, the route (city, overland) can influence the energy consumption of up to 10% (each of them). The energy consumption is especially high when driving uphill: up to 8 times higher than the averaged energy consumption.

This results explains how deviations of up to 60% of the manufacturers' specification can occur. If the manufacturer specification is done at ideal conditions (ideal ambient temperature, no auxiliary loads, no uphill etc.) the energy consumption is a lot lower than in reality. Therefore it is important to consider everything if you want to get reproducible and realistic specifications for energy consumption.

Therefore the energy consumption of different electric vehicles were analysed under real driving conditions. The next picture shows and screenshot of the measurement software DEWESoft:

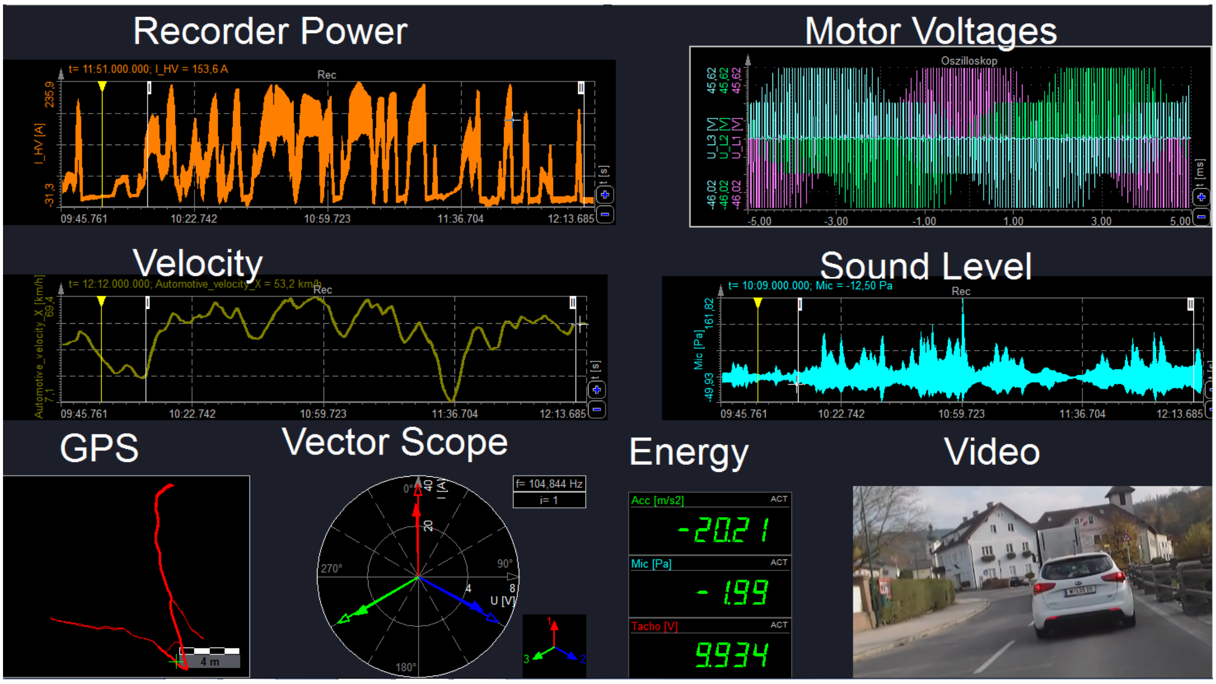

Figure 7: Screenshot of measurement software DEWESoft

The software allows to determine the efficiency and energy consumption already during driving. Main benefits of using DEWESoft software is getting all different kind of data (digital, analog, vehicle bus) completely synchronized. Furthermore it combines functionalities of a Power Analyser, Scope, FFT Analyser, Combustion Analyser, Data Logger, and Power Quality Analyser in just one instrument. This allows detailed analysis of energy consumption for any kind of driving situation.

Now we will look at the results of one certain vehicle. The test track was chosen so that all parameters which can influence the energy consumption are considered. It covers downhill driving with recuperation, uphill driving, city-, overland- and highway driving. The following picture shows the results of the efficiency analysis of an electric vehicle during real-driving tests via a Sankey Diagram.

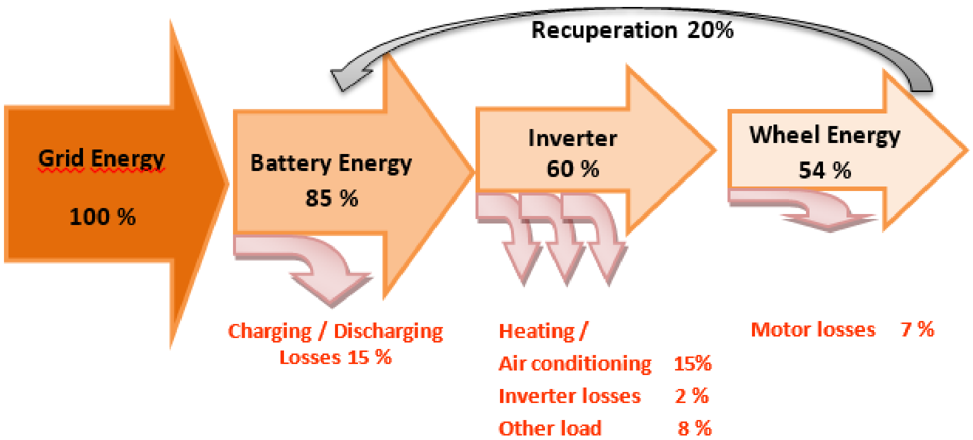

Figure 8 - Efficiency analysis of electric vehicle

In this case the power was measured at 6 different points including battery power, motor power and power of major loads. The averaged energy consumption over the test track was 24.6 kWh/100km.

The charging/discharging process already causes a 15% loss. So this charging/discharging process is already responsible for the major energy loss. At other vehicles this loss was even higher: up to 90% (cheap vehicle design).
Due to this loss, only 60% of the grid energy arrive at the motor. This is again a 15% loss, but it is not wasted, because it is used by auxiliary loads, like: heating, air conditioning etc. Finally 54 % of the grid energy arrives at the wheel. The motor loss is 7%.
The recuperation rate of the whole test-cycle was 20%, which is quite high.

The following table shows the range of empirically determined efficiency values of the different parts:

Table 2: Averaged Efficiency Values for EV components

Description	***Efficiency***
Charging / Discharging	20 – 90 %
Battery	60 – 95 %
Inverter	80 – 98 %
Electric Motor	70 – 99 %
Recuperation	0 – 20 %

As you can see, especially the charging-discharging loss can be very high for cheap constructions. In some cases the equivalent energy consumption compared to gasoline driven cars is then higher.
The battery type and realisation, also have a major effect to the efficiency. The main factor for the loss is determined by the technology (Lead-Acid, Lithium, etc.). The averaged useable capacity of batteries is about 75%.
Most inverters are operating on a really high efficiency level and only contribute for slight losses in the overall process. They have an averaged efficiency of about 95%.
The electric motor also impacts efficiency considerably. Using cheap motor constructions can lead not only to reduce life-time, also the efficiency is often lower.
The recuperation of electric vehicles can improve the total efficiency. While some manufacturers do not bank on recuperation, the recuperation rate of the best measured vehicle for a whole test-cycle was 20%. At some parts of the test track (e.g. downhill, city driving) this rate was a lot higher.

Out of the measured data a couple of other analysis can be extracted, like the energy consumption analysis for different speed classes. The following chart shows the overall energy consumption for the test-drive in 20km/h speed classes.

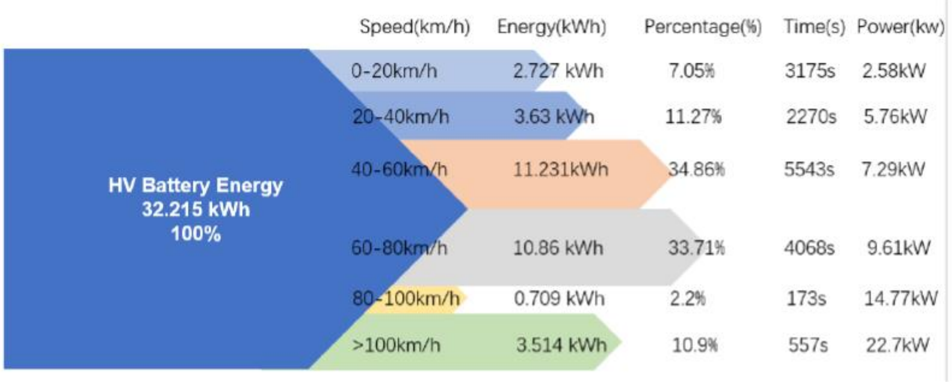

Figure 9: Charging Process of an electric two-wheeler

For this test-drive 2/3 of the energy consumption was needed for the speed classes from 40-60 km/h and 60-80 km/h.

Finally also the charging process of electric vehicles were analysed. The next figure (Figure 7) shows an example of the charging process of an electric two-wheeler battery:

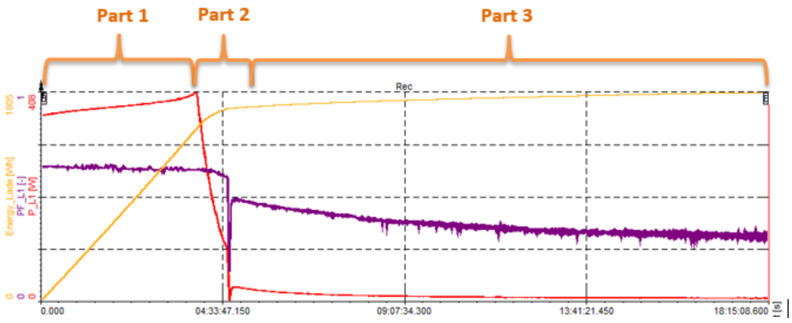

Figure 7: Charging Process of an electric two-wheeler

The charging process is divided into three parts. In the first part the battery is charged continuously with high power. Within 4 hours 80% of the battery is charged. In the second part the battery is reaching the desired charging voltage and the process then has a short interruption. At this time 86% of the battery is charged. Finally in the last part of the charging process, the battery is only charged with low power. Within 14 hours the battery is finally fully charged.

6 SUMMARY

This paper shows the determination of the energy consumption of an electric vehicle during real-driving. In addition the factors with the highest influence on the energy consumption are determined. This analysis and the experience of testing electric vehicles under real-driving conditions shows how deviations of up to 60%[2] of the manufacturers' specification can occur and how important it is to test vehicles under realistic conditions. The energy-flow chart shows in which part most energy is lost and also which factors can be responsible when electric vehicles have a worse environmental result than gasoline ones. Test-bed results and simulation are giving more and more realistic values, but if you want to know the real-energy consumption of electric&hybrid vehicles Real-Drive tests are needed.

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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.