On-Road Measuring and Testing Procedures for Electric Vehicles

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Abstract
Testing procedures and measurements on Electric Vehicles (EVs) are very important to obtain a reliable evaluation of their behaviour and efficiency in day-by-day use as well as in non-usual road conditions. Therefore the VUB has developed a complete testing method and has gained a significant experience during the past few years by testing a large number of vehicles. An on-road data-acquisition measurement system has been developed, with a variety of parameters that can be measured, such as voltages, currents, speed,... Road tests and rolling bench tests are performed. A range of testing procedures have been defined in order to perform a complete evaluation of the vehicles. Three objectives have been defined : acquiring enough data to determine statistical models for each component of the vehicles drive line, comparing the vehicles concerning different performances and comparing the vehicles concerning driving comfort. During the last 5 years more than 15 different vehicles have been tested, which includes scooters, cars, vans and buses, pure electric as well as hybrid. This gave us the opportunity to build up a large experience and a big database in which all the results have been processed.

Objectives
Three main objectives are at the base of the development of a complete testing method with data-acquistion measurement system.

- To acquire enough data to determine statistical models for each component of the vehicles drive line (battery, charger, motor, chopper,...). These models are used in a vehicle simulation program VSP [1]. In this way different vehicles, thermal, pure electric as well as hybrid, can be compared on energy/fuel consumption, emissions and performances. On the other hand these characteristics can be evaluated when some elements of the drive line would be changed by others (e.g. changing a lead-acid battery by a nickel-cadmium battery)
- To acquire enough data to compare the vehicles concerning different performances (autonomy, energy consumption, maximum speed, maximum acceleration,...)
- To acquire enough data to compare the vehicles concerning driving comfort (dashboard, heating, steering, accessibility,...)

The used test equipment is composed of the following instruments :

- data acquisition measurement system 1 (only DC)
- data acquisition measurement system 2 (DC and AC)
- rolling bench
- special battery test equipment

Data-acquisition Measurement System

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are needed to see this picture.

Figure 1 : the first measurement system in action inside an electric vehicle

In collaboration with CITELEC, the first data-acquisition measurement system has been developed five years ago and since then continuously improved. A whole test programme has been developed and a wide range of vehicles have been tested. In 1997 a second data-acquisition system has been designed and constructed.

A big variety of parameters can now be measured as shown in Table 1.

Table 1
Listing of measurable parameters

	Data-acquisition system 1	Data-acquisition system 2
DC Voltages	3x300 V, 1x800 V	3x250 V, 3x300 V, 1x800 V
AC Voltages	-	3x300 V
DC Currents	2x600 A	3x300 A, 2x100 A
AC Currents	-	3x300 A, 2x100 A
Vehicle speed	2x200 km/h (1 analogue, 1 digital)	
Torque of rolling bench	1x200 Nm	
Temperature	-	5x-100 to 200 °C

Both systems have free channels for additional data inputs (e.g. power from mains, 12 V auxiliary battery, noise,...)

Data-acquisition measurement system 1

An intern serial datalogger, built in a portable 19”-rack, provides all the signal conditioning, multiplexing, discretisation and digitalisation. The rack is small and meets the needs that are demanded for such a device (electric and electromagnetic isolation, proof against external shocks, no obstacle for driver nor passengers,...). In Figure 2 one can see the principal outline of the measurement system.

Voltages, currents and digital speed measurements are converted into load-independent output signals by internal transducers with linear characteristics. Outputs from the LEMs (Hall effect shunts) are converted into input voltages for the transducers by means of precision measuring resistances. The transducers provide filtering and galvanic isolation for the signals. Other parameters pass a buffer and a low-pass filter (Butterworth 5th order). The logger accepts input voltages up to 10 V. Data-acquisition is done by a serial logger, consisting of a 16 channel data-acquisition card an a 64 Kbytes buffer microcontroller card.

A 24 V NiMH-battery inside the rack provides the supply of all the electronics and auxiliary devices, except for a speed sensor that has its own external 12 V maintenance-free Pb-battery.

The logger is controlled by a Macintosh Powerbook via a serial connection, and is controlled by a specific application, EV-Powerlogger, written in LabVIEW. On the front panel the setting parameters include : scan rate (Hz), number of channels, path name,...While measuring, the data are stored in ASCII-files for easy data processing.

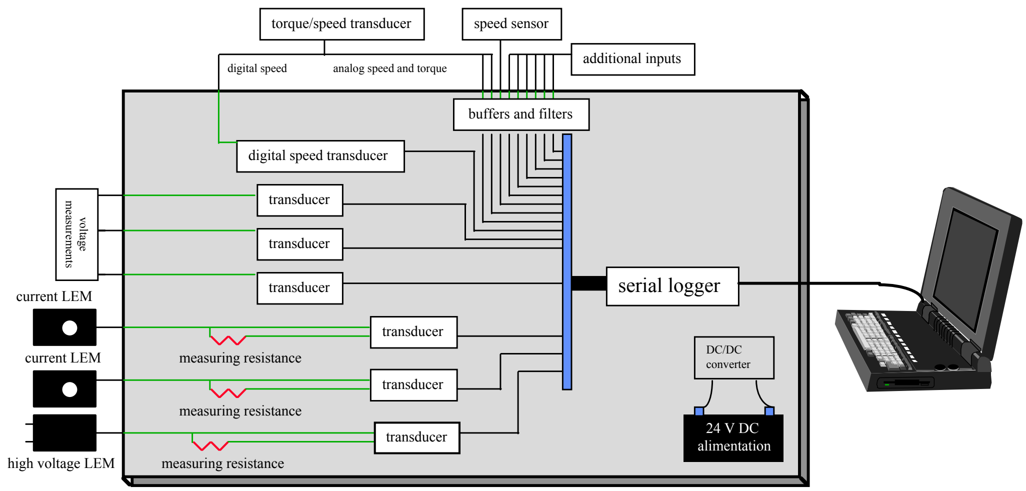

Figure 2 : principal outline of the measurement system

Description of the external components

In Table 2 one can see a listing of the external components with their their characteristics.

Table 2
description of the external components

device	measuring range	overall accuracy
current LEM module LT 1000 SI	0-1500 A	± 0.3 % of nominal current (1000 A)
high voltage LEM module LV 100	0-1200 V	± 0.7 % of nominal voltage (800 V)
speed sensor DATRON LM-sensor	0.5-400 km/h	± 0.2 %
torque-speed transducer TT 109	2-400 Nm max. speed 15000 rpm	± 0.1% of rated torque (200 Nm)

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are needed to see this picture.

Figure 3 : the speed lamp, mounted on an electric Fiat Panda

The speed sensor is based on a correlation optical method with spatial-frequency filtering and produces an excellent result with very high accuracy. It’s easy to mount on the vehicle as can be seen in Figure 3. A 12 V lead-acid battery provides the supply voltage.

The torque is not measured at the wheels, but on the shaft of the drive motor of the rolling bench (with a transmission belt in between). To convert the measured torque to the torque at the wheels, the losses of the belt, the transmission ratio, the circumference of the rolls and the slip of the wheels are taken into account.

A last external device is the Macintosh Powerbook 190cs, that controls the serial logger and stores the measured data in ASCII-files. The Powerbook has a hard disk of 512 MB, which is more than sufficiently enough when doing these tests.

Data-acquisition measurement system 2

Figure 4 : second measurement system, ready for action

Since the first data-acquisition system is not able to measure AC-currents and voltages, the need for a second measurement system became urgent. In the beginning of 1997 the necessary steps were taken and a second device was built. It’s slightly bigger than the first one, but still meets the needs of a mobile data-acquisition system and is more powerful. The energy supply is provided by an external 12 V maintenance-free lead-acid battery. In this case a SCXI-system with plug-in modules was chosen. A principal outline is shown in Figure 5.

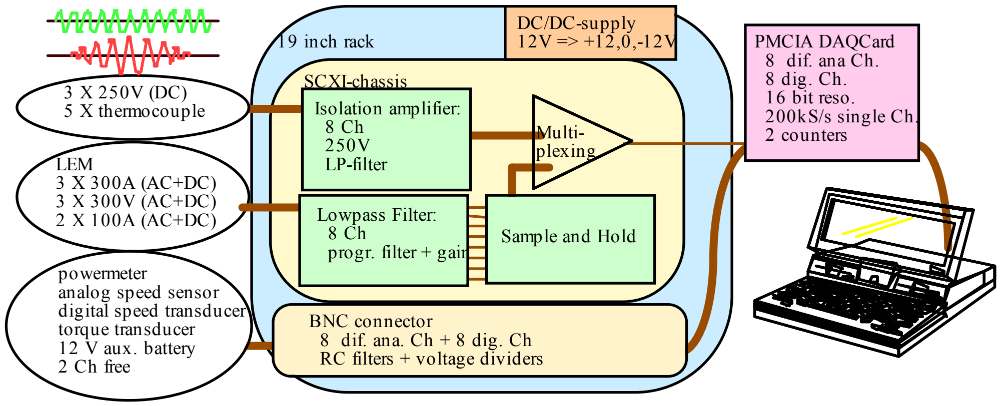

Figure 5 : principle outline measurement system 2

The SCXI-chassis contains 3 modules :

- an isolation amplifier with 8 isolated input channels for measuring thermocouples and voltage inputs; the use of an additional module with cold-junction sensor also assures an extended voltage input range to 250 V; low pass filtering can be chosen between 4 Hz or 10 kHz for each channel
- a module with 8 programmable low-pass filters is used for measuring AC and DC currents and voltages; each channel has a differential instrumentation amplifier with software-programmable gains and an eight-order elliptic lowpass filter (between 10 Hz and 25 kHz)
- an 8-channel differential amplifier with sample and hold function

An additional BNC-connector with 8 differential analogue and 8 digital channels is put in a 19”-rack together with the SCXI-chassis. RC-filters and voltage dividers are installed to have appropriate measurements. The logger is controlled by a pentium PC by means of a PCMCIA data-acquisition card. The software is also written in LabVIEW.

The external devices are the same or very similar to the ones from the first system.

Other Measuring Equipment

Rolling bench

The rolling bench is an essential part of the measuring equipment for electric vehicles. The one available at VUB is equipped with an electromagnetic brake and can also be driven by a separately excited DC-motor. This allows us to impose a speed cycle with corresponding torque, either positive or negative. This is a vital aspect when simulating road resistance (real road conditions). For determining statistical models for each part of the vehicles drive line, it’s necessary to do measurements, imposing constants speeds and torques to cover the whole speed-torque range of the tested car.

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Figure 6 : rolling bench at the VUB-laboratories

A PLC-driven system gives the opportunity to impose different cycles (e.g. ECE-15 cycle).

Battery test equipment

In order to obtain a more profound knowledge and understanding of the functioning of traction batteries, measurements on a battery mounted in a vehicle are often not sufficient, and the battery has to be considered separately. To this effect, a battery test installation has been installed at VUB, which is able to perform user-defined charge and discharge cycles on both single cells or modules and assembled batteries. Four "Digatron" test units are present; for security reasons and to ensure proper temperature control, the batteries under test are located in a dedicated shed.

Measurement methodology

Testing an electric vehicle with the assumed objectives, asks for a complete methodology of measurement and testing procedures. A whole variety of tests needs to be defined and executed. The procedure at the VUB consists of two main parts : road tests and rolling bench tests.

Measurements on rolling bench

The main purpose in these tests is to determine the efficiency field of each component of the vehicle's drive line. It consists in covering the whole speed-torque range of the car. Therefore a step-by-step working procedure is carried out. Different working points are imposed and measured, by increasing the speed and torque alternatively step by step, as shown in Figure 7.

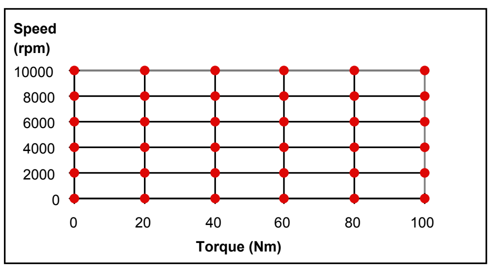

Figure 7 : speed-torque range

The same can be done in the opposite way, the so-called regeneration tests : at different speeds and positive torques, the working points are measured. In this way it is possible to characterise different components of the vehicle's drive line and to determine statistical models for each of them.

Battery tests are a specific case : a sequence of charging and discharging cycles at different state of charges (SoC) gives additional data to determine a model for the battery. Supplementary tests are done with special battery test equipment.

In addition several other interesting tests are performed on the rolling bench to determine the performances on the car : maximum speed and maximum acceleration tests with different road resistances, maximum slope test, maximum range test and an imposed ECE-15 cycle.

Measurements on the road

Road tests are a very important factor in evaluating electric vehicles, since real road conditions are very hard to simulate (weather, traffic conditions,...). The every day use of the car is one of the main aspects for the future owner of a car. The vehicles are used on a daily base by a variety of different drivers during the testing period. A logbook, filled in by the drivers, records all the useful parameters. Energy consumption is measured by means of kWh-counters, installed on the charging station. The acquired data include total distance per day (km), number of trips per day, energy consumption (kWh/km), state of charge (% or Ah),... complemented with data, depending on the on-board counters of each specific car).

Tests with the measurement system are regularly done and produce additional information for evaluation. An appreciation is given by the different drivers, concerning driving comfort and more specific : dashboard, heating, charger, steering, braking, accessibility,...

Next to the day-by-day use, tests in determining the performances of the vehicles are an other important factor. Therefore the following are also performed on road : maximum speed and maximum acceleration tests, maximum recuperation tests, coastdown test, maximum range tests and an ECE-15 cycle.

Additional measurements

The charging characteristic is of course a necessary instrument to come to a global evaluation of the car : what kind of characteristic is used (IU, WoWa,...), the efficiency of the charger, global charging time, Ah charged and surcharged are some of the parameters that are measured.

A last kind of test concerns the auxiliary device consumption. What is the direct consumption (in A) of all the possible auxiliary devices (lights, screen wipers, heating, airco,...) and how is it delivered (12 V battery, DC/DC,...).

The total of the above mentioned tests and measurement are gathered and a global evaluation of the car to be tested can be done. Some of the results will be shown in the next paragraph.

Results

Testing programme

During the past five years, in co-operation with CITELEC, a fleet of about 15 vehicles have been tested, electric as well as hybrid, cars, vans, busses and a scooter. A list of the vehicles is given in alphabetical order.

- Altrobus 12 m CNG hybrid bus
- Altrobus 6 m hybrid bus
- Boxel utility van
- Carica small van
- Cushman Bin Carrier utility vehicle
- Cushman ZEV tricycle
- Elcat cityvan
- Fiat Panda elettra
- Opel Astra Impuls estate car
- Peugeot 106 passenger car
- Peugeot J5 large van
- Peugeot Scootelec electric scooter
- Renault Clio passenger car
- Renault Express small van
- Renault Master large van
- Volkswagen Golf Cityströmer passenger car
- Volta small van

This diversity in vehicles allowed us to built up a large database and a great experience in testing and measuring. An overview of the results from different tests for this variety of vehicles is displayed in tables and figures below.

Day-by-day use

All vehicles have been tested by different drivers in normal traffic conditions in the city of Brussels. A special regard was placed upon following aspects : energy consumption, maximum speed, range. In Table 3 one can see some results of the past few years, regarding those aspects.

Table 3
data recorded during testing at VUB

vehicle	battery	motor	average range (km)	max.speed (km/h)	average energy consumption (Wh/km)
Peugeot Scooter	NiCd 18 V 100 Ah	sep.exc. DC	35	50	80
Volkswagen Cityströmer	Lead-gel 96 V 160 Ah	synch PM	75	115	300
Opel Astra Impuls	NaNiCl 284 V 90 Ah	asynch	150	110	225
Elcat	Lead-acid 72 V 250 Ah	series DC	80	80	275
Renault Master	Lead-gel 216 V 160 Ah	sep.exc. DC	80	90	430

An example of road tests is the acceleration test, given in Figure 8..

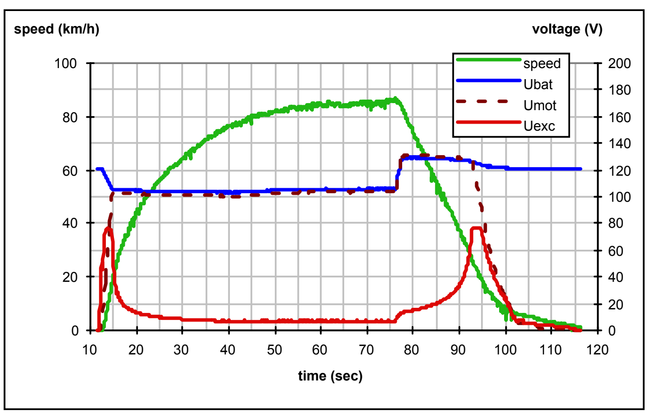

Figure 8 : acceleration-deceleration curve

One can see clearly that it concerns a separately excited motor driven vehicle with recuperation

As an example of rolling bench test results, Figure 9 is a good illustration.

After doing the tests, statistical and mathematical processing of the data is done to determine the models for each part of the vehicle's drive line. Figure 9 is a model for a DC-motor in the torque-speed plane. One can see clearly the optimal working point with highest efficiency is around 92 %.

Other models that are calculated include drive line components such as batteries, chargers and converters.

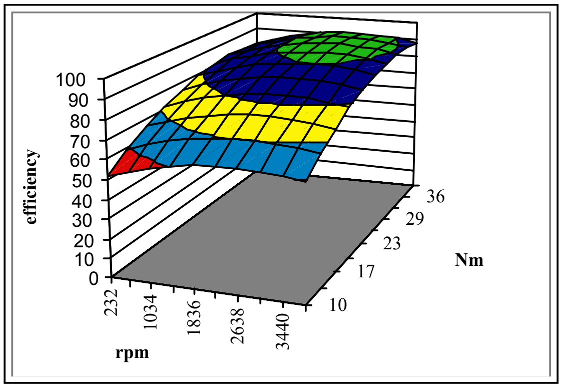

Figure 9 : motor model in torque-speed plane

The recording of the charging characteristic of the car is also an important factor in evaluating an electric vehicle. On Figure 10 one can see an example of a charge with WI-characteristic (power in kW) : main charge with constant power, followed by a constant current during final charge.

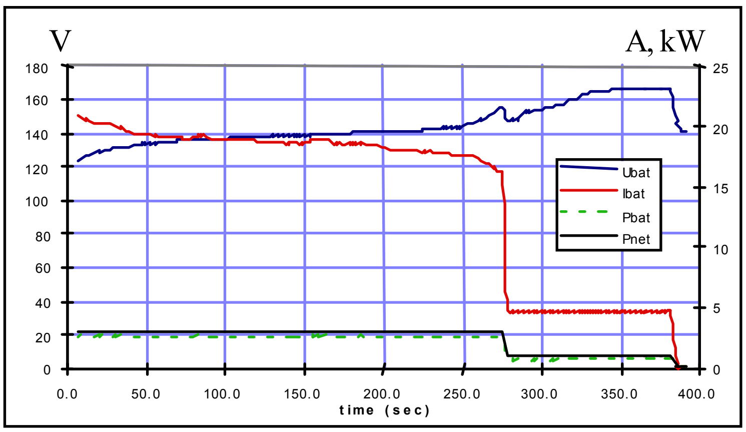

Figure 10 : charging characteristic

The power from the net is also measured to determine the efficiency of the charger, which is 85 % during main charge and 75 % during final charge.

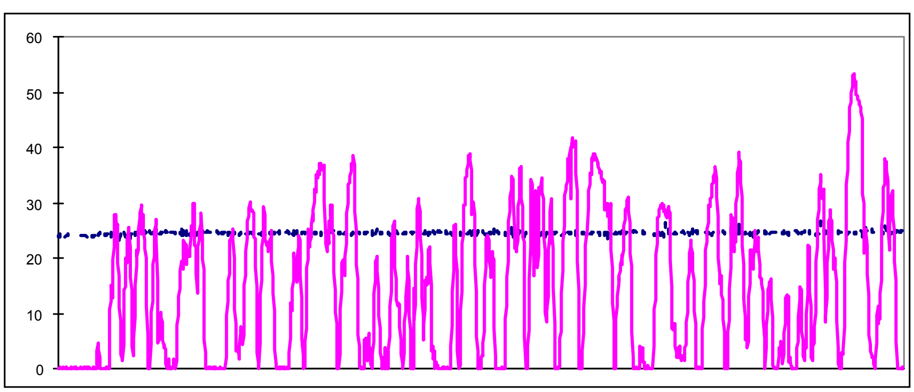

Figure 11 : bus route 71 (speed and generator power)

Evaluating and testing a bus asks for a different approach, especially when it is a hybrid bus.

The 12 m CNG hybrid Altro bus has an ICE-PM generator set that delivers a constant power of 24 kW. A 600 V battery provides additional power and energy in peak demands (accelerations, uphill driving). While standing still and in the other moments, the battery is charged by the generator.

Tests were accomplished by driving specific bus lines in Brussels, while measuring battery voltage, battery current and generator current. Figure 11 reproduces a speed profile of bus line 71 in Brussels with a measurement of the generator power. The speed profile is typical for a city bus : frequent stops and no high speeds (maximum speed is around 52 km/h). As expected, the generator power has a constant value of 24 kW.

The management of the battery SoC in this hybrid city bus aims to keep the batteries SoC practically constant during the vehicle driving continuously hybrid. At the end of the bus line (back and forth), the SoC should be the same as at the beginning. Figure 12 illustrates this very well. The Ah discharged and charged during the drive of route 71 are at the same level. One can see clearly the stops at the two terminus of the route (no discharge).

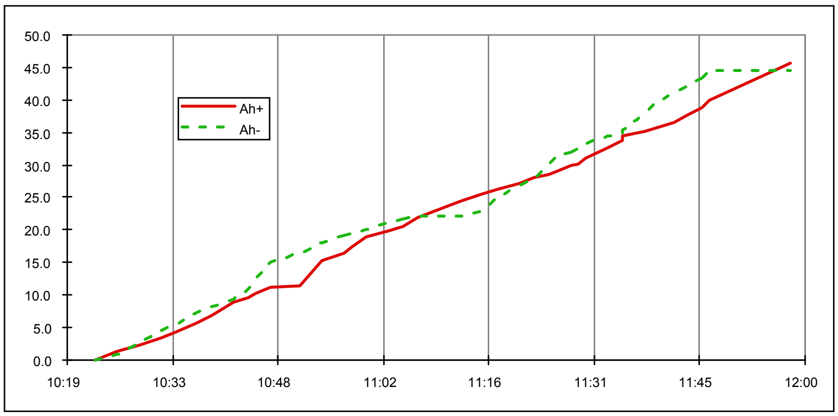

Figure 12 : SoC battery

If a pure electric driving section would be introduced then the Ah balance would be different. This is a choice depending on the exploitation filosophy of the line.

Conclusions

In co-operation with CITELEC, a powerful instrument has been developed for testing electric vehicles, consisting of 4 main devices : two data-acquisition systems for measuring a wide variety of parameters, a rolling bench and a battery test infrastructure. In addition with well-structured test procedures a global evaluation of the vehicles can be done. A test programme during the last five years allowed us to built up a large experience in testing en measuring. Furthermore a large database is now at our disposal. CITELEC, in collaboration with the VUB test infrastructure can present itself as a valuable test centre for electric and hybrid vehicles and has been appointed for the evaluation and testing procedure for the European THERMIE programme named SAGITTAIRE (12 hybrid buses), THERMIE-LUXEMBURG (3 hybrid buses) and THERMIE-TRENTO/OXFORD (5 hybrid buses).

The same test plant is being currently used for measurement activities for the "Tour of Flanders" demonstration programme, described in another paper of this symposium.

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