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Data Acquisition System for Optimization of Series Hybrid Propulsion Systems.

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Abstract

In this article the development and use of a data acquisition system for the optimization of hybrid propulsion systems is proposed. This versatile system can be used for different hybrid driveline architectures and for off- and on-road data logging. It retrieves the necessary parameters to develop or assess the power flow control algorithm of the vehicle under test, in order to optimize the driveline and reduce energy consumption and emissions. It is based on a cRIO™ programmable controller of National Instruments in combination with dedicated sensors and interfaces for the data acquisition of electrical and mechanical parameters. The assets and configuration of the system are discussed. Experimental data are given and discussed. In addition the HEV simulation platform developed in parallel is briefly described.

Keywords: efficiency, energy consumption, HEV (Hybrid Electrical Vehicle), optimization, power management

1 Introduction

The future shortage of fossil energy resources as well as the daily increasing evidence of global climate changes, urge many to decrease energy consumption. The automotive industry forms no exception: hybrid and electric cars are slowly but surely making part of the street scene. On short term, hybrid vehicles seem to be most adequate alternative technology for the classical combustion-based vehicles, at least when somewhat larger distances need to be covered [1,2]. Several hybrid topologies, parallel, series and combined, have been developed in order to improve the vehicles efficiency and performances. No topology is superior to all others in all circumstances, hence the drivetrain configuration has to be chosen in function of the type of vehicle as well as its use [3]. Once the topology is chosen, an adequate power flow control algorithm has to be applied [4,5]. This algorithm is an extremely important factor in the optimization of the driveline efficiency. Moreover it is closely related to the drive cycle of the vehicle. Hence a real-time monitoring of the power flow within the drivetrain of an on-road functioning vehicle, yields valuable information for the development of a power flow control strategy. In this paper we propose a measurement setup that is able to retrieve the necessary power flow parameters in a continuous way and real-time. It is based on a NI cRIO-DAQ, allowing one to

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monitor a multitude of parameters simultaneously. The set-up has been designed to be versatile and flexible. As a result, it can be used for any hybrid topology. In parallel a HEV simulation software platform has been developed. The simulation model uses the characteristics of the vehicle and its component as well as typical speed cycles in order to come up with the best possible power flow management for the vehicle. Comparing the measurements with the simulated results can 1: yield suggestions for improving the power flow management of the vehicle and 2: evaluate and improve the accuracy of the simulation platform.

2 Data acquisition system (DAQ)

2.1 Requirements for data acquisition system

The power consumption of a vehicle depends on the traction effort it delivers. It is hence a direct function of the acceleration of the vehicle and the resistive forces working on it. The acceleration of the vehicle is given by equation 1:

$$a = \frac{F_t}{M} = \frac{1}{M}\left(F_{tract} - F_R\right) \qquad (1)$$

With F_t the total resulting force on the vehicle, M the total mass of the vehicle, F_R the total resistive force and F_{tract} the traction force. The traction force, acting via the tire contact surface of the driven wheels, is determined by the engine or motor torque, and by the gear ratios, inertias and efficiencies of the driveline.

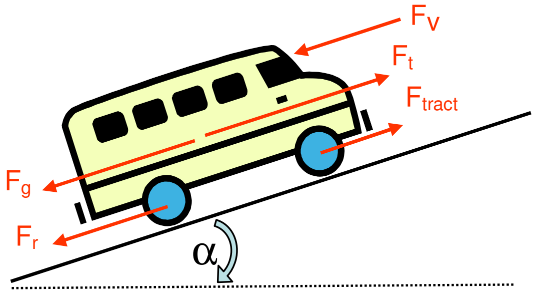

Figure 1: forces working on vehicle

When F_{tract} equals F_R the vehicle runs at constant speed, when F_{tract} is larger than F_R the vehicle accelerates, and when F_R is larger F_{tract} the vehicle decelerates. The total resistive force F_R can be expressed by the following formula:

$$F_R = \frac{1}{2}\rho S C_x\left(\frac{v + v_w}{3.6}\right)^2 + Mgf_r\cos(\alpha) + Mg\sin(\alpha) \qquad (2)$$

The first term on the right (F_v in figure 1) is the result of the air resistance and the wind. This force is determined by the density of the air ρ, the frontal surface of the vehicle S, the coefficient of drag C_x. the speed of the vehicle v, and the speed of the wind v_w. The second term on the right side (F_r in figure 1) is the result of the friction at the tires: it is determined by the mass of the vehicle M, the gravitational constant g, the angle α under which the vehicle is oriented with respect to the earth surface, and f_r, the friction coefficient. This coefficient is dependent on the type of tires, the tire pressure, the road surface, the temperature and the vehicle speed. Finally the last term on the right side of the equation (F_g in figure 1) describes the force of gravity when the vehicle climbs or descends a slope.

As noticed from equation 2 the traction effort depends not only on some constants like S and M related to the construction of the vehicle, but also on dynamic parameters that change during the testing of the vehicle, such as the speed, acceleration and slope. Hence the data acquisition system needs to be able to monitor these parameters during the on-road testing. In addition, the system needs to able to measure parameters that are specific to the architecture of the driveline of the vehicle. Therefore consider the example of a series hybrid topology as depicted in figure 2. The wheels are directly driven by the AC electric motor. The motor is fed by the generator, the battery and/or the peak power unit (flywheel or capacitor). In the given case the battery works as an energy buffer, and the peak power unit caters for the break and acceleration peaks. Configurations without battery or power peak units are also possible [2]. There are different ways to manage the power streams in such a driveline. In order to minimize the energy consumption it is of primordial importance to implement an adequate power flow management algorithm in the vehicle [5]. Hence a measurement system that monitors the power flows between the different components of the driveline is required for an adequate assessment of the implemented power management of the vehicle. These power flows can be electrical (DC and AC) or mechanical. In addition to thorough measurements of a complete driveline, a good knowledge of the behaviour and characteristics of its components is necessary. In

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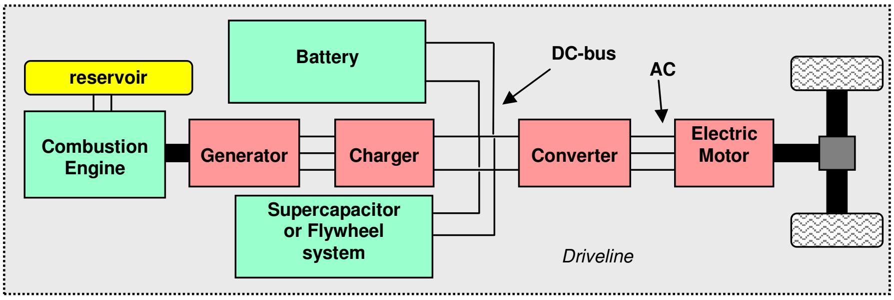

Figure 2: Series hybrid topology

general this should be provided by the component's manufacturer.
Finally, the system should be able to yield a complete set of measured data points every 100ms

2.2 Configuration of the data acquisition system

In the case of the mentioned series hybrid driveline topology this would mean that the data acquisition system monitors parameters as shown in figure 3. In this example we have omitted the battery and only consider a supercapacitor as a peak power unit.). The hart of the setup consists of the NI cRIO-DAQ system. Due to its modular build-up, it allows one to connect it to a multitude of sensors and interfaces.
The DAQ system consists of a chassis containing an embedded real-time processor and a reconfigurable FPGA. Different types of modules can be plugged in the chassis in order to measure different types of parameters. The FPGA offers the possibility to monitor several parameters simultaneously. Although the FPGA has a clock frequency of 40Mhz, its data rate is limited by the data rate of the individual modules.
As one can see from figure 3, part of the power

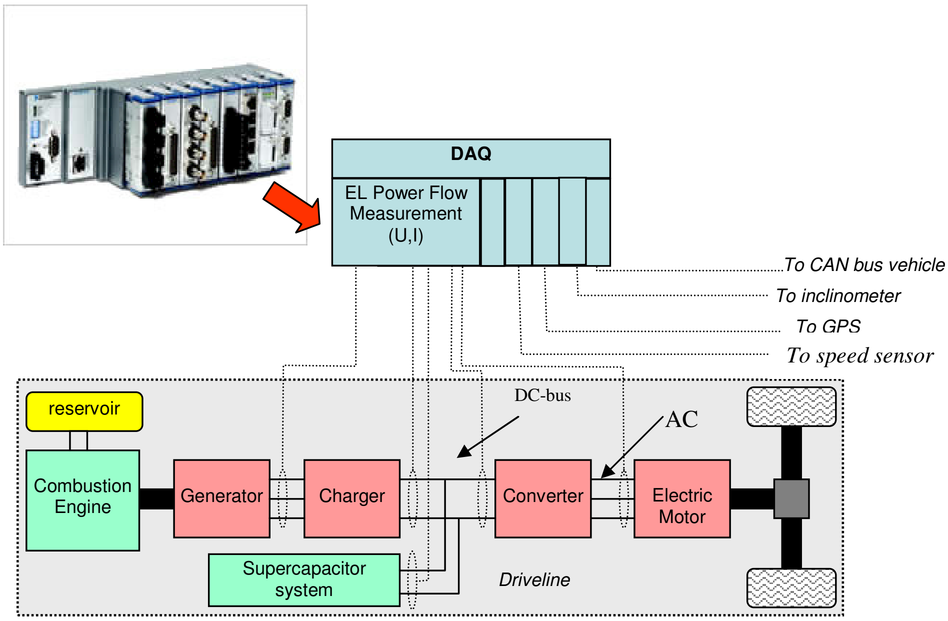

Figure 3: DAQ system setup

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flow has to be measured between the generator and the electrical motor, this means within the electrical part of the driveline. This includes measurements on the DC bus (between charger and converter) as well as AC measurements, since the current produced by the generator, and the current that feeds the motor is alternating. LEMs are used to measure the electric current and voltage. These LEMs are connected to National Instruments Analog Input modules. An overview of the used modules is given in table 1.
The measurement of the mechanical power flow is more complex, since it is for instance very complex to measure torque in an assembled driveline. Ideally the characteristics and the efficiency diagrams of the (partially) mechanical parts such as the combustion engine, the generator, and the electric motor are measured prior to the vehicle assembly, or are provided by the manufacturer. This data are of primordial importance to work out an adequate power flow management system.
Some of the mechanical parameters, like for instance the speed of the combustion engine, can often be found back on the Controller Area Network (CAN) bus of the vehicle. Therefore we have integrated the NI 9853 CAN bus module in our measurement platform. Other parameters can generally be monitored on the CAN bus: speed of the vehicle, power consumption of the auxiliaries, part of the power flow in the driveline, temperature of certain driveline components, speed of generator and electric motor. Besides the electric parameters and the data available on the CAN-bus, the measurement system uses additional sensors and transducers. We have integrated an inclinometer, based on a seismic mass MEM (Gemac). This allows one to study the influence of the road slope as described in equation 2. In addition an extra speed sensor (DLS1 of Datron), which has to be mounted externally on the vehicle, is implemented. Both sensors can be read out easily by means of a simple analogue measurement voltage. Finally we have implemented a GPS module that allows one to keep track of the vehicle's position. This can be combined with topographical maps in order to estimate the inclination and cumulated height difference, should the inclinometer be too much influenced by fast accelerations/ decelerations or abrupt curves the vehicle is following.

3 Software simulation platform

In parallel with the data logging setup a HEV simulation platform has been developed [6,7,8]. The latest generation of this platform is written in a Matlab^{TM} environment and allows one to simulate the minimal consumed energy starting from a well-defined drive cycle, taking into account the efficiency diagrams of the different components in the driveline. Comparing the simulated power flow and energy consumption with the actually measured values, one can come up with an improved power flow algorithm.
The software model is mainly based on the 'backwards-looking' or 'effect-cause' method [6], which simulates the energy consumed by a vehicle following a predefined speed cycle. It calculates the vehicle's energy consumption by starting from the requested speed at the wheels and going upstream the driveline while accounting for the losses of the individual drive line components, as illustrated by figure 4. These losses are of course dependent on the working point of each component. Hereby the model starts from the assumption that the vehicle is able to follow the desired speed cycle. However this may not be the case: in some circumstances, the power (or another quantity such as current, torque, etc.) requested to

Table1: overview of used NI-DAQ modules

Module DAQ	**Function**	**Resolution**	**# Channels**	**Sampling Rate/Ch (S/S)**
NI 9215	±10 VDC Sampling Analog Input Devices	16bit	4	100,000
NI 9239	Sampling Analog Input Devices	24 bit	4	50,000
NI 9219	Universal Analog Input	24 bit	4	100
NI 9206	Analog Input for Fuel Cells	16 bit	16	250,000
				Data rate
NI 9870	5V TTL module		32	40Mhz
NI 9853	Area Network (CAN) Module	11-29bit arbitration ID	2	1 Mb/s
cRIO-GPS	Gps_module		1	4hz

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a vehicle component such as the motor or the ICE is higher than the component rating. To overcome this problem, a 'forward-looking' module is introduced. As soon as one of the elements of the driveline is requested to deliver a higher power (or other physical parameter) than its rating, this module will calculate forwards instead of backwards, and will eventually generate the actual speed. At this moment the actual speed is limited by the rating of the challenged element. A simple controller is

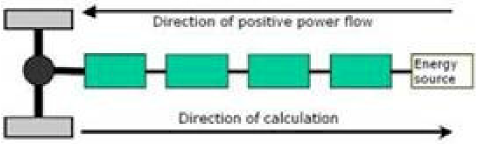

Figure 4: backwards-looking method

needed to set the vehicle power when any of the components is not capable of following the driving cycle. This is done in a similar manner to that of commercial packages like Advisor [9.10] with some differences:

-Backwards and Forward model are two different subsystems. The forward block is only executed when a component is out of its working boundaries. Hence, simulation time is shortened.

-The efficiency in the backwards and forward path are not necessarily the same, they are re-calculated on the forward path following the real delivered power.

-Within the general 'quasi-static' approach, the model of the ICE subsystem is dynamic. Therefore it considers the ICE transients, torque limitations and calculates the ICE actual speed, which may be different than the desired, and hence yields a more realistic approach.

Since, the simulation starts from the known characteristics of the vehicle and its components.
it can suggest a power flow management method for minimizing fuel consumption and/or gas emissions. Comparing the simulations to the measurements, yields suggestions for an improved power flow management system for the vehicle. On the other hand the measurement results may improve the accuracy of the simulation in case the initial characteristics of the vehicle components are incomplete or not completely correct.

4 Experimental results

Preliminary testing of the DAQ system for on-road use was carried out on an electric driven caddy for outdoor use. The electric driveline of this caddy consists of a DC permanent magnet motor powered with a battery pack. An example of a measurement can be seen in figures 5a and 5b. Speed, inclination and battery current can be read from this figure. Typical speed is 5km/h (walking speed). The caddy has performed the following drive cycle: flat surface, going downhill (rather steep, 10^{o}), flat surface with short U-turn, going uphill, flat surface and going downhill again. As can be seen in the figures, these elements can be

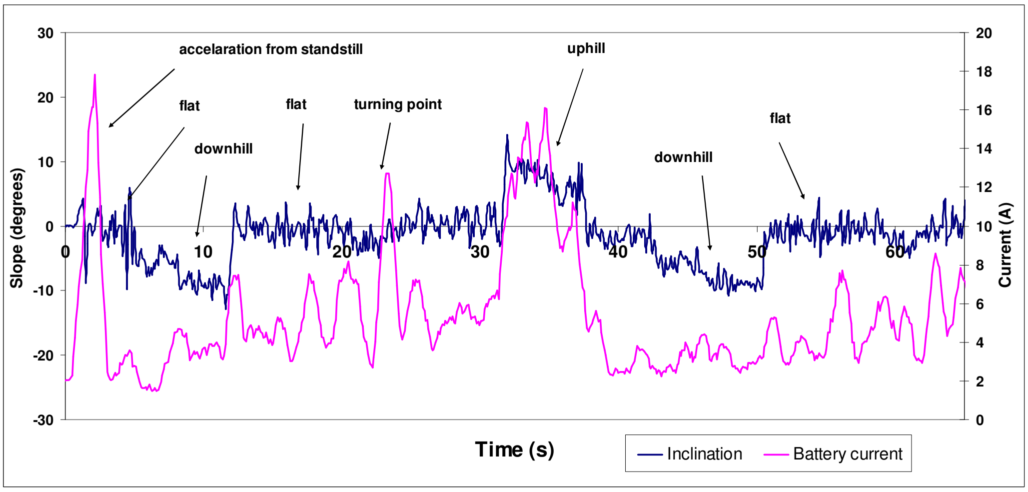

Figure 5a: vehicle inclination and battery current as a function of time

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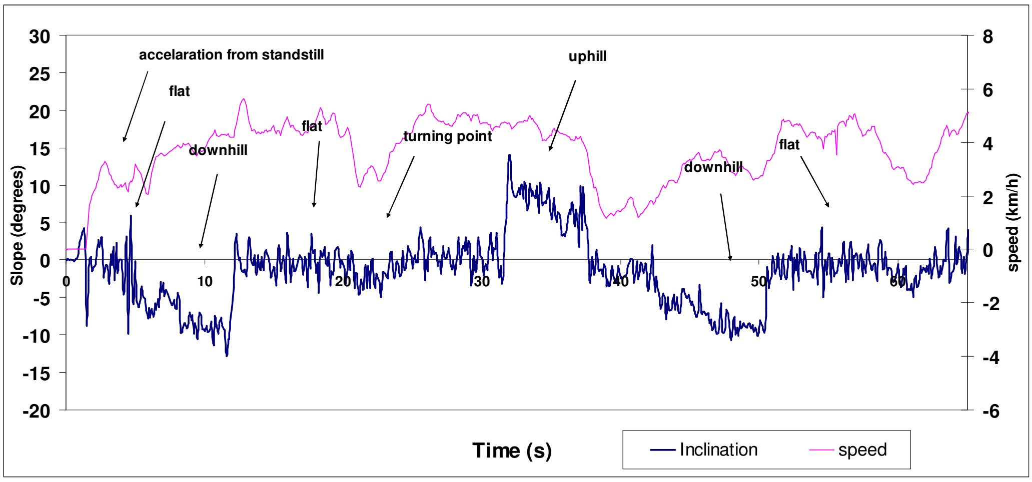

Figure 5b: vehicle inclination and speed as a function of time

found in the measured curves. At first the caddy needs to depart from standstill and a large current is drawn from the batteries. As a result the speed increases. Then the caddy roles downhill, what results in an increased speed, however without drawing too much current. At the flat surface the current is moderate and the speed remains globally constant, except at the U-turn where the caddy slows down. When the U-turn is made more current is drawn again in order to achieve its original speed, after which the current falls back again. When the uphill slope is reached a large current is drawn in order to climb up the slope. At the end of the slope the speed is almost zero. Then the caddy gains speed again on the downhill slope, without drawing much current.

5 Conclusions

We have developed an adequate and flexible data logging system that can monitor vital parameters during on- and off-road testing of hybrid and electric vehicles. In combination with the developed simulation tools, it can form an asset for the optimization of the power flow management and design of hybrid drivelines.

References

[1] Van Mierlo J, Maggetto G, et al., “Which energy source for road transport in the future? A comparison of battery, hybrid and fuel cell vehicles.”, Energy Conversion and Management, Vol 47, Issue 1, Pg 2748-2760, Octobre 2006

[2] Chan C.C., ‘The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles’, Proceedings of the IEEE, Volume 95, Issue 4, April 2007, Page(s):704 – 718.

[3] Emadi, A.; Rajashekara, K.; Williamson, S.S.; Lukic, S.M., ‘Topological overview of hybrid electric and fuel cell vehicular power system architectures and configurations’, IEEE Transactions on Vehicular technology, Volume 54, Issue 3, May 2005 Page(s): 763 – 770

[4] Van Mierlo J, Maggetto G, ‘Views on hybrid drivetrain power management strategies’EVS-17, Montréal, Canada, 2000

[5] Chau K.T, Wong Y.S., ‘Overview of power management in hybrid electric vehicles’, Energy Conversion and Management, Volume 43, Number 15, October 2002 , pp. 1953-1968(16).
Elsevier

[6] Van Mierlo J, Maggeto G, ‘Innovative iteration algorithm for a vehicle simulation program’, IEEE transactions on vehicular technology. vol 53 (2). pg 401-412. MAR 2004

[7] Van Mierlo J, Van den Bossche P, Maggetto G, ‘Models of energy sources for EV and HEV: fuel cells, batteries, ultracapacitors, flywheels and engine-generators’, Journal of power sources. Vol. 128 (1), pg. 76-89, MAR 29 2004

World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE

[8] Barrero R., Tackoen X., Van Mierlo J., 'Quasi-static simulation method for evaluation of energy consumption in hybrid light rail vehicles', in proceedings of IEEE Vehicle Power and Propulsion Conference 2008. 3-5 September, Harbin (China)

[9] Wipke K.B., Cuddy M.R., Burch S.D., 'ADVISOR 2.1: a user-friendly advanced powertrain simulation using acombined backward/forward approach', in IEEE Transactions on Vehicular Technology, Nov 1999,Vol. 48, Issue: 6, pg: 1751-1761. ISSN: 0018-9545

[10] Markel T. et al., 'ADVISOR: a systems analysis tool for advanced vehicle modeling' in Journal of Power Sources, Volume 110, Issue 2, 22 August 2002, Pages 255-

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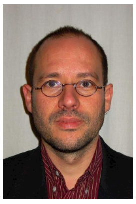

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