LiTHIUM BALANCE
BATTERY MANAGEMENT SYSTEMS

Final report

2011

EUDP-08 I

Integration of BMS (Battery Management System) in electric versions of conventional cars

Integration af BMS (Battery Management System) i elektriske udgaver af konventionelle biler

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Contents

Summary and conclusions

The purpose of the project was to develop a hybrid power pack system for hybrid-electric cars, consisting of a 275V Battery Management System, a 40 kW/h Li-ion battery pack and a 6 kW HTPEM methanol fuel cell, which can both be charged from the power grid and driven purely on the battery in daily use for shorter distances, while using the fuel cell as a range extender would allow the car to drive longer distances and be refueled with methanol quickly when needed.

This project has proved that a practical HT PEM FC using reformed methanol as its fuel source is viable and practical. Although it was not possible to drive 500 km on one charge of the battery and one tank of methanol for the 6 kW fuel cell as originally expected, further modeling based on the test result showed, that with the right configuration of the power pack components it is possible to build a li-ion battery/methanol HTPEM fuel cell power pack that could replace ICE power trains in conventional cars and obtain the save freedom of operation.

This technology when used in an electric car provides a 68% CO_2 saving compared to a gasoline fueled vehicle operated under the same conditions and methanol as an energy carrier in hybrid electric vehicles is also potentially significantly cheaper than other fuels.

The hybrid vehicle was demonstrated during the COP15 conference in Copenhagen December 2009, and the project results presented at the IAMF conference in Geneva, Marts 2010.

The project was finally concluded in June 2010 with a 9 month delay due to technical problems with the electric vehicle purchased for the project. Mainly due to these problems more work than planned was needed and the project budget was exceeded by 13%.

Resume og konklusion

Projektets formål var at udvikle en hybrid power pack til hybrid-elektrisk biler bestående af et 275V Battery Management System, en 40 kW/h Li-ion batteripakke og en 6 kW HTPEM metanol brændselscelle. Med denne power pack kan hybridbilen både oplades fra el nettet og køres alene på batteriet over kortere distancer, samt kan anvende brændselscelle som “range extender” og dermed kunne køre længere distancer og hurtigt genfyldes med metanol, når det er nødvendigt.

Dette projekt har bevist, at en løsning med en HT PEM brændselscelle, der anvender metanol som energibærer både er bæredygtig og praktisk mulig. Selvom det ikke var muligt at køre 500 km på en opladning og en tank metanol til den 6 kW store brændselscelle, som det oprindeligt var forventet, så viste modeller udarbejdet på baggrund af testresultaterne, at med den rette konfiguration af power pack komponenterne vil det være muligt at bygge en li-ion batteri/metanol HTPEM brændselscelle power pack, som kan erstatte ICE motorer i konventionelle biler uden at miste rækkevidde eller muligheden for at kunne genfylde tanken og køre videre.

Når denne teknologi anvendes i en elektrisk bil opnår man en CO_2 besparelse på 68% sammenlignet med benzin-drevne biler, når man kører under samme forhold. Og metanol som energibærer i hybrid elektriske biler er endvidere også potentielt markant billigere end andre brændstoffer.

Hybridbilen blev demonstreret under COP15 konferencen i København i december 2009, og projektets resultater blev præsenteret på IAMF konferencen i Geneve, marts 2010.

Projektet blev endeligt afsluttet i juni 2010 med en 9 måneders forsinkelse, som skyldtes tekniske problemer med det elektriske køretøj, som var blevet indkøbt til projektet. Primært pga. disse problemer blev arbejdsomfanget betydeligt større end planlagt, hvilket resulterede i en budgetoverskridelse på 13%.

Introduction

This is the final reporting of the results from the EUDP 08-I project “Integration of BMS (Battery Management System) in electric versions of conventional cars” (In Danish: ”Integration af BMS (Battery Management System) i elektriske udgaver af konventionelle biler”) (j.nr. 63011-0043). This report describes the background for the project and the activities and results produced.

The purpose of the project was to develop a hybrid power pack system for hybrid-electric cars, consisting of a 275V Battery Management System, a 40 kW/h Li-ion battery pack and a HTPEM methanol fuel cell, which can both be charged from the power grid and refueled with methanol to facilitate long range drives.

A pure battery driven electric car with a reasonable sized battery pack will typically drive up to 150 km per charge, which is adequate for the typical daily driving pattern experienced by most Danes (90% drives less than 100 km per day), but recharging takes time and the pure battery driven car is therefore less appropriate for long distance trips.

By installing a fuel cell in the electric car it would be possible to both drive on battery in the daily use, and to take long trips and refuel quickly when needed. Such a hybrid electric vehicle would also be more suitable for uses where daily distances above 150 km are normal – such as taxis and freight services.

The Danish Energy Agency concluded in the report ”Alternative fuels in the transport sector” (Danish title: ”Alternative drivmidler i transportsektoren”) published January 2008 that the combination of fuel cells and methanol is the second most energy efficient solution after pure battery driven electric vehicles.

This project was executed by Lithium Balance A/S (project manager) and Serenergy A/S. A key component in this conversion was the Battery Management System developed by Lithium Balance with support from the Danish Energy Agency in the project EFP07-II ”High Voltage BMS for Li-ion nano-batteries for automotive purposes”. Another key component was the methanol based fuel cell from SerEnergy for which SerEnergy previously developed a methanol reformer for the HTPEM fuel cell with support from the Danish Energy Agency in the project EFP07-II, ”Integreret HTPEM metanolreformer system til nødstrøms- og transportanvendelser”.

The goal of the proejct was to integrate these components into a power pack and install it in a demonstration vehicle and test drive it over a period of time to demonstrate whether this combination would be a viable alternative to conventional cars.

Conversion of Commercial Vehicles to Electric Drive

The challenge of passenger car OEMs when trying to develop electric vehicles are many fold. Starting with the market – there is no clear idea of market size or future demand, current technology and infrastructure makes it impossible to provide the same levels of range and flexibility found in conventional internal combustion engine (ICE) vehicles. Additionally, there are major concerns about the potential warranty exposure due to battery failures.

Commercial vehicles on the other hand are more predictable in their usage and it is often possible to make a straightforward calculation relating to running costs versus initial purchase cost over the life time of the vehicle. This has meant the adoption of electric commercial vehicles for urban delivery chores and a range of other short range transport activities.

There has also been a push from central and local governments (1) to run electric vehicles. This has created a demand that is typically being satisfied by aftermarket conversions of existing ICE engine vehicles to EVs by a range of companies including:

- Smiths Vehicles UK
- Microvett Italy
- EnerBLU Italy
- Allied Vehicles Scotland
- CEV Canada

Range Anxiety – the Need for Range Extender in EVs

The lack of suitable charging infrastructure means that it is relatively easy to strand an EV by depleting its battery. This can occur accidentally under a range of conditions such as misuse of onboard ancillaries like the cabin heater, defective battery cells within the pack or simply the requirement to drive beyond the normal range. This is both expensive (vehicle recovery costs) and inconvenient. The problems related to the limited range of an EV are typically described as Range Anxiety.

The move to using larger battery packs that would give a range of 200km or more without compromising battery cycle life presents obvious problems of cost, additional weight (20% of vehicle weight giving an additional 90% increase in range)[2] and space (reducing payload).

Fast charging is another suggested route but creates a whole host of challenges including:

- Battery longevity – conventional Li Ion batteries can only be safely fast charged within a limited area of their state of charge (SOC) range without causing damage

[1] Currently 800,000 trucks in the Federal fleet all candidates for electrification – Matt Rodgers Senior Adviser to the Secretary for the Recovery Act

[2] FreedomCar

- Suitable infrastructure – high power outlets >20kW need to be made available all over
- Grid load balancing – higher daytime loading on the grid which is precisely what power utilities do not want

The idea of an onboard range extender is not new and both internal combustion engines (ICE) and fuel cells (FC) have been considered in this application. The ICE benefits from being cheap and reliable with an existing refueling infrastructure. However there are many issues surrounding the use of ICEs, and although both BYD and GM have chosen this technology for range extension, it is viewed by many as not being the preferred route.

Another promising route is the FC. This is a device that uses a continuous electrochemical reaction to generate electricity from its fuel (typically H_2 and O_2) without any moving parts. It differs from a battery in the sense that the energy is produced by the consumption of the fuel, rather than from a stored charge. This makes a FC easy to refuel.

Advantages and Disadvantages of Different Fuel Cell Technologies

The common core reaction is the oxidation of H_2 to produce water, electric potential (0.7V) and heat.

The Fuel cells types that are suitable for use in industrial or transport applications can be categorized according to construction and operating temperature.

The commonly used technology is the PEM – Polymer Exchange Membrane type. Here, H_2 is introduced at the anode where it is catalytically split to a proton and a free electron. The PEM allows the proton to migrate through it to the cathode where it combines with O^{2-} ions to create water vapour and heat. The electron that was stripped from the proton passes through an external circuit where it does work before reducing O_2 molecules taken from the air that subsequently combine with protons to form water vapour and heat.

This technology operates between 80-120°C and must be operated with pure H_2 as the catalyst at the anode can be contaminated by CO. This technology is the preferred technology for automotive applications as it starts in a matter of seconds, emits only water vapour and presents only minor thermal management issues. With proper load matching 50% operational efficiency is achievable making it at least 2.5x as efficient as simply burning the H_2 in an ICE. Most of technical challenges have been overcome – membrane life, onboard H_2 storage, water vapour management (to avoid icing at low temperatures). GM, Honda and Mercedes have all demonstrated matured technologies that are serviceable. The major concerns are H_2 infrastructure and of course, cost. Neither of these two issues is even close to being resolved.

A variation on this technology is the High Temperature Polymer Exchange Membrane (HTPEM) FC. This technology is able to operate at elevated temperatures between 120-180°C and unlike PEMs it does not use water as the conductive medium in the membrane. At this temperature, the catalysts are less susceptible to poisoning by CO which lessens the purity requirements for the H_2 supply. The elevated temperature of operation also requires a degree of pre-heating before the FC becomes operational.

Another technology is the SOFC (Solid Oxide Fuel Cell). This technology differs from the two previously mentioned by performing the reaction of combining H^+ or a similar positive ion with O^{2-} at the anode rather than the cathode. The reaction involves the reduction of the O_2 molecules at the cathode before they migrate through the solid oxide separator. SOFCs have the draw back that they must operate at very high temperatures (800 -1000°C) which means that they cannot effectively be shut off as the time to start them and the thermal strains endured during cooling and heating up are extreme. In their favour, such systems require little or no catalytic material to promote the reaction, saving on the cost of precious metals and removing the concern relating to contamination of the catalyst.

Fuel Sources

Pure H_2 is both expensive to produce and store. Modern automotive H_2 tanks operate at up to 700bar[3] and for reasons of weight composite construction is replacing traditional steel tanks. The state of the art units such as the unit from Quantum are made up of three layers (TriShield™) including a structural composite shell and a polymer inner shell that is gas tight. These tanks are much lighter than conventional steel tanks with a ratio of stored H_2 to tank weight of 1:14 as opposed to 1:130 for a steel tank @ 700bar. One kg of H_2 will typically run a passenger car for close to 70km[4].

Figure 1 Quantum 700bar tank cut away

These tanks are naturally very expensive and there is no long term data on real world behavior of these tanks. Another technology that has been explored is storing the H_2 as a hydride where the H_2 combines with the metal as an unstable hydride on the metal's surface. The H_2 gas can then be recovered by heating the hydride. This technology although safer (15 bar storage pressure) and more compact (about a third of the volume of compressed H_2 at 700bar) does not enjoy the fast fuelling capability of compressed H_2 and has a 1:60[5] weight of H_2 to storage hardware.

If a high temperature fuel cell is used then the H_2 does not need to be as pure as when used with a normal PEM FC. This means that it is economic to obtain the H_2

[3] Quantum fuel System technologies World Wide

[4] GM Chevrolet Sequel, Berlin technology demonstrator

[5] Rosa Young Energy Conversion Devices

from a reformed hydrocarbon without the need for extensive purification (scrubbing) apparatus.

Whereas most H_2 rich hydrocarbons can be reformed, we will focus on Methanol, as it is a liquid (easily stored and transported) and is easily manufactured from other hydrocarbons.

Reformation equation: $CH_3OH+H_2O = CO_2+3H_2$.

Although this produces CO_2 as a bi product the efficiency of a FC powering an EV is close to 45% compared to the <20% for a gasoline engine and <30% for a Diesel. Additionally, Methanol produces slightly less CO_2 (6% approx) for each unit of energy released.

The demonstration system

The purpose of the project was to equip a Fiat Scudo 9 seater passenger vehicle converted to electric drive by enerBLU of Italy, with a fuel cell to act as an onboard recharger. This vehicle could be used as a 6-9 person taxa or van.

Figure 2 Fiat Scudo converted by enerBLU

This electric hybrid vehicle was powered by a 275V Li-Ion battery pack and a Battery Management System (BMS) developed by Lithium Balance, and a 6kW HTPEM methanol FC developed by Serenergy that would act as range extender. It was also possible to refuel the car with methanol easily and within minutes to allow the driver to continue driving the car.

In this project the partners developed this ”hybrid power pack” for hybrid-electric vehicles by integrating existing components, and by developing and optimizing the interfaces between these components.

The demonstration phase of the project assembled the following;

1) An electric Fiat Scudo with a 160Ah 275V battery pack
2) A state-of-the-art battery management system controlling the both charger and range extender
3) Two 3 kW fuel cell range extenders with control electronics and monitoring facilities
4) Power electronics to control charger, load and range extender in a safe and reliable fashion.

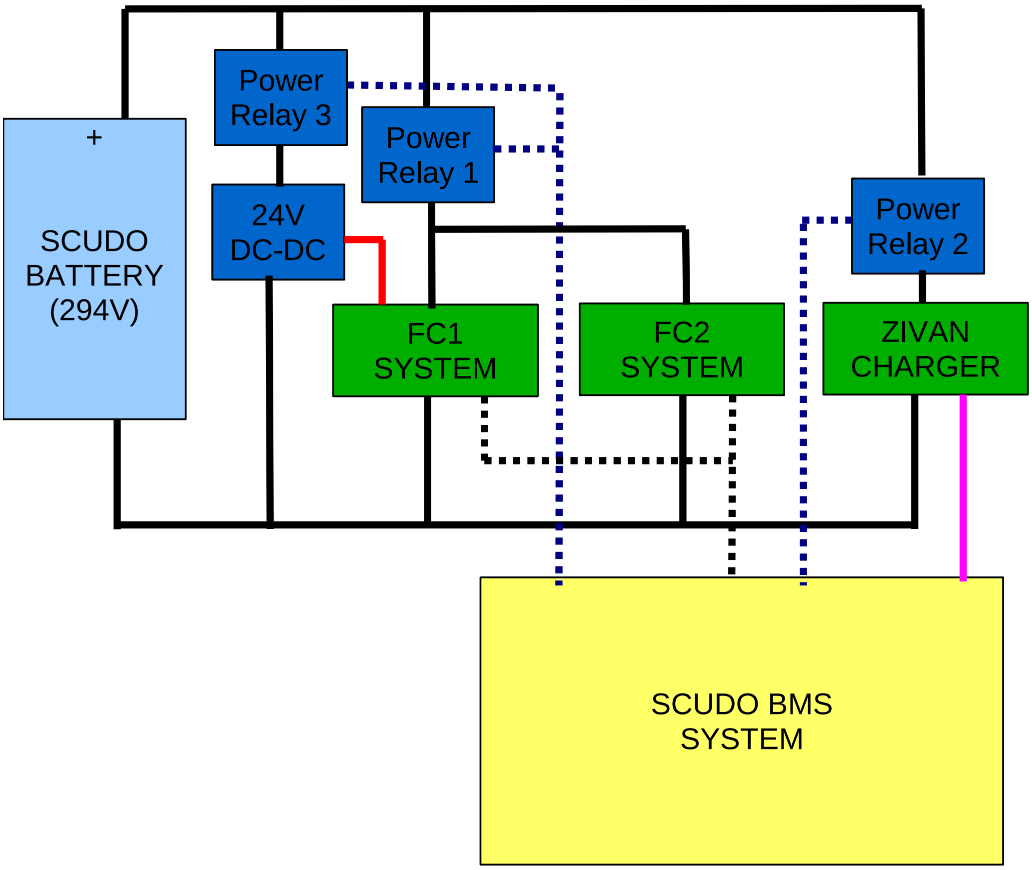

Figure 3 System overview

This design differs from typical fuel cell installations by using a relatively small FC. The FC was dimensioned to the modeled energy consumption during low speed urban driving cycles. In addition, instead of connecting the FC in parallel with the battery pack to give a direct connection to the load (traction motor), the FC only recharges the battery.

The HT PEM FC from Serenergy uses the specially patented high temperature membrane from BASF. The reformer is an inhouse design which is very compact and does without any scrubbing technology.

The system runs on a 40% water, Methanol mix. The water acts additionally to reduce the CO that occurs due to the unwanted side reaction $CO_2 + H_2 = CO + H_2O$. CO poisons a conventional PEM when present in concentrations above a few ppm.

The FC system was assembled inside a custom aluminum shell residing in the trunk of the vehicle and it included the following components

- 2 x Serenus 390 Series HTPEM modules
- 2 x prototype methanol reformers
- 100L integrated fuel tank with fuel pumps
- DC power supply
- Integrated fire suppression system

- Integrated control board with safety shut down
- Protective shielding

Figure 4 Fuel Cell with reformer

The battery pack was also assembled inside an aluminium case residing below the vehicle and it included the following components:

- 86x160Ah prismatic $LiFePO_4$ cells in series
- Lithium Balance Battery Management System
- Switching circuit
- Onboard Charger

Figure 5 Battery pack dismounted from car. BMS and switching components are placed in the two small boxes on the side. The right picture shows the battery cells inside the pack.

Optimal operation of a fuel cell is to deliver a constant current under constant voltage. The lithium ion battery pack on the other hand needs to be carefully managed in terms of cell voltages. While a vehicle is driving the pack voltage can vary significantly due to the internal resistance of the pack and the rapidly fluctuating current. To protect the fuel cells a DC/DC converter is used to regulate the pack voltage.

The battery management system periodically informs the fuel cell controller about current operating conditions, and the fuel cell controller gradually adjusts the fuel cell parameters to match the requests. Only in potentially dangerous situations will the battery management system cut the connection between fuel cell and battery. Doing so under operation may cause damage to the fuel cell, or gas leakages. But it is preferable to over charging the battery with potentially dangerous effects.

In this integration the fuel cell was only allowed to start while the vehicle was driving, and only when the SOC had dropped to 80% or lower, leaving a 20% gap to maneuver in case the fuel cell operation had to be aborted for some reason.

Tests and modeling

The Serenergy power pack was successfully installed in the Fiat Scudo and interfaced with the Lithium Balance BMS and the battery pack. Preliminary testing indicated much larger fluctuations in battery pack voltage than expected causing the initial concept of direct electrical connection of the fuel cells to the battery pack to be abandoned. An example of battery pack fluctuations while driving can be seen in Figure 6.

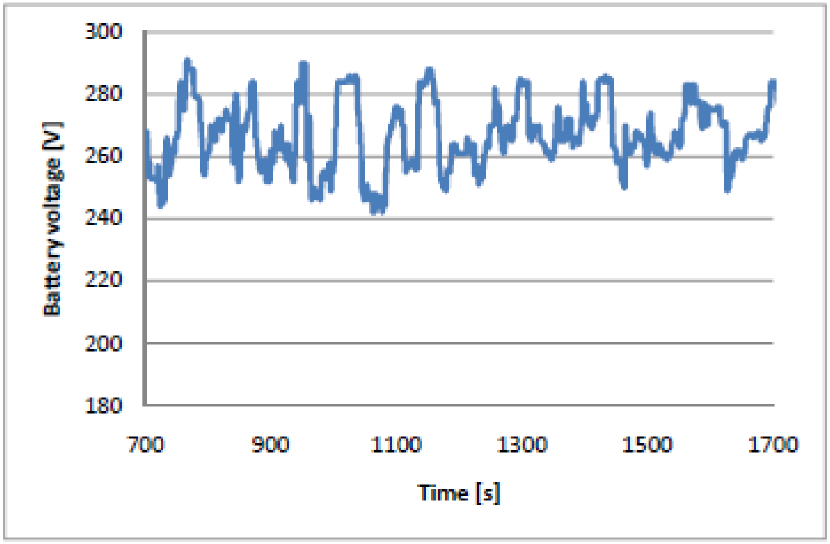

Figure 6 Real time battery pack voltage

After this discovery, a DC/DC converter was installed between the fuel cell and the battery pack to allow independent control of fuel cell operation. This will significantly increase fuel cell life time. Testing both in the lab and in the car showed the merit of this solution.

Upwards of 50 hours of testing was completed on the power pack both in the car and in the lab. During this testing the safety protocols established between Serenergy’s and Lithium Balance’s control systems were tested and found to be successful. The largely automated software for control of both the reformer and the fuel cell in the power pack was also found to operate satisfactorily.

The demonstration vehicle was driven in a road test with the fuel cells running. The fuel cell was able to deliver approximately 20% of the power required to drive the vehicle, which is according to expectations.

After a few days of testing the project suffered a setback. The test vehicle completely stopped working. At first we assumed we had damaged it somehow, but it turned out that the problem was known by the manufacturer and we eventually got the vehicle repaired under warranty. These problems limited the amount of test data we could get out of the actual test driving.

In order to use the data we had assembled we constructed a mathematical model for the fuel cell <-> battery interaction into which we could feed the actual drive data we had been able to collect. The model takes the following parameters into consideration:

- Battery pack size
- Fuel cell start up algorithm
- Fuel cell capacity
- Fuel cell tank capacity
- Fuel cell warm up energy costs

The modeling tool, using the real drive data from our road tests is what we use for the conclusions below.

We conclude from our tests that the functionality of the integrated ranged extended lithium ion battery pack is sound. We detected a couple of weak points in the design that we aim to further develop in future projects:

a) The fuel cell was too small for the vehicle. To reach the desired range we would have need at least twice as high capacity on the fuel cell. This could be addressed by smaller and lighter fuel cell designs.
b) Starting the fuel cell consumed too much energy from the battery. This can be addressed by heating the fuel cell using fuel and running the burner rather than using electric energy.
c) Starting the fuel cell took too long time for practical application. Again this could be improved by using the burner rather than an electrical heater.
d) The battery management system was suffering from congestion and noise on the communication bus. This can be addressed by reworking the communication protocols and underlying physical layers of communication.

The project did produce a valuable tool for engineering and dimensioning ranged extended lithium ion battery pack however. The tool uses the data acquired during our road tests and accurately matches the behaviors we observed in the field.

Some samples of the output from the model are showcased below.

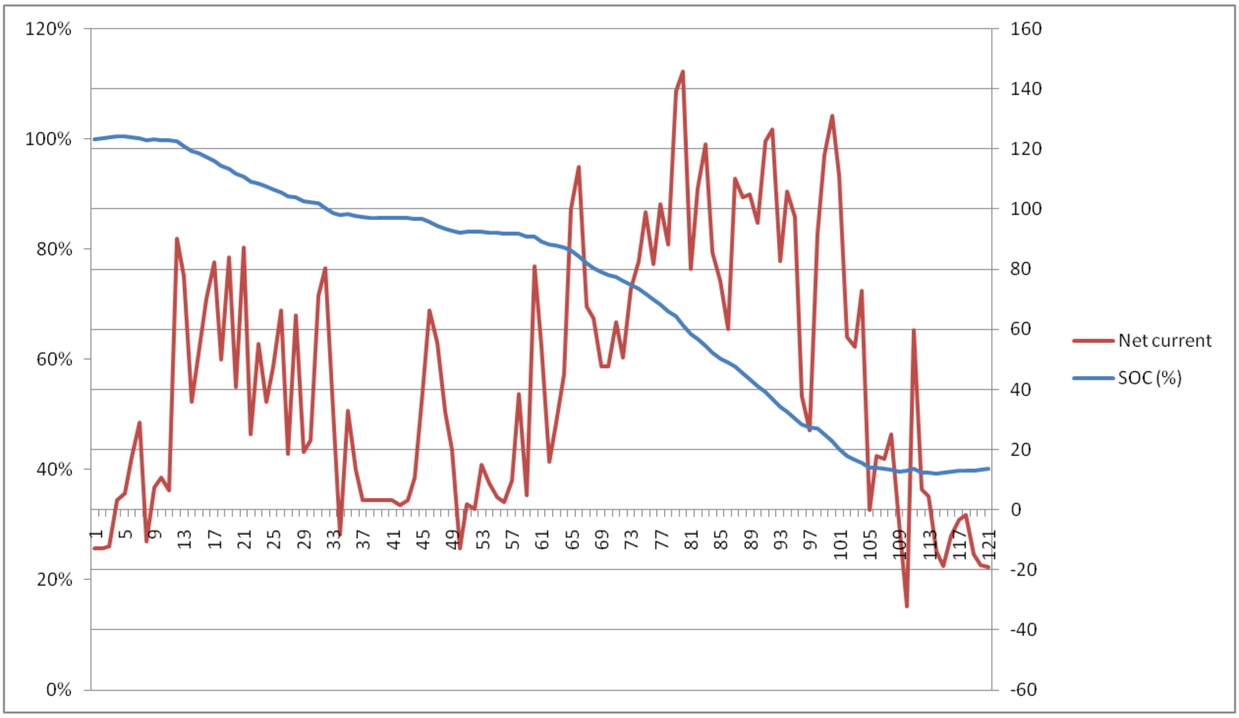

Figure 7 Drive data from the Fiat Scudo with a 6 kWh, fuel cell starts at 80%. Note that the net contribution is in fact negative since it consumes so much power to warm up. End SOC 40%.

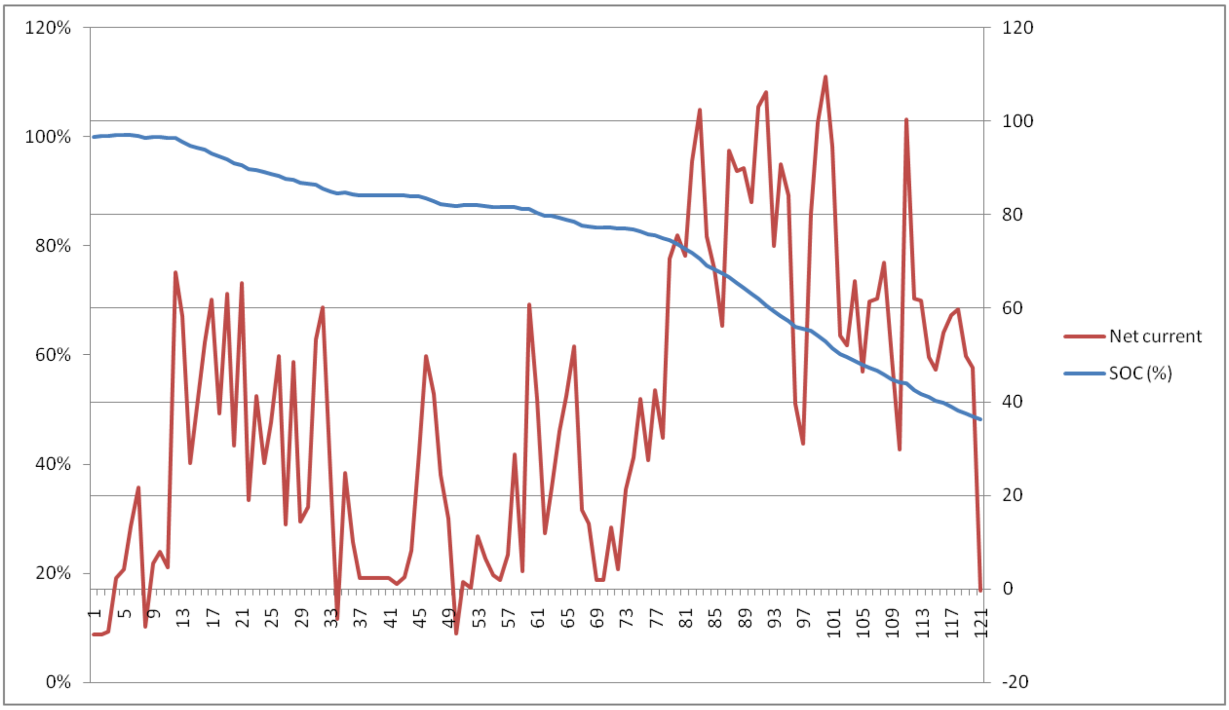

Figure 8 Smaller vehicle (25% lower energy consumption) fitted with the same fuel cell. Net contribution is still negative. End SOC 48%.

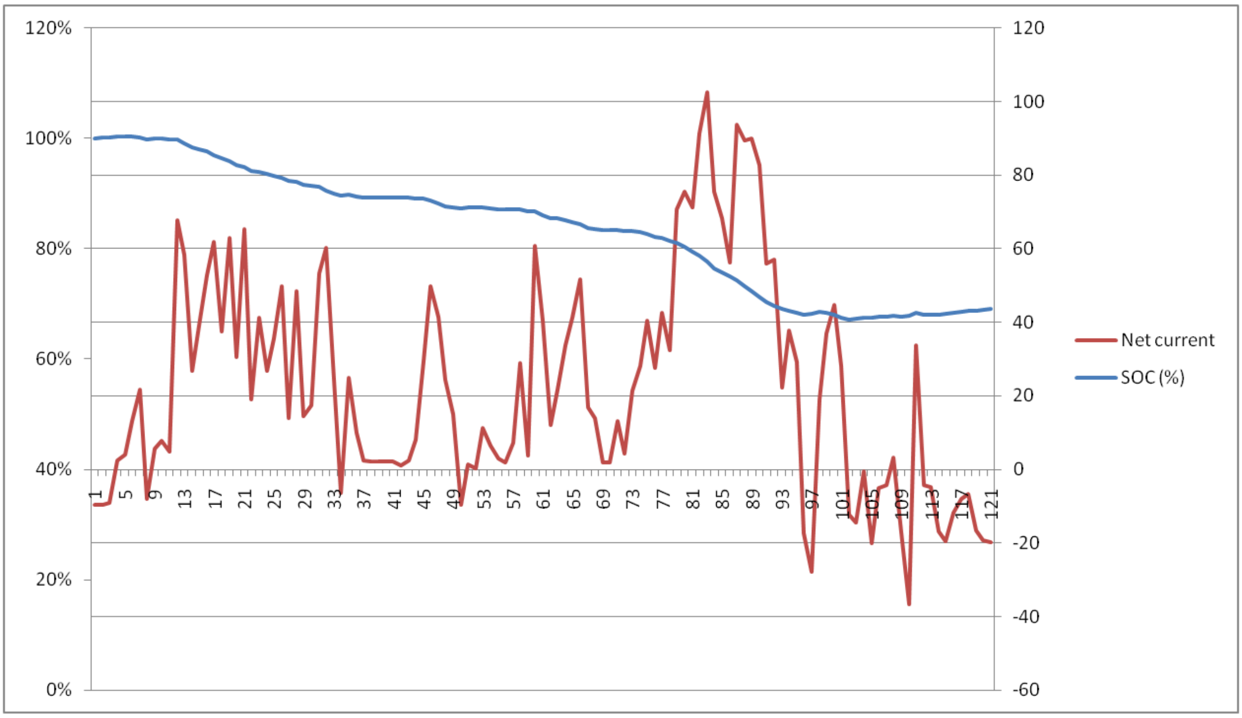

Figure 9 Smaller vehicle (25% lower energy consumption) fitted with a fuel cell that can heat up in only 10 minutes. Net contribution is now positive. End SOC 70%.

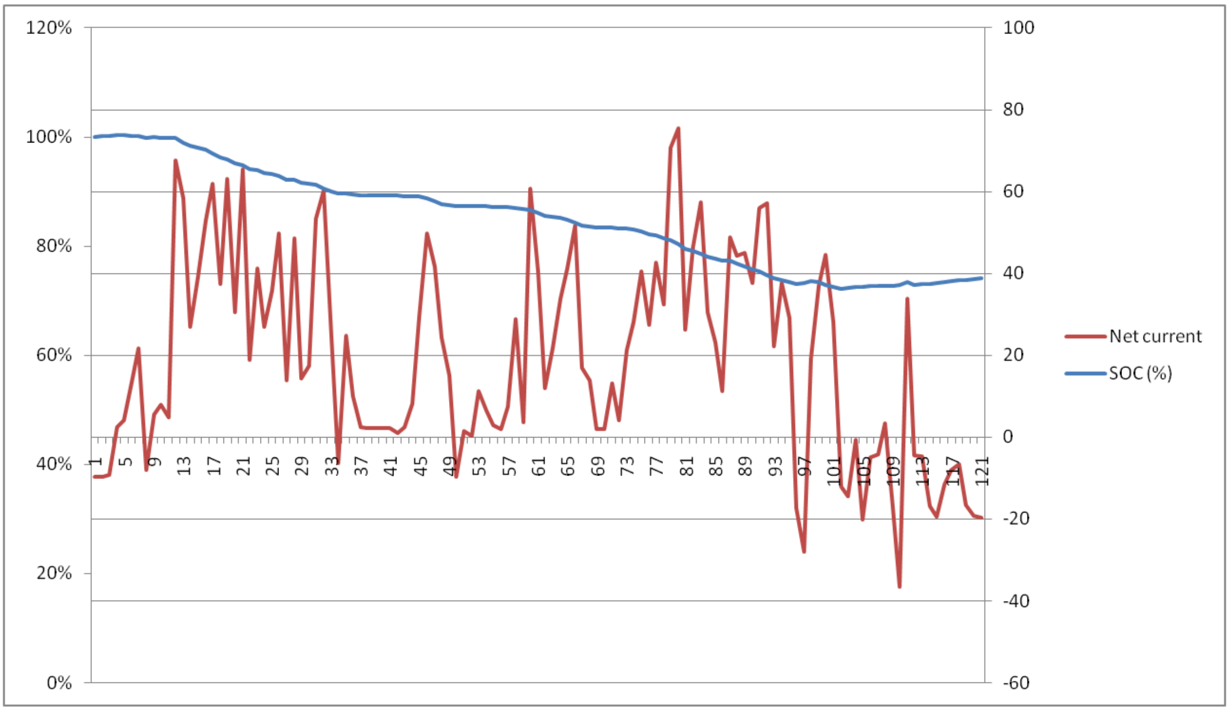

Figure 10 Smaller vehicle (25% lower energy consumption) fitted with a fuel cell that can heat up in only 10 minutes without consuming any power from the battery. Net contribution is still even better. End SOC 78%.

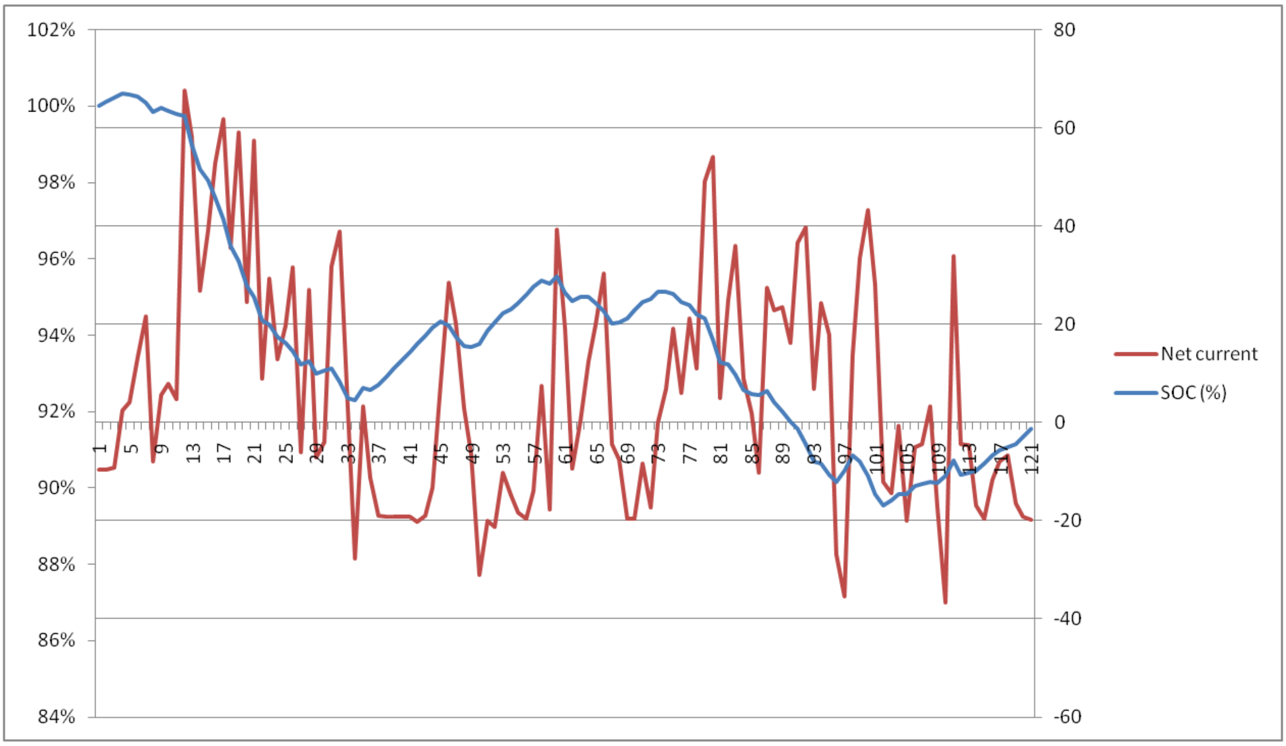

Figure 11 Smaller vehicle (25% lower energy consumption) fitted with a fuel cell that can heat up in only 10 minutes without consuming any power from the battery. The fuel cell is now also allowed to start at 100% SOC. Now the SOC is dropping very slowly, leaving the fuel cell tank as the key limiting factor to achieving a very long range. End SOC 91%.

Conclusion

This project has proved that a practical HT PEM FC using reformed methanol as its fuel source is viable and practical. This technology when used in an EV provides a 68% CO_2 saving compared to a gasoline engined vehicle operated under the same conditions and methanol as an energy carrier in hybrid electric vehicles is also potentially significantly cheaper than other fuels.

Energycarrier	Price in €/unit	Energy content/unit	Electric efficiency	€/KWh electricity
Methanol	€0.64/kg	5,47 KWh/kg	0,4	€0.29
Hydrogen	€6.7, 10.7, 14.7 /kg	33,33 KWh/kg	0,4	€0.5 / 0.8 / 1.1
Gasoline	€1.3/L	8,8 KWh/L	0,2	€0.68
Diesel	€1.1/L	10 KWh/L	0,25	€0.43

Table 1 Cost comparison of various energy carriers

The safe, cheap readily available and easy to transport methanol could be distributed via the existing fueling infrastructure without huge investment. This means that the key challenge for the further commercialization of this technology in automotive applications is the challenges relating to finalizing the product development to arrive at a robust, automotive certified and cost competitive Li-ion battery / methanol driven HT PEM FC power pack.

In that respect this project identified a number of technological challenges that where either solved in the project or should be further investigated in future research:

1. Voltage fluctuations - Under the various driving conditions, it became quickly clear that the battery pack voltage fluctuations were of a severity as to effect the performance of the fuel cells. Under hard acceleration, a drop in pack voltage would lead to an increase in current draw from the FC leading to H_2 starvation as the reformer is unable to ramp up quickly enough to handle transient load changes. Under stationary conditions or regenerative braking, higher pack voltage leads to a drop in current from the FC and a heat spike at the anode. FCs have a sweet spot relating to load and voltage where they operate at their most efficient, this is always the targeted operating window.

2. Start up time for the reformer and HT PEM FC, both of these devices require pre heating. This is currently done electrically, partially draining the traction batteries.

3. Interfacing with the battery pack – To ensure proper operation the FC system needs to constantly receive state of charge information from the battery pack battery management system. In event of errors or system problems, the BMS is required to open the necessary contacts to isolate the battery pack.

4. Pack Health – The battery pack in this installation requires balancing as expected, but the additional mini cycling due to the presence of the FC further increases this need

5. SoC estimation - Safe operation requires that the battery not be overcharged or allowed to empty. The $LiFeO_4$ cell chemistry employed has a flat discharge curve making SoC estimation a more complex problem.

6. Thermal management – The cathode of the fuel cell needs cooling, to run at a steady 160-180°C the reformer needs to be heated up to 220-250°C to minimize CO production (<1%).

The possible next steps for further research are therefore the following:

1. Pack Voltage variations. This can be countered by the addition of DC/DC converters to control the load on the FC or choice of different battery cells with lower internal impedance, and correspondingly lower changes in pack voltage under varying load.

2. Integrated thermal management, possibly using methanol burner to heat the reformer. Optimised management of the various cooling and heating air streams, providing heating to the vehicle cabin on demand during winter, or heating to the batteries to allow charging at low external temperatures.

3. Full integration of control system to make a fully automated requiring no external intervention beyond refuelling

In conclusion we have developed a lot of knowledge about the energy economics of a ranged extended lithium ion pack in this project. That knowledge can be applied in future development project to enhance the products of both partners, in addition the knowledge in very valuable when designing commercial solutions for our customers. We hope to see this technology flourishing in many future applications. The partners have during the project received significant attention from car manufacturers worldwide for the developed power pack concept resulting in agreements for pilot projects.

Project plan

The original project plan was:

- Project start 1.1.2009
- 2009 Q1: project kick-off, develop BMS-FC interface and user interface
- 2009-Q2: integrate the system in the car and begin a three months test period
- 2009-Q3: complete testing and report the results
- Project finished 1.9.2009

In reality the projected suffered a substantial delay due to noise and other technical problems with the car. The actual project time line looked like this:

- 2009-Q1: Project kick off, car purchased, delivered and prepared for system integration, BMS-FC interface and user interface developed. On plan
- 2009-Q2: BMS installed in the car, but technical issues delayed the fuel cell installation and vehicle test. Small delay
- 2009-Q3: The vehicle suffered from large noise problems and other technical problems. In cooperation with the manufacturer, the problems were solved and the BMS integration successfully completed and tested in the car. Delay estimated to four months
- 2009-Q4: The fuel cell was integrated in the car. The first test showed problems with voltage fluctuations. A solution with DC/DC converters were develop, but it was not possible to start user tests. The car was demonstrated at COP15
- 2010-Q1: user test started but the car engine broke down shortly thereafter. The car had to be returned to Italy for repair. The test results were instead used to develop a modeling tool.
- 2010-Q2: As the car had still not been returned from repair, the project was closed as significant results had already been collected.
- Project finished June 15, 2010

Dissemination of results

The vehicle was during the project demonstrated at the COP15 in Copenhagen in December 2009. The attached leaflet was produced for this occasion also.

Just prior to the convention the vehicle was also presented in Danish television.

The project and its results have later on been presented at the IAMF conference in Geneva, Marts 2010.

Finally, an article about the project has been published by Lithium Balance in their newsletter and on their homepage.

Project economy

The total project budget and the actual project expenditures are shown in this table:

	Budget				Actual			
Salaries (Researchers)	Hours	2088	kr.	720.000	Hours	2568	kr.	860.504,02
Salaries (techn/adm)	Hours	200	kr.	40.000	Hours	232	kr.	46.400,00
Equipment			kr.	320.000			kr.	320.000,00
Materials			kr.	320.000			kr.	364.216,82
Travel			kr.	0			kr.	0
External services			kr.	200.000			kr.	215.117,98
Rapporting			kr.	0			kr.	0
Other			kr.	0			kr.	0
Overhead			kr.	400.000			kr.	450.465,59
Total			kr.	2.000.000			kr.	2.256.704,41

Paid by EUDP	kr.	998.229,51	44%
Paid by LiBal/Serenergy	kr.	1.258.474,90	56%

The technical problems seen with the vehicles during the project resulting in significantly more work for both participants in order to complete the project. As a consequence the project budget was exceeded by 13%.

Attachments

The following documents are included as attachments to this report:

- Leaflet describing the hybrid car
- Newsletter published by Lithium Balance

TECHNICAL INFORMATION

Electric Fiat Scudo 9-seat minibus with fuel cell range extender

Introduction

Even with current technology, electric drive, commercial vehicles make good economic sense for local or urban operation. However, range limitations and a lack of recharging infrastructure still present challenges. The solution is certainly not more or bigger batteries.

Range Extension

Dramatically change the capability of electric commercial vehicles by adding an onboard fuel cell range extender. Fuel cells enjoy conversion efficiencies of up to 50% compared to the 20-25% achievable with an ICE.

The range extender works as an onboard charger for the battery pack continually feeding energy in during the working day, extending the range between recharges by anything up to 400%!

Innovative Technology

No need for expensive hydrogen tanks, the system runs on diluted methanol. A patented, compact, reformer/high temperature PEM fuel cell system from Serenergy A/S integrated with a Lithium balance A/S developed battery system are at the heart of the solution. This unique blend of Danish technology brings real world benefits from state-of-the-art technology.

Contd. on following page

Specifications

Range: 500km with fuel cell; 100km without
Topspeed: 110km/h approx
Engine Power: 30kW nominal
Battery pack capacity: 44kWh
Battery pack voltage: 275 volts nominal
Fuel cell type: HTPEM, High temp polymer electrolyte membrane with attached methanol reformer

LiTHIUM BALANCE
BATTERY MANAGEMENT SYSTEMS

Serenergy
The Power of Simplicity

MethaEnergy

TECHNICAL INFORMATION

Serenergy

Serenergy is a leading manufacturer of fuel cell stack modules featuring HTPEM (High Temperature Polymer Electrolyte Membrane) technology. By combining a compact and efficient methanol reformer with their renowned fuel cell stack technology, Serenergy have created an ultra low emissions power source suitable for both transport and other applications. Methanol is an inexpensive fuel in comparison to petrol or diesel and given the high energy conversion efficiency of the fuel cell; this solution provides cost benefits, even before environmental considerations and potential tax benefits are considered. No moving parts and the availability of heat as a useful by product for warming the vehicle cabin or batteries during cold weather, makes this a very practical proposition for use all year round, all over the world. Serenergy supplies a full range of fuel cells and accessories.

To learn more visit **www.Serenergy.com**
This solution is marketed in cooperation with Metha Energy.

Metha Energy is a US based company focusing on commercializing innovative fuel cell technologies able to use methanol as an energy source.
www.methaenergy.com

Serenus 390 Air C
HTPEM fuel cell from Serenergy

LiTHIUM BALANCE

Located in Denmark, Lithium Balance is a leading supplier of Battery Management Systems (BMS) for industry. With two BMS platforms covering all applications from small machines and robots up to large trucks; Lithium Balance provides the key tools and technologies necessary for the safe use of Lithium Ion batteries in industrial applications. Full in-house engineering and development capabilities allow us to deliver fully integrated solutions for both transport and other industrial applications. Our award winning S-BMS (scalable BMS) provides system level management for the vehicle battery pack and the range extender, continuously monitoring the battery pack at individual cell level and controlling the fuel cell to prevent overcharging.

In addition, the BMS provides the necessary communications interface to the vehicle drivetrain and chassis.

To learn more visit
www.Lithiumbalance.com

Lithium Balance S-BMS, Control Unit & Cell Monitoring Unit with cables

LiTHIUM BALANCE
BATTERY MANAGEMENT SYSTEMS

Newsletter no. 3 - 2011 Page 3/6 6.March 2011

Long on range, short on emissions, the addition of a range extender to a battery electric vehicle

LiTHIUM BALANCE were involved in a project to add a Fuel Cell range extender to a battery electric vehicle

Electric commercial vehicles are starting to find a role in commerce. Commercial vehicles often benefit from being predictable in their usage making it possible for a straightforward calculation of running costs versus initial purchase cost over the lifetime of the vehicle, to be made. Additional benefits from government subsidies and branding opportunities further improve the attractiveness of electric commercial vehicles.

Figure 4 9 seater Fiat Scudo Electric Vehicle - donor vehicle

Range Anxiety

The lack of a wider suitable charging infrastructure means that it is relatively easy to strand an EV by depleting its battery. This can occur accidentally under a range of conditions such as use of onboard ancillaries like the cabin heater, defective battery cells within the pack or simply the requirement to drive beyond the normal range.

The idea of using larger battery packs that would give a range of 200km or more presents obvious problems of cost, additional weight and space (reducing payload).

The Project

To counter these problems The Danish Energy Agency funded a development project to add a Fuel Cell (FC) range extender to a battery electric vehicle. The principal members of the project were LiTHIUM BALANCE who supplied the donor vehicle including battery pack and the battery management system and Serenergy who provided the fuel cell and its control electronics.

The concept differed from typical FC installations by using a relatively small FC (6kW). The FC was dimensioned to the modelled energy consumption during lowspeed urban driving cycles. FC only recharges the battery.

The vehicle's battery range was over 100km. The addition of an FC potentially extended this range up to 500km.

Technology and operation

The HT PEM (see box) FC from Serenergy uses the patented, high temperature membrane from BASF. The reformer is an inhouse design which is very compact and does without any carbon monoxide (CO) scrubbing technology.

The system runs on a 40% water, Methanol mix. The water acts to reduce the CO that occurs due to the unwanted side reaction $CO_2 + H_2 = CO + H_2O$. CO poisons a conventional PEM when present in concentrations above a few parts per million (ppm).

Short introduction to Fuel Cell technology

The commonly used technology is the PEM – Polymer Exchange Membrane type. Here, H_2 is introduced at the anode where it is catalytically split to a proton and a free electron. The PEM allows the proton to migrate through it to the cathode where it combines with O_2- ions to create water vapour and heat. The electron that was stripped from the proton passes through an external circuit where it does work before reducing O_2 molecules taken from the air that subsequently combine with protons to form water vapour and heat.

With proper load matching 50% operational efficiency is achievable making it at least 2.5x as efficient as simply burning the H_2 in an ICE.

A variation on this technology is the High Temperature Polymer Exchange Membrane (HTPEM) FC. This technology is able to operate at elevated temperatures between 120-180°C. At this temperature, the catalysts are less susceptible to poisoning by CO which lessens the purity requirements for the H_2 supply.

Challenges

Pack voltage fluctuation – Under various driving conditions, it became clear that the battery pack voltage fluctuations were affecting the performance of the fuel cell. Under hard acceleration, a drop in pack voltage would lead to an increase in current draw from the FC leading to H_2 starvation as the reformer was unable to ramp up H_2 generation quickly enough to handle transient load changes. Under stationary conditions or regenerative braking, a higher pack voltage lead to a drop in current from the FC and a heat spike at the anode.

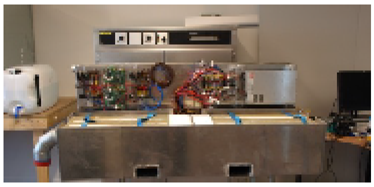

Figure 5 Prototype system prior to vehicle installation

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FCs have a sweet spot relating to load and voltage where they operate at their most efficient, this is always the targeted operating window. To keep the FC operating in its sweet spot, twin DC/DC converters were added between the battery pack and the FC to ensure that the pack voltage swings did not affect the operation of the FC.

System Management

System wide coordination was handled over CAN by the BMS with the BMS providing information to the FC controller for FC operation and to the motor controller for load control. The BMS also provided the system safety logic controlling the contactors to isolate the battery pack.

Conclusions

This project has proved that an HT PEM FC using reformed methanol as its fuel source is viable and practical. This technology when used in an EV provides a 68% CO_2 saving compared to a gasoline engined vehicle operated under the same conditions. The principle of using an FC as an energy source to recharge the power source (batteries), has merit, by reducing the size of the fuel cell required, while the system keeps its overall emissions footprint low due to the use of mains power for bulk charging the battery pack.

Methanol is safe cheap and easy to transport and could be distributed via the existing refueling infrastructure. Unlike its cousin, Ethanol, methanol is not produced from food sources, but from an industrial process instead.

The vehicle was on taxi duty at the COP15 summit in Copenhagen and road testing will continue along with a stage two project to further refine the technology.

Using reformed hydrocarbons

If a high temperature fuel cell is used then the H_2 purity can be lowered such that the H_2 can be manufactured from a reformed hydrocarbon without the need for extensive purification (scrubbing) apparatus.

Whereas most H_2 rich hydrocarbons can be reformed, we will focus on Methanol, as it is a liquid (easily stored and transported) and is easily manufactured from other hydrocarbons. Reformation equation: $CH_3OH + H_2O = CO_2 + 3H_2$.

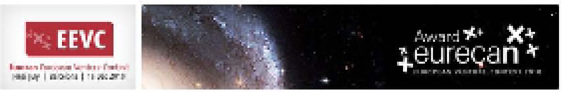
Although this produces CO_2 as a bi product the efficiency of a FC powering an EV is close to 45% compared to the <20% for a gasoline engine and <30% for a Diesel. Additionally, Methanol produces slightly less CO_2 (6% approx) for each unit of energy released.

Let's celebrate

LiTHIUM BALANCE received the prestigious Frost and Sullivan 2009 European Automotive Powertrain New Product Innovation Award and are runners up in the 2010 Eurecan Venture Contest

Frost & Sullivan presented LiTHIUM BALANCE Battery Management Systems A/S with the "2009 European Automotive Powertrain New Product Innovation Award". Points that counted in LiTHIUM BALANCE's favour, according to Frost & Sullivan research analyst, Bharath Kumar Srinivasan were the vehicle-to-grid features and the significant life extension of battery cells due to the s-BMS's performance. The extended battery life translates to sustained vehicle performance over time.

LiTHIUM BALANCE was also a runner up in the Eurecan European Venture Contest which saw 987 applicants from all over Europe compete for the top honors. LiTHIUM BALANCE, represented by Lars Barkler made it through, first to the last 150, before going on to the last 25 and finally ending up second in the Cleantech category. More cause for celebration!



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