Journal of Asian Electric Vehicles, Volume 9, Number 2, December 2011

An Electric Vehicle Conversion using Batteries and Ultracapacitors: Preliminary Performance Investigation

Manoj Embrandiri [1], Dino Isa [2], and Roselina Arehli [3]

[1] *Department of Electrical & Electronic Engineering, University of Nottingham Malaysia, keyx9mem@nottingham.edu.my*
[2] *Department of Electrical & Electronic Engineering, University of Nottingham Malaysia, dino.isa@nottingham.edu.my*
[3] *Department of Electrical & Electronic Engineering, University of Nottingham Malaysia, roselina.arelhi@nottingham.edu.my*

Abstract

The initial findings and performance of a prototype electric vehicle conversion of a famous Malaysian city car; the perodual kancil, is presented in this paper. The 660 cc, three cylinder carbureted engine rated at 31 Hp (22.1 KW) was replaced with a 48-72 V series wound DC motor rated at 8 KW continuous and 20KW peak. The battery pack consists of eight T105 Trojan 6 V, 225 Ah deep cycle lead acid battery which builds up a voltage of 48 V. In addition to this, an ultracapacitor module (165 F, 48 V) is connected in parallel using high power contactors in order to investigate the increase in performance criteria such as acceleration, range, battery life etc which have been proven in various literatures via simulation studies. A data acquisition system is setup in order to collect real world driving data from the electric vehicle on the fly along a fixed route. Analysis of collected driving data is done using MATLAB software and comparison of performance of the electric vehicle with and without ultracapacitor module is made.

Keywords

electric vehicle, ultracapacitor, drive cycle, MATLAB, data acquisition

1. INTRODUCTION

A growing concern in today's world is environmental protection and energy conservation. Automotive manufacturers are developing alternatives to existing fossil fuel-driven vehicles. This has paved way for the development of Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV). While HEVs tend to reduce the emissions from internal combustion vehicles as a result of greater fuel efficiency, they do not completely solve the problem. Electric vehicles on the other hand are much more energy efficient, produce absolutely no tail pipe emissions and requires less maintenance as compared to the conventional internal combustion vehicles. However, the reason the automotive industry has not gone pure electric or able to compete favorably with existing gasoline cars, lies in the inherent problem of existing battery technologies. Even with ICE energy conversion efficiency figures of below 20 %, the energy density (Joules/kg) of petroleum far surpasses the energy density of any known battery technology. Batteries are the weak link in EVs at the moment. The lack of a single reasonably priced energy storage device that can simultaneously provide high power density and high energy density for EVs has been the main stumbling block to the acceptance of EVs as the main form of private and public transportation [Larminie and Lowry, 2003; Brant, 1993]. Presently the only viable solution to this problem is to combine a high energy storage device such as an electrochemical battery or fuel cell with a high power device such as an Electric Double Layer Capacitor (EDLC) or ultracapacitor or more often called a supercapacitor [Pasquier et al., 2003]. In this work, we investigate the effect of integrating the ultracapacitor with the main power source (deep cycle lead acid batteries) of an EV conversion. In the first phase which is mainly described in this work, a direct parallel connection between the battery pack and ultracapacitor module was adopted.

As the name implies, a ultracapacitor is a capacitor with capacitance greater than any other, usually in excess of up to 4000 Farad. Ultracapacitors do not have a traditional dielectric material like ceramic, polymer films or aluminum oxide to separate the electrodes instead a physical barrier made of activated carbon. A double electric field which is generated when charged, acts a dielectric. The surface area of the activated carbon is large thus allowing for the absorption of large amount of ions [Tuite, 2007; Schneuwly et al., 2005].

(1) Advantages of Ultracapacitors
- Cell voltage determined by the circuit application not limited by cell chemistry
- High power density
- Can withstand extreme temperatures
- Simple charging methods
- Very fast charge and discharge

- Overcharging not possible
- Long life cycle
- Low impedance

(2) Disadvantages/Shortcomings

- Linear discharge voltage characteristic prevents use in some applications
- Power only available for very short duration (short bursts of power)
- Cell voltage restricted to 2.7-3 V
- Low energy density
- Voltage balancing required when banking
- High self discharge rate

Electric load profile for EVs and HEVs consists of high peaks and steep valleys due to repetitive acceleration and deceleration. The resulting current surges in and out of the battery tend to generate extensive heat inside the battery, which leads to increased battery internal resistance – thus lower efficiency and ultimately premature failure [Pay and Baghzouz, 2003]. However, if the main battery is sized for average power needs and the ultracapacitor (owing to the above mentioned properties) sized for peak power surges, then we have an energy source which has both high energy and power densities. Direct connection of the ultracapacitor across the battery terminals does reduce transient currents in an out of the battery; the best way to utilize the ultracapacitor bank is to be able to control its energy content through a power converter [Dixon and Ortuzar, 2002; Jinrui et al., 2006; Ortuzar and Moreno, 2007].

Section 2 describes the mechanical aspect and electrical wiring of the EV conversion. Section 3 discusses the data acquisition system and testing procedure carried out and finally section 4 discusses the relevance of the results obtained and outlines the future work to be carried out.

2. ELECTRIC VEHICLE CONVERSION

A famous city car in Malaysia, the Perodua Kancil, was chosen for conversion into a fully electric vehicle due to its light weight, readily available spare parts and also suitability for a lower voltage conversion. It has a 660 cc (1997 model), three cylinder carbureted engine rated at 31 Hp (22.1 KW), other specifications can be found below:

Table 1 Technical specifications of the Perodua Kancil

Length	3365 mm	Engine	659 cc, water cooled, 4 stroke, 3 cylinder
Height	1405 mm	Max output power	22.8 KW (31 hp)/6400 rpm
Wheel base	2280 mm	Max torque	49 Nm/3200 rpm
Kerb weight	681 kg	Fuel system	Carburetor; 32 liter fuel tank
Seating	5	Power train	Clutch, 5-speed manual
Coeff. of drag	0.37	Tires	155/70R12
Frontal area	0.619 m^2		

The first stage in any EV conversion is usually very mechanical. This involves removing the engine block totally from the vehicle which will make way for the electric motor. Also, the fuel tank was taken out.

After the engine block and fuel tank was removed from the vehicle there was a weight reduction of about 150kg. Battery racks made of solid cast iron were fabricated and fitted to the rear compartment of the vehicle as shown in the figure below. Eight (6V, 225Ah) Trojan T105 deep cycle lead acid batteries were connected in series to produce a 48V, 225Ah battery pack. The overall weight of the battery pack was 240Kg; concentrated in the rear compartment due to convenience of installation and lack of space in the front compartment. However tougher coil springs were used instead of the normal springs installed in

Fig. 1 Perodua Kancil to be converted into a fully electric city car

Fig. 2 8 x (6 V 225 Ah) T105 Deep cycle Lead Acid Batteries installed

the vehicle in order to reinforce the rear suspension.

2.1 Electric motor mounting and coupling

In an internal combustion engine (ICE), the clutch is used to disengage the transmission from the engine (idle) and also to bring the vehicle up to speed in gears. An electric motor's RPM can be easily varied from zero to maximum at full torque eliminating the need for a clutch and also the flywheel which is used for building up inertia between the power strokes of the ICE. Hence drivability is only about shifting from second to third gears without a clutch which many cars can do rather smoothly. The clutch, flywheel and pressure plate assembly was removed and the electric motor was attached directly to the transmission input shaft by using the roller chain type coupling. A roller chain coupling consists of one duplex roller chain and two sprockets for a simplex chain (see Figure 3 below). Handling is very simple as both the shafts (driving shaft and driven shaft) can be connected and disconnected by inserting or removing connecting pins.

One sprocket was attached to the electric motor by a keyed shaft while the other sprocket was fitted with a splinned shaft to match the spline on the drive shaft coming from the gearbox. For this project, the center piece of the removed clutch plate was welded out and fitted into the other sprocket. This provided a simple yet sturdy coupling of the electric motor to the clutchless transmission which is capable of transmitting a large torque owing to the fact that the roller chain engages the sprockets at all the teeth. The roller chain coupling has a standard aluminum alloy housing (see Figure 3) which serves as a grease box for lubrication, protection from dust, moisture and grease scattering.

Custom-made mounting was fabricated with hardened steel in such a way that it formed a tight grip around the center of the motor making sure no air ventilations are blocked. Flexible padding was placed between the motor and the mounting jaws in order to reduce the vibration from the motor being transmitted to the mounting. The original mounting points to the chassis of the car were used where possible, similar mounting points were created using standard engine mounting rubber. Owing to the play between the respective components of the chain and the play between the roller chain and the sprockets, the alignment of the center of the motor shaft to the center of the transmission shaft is allowed to have a certain play as well. Alignment ultimately boils down to sprocket- to- sprocket matching on both driving and driven shafts. The motor was finally placed in with the help of a jack and then locking the mounting points in place. Careful adjustment was done to align the sprockets and then mounting points secured firmly in place. The aligned sprockets were connected by the roller chain and locked using the cotter pins.

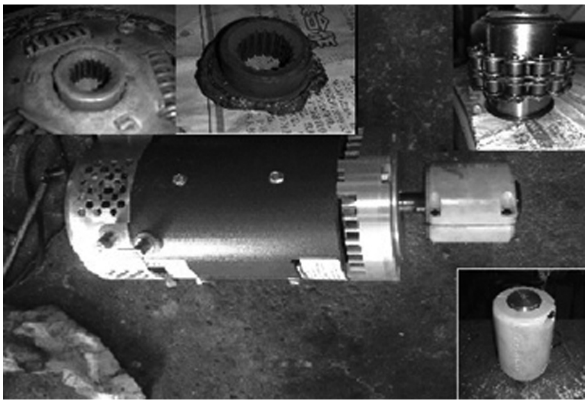


Fig. 3 Center spline (top center) from clutch disk attached to sprocket on one side and keyed into motor shaft on the other, Housing for coupling to act as grease box.

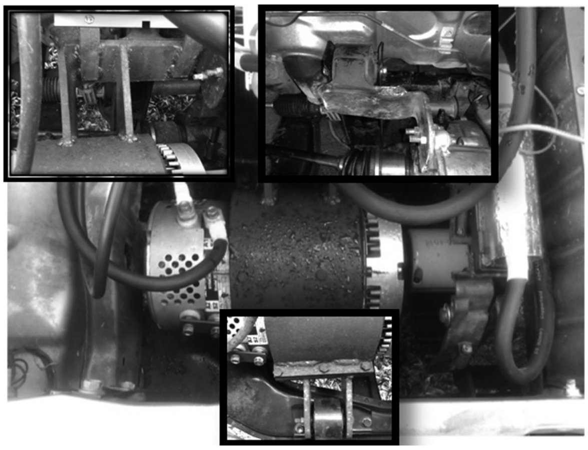


Fig. 4 Motor successfully mounted, showing the mounting points used

2.2 Electrical wiring

After all the main mechanical conversion part was done, the next stage was to wire it all up. The table below lists out all the parts which were used for this conversion and their specifications.

The parts listed in the table above were connected according to a certain wiring diagram (see Figure 7 below). The thick lines represent 2/0 gauge welding cables which were used for the main traction wiring. It should be noted that wherever possible, fuses (10 A, 5 A) were used to protect the auxiliary circuit. The 12 V chassis ground must be isolated from the 48 V system. This is to ensure that through error, or accident, the chassis ground cannot complete a 48 V potential loop. The 48 V system has no common grounded chassis like the 12 V system.

Table 2 EV conversion parts and specifications

	Equipment/Part	Specification
1	DC series motor (D&D ES-15-6)	• 48-72 VDC series motor • 9 HP @ 72 V continuous rated • 88 Nm torque peak • 25 HP peak • Actual weight 25 Kg
2	Alltrax Axe 7245 dc series wound motor controller	• Programmable via RS232 • 450 A current limit • 36 V-72 V DC
3	Trojan T105 deep cycle lead acid batteries	• 6 V, 225 Ah (20 hr rate)
4	Maxwell ultracapacitor module BMOD0165P048	• 165 F, 48.6 V • ESR 7.1 milliOhms • Individually balanced cells • Compact, rugged fully enclosed • Max, continuous current 150 A
5	12 V Albright contactor SW200B-84 12 V	• 12 VDC continuous duty coil with blowouts • Weld resistant silver alloy contact tips • 70 % duty 300 A
6	Throttle PB-6	• 0-5 ohms resistance • Microswitch contactor control • Compatible with existing accelerator cable
7	Emergency disconnect/kill switch	• Heavy duty 500 A • Key operated
8	Panel meters: voltage, current (analog and digital meters)	• Voltage (0-80 V) • Current (0-300 A) with 50 mv shut
9	Auxiliary DC-DC converter	• Input: 40 to 64 VDC • Output: 13.2 Vdc, 12 A, 158 W • Efficiency: 82 %
10	Automotive lead acid battery charger	• Input: 240 Vac, 50 Hz • No of batteries: 4 x 12 Vdc or 8 x 6 Vdc • Charging current: adjustable (20 A max)

In conventional vehicles, the 12 V auxiliary battery used for startup and accessories is usually charged by the alternator when the engine is running. In this EV conversion, a step down dc-dc converter was used to replace the alternator for charging the 12V battery. This converter taps 48 V from the main battery pack and steps it down to 13.2 V dc. Its operation is controlled by a relay which is activated by the ignition key switch of the car.

For safety reasons, the micro switch on the throttle was used to turn the main contactor on and off, in other words if your foot is off the throttle, the main contactor goes off. If something goes wrong such as a runaway motor, then my releasing the throttle (usually happens on instinct), the main contactor is turned off and the circuit is broken.

Also an emergency kill switch was installed in an accessible area (just beside the gear stick). This serves as emergency disconnect from battery pack in case of motor/controller failure.

2.3 Installation of ultracapacitor module

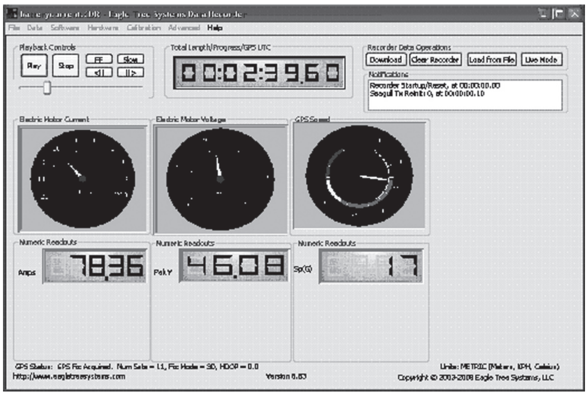
Custom made rack was fabricated to house the ultracapacitor module in the front compartment, right above the electric motor mounting assembly. A 300 A fuse was connected as well as digital voltmeters and ammeters in order to monitor the charging and discharging capabilities of the ultracapacitor module.

3. DATA ACQUISITION AND TESTING

For initial testing purposes, a fixed driving route within the university's campus was chosen. A data logging device along with a wireless telemetry system was installed in the car to collect data from current and voltage sensors which were used to monitor the power flow from the battery pack and the ultracapacitor module.

Due to existing local traffic regulations, an electric converted vehicle is not road legal, so testing was done within the university's campus. The route chosen is 1.7 km from the university's engineering faculty, all around and back to the original starting point. This route is very similar to city driving conditions or speed restricted driving conditions such as in residential areas with a lot of speed bumps. We shall refer to this drive route (cycle) as UNMC cycle.

A MATLAB program was written to calculate certain parameters from the above real world drive cycle in order to characterize it and compare it with existing standard drive cycles.



Recorder Startup/Reset, at 00:00:00.00
Seagull Tx Reinit: 0, at 00:00:00.10

GPS Status: GPS Fix Acquired. Num Sats = 11, Fix Mode = 3D, HDOP = 0.0
Units: METRIC (Meters, KPH, Celsius)
http://www.eagletreesystems.com
Version 6.83
Copyright © 2003-2008 Eagle Tree Systems, LLC

Fig. 5 Eagletree system's USB car data recorder with live laptop display of battery pack voltage & current, GPS speed and timestamp etc.

Table 3 summarizes the main characteristics of the UNMC drive cycle (see Figure 7). For over 70 % of the total drive cycle, speeds of between 10 kmh-1 and 45 kmh-1 were recorded and none above. Idling time recorded was 9.8 % which could vary depending on amount of traffic on campus at the time of testing. In the real world, this could represent a driving trip in a residential community from say the house to the grocery shop encountering a lot of speed bumps on the

Table 3 Characteristics of the UNMC drive cycle

Distance	1.7 km	% Idle time	9.48 %
Duration	773 seconds	% time btw 0-10 kmh^{-1}	22.13 %
Average speed	15.37 kmh^{-1}	% time btw 10-20 kmh^{-1}	34.65 %
Average acceleration	1.39 ms^{-2}	% time btw 20-45 kmh^{-1}	33.73 %
Average deceleration	-1.44 ms^{-2}	% time > 45 kmh^{-1}	0
No of stops	3		

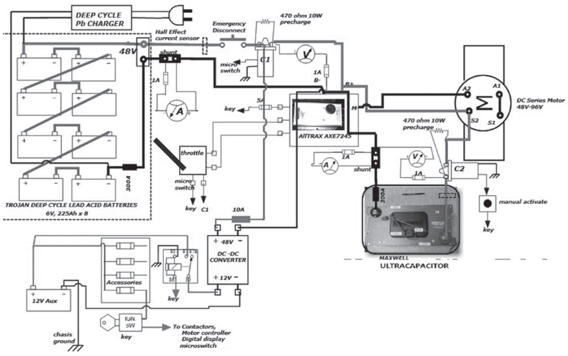


Fig. 6 Electrical wiring diagram for EV conversion

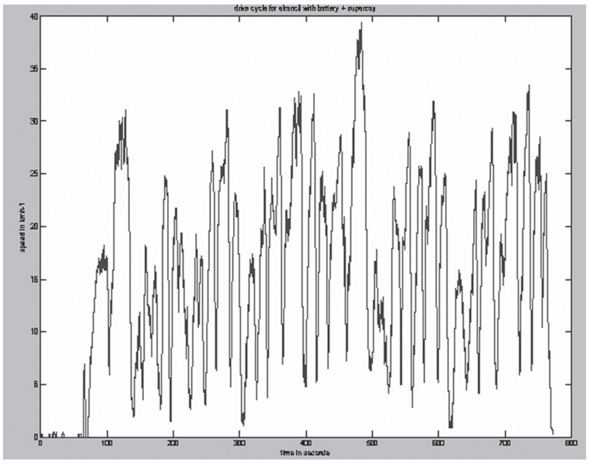


Fig. 7 UNMC drive cycle

way.

3.1 Testing the electric Kancil

In order to verify the effects of integrating an ultracapacitor into the system, the vehicle was tested with and without the ultracap module as shown in the figure below. It should be noted that the schematic below is simplified for better understanding. In reality the switch is a high current contactor which is controlled by a 12 V relay coil, also protection diodes, fuses have been left out of the schematic.

The prototype electric kancil was driven through a specific route on the university campus with the switch OFF i.e. battery alone to acquire reference data for comparison. This was repeated, but with the switch ON. Although the test driver simulated the same driving pattern with or without the ultracapacitor, the status of traffic congestion and receiving stop light signals slightly varied through the test time. The results are described in the sections below.

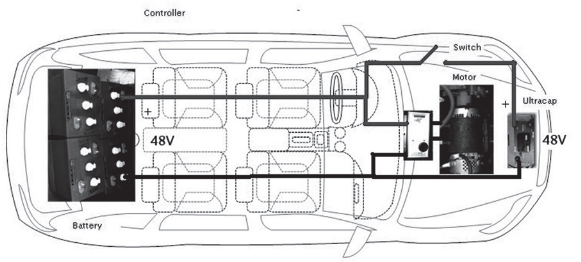


Fig. 8 Simplified schematic of battery + ultracapacitor parallel combination

3.2 Results

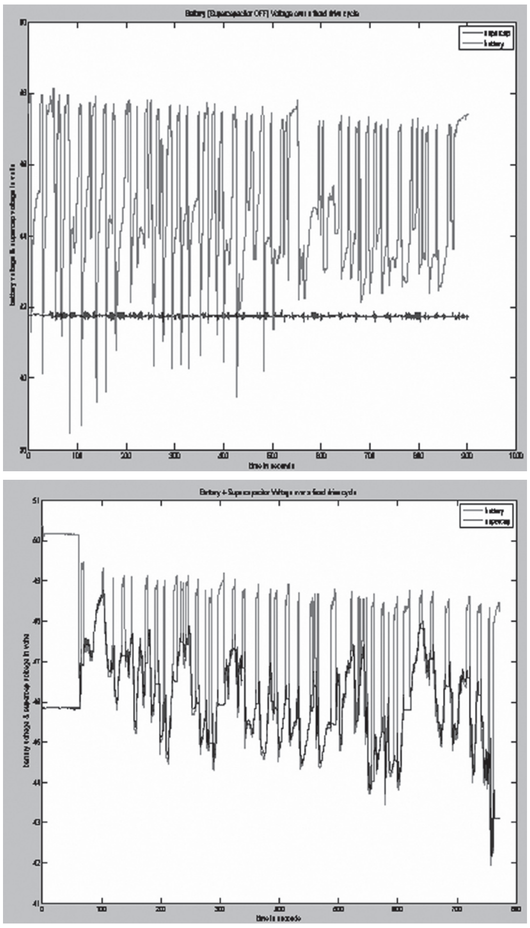


Fig. 9 Battery voltage, ultracap off (top); battery and ultracap voltage (bottom)

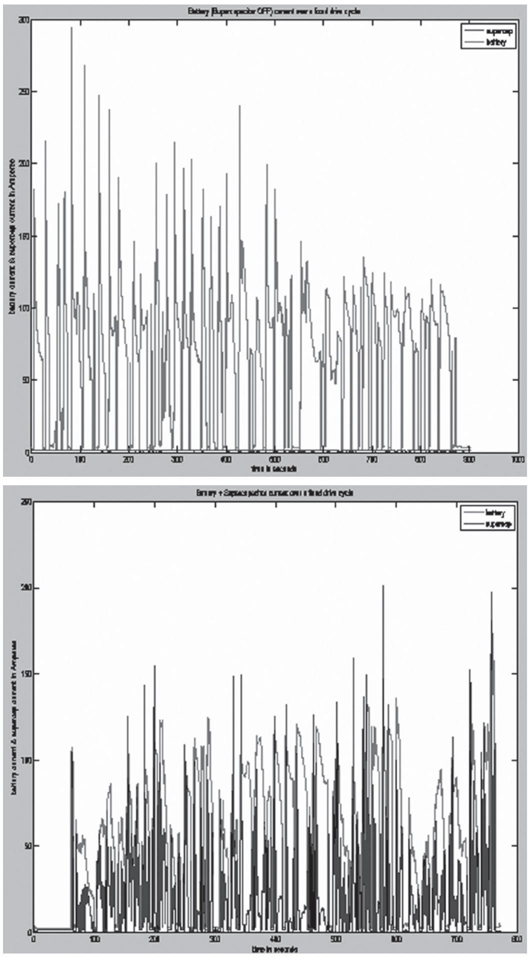


Fig. 10 Battery current, ultracap off (top); battery and ultracap current (bottom)

Table 4 Summary of the results

Battery only		battery + ultracapacitor combination	
Peak current	294 A	180 A	200.9 A
Peal power	11306 W	7680 W	8786W
Average power	7000 W	5700 W	N/A
Highest recorded battery voltage drop	10 V (48 V to 38.44 V)	6 V (48 V to 42 V)	N/A
Max speed	36.5 Kph	40 Kph	

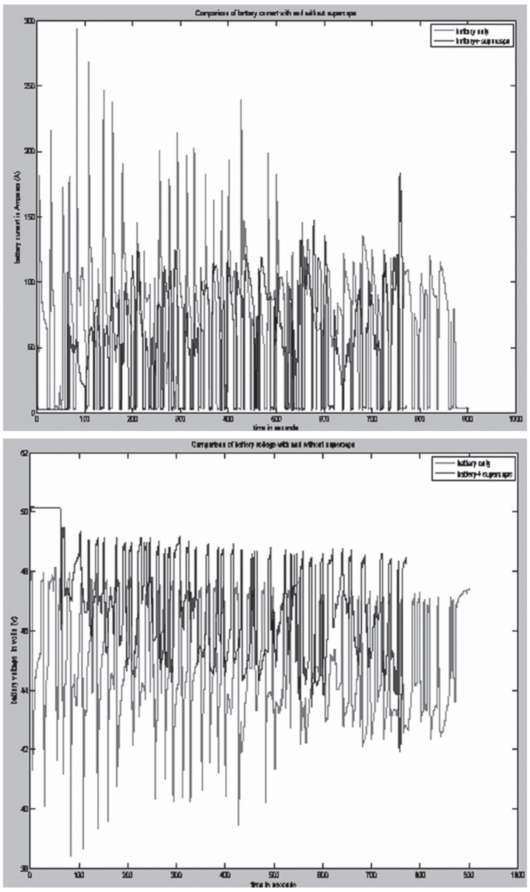


Fig. 11 Comparing battery current (top) and battery voltage (bottom) with and without ultracap assist

4. DISCUSSION AND CONCLUSION

The results showed the ultracapacitor could improve electric vehicle performance and the battery life since the peak current demand from traction battery was significantly reduced (from 294 A to 180 A). Also, the highest voltage drop recorded during the test was significant reduced by the ultracapacitor (10 V to 6 V) while the average power drawn from the battery also dropped from 7000 W to 5000 W.

For every instance in time, the current drawn from the battery-only power source is always greater than the current drawn from the battery + ultracapacitor power source. However, there appears to be certain discrepancies which is caused by variation in driving pattern although data collection for both instances where taken by following exactly the same route. The voltage profile of the hybrid power source is smoother with less variations than the profile of the battery only power source. Since the voltage of the ultracapacitor is always tied to the battery pack (direct parallel connection), we cannot fully unravel its true potential which is its ability to charge and discharge very fast. A simple efficiency analysis shows that only 23 % of the total energy of the ultracapacitor was used up. The remaining 77 % cannot be utilized due to the direct parallel configuration.

This test was just part of comprehensive tests that was scheduled to be carried out in near future to optimize ultracapacitor integration with the EV. Significant amount of engineering work still remains for the optimization especially the “smart” control algorithm for the ultracapacitor to be switched “on” and “off” at most appropriate driving pattern. This would enable a wider range of usage of the ultracapacitor's energy of up to 75 %.

Acknowledgements

The author of the work would like to thank MOSTI (Ministry of Science Technology and Innovation Grant No: 01-02-12-SF0095) Malaysia, Sahz holdings & Mr. K Parthipan.

References

Brant, B., Build your own electric vehicle, Published by McGraw-Hill Professional, 1993.

Dixon, J. W., and M. E. Ortuzar, Ultracapacitors + DC-DC converters in regenerative braking system, IEEE Aerospace and Electronic Systems Magazine, Vol. 17, No. 8, 16-21, 2002.

Jinrui, N., S. Fengchun, R. Qinglian, A study of energy management system of electric vehicles, Vehicle Power and Propulsion Conference, 2006.

Larminie, J., and J. Lowry, Electric vehicle technology explained, John Wiley and Sons, 2003.

Ortuzar, M., J. Moreno, J. Dixon, Ultracapacitor-based auxiliary energy system for an electric vehicle: Implementation and evaluation, IEEE Transactions on Industrial Electronics, Vol. 54, No. 4, 2147-2156, 2007.

Pasquier, A. D., I. Plitz, J. Gural, and G. Amatucci, Bridging the gap between Li-ion and supercapacitor technologies, Telcordia Technologies 331 Newman Springs Rd Red Bank, NJ 07701.

Pay, S., and Y. Baghzouz, Effectiveness of battery-supercapacitor combination in electric vehicles, Power Tech Conference Proceedings, Vol. 3, 23-26, 2003.

Schneuwly, A., B. Maher, and J. Auer, Ultracapacitors, the new thinking in the automotive world, Maxwell Technologies Inc.

Tuite, D., Get the lowdown on ultracapacitors, Technology report electronic design online, 2007.

(Received September 23, 2011; accepted November 9, 2011)