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DC DRIVE TESTING FOR PROTOTYPE ELECTRIC VEHICLES

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ABSTRACT

The shortcoming of fuel in the future has forced by the government and car manufacture to find new power source to propel the vehicle. Electric vehicle is one of solution of this problem. The aim of this research is to investigate main component of propulsion system of electric vehicle namely battery, DC-DC converter, motor drive and motor. Since building actual vehicle is expensive, the component ratings were reduced to save money. From the experiments, it was found that each component need is critical and need detailed analysis to produce a reliable and energy-efficient electric vehicle.

Keywords: DC-DC convereter, motor drive, electric vehicle, energy-efficient.

1. INTRODUCTION

Today, most vehicles employ internal combustion engine (ICE) using gasoline or diesel fuel (Vinsome, 2009). Every litre, diesel has energy density higher than gasoline but both Today, most vehicles employ internal combustion engine (ICE) using gasoline or diesel fuel (Vinsome,2009). Every litre, diesel has energy density higher than gasoline but both produce CO, CO_2 and NO_2 that cause pollution and global warming. Another problem is that oil price increase significantly, from $50/barrel in 2005 to $100/barrel in 2008 (Vaughan, 2008). To address these problems, researchers managed to develop electric vehicle sourcing from battery and hybrid vehicle combining fuel and electric energy to drive the vehicle.

This leads us to complex control system managing all components in order to work properly. Since stored energy is much lower than fossil fuel in a vehicle, efficiency of electric powertrain is the main issue. One problem needs to overcome in near future is long battery charging time, compared with few minutes in ICE-based vehicle to fill the tank. One major step to improve driving efficiency is regenenerative braking. Another way is to apply high efficient electric motor such as Permanent Magnet Brushless Motor (PMBL).

This paper aim to develop simple DC drive system for electric vehicle application. But in the future prototype electric vehicle is fabricated that meet efficiency expectation and safety lavel. It is realised that electric vehicle performance mainly determined by its powertrain dan braking system. Other features such as comfort and aerodyanamics can be adopted form ICE vehicles.

2. MATERIALS AND METHODS

Modern electric powertrain

Electric powertrain has four major elements namely electric motor, sensors, controller and power processing unit. System operation as follow, the controller accepts command and feedback signals and then switch on or off the respective electronic switches in power processing unit. As a result, power flow to the motor can be adjusted. Electric drive is classified according to electric motor employed such as DC series drive, induction drive or PMBL drive. A number of electric vehicles together with its drive system can be seen in Table-1.

Table-1. Electric drive applications in EV And HEV (Chau *et al*., 2008).

EV and HEV	Drives
Fiat Panda Elettra	DC Series
Mazda Bongo	DC Shunt
Conceptor G-Van	Separated excitation -DC
Suzuki Senior Tricycle	PMBL
GM EV1	Induction
Toyota Prius	PMBL
Chloride Lucas	Switched-reluctance (SR)

Electric motor either works in constant torque region at low speed or constant power region at high speed, where region transition occurs in base of speed point. Efficiency map of electric motor is usually combined with speed-torque curve to give optimal region of driving. Figure-1 shows motor efficiency curve of Nissan leaf electric vehicle.

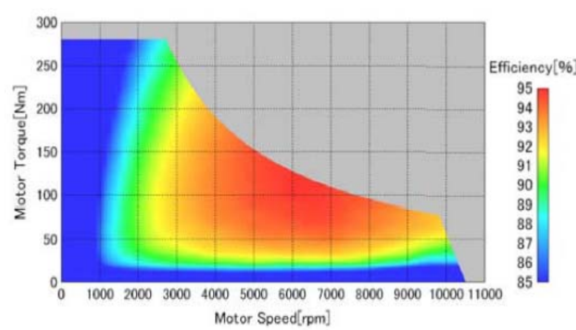

Figure-1. Motor efficiency and speed-torque curves of Nissan leaf (Sato *et al.*, 2011).

Battery size is determined by selection of powertrain, whether supplied from battery, hybrid or fuel cell. Battery specification for EV application is shown in Table-2. Battery can be modelled with controlled voltage source in series with internal resistance as depicted in Figure-2.

Table-2. Battery types for EV and HEV application (Duoba dkk., 2001; Kawamura dkk., 2011).

Vehicle	Battery	Energy (kWh)	Power (kW)	Weight (kg)
Toyota Prius	Nickel Metal Hydride (NiMH)	1.8	21	40
Honda Insight	NiMH	0.9	10	20
Nissan Leaf	Lithium Ion (Li-Ion)	24	90	300

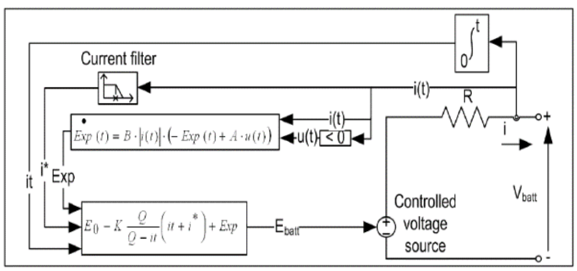

Figure-2. Electro-chemical battery model (Tremblay and Dessaint, 2009).

Research methodology

Firstly, the experiment to produce battery characteristic during charging and charging for both lead-acid and li-ion batteries are conducted. According to battery model in Figure-2 above the current depends on internal voltage, resistance and applied load. Secondly, DC-DC converter to increase battery voltage and match with motor voltage is investigated. According to Figure-3, output voltage *Vo* would be higher or equal to input voltage *Vd*. When the switch S is closed, DC current will produce magnetic energy in inductor and stored as the current flowing. Afterward the switch is opened, the stored magnetic energy would induce voltage and results in higher output voltage. Duty cycle of electronic switch S will be adjusted to meet voltage level demanded. Lastly, pulse-width modulation to control DC motor torque is studied. The motor voltage is no longer constant but pulse waveform.

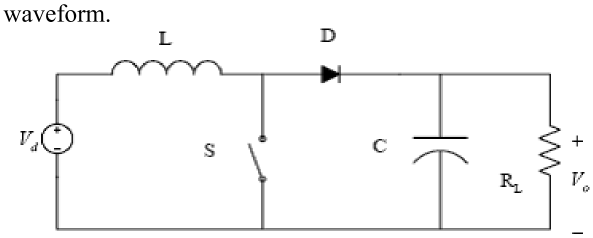

Figure-3. DC-DC boosts converter circuit.

3. RESULT AND DISCUSSION

Figure-4 shows relation between lead-acid battery discharge and open circuit voltage of a pack consisting of 12V battery 7 modules. It can be seen that the relation is not linear, higher voltage drop is observed in low DoD (Deep of Discharge) and afterward the voltage drop is reduced slowly. At average, the voltage drop is 3.5 V when the DoD value of 25.2 Ah.

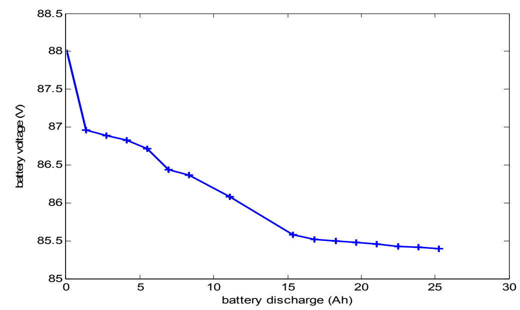

Figure-4. Discharge curve of lead acid battery.

The second test is to observe battery voltage and current during charging. As shown on Figure-5, the initial open-circuit voltage is 12.5 V. At 7 seconds, the battery charger is turn on and current starts flowing to the lead-acid battery. When t > 11 seconds, the charging current is about constant at 6 A, on the other hand, the terminal voltage continues rising to maintain constan current operation.

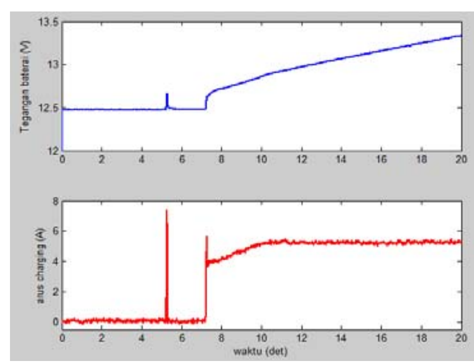

Figure-5. Voltage and current of lead-acid battery during charging.

For Li-ion battery testing, the pack consists of 4 modules with 3.8 V nominal voltages and 200 Ah capacity. Since the voltage rating of DC motor is 24 V, a DC-DC booster is needed to supply power at higher voltage level. As shown in Figure-6, the test rig constitutes DC motor fitted to front wheel of motorcycle using pulley. Motor power would be dissipated through mechanic brake at the wheel. The test result shown relation between DoD and open-circuit voltage of battery as plotted in Figure-7. It is observed that the terminal voltage decrease is not linear with battery discharge, similar with lead-acid. Higher drop is found in range 0-15 Ah of DoD.

Figure-6. Test rig of battery powered DC drive system.

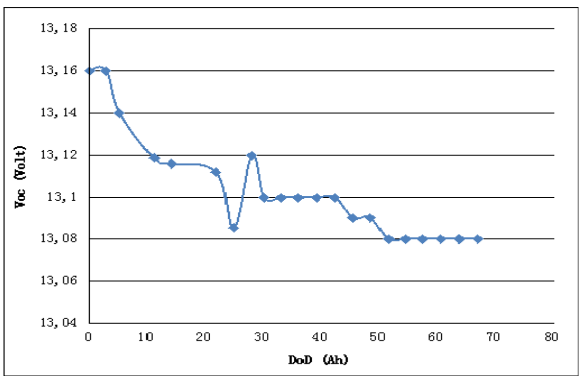

Figure-7. Discharge curve of Li-ion battery.

The next step is to analyse the effect load fluctuation to output voltage of DC-DC boost converter. Block diagram of experiment is illustrated in Figure-8. On the mechanic brake, servo motor is connected to brake lever to adjusting braking force on drum. This would simulate load variation in the motor shaft.Servomotor angle position is controlled from Arduino microcontroller to select one of four possible position i.e 90, 60, 30 and 0 degrees and each position is held for 1 second. Voltage profile of boost converter for 20 seconds is shown in Figure-9 and strongly indicates the large voltage drop as a result of load increase on te motor shaft.

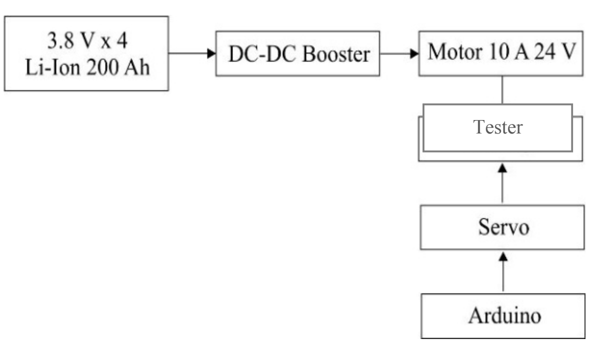

Figure-8. Block diagram of boost converter testing.

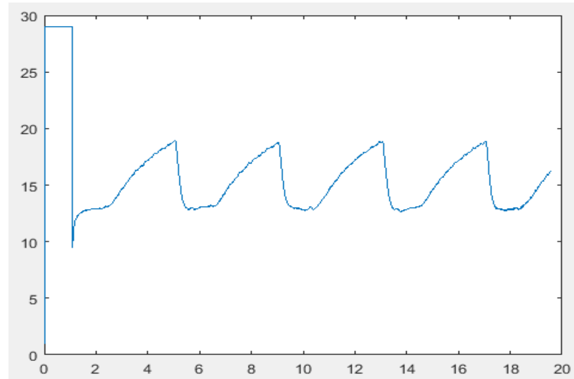

Figure-9. Variation of boost converter voltage due to load changing.

In the last experiment, motor terminal voltage is controlled using PWM technique. As shown in Figure-10, Energy source is 2 lead acid battery modules with 12V nominal voltage to avoid using boost converter to match the battery. The power processing element employs IC BTS7960 H-bridge 27V 43 A with 4 control signal. Low-level PWM signal from Arduino board will be converted to high power pulse voltage applied to the motor. As the result, the motor voltage is not constant anymore but in the form of 24 V pulse waveform like PWM signal from the controller. It is observed from Figure-11 that the current also not constant but ripple current when following the voltage waveform.

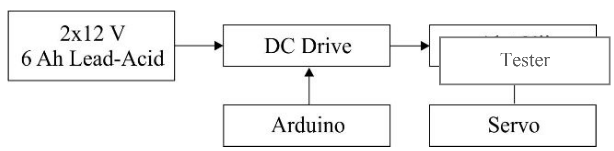

Figure-10. Block diagram of boost converter testing.

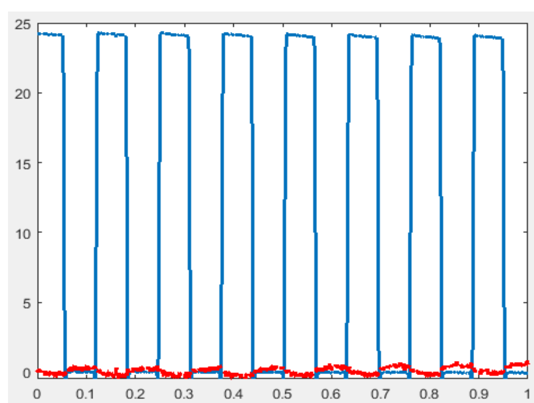

Figure-11. Motor voltage and current as results of PWM technique.

4. CONCLUSION AND FURTHER WORK

From the testing result of DC drive system can be concluded that the performances of main elements namely battery, boost converter and DC motor have analysed. It is understood that the power level of DC drive is lower than actual electric vehicle. But this open the path to better understand of electric vehicle operation in real-world. In the future, the power level of electric powertrain will increase and PMBL motor will be adopted.

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