DEVELOPMENT OF A LIGHT SHORT RANGE ELECTRIC COMMUTER VEHICLE

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Abstract

In order to promote electric vehicle research in Darwin, the Northern Territory Centre for Energy Research in association with the Northern Territory Power and Water Authority (NT PAWA) is developing its own short-range electric commuter vehicle. Outlined below is the procedure used to determine the vehicle specification including range, acceleration and top speed as well as a justification of the type of vehicle used. Also outlined is the vehicle propulsion system which includes an innovative DC-DC converter utilising Maxwell ultracapacitors in parallel with Zinc Bromide batteries and a variable gap axial flux permanent magnet brushless DC machine (BDCM).

1. INTRODUCTION

Electric vehicles in the past have been plagued with problems including poor performance, short range and a general lack of knowledge about how to design and run such vehicles. Advancements over the past 10 years, especially in the fields of battery research and high efficiency motors have led to more reliable vehicles with a longer range and excellent performance.

The Northern Territory Centre for Energy Research has been involved with electric vehicles since 1987, designing their own solar car to compete in the World Solar Challenge. They have competed successfully in each race winning the Technical Award for Excellence in 1993 with an Axial Flux BDCM [1].

The natural progression from this was to develop its' own electric vehicle through knowledge gained in solar car racing. Supported by the NT PAWA with an ARC SPIRT grant, this project involves using their BDCM, (now being sold commercially in America by New Generation Motors) and trialing this in a small two person commuter vehicle.

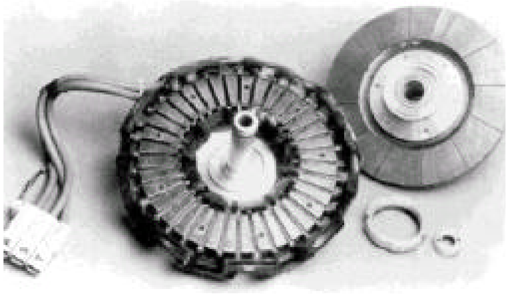

Figure 1 NTU Brushless DC Motor

2. VEHICLE CHOICE / SPECIFICATION

The aim of this Electric Vehicle (EV) project is to develop a small, lightweight commuter electric vehicle (CEV) used daily by commuters with the dual role of being used by companies for short range, known profile trips. In order to design a practical vehicle the following questions had to be answered: - what range is required, what acceleration rates will be adequate and what top speed is required for city driving.

A typical commuter profile in Darwin is driving to work in the morning from the outer suburbs and home in the evening possibly with a side trip to the shops or to pick up children. This sort of profile is particularly suited to electric vehicle use, ie. short range with the ability to recharge while at work or at home.

A study was conducted in the Darwin area to determine the number of people travelling to work in vehicles and the average number of people in each vehicle. A sample of the results over 1 hour on a major road into Darwin city during peak hour is shown in Table 1:

Table 1 People in cars during morning peak hour

Total Cars Counted	1767
Total No. of people	2228
Average People per car	1.26
% of 1 person cars	76.7%
% of 1 and 2 people cars	98.2%

The results show that over 98% of the vehicles surveyed commute with either 1 or 2 people to work. A two-seat vehicle was therefore chosen for our CEV.

3. COMMUTER / METER READER DRIVING PROFILE

In order to establish a commuter profile to work with, a datalogging system was installed in a PAWA meter reader vehicle. This profile is very similar to a Darwin commuter. The PAWA meter readers have three different profiles: - commercial, domestic and overnight. The commercial route involves driving short distances, leaving the car, inspecting meters, and continuing in this fashion for the rest of the day. Domestic routes involve driving into the suburbs usually along highways at high speed, followed by short slow driving to the final location. The third involves travelling hundreds of kilometres outside Darwin to the rural communities, which we shall not consider in this study.

A typical days profile for the commercial route is shown in Figure 2. Of interest to this study is the average speed of ~45km/h obtained for all profiles.

Correlating the data for all days studied the following results were also obtained. Firstly time required to accelerate to 60km/h was recorded with the results shown below in Figure 3.

These results provided us with sufficient data to compile a system specification for the CEV. This is shown in Table 2:

Table 2 Performance specification for CEV

Parameter	Goal	Units
Acceleration		
0-60 km/h	9	secs
Top Speed	90	km/h
High Speed Gradeability		
3% Grade	80	km/h
6% Grade (500m)	60	km/h
Range between Charges	60	km

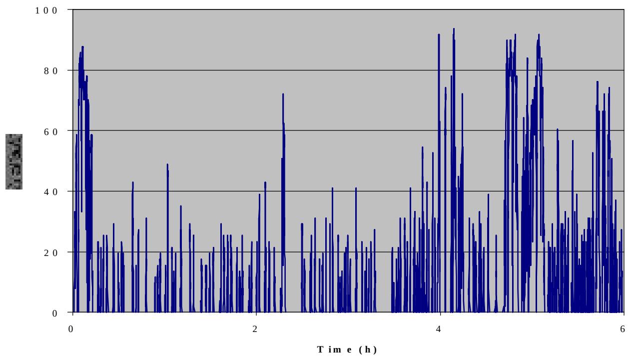

Figure 2 – PAWA meter readers profile

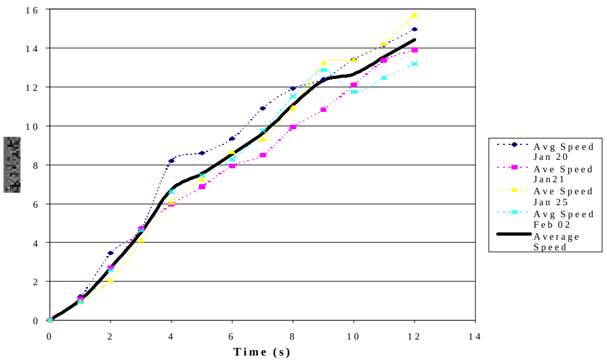

Figure 3 Time to accelerate to 60km/h

4. VEHICLE POWER ANALYSIS

Considering all the forces acting upon a vehicle we can determine the most important parameters of our CEV. Equation 1 gives the total power required to drive a vehicle. [2]

$$P_{total} = 1/n\,(P_{acc} + P_{clm} + P_{rr} + P_{aero}) \qquad \textbf{(1)}$$

where: -

P_{acc} = [m x a] x v
= acceleration power
P_{clm} = [m x g x sin (α)] x v
= power to climb grades
P_{rr} = [C_{rr} x m x g x cos (α)] x v
= power to overcome rolling resistance
P_{aero} = [1/2 x ρ x C_d x A x $(v-v_w)^2$] x $(v-v_w)$
= power to overcome aerodynamic drag

Table 3 Power equation parameters

Symbol	**Description**
m	total vehicle mass
C_{rr}	co-efficient of rolling resistance
g	Gravity
ρ	Air density
C_d	Co-eff. of aerodynamic drag
A	Projected frontal area
α	road slope
v	vehicle velocity
v_w	wind velocity
n	Drive train efficiency
a	vehicle acceleration

If we assume the vehicle is travelling along the flat and not accelerating we can plot the 2 remaining components of total power. This is shown in

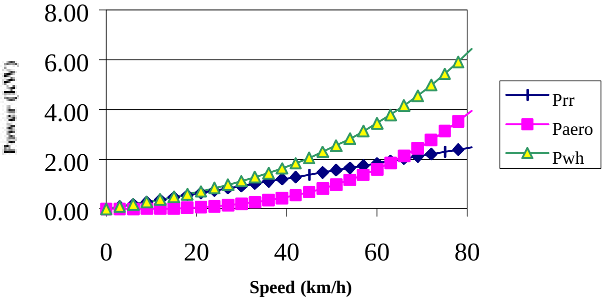

Figure 4:

Figure 4 Components of vehicle power v speed

From this figure we can see that the most important factor in reducing power at the speeds we are most concerned with ie. <45km/h, is the rolling resistance drag. From Equation 1, the variables we need to minimise are vehicle mass, tyre-rolling resistance and of course maximisation of drive train efficiency.

Therefore, in contrast to a solar car in which aerodynamic drag is the most important parameter to minimise, in commuter electric vehicles weight or mass must be minimised. This is hard to achieve by converting existing Internal Combustion Engine vehicles where mass is only a secondary concern.

From all the above findings, the following parameters were rated in order of performance for vehicle choice: -

- minimisation of mass
- maximisation of drive train efficiency
- 2 seat vehicle
- aerodynamic shape

5. DERIVATION OF DRIVE TRAIN PARAMETERS

From Table 2 we see that the range requirement for the commuter electric vehicle is 60km. A battery voltage of 120V was chosen for a number of reasons: -

(1) accommodation of efficient boosting of ultracapacitor voltage ie. ultracapacitor voltage 23-46V (see Stage 1 Design below).
(2) boosting of battery voltage only when the speed is greater than 60km/h ie. better efficiency at lower speeds

An analysis of the vehicles power profile was conducted as shown in Figure 4. An estimation of range can be made from the power consumed while the vehicle is running. Data obtained indicates that for any day the average speed is 45km/h (see Figure 2). We will use this figure as the basis for calculating range ie. range @ 45km/h. Table 4 shows power consumed at 45km/h for the above parameters (Note:- assume flat road, no wind and not accelerating).

Table 4 – Vehicle power requirements at 45km/h

v (km/h)	**$P_{car\ total}$**	**η_{total} x η_b**	**P_{batt} (W)**
45	2434	83%	2933

Assuming an intended range of approximately 60km at this speed we can calculate the total capacity required for the batteries. Also factored into this equation are non-linearities in the system.

Battery Capacity = (power @ 45km/h) x time (2)
= 4.205 kw-hrs
or = 35A-h @ 120V.

42A-h deep cycle Genesis EV batteries were therefore chosen for Stage 1 testing.

The ultracapacitors, used primarily for acceleration and regeneration were sized according to acceleration data obtained from the meter reader vehicle. Above 45km/h the acceleration energy required increases dramatically and thus it is not economical to use super capacitors. To determine the number and voltage of ultra capacitors used, data was therefore analysed for accelerations up to speeds less than 45km/h The results are shown in Figure 5:

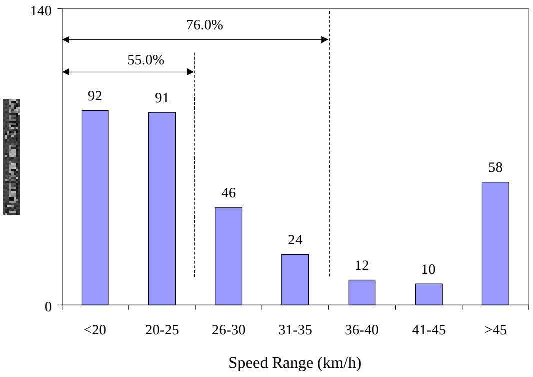

Figure 5 – Final acceleration speeds from rest for meter reader vehicles

From this figure we can see that over 75% of vehicle accelerations are to a speed of 35km/h or less. This equates to 54.02kJ of energy required from the ultracapitors with each of the ultracapitors able to provide 3.52kJ. Twenty ultracapacitors was therefore chosen as the number to use being a good compromise between cost, capacity and voltage.

6. STAGE 1 DESIGN

Stage 1 of the CEV project is trialing an innovative DC/DC converter. This converter serves as a bidirectional dc-dc converter, with Maxwell ultracapacitors connected to its lower-voltage side and lead acid batteries to its higher-voltage side. The purpose of the ultracapacitors is for load levelling the battery and high-efficiency recovery of the regenerative braking energy [3].

Secondly, the converter serves as another bidirectional dc-dc converter, with the battery connected to the lower-voltage side and the motor/inverter to the higher-voltage side, for constant power operation of the brushless dc motor drive above its base speed, and its regeneration control. This boosts the DC bus voltage enabling overspeed of the motor to reach higher speeds road (>60km/h).

7. STAGE 2 DESIGN

After the completion of Stage I, the CEV will trial a set of Zinc Bromide Batteries developed by Bjorn Johansen at Murdoch University in Perth [4].

These batteries are available in two forms, a flow battery where the electrolyte is held in tanks and pumped into the battery and a newly developed non-flow technology.

The non-flow technology, which we expect to trial has the following properties:-

- significantly increased lifetime over commercial lead acid batteries
- potentially higher energy density than commercial lead acid batteries
- higher internal impedance than lead acid ie. lower power density

For a commuter EV, as already mentioned, the weight saving available for the same capacity battery will overcome the problems associated with the lower power density batteries.

The second part of the Stage II Design involves using active variation of the air gap. This is only achievable currently in an axial flux motor such as that developed at the Northern Territory Centre for Energy Research.

To achieve this a small stepper motor will be placed on the stator of the motor and when overspeed is required, >60km/h, the stepper motor will increase the air gap, thus reducing the flux density and hence reducing the motor's back EMF.

8. CONCLUSIONS

A commuter vehicle in which the maximum range is approximately 60km is easily achievable with a light, high efficiency electric vehicle. In order to achieve this economically, emphasis must be paid to keeping the weight to a minimum and drive train efficiency to a maximum. The Northern Territory Centre for Energy Research is achieving this through their innovative Brushless DC Axial Flux Permanent Magnet Motor in conjunction with firstly ultracapacitors and secondly through Zinc Bromide batteries. An innovative DC/DC converter is also being designed in order to achieve overspeed of the motor which will be compared with active flux variation using a small stepper motor.

9. ACKNOWLEDGEMENTS

NTCER would like to thank the Northern Territory Power and Water Authority for their support with this project.

10. REFERENCES

[1]. D. J. Patterson and R Spée "The Design, and Development of an Axial Flux Permanent Magnet Brushless DC Motor for Wheel Drive in a Solar Powered Vehicle" IEEE Trans. on Industry Applications, Vol 31, No. 5 September/October 1995, pp 1054-1061.

[2]. David M. Roche, Antony E. T.Schinckel, John W.V.Storey, Clive P.Humphris, Michelle R. Guelden, "Speed of Light – The 1996 World Solar Challenge", 1997, pp 35-46

[3]. Xinxiang Yan, Dean Patterson and Byron Kennedy "Employing a Multifunctional DC-DC Converter In an EV Drive System", 16th Electric Vehicle Symposium, Beijing, China October 1999

[4]. B. Jonshagen, "The Zinc Bromide Battery Advanced Energy Storage System", 1996 National Energy Conference, Darwin NT 21-24th April 1996