Optimization Of Battery - Ultracapacitor For Electrically Operated Vehicle For Urban Driving Cycle In India

Vishnu Kokate, R M Holmukhe, P B Karandikar, D S Bankar, Ms. Poorva Aparaj

Abstract: Depleting fossil fuels will be a major challenge in front of coming generation. This is going to hit the transportation sector heavily. Compressed air vehicles and electric vehicles are seen as viable solution for future transportation. Electric vehicle system can be implemented from small vehicle to very large transportation system like train or aeroplane. Use of ultracapacitor is inevitable in most of the electrically operated vehicle as it is the only way to supply pulse current requirement of electric motor. Electrical energy storage is as persistent problem in electric vehicle. Battery has its limitations. Use of battery- ultracapacitor combination is most viable option. Optimization of battery- ultracapacitor rating is addressed in this paper.

Index Terms: Ultracpacitor, Battery, Electric Vehicle, urban transpiration

1 INTRODUCTION

Electric transportation is at tipping point. Use of more electric vehicles presents new challenges in energy storage devices and their effective unitization. Existing IC engine based vehicles, hybrid vehicles also uses battery. Use of ultracapacitor is considered only for starting of vehicle as this device is pulse current device[1]. Energy density of ultracapacitor has increased considerably by various improvements in electrode, electrolyte and separator materials through modelling approach [2],[3]. Development of any new device/ product involves system formation, material selection, optimization of material/ process, prototype development and then final product manufacturing [4],[5]. It is often found that manufacturing requirements / issues are neglected at design and development stage which results in failure of commercialization of the product [6],[7].Use of only battery lead to over sizing of this device in electric vehicles which is sensitive to self weight[8]. Photovoltaic charging of ultracapacitor has been very effective in automobile application [9]. Use of desulphesion in lead acid battery has been investigated [10]. Ultimately goal of all scientific community, researchers and industry is to reduce stresson battery used in electrically operated vehicles [11]. Reduced maintenance and cost with improvement in the life is achieved by this. Pulse current is just not required at the time of starting but it is also required to give extra push to motor during top speed operations and acceleration. High speed and quick acceleration are quite common in urban and rural drive cycle. Such conditions are more predominant in urban drive cycle at peak hours i.e at 9am and 5pm. There is possibility that charged ultracapacitor can help battery to give extra power to electric motor during every high acceleration apart from helping battery in every starting.

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This paper presents study related to use of ultracapacitor in high acceleration during urban drive cycle. Optimization of size of ultracapacitor and battery is investigated by using peak hour urban drive cycle developed through trials on actual vehicle. Standard mathematical equations are used for energy and power calculations. In short, this paper attends to optimization of battery ultracapacitor combination for electric vehicle in Indian road conditions. This paper is organized as follows: Section 2 is based on drive cycle data collection. Section 3 is about use of ultracapacitor in electric vehicle. Section 4 presents the optimization of battery ultracapacitor combination of electric vehicles mainly running in city driving conditions. Section 5 has concluding remarks.

2 Drive Cycle Data Generation

Typically drive cycle data consist of speed variation with respect to time. This data can give us the acceleration and retardation information. It can also give us information regarding distance covered and other parameters of vehicle. Some standard drive cycles are available, requires to be periodically updated. Geographical conditions of road due to construction of flyovers, underground tunnels and grade separators are changing. Introduction of dedicated lanes for public transport is gaining momentum. This is affecting the movements of private vehicles. Improvement of road surfaces from tar based to concrete and plastic based is also causing changes in pattern of vehicle movements. In some cases, there is hardly any change Insome cases road condition is not changing but there is change in population density, this is slowing down the vehicle movements. Drive cycle data in growing urban areas where there is drastic growth in vehicle density is heavily dependent on time at which data is collected. This time dependency can be easily experienced in metropolitan cities around the globe. Unpredictable weather conditions are also affecting the drive cycle data. Drive cycle data is also dependent on type of vehicle use for data collection. Due to heavy competition in automobile industries, vehicles with wide range in terms of engine capacity and size can be seen on road Hence it was decided to collect the derive cycle data for optimization of battery ultracapacitor combination in electric vehicle. Pune is a city with heavy vehicular traffic of two wheelers, three wheelers. Number of four wheelers and multi axle vehicles are growing in recent past. Hence the timings of drive cycle were chosen so as to accommodate for maximum vehicular density. The drive cycles were made with standard test drive [1]. A stretch of 16 kilometres was selected for a test drive. For the purposes of maintaining the city driving conditions the speed limits were restricted to 60 kilometres per hour. The following figures show a plot of 30 min drive for 16 kilometres with every point being separated by duration of 30 seconds. The figures are representation of the cycles generated during 0900hrs and at 1700hrs respectively. The morning drive cycle was considered to be from koregoan park to magarpatta cyber city via pune cantonment hadapsar. The evening cycle was considered from vishrantwadi to balewadi near baner via shivajinagar and aundh. The roads were so chosen to accommodate for different types of vehicular traffics, in the first case moe emphasis was on four wheelers and in the second case more emphasis was given to the movement of buses and two wheelers. Thereby compiling the data as mentioned above we have

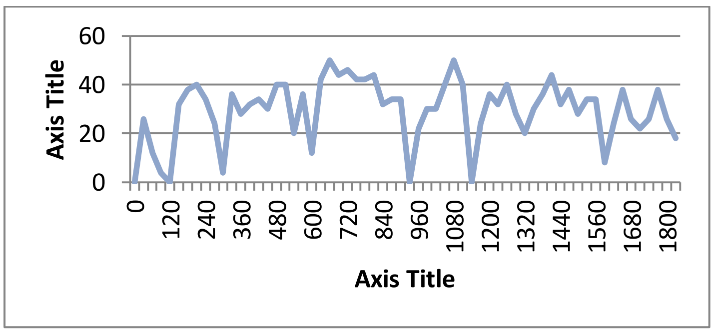

Figure 1 *Drive Cycle-1at 09.00 hrs on a busy urban road in Pune city*

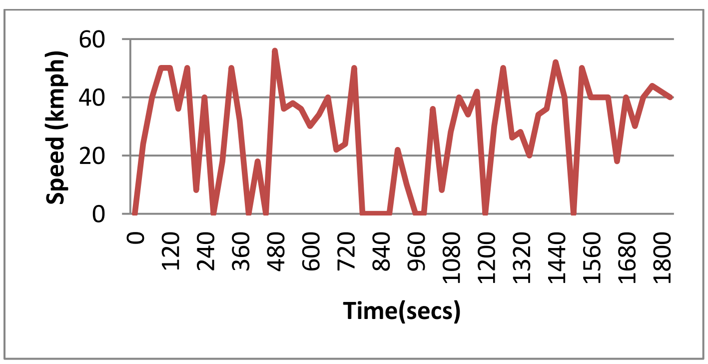

Figure 2 *Drive Cycle-2 at 17.00 hrs on a busy urban road in Pune city*

From Fig 1 and Fig 2 which shows drive cycles at various times, we have calculated the acceleration and eventually the maximum power required to run a vehicle weighing 1500 kg in Pune during peak traffic hours. Fig 3 and Fig 4 depict the change in acceleration versus time in which the acceleration was found out by the following formula

$$Acceleration = \frac{\Delta \text{velo}\text{ctiy}}{30}$$

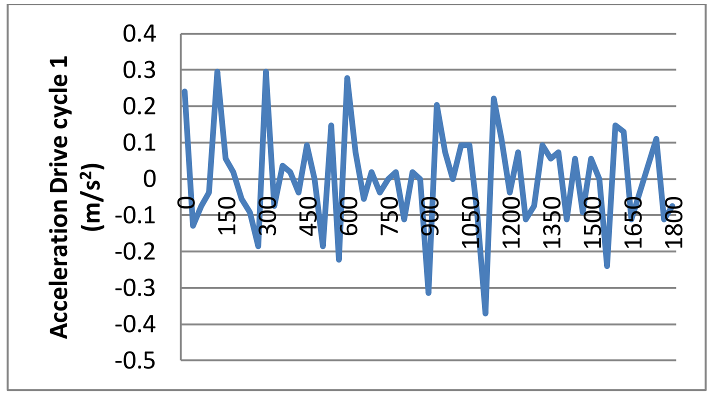

Figure 3 *Acceleration variation for drive cycle- 1*

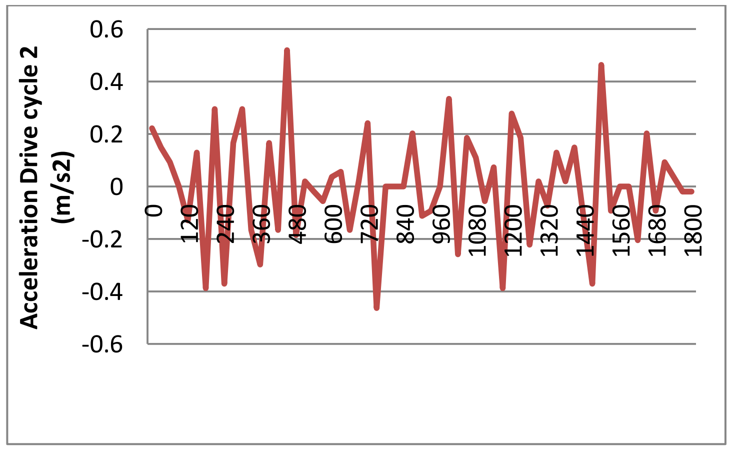

Figure 4: *Acceleration variation for drive cycle- 2*

The following graphs depict the variation of power required during the entire drive cycle with time. The graphs were generated by taking a simple expression for power developed as,

$$Power = Force * velocity$$

It should be noted that the power so achieved by the formula depicts an instantaneous power requirement which is represented with respect to time in the Fig 5 and Fig 6

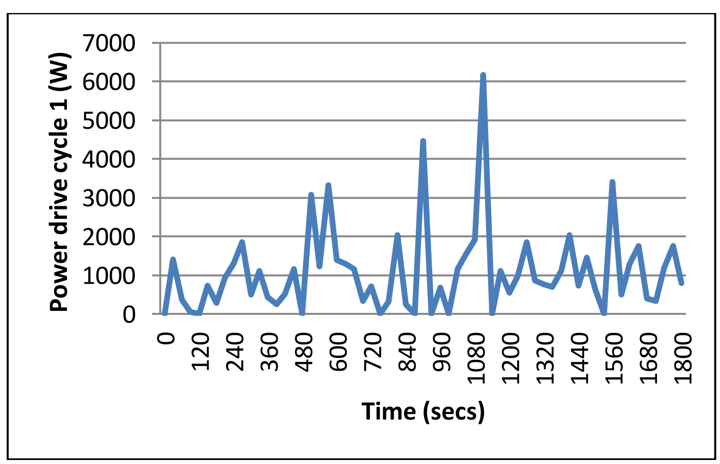

Figure 5 *Power required for drive cycle- 1*

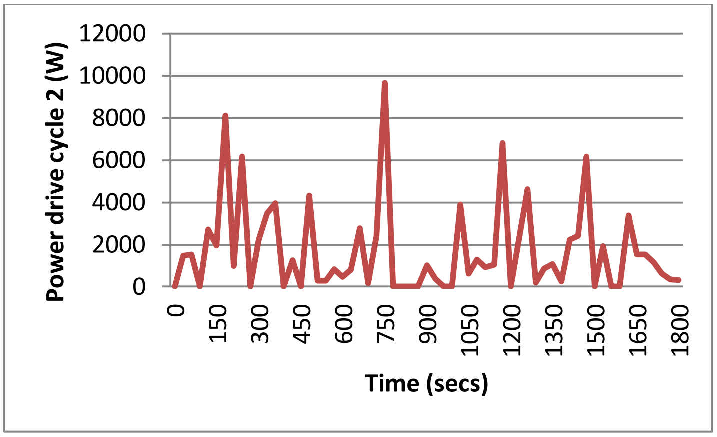

Figure 6 *Power required for drive cycle- 2*

3 Use of Ultracapacitor in Electric Vehicle

Keeping the safety issues in mind, the speed of the vehicle was limited to 60 kilometres per hour. During the generation of the drive cycle it was observed that only 10% time in the drive cycle that the speeds crossed the limit of 40 kilometres per hour where the motor requires providingdriving action. It was also found that only about 2.5% of the entire drive cycle that the speed crossed the limits of 50 kilometres per hour It is during this time that regeneration is possible Hence it was decided to employ ultracapacitor bank for speeds above 40 and 50 kmph in the two cases under consideration. Use of ultracapacitor reduces the battery sizing. During the work of optimize the ultracapacitor – battery combination, following two cases were considered

- Restraining the battery bank to power the vehicle up to the speeds of 40 kmph.
- Restraining the battery bank to power the vehicle up to the speeds of 50kmph.

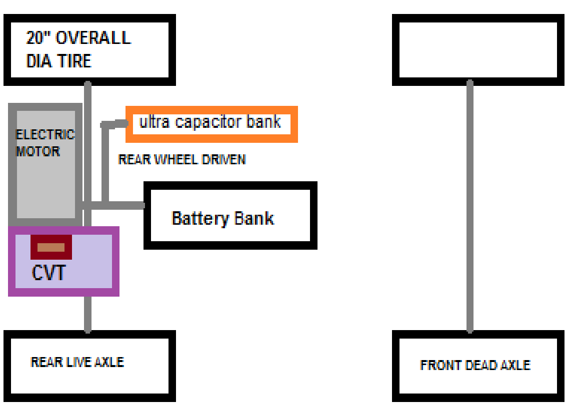

Figure 7 *Proposed Driveline*

In the proposed scheme shown in Fig 7, two ultracapacitor banks, one is specifically for starting the motor and the other to propel the vehicle when the need arises. However both the systems are inter-linked so that if the ultra-capacitors meant for propulsion decay out before their purpose has been served, the capacitor bank meant for the purpose of starting the vehicle can then come into play.The entire system is basically a combination of a battery bank and a capacitor bank; it is figuratively depicted in the proposed driveline and can be logically be understood with the flowchart shown in Fig 8.

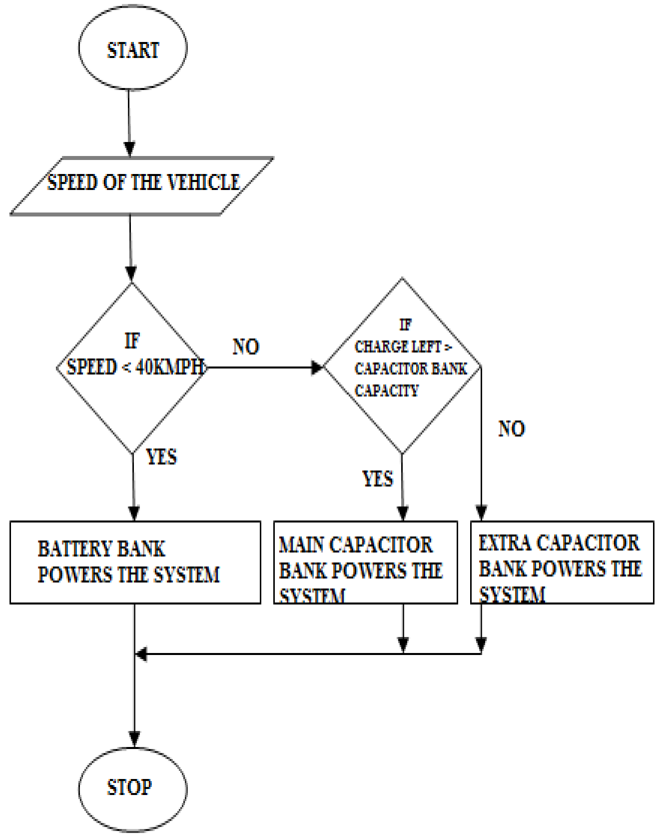

Figure 8 *Flow chart for controller of battery- ultracapacitor scheme in electric vehicle*

4. Optimization of battery and ultracapacitors

The main objective was to get a relation between ultracapacitor and battery sizing based on voltage and speed values during urban drive cycle. Entire system is propelled by the battery and ultracapacitors are put in service during pulse power requirements over the entire drive cycle. Following two cases with switch over speeds of 40kmph and 50 kmph were considered during in this study,

- The battery provides power for speeds up to 40 kmph and ultracapacitor provides power for speeds above this limit.
- The battery provides power for speeds up to 50 kmph and ultracapacitor provides power for speeds above this limit.

The total value of energy required for the entire cycle was calculated by taking the area under the power and time curve. This area was calculated by using the simpson's 1/3rd rule.Three sets of areas of speed vs time were calculated using the same rule as follows,

1. The total area under the curve was calculated. The area so obtained gave the energy required, if the battery were to power the entire vehicle without the use of any ultracapacitors.
2. It was decided to use the battery to provide power only up to speeds of 40 kmph. Area under the power vs time up to a speed of 40 kmph was calculated and it gives the energy requirement from battery. This decides the rating

of battery. Area of the power vs time graph, which falls above line of 40kmph gives the energy requirement of ultracapacitor. This decides the rating of ultracapacitor.
3. Similarlyenergy requirements from battery and ultracapacitor were estimated by considering the switch over speed of 50 kmph.

Assumptions in the battery ultracapacitor rating calculations,
1) Battery voltage is assumed to be constant
2) Battery cost is Rs 500 / Ah
3) Ultracapacitor cost is Rs 800/ F

Let the voltage of the system be V, and the system capacitance to be C, We have collected data for 16 kilometres and is presented in Table 1.

Table 1
Charge values for drive cycles

Top speed from battery	Drive cycle 1		Drive cycle 2	
	Charge from battery (watt second per volt)	Charge from ultracapacitor (watt second per volt)	Charge from battery (watt second per volt)	Charge from ultracapacitor (watt second per volt)
60	2354630/V	0	3228549/V	0
50	2354630/V	0	3167747/V	113272/V
40	2241358/V	60802/V	2221605/V	1006944/V

The charge from the ultracapacitor is given by,

Charge = Battery voltage (V) X Capacitance (C)

Hence the ranges for the entire cycle can be given as shown in Table 2.

Table 2
Charge values for drive cycles

Switch over speed above which ultracapacitor bank is put in service (Km/hr)	Capacitance value (taking the higher value)
60	0(the capacitance value is zero)
50	$113272/V^2$
40	$10677460/V^2$

As it can be seen from the Table 2 that the value of capacitance required increasesas switch over speeddecreases. Fig 9 shows approximate variation in ultracapacitorcapacitance and Ah battery for various switch over speeds. It also shows the trend in cost of the battery / ultracapacitor and total cost of combination for various switch over speeds. Best operating region is marked in the same figure.

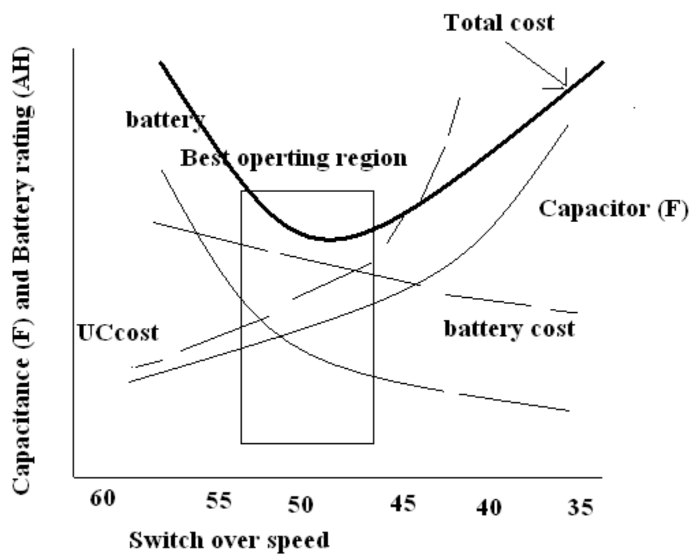

Figure 9 *Graphical optimization of UC battery combination*

5 Conclusions

Capacitance value increases by square relation with switch over speed. Battery capacity reduces linearly. Total cost of battery ultracapacitor cost is a 'V' curve and hence the bottme of V curve is the best battery ultracapacitor combination

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