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Analysis of Lithium Ion Battery Performance for Different Driving Patterns of an Electric Vehicle in Indian Road Conditions

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Abstract

The performance of battery on different driving patterns is very important in the case electric vehicles energy storage system. Usually lithium ion batteries are used in electric vehicles due to its superior parameters and lightweight. According to the driving patterns the current drawn from the battery will change. Also the graph of current, load and speed versus time also changes according to driving patterns. An electric vehicle or automobile can be driven in several patterns. This can be varied according to road conditions and traffic. The different driving patterns are namely 1) city traffic (light & heavy) 2) suburban 3) state high way 4) national high way 5) express highway 6) local/country loads 7) small town 8) high range/hilly area. According to the above patterns vehicles must be controlled in different ways. This will cause power loss, heavy current drawing and continuous braking and starting which will increase the strain on the battery. So this will reduce or in simple term vary the discharge time. Also the cycle life of the battery will reduce. This paper is an analysis and comparison of different driving patterns and the change in lithium ion battery performance in Indian road conditions.

Keywords: Battery energy storage, cycle life, battery management, driving patterns, performance analysis.

INTRODUCTION

Selection of Energy storage system for electric vehicles is very important mainly because energy density and weight are important factors. The performance of a vehicle is mainly based on 1) design, construction and fuel efficiency 2) according to driving patterns [1]. Considering an electric vehicle battery capacity and driving pattern are the main parameters. The cycle life of a battery and discharge time is based on the mainly 3 factors 1) Capacity of the battery 2) type/construction of the battery 3) driving patterns and load of a vehicle. The main driving patterns are 1) city traffic (light & heavy) 2) suburban 3) state high way 4) national high way 5) express highway 6) local/country loads 7) small town 8) high range/hilly area [1].

DRIVING PATTERNS

City traffic

City traffic consists of large number of vehicles. So speed will be low. Heavy traffic causes continuous starting and breaking which causes sudden rush of current from battery. At this time there will be constant strain on battery which may cause reduction of cycle life of the battery. This type of driving will reduce the performance of the battery.

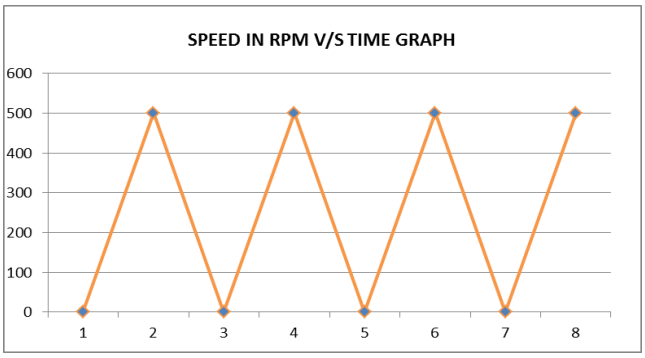

Figure 1. City Traffic

Suburban

This involves low or medium speed driving with intermediate braking. Also causes some strain on the battery. But there is no continuous breaking and starting. Also speed will gradually increase and decrease.

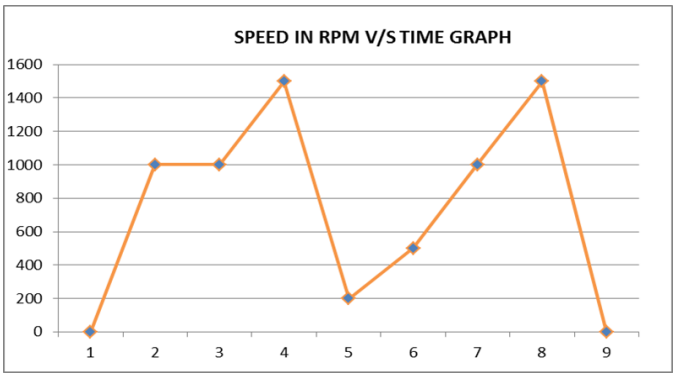

Figure 2. Suburban

State high way

This type involves considerable high speed without much braking and smooth driving .Battery operation ideal and less strain with gradual and steady increase of speed.

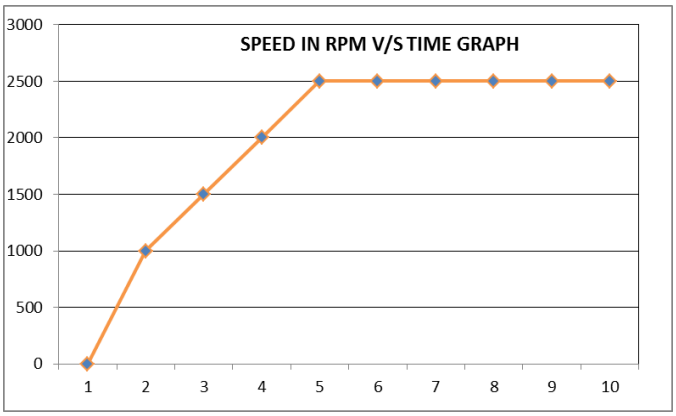

Figure 3. State Highway

National high way

In this type speed is high and battery supplies high current. No much strain on batteries but batteries may drain fast due to speed of the vehicle i.e. current supply is high. So speed must be controlled in order to increase the discharge time of the battery.

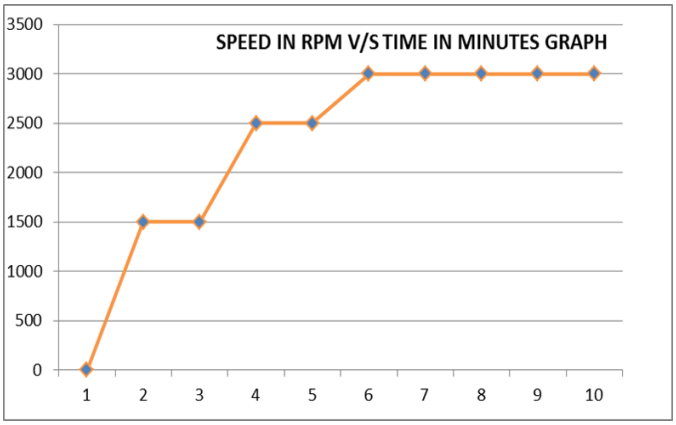

Figure 4. National Highway

Express highway

Here electric vehicle goes in cruise mode and take heavy current from battery. Very smooth driving and braking and intermediate stopping is considered nil or practically zero.

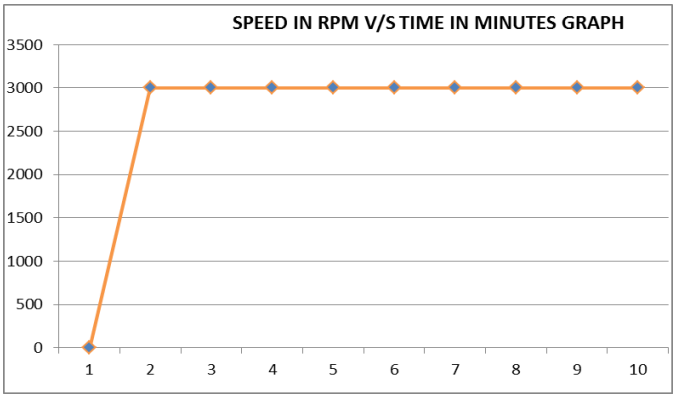

Figure 5. Express Highway

Local/Country Roads

Here speed will be low and there will be braking. Speed variation will be there continuously .So the graph of battery current will be variable.

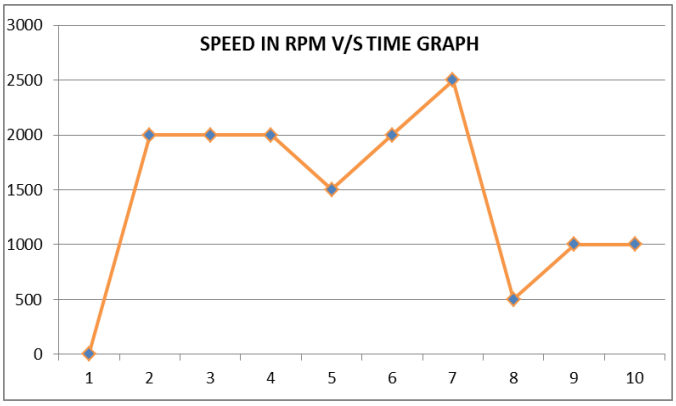

Figure 6. Local/Country Roads

Small Town

Here the graph of battery current is a combination of suburban and local driving patterns. Usually vehicle runs at low speed.

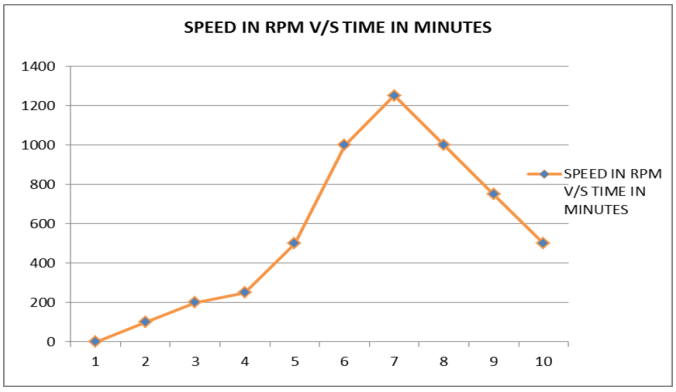

Figure 7. Small Town

High range/Hilly Area

Here the vehicle will go through several steps , uphill or high gradient and downhill or low gradient and sharp hair pin curves while climbing up and climbing down which will cause strain in the battery. There will be continuous breaking then start and current goes up very high due to climbing road. So there will be uphill driving pattern.

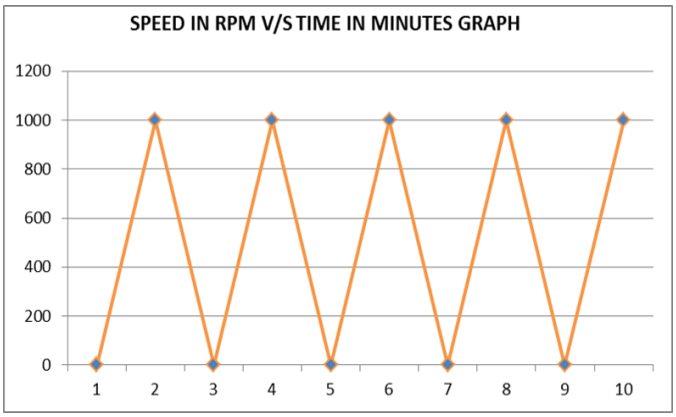

Figure 8. High Range/Hilly Area

Importance of Driving patterns in determining the performance of battery

The driving patterns decides the current to be taken form the battery and the time of discharging [2]. So the cycle life of the battery is determined by the type of driving patterns of the vehicle. So according to driving patterns battery performance will vary.

The variation in driving patterns is simulated and various graphs obtained are analyzed using Matlab/Simulink. The below simulation model shows the different variations in torque, current and speed according to different driving patterns.

Simulation of Electric Vehicle Motor Drive for different driving patterns

Electric Vehicle Performance Model According To Driving Pattern

Motor rating: 48V, 120 A, 19.2 kW, 58 N-m, 3750RPM, PMSM motor

Battery rating: 48V, 600 Ah, Lithium ion battery (LiFePO4)

The performance of battery will be reduced reducing if the current drawn is higher than the full load current rating of the battery which is drawn from the battery [2]. Also discharge time is reduced and the cycle life of the battery is reduced. Here there are two simulation diagrams showing operation of BLDC motor powered by lithium ion battery with constant current and also with variable currents for different driving patterns. The change in battery current output is shown in the graph. According to different driving patterns the characteristics of current drawn from the battery will differ [3].

The below simulation and graphs shows the operation of an electric motor driven by battery under constant loads (discrete variation) and variable loads (different driving patterns and analyzes the difference in performance parameters such as discharging time , load current and also the number of charging and discharging cycles required[3,4].

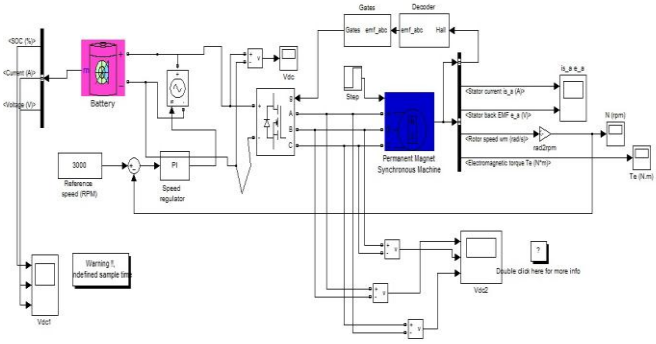

Figure 9. Simulation diagram of electric motor drive at constant speed [22]

Table 1. Battery Discharge Characteristics (Ideal)

BATTERY				
V(Volts)	I(A)	C(A-h)	tc(hours)	td(hours)
48	600	600	5	1.5
48	450			2
48	300			3
48	150			6
48	60			15
48	0			0

The above Table 1 shows the variation of discharge time according to variation in current .The variation in current drawn from the battery is according to the variation in load connected to the battery. The corresponding graph is also shown below in the Figure10. It is shown that as the current increases discharge time is reduced and as the current decreases discharge time is increased.

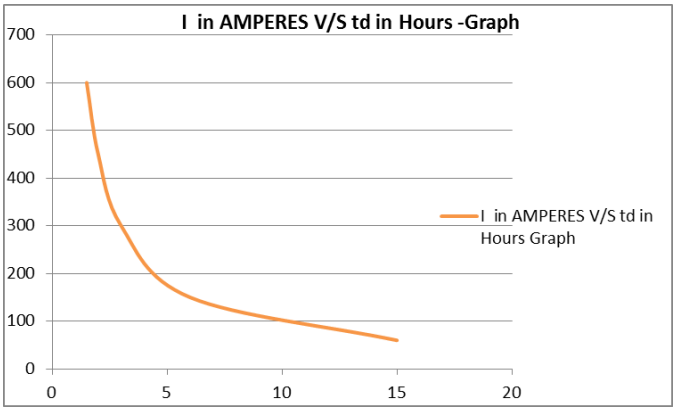

Figure 10. I v/s $t_d$of BLDC motor drive with lithium ion battery

The below table 2 shows the variation of current according to load and the variation in vehicle speed.

Table 2. Electric Motor Load Characteristics

V(volts)	I(A)	Load Factor (%)	W(Watts)	N(RPM)	RADIUS OF WHEEL	T(N-m)	V(KM/H)
48	400	1	19200	3750	.3048 m	4.84	95.71
48	300	0.75	14250	2812.5		12.1	71.78
48	200	0.5	9500	1875		24.2	47.85
48	100	0.25	4750	937.5		36.3	23.93
48	40	0.1	1900	375		48.91	9.57
48	0	0	0	0		0	0.00

The below diagram shows the simulation model of an electric vehicle which employs permanent magnet synchronous motor with power electronic inverter. The variation in driving patterns is shown in each graph shown. The driving patterns change is evident in the torque and current graphs shown. It can be seen that as constant or steady speed will decrease the torque and its variation but at the same time low speed and sudden variations in the speed will increase the torque and draws high current which will not contribute to vehicle movement. So that will increase the strain on battery and reduces mileage of the battery [5].

Figure 11 Simulation diagram of electric motor drive according to different driving patterns (driving pattern as a load /speed variation parameter) [2]

The Figure12 shows the city traffic driving pattern which involves speed variation and braking and starting abruptly. This will cause variation in current from zero the maximum possible value at that particular speed and also torque variation which is similar to speed variation [3, 5, 8, and 9].

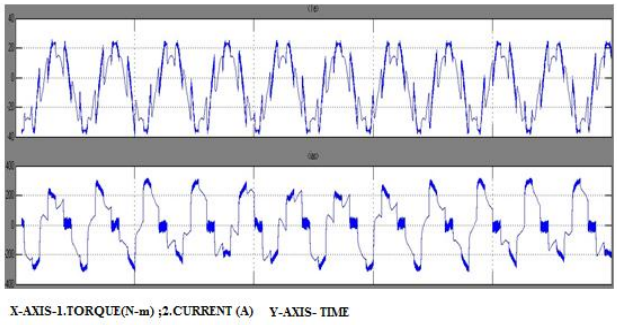

Figure 12. Variation in torque and current in city traffic driving pattern (simulation)

The Figure 13 shows Variation in torque and current in suburban driving pattern (simulation) .It shows the variation of torque and current according to starting .braking, speed variations etc. [3,5,8,9].

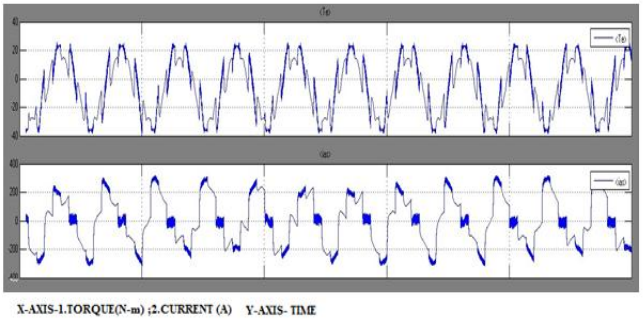

Figure 13. Variation in torque and current in suburban driving pattern (simulation)

The graph showing the torque current characteristics of variation in torque and current in state highway driving pattern is shown in the Figure 14. So the torque is steadily increasing and then it is constant for a particular time and then decreases steadily. The current waveform is very constant and symmetric unlike above mentioned driving patterns [3, 5, 8, and 9].

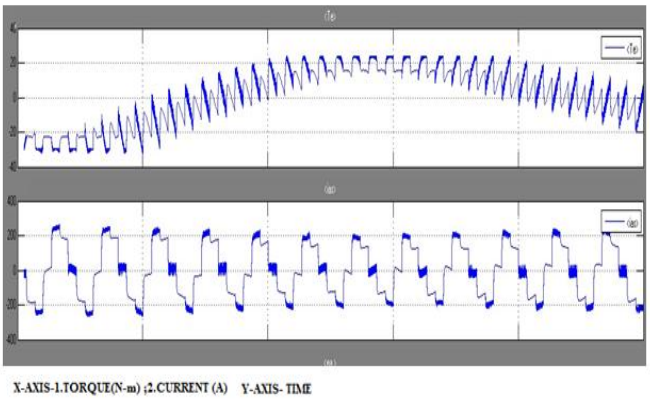

Figure 14. Variation in torque and current in state highway driving pattern (simulation)

The graph showing the torque current characteristics of variation in torque and current in state highway driving pattern is shown in the Figure 15. So the torque is steadily increasing and then it is constant for a particular time and then decreases steadily. The current waveform is very constant and symmetric unlike city traffic or suburban driving cycles. The national highway and express highway driving patterns is similar to state highway driving patterns. But they have more speed and symmetric and constant current waveform [3, 5, 8, and 9].

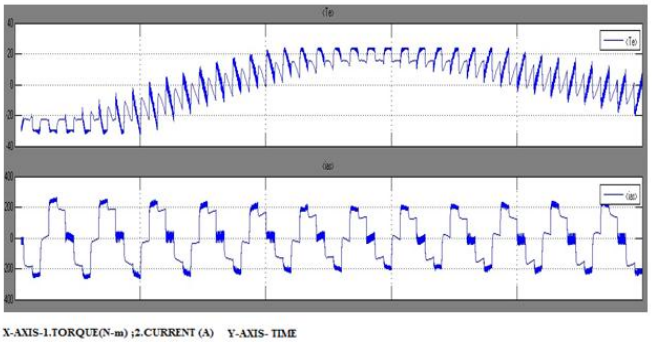

Figure 15. Variation in torque and current in national highway driving pattern (simulation)

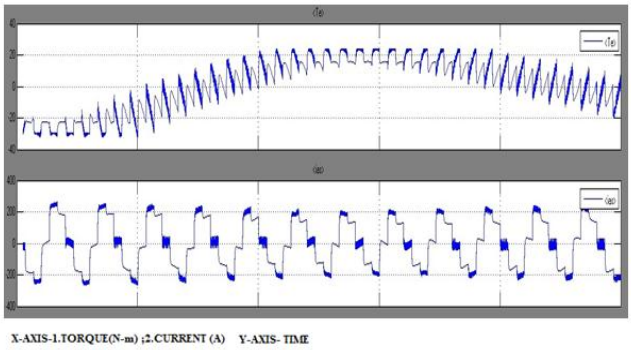

Figure 16. Variation in torque and current in express highway driving pattern (simulation)

The country roads driving patterns is also a similar with less speed comparing with highway driving patterns shown in Figure17. The torque and current in small town driving pattern shows a constant variation in torque and current is symmetric and constant which is shown in Figure18 [3, 5, 7, and 9].

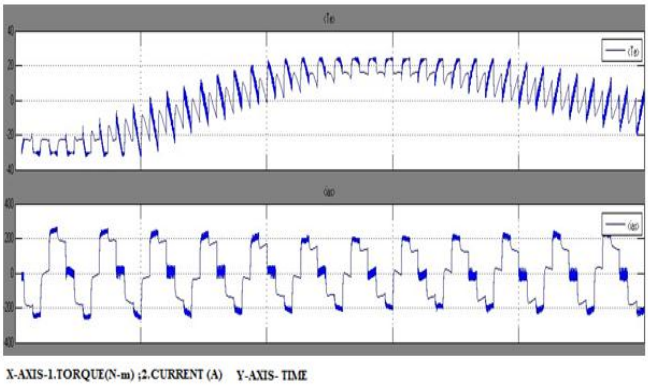

Figure 17. Variation in torque and current in country roads driving pattern (simulation)

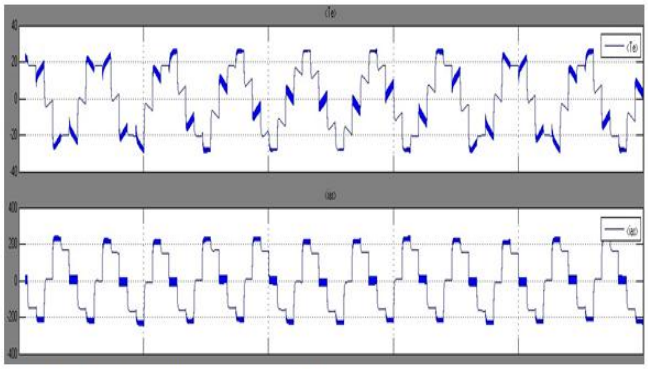

Figure 18 . Variation in torque and current in small town driving pattern (simulation)

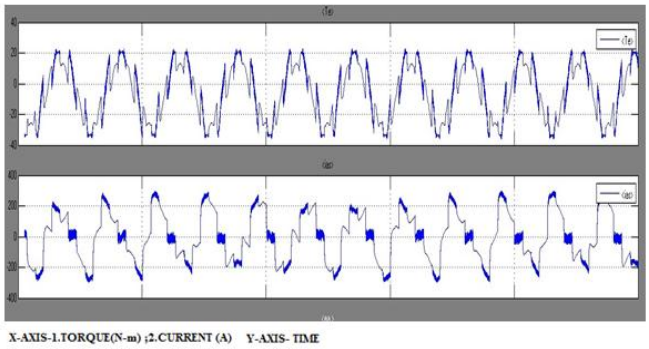

Figure 19. Variation in torque and current in high range or hilly area driving pattern (simulation)

The Figure19 shows the variation in torque and current in high range or hilly area driving pattern. It is evident from the simulation graph that the torque is increasing suddenly and then decreasing in up and own manner. The current also is not symmetrical or constant and it is varying from cycle to cycle. The above simulations shows that driving patterns always affect the current drawn from the battery, discharge time and in effect cycle life of the battery. The battery discharge time for each condition will vary but that variation is not linear [6, 7, 8, and 9].

Table 3. Electric Vehicle Battery Discharge (Practical Data)

BATTERY CAPACITY(A-h)	CURRRENT DRAWN(A)	DISCHARGE TIME (HOURS)
600	600	0.89
	550	0.97
	400	1.34
	450	1.19
	400	1.34
	350	1.53
	300	1.79
	250	2.14
	200	2.68
	150	3.57
	100	5.36
	50	10.71
	10	53.57
	0	0

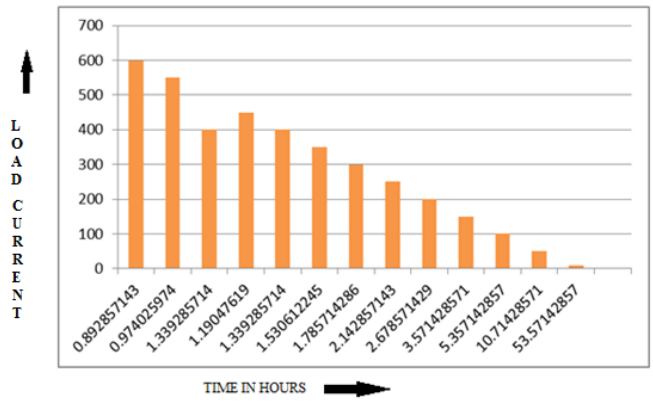

Figure 20. Electric Vehicle Battery Discharge (Load current versus Discharge time graph (Practical Data)

ANALYSIS AND DISCUSSION

From the above readings it is evident that driving patterns have an effect on discharge time, cycle life and performance of a lithium ion electric vehicle battery. Over current drawn from the battery will cause the battery to damage easily. The sudden rise and fall of current will reduce the cycle life of the battery. So a control system must be there to control and also a support system like super capacitor should be there to improve the performance of the battery [10-18, 27].

Role of super capacitor as power back up

Super capacitor which has high power density and high rate of discharge could provide high power and current for short bursts thus saving the battery from large current drain which may be very helpful in saving battery from heavy strain at the time of starting of vehicle or continuous starting and braking conditions which is a part of some driving patterns. The peak current is drawn from a battery at the time of starting of the vehicle. At the time of starting speed is zero and so torque is maximum. This is affecting the proper functioning of lithium batteries. This problem can be avoided by employing a super capacitor bank and controller to switch over between battery and super capacitor to provide the current/power according to the condition [19-27].

FUTURE SCOPE AND DISCUSSION

The low performance of lithium batteries can be optimized by using super capacitor along with different types of controllers and monitoring systems. These controllers will control the battery according to different driving patterns, current, temperature and other battery parameters such as state of charge and state of health which will improve the battery performance [16].

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