Development of Battery Management System for Maximizing Battery Performance in AVL Cruise/MATLAB/Simulink

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Abstract -*: In recent times the electrification of automotive powertrains is a major area of research and a lot of work has been carried out to improve its performance in comparison with its internal combustion counterparts. Among all ongoing research work, Battery Management System is one of the major areas, which is used to improve the transient performance and life of an electrochemical battery mainly a Li-ion one. In this paper, we have focused our attention on the crucial parts of the Battery Management System which is, Cell balancing, the State of charge of the battery, etc. Based on the literature review, various control strategies are studied and a new optimal control strategy is defined to improve the battery performance according to application. The control strategy is developed using MATLAB/SIMULINK. In this paper. we developed an active and passive cell balancing model. For the active cell balancing technique, we chose switched capacitor technique. To have longer battery life, time required for the cell balancing must be as low as possible for which many control logics have been defined. So, various graphs are compared, to find the effect of these cell balancing techniques on the performance of the battery pack.*

Key Words: *AVL Cruise, BMS, Cell balancing, MATLAB, SIMULINK, Passive, Active, Switched-Capacitor*.

1. INTRODUCTION

Because BMS is the connector between the battery and the car, it plays a critical role in enhancing battery performance and optimizing vehicle operation in a safe and dependable manner. Consequently, considering the rapid growth of EV and HEV markets, there is an urgent need to develop a comprehensive and mature BMS.

In this study, first, we simulated the vehicle standard data in order to understand the AVL cruise then, the similar vehicle is transformed into an electric vehicle. Further analysis of developed model will be examined using AVL cruise and performance will be evaluated in real time environment. Further to optimise the battery performance, we are using different cell balancing techniques to increase the battery pack performance in MATLAB-SIMULINK. Today Rechargeable batteries are most widely used for many applications such as electrical appliances, smartphone, industry etc. They are considered as best option for electrical and hybrid vehicles due to their advantage of having High energy density, low maintenance, more charge cycles, Low self-discharge rate compared to other batteries available in the market. But the due to low cell voltage of this cell we need a high-power battery pack to use them in case of electric vehicle. But considering the disadvantage of temperature rise in the cell we cannot use single battery cell in a bulk rather we have to use multiple cells connected in series to get higher output voltage [1].

Major factor that is affecting the uniformity of the cells is the non-uniform temperature distribution. Due to multiple charging and discharging cycles the net cell voltage will drift down and will cause a decrease in the net capacity of the cell. For example, consider multiple cells connected in series, now cell with the higher internal impedance will show higher voltage than that of other cells connected in series. Till time other cells reach the maximum capacity first cell be overcharged and this will lead to increase in the temperature and the gaseous pressure within the cell causing its failure. Hence to increase the overall battery capacity and to avoid the battery failure battery management system has to be adopted. In this case we mainly focus on the cell balancing techniques to avoid overcharging of the cells for which we have two main methods: Passive and active balancing. The passive balancing technique uses shunt resistors to bypass the additional voltage in the form of heat during the charging and discharging cycle [2,3]. In case of active balancing charge from higher voltage cell is transferred to the lower voltage cell using active elements like capacitors and inductors and fly back DC-DC converters [4,5,6,7]. There are several embodiments of capacitor cell balancing methods in the literature [8,9,10,11].

Therefore, in this study, we emphasize on using MATLAB-SIMULINK software for control technique used for cell balancing to reduce the balancing time for each cell in battery pack to attain the responses (charge-discharge, variation of SOC of each cell, etc). Further, we can also study to implement or do a co-simulation of proposed technique in Simulink with the vehicle model in AVL Cruise.

2. BATTERY PACK DESIGN:

There are many battery cells available but considering the specific energy of lithium-ion batteries, most of the automobiles use lithium-ion cells to develop a battery pack. Based on the required output capacity we can design the battery pack. For an electric vehicle very high voltage rating is required and the battery pack required is thereby of higher capacity.

This high-power output can be obtained by connecting cells in series and parallel. The power rating of the battery depends on the total terminal voltage of the battery. This is given by the below relation:

$$P = U * I$$

Where; U = Voltage
I = Current.

(NOTE- Higher current across the circuit generates higher thermal heat so one has to consider optimum value for voltage as well for the current rating. Also, an appropriate cooling system has to be considered for heat dissipation across the battery pack.)

2.1 DESIGNING OF MOTOR AND BATTERY:

The vehicle's propulsion unit generates the force required to propel the vehicle forward. This force assists the vehicle in overcoming resistive factors such as gravity, air resistance, and tire resistance. To find the longitudinal performance characteristics of a car we need to consider first the forces acting on it while traveling in a straight line. The major external forces acting on a two-axle vehicle are –

1. Aerodynamic resistance Ra.

2. Rolling resistance Rr of the front and rear tires Rrf and Rrr.

3. Drawbar load RD.

4. Grade resistance RG, (W sin θ).

5. Tractive effort of the front and rear tires Ff and Fr (For a rear-wheel-drive vehicle, Ff = 0, whereas for a front-wheel vehicle, Fr = 0).

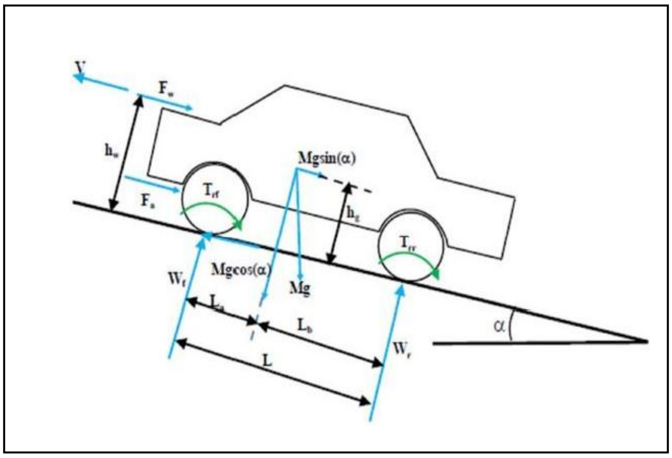

Fig -1 Free body diagram of the vehicle

Total aerodynamic drag acting on the vehicle is given by:

$$F_{aero} = 1/2\, \rho\, C_d\, A_f\, V^2$$

Where:
V = Car Velocity
ρ = Air Density
Cd = Drag Coefficient Af = Frontal Area

Rolling Resistance acting on vehicle due to tyre is composed primarily of

1. Resistance from tire deformation
2. Tire penetration and surface compression
3. Tire slippage and air circulation around wheel
4. Wide range of factors affect total rolling resistance

Total rolling resistance acting on the vehicle due to tyre is:

$$F_{rr} = m\, g\, C_{rr}$$

Total gradient resistance acting while climbing the slope Is

$$F_{grade} = m\, g\, sin(\theta)$$

A combination of the l above forces will give us the total force acting on the vehicle at that constant speed.

Total Vehicular Resistance at Constant Velocity:

$$Ftr = Frr + Fad + Fgr$$

Power rating required by the motor can be given as:
Motor Power Required = Ftr * V (Vehicle speed in m/s)

Motor has to develop a torque that is required by the vehicle based on the resistive forces acting on it. Power output of the motor will be determined by considering the losses. Below isthe total power developed by the motor.

$$P_{mot} = \tau_{mot}\,\omega_{mot}$$

Net power input provided by the motor is given by below relation which will account for the losses. This power will be further transferred to the drivetrain.

$$P_{in} = \tau\,\omega + P_{Loss}$$

Where,

$$P_{loss} = k_c \cdot T^2 + k_i \cdot \omega + k_w \cdot \omega^3 + C$$

The total energy required by the motor can be determined by integrating the power that the motor has developed.

Based on calculation T = 27.35 Nm at 393.206 RPM Using motor catalogue motor selected is PM BLDC 2000W,48V,4200RPM

3. Battery Capacity

The range of electric vehicles based on the battery capacity is given by the relation:

Range of the vehicle = (Battery capacity kWh @ rated Ah) X Speed of the Vehicle

(Load at the wheels (kW)) + Other Electric Load of the Vehicle (kW)

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VEHICLE PARAMETERS	
Aerodynamic Drag Coefficient	0.38
Air Density	1.23
Front Area	2.1
Mass of Vehicle	2300
Rolling Resistance Coefficient	0.01
Wheel Radius	0.34
Accessory Load	600
Vehicle Speed	50kmph
Gear reduction Ratio	3.55

Table 1 - Important parameters

Power(W)	Torque at Wheel (Nm)	Motor RPM Required
4505.49288	17.23523379	686.4820798
10015.59941	38.31349909	686.4820798
15524.02921	59.38535025	686.4820798
21029.10605	80.44437509	686.4820798
26529.15475	101.4841653	686.4820798
32022.50162	122.4983185	686.4820798
37507.47505	143.4804401	686.4820798
42982.40594	164.4241451	686.4820798
48445.62827	185.3230604	686.4820798
53895.47957	206.1708265	686.4820798
59330.30146	226.9610992	686.4820798
64748.44011	247.6875522	686.4820798
70148.24677	268.3438783	686.4820798

Table 2 - Calculations

Motor Torque (Nm)	Accessory Load(W)	Battery Capacity (kWh)
4.854995434	600	7.65823932
10.79253495	600	15.92339911
16.72826768	600	24.18604381
22.66038735	600	32.44365908
28.58708883	600	40.69373212
34.5065686	600	48.93375243
40.41702538	600	57.16121257
46.3166606	600	65.37360891
52.203679	600	73.5684424
58.07628914	600	81.74321936
63.932704	600	89.89545219
69.77114146	600	98.02266016
75.58982487	600	106.1223702

Table 3 - Calculations

Based on the above calculation it is found that the capacity of battery required is around 8 kWh on the plain road when the vehicle is running at a speed on 50 kmph. And that on the road with 12- a degree gradient battery capacity required is equivalent to 100 kWh. But in the actual road driving scenario we don't drive at constant speed rather it depends on thedriving condition due to which theoretical calculated capacity is to high. Hence to determine the actual performance we simulate the vehicle model in AVL Cruise software or in MATLAB. We can consider the mean velocity of the driving cycle and calculate the power and capacity required using the above calculations.

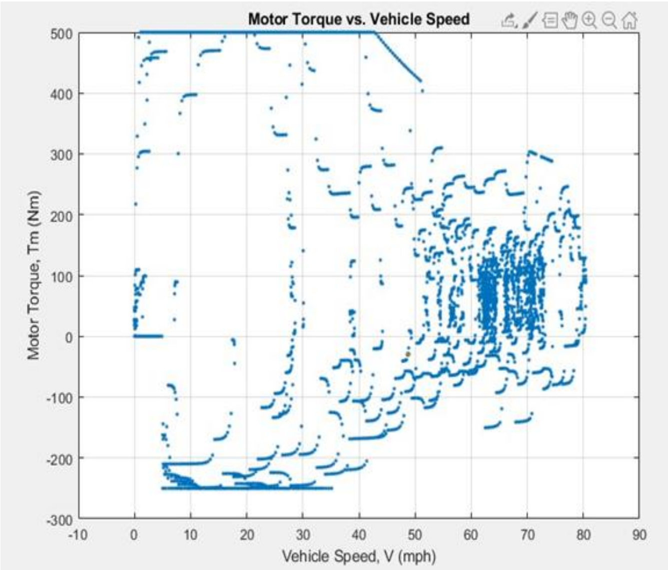

Chart 1- Motor Torque Vs. Vehicle Speed Variation

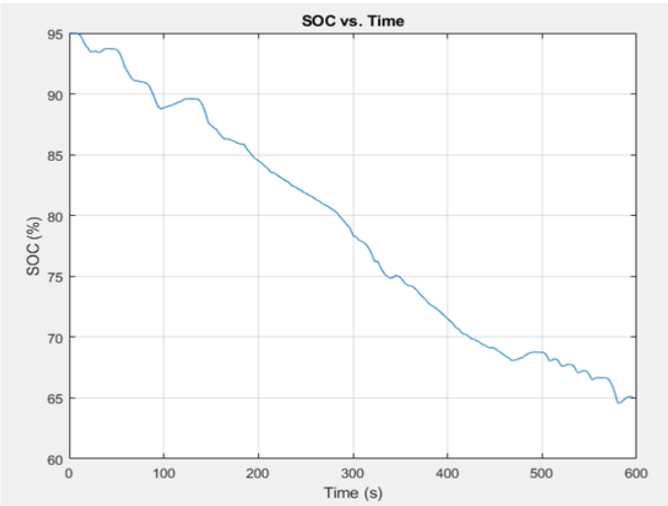

Chart 2 - SOC Vs. Time Variation

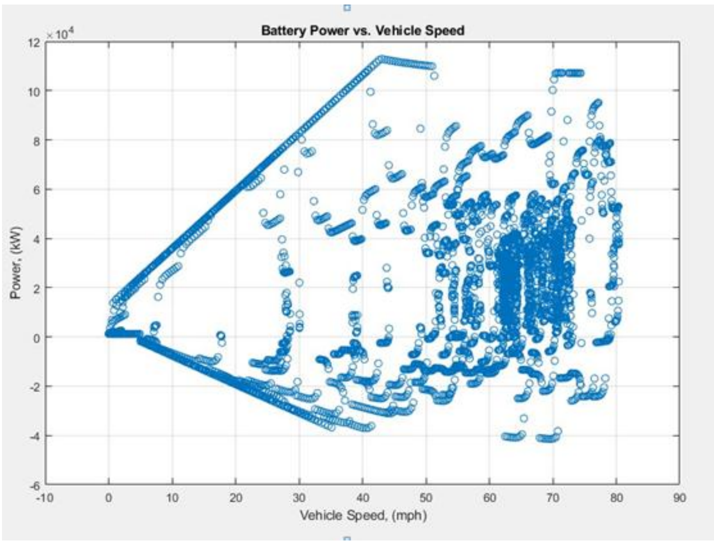

Chart 3- Battery Power Vs. Vehicle Speed

Chart 2 shows all the points at which my motor is operating at. From figure we can tell that atspeed of 25-35 mph motor is operating a lot. Graph also helps to decide the size of the motor based on the working point distribution. If points are running out from the Torque line means we need to have larger motor for that particular drive cycle.

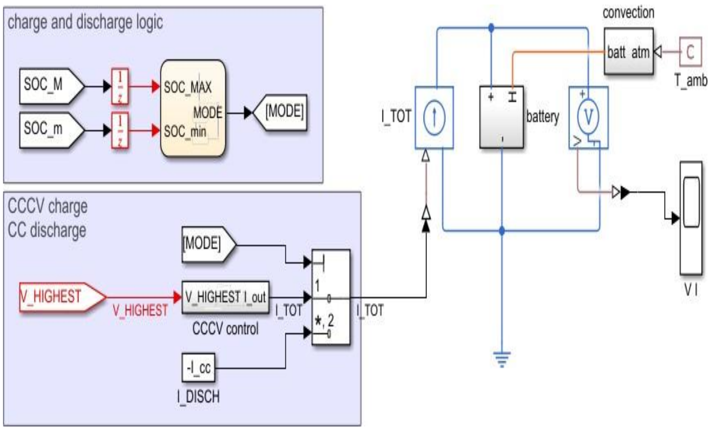

Fig 2- Simulink Model

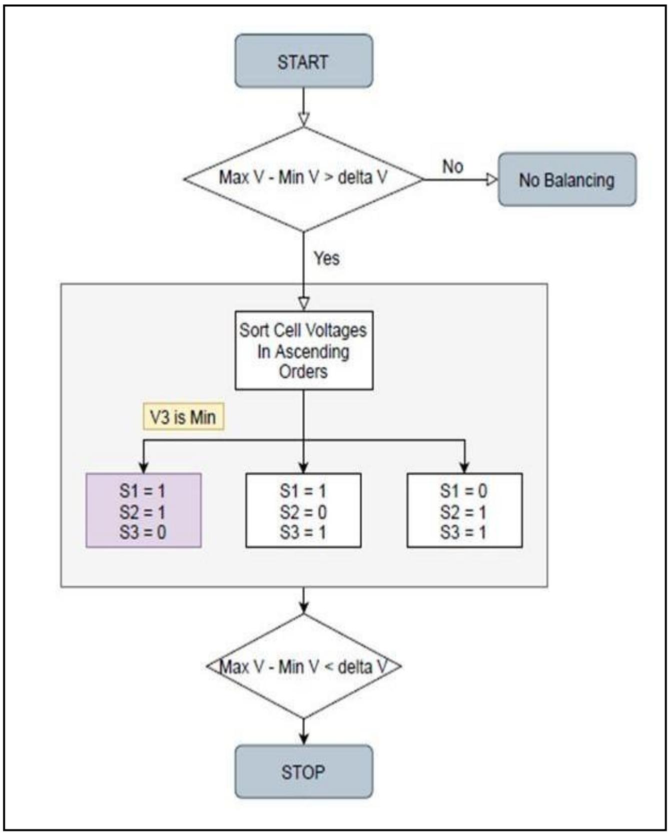

Fig 3 - Control logic flow chart for a passive system

In state flow diagram, operations are carried out based on the current state of the system and based on the logic provided system goes into the next state. This concept can be easily understood from the flow chart given in fig. 15. System will be continuously monitoring the state of charge and voltage of each cell within the battery pack. When in the difference between the maximum Voltage

and the minimum Voltage is greater than 2% its assumed that cells are imbalanced and balancing protocol will be executed ad system will go into balancing state. Now the system will monitor Voltage of each cell and based on the logic provided it will arrange the cell in ascending order on their voltages. From the flow chart above let's assume that cell 1 has the lowest voltage (or say SOC) in this case other two cells should be discharged unless and until their SOC is equivalent to the third cell (approximate Error of 2%). For this to happen system will ON the switch 2 and switch 3 which will connect cell 1 and cell3 to shunt resistor which is connected in parallel to cell. The resistor will discharge the cell by giving out charge in form of heat. Meanwhile system will keep checking the SOC difference once the difference is below 2% balancing sequence will stop and all the MOSFET will on OFF state.

4. Result

Based on the results obtained it can be seen that time required for the balancing is 6000 seconds. Once the cells are being balanced based on the discharger logic battery will start to drain and cycle repeats for given time span.

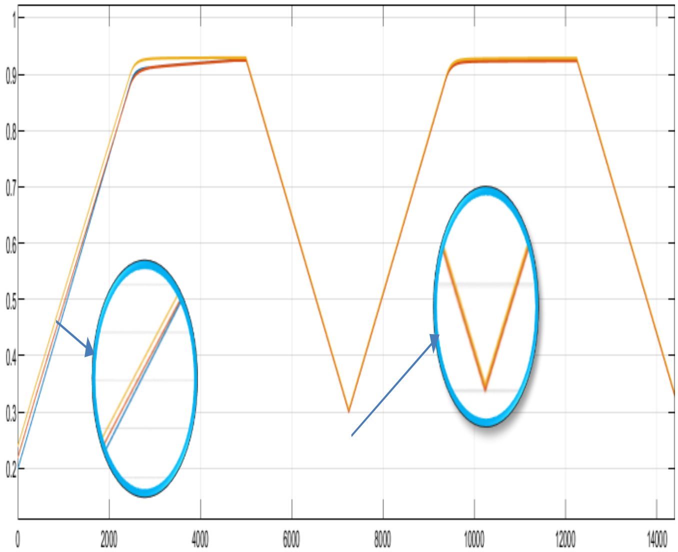

Fig 4 - SOC change during charge and discharge cycle Vs Time

5. CONCLUSION

It is very important for BMS to be well-maintained for battery reliability and safety, proper state monitoring and evaluation, and functional cell balancing and charge control. Dueto these reasons, there is a need for BMS optimization for EVs to increase the reliability of BMS and optimize Ev's power performance. From this paper, we can conclude with the following points-

- Active balancing was continuous whereas passive balancing was not continuous and the time taken at higher SOC is very high.
- Costing of passive balancing could be very high for the larger battery pack and the cost does not justify the balancing time required.
- By adopting different active balancing techniques and different control logic we can further reduce the balancing time and hence increase the overall life and performance of the battery pack.

In the future, we can implement or do a co-simulation of the proposed technique in Simulink with the vehicle model in AVL Cruise for validating the effect of techniques used in BMS.

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