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Dynamic Modeling and Simulation of a Series Motor Driven Battery Electric Vehicle Integrated With an Ultra Capacitor

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Abstract: *In this paper the dynamic model of a series motor driven Battery Electric Vehicle integrated with an UC is simulated using MATLAB Simulink. The Battery UC configuration used in the paper enables the use of a less power rated converter thus decreasing the cost of the system and at the same time increasing the life time of the Battery bank as frequent charging and discharging is avoided. The control algorithm focuses on increasing the efficiency of the system by using single pedal driving scheme in which the regenerative braking is activated when the pedal is not operated thus giving a better control on the vehicle and less wastage of energy during braking. The flow chart of the control scheme used is also included in the paper.*

I. Introduction

Battery electric vehicles (BEVs) are going to be one of the most used vehicles for transportation by the future generation. Researchers have been working on them since decades to improve their range, performance and reliability. Integrating an Ultra capacitor (UC) with the battery bank has proved to be a better option as the battery charge ratio has smoother and less fluctuations compared to the electric vehicle model without UC and there is also evident reduction in the voltage fluctuations with the UC module installed [1,2]. The power converters required to integrate the UC with the battery bank are to be of high power rating thus increasing the cost of the system. Different configurations have been proposed to efficiently integrate the UC with Battery bank [3, 4]. A new topology has been proposed by Jian Cao in [5] that provides the advantages of low power rated converter, better load profile for the battery bank, and increased life time of the battery bank. This topology is used for integrating the battery and UC in the simulated BEV.

The BEVs also suffer from a major disadvantage of low driving range, which has restricted them from dominating the high emission, low efficiency Internal Combustion Engine Vehicles [6]. Thus efficiently using the energy in a BEV has become the key for its success as a reliable choice for road transportation. The energy efficiency can be amplified by using regenerative braking and at the same time choosing a better control scheme for the vehicle controller.

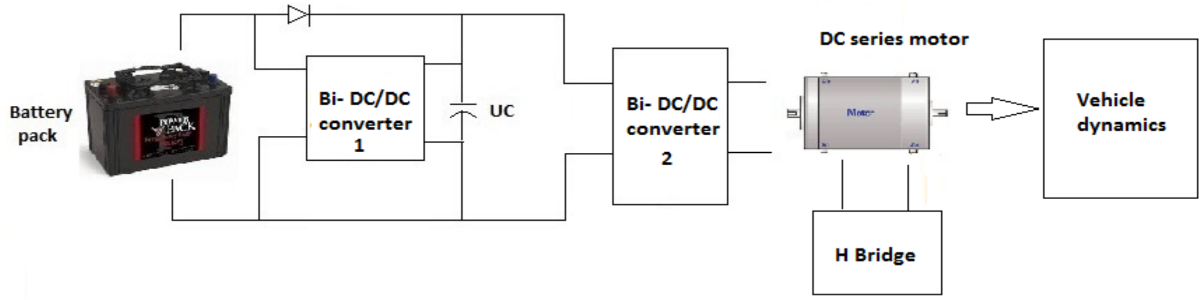


Fig.1. Topology of the BEV

II. Topology Of The Bev

The topology of the simulated BEV is shown in the fig.1.

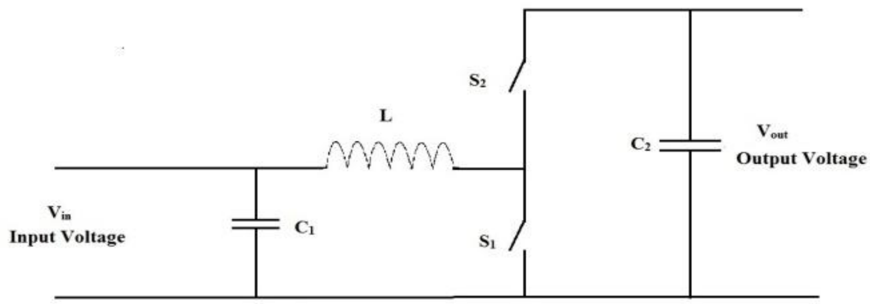
A. Battery UC configuration

The battery UC configuration shown in the topology of the vehicle uses a low power rated converter (about 25% of the load) to integrate UC with the Battery bank. The nominal voltage of the UC is higher than that of the battery (about 2 times of that of the battery). When the power required by the load is less than the power rating of the power converter the load is fed by the battery through the converter. When the power required by the load is higher than the power rating of the converter, the UC feeds the load until the voltage of the UC falls below that of the battery and there on the battery feeds the load through the power diode [5,7].

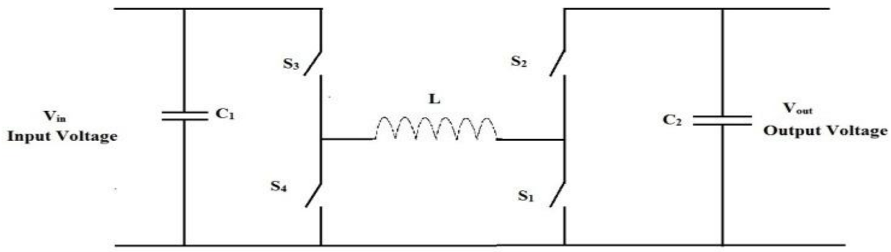
This configuration not only enables the use of low rated power converter, it also provides better load profile for the battery bank as it directly provides power when the UC voltage drops below the battery voltage.

B. Bi-directional converters

The bi-directional DC/DC converter used to integrate the battery and UC is a half bridge converter which can give boost operation in one direction and buck operation in the other [6,8].The bi-directional converter 2 that is used to control the power flow to the series motor is a Cascade converter which uses 4 switches and is capable of operating bidirectionaly facilitating buck boost operation in both the directions [6,8].



(a)



(b)

Fig.2. Topologies of (a) Half bridge converter, (b) Cascade converter [6].

The bidirectional buck boost capability helps for better energy retrieval during regenerative braking and also makes the vehicle suitable for a single pedal driving scheme. Fig.2. shows the topologies of half bridge converter and cascade converter.

III. Vehicle Dynamics

A four wheel vehicle is modeled using the following mathematical equations relating to vehicle dynamics [9].

V: Vehicle speed
V_w: Wind speed
ρ: Air density
A_f: Vehicle frontal area
C_d: Aerodynamic drag coefficient
M_v: Total mass of vehicle
α: Road angle
i_g: Gear ratio of transmission
i_o: Gear ratio of the final drive
η_t: Efficiency of driveline
T_p: Torque output from the power plant
r_d: Effective radius of the tire

Rolling resistance: $F_r = 0.01\left(1 + \frac{V}{100}\right)$

Aerodynamic drag: $F_w = \frac{1}{2}\rho A_f C_d (V + V_w)^2$

Grading resistance: $F_g = M_v g \sin\alpha$

Total resistance: $F_{tr} = F_r + F_w + F_g$

Tractive effort of the vehicle: $F_t = \frac{i_g\, i_o\, \eta_t T_p}{r_d}$

Resistance torque at the power plant: $T_r = \frac{F_{tr}\; r_d}{i_g\, i_o\, \eta_t}$

IV. Control Algorithm

Rule based algorithm is used for programming the controller. The inputs fed to the controller are:

Ped: Pedal input given by the driver
V: velocity of the vehicle
V_{uc}: voltage of the UC

The controller based on these inputs identifies what needs to be done based on the algorithm. Fig.3. shows the flowchart of the outline of the control algorithm used for the vehicle controller.

V_{ref} : Reference motor voltage
P_{ref} : Reference power required by the load
P_{con} : Power converter rating

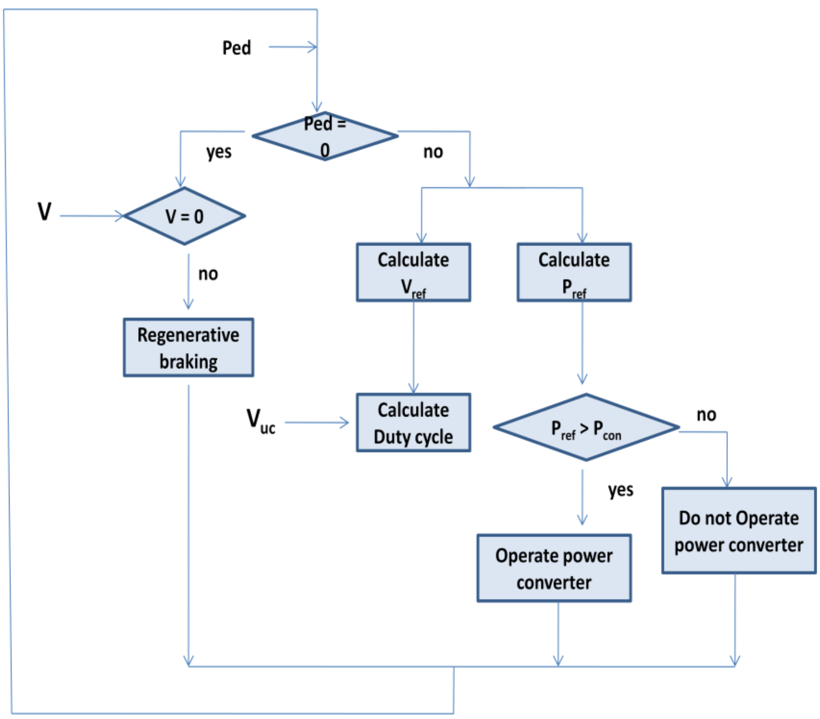


Fig.3. Flow chart of the outline of control algorithm

As seen from the flow chart, the power converter is operated only when required power is lower than the converter rating, else the load is fed through UC until its voltage is lower than battery voltage. If the pedal is at zero value and vehicle has some velocity, then regenerative braking is operated thus implementing the single pedal driving scheme.

V. Model Simulation

Fig.3. shows the Simulink model of the BEV. The parameters of the simulated model are given in Table-1. Fig.4. shows the simulated results of the topology discussed.

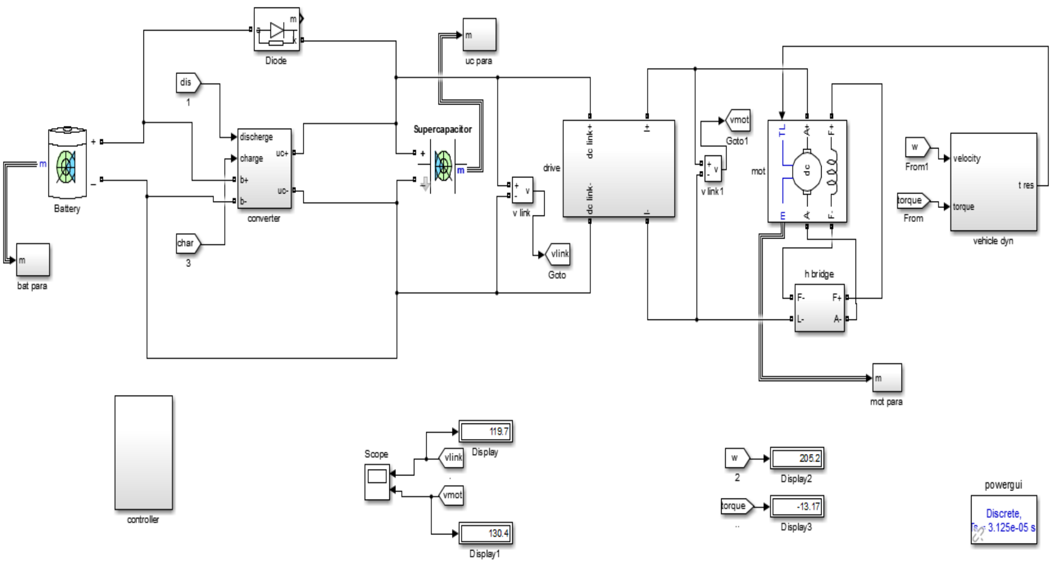
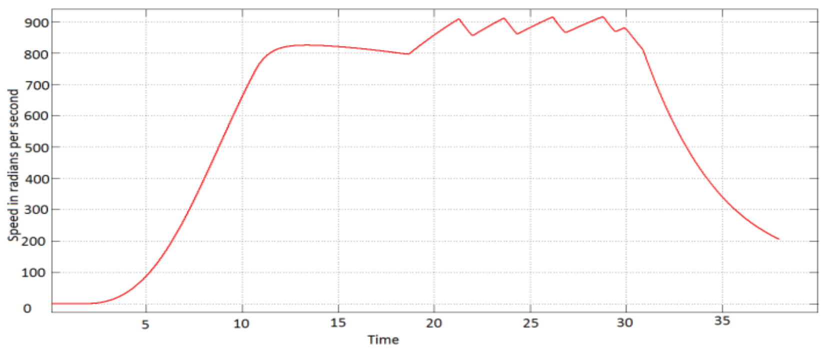


Fig.4. Simulink model

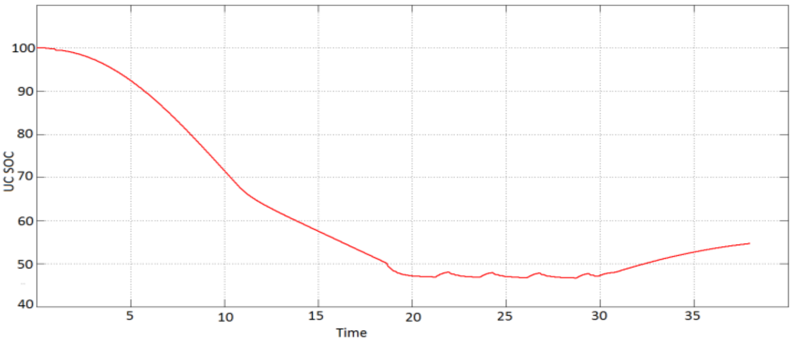
Table-1. Parameters of the simulated model

Parameter	value
Dc motor	55kw
Battery	600Ah
UC	100 F
ρ	1.2 kg/m^3
A_f	2.6 m^2
C_d	0.3
V_w	3 m/s
M_v	1300 kg
α	0
P_{con}	15 kw
r_d	0.32 m
Battery voltage	100 v
UC voltage	200 V
Battery SOC	80
UC SOC	100

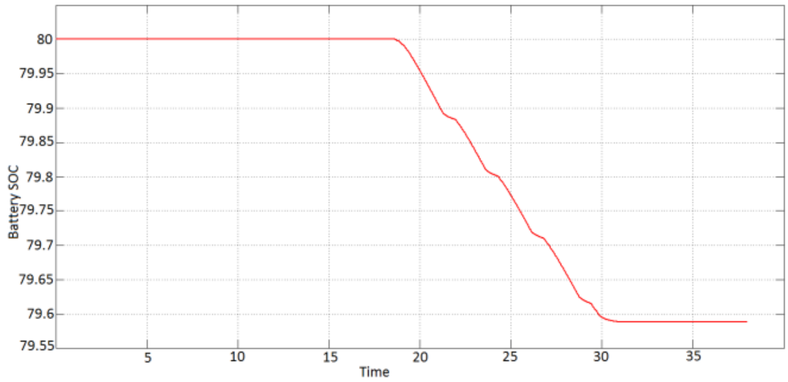
Fig.4 (a) shows the speed of the motor in radians per second vs time. In the time period 0-30 sec the vehicle Was operated in motoring mode and 30-37 sec in regenerative braking mode. The UC SOC can be seen in Fig.4(b), which shows the decrease in SOC of the UC when it was supplying the load, later a constant value of SOC is observed when the battery was supplying the UC and finally increase in SOC during regenerative braking. Similarly the battery SOC has been constant until UC voltage has gone below that of the battery voltage and later when battery supplied the load the SOC of the battery has decreased Fig.4(c).



(a)



(b)



(c)

Fig.4. (a) Speed, (b) UC SOC, (c) Battery SOC

VI. Conclusion

The BEV with the discussed topology has been simulated and the results have been discussed. The battery UC configuration has enabled the use of a low rated power converter hence decreasing the cost of the system. Single pedal driving mode has been attained using controller and provided an increase in the efficiency due to better energy recovery during regenerative braking and at the same time a better control over the vehicle is attained.

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