

Control of Hybrid Energy Storage System for an Electric Vehicle Using Super Capacitor and Battery

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Abstract - This study looks into the power flow control of a battery/super capacitor hybrid energy storage system when applied to electric vehicles. The controller is based on advanced model predictive control method and aims at smoothing the power flow from/to the battery to protect it from undesirable fast discharging/charging. The second objective of the controller is to control the electric vehicle to track a predefined speed profile. The dynamics of the vehicle and the super capacitors are modeled from first principles to facilitate the controller design. It is assumed that the battery, as the primary energy source for the vehicle, is properly sized such that there is no need to control its state-of-charge. In addition, the controller is designed at the energy management level instead of power electronics control level. Therefore, it severs to optimize the power flows of the hybrid energy storage system instead of controlling the power converters involved. Simulations based on two commonly used urban driving cycles are carried out to verify the effectiveness of the design.

Keywords: Electric vehicle, hybrid energy storage system, power source coordination, model predictive control, power flow control.

I. INTRODUCTION

With increasing concerns on global warming and climate change the auto mobile industry is moving towards electrification of automobiles using partial hybridization to fully electric vehicles (EV). Apart from the advantage of more efficiency and less emissions for EVs compared to conventional combustion engine vehicles, there are numerous other advantages such as higher starting torque and easy control of power flow for electric motors. In combustion engines the starting torque is less so they require a transmission system to increase the torque [1]. The on board energy storage system (ESS) plays a very important role in knowing the performance and electric vehicles electric range. Most of the electric vehicles nowadays use Lithium ion rechargeable batteries because of their high energy density and design flexibility and some exceptional electrochemical properties exhibited by lithium [2]. To increase the all electric

range of the vehicle by 15%, the incremental cost of ESS almost doubles.

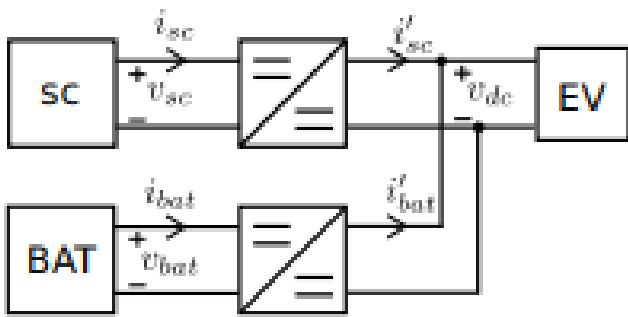
For effective operation of the electric vehicle, the ESS should possess high energy and high power densities which is not available in any single energy source. Batteries generally have higher energy density but low specific power and life cycle [3]. Also battery efficiency reduces if the load draws very high current in case of peak demands when the battery state of charge (SOC) is low and it might lead to thermal stress in the battery. Here comes the importance of super capacitor which has higher power density, life cycles and efficiency and a fast response on charge/discharge cycles when drawing high current, but has lower energy density [4]. So both the energy storage device complements each other in terms of energy density, life cycle and power density. Batteries with higher capacity can be used for higher power densities but it is not a commercially viable solution. Size and weight should not be constraint for an automotive application.

II. METHODOLOGY

The diagram of an EV powered by an HESS consisting of batteries and super capacitors is shown in Fig. 1, in which the battery and super capacitor banks are connected in parallel to the DC bus by two-quadrant DC-DC converters. This configuration allows the battery to hold the DC bus voltage at desired level and enables bidirectional power flow from and to the HESS, which allows the vehicle to charge the battery and supercapacitor during regenerative braking periods.

It also allows the battery to charge the supercapacitor and vice versa to help to smooth the power flow of the battery. Whereas it is assumed that the battery is properly sized which is sufficient to run through a specified range, the vehicle dynamics and the characteristics of the supercapacitor must be modeled in order to design the power flow controller. The following two subsections detail the modeling of the EV and the HESS. EV model Motion dynamics of the EV is governed by Newton's Law and is given as follows.

$$\begin{cases} \dot{x} = v, \\ \dot{v} = f_{tr} - f_{aero} - f_r, \end{cases} \quad (1)$$



Where x and v are the position and speed of the vehicle, respectively. f_{tr} is the traction force provided by driving motor using power supplied by the energy storage systems, f_{aero} is the aerodynamic drag force and f_r consists the rolling resistance and gravitational acceleration force. In particular,

$$f_{tr} = \frac{\eta_d}{v} (\eta_{bat} p_{bat} + \eta_{sc} p_{sc}),$$

Where η_d is the power train efficiency of the EV, η_{bat} and η_{sc} are the efficiency of the DC-DC converters for the battery and supercapacitor, respectively. p_{bat} and p_{sc} are the battery and supercapacitor power supplied to (absorbed from) the EV, respectively. The aerodynamic drag can be calculated by

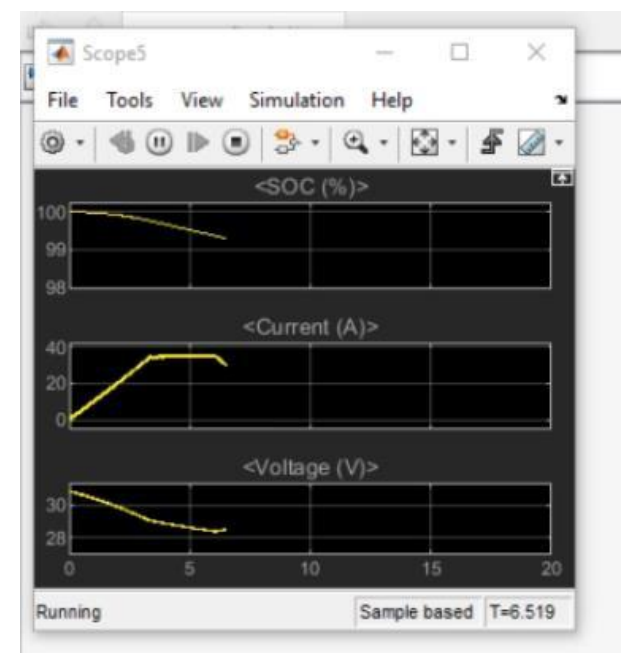
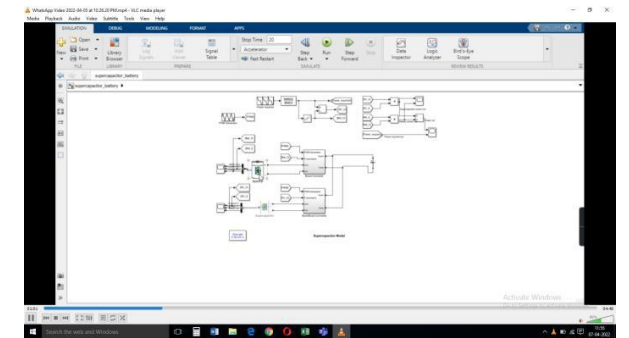
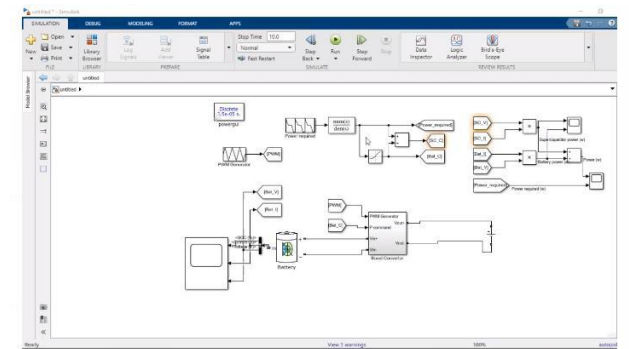
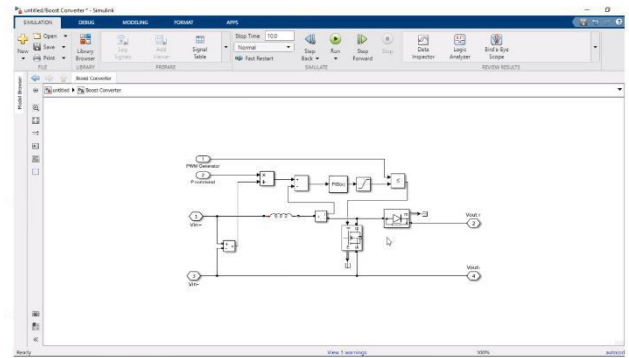
$$f_{aero} = \frac{1}{2} \rho_a C_d A_f v^2,$$

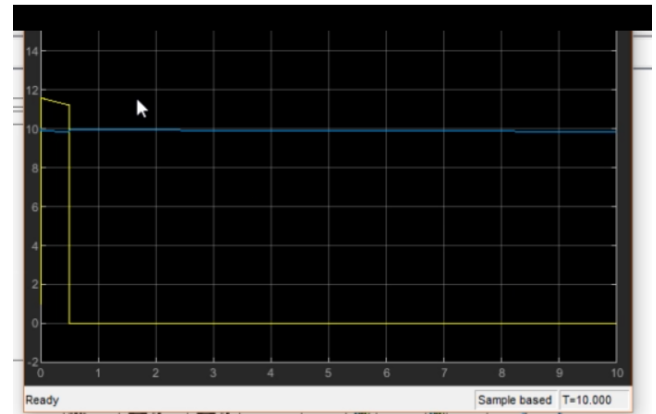
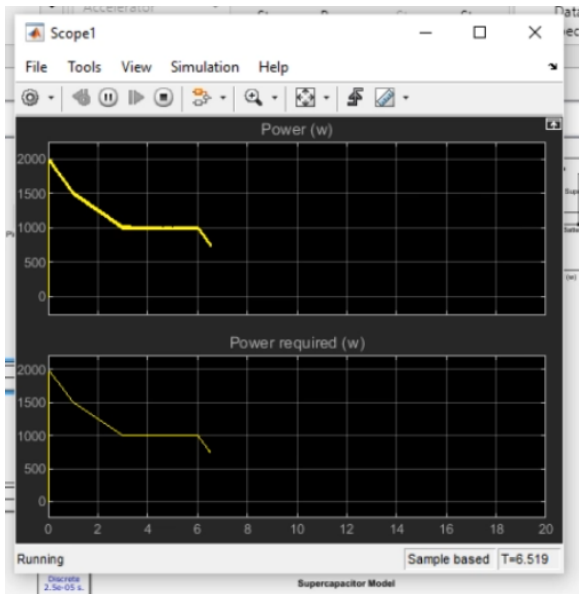
Where ρ_a is the air density, C_d is the air drag coefficient and A_f the front cross sectional area of the vehicle. The last term is obtained by

$$f_r = mg\mu \cos(\alpha) + mg \sin(\alpha),$$

Where μ is the rolling resistance coefficient, g is the gravitational acceleration and α is the slope of the road. The model shown in Eq. (1) governs the movement of the EV and is used for the controller design. The power provided by the HESS, p_{bat} and p_{sc} , is modeled in the following subsection 2.

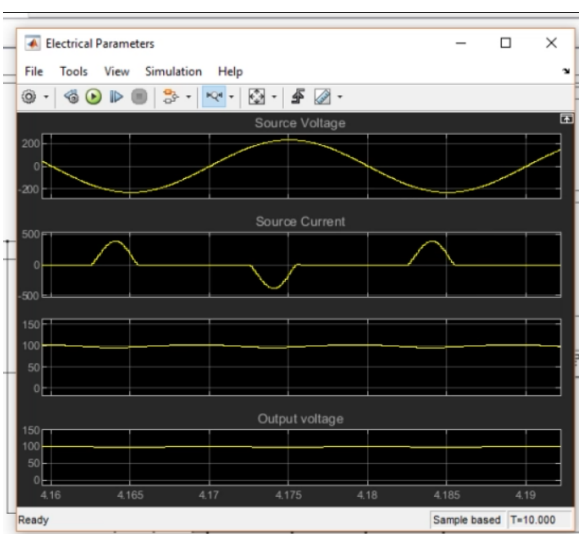
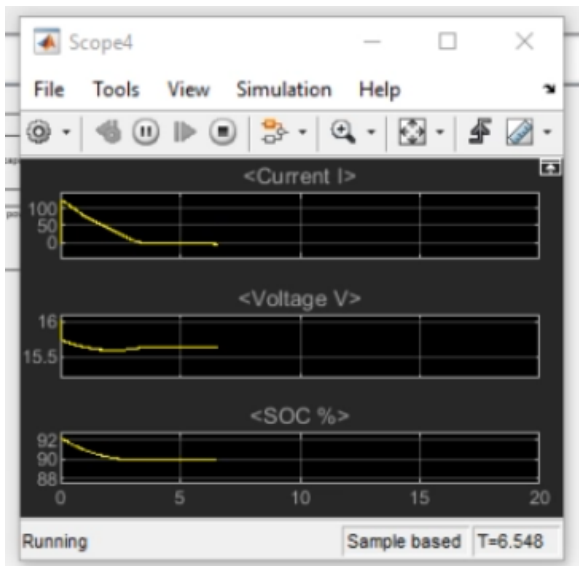
Parameters: The parameters of the relevant components are given in Table 1. The supercapacitor bank consists of two strings of cells connected in parallel. Each string consists of 141 cells connected in series. Each cell has a nominal voltage of 2.7 V and a capacitance of 1500 F. The total weight of the EV, including the HESS, is 500 kg and the maximum speed of the vehicle is 100 km/h. The EV utilizes a DC motor; therefore, inverting of the DC power supplied by the HESS is not required.





III. RESULTS AND CONCLUSION

A model predictive controller has been designed for the power flow control of a hybrid energy storage system (HESS) consisting of batteries and supercapacitors for electric vehicles. The objectives of the controller are to track a given speed profile for the vehicle by proper power distribution within the battery and supercapacitors of the HESS and to avoid abrupt variations in the power flow of the battery in order to protect the battery. The vehicle dynamics and supercapacitor dynamics are modeled from first principles to facilitate the controller design. The designed controller is tested with two standard urban driving cycles, one developed by the US and the other commonly used in the European countries. The results obtained verified that the controller is able to fulfill its objectives. In particular, the controller can track the speed profile and is able to split the low frequency and high frequency power demands of the vehicle to the battery and supercapacitor, respectively. In addition the weighting factor, k_v , introduced in the objective function of the controller allows tuning of the controller to achieve better speed tracking or smoother battery power flow.



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