Optimal Sizing of a Li-Ion Battery, a Fuel Cell and a Capacitor for a Hybrid Power System

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With dwindling petroleum resources and stringent pollution laws, the future clearly belongs to hybrid electric vehicles [1]. A hybrid electric vehicle has an electric drive train and derives its power from a hybrid power source. Apart from the hybrid vehicles, the hybrid power systems find applications in various other places ranging from domestic heating to space programs and hence their study is very important. Presently, hybrid power systems that consist of a combination of a fuel cell, a battery and a super capacitor are being heavily tested and show much promise. Issues such as interaction between sub-system components and energy-power trade-offs between these devices naturally arise. This work aims to address some of these issues.

Fuel cells are designed for continuous energy supply and are best operated at constant operating conditions. They perform poorly in the presence of power fluctuations and cannot handle high power demands. Lithium Ion batteries, on the other hand, have relatively lower energy densities and higher power densities. Super Capacitors are at the other extreme from fuel cells with very low energy densities and very high power densities. A hybrid power system comprising of two or all three of these components is shown to have the benefits of high energy densities of the fuel cell as well as high power densities of the capacitor and lead to longer battery life [2]. Most of the major car companies like Ford, Chrysler and General motors have already launched some prototype models of the hybrid vehicles. Studies have shown that hybrid power systems are clearly better than the individual components alone for operating over a wide range of conditions and for longer duration [3]. When a super capacitor is in parallel with a battery, the high power deliverability of the capacitor can be used to deliver battery's energy. The system or power- bus voltage is floating at the battery voltage and a decoupler (DC to DC power converter is needed or the internal battery resistance is sufficient) is used to connect the capacitor and the fuel cell to the power bus. Constant current pulsing or power pulsing techniques have been used not only to deliver high power pulses but also to improve the battery life [4]. The characteristics of the pulse, namely frequency, duty cycle and amplitude have a bearing on the total energy and average power delivered and the optimum values of these parameters can also be found.

In this work, physics based models of the involved battery, capacitor and fuel cell are developed to match real experimental data. The idea behind these models is that these models should be able to capture the essential characteristics of the respective components and also should be simple enough to facilitate system-wide studies. Two or more of these components are connected in parallel to each other to form a hybrid source.

Figure 1 shows the Ragone plot of a 1.4 A-hr Polystor Li-Ion cell and a 100 F super capacitor in parallel at 10% and 100 % duty ratios at a pulse frequency of 0.1 Hz. The advantages of hybrid over the individual components are obvious from the figure. The region of operation of the hybrid extends beyond that of individual components. The current profiles of the 1.4 A-hr Li-Ion battery and 5 F super capacitor hybrid from experiment and from simulation at 1 A, 25 % duty ratio and 0.25 Hz are shown in figure 2. These studies would be extended to a hybrid system consisting of fuel cell too.

Ragone plots, that give information about specific power- specific energy trade-offs of the system, can be constructed and used to find the optimal combination (relative sizes) of the fuel cell, the capacitor and battery for a given energy and power requirement. This optimum can be based on either minimum cost, minimum weight or minimum volume criterion of the entire system. These plots also help in choosing values of frequency, duty cycle and the amplitude of the pulse, which minimize the over-all system based on weight or volume. It will be shown that, with the hybrid power sources, it is possible to operate at specific power and specific energy regions that are not accessible with the individual devices alone. Comparison of the ragone plots and the voltage current profiles of the hybrid with experimental data will be presented.

References

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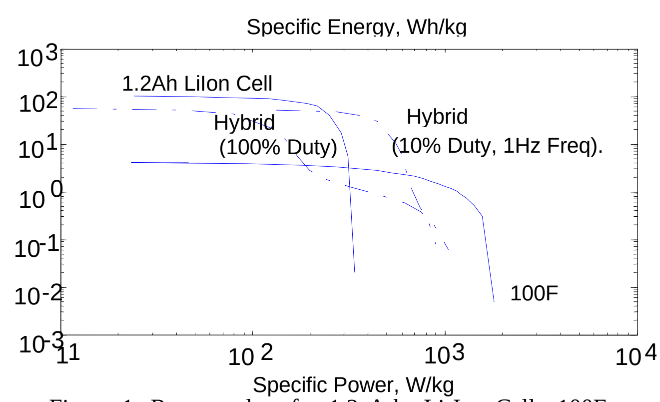


Figure 1: Ragone plots for 1.2 A-hr Li-Ion Cell –100F Cap. Hybrid at 10% duty, 1 Hz frequency and 100 % duty

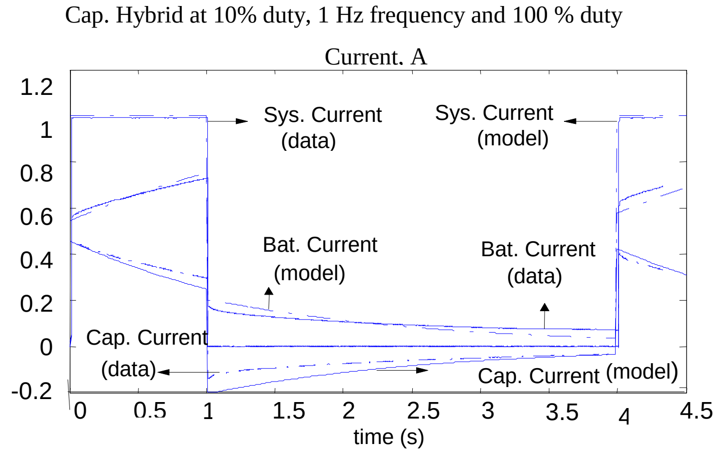
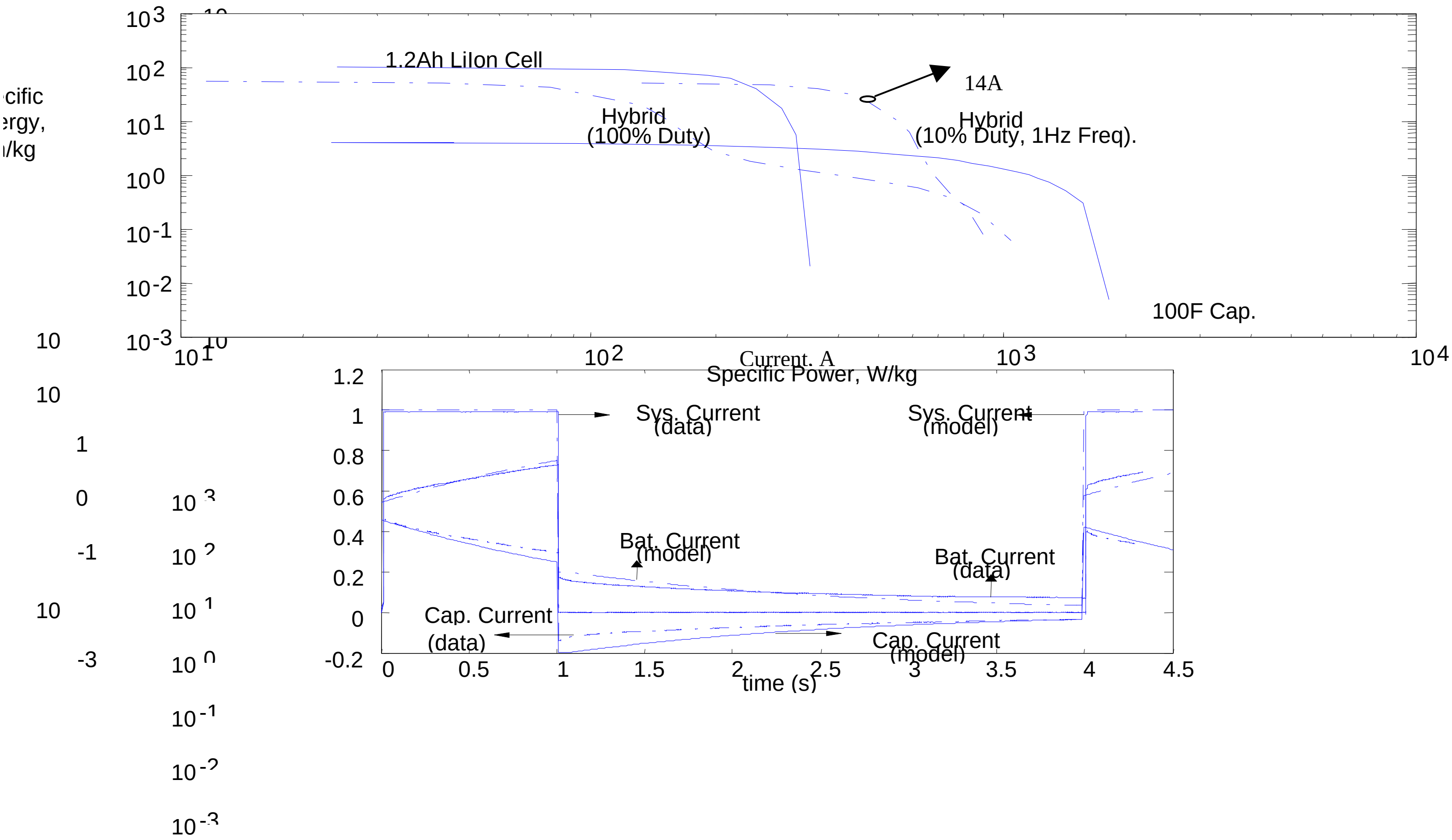


Figure 2: Comparison of current profile from data and model for a 1 A, 0.25 Hz, 25 % duty ratio pulse on a 1.2A-hr Li-Ion battery-5 F Cap. Hybrid.



1.2Ah LiIon Cell
14A
Hybrid
(100% Duty)
Hybrid
(10% Duty, 1Hz Freq).
100F Cap.
Current, A
Specific Power, W/kg
Sys. Current
(data)
Sys. Current
(model)
Bat. Current
(model)
Bat. Current
(data)
Cap. Current
(data)
Cap. Current
(model)
time (s)