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# A Multi-Objective Power Component Optimal Sizing Model for Battery Electric Vehicles

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## Abstract

With recent advances in electric vehicles, there is a plethora of powertrain topologies and components available in the market. Thus, the performance of electric vehicles is highly sensitive to the choice of various powertrain components. This paper presents a multi-objective optimization model that can optimally select component sizes for batteries, supercapacitors, and motors in regular passenger battery-electric vehicles (BEVs). The BEV topology presented here is a hybrid BEV which consists of both a battery pack and a supercapacitor bank. Focus is placed on optimal selection of the battery pack, motor, and supercapacitor combination, from a set of commercially available options, that minimizes the capital cost of the selected power components, the fuel cost over the vehicle lifespan, and the 0-60 mph acceleration time. Available batteries, supercapacitors, and motors are from a market survey. The considered lifespan is taken as 10 years, and the traveling distance is estimated at 50.9 miles per day using a combination of standard driving cycles. The resulting optimization problem is solved with the help of a quasi-static powertrain model which is developed using MATLAB/Simulink. A Genetic Algorithm is used to find the optimal solution in the case study. Normalized weighting factors are given to help users meeting their preferred performance during the power component design. Battery packs in the case study are chosen from LiFePO4 18650 cells with total capacity up to 100 kWh. Seven available types of supercapacitors along with 6 popular motors are also included in the design options. Two samples of the design results are compared to analyze the relevant tradeoff between performance indicators and cost.

## Introduction

Electric vehicles usually use Li-ion batteries as their primary source of energy. Due to limitations on the power discharging speed of batteries, many automakers have utilized supercapacitors to provide high power and thus extend battery life [1]. With this new growth in demand for electric vehicles, it has become important to maximize both efficiency and performance of these new forms of hybrid electric vehicle powertrain components. Consumers demand maximum possible performance at the least possible total cost of ownership. Therefore, this paper targets the power source component selection optimization problem for BEVs considering the trade-off between vehicle performance and component investment cost.

In the literature, there have been many studies investigating BEV power source component selection designs, and such a design is usually formulated as an optimization problem. For example, the optimization of the motor design of an interior permanent magnet synchronous motor is discussed in [2] for a BEV, and a multi-objective genetic algorithm is used to solve the relevant optimal design model.

A multi-objective design optimization approach to select the best powertrain layout and size corresponding components simultaneously is presented in [3]. Though only acceleration and fuel economy are assessed while choosing from a variety of engine and motor options. The paper [4] presents an optimal EV sizing approach considering both supercapacitors and batteries but only minimizes a single objective which is the cost of the energy and components used.

An EV design consisting of a solid oxide fuel cell that acts as a range extender is given in [5]. The paper uses a very simplified physical model of the vehicle powertrain to achieve lowest environmental and techno-commercial impact. In [6], a high-performance EV is developed using battery and supercapacitor combinations while minimizing the cost of the drivetrain over the vehicle’s lifetime while considering battery degradation constraint by vehicle performance but it does not consider the traction motor and the driving range. Similarly, [7] optimizes the electric vehicle topology selection and sizing based on the battery, supercapacitor and DC-DC converter specifications while not considering the traction motor.

With regards to the presence of supercapacitors in EVs, findings in [8] show that having a supercapacitor can increases battery life of an EV by about 2.5 times. However, that paper does not deal with the optimal sizing of the supercapacitor and battery to achieve desired objectives unlike the approach outlined in this paper. In [9], a comprehensive approach for optimal sizing of an electric vehicle is presented to decide specifications of battery, supercapacitor, and power converter. Although it does consider constraints on component-level

**TABLE 3** Comparison between optimal and sub-optimal solutions

| | Battery | Motor | | Supercapacitor | Decision factors | | | |
|---|---|---|---|---|---|---|---|---|
| Sr. No. | Capacity (kWh) | Peak torque (Nm) | Peak power (kW) | Max discharge current (A) | Total cost ($) | Acceleration time (sec) | Range (miles) | Objective function cost |
| 1 | 90 | 596 | 200 | 210 | 41,751 | 5.26 | 161.19 | 0.288 (Optimal) |
| 2 | 95 | 759.36 | 313.194 | 225 | 52,593 | 4.64 | 184.23 | 0.321 |
| 3 | 85 | 759.36 | 313.194 | 210 | 49,066 | 4.65 | 166.73 | 0.329 |
| 4 | 40 | 298 | 100 | 140 | 1,024,069 | 6.49 | 66.32 | 12.034 |

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**TABLE 4** Normalized weights

| Decision factors | Scenario 1 | Scenario 2 |
|---|---|---|
| Total cost | 0.8 | 0.1 |
| Acceleration time | 0.1 | 0.1 |
| Driving range | 0.1 | 0.8 |

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**TABLE 5** Optimal solutions for the different scenarios

| Specification | Scenario 1 | Scenario 2 |
|---|---|---|
| Electric motor | Peak power: 100 kW, Peak torque: ~300 Nm | Peak power: 310 kW, Peak torque: 760 Nm |
| Battery | 55 kWh | 100 kWh |
| Supercapacitor | Max current: 140 A | Max current: 225 A |
| Total cost | $ 27,939.00 | $ 53,733.34 |
| Acceleration time | 7.63 sec | 4.64 sec |
| Driving range | 133.20 miles | 191.79 miles |
| Top speed | 100.56 mph | 181.62 mph |

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the driving range constraint. As the acceleration time has a low weightage, the most cost-effective supercapacitor is selected. For the second scenario, the priority is to improve the driving range of the vehicle. The total mass and the battery capacity play a critical role while determining the driving range of the vehicle. Thus, the algorithm selects lightest motor. The driving range of the vehicle is more sensitive to increase in the battery capacity than to reduction in total weight of the battery pack. Thus, the algorithm selected the battery with the highest capacity.

# Conclusion

This paper has successfully presented a novel validated method for designing hybrid electric vehicles using batteries and supercapacitors as energy storage devices. The methodology outlined herein allows the simultaneous selection of electric vehicle battery, supercapacitor and motor while optimizing the design for certain vehicle-level design objectives, namely, acceleration time, driving range and total cost of selected components. The importance of one design objective over another can be defined by the user and thus can result in an optimal design that best fulfills those requirements. A detailed case study showing three different designs is presented. One of these designs with 50% weight on total cost and 25% each for range and acceleration give a relatively balanced design option. The other two results show edge cases, one of which gives high importance to lower cost and the other gives high importance to driving range. Both give drastically different yet reasonable vehicle designs that fulfill the user's requirements accordingly. As a future study, this design method will be further validated using a big database of commercial products.

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