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MODELING AND ANALYSIS OF AN ELECTRIC VEHICLE USING PAMVEC

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Abstract. *Electric vehicles are considered a key technology to reduce fossil fuel consumption, emissions and energy consumption. However, Electric Vehicles require larger battery packs to reach acceptable range levels. The development of new batteries with higher specific energy could reduce the mass and the cost of Electric Vehicles and increase their driving range. This work analyzes the influence of battery specific energy on battery pack mass, energy consumption and the cost per kilometer of a Tesla Model S Electric Vehicle. The energy consumption and the cost per kilometer calculated were 0.221 kWh/km (22.1 kWh/100 km) and 0.024 US$/km respectively.*

Keywords: *Electric Vehicles; Advanced Automotive Batteries; Energy Consumption.*

1. INTRODUCTION

Electric Vehicles (EVs) have the potential to improve air quality and decrease fossil fuel dependence. EVs require larger battery packs (BPs) to reach acceptable range levels and high specific power capacities for acceleration, climbing, etc. Barriers such as limited driving range, high purchase cost and slow recharging time delay the mass adoption of these vehicles (Newbery *et al*., 2016; Franke *et al*., 2013; Ajanovic *et al*., 2016).The development of new batteries with higher specific energy could reduce the mass and the cost of EVs and increase their driving range.

Currently, the most commonly used batteries in EVs are Li-ion batteries, but other types of batteries are being developed, for example, Li-sulfur and Li-air batteries (Cosmin *et al.*, 2013; Christensen *et al.*,2011; Brutti *et al.*,2012). These new batteries present theoretical specific energy values from 4 to 10 times the current Li-ion specific energy (Song *et al*., 2013; Zhu *et al*., 2015).

This paper presents a modeling of a Tesla Model S EV and analyses the impact of the battery specific energy on BP mass, energy consumption and cost per kilometer. The Tesla Model S was chosen for this study due to its fast recharging time (the battery bank reaches 50% of full charge within 20 minutes), its global sales and due to the vehicle´s high driving range when compared to other models on the market.

2. METHODOLOGY

In order to analyze the vehicle performance, the Parametric Analytical Model of Vehicle Energy Consumption (PAMVEC) was used (Simpson, 2005). PAMVEC is a modeling tool that allows users to compare the performance of different combinations of vehicle propulsion systems and fuels.

One of the main parameters affecting battery electric vehicles (BEVs) performance is their mass. The calculation of the mass of a BEV is described by Eq. (1).

$$M_{curb} = M_{glider} + K_{struct} \times (M_{bat} + M_{motor} + M_{transmission}) \quad (1)$$

where:

Mcurb is the curb mass;
Mglider is the glider mass;
Kstruct is the structural mass factor;
Mbat is the battery pack mass;

Mmotor is the electric motor mass;
Mtransmission is the transmission mass.

The structural mass factor (Kstruct) is related to the structure that is necessary to endow the vehicle in order to support the propulsion system components. Electric motor mass, transmission mass and glider mass are given as inputs on PAMVEC.

The battery pack mass (Mbat) will be dimensioned to meet the energetic needs of the electric vehicle's driving range, electric motor power and accessory load.

The Tesla Model S RWD, 85 kWh BP, is energized by Li-ion batteries manufactured by Panasonic (Menahem, 2014). The main characteristics of the modeled vehicle are described in Tab. 1.

Table 1. Inputs of Tesla Model S configurations.

Platform Parameters	
Glider mass (m_{glider})	1,474 kg
Curb mass	2,108 kg
Drag coefficient (C_D)	0.24
Rolling resistance coefficient (C_{RR})	0.007
Cargo mass (two persons)	150 kg
Accessory load	1,000 W
Performance Parameters	
Acceleration: 0 to 100 km/h	5.6 s
Top speed	225 km/h
Driving range	426 km
Powertrain	
Electric motor	285 kW
Lithium ion battery	Panasonic NCA18650
Specific energy	233 Wh/kg
Energy density	630 Wh/l

3. RESULTS AND DISCUSSION

This paper presents a modeling of Tesla Model S and analyzes the impacts of driving range and the battery specific energy on battery pack mass, energy consumption and cost per kilometer. As discussed above, new batteries with higher specific energy could reduce the mass and cost of EVs and increase their driving range.

In order to analyze the vehicle performance, the Parametric Analytical Model of Vehicle Energy Consumption (PAMVEC) was used. PAMVEC predicts vehicle energy consumption on the basis of the driving cycle description, total vehicle mass and other inputs of the vehicle platform (such as drag coefficients and accessory loads) and the powertrain component characteristics and efficiencies.

1.1 3.1 Battery pack mass and vehicle curb mass

Figure 1 analyzes the influence of battery specific energy on the BP mass (Mbat) and on the vehicle curb mass (Mcurb). The green line (Ratio) shows the Mbat/Mcurb ratio. The dashed line (A) represents the specific energy of the original vehicle, Tesla Model S. The dashed line (B) represents the specific energy of a Li-sulfur battery reported by Song *et al.* (2013).

Figure 1 shows that battery specific energy has a significant influence on the vehicle mass. As can be noted in Fig. 1, for values up to 200 Wh/kg, small variations in specific energy produce a strong change in the BP mass. For a battery specific energy of 200 Wh/kg, the BP mass, that attends to the energetic needs of the simulated vehicle, is 440 kg. If the battery specific energy doubles (400 Wh/kg), the BP mass is reduced by 45.6%, becoming 200 kg. However, the reduction is less drastic for higher specific energy values: for an increase in the specific energy from 400 Wh/kg to 600 Wh/kg, a reduction of 72 kg is achieved, i.e., approximately 35% of the BP mass.

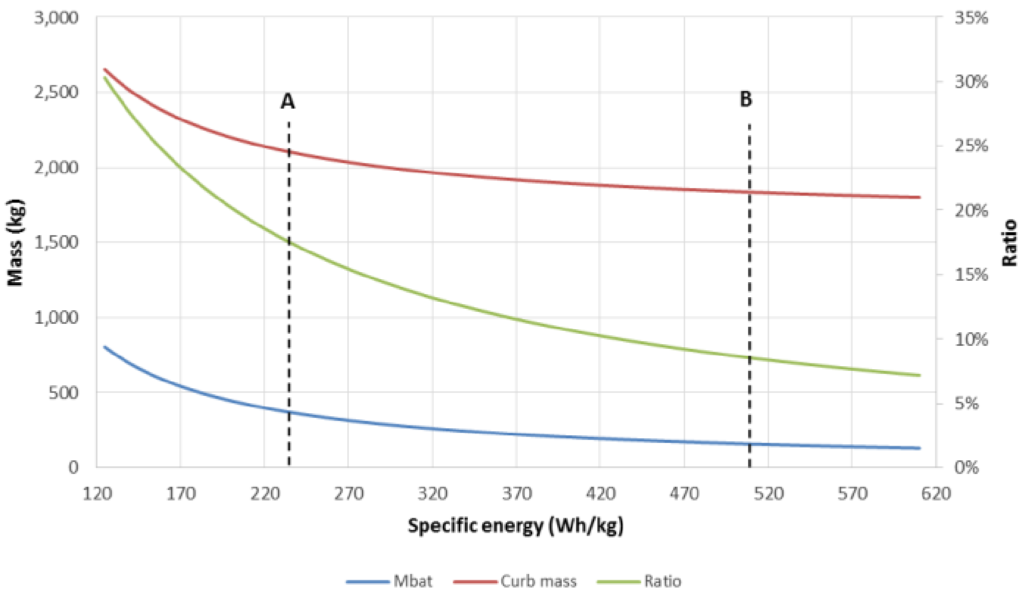

Figure 1. Battery pack mass and vehicle curb mass as a function of the battery specific energy of Tesla Model S

3.2 Energy consumption and on the cost per kilometer

The effects of battery specific energy on vehicle energy consumption and cost per kilometer are showed in Fig. 2. The analysis of Fig. 2 shows that the higher the battery specific energy, the lower the energy consumption of the vehicle. This is due to the fact that a higher specific energy allows a lower battery mass and less energy is needed to power the vehicle.

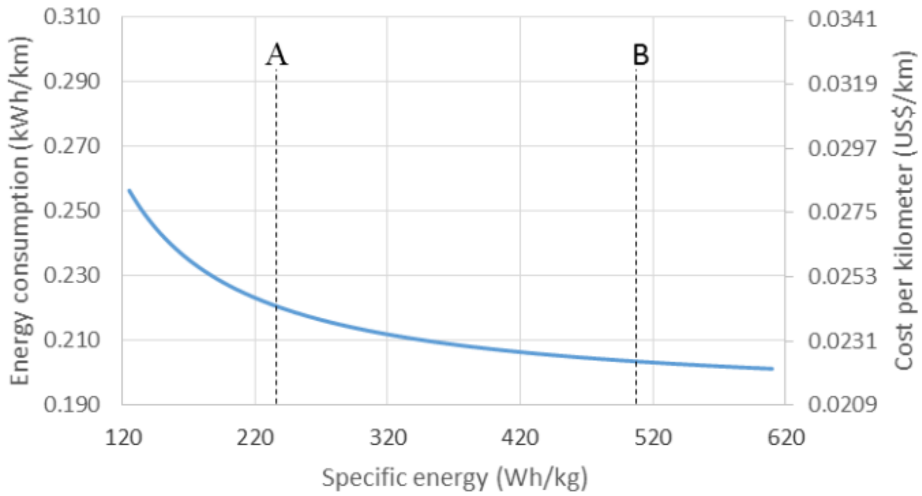

Figure 2. Influence of battery specific energy on energy consumption and cost per kilometer of the Tesla S.

Low energy consumption and high efficiency are two advantages of BEVs. These factors, associated with the low electricity cost in comparison to conventional fuels, result in a low cost per kilometer for BEVs.

According to the model developed with PAMVEC, for a battery specific energy of 233 Wh/kg, the energy consumption calculated is 0.221 kWh/km (22.1 kWh/100 km) and the cost per kilometer is 0.024 US$/km (2.4 US$/100 km). Increasing the battery specific energy to 400 Wh/kg results in 0.207 kWh/km (20.7 kWh/100 km) of energy consumption and in a cost per kilometer of 0.023 US$/km (2.3 US$/100 km), i.e., about 5 % lower.

EPA rates Tesla S 85kWh energy consumption at 24 kWh/100 km for a combined fuel economy (DOE, 2016). For purposes of comparison with conventional vehicles, the energy consumption of an internal combustion engine vehicle is approximately 0.60 kWh/km (60 kWh/100 km) (Nylund, 2013).

4. CONCLUSIONS

According to the model developed with PAMVEC, the battery specific energy affects the curb mass, energy consumption and the cost per kilometer of a BEV. The higher the battery specific energy, the lower the BP mass, the energy consumption and the cost per kilometer.

There is a strong decrease in BP mass in low battery specific energy range (120-200 Wh/kg). In the range of high battery specific energy values (~ 500 Wh / kg), the effect of increasing specific energy is more modest, leading to small reductions in mass.

The energy consumption calculated for Tesla Model S, energized by its original BP, is 0.221 kWh/kg (22.1 kWh/100km) and the cost per kilometer is 0.024 US$/km.

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