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Electric Vehicle Battery Subsystem Optimization

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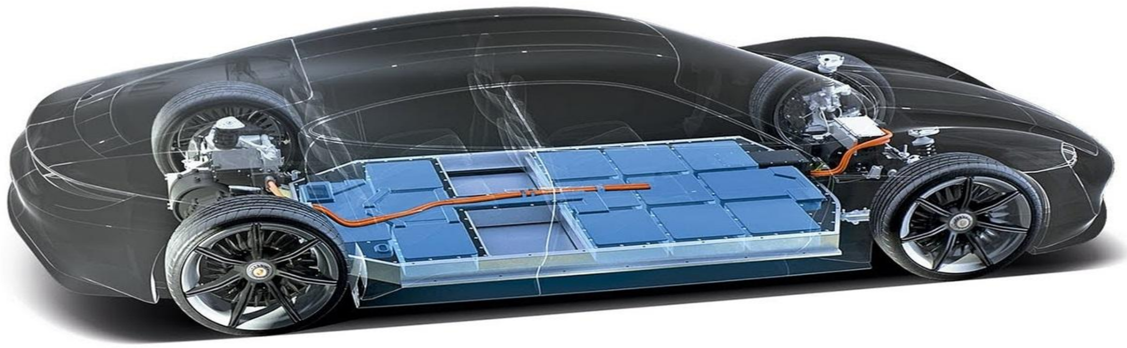
Abstract: ***Battery subsystem optimization refers to the process of improving the performance, efficiency and overall functionality of a battery system. It involves various techniques and strategies aimed at maximizing the energy storage capacity, extending the battery life. Paper shows the resultant graph of range in km versus battery kWh with respect to Zero grade and 7.5% grade of the road.***

Keywords: Driving Range, Kerb Weight, Battery Capacity, Rolling Resistance, Aerodynamic Drag, Road Grade Angle, Frontal Area

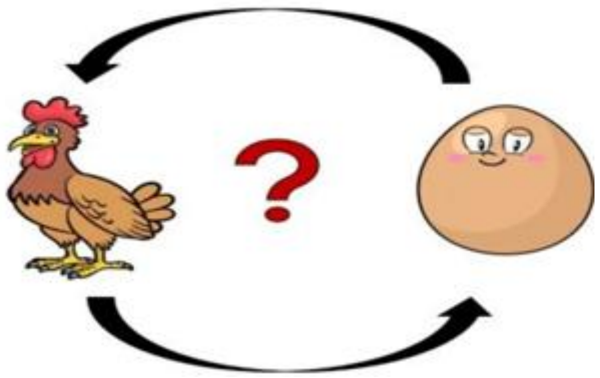
1. Introduction

As an EV system engineer your management has given tasked you to enhance the range of an existing EV family as much as possible to beat upcoming competition. There is a general problem arise that if we increase the no of battery packs in our vehicle for increasing the range so it definitely increase the weight of the vehicle and we saw our vehicle efficiency goes down. The solution of this problem is to find the optimum size of battery pack, which gives maximum driving range. Our scope is to study about battery subsystem optimization and plot the graph between driving range (km) and battery capacity (kWh) with respect to zero grade and 7.5% grade of the road.



2. A Chicken and Egg Problem

For the ease of calculations, assume 60km/hr constant speed. This would meet the requirements of our problem statement since we are only interested in comparative calculations for various battery capacities scaled with 200kg battery modules each 16kwh capacity. Addition of batteries would only enhance vehicle weight. This would further decrease the range from the desired target. In real life driving you never, encounter a flat road. To account from the same we calculate the range for an ideal case of zero road grade and real life nominal grade of 7.5% road grade. This will lend us with real life application insights.



3. Adding more batteries to enhance a range

Assume different battery options with 16kwh, 32kwh, 48kwh and 64kwh with respective weights of 200kg, 400kg, 600 kg and 800kg. Plot range in km versus battery kWh for above four battery options to asses impact on range due to battery capacity increase.

Relevant technical specifications for the EV are as - Kerb weight without battery (980kg), drag coefficient Cd (0.308), Rolling resistance fr (0.009), Frontal Area af (2.22m^2), Accessory electric power (700 w), air densityρ (1.18 kg/m^3), Road Grade Angleα (4.29), vehicle velocity (60km/h or 16.67 m/s). Calculate the range for zero grade and 7.5% grade of the road.

4. Formulae to be used

- Driving range dx = Vx*Eb/P; where dx is the distance, Eb is the battery energy capacity and P is the power in kW, Vx is the vehicle velocity.
- Power P = [Mvgfr + (ρCdAf/2). Vx2 + MvgSinα] Vx + Pel; where ρ is the air density, Mv is the vehicle gross mass (kerb weight + battery weight) and α is the grade angle of the road. Cd is the drag coefficient, Af is the frontal area, g = 9.8 m/s/s.

Left hand side gives us power on rate of energy at given time. Since it is a function of the vehicle speed (constant at 60 km/hr. it gives us instantaneous power at all time.
(Mvgf) is the force consumed due to vehicle Rolling Resistance in N
(ρCdAf/2). Vx2 is the force consumed due to Aerodynamic Drag.
(MvSinα) is the force due to road grade. Tan α is the slope of the road.

- POWER = TOTAL FORCE * VELOCITY
  P = F*V

All the above three terms are summed - up to obtain the total force opposing the motion of the vehicle. Remember as per the Newton`s first law, a uniform velocity needs net zero force. Therefore, the EV powertrain needs to exert an equal force to make the net force as zero. Multiplying the force with velocity gives us the total power needed to maintain the vehicle at constant speed. Pel is the equipment power such as air conditioning, lighting etc. we have assumed the same as 700 watts.

5. Calculations

For 7.5 % road grade:
Power P = [Mvgfr + (ρCdAf/2). Vx2 + MvgSinα] Vx + Pel

P = [1180*9.8*0.009 + 1.18*0.308*2.22/2*16.67*2 + 1180*9.8*sin4.29]16.67 + 0.7
P = 17.078 kW

Driving range dx = Vx*Eb/P
Dx = 60*16/17.078
Dx = 56.211 km

For zero% road grade:
P = [1180*9.8*0.009 + 1.18*0.308*2.22/2*16.67*2 + 1180*9.8*sin0]16.67 + 0.7
P = 2.659 kW

Driving range
Dx = 60*16/2.659
Dx =361.065 km

Note:
Further, we calculate driving range for 7.5% and zero% grade road with respect to 32kwh, 48kwh and 64kwh battery capacity, which have 400kg, 600kg and 800kg their respective weights. Then we plot a range chart in km versus kWh using Ms Excel.

6. Results

- The blue trace is for zero road grade (flat road). It shows near linear increase in the range at constant velocity but still some reduction can be noticed from ideal range.
- With 7.5% road grade, the range figures are drastically reduced. Because grade related energy, loss is mass dependent. It eats into the battery energy with increasing the mass. Hence, in real life condition, increase in battery weight for EV causes significant range reduction.

7. Conclusion

- Increasing the battery capacity will not meet our goal of corresponding increase in the EV range in real life condition.
- Real solution is to enhance battery energy density through use of advanced battery technologies.
- The battery weight should roughly not exceed 20% of the gross vehicle weight.

- The way ahead is to benchmark competition EVs energy density and also interact with EV battery management system vendors understand their energy density roadmap. Our EV development roadmap needs to be tailored around the same.
- Vehicle range is impacted by road grade. It adds a term containing vehicle mass and hence higher battery weight reduces the range at higher road - grades.

References

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