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Optimal Energy Management System for Electrical Vehicles to Further Extend the Range

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***Abstract*—**This research targets at alleviating the problem of range anxiety associated with the battery electric vehicles (BEVs) by considering mechanical and control aspects of the powertrain. In this way, all the energy consuming components and their effect on reducing the range of the BEV and battery life index are identified. On the other hand, an appropriate control strategy is designed to guarantee the performance of the BEV and the extended electric range which is evaluated by an extensive simulation procedure and a real-world driving schedule.

***Keywords*—**Battery, electric vehicles EV, ultra-capacitor.

I. Introduction

NOWADAYS, the stringent environmental standards and concerns on energy security motivate sustainable transportation more than ever [1]. If mankind continues his current life style, he should be able to drive his gasoline cars for 40 more years because of the shortage of fossil fuels and its rising price. So even if mankind was not concerned about global warming, he still has to find an alternative to current vehicles and start on the path to a sustainable energy consumption and production civilization

While challenges such as high cost, low range and long recharging time still exist, many solutions can be found by looking at the emergence and fall of modern EV's in the 90's. At that time, the California Air and water Resources Board (CARB) passed a law under which all auto makers willing to sell their products in that state should provide, as a portion of their sales, zero emission vehicles. Many similar efforts have been done worldwide to spread out the use of electric vehicles. However, the following issues remain as serious obstacles for commercializing the electric vehicles:

- Infrastructure
- Battery technology
- Consumer concerns about range

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- The small number of EV's and high repair costs
- Cheap fuel and the influence of oil and gas companies

One goal of this paper is to find how to use an EV. In Fig. 2 it can be seen that half of all journeys are less than 40 kilometers, 75% about 64 kilometers and 94% less than 161 kilometers (X-axis is divided between 0 and 240 kilometers). Achieving this goal requires an energy source that can meet the amount of energy needed to make the trip and also being able to provide the power needed too. So, the choice of battery type should meet two main needs [3]:

- Energy density
- Output power

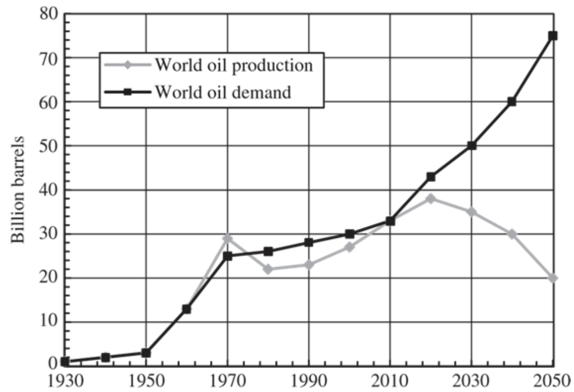

Fig. 1 Global demand for oil and its production [2]

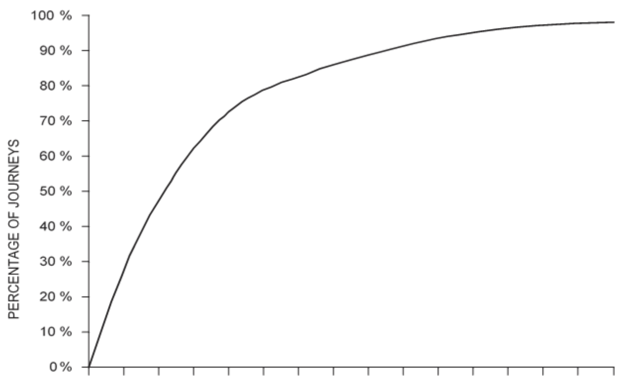

Fig. 2 Range of journeys in USA [4]

Comparing different types of energy storages in Fig. 3, it is evident that Li-ion battery stands out for high energy output over time and medium power output while ultra-capacitors are favorable for high power output and medium energy output.

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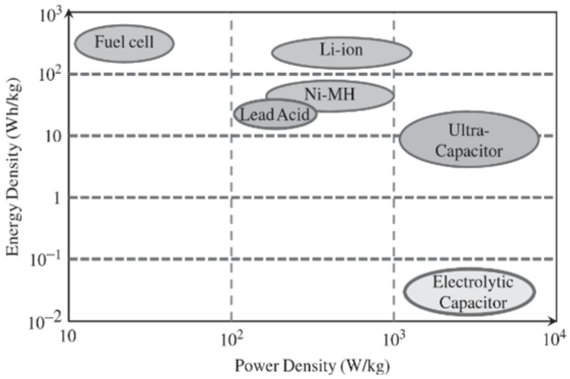

Fig. 3 Comparing energy density and power density for different energy storage systems [3]

It can be concluded that when the price of ultra-capacitors declines in years to come, its usage alongside batteries would be economically feasible. Another assumption that must be made is the amount of tractive power needed for the vehicle, which would be discussed in the following context.

II. Drive Cycle

When driving a vehicle, the power generated by the motor relies heavily on the path the driver has chosen, whether it is the tilt of the road, the acceleration, speed or constantly starting and stopping the car in heavy traffic, the required power can be obtained using [2]:

$$F_{\text{tractive}} = \delta M \frac{dV}{dt} + \frac{\rho C_d A V^2}{2} + f_r M g \text{Cos}\theta + M g \text{Sin}\theta \quad (1)$$

where δM is the effective mass of the vehicle, ρ is the air density around the vehicle, C_d is the drag factor, f_r represents the friction coefficient of the road and θ the tilt of the road.

The Vehicle used for this simulation is TIBA 2, a product of SAIPA company, which was modified for becoming an EV, the total mass as discussed in the following chapter would be calculated as 1615 kg. But, what is needed is the power not mere force, which can be expressed as [2]:

$$Power = Torque \times Angular\ Velocity = f(Force, Velocity) \quad (2)$$

Bearing in mind these two equations all possible scenarios for speed and acceleration should be calculated to find all possible power outputs and then choosing the minimal one as the optimal one [5], [6].

The assumptions that must be made to calculate the desired values are the speed limits on the roads, the maximum amount of allowed acceleration, which is considered 0.5 g bearing in mind the comfort of the passengers [2] and a minimum amount of $1\ {}^{m}/_{s^2}$ is also considered because the human body would feel discomfort if it's constantly exposed to small amounts of acceleration.

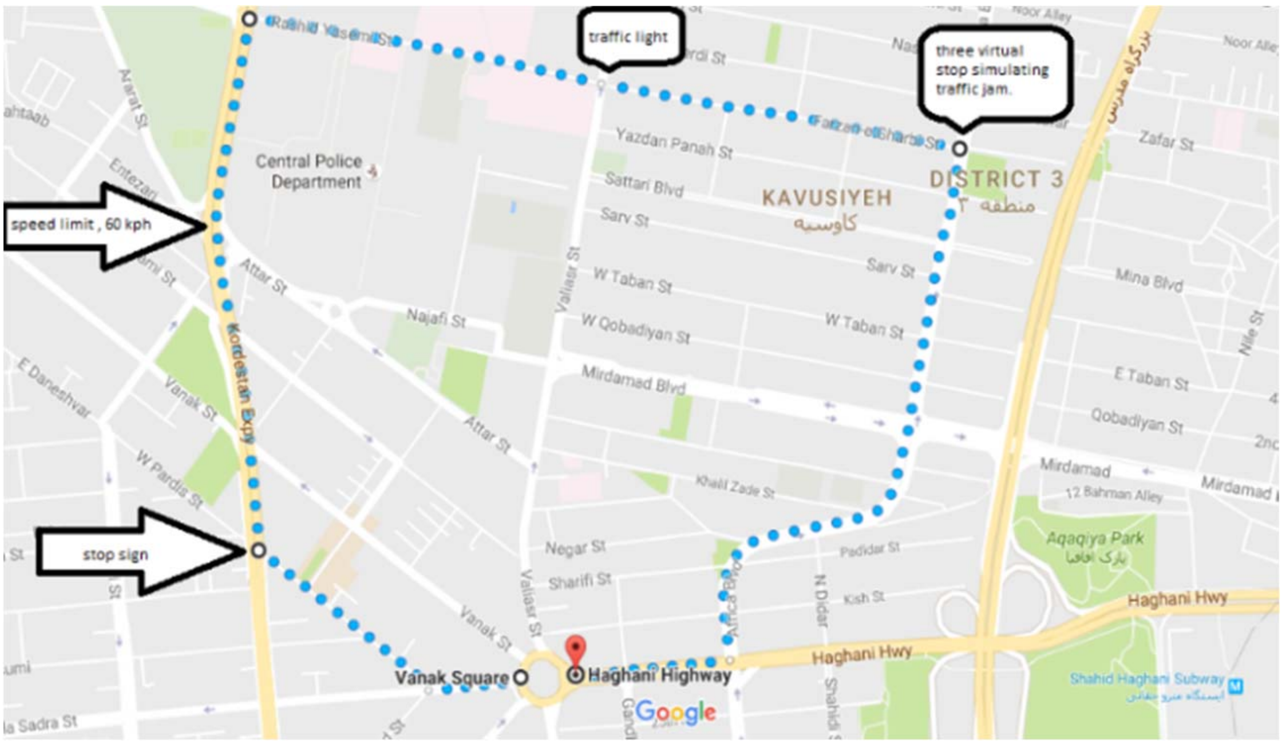

Fig. 4 The chosen track for optimization

By assuming a nominal value for the initial speed at which the vehicle starts the track, the average velocity can be obtained, which is of benefit in calculating other factors such as altitude. The track chosen for obtaining these values is a path containing all of the parameters that should be considered like positive and negative tilt, speed limit of 45 km/h, complete stopping and a flat street which can be viewed in the Google map below. So the desired trajectory would be plotted as Fig. 5.

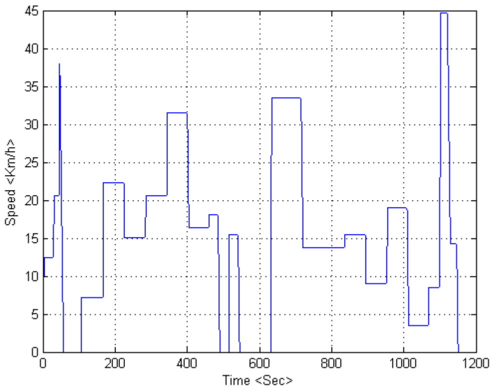

Fig. 5 The ideal trajectory

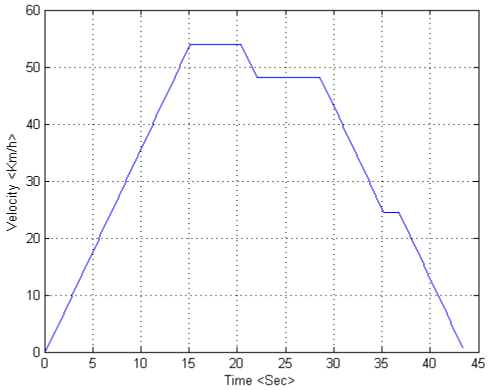

Fig. 6 Simplified Trajectory

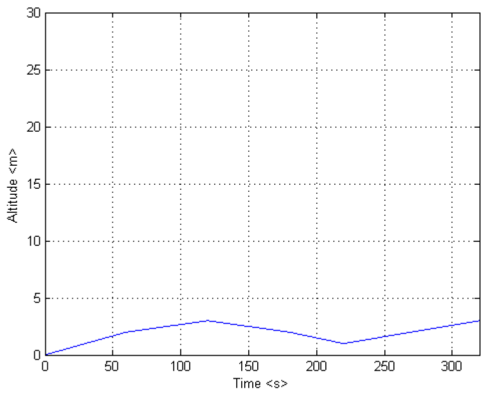

Fig. 7 Altitude vs Time

Knowing the core elements in Fig. 5, a simpler trajectory is created for the sake of more moderate calculations.

Using the obtained average speed and distance data from Google maps the altitude as shown in Fig. 7 is derived. The inputs for designing a control algorithm are the starting point, finish line and altitude so that tilt, distance and elapsed time can be calculated. From these inputs, the average velocity may be obtained which in turn yields the key for calculating speed as a function of the vehicles distance from the starting point and their respective accelerations.

If the drive cycle is considered as a series of accelerating, maintaining a constant speed and then decelerating, a specific power can be derived for every possible scenario which yields every possible way the vehicle can reach a desired speed.

Using (1) and (2), the power required for TIBA 2 is shown in Fig. 8. The dotted line indicates the maximum power this vehicle can produce.

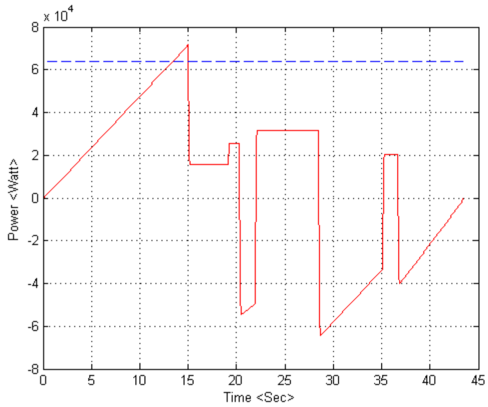

Fig. 8 TIBA 2 power for the respective trajectory

III. Engine Management System

The primary goal of this paper is to divide the power between the battery and ultra-capacitor in a way that maximizes the range. There are situations in the drive cycle where using one source of power is much more plausible; these situations can be determined by the limitations or strengths of one source over the other. The fast discharge ability of ultra-capacitor, more endurance on batteries side, recharging of ultra-capacitor and their price ratio are considered as their limitations or strengths.

For calculating the weight of modified TIBA 2 and simulating a battery- ultra-capacitor chassis, the chassis is divided based on the inverse ratio of their prices. The maximum output power is chosen as of Tesla Model 3, which itself is considered 70% of Model S and close to TIBA 2.

For deriving and proving the needed functions, the equations for both batteries and ultra-capacitors are written below [2], [3] and the symbols used throughout this section are listed in Table I as well.

$$SOC = \frac{\int_{t_0}^{t_1} i(t)dt}{\int_{t_0}^{t_{Total}} i(t)dt} \tag{3}$$

TABLE I
LIST OF SYMBOLS

Symbol	QUANTITY
SOC	State of charge
t_0	The initial moment in time
t_1	Start of a chosen period of time
t_2	Stop of a chosen period of time
t_{Total}, T	Total Period of time
E	Energy
$\dot{SOC}$	Rate of SOC depletion
R	magnetic dipole moment
V_{oc}	Battery voltage
Q	Electric Charge
C	Ultracapacitor coefficient
V	Total Voltage

$$E_{Battery} = \int_{t_0}^{t_{Total}} i(t)dt \times \frac{\int_{t_0}^{t_2} i(t)dt - \int_{t_0}^{t_1} i(t)dt}{\int_{t_0}^{t_{Total}} i(t)dt} \quad (4)$$

$$E_{Battery} = E_{Total} \times [SOC(i+1) - SOC(i)] \quad (5)$$

$$E_{Battery} = E_{Total} \times \frac{[SOC(i+1) - SOC(i)]}{T} \times T \quad (6)$$

$$E_{Battery} = E_{Total} \times \dot{SOC} \times T \quad (7)$$

For controlling purposes, the $\dot{SOC}$ is connected to voltage and current with the following equation:

$$\dot{SOC} = \frac{-V_{oc} \pm \sqrt{{V_{oc}}^2 - 4RP_{Total}}}{2RQ} \quad (8)$$

The main challenge of this paper was to derive a similar concept of SOC for ultra-capacitor, which is proven as:

$$E_{ultra-capacitor} = \frac{1}{2}CV^2 \quad (9)$$

$$SOC = \frac{V - V_{min}}{V_{max} - V_{min}} \quad (10)$$

$$V = SOC \times \Delta V + V_{min} \quad (11)$$

$$E_{ultra-capacitor} = \frac{1}{2}C(SOC \times \Delta V + V_{min})^2 \quad (12)$$

$$SOC(i+1) - SOC(i) = \frac{\Delta V}{V_{max} - V_{min}} \quad (13)$$

$$\Delta V = \Delta SOC \times (V_{max} - V_{min}) \quad (14)$$

$$\frac{\Delta V}{T} = \frac{\Delta SOC}{T} \times V \quad (15)$$

$$\dot{V} = \dot{SOC} \times V \quad (16)$$

$$i_c = C \times V \times \dot{SOC} \quad (17)$$

$$E_{Ultra\ Capacitor} = C \times V \times \dot{SOC}_{ultra-capacitor} \times T \quad (18)$$

$$Cost\ Function = E_{Tractive} + E_{Battery} \times \dot{SOC}_{Battery} \times T + C \times V \times \dot{SOC}_{ultra-capacitor} \times T \quad (19)$$

SOC variation is negative during the charge depletion mode and positive while the regenerative braking is active. The amount of this parameter differs between 0.01 and 0.03 for batteries and between 0.1 and 0.3 for ultra-capacitors [3]. As for the cost function mentioned in (19) which is written in terms of energy, the goal is to get this function squared closer to zero. The reason of squaring the function is merely having a better understanding of the efficiency of optimization as opposed to having to contemplate what it means to have a value close to -∞. Now if the value of this function reaches zero, it is concluded that the algorithm for optimization has done its job perfectly. Using the computing power of MATLAB, Fig. 9 is obtained.

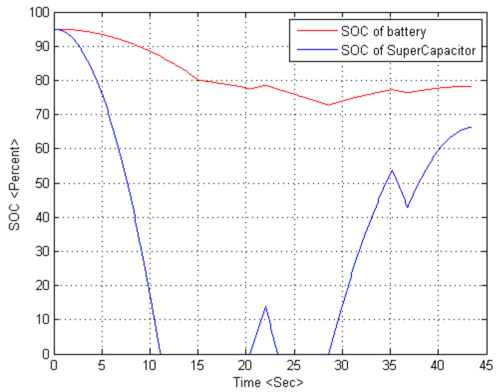

Fig. 9 Usage of power divided between the two sources (the upper line represents battery SOC and the lower one the ultra-capacitor)

As apparent in Fig. 9, the battery charges and discharges with considerably lower tilt than ultra-capacitor.

In the first stage in which the vehicle is experiencing positive tilt, the ultra-capacitor provides most of the power and in the negative part the ultra-capacitor is quickly recharged.

The initial state of charge begins at 95%; the reason is that the relationship between itself and time can only be considered linear between 20-95% [2].

IV. CONCLUSION

Controlling the EVs energy consumption is a great step in solving one of the most major issues in this industry, the ability to travel greater distances and reducing recharging instances gives the consumers the confidence that it is time to choose this option as the one that is economically pleasing and also environmentally beneficial.

The usage of ultra-capacitors is not yet common and the reason is simply its cost, but the authors believe that in the near future using the economics of scale the cost would become feasible.

Another use of the derived algorithm shows itself on the subject of auto-pilot which in turn can be turned into a cloud computed V2V[1] and V2I[2] and thus create a much safer driving experience and by monitoring the drive cycle in real time can reduce energy consumption as well.

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[1] Vehicle to vehicle transmission
[2] Vehicle to infrastructure transmission