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Optimum Utilization of Power in Electric Cars

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***Abstract*: There are millions of cars that exist on road today. In the future more cars will be competing for space on the roads around the world. The gasoline cars create harmful global and local emissions. Therefore the automotive industry has turned to the electric vehicle owing to the problems caused by gasoline engine on people as well as the environment. This paper explains an optimum way to use the power in electric cars in order to improve the performance of electric car. The proposed method makes use of ultra-capacitors along with the battery for better power management. Usage of ultra-capacitor to power the vehicle will avoid continuous charging and discharging of battery and hence battery life can be improved.**
Keywords: ***Electric cars, plug in cars, hybrid cars, lithium ion batteries, ultra-capacitors***

I. INTRODUCTION

The vehicle population on roads is increasing day by day. With the number of expected vehicles doubling on the roads in the near future, there is an increasing demand for oil. Moreover vehicles that are based on gasoline engine emit harmful pollutants which affect the environment. In order to save the environment from harmful emissions and reduce the dependence on limited source oil the use of electric cars are evident [1].

electric cars are of two types: plug-in cars and hybrid cars. Plug in cars offer high energy efficiency, allow diversification of energy resources, enable load equalization of power systems, show zero local and minimal global harmful emissions and operate quietly. In spite of being one of the cleanest and most eco-friendly cars, these are not as much in use as the gasoline cars. The reason is the short driving range and high initial cost offered by the electric cars [2].

As such, the hybrid car, incorporating an electric motor and an engine, has been introduced as an interim solution before the full implementation of electric cars. The definite advantages of the hybrid cars are to extend greatly the original plug in car driving range by two to four times and to offer rapid refueling of diesel or liquid gasoline. An important plus is that it needs only minor changes in the energy supply infrastructure. The major drawbacks of the hybrid cars are loss of the zero emission concept and increased complexity [3]. The solution to this problem lies in designing a power management system for an electric car. The reliability studies in order to provide a basis for comparing different structures of an electric vehicle are discussed in [4]. The reliability study can be used as a tool to improve the system design. The Markov model of different kinds of EV is presented and the relations developed for computing the availability. The obtained results show that the electric vehicles have a much higher of the reliability compared to gasoline cars. While driving as the car accelerates or decelerates or when the brakes are applied, there is a lot of energy in the form of momentum of the car. As energy cannot be destroyed, when a car slows down, the kinetic energy that was propelling it ahead has to go somewhere. Most of it is dissipated as heat and becomes useless. The energy, that could have been used to do work, is essentially wasted. This kinetic energy can be converted into electricity, which can be used to charge the batteries of the car. Braking energy recovery of an electric vehicle can be done in various ways. In [5] one of the scientific and effective way is implemented which is based on motor generator integration system. The gearbox is integrated into the driving system of electric vehicle that plays significant role to recover energy. Additionally, a specific model is built up for simulation. Motor-generator integration system could be used in electric vehicle and energy recovery system integrated with gearbox is more effective. Electric vehicles created by Mitsubishi Motors Corporation feature leading-edge technologies characterized by lithium-ion battery. The features of electric vehicle, requirements for control systems With regard to protection of lithium ion battery and the power management techniques implemented for compliance with the need for battery protection while charging and driving are focused in [6]. The power management techniques during charging include charging current control during normal charge and quick charge. The power manaement techniques during driving include Motor torque control to keep battery-voltage limit and battery-current limit. In order to meet the various performance requirements of electric car the dual energy storage system (DESS) is proposed in [7]. The DESS combines lithium ion battery and sodium ion battery to power the electric car. The results show that the power system with the DESS is excellent in both powers and economics, especially in high power and high torque conditions, compared with single power system.

However, there is a critical factor with these batteries: they have low peak currents. This fact produces a large constraint, since the stored energy in the batteries cannot be delivered in a short time. Therefore, it is necessary to combine them with another storage technology. The ultra-capacitors have the ability to provide a large amount of power in short periods of time can be incorporated with

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batteries to power the electric car [8] [9]. It is observed that the mass of ultra-capacitors is lower than the mass of batteries, this is a great advantage for the weight of the vehicle, because this has a progressive impact on the longitudinal dynamics ensuring a better time in the race [10]. The optimal charging profile of an ultra-capacitor energy storage system during a regenerative braking event is discussed in [11]. To maximize energy recuperation while satisfying braking request, Pontryagin's maximum principle is used. It is showed, analytically, that an ultra-capacitor can be charged more efficiently and with lower currents if operated in a narrower and higher state of charge band. This implies that a larger ultra-capacitor operated at higher state of charge can be charged more efficiently than a smaller size ultra-capacitor. Larger resistance or capacitance (RC) negatively affects the rapid charging efficiency. The combination of ultra-capacitors and ZEBRA battery is used to power the electric vehicle [12]. The ultra-capacitors get charged during regenerative braking and when battery charge is low then ultra-capacitors supply energy to the battery. But this system lacks in regenerative braking capability during downhill as well as uphill. Taking this concept into the consideration, a mechanism is needed to be designed where both ultra-capacitors and battery will get charged through regenerated power. Hence the available power as well as recovered power will be used optimally to improve the range of electric car. The remainder of the paper is organized as follows. Section II discusses the system design. Section III discusses the results and analysis and Section IV concludes the paper.

II. SYSTEM DESIGN

There are three main areas in system design as shown in Fig.1: control, electrical and vehicle model. Control area focuses on motor controller and mode logic. Motor controller takes demanded motor speed, required motor RPM, motor enable input and provides required torque to electrical area. Mode logic is developed in order to design power management strategy. Electrical part consists of synchronous motor and drive, dc-dc converter and a storage system. A storage system is a combination of lithium ion battery and an ultra-capacitor. Lithium ion battery is a good option because it has high specific power and energy. Also, lithium is not a toxic element and readily available. The ultra-capacitor has ability to hold hundreds of charge and it can be recharged fast as compared to battery. DC-DC converter is used to boost the voltage from battery to the required voltage on the dc network. Vehicle model constitutes tyre model and longitudinal dynamics of car.

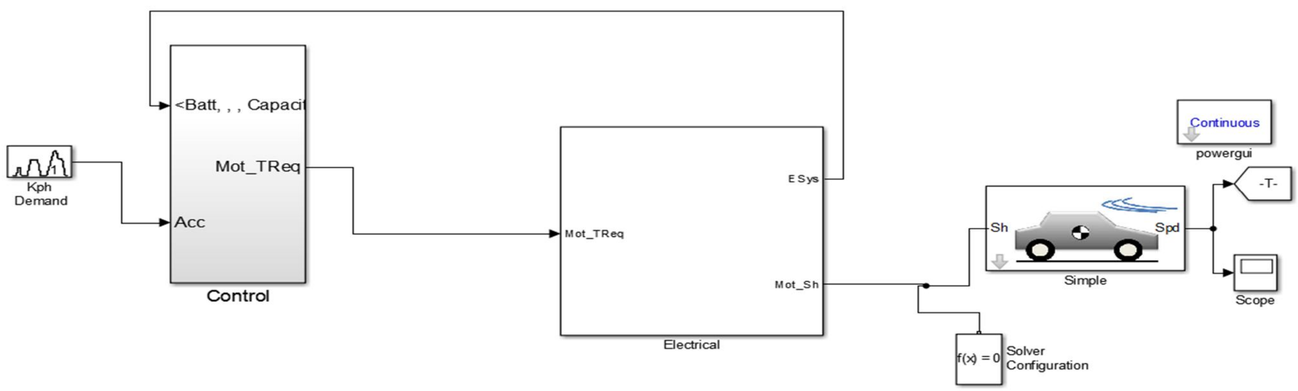

Fig. 1 System design

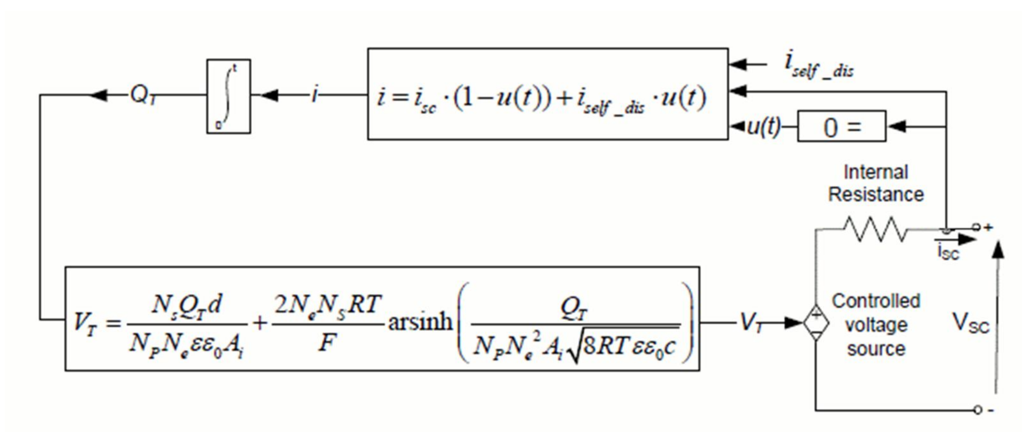

Fig. 2 Equivalent circuit of ultra-capacitor

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The ultra-capacitor block implements a generic model parameterized to represent most popular types of ultra-capacitors. Fig.2 shows the equivalent circuit of the ultra-capacitor:

The ultra-capacitor output voltage is expressed using a Stern equation as:

$$V_{SC}=\frac{NsQTd}{NpNe\varepsilon\varepsilon 0Ai}+\frac{2NeNsRT}{F}\sinh^{-1}\left(\frac{Q}{NpNe.NeAi\sqrt{8RT\varepsilon\varepsilon 0c}}\right)-R_{SC}\cdot i_{SC}$$

with $Q=Zi_{SC}dt$

To represent the self-discharge phenomenon, the supercapacitor electric charge is modified as follows (when $i_{SC}=0$):

$Q=Zi_{self\_dis}dt$

where

$$i_{self\_dis}=\frac{CT\alpha 1}{1+sRscC} \qquad if\ t-toc\leq t3$$

$$=\frac{CT\alpha 2}{1+sRscC} \qquad if\ t3<t-toc\leq t4$$

$$=\frac{CT\alpha 3}{1+sRscC} \qquad if\ t-toc>t4$$

The Battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries. Fig.3 shows the equivalent circuit of a battery.

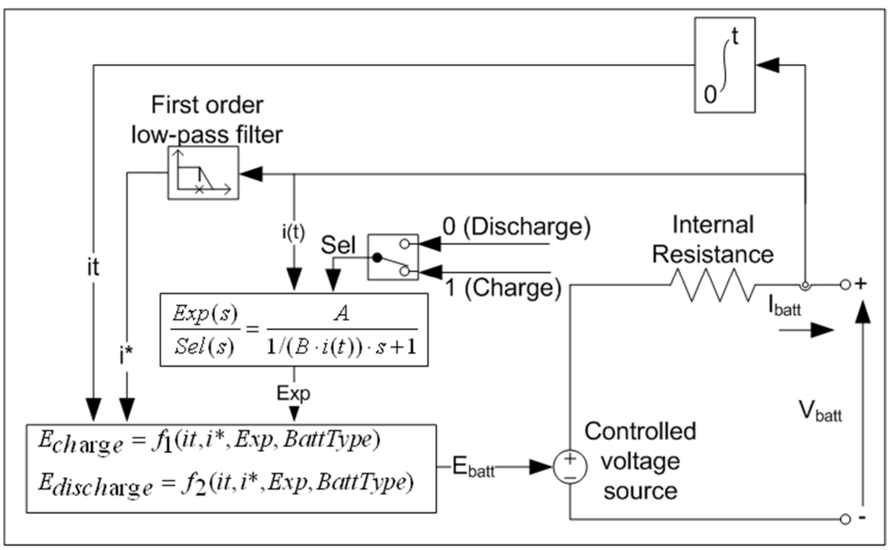

Fig. 3 Equivalent circuit of battery

The discharge model ($i^* > 0$) is expressed as

$$f_1(it,i*,i)=E_0-K\cdot\frac{Q}{Q-it}\cdot i*-K\cdot\frac{Q}{Q-it}\cdot i+A\cdot\exp(-B\cdot it).$$

The charge model ($i^* < 0$) is expressed as

$$f_2(it,i*,i)=E_0-K\cdot\frac{Q}{it+0.1\cdot Q}\cdot i*-K\cdot\frac{Q}{Q-it}\cdot it+A\cdot\exp(-B\cdot it).$$

A. Defining System Mode Logic

The operating mode can be divided into acceleration mode, regeneration mode and braking mode. In acceleration mode the ultra-capacitor will be used to power the vehicle. As soon as the state of charge (SOC) of ultra-capacitor goes below a certain limit, battery will be in use to power the vehicle. The ultra-capacitor will be resumed to power the vehicle when its SOC will get increased through regenerated power. In regeneration mode, the power regenerated through braking or deceleration will be used to charge the ultra-capacitor first. As soon as the SOC of ultra-capacitor increases to desired level, the regenerated power will be used to charge the battery. In braking mode, as the brakes are applied the car will slow down and enters into regeneration mode. When the brakes are released, the car will enter into acceleration mode.

III.RESULT AND ANALYSIS

In order to verify the effectiveness of the solution proposed in this paper, different urban driving cycles are selected to analyze energy allocation and following of the speed when the car is running on urban traffic. In addition, to study on energy supplying in the high-power demand condition, the simulations about acceleration and deceleration performance of the car are carried out in the followings. In the simulation, the Initial SOC of the ultra-capacitor is set at 49% while for lithium-ion battery it is set to 100%. Fig. 4 shows the urban driving cycle with speed related to urban traffic conditions and time up to 400 seconds. Fig. 5 and Fig. 6 show the SOC of ultra-capacitor and the battery respectively. Both ultra-capacitor and battery go through acceleration and regeneration mode. The initial SOC of ultra-capacitor is 61% while the final SOC is 40%. For the battery, the initial SOC is 59% and final SOC is 43%. Fig. 7 and Fig. 8 show the graph of current drawn by ultra-capacitor and lithium ion battery respectively. The ultra-capacitor has high peak current making it reliable to deliver the stored energy in a short time. The simulation results demonstrated that the acceleration and regeneration performance of the electric car are excellent and fully meet the design requirements.

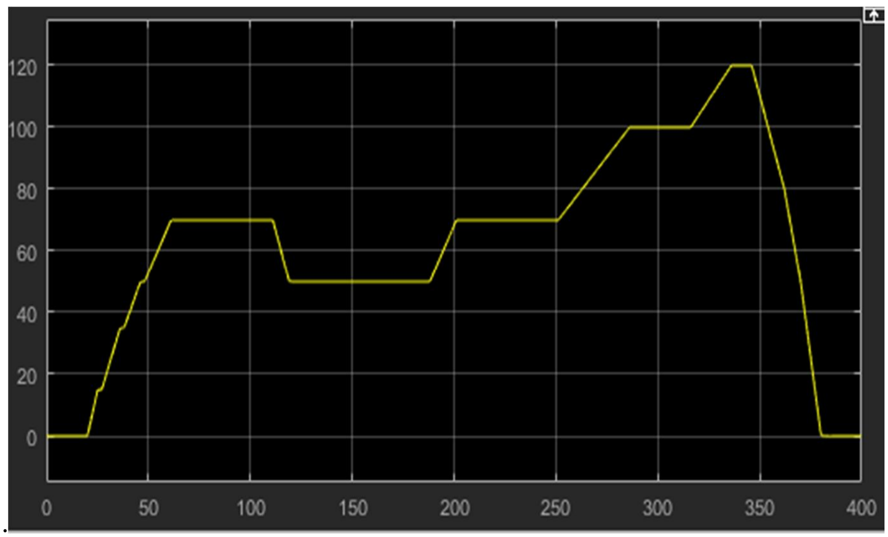

Fig. 4 Urban driving cycle

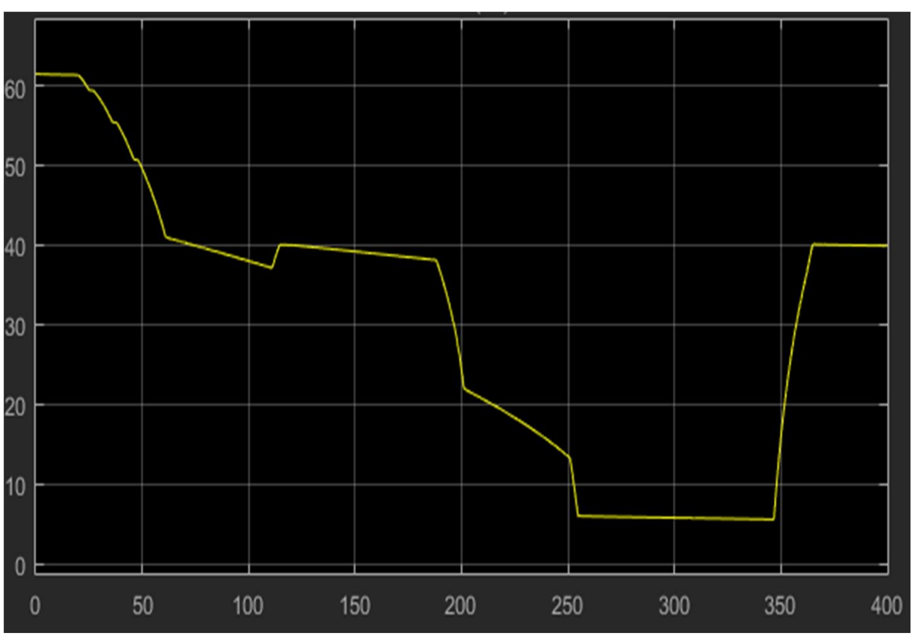

Fig. 5 SOC of ultra-capacitor

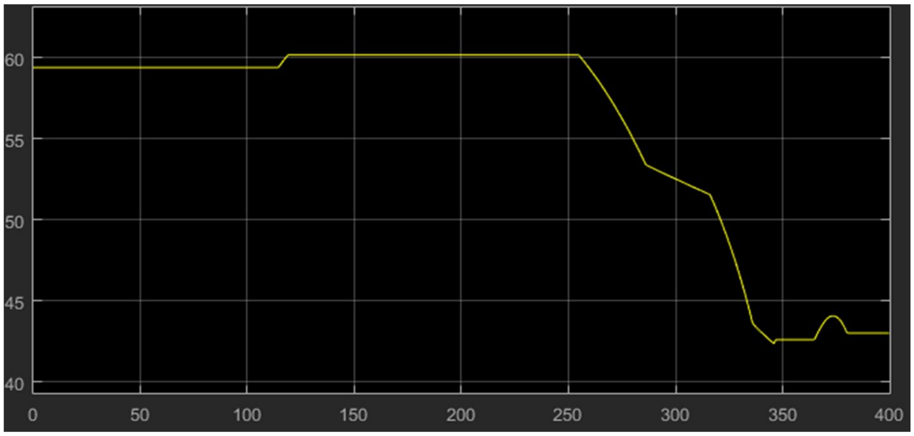

Fig. 6 SOC of lithium ion battery

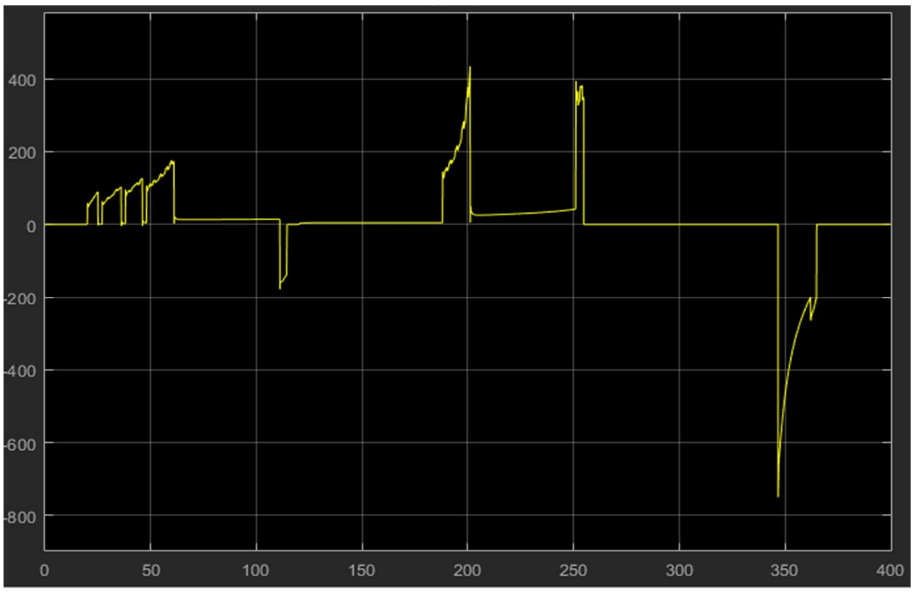

Fig. 7 Discharge current of ultra-capacitor

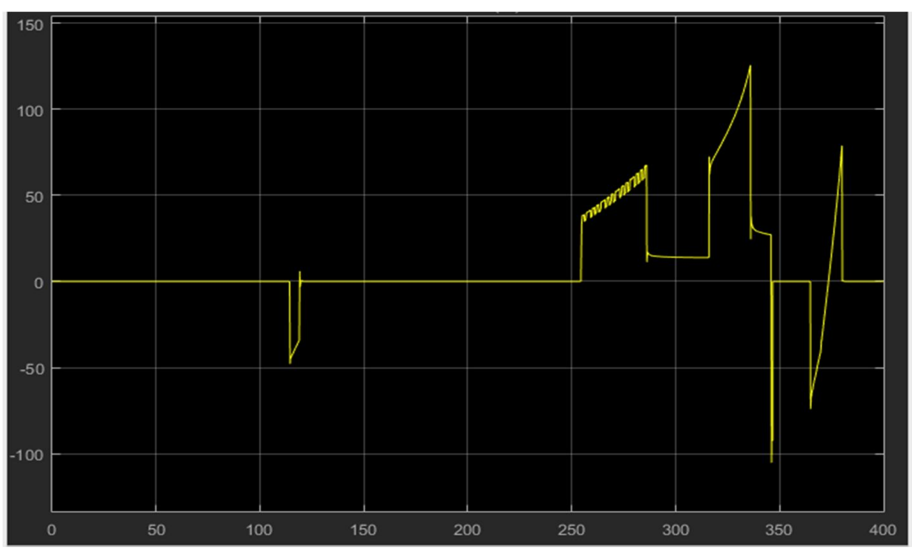

Fig. 8 Discharge current of lithium ion battery

IV. CONCLUSIONS

This paper shows a simple methodology for optimal usage of power in electric cars. The design involves two types of storage system: lithium ion battery and ultra-capacitor bank, showing the best performance in overall driving conditions. Both the storage system types exhibit optimal power management strategy by developing their advantages and avoiding disadvantages.

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