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Electric Vehicle Battery Modelling and Performance Comparison in Relation to Range Anxiety

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Abstract

In electric vehicle, rechargeable battery served as energy source for all its system operation which include electric motor for propulsion system and also other auxiliary components. Therefore, it becomes an important issue to be tackled in EV technology in order to enhance the battery energy capacity for long range operation. In general public view, people tend to be very concern in purchasing the electric car. One of the concerns lies on the question of how far they can travel with only battery for their car propulsion means. Therefore, this study tries to investigate the relation between battery types and the range anxiety faces by electric car makers. The investigations reveals that, Li-ion as the battery with high energy density cover more area or distance travel.

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Keywords: Electric Vehicle (EV); range anxiety; battery SOC; battery OCV.

1. Introduction

The emergence of electric vehicle (EV) technology in this era is heavily related to the continuous rising consciousness of global warming, climate changing and crude oil crisis [1]. In electric vehicle, rechargeable battery

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served as energy source for all its system operation which include electric motor for propulsion system and also other auxiliary component in EV system. Among all the subsystem in EV, the propulsion subsystem itself consumed up to 75% of battery energy to run the car [2]. Therefore, it become an important issue to be tackled in EV technology in order to enhance the battery energy capacity for long range operation.

In general public view, people tend to be very concern in purchasing the electric car. One of the concerns lies on the question of how far they can travel with only battery for their car propulsion means. The lack of exposure on EV technology frequently affect their decision to purchase an electric car [3]. According to the expert, the performance of EV battery in terms of driving range plays a vital role in determining the success of the electric mobility system [4]. This issue raises a concern among car makers as they face "range anxiety" where they worry that the consumer will hesitate to buy an electric car which run only a few miles [5].

Many researches has been done on extending the driving range of EV especially in the area of energy sources. Current development in battery technology listed the Li-ion and NiMH batteries as the major technologies used in EV [5]. The Li-ion recognized as the most potential candidate thanks to its light weight and small size feature. Li-ion battery however is high in cost and have detrimental effect specifically in the battery thermal limitation [5]. Several researches on modeling Li-ion battery are done to improve its performance by manipulating the thermal management system [6]. However, very limited research conducted in regards of the range anxiety faced by EV technology.

Therefore, this study aims to explore and compare the existing battery technology in EV in terms of their driving range. How far the car can go is a key component to be explained in changing the perception of the consumer where the anxiety range becomes a barrier to purchase an EV. Driving range is closely related to the energy capacity of the battery. Battery with high energy capacity will result in longer driving distance. Thus, this study will be focusing on several types of battery used in EV with their performance measurement in terms of travel range and vehicle speed to be compared.

Nomenclature

EV	electric vehicle
HEV	hybrid electric vehicle
SOC	state of charge
OCV	open circuit voltage
Li-ion	lithium ion
NiMH	nickel metal hydrite
NiCd	Nickel cadmium
R_0	resistance of the fully charged battery
i	discharge rate
A	constant discharge current in amps
h	time of discharging in hours
C_{10}	10 hour capacity of the battery in amp-hours

2. Types of battery used in EV

There are several different types of battery used for EV application such as Lead-acid, Nickel-Metal-Hydrite (NiMH), Nickel-Cadmium (NiCd) and Lithium-ion (Li-ion).

2.1. Lead Acid

This type of battery is used in conventional car also for the starting, ignition, lighting and other electrical function. This type of battery were used during the earlier time of EV technology. It is relatively inexpensive however the built of this battery is too heavy and suffer an insufficient range for EV application.

During the charging and discharging process of the electromechanical reaction follows as in equation (1).

$$PbO_2 + Pb + 2H_2SO_4 \underset{charge}{\overset{discharge}{\rightleftarrows}} 2PbSO_4 + 2H_2O \quad (1)$$

2.2. Nickle-Metal-Hydrite (NiMH)

Currently, this type of battery are among two leading battery used for EV . It is widely used in hybrid EV due to its ability to hold energy far more than lead-acid, much longer life cycle and lighter weight compared to lead-acid. In hybrid EV, the power source for the vehicle is either from an internal combustion engine or electric motors. This battery have higher self-discharge rate and capable to deliver rapid power burst. However, the battery's cycle life will be reduced if it has experienced repeated rapid discharges with high load in order to give rapid power burst. Therefore, this type of battery is more suitable in hybrid EV application rather than battery EV which typically experiencing deep discharge cycles.

The electromechanical reaction for this battery can be represented by equation (2) for charging and discharging processes.

$$MH + NiOOH \underset{charge}{\overset{discharge}{\rightleftarrows}} M + Ni(OH)_2 \quad (2)$$

2.3. Nickel-Cadmium (NiCd)

NiCd battery have longer life cycle as it can tolerate deep discharge cycle longer than NiMH. It is also lighter in weight compared to lead-acid. However, this battery suffered low relative electrical capacity. The low capacity of electric may cause melting or burning of battery if it experiences deep discharge and quick charging in short of time. Unlike NiMH, it also have disadvantage of having "memory problem" or memory effect. The memory problem happens when the battery is repeatedly recharged before it has been completely discharged.

Equation (3) represents the complete electrochemical reaction of NiCd battery during charging and discharging processes.

$$Cd + 2NiO(OH) + 2H_20 \underset{charge}{\overset{discharge}{\rightleftarrows}} 2NiO(OH)_2 + Cd(OH)_2 \quad (3)$$

2.4. Lithium Ion (Li-ion)

The Li-ion battery is one of the two leading battery used in the EV technology aside from NiMH [7]. This type of battery wins over Nickle chemistries due to several factors which include more energy capacity in much lighter package, low in self discharge and good temperature performance. And the good news about Li-ion is the environmental friendly factor where almost all parts of battery components are recyclable. Due to all the good qualities, the battery comes with more expensive cost compared to all other battery types. Despite that, Li-ion is still a preferred choice for most of hybrids and battery EV.

The complete electromechanical process of charging and discharging of this battery is governed by equation (4).

$$Li_{t-x}CoO_2 + C_nLi_x \underset{charge}{\overset{discharge}{\rightleftarrows}} LiCoO_2 + C_n \quad (4)$$

3. System modelling

In this study, an EV system is designed and developed to test for all the batteries performance. A complete system block diagram comprises an EV system together with the measurements of battery state of charge (SOC), battery voltage measurement, range of the vehicle and also speed of the vehicle. Fig. 1 shows the block diagram of the system used in this study.

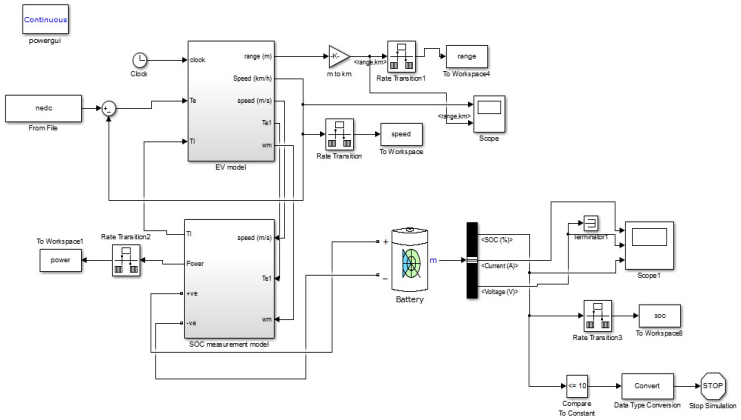

Fig. 1. EV block diagram with SOC measurement.

Battery modelling served as a basis in battery design and control. Variety of battery models has been developed due to the extensive research in this area. The battery models can be generally categorized in either electromechanical models or equivalent circuit models. The electromechanical model is suitable for battery design purpose while equivalent circuit models are designed for dynamic and long-run simulation studies.

Equivalent circuit models include Simple Battery Model [8, 9], Modified Simple Battery Model [10], Thevenin Battery Model [11] and Modified Thevenin Battery Model [12]. In this study, a modified simple battery model is applied in the system. This model has the same electrical circuit as the simple battery model as depicted in Fig. 2. However, the internal resistance of battery is a function of the SOC of the battery. Because of this factor, the internal resistance of the battery is varying according to Equation (5). And the SOC is calculated using Equation (6).

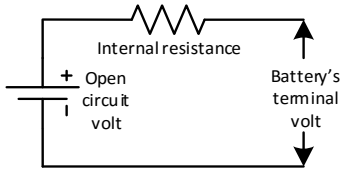

Fig. 2. Simple battery model.

$$R_{\text{int}ernal} = \frac{R_0}{SOC^i} \tag{5}$$

$$SOC = 1 - \frac{Ah}{C_{10}} \tag{6}$$

where R_0 is the resistance of the fully charged battery, i is the discharge rate, A is the constant discharge current in amps, h time of discharging in hours and C_{10} is 10 hour capacity of the battery in amp-hours.

4. Result and discussion

The simulation was performed using Matlab/Simulink on a Dual Core CPU P8400 2.26GHz computer with 4.00GB RAM. In order to verify the findings, a comparison between each type of battery is made in terms of SOC and range which the vehicle can travel using that particular battery type. Table 1 listed all the battery types with

their nominal values and capacity. All these batteries are tested and run in the simulation by allowing the battery to fully discharge.

Table 1. Different types of EV batteries.

Battery type	Nominal Volt. (V)	Rated Capacity (Ah)
Lead acid	6	225
NiCd	6	180
NiMH	201.6	6.5
Li-ion	360	33.1

From Table I, the four major types of battery chemistries are listed. Lead acid battery properties are based on the 6V electric golf car, the NiCd properties are based on the Saft STM 5-180 battery used in 1980 Volkswagen Pickup, the NiMH properties are based on Prius 2010 and Li-ion properties are based on Nissan Leaf.

The following figures can provide an overview of the relation between the OCV and the remaining battery capacity. From Fig. 2 - Fig. 5, note that the voltage diminishes in direct proportion to the remaining battery capacity. Since NiMH and Li-ion are the current major technologies used in EV [13], only these two types of battery are considered in this work. Based from the results also show that at the remaining 20% of battery capacity, Li-ion still have more voltage left compared to NiMH.

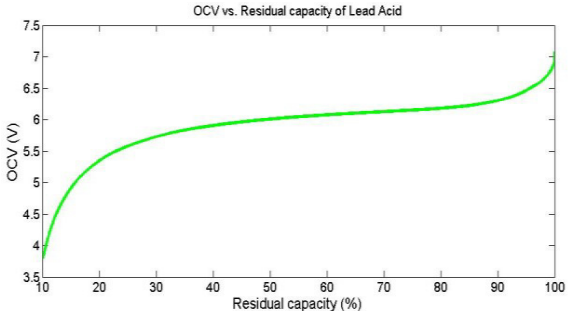

Fig. 3. OCV vs. battery capacity of Lead Acid

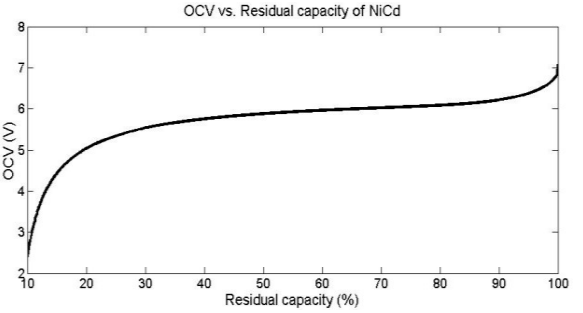

Fig. 4. OCV vs. battery capacity of NiCd

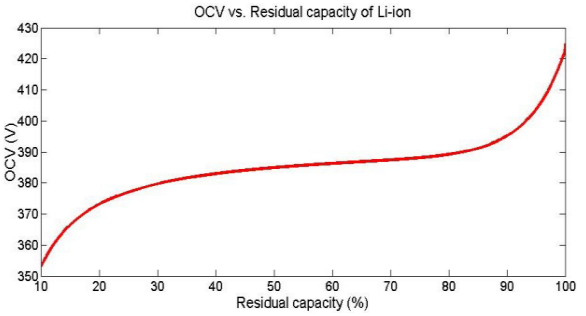

Fig. 5. OCV vs. battery capacity of Li-ion

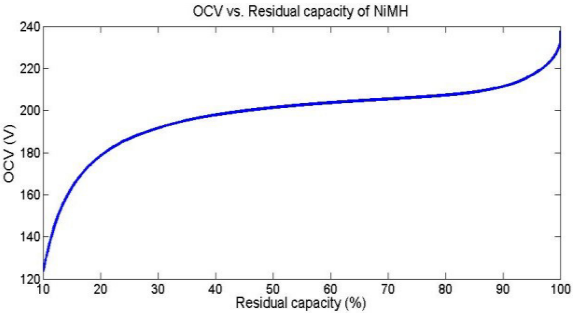

Fig. 6. OCV vs. battery capacity of NiMH

In relation to the range anxiety, the the distance range of travelling EV is very crucial. In Fig. 7, the range travel and speed of the car using NiMH battery is illustrated. Fig. 8 shows the speed vs range profile when Li-ion battery is used. It is observed that the range travel by car with NiMH is less than Li-ion.

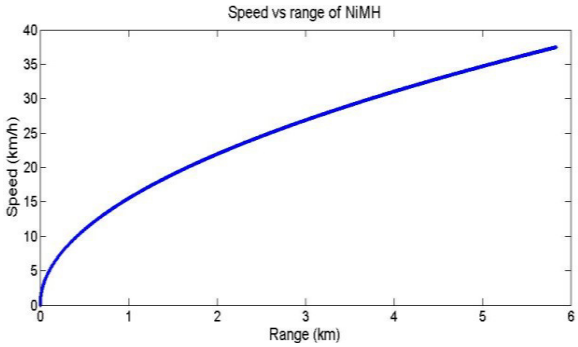

Fig. 7. Speed vs. range for NiMH.

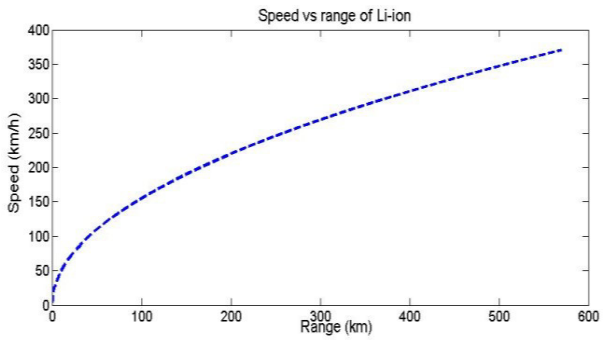

Fig. 8. Speed vs. range for Li-ion.

Current battery technology listed NiMH as the dominating battery technology in Hybrid EV (HEV) due to its mature technology [14]. However, the potential of expending higher specific energy and energy density of Li-ion is the key factor of its growing technology [6]. Fig. 9 shows the range comparison between Li-ion and NiMH. Based from Fig. 9, Li-ion provides more distance travelled by the vehicle as it have more energy density than NiMH. Table II tabulated the simulation outcome between Li-ion and NiMH.

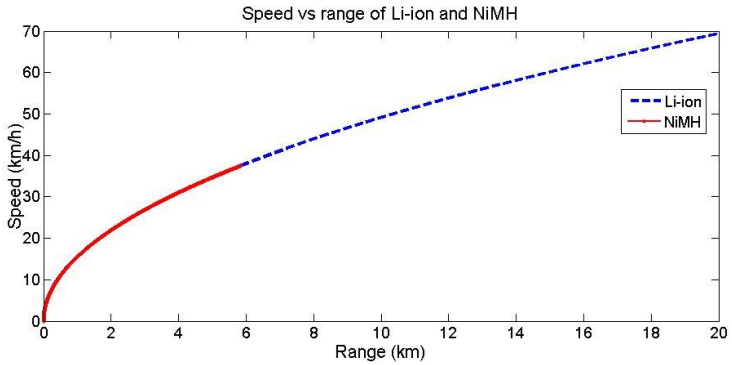

Fig. 9. Speed vs range between Li-ion and NiMH.

Table 2. Comparison of speed and range for li-ion and nimh.

	Range (km)	Speed (km/h)
Li-ion	20	70
NiMH	6	40

5. Conclusion

This study tries to investigate the relation between battery types with the range anxiety faces by electric car makers. The range anxiety arises from the concern among car makers in selling their electric car related to how far their car can travel. Therefore, battery selection plays an important role in this problem. Different battery have different energy capacity which in turns directly related to the car travel range. This paper investigates four different types of battery used in EV application such as Lead acid, NiCd, NiMH and Li-ion. The batteries are simulated in the same EV model for distance travelled comparison. The investigation reveals that, Li-ion as the battery with high energy density cover more area or distance travelled.

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