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# EV Batteries Performance Study

**O. A. Monem**

*Electronic and Communication Departement*
*High Institute of Engineering and Technology Aloubor*
Cairo-Belbes desert road, Obour, Egypt
osamaa@oi.edu.eg

**Abstract**
With the rapid development of the automotive industry, the demand for gasoline increases sharply. The gasoline cars cause serious environmental pollution. The application of electric vehicles can solve these problems. 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. There are many types of batteries found in the construction of today's Electric Vehicles, being hard to decide which one fulfils best all the most important characteristics, from different viewpoints, such as energy storage efficiency, constructive characteristics, cost price, safety and utilization life. Therefore, it becomes an important issue to be tackled in EV technology in order to improve electric vehicle overall performance. 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 will compare between two types of batteries; NMH and Li-Ion. The novelty of this study will focus on battery performance evaluation from the load point of view. And how the driving system type could affect EV battery performance. EV Model is constructed using Permanent magnet synchronous motor and DC motor. Both are supplied by two different types of batteries; Nickel Metal Hydride and Lithium Ion type. Electric vehicle system is modeled using MATLAB software. Comparison between these batteries performance is conducted in terms of battery voltage, State of charge and discharge characteristics. By the end of this work, analysis for simulation concludes that Li-Ion has the best performance in terms of travelled distance and operation characteristics.
**Keywords: Electric vehicle, Li-Ion battery, Nickel Metal Hydride, State of Charge, Battery management system**

## 1- Introduction

The rise of electric vehicle (EV) technology in recent years is closely linked to growing concerns about global warming, climate change, and the need to address the crude oil crisis (Zhao, J., et al., 2008). In an electric vehicle, a rechargeable battery serves as the primary energy source for all systems, including the electric motor for propulsion and other auxiliary components. The propulsion subsystem alone accounts for approximately 75% of the battery's energy consumption to power the vehicle (Tie, S.F. and C.W. Tan, 2013). Hence, it is crucial to address the issue of enhancing the battery energy capacity in electric vehicle (EV) technology to enable long-range operation. This concern is particularly significant for potential buyers who are uncertain about the distance they can travel solely relying on the car's battery for propulsion. Limited exposure to EV technology often influences their decision-making process when considering an electric car purchase (Halderman, J.D. and C.D. Mitchell, 2010). Experts emphasize that the driving range performance of EV batteries plays a pivotal role in determining the overall success of the electric mobility system (Kitamura, M. and Y. Hagiwara, 2010). 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 (Xuewu, J., Z. Xuefeng, and L. Yahui, 2012). 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 (Xuewu, J., Z. Xuefeng, and L. Yahui, 2012). The Li-ion is 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 (Xuewu, J., Z. Xuefeng, and L. Yahui, 2012). Several researches on modeling Li-ion battery are done to improve its performance by manipulating the thermal management system (Young, K., et al., 2013). However, there has been limited research conducted on studying battery performance specifically in relation to different load types. Therefore, the objective of this study is to investigate and compare the performance of existing battery technologies in electric vehicles (EVs) in terms of battery voltage, state of charge and discharge characteristics with respect to the load side nature; whether EV system is designed based on AC or DC driving system.

## 2- Power and Energy Capacity of EV Battery

The energy consumption of an electric vehicle (EV) is influenced by several factors, including the weight, size, and shape of the vehicle, road conditions, and the driving habits of the driver. Additionally, the energy consumption is also affected by the size of auxiliary systems such as cooling, heating, and lights. On average, a mid-sized EV consumes between 160 and 200 watt-hours per kilometer (Wh/km). The standard size of the traction battery in electric cars can vary from 20 kWh to 60 kWh, or even higher for extended driving ranges. In the case of buses, the battery size typically falls within the range of 90 kWh to 150 kWh, or higher. (K. Young, C. Wang, L.Y. Wang, and K. Strunz, 2013).

Table I provides a comparison of key features for several popular batteries [8], (Y. Miao, P. Hynan, A.V. Jouanne, and A. Yokochi, 2019). When compared to the specific energy of petrol, which is 13,000 watt-hours per kilogram (Wh/kg), batteries have significantly lower energy density, ranging from 50 to 100 times less. This difference in energy density becomes evident when considering a scenario: a conventional engine car, such as the Suzuki SX4 with a fuel efficiency of 16-20 kilometers per liter (km/L), can cover a distance of over 700 kilometers with 50 liters of petrol. However, a battery pack with an equivalent energy content to 50 liters of petrol would be excessively heavy and large in size. With current battery technology, a 100 kWh lithium-ion battery capable of providing a range of approximately 500 kilometers may weigh between 800-900 kilograms.

**Table 1:** Comparison between different types of batteries

| Battery Type | Nominal voltage (V) | Specific power (W/kg) | Specific energy (Wh/kg) | Energy density (Wh/L) | Life cycle |
|---|---|---|---|---|---|
| Lead Acid | 2.1 | 180 | 30-40 | 100 | 500 |
| Nickel cadmium | 1.2 | 200 | 50-80 | 300 | 2000 |
| Nickel Metal Hydride | 1.2 | 200-300 | 60-120 | 180-220 | < 3000 |
| Lithium Ion | 3.6 | 200-430 | 120-250 | 200-600 | 2000 |

There have been several significant advancements in the field of electrochemical batteries that can be used to power electric vehicles (EVs). Some of the popular battery chemistries include Lead-Acid, Nickel-Cadmium (Ni-Cd), Nickel-Metal Hydride (Ni-MH), Lithium-ion (Li-ion), and Lithium-metal (Li-metal). The energy storage capabilities of these batteries are depicted in Figure 1 (J.M. Tarascon, and M. Armand, 2001).

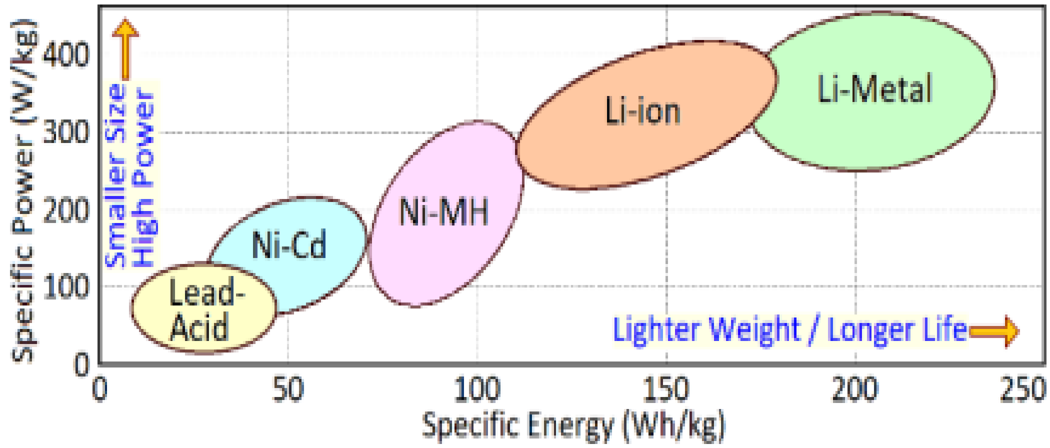


**Fig. 1**: Specific power and energy for different types of batteries

The desired qualities of a battery for electric mobility are: high specific energy for longer driving distances, high specific power for good acceleration, high safety features, wide operating temperature range, and low toxicity, fast charging capability, long lifespan, and affordability [11].

The charging and discharging rates of a battery are indicated by C-rates. For example, 1C-rate means the battery can be fully charged in one hour, 2C-rate means it can be fully charged in 30 minutes, and C/2 or 0.5C indicates it takes two hours for a full charge. Li-ion batteries have specific C-rates. Level-1 and Level-2 chargers, both AC and DC, usually take longer than the 1C-rate to fully charge a battery, requiring several hours. However, for quick recharging during long trips, DC superchargers are available. A supercharger can charge a battery up to 80% state of charge (SOC) within approximately 15-30 minutes and provide an additional travel range of 100-150 km or more within 20 minutes. It is important to monitor and control the cell temperature when opting for superfast charging, as it can cause significant stress on the battery due to heat and internal resistance power loss. The typical fast charging pattern for Li-ion batteries involves constant-current constant-voltage (CCCV) step charging, where the battery is charged with a relatively high constant current during low SOC regions and the charging current is gradually reduced as SOC increases. This approach aims to limit cell temperature and degradation, although lithium plating may still occur, eventually reducing the battery's cycle life. Fig. 2 illustrates the comparison between standard charging and fast step charging of Li-ion batteries, moreover, Fig. 3 shows effects of charging style on cycle life of Li-Ion batteries ( D. Kim, J. Kang, T. Eom, J. Lee and C. Won, 2018).

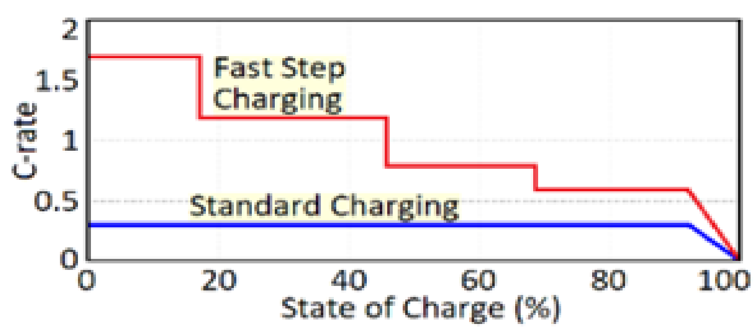


**Fig. 2**: Comparison between Li-Ion standard charging and fast charging

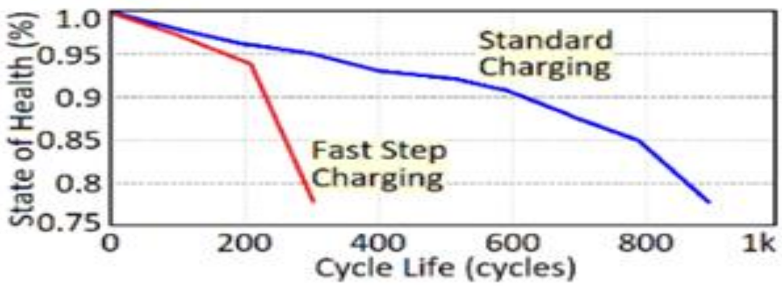


**Fig. 3** Effect of fast and standard charging on Li-Ion battery cycle life

**3. System Modelling**

In this study, two models are designed and developed to test batteries performance. A complete system block diagram comprises an EV system together with the measurements of battery state of charge (SOC), battery voltage measurement and discharge characteristics. Fig. 4 shows the block diagram of the first EV model based on Permanent magnet synchronous motor (Shi, G., S. Zhao, and J. Min, 2012). The battery voltage is 360 volt and current capacity is 100 Ah. Giving total energy capacity of 36 KWh. Two types of batteries are simulated, Nickel Metal Hydride; (NMH) and Lithium Ion battery.

Figure 5 shows the second model for EV system based on DC motor (Young-Kyoun, K., R. Se-Hyun, and J. In-Soung, 2010). The load torque is 100 N.m, the total power will be 15.7 KW according to Eq. 1 and battery capacity in KWh can be expressed in Eq. 2.

$$P = T*\omega/9950 \qquad (1)$$

Where P is power in KW, T is torque in N.m and ω is the speed in rpm

*Battery capacity in KWh = I (Ah)* Battery voltage* (2)

Battery capacity = 100 * 360 = 36 KWh

Rated current drawn from the battery by the EV will be 43.6 A according to Eq. 3

$$I = P/V \qquad (3)$$

I = 15.7*1000/360 = 43.6 A

Considering the wheel diameter is 0.6 m, so each revolution will travel linear distance of π*D or 1.88 m.

The no. of revolution per minutes is 1500 rpm, so the total distance travelled can be expressed in Eq. 4 and Eq. 5:

*EV Speed (m/s) = Distance (m)/time (s) = ω * π * D/60* (4)

*EV Speed (Km/h) = ω * π*D* 60/1000 = ω * D/5.3* (5)

For 1500 rpm motor, EV Speed will be 170 Km/h.

The total distance travelled per one full charge will depend on discharge time, for 100 Ah battery, only 80% of battery capacity can be utilized. In other word, we can calculate the operation time based on this assumption according to Eq. 6 as follows:

*Full charge trip time = 0.8*Ah/I* (6)

Where I is the rated current drawn by the EV which is already calculated using formula in Eq. (3)

So, Full charge trip time = 0.8*100/43.6 = 1.834 Hrs

*Total travelled distance per full charge (Range) = Speed in Km/h * trip time (h)* *(7)*

$$= 170 * 1.834 = 312 \text{ Km}$$

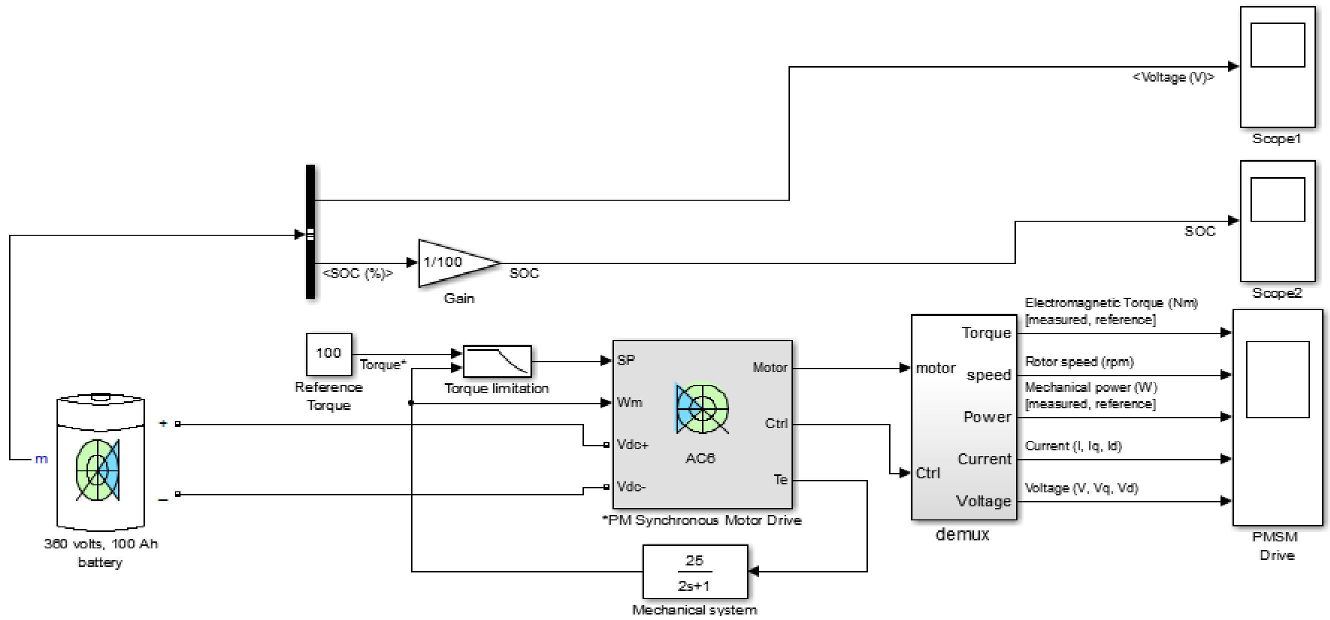


**Fig. 4:** EV Model based on PM synchronous motor

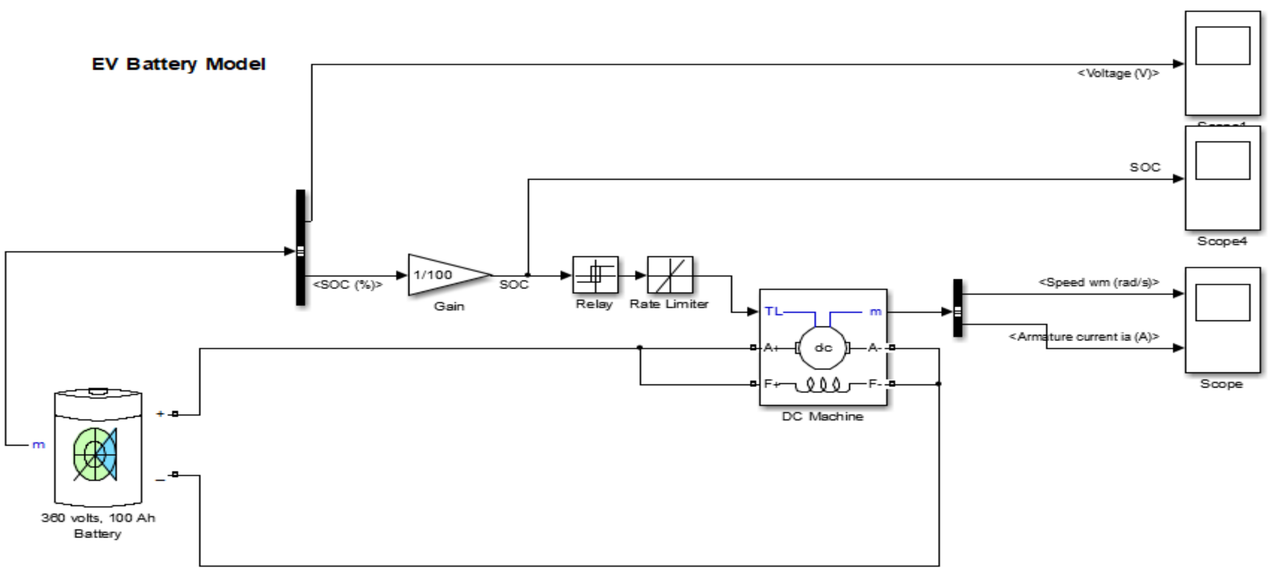


**Fig. 5:** EV Model based on DC motor

## 4. Result and Discussion

The simulation was performed using MATLAB/Simulink on AC and DC motor EV models in order to conduct a comparison between battery performances in both cases. Battery performance is expressed in terms of SOC, battery voltage and battery discharging current.

Figure 6 shows Li-Ion battery voltage waveform with negative slope due to energy consumption with time. A zoom in for voltage variation can be indicated in Fig. 7. Showing high ripple in the voltage waveform. And also high frequency of voltage ripple due to the switching action of the inverter.

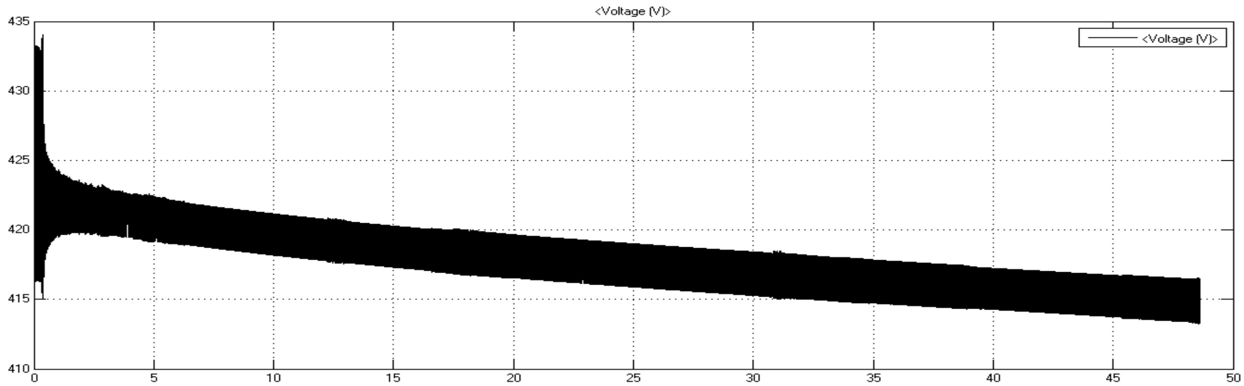


**Fig. 6:** Li-Ion Battery voltage waveform versus time- PMSM Model

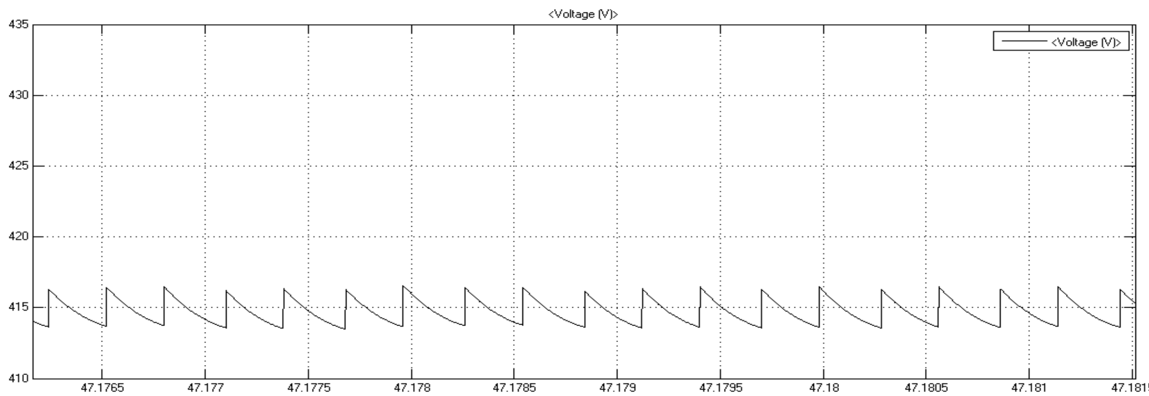


**Fig. 7:** Battery voltage waveform zoon in

Battery state of charge; SOC is shown in Fig. 8. Battery level initial condition is 100%. The battery discharges 0.1% in 48 seconds. So it will reach 20% of its capacity in 10.6 hrs. Because the utilization level of the battery will be at 80% of the battery capacity according to formula in Eq. 6.

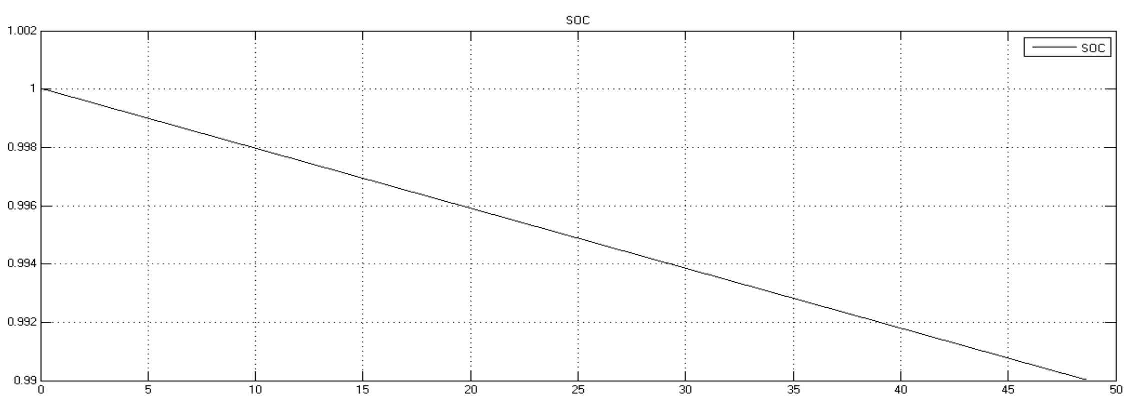


**Fig. 8:** Li-Ion Battery state of charge variation- PMSM Model

**4.1 NMH Battery Supplying DC Motor**

Figure 9 represents battery voltage waveform using Nickel Metal Hydride with less voltage ripple and Fig. 10 illustrates battery state of charge. Figure 11 indicate the discharging current waveform in three cases; if the battery current is 6.5, 13 and 32.5 A showing the normal grey area and exponential yellow discharging area at the starting of discharge period.

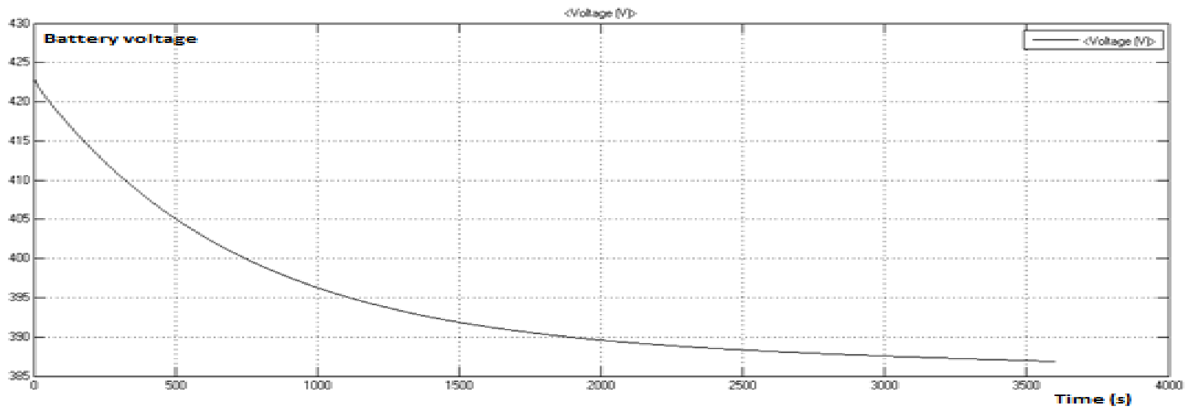


**Fig. 9**: NMH Battery voltage- DC Model

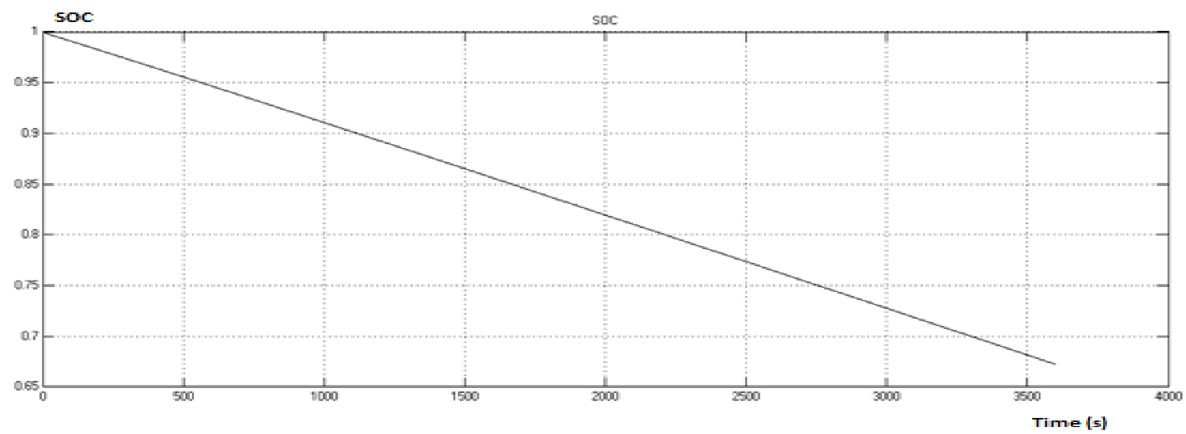


**Fig. 10:** NMH Battery state of charge variation- DC Model

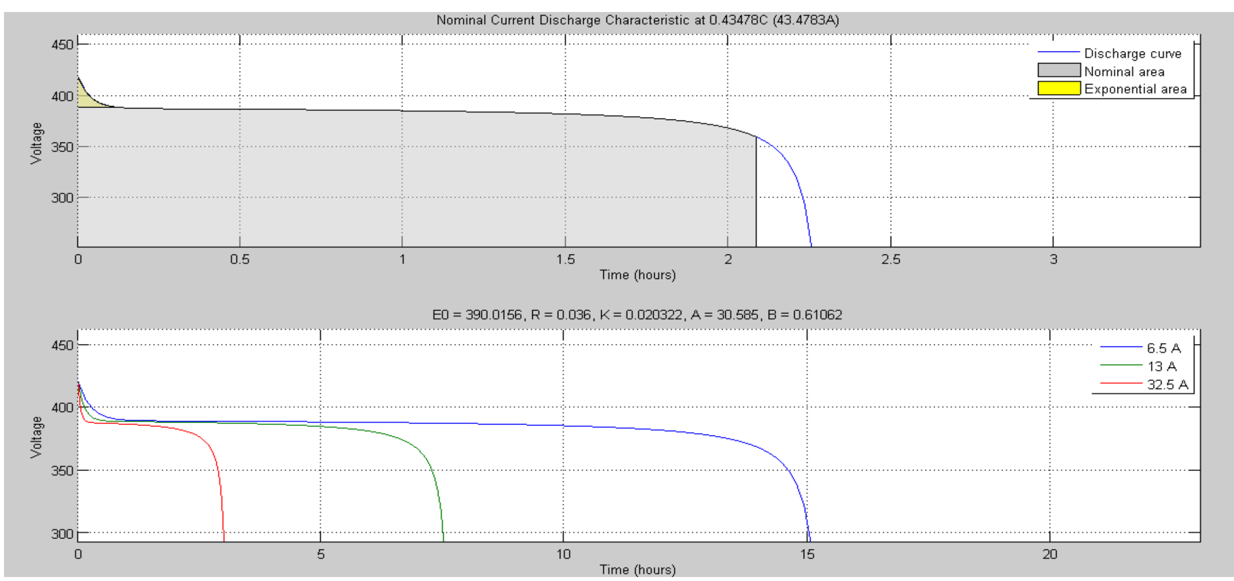


**Fig. 11:** Nominal current discharge characteristics for EV battery

### 4.2 Li-Ion Battery Supplying DC Motor

Figure 12 describes battery voltage using Li-Ion battery instead of NMH type indicating better voltage variation at the same load level. Finally, Fig. 13 views DC model Li-Ion battery SOC.

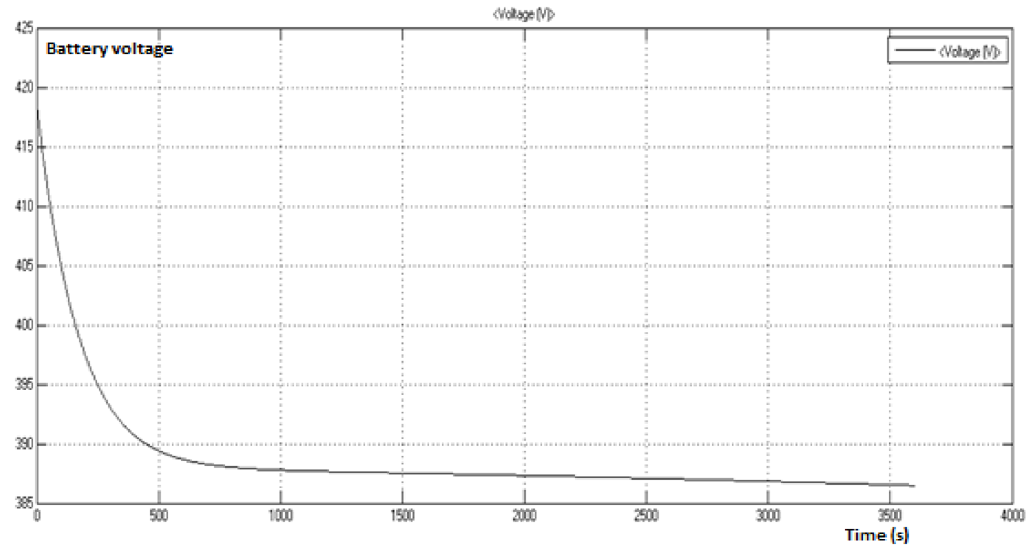


**Fig. 12:** Li-Ion Battery voltage variation with time- DC model

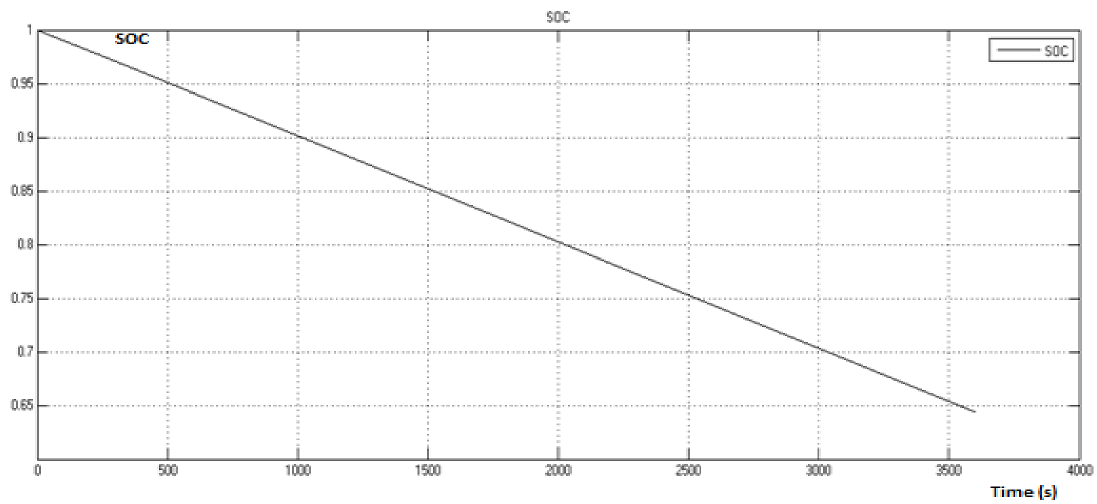


**Fig. 13**: Li-Ion Battery State of charge- DC model

## 5. Conclusion

This study tries to investigate the performance of the batteries from the load type point of view. The comparison is done between AC and DC machine as a load utilized to drive the EV. Battery key performance indicators under this study is the battery voltage, battery state of charge and discharge characteristics. The PMSM model presented as AC load with high level of battery voltage ripple and current ripple that will lead to a stress on the battery causing temperature rise and life time derating of the battery that may need special attention during designing the battery management system and temperature management system. For the DC motor model the voltage and current ripples are considerably less and it will keep the battery health for longer time and avoid any thermal runaway due to excessive ripples. Moreover the efficiency of the system using the PMSM is less than the efficiency of the DC motor model due to the extra losses in the inverter stage; DC/AC. Another advantage of DC motor is the simplicity of speed control with respect to AC machine speed control. On the other hand the DC motor is more expensive than PMSM and also it needs more frequent maintenance than the AC machine.

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