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(RESEARCH ARTICLE)

Performance analysis of nickel metal hydride (NiMH) rechargeable battery using Matlab/Simulink

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Abstract

This research presents the performance analysis of Nickel Metal Hydride (NiMH) rechargeable battery using MATLAB/Simulink. Nickel Metal hydride (NiMH) batteries are used as hydrogen storage material with high hydrogen volumetric capacity and reversible hydrogen absorption/desorption reactions. The study helps contribute to the lingering research gap regarding the NiMH battery. Recent research works conducted on NiMH battery cover areas such as the battery capacity and its memory effect. This research work addresses the charge/discharge characteristics and the battery voltage. The methodology employs the use of a generic battery model which is modeled using the Simulink library materials. Simulation using nickel hydrogen battery model thus makes it possible to analyze the characteristics of chargeability and discharge ability. The result showed that the battery has a nominal voltage of 200 volt. The machine runs at 120 rad/s and the charge and discharge characteristics showed that the battery is least affected by its memory.

Keywords: Rechargeable batteries; Nickel Metal Hydride; State of Charge

1. Introduction

Rechargeable battery or accumulator is kind of electric battery that can be charged and discharged through a load. It is recharged many times as unlike disposable battery and discarded after use. It is an electrochemical cell and also termed as accumulator as it accumulates and stores energy through a redox reaction. Rechargeable batteries are available in many forms of sizes and shapes (button cells to megawatt systems). The several types of electrode materials and electrolytes are combined in different ways to form different types of rechargeable batteries such Lead–Acid (Pb-Ac), Nickel–Cadmium (Ni-Cd), Nickel–Metal Hydride (Ni-MH), Lithium-Ion (Li-Ion) etc [1]. Although batteries seem to be simple, they are nonlinear and complex systems because oftheir physical and chemical structure. Moreover, it is important to estimate SOC of the batteryaccurately in battery management systems to use the battery efficiently [2].Applications of rechargeable Nickel metal hydride (Ni-MH) battery began with hydrogen storage alloy as negative electrode. Ni-MH batteries have received much attention because of their higher energy density, superior charge-discharge characteristics, comparatively less memory effect and reduced polluting nature. Ni-MH batteries have higher gravimetric and volumetric energy densities as compared to Nickel Cadmium (Ni-Cd) batteries of the same size by approximately 30–40% (N. Cui et al, 2000). On the other hand, rechargeable Lithium ion (Li-ion) batteries present as strong competitors to the Ni-MH batteries, with their high specific power density and light weight. For safety reasons, however, they cannot be operated without an electronic control. Li-ion batteries are quite expensive as compared to other rechargeable batteries.

The power battery and batterymanagement system are core component of the new energy vehicles, which has a significantimpact on the vehicle's dynamics, the accuracy and the stability. Battery modeling reflects outerdynamic characteristics, which is the key point in battery State-Of-Charge estimation and playsan important role in the design of the battery management system [3].These batteries initially are costlier than disposable batteries, but have the total cost of ownership and environmental impact is lower, as it easily recharges many times before they replaced. Disposable

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batteries may also be available in the same rating as the rechargeable batteries and can be used interchangeably sometimes. The positive active material is oxidized during charging which produces electrons while negative material is reduced by consuming electrons. The electron which moves constitutes the current flow in external circuit. The electrolyte will serve as a buffer for the ions to flow between the electrodes internally, as like in nickel-cadmium and lithium-ion cells whereas an active participant in the electrochemical reaction as in lead–acid cells.

A charger is used to supply energy to rechargeable battery through AC main electric supply which is to be maintained at higher potential so that current is forced to flow from charger towards the battery limiting to maximum current otherwise the battery will explode because of excessive input currentrate. Since the input current to charge an electrochemical battery is limited, the charging time is very high to fully recharge a battery to charge without damaging. Recently new quick chargers have come with cooling fans to check the heating cells but still take hours to fully recharge a battery [4].As a battery stores electrical energy in a reversible chemical reaction, the need to estimate its storage capability under various conditions, such as environmental and electrical factors, is very much important. Early trends in battery development suffered a great deal of memory effect (degradation in battery capacity). It was found however, that Nickel Metal Hydride (NiMH) batteries have much better efficiency and storage capability than earlier technologies (such as Lead-Acid batteries), hence the need to evaluate its performance to improve its storage capacity and reduce charging time and increase discharge time.

2. Related Work

Accurate battery modeling and simulation was proposed by [5]. The Thevenin equivalent circuit model of NiMH battery was established for the poor accuracy of traditionalmodel. Based on the data which were brought from the 6V 6Ah NiMH battery hybrid pulse cycling test experiments, Thevenin model parameters were identified by means of the linear regression analysismethod. Then, the battery equivalent circuit simulating model was built in the MATLAB/Simulinkenvironment. The simulation and experimental results showed that the model has better accuracy and canbe used to guide the battery state-of-charge estimation.A battery model able to simulate the effect of temperature on the battery behavior was proposed [6]. In this proposal, the effect of temperature on lithium-ion battery is studied. An enhanced modeling scheme/method is used in which the thermal effect is considered. It was found that the combination of thermal and electrical models by making use of a thermal function to model the difference made by temperature exhibit better representations of the actual characteristics of the battery.

A low-cost embedded system is used to determine the state of charge of an electric car. A Li-Ion batterycell is trained using a feed-forward neural network via Matlab/Neural Network Toolbox [7]. The trainedcell is adapted to the whole battery pack of the electric car and embedded via Matlab/Simulink to a low-cost microcontroller that proposed a system in real-time. The experimental results indicatedthat accurate robust estimation results could be obtained by the proposed system.A discharge test for SOC prediction is easy, has high accuracy, is suitable for all batteries, and it isindependent of the state of health of the battery. Artificial intelligence techniques can be adapted to allkind of batteries. It requires training data and works in real time [8].A thermal model for a lithium-ion polymer (LiPo) battery was able to predict the cell behavior. The Simulink results were compared with experimental tests [9]. The relationship between the estimated battery state of charge and the temperature was proposed as well. It was found that the use of temperature-dependent cell model can improve state of charge estimation, as temperature changes dramatically affect lithium-ion battery behavior. Experimental evidence is provided using the developed temperature dependent cell model of lithium-ion polymer battery inside a promising state of charge estimator that mixes the standard coulomb counting, i.e. battery current integration with the model based approach. The Dynamic Modeling and simulation of temperature and current effects on an electric vehicle lithium-ion battery was performed by [10]. The methodology used MATLAB/SIMULINK to model a lithium-ion battery using a generic battery model. It was found that lithium-ion battery is affected by temperature.

Most of the researches conducted so far focused mainly on the effect of temperature on the battery capacity or cycle life for lithium-ion battery. However, some papers chose to compare different types of electrical vehicle batteries to see which of the batteries has the basic characteristic that best suits the intended purpose while other papers focused on the effect of temperature on fuel consumption. This paper presents Modeling and simulation of nickel metal hydride battery to determine the charge and discharge characteristics as well a battery voltage.

3. Methodology

The aim of the project is to evaluate the performance of a Nickel Metal Hydride (NiMH) battery. After modeling the Ni-MH battery in MATLAB/SIMULINK environment, a simulation of the battery models in order to determine its charging and discharge rates will then be run in Simukink to estimate the State of Charge (SOC) of the battery. The modeling and subsequent simulation of a Nickel Metal Hydride rechargeable battery involve the systematic bringing together of different models of components in MATLAB/Simulink library. The methodology uses a MATLAB/Simulink interface to model a Nickel Metal Hydride (NiMH) rechargeable battery.

3.1. Equivalent Circuit of the Battery Model

The model in this project is decided to be similar for both Li-ion and for Ni-MH but with different values of the components. This is possible due to that this model models the most relevant features of the batteries such as diffusion and polarization. It is also assumed that the state of charge should be held between 20% and 80% where these batteries are quite linear; Figure 1 illustrates the equivalent circuit of the model.

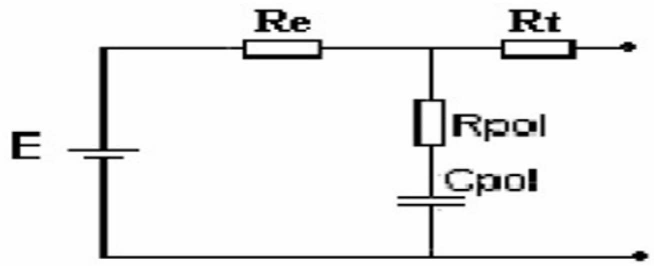

Figure 1 Battery Model

This model is implemented with blocks in MATLAB/Simulink. In order to make it more flexible e.g. make it easier to change the equivalent circuit to a different one and to have multiple input/output ports. The drawback with this model is that it doesn't take into account all the specific electrochemical features of the batteries but only the most common ones [11].The state space model presented in Figure 2 is the proposed dynamic model of NiMH battery. This represents not only NiMH battery but also most popular types of rechargeable batteries. The state of charge of the battery is (0 - 100%). The SOC for a fully battery is 100% and for an empty is 0%. The battery equivalent circuit as shown in Figure 1 is fully implemented with blocks in MATLAB/Simulink. The battery model implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries, which in this case is the Nickel Metal Hydride Battery (NiMH).

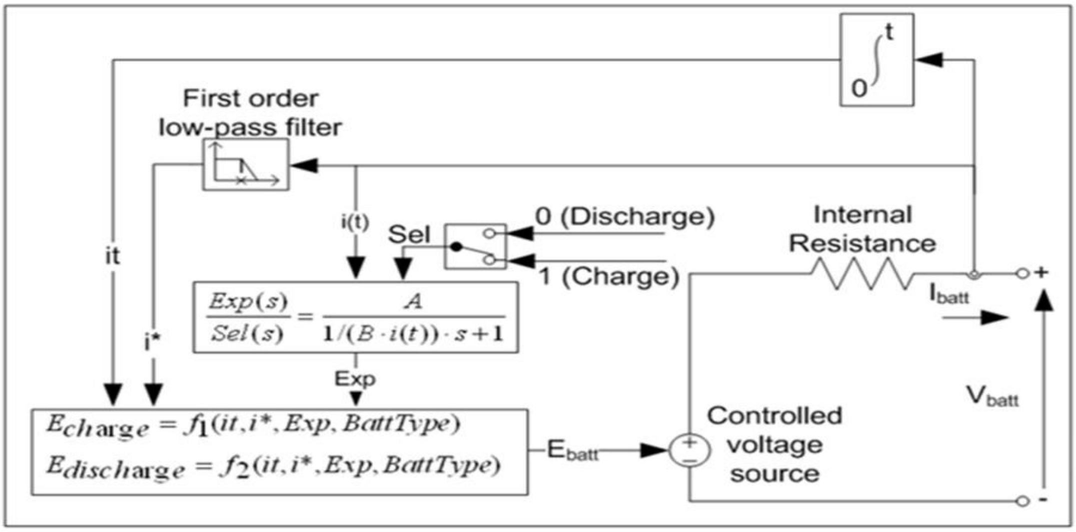

Figure 2 Battery Model Equivalent Circuit

Discharge and charge model equations for the system are given in equation 1 and 2 respectively.

- Discharge Model ($i^* > 0$)

$$f_1(it, i^*, i, Exp) = E_0 - K.\frac{Q}{Q-it}.i^* - K.\frac{Q}{Q-it}.it \quad + Laplace^{-1}\left(\frac{Exp(s)}{Sel(s)}.0\right) \tag{1}$$

- Charge Model (i*< 0)

$$f_2(it, i^*, i, Exp) = E_0 - K.\frac{Q}{|it| - 0.1 \cdot Q}.i^* - K.\frac{Q}{Q-it}.it \quad + Laplace^{-1}\left(\frac{Exp(s)}{Sel(s)}.\frac{1}{s}\right) \tag{2}$$

- State of Charge (SOC)

SOC = $100(1 - \frac{1}{Q}\int_0^t i(t)dt)$ (3)

The terms in the equation are defined thus;

E_{Batt} = Nonlinear voltage (V)

E_0 = Constant voltage (V)

Exp(s) = Exponential zone dynamics (V)

Sel(s) = Represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.

K = Polarization constant (Ah−1) or Polarization resistance (Ohms)

i* = Low frequency current dynamics (A)

i = Battery current (A)

it = Extracted capacity (Ah)

Q = Maximum battery capacity (Ah)

A = Exponential voltage (V)

B = Exponential capacity (Ah)−1 The parameters of the equivalent circuit as Fig 2 can be modified to represent a particular battery type, based on its discharge characteristics.

3.2. Components Required for Modelling in Simulink Environment

The following components are required from MATLAB library to assemble a suitable model of a Nickel Metal Hydride (NiMH) rechargeable battery.

NiMH battery (200 volts, 6.5 Ah) Model

- DC Machine Model
- Voltmeter Model
- Ammeter Model
- Ohmmeter Model
- Oscilloscope Model

The Nickel Metal Hydride (NiMH) battery will provide the virtual power needed to run the entire model setup. The DC machine is to be used as a load in the motoring mode and as a generator to charge up the battery when the battery goes below the specified voltage. The voltmeter is to measure the open circuit terminal voltage as well as the load voltage when the DC machine acts as a motor. The circulating current is to be measured by the ammeter connected in series with the battery. Internal resistance of the battery is to be measured using the ohmmeter. The voltage and current waveforms are to be displayed on by the oscilloscope model. The information obtained from individual models is to be summed up to estimate the model voltage and the virtual state-of-charge (SOC) of the battery.

3.3. Model Implementation

The goal of the system simulation is to predict how system performs when it is build. So, it is not feasible to experiment with a system when it is already put into use. The models provide adequate description of reality, experimenting with them can save money, time and tenderness. Battery modeling is vital component of a dynamic electric vehicle simulator. Battery modeling plays an important role in the approximation of battery performance and in design. At this stage of the methodology, the individual models are to be identified from the MATLAB library and modeled or assembled in the work interface. The complete model setup is as shown in Figure 3. The power battery is to be connected to a constant load. The DC machine is connected in parallel with the said load, which is to be operated on no – load. When the State of Charge (SOC) of the battery goes under certain level, a negative load torque is applied to the machine so it acts as a generator to charge the battery. However, when the SOC goes above specified higher level, the torque is going to be removed so that the battery supplies the load. The sequence is repeated until the actual battery voltage and state of charge are estimated.

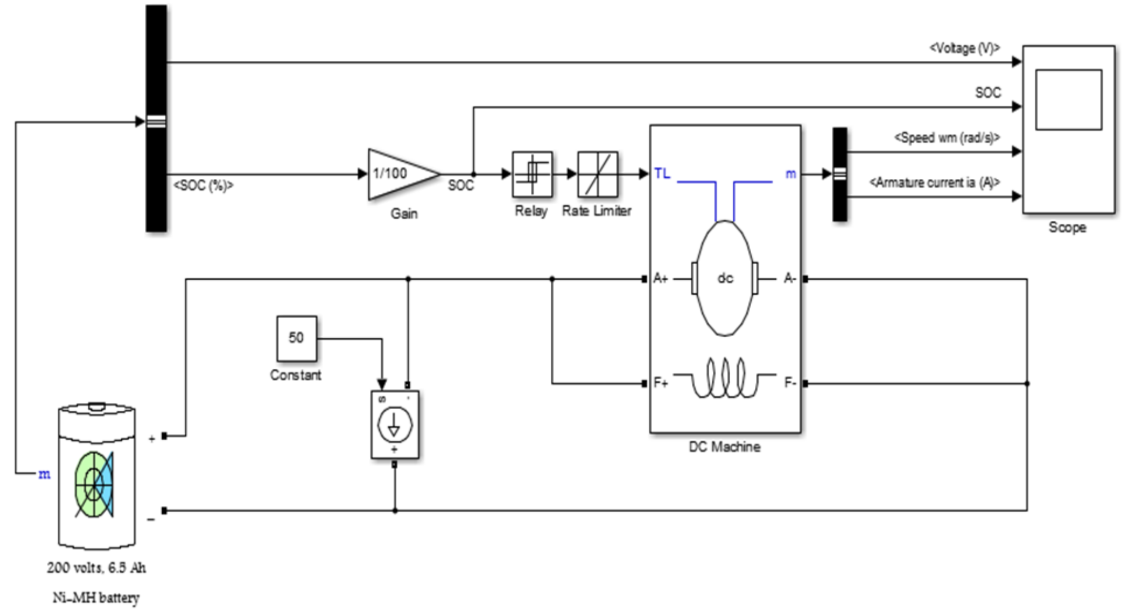

Figure 3 NiMH Simulink System Model

The following assumptions are made:

- The internal resistance is supposed constant during the charge and the discharge cycles and doesn't vary with the amplitude of the current.
- The parameters of the model are deduced from discharge characteristics and assumed to be the same for charging.
- The capacity of the battery doesn't change with the amplitude of current.
- The model doesn't take the temperature into account.
- The Self-Discharge of the battery is not represented. It can be represented by adding a large resistance in parallel with the battery terminals.
- The battery has no memory effect.

And the model limitations are

The minimum no-load battery voltage is 0 volt and the maximum battery voltage is equal to $2*E_0$.

The minimum capacity of the battery is 0 Ah and the maximum capacity is Qmax.

The experimental facilities and systems were comprised of a 6.5 Ah whose voltage and state of charge are to be determined. Battery experiments were accomplished by employing a MATLAB/Simulink to record the outcomes of the battery model experiments. The inputs of the study model shown in Figure 3 are the applied load current and the initial *SOC*, while the output of the model is the estimated battery voltage; additionally, the model can return information about the battery *SOC* at every moment. Furthermore, since no thermal model is to be developed for the battery, the temperature of the battery is considered constant during the whole simulation.

3.4. State-of-Charge (SOC) Estimation

State of charge estimation is one of the most important tasks of Battery Management Systems. Knowing the amount of charge stored in the cell is indeed crucial for effective battery utilization that prevents battery cell from damaging and extends the lifetime. However, the assumption that the battery temperature and the capacity as well as memory effect have no effect on the battery life cycle has, to a greater extent, made the task for estimating the state of charge much easier. The SOC is determined from the study model shown in figure 3.3 during full charge and complete discharge respectively.

In conclusion, this chapter presents the methodological procedures used to accomplish the project objectives. It focused on models to be used, how they should be put together or modeled on the MATLAB/Simulink work interface as well as how the model's voltage, and the charge/discharge characteristics of the battery are to be Estimated.Simulation result comes after modeling. At this stage the model is run to predict its actual behavior.

4. Results and discussion

This section presents the results of the simulation been carried out based on the methodology outlined. It also dwelled on the necessary discussions of such results. The simulation was prepared using MATLAB/Simulation package available in Matlab/Simulink. The battery model was simulated during charge and discharge process. The simulation results capture the battery voltage, State of Charge (SOC) of the battery, motor speed and motor armature current signals as available at the output of the block as shown in Figure 4, 5, 6 and 7 respectively. The simulation of 200 volt, 6.5 Ah NiMH battery connected to a constant load of 50A in parallel with a DC machine was performed and the result presented.

4.1. Battery Voltage Magnitude

At time t = 0 sec, the DC machine started with the battery power at a 200V as shown in Figure 4. The battery was also discharged by the constant DC load of 50 amp connected in parallel with the DC machine as depicted in Simulink model of Figure 3.

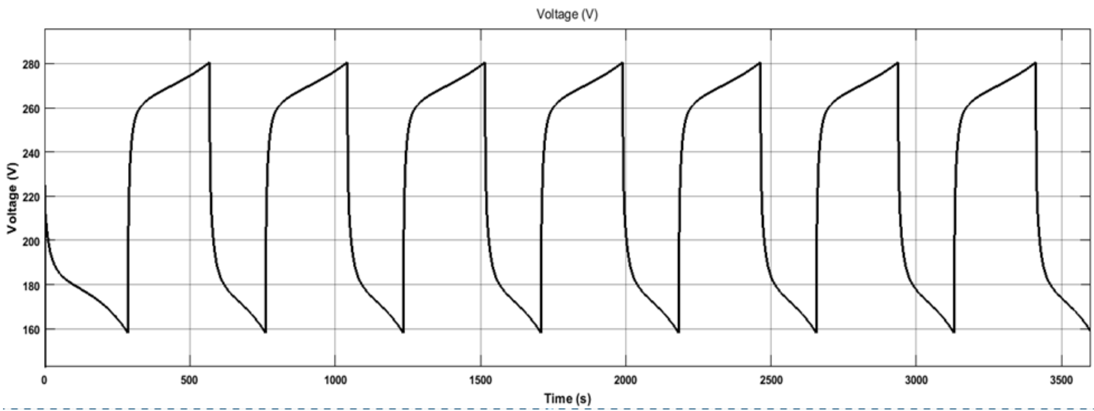

Figure 4 Battery Voltage Magnitude Measurement in volt

4.2. Battery State of Charge (SOC)

From Figure 5 at t = 0 sec, the battery state of charge was 100%. As the time reaches t = 280 second, the state of charge (SOC) of the battery drop to 40%, a mechanical toque (negative load torque) of 200NM was applied to the machine so it acts as a generator to recharge the battery and provide a current of 100amps.

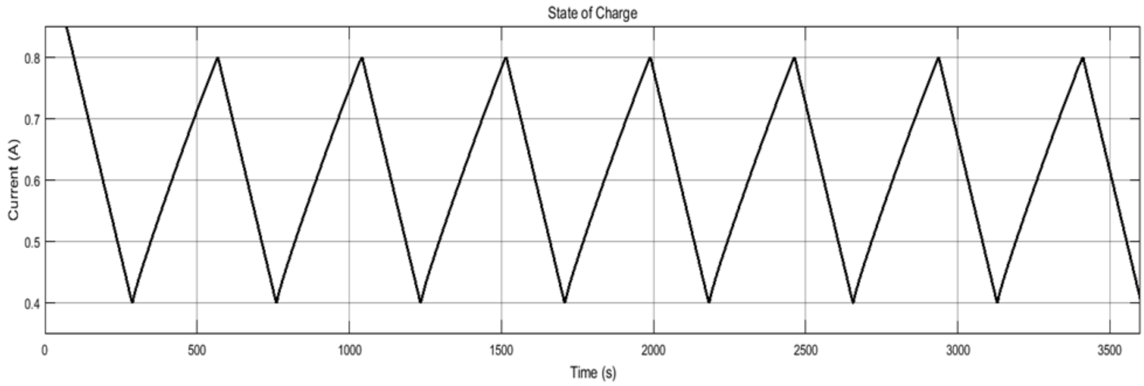

Figure 5 Behavior of the Battery State of Charge (SOC) in Per Unit (p.u)

Hence, 50 amps go to load and 50 amps goes to recharge the battery as shown in Figure

4.3. Motor Current and Speed Characteristics

It can be observed from Figure 5, At t = 500 sec, the state of charge of the battery goes over 80% and the mechanical torque is removed. So now only the battery supplies the 50-amp load. Finally, result of Figure 7 reveals the machine's response by raising the voltage of Figure 4and SOC of Figure 5 to nearly 250V and 80% charge respectively. The initial speed was at to 120 rad/sec. Observed from Figure 4,At t=280 sec when only the battery supplies 50amp load, there's a sharp drop in source voltage. Likewise, Figure 5 reveals the effects on the SOC, which equally falls to 40%. Therefore, at the same time (negative load torque) of 200NM was applied to the machine so it acts as a generator to recharge the battery and provide a current of 100amps as displayed in Figure 6.

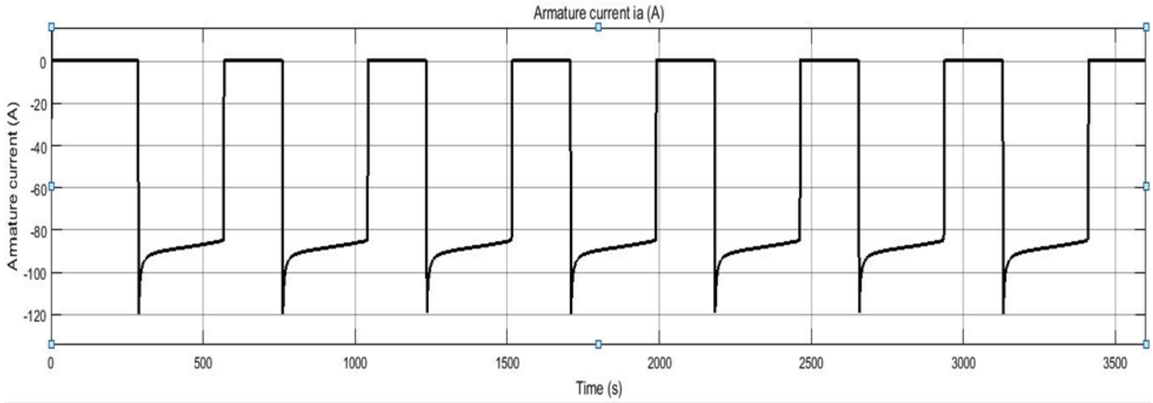

Figure 6 Motor current signal in (A)

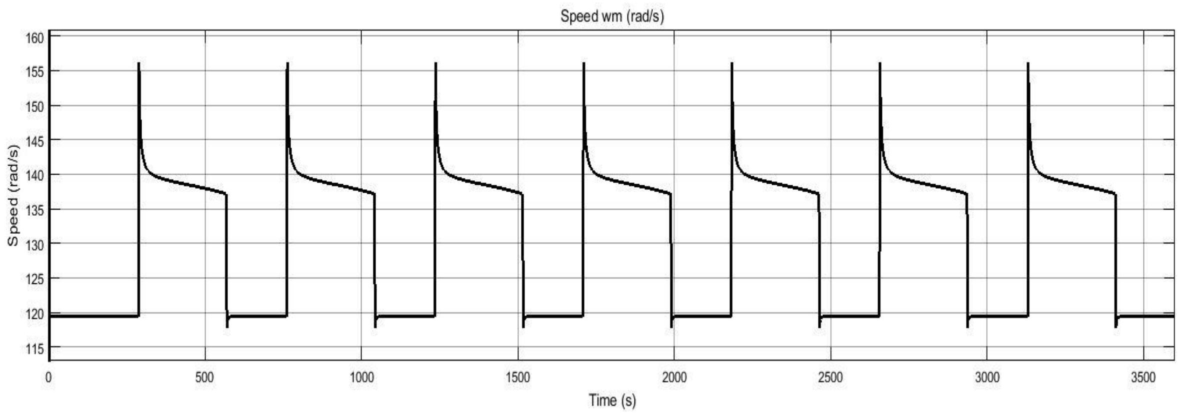

Figure 7 Motor speed characteristics**.**

When the SOC goes over 80%, the load torque was removed so only the battery supplies the 50 amps load. Therefore, the machine operates free and the cycle restarts.

4.4. Simulation Discussion

The simulation result showed that the SOC of the battery kept increasing from 40% to 80% while charging and vice-versa while discharging. The battery voltage is 200V. It took the battery 280 seconds to discharge from 100% SOC to 40% to a load of 50 Ah, whereas upon application of negative load torque of - 200Nm, the motor acted as a generator producing 100 Ah of which 50% supplies a load and 50% goes to recharge the battery. It took 220 seconds for the battery to recharge to 80%. The negative load torque is removed at this point. The circle is repeated continuously to examine whether the battery is affected by memory effect. It was found that the state of charge and the charge/discharge time remained the same for all repeated circles. This means that the battery, NiMH is not affected by memory effect.

5. Conclusion

This paper presents the performance evaluation of Nickel Metal Hydride (NiMH) battery using MATLAB/Simulink. The model is able to estimate state of charge as well as battery voltage. Detailed procedure used in modeling the battery was also presented as well as the model based on the charge/discharge characteristics. Based on the simulation results obtained, it can be concluded therefore, that nickel metal hydride battery not only has high battery capacity but also study its charge discharge characteristics.

One of the limitations of the research is that the model doesn't take the temperature into account and the Self-Discharge of the battery as well.It is recommended therefore, that future researchers should work to reduce if not eliminate the limitations. The following recommendations are made;

- Performance evaluation using other methods to estimating the SOC, and other battery parameters.
- Other rechargeable batteries, like Lead acid battery, lithium-ion battery base on different assumptions can also be model and compare its performance with NiMH
- Due to wide presence of batteries in a large variety of applications, it is important to study and ensure the improvement and efficiency of the batteries.

Compliance with ethical standards

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Disclosure of conflict of interest

To the best of our knowledge, the named authors have no conflict of interest, financial or otherwise.

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