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Study Vehicle Battery Simulation and Monitoring System

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Abstract This paper presents battery model applied to dynamic simulation software. Simulation using nickel hydrogen battery model thus makes it possible to analyses very complex phenomena. The model was realized in Matlab / Simulink software packages. The Battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries. In this case, the battery's model parameters are not exactly the same as those of the electric vehicle battery but it is nevertheless possible to study, with good precision, phenomena caused by the battery. Moreover, this model helps to develop the energy management system (EMS) which controls the flow of energy between the solar panels and battery. Finally, it is possible to control the charge and the discharge of the battery with precision. The results obtained show that the use of this battery model makes it possible to properly represent the transient states. It is thus possible to analyses them in order to fine-tune the various control devices and they show accurately represent the general behavior of the battery. The battery monitoring system developed is used to prevent people from being stranded. This device makes sure that no matter what, a car will be able to start and that a person will not be left with a dead battery. This paper is about the Features and Specifications related to the battery monitoring system.

Keywords: *vehicle battery simulation, hybrid vehicles modeling, nickel hydrogen, Battery and Battery Monitoring*

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1. Introduction

The secondary energy storage is a vital component in hybrid electrical vehicles. As electric energy storage the lead acid battery is traditionally used, in particular as 12 and 24 V system battery in vehicles. However, in the last years the nickel metal hydride battery has become used in several vehicles, and today the lithium technology is also of interest. A widespread experience with battery technology in vehicles is that the cost relate to lifetime is a limitation. Without this limitation it would be possible to install a sufficient amount of battery so that a passenger car easily can be driven most of the everyday mileage pure electrically. This would result in a considerable reduction of apparent fuel consumption. An important alternative is the super capacitors that are assumed to have almost unlimited lifetime. The drawback with this is its low energy density. This limits the possibility to drive a long mileage on pure electric power. However consider the possibility, in a hybrid electric vehicle, not to have the need of changing worn-out batteries. Research on the NiMH system started in the 1970s as a means of storing hydrogen for the nickel hydrogen battery. Today, nickel hydrogen is used mainly for satellite applications [1]. Nickel hydrogen batteries are bulky, require high-pressure steel canisters and cost thousands of dollars per cell. In the early experimental days of NiMH, the metal hydride alloys were unstable in the cell environment and the desired performance characteristics could not be achieved. As a result, the development of NiMH slowed down. New hydride alloys were developed in the 1980s that were stable enough for use in a cell. Since then, nickel metal hydride has steadily improved. The success of nickel-metal hydride has been driven by high energy density and the use of environmentally friendly metals. The modern NiMH offers up to 40% higher energy density compared to the standard nickel cadmium. There is potential for yet higher capacities, but not without some negative side effects. NiMH is less durable than nickel cadmium. Cycling under heavy load and storage at high temperature reduces the service life. NiMH suffers from high self-discharge, which is higher than that of nickel cadmium. NiMH has been replacing nickel cadmium in markets such as wireless communications and mobile computing. Experts agree that NiMH has greatly improved over the years, but limitations remain. Most shortcomings are native to the nickel based technology and are shared with nickel cadmium [2,3,4]. It is widely accepted that NiMH is an interim step to lithium based battery technology. Here is a summary of the advantages and limitations of NiMH batteries. Advantages.

- 30-40% higher capacity than standard nickel-cadmium. Nickel-metal-hydride has potential for yet higher energy densities.
- Less prone to memory than nickel-cadmium - fewer exercise cycles are required.

• Simple storage and transportation - transport is not subject to regulatory control.

• Environmentally friendly - contains only mild toxins; profitable for recycling.

Limitations

• Limited service life - the performance starts to deteriorate after 200-300 cycles if repeatedly deeply cycled.

• Relatively short storage of three years. Cool temperature and a partial charge slows aging down.

• Limited discharge current - although nickel-metal-hydride is capable of delivering high discharge currents, heavy load reduces the battery's cycle life.

• More complex charge algorithm needed - nickel-metal-hydride generates more heat during charge and requires slightly longer charge times than nickel8 cadmium. Trickle charge settings are critical because the battery cannot absorb overcharge.

• High self-discharge - typically 50% higher than nickel-cadmium.

• Performance degrades if stored at elevated temperatures - nickel-metal hydride should be stored in a cool place at 40% state-of-charge.

• High maintenance - nickel-metal hydride requires regular full discharge to prevent crystalline formation. nickel-cadmium should be exercised once a month, nickel-metal-hydride once in every 3 months [5].

2. Basic Operation of Ni-MH

The basics of the nickel hydrogen battery (Ni-MH cell) are based on its ability to absorb, release and transfer hydrogen between the electrodes. The success of NiMH technology comes from their rare earth metal alloys used in the negative electrode, which contributes to larger volume available for the positive electrode. This is the primary reason for higher capacity and longer service life over competing technologies. Ni-MH battery is an alkaline battery and it has an aqueous electrolyte (potassium hydroxide, KOH). Rechargeable alkaline batteries are dominant in the market for several technical reasons, such as high electrolyte conductivity (good for high power applications), operation over a wide range of temperature and higher energy density, which results in lower cost per watt-hour. The electrolyte has a very high conductivity, due to its aqueous solution, and it doesn't take part in the process to any significant extent. The concentration of the electrolyte remains rather constant over the charge and discharge process. Due to this the resistance of the cell also remains almost constant over the SOC range. This leads to a battery with high power performance and long cycle life. The NiMH cells active materials are made of metal alloys or metallic oxides that are good conductors in a charged state. The nickel oxide hydroxide electrode exchanges a proton only in the charge-discharge process and the electron transfer is very quick. This corresponds to a high power capacity. The small change in size of the electrode during charge and discharge also results in greater mechanical stability and therefore longer cycle life [6].

3. Battery Model

The model in this thesis 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 and Figure 2 illustrates the equivalent circuit of the model.

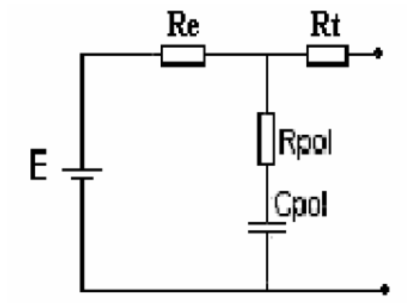

Figure 1. Battery model

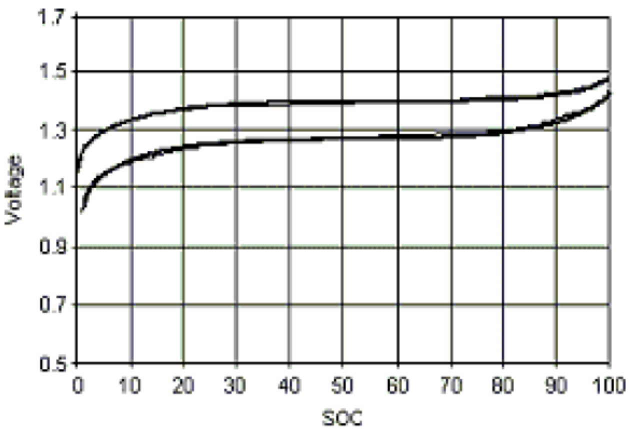

Figure 2. Charge and discharge curves for NiMH

This model is implemented with blocks in Matlab / Simlink. It could also be done with an s-function 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. For example it doesn't models the hysteresis effects of the batteries. This is more essential in the Ni-MH technology. The hysteresis effect of the battery is shown in Figure 2 This effect shouldn't be very hard to implement in the model, it is only to use one resistor for charge and another for discharge. The problem is to find the values of the 25 components. Fitting a curve by the “cut-and-try” principle could do it. However this isn't very accurate for different conditions. It is much better with values that are tested and measured at different SOC and temperatures. This is a big problem when modeling a chemical cell because all suppliers are very cautious with whom they are sharing their information. This is probably because of that the battery market is in a research era right now. Therefore it is very seldom that they supply any other than their customer with data of the battery (and sometimes not even them). This model was converted into a state space model in order to implement it into a vehicle simulation program called Advisor. The Battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries [7]. The equivalent circuit of the battery is shown Figures 3

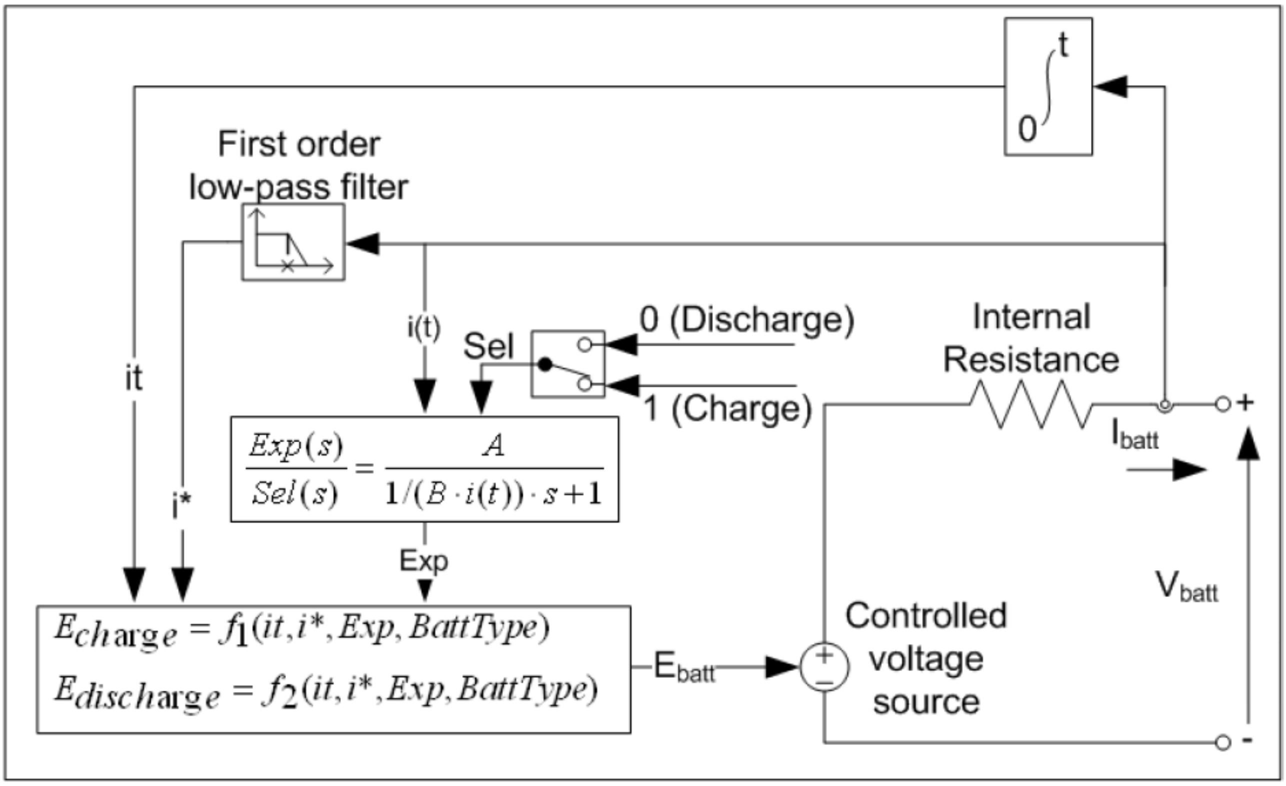

Figure 3. The equivalent circuit of the battery

Where:
E = No load voltage (V)
E0 = Constant voltage (V)
K = Polarization voltage (V)
Q = Battery capacity (Ah)
A = Exponential voltage (V)
B = Exponential capacity (Ah)-1.

3.1. Lead-Acid Model

Discharge model (i* > 0)

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

Charge Model **(i* < 0)**

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

3.2. Lithium-Ion Model

Discharge Model (i* > 0)

$$f_1(it, i^*, i) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + A\exp(-B \cdot it). \quad (3)$$

Charge Model (i* < 0)

$$f_2(it, i^*, i) = E_0 - K \cdot \frac{Q}{it - 0.1Q} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + A\exp(-B \cdot it). \quad (4)$$

3.3. Nickel-Cadmium and Nickel-Metal-Hydride Model

Discharge Model (i* > 0)

$$f_1(it, i^*, i, Exp) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + Laplace^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot 0\right). \quad (5)$$

Charge Model (i*< 0)

$$f_2(it, i^*, i, Exp) = E_0 - K \cdot \frac{Q}{|it| - 0.1 \cdot Q} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + Laplace^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot \frac{1}{s}\right), \quad (6)$$

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 Figure 4 can be modified to represent a particular battery type, based on its discharge characteristics. A typical discharge curve is composed of three sections, as shown in the next figure:

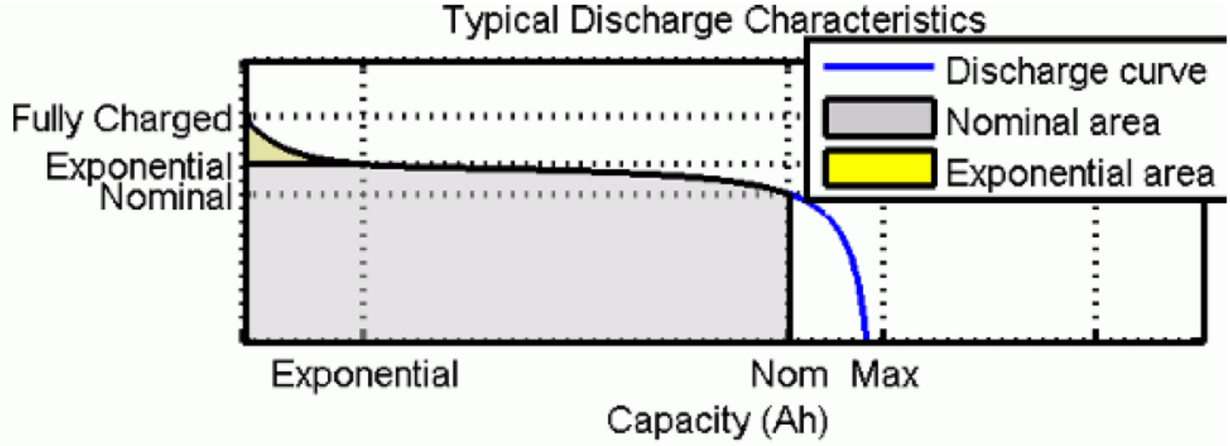

Figure 4. Typical discharge characteristics

The first section represents the exponential voltage drop when the battery is charged. Depending on the battery type, this area is more or less wide. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly [1]. When the battery current is negative, the battery will recharge following a charge characteristic as shown below Figure 5.

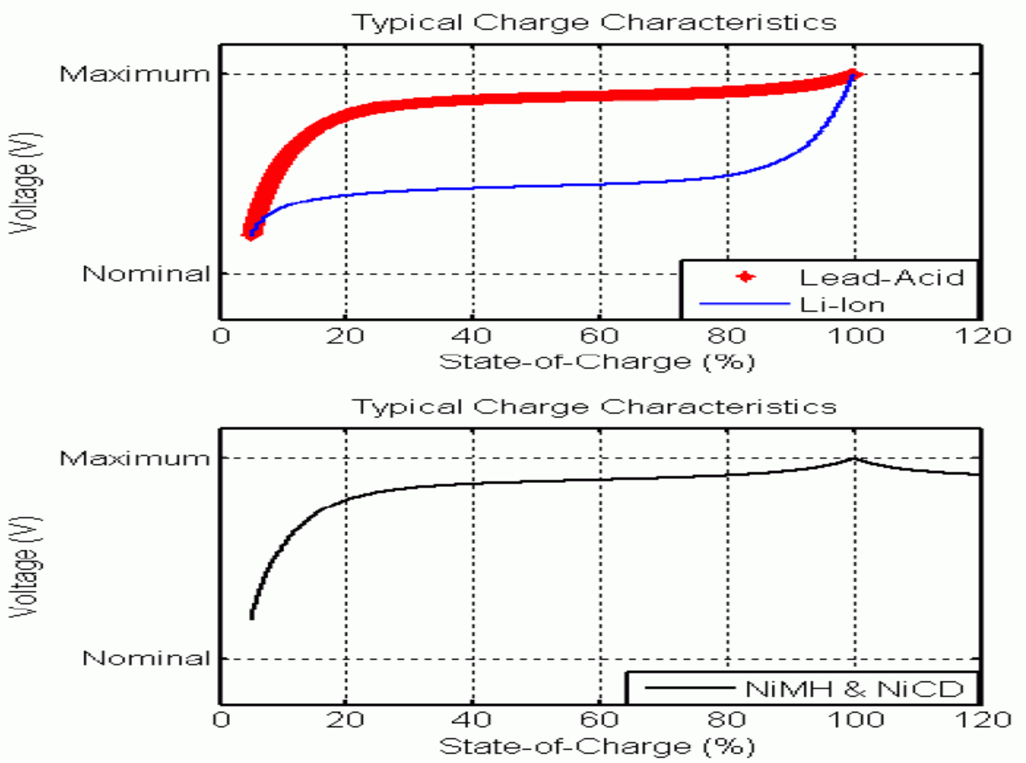

Figure 5. Typical charge characteristics

The parameters of the model are deduced from discharge characteristics and assumed to be the same for charging. The Exp(s) transfer function represents the hysteresis phenomenon for the Lead-Acid, NiCD and NiMH batteries during charge and discharge cycles. The exponential voltage increases when battery is charging, no matter the SOC of the battery. When the battery is discharging, the exponential voltage decreases immediately shown Figure 6.

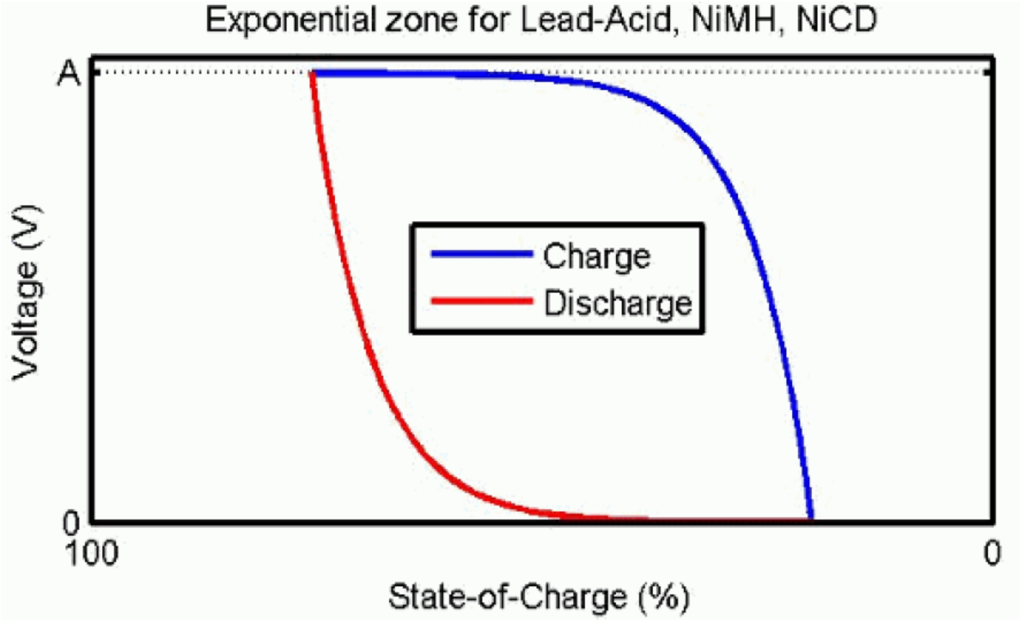

Figure 6. Exponential zone for lead –acid, NI-MH and NiCD

3.4. Block Inputs and Outputs

The Simulink output of the block is a vector containing three signals. You can demulti plex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
SOC	The State-Of-Charge of the battery (between 0 and 100%). The SOC for a fully charged battery is 100% and for an empty battery is 0%. The SOC is calculated as: $SOC = 100\left(1 - \frac{1}{Q}\int_0^t i(t)dt\right)$.	%
Current	The Battery current	A
Voltage	The Battery voltage	V

4. Modelling and Simulation of Vehicle Nickel Hydrogen Battery (NiMH)

4.1. Model Validation

Experimental validation of the model shown a maximum error of 5% (when SOC is between 10% and 100%) for charge (current between 0 and 2C) and discharge (current between 0 and 5C) dynamics.

4.2. Model Assumptions

• 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 (No Peukert effect).

• 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.

Limitations

• The minimum no-load battery voltage is 0 volt and the maximum battery voltage is equal to 2*E0.

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

4.3. The Simulation Produces the Followings Results

The power battery example illustrates a 200 volts, 6.5 Ah NiMH battery connected to a constant load of 50 A. The DC machine is connected in parallel with the load and operates at no load torque. When the State-Of-Charge

(SOC) of the battery goes under 0.4 (40%), a negative load torque of 200 Nm is applied to the machine so it acts as a generator to recharge the battery. When the SOC goes over 80%, the load torque is removed so only the battery supplies the 50 amps load shown in Figure 6.

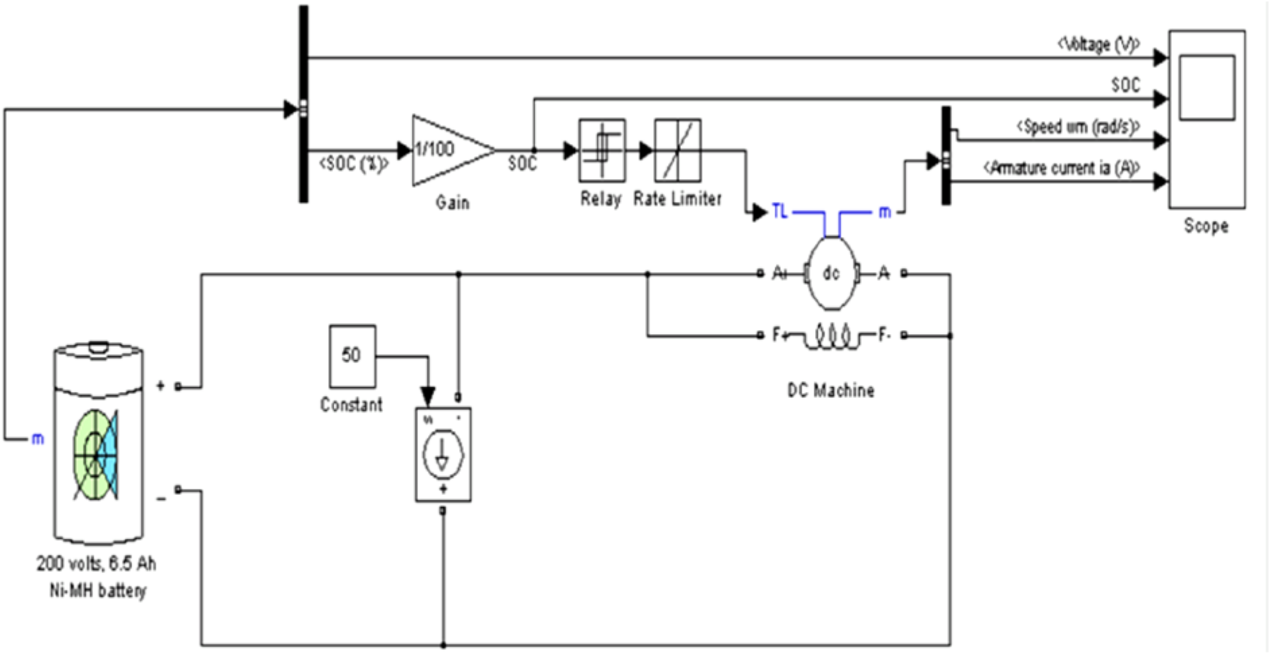

Figure 7. Simulation Model in SIMULINK for Vehicle nickel hydrogen battery (NiMH)

5. Simulation Results

5.1. Description

The battery is connected to a constant load of 50 Amps. The DC machine is connected in parallel with the load and operates at no load torque. When the State-Of-Charge (SOC) of the battery goes under 0.4 (40%), a negative load torque of 200 Nm is applied to the machine so it acts as a generator to recharge the battery. When the SOC goes over 80%, the load torque is removed so only the battery supplies the 50 amps load. Battery voltage, SOC, Motor speed and Motor current signals are available at the output of the block Figure 7.

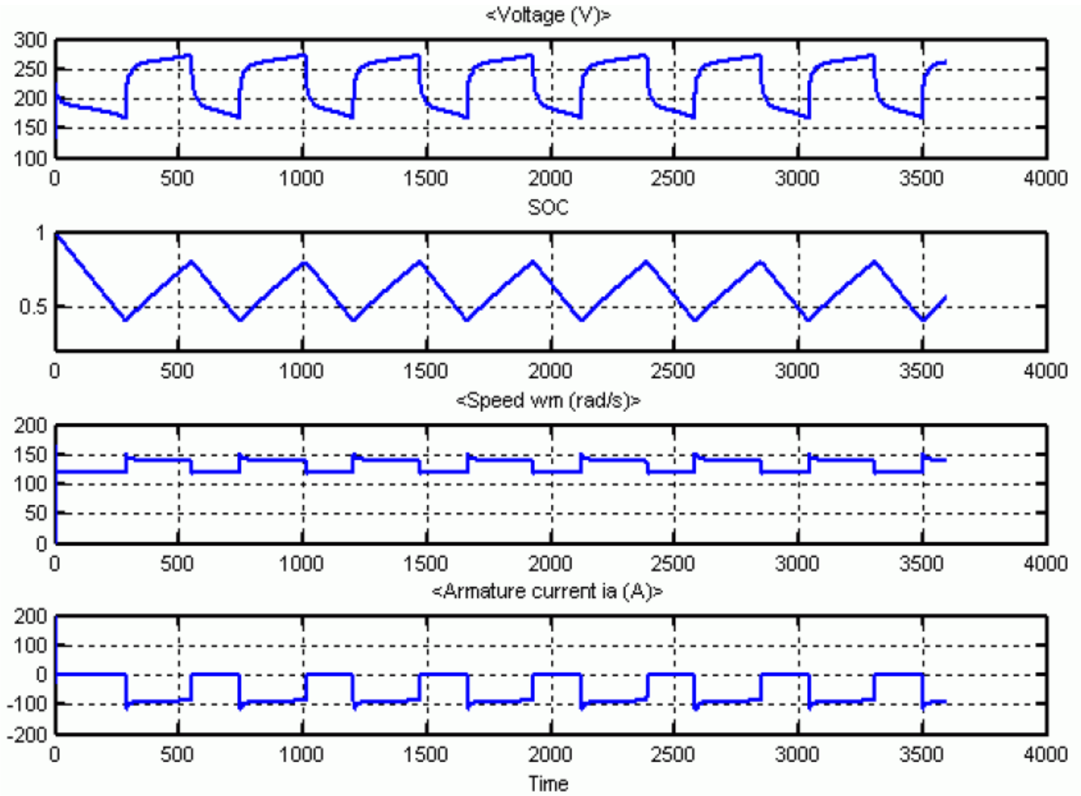

Figure 8. Description of Full Vehicle Simulation

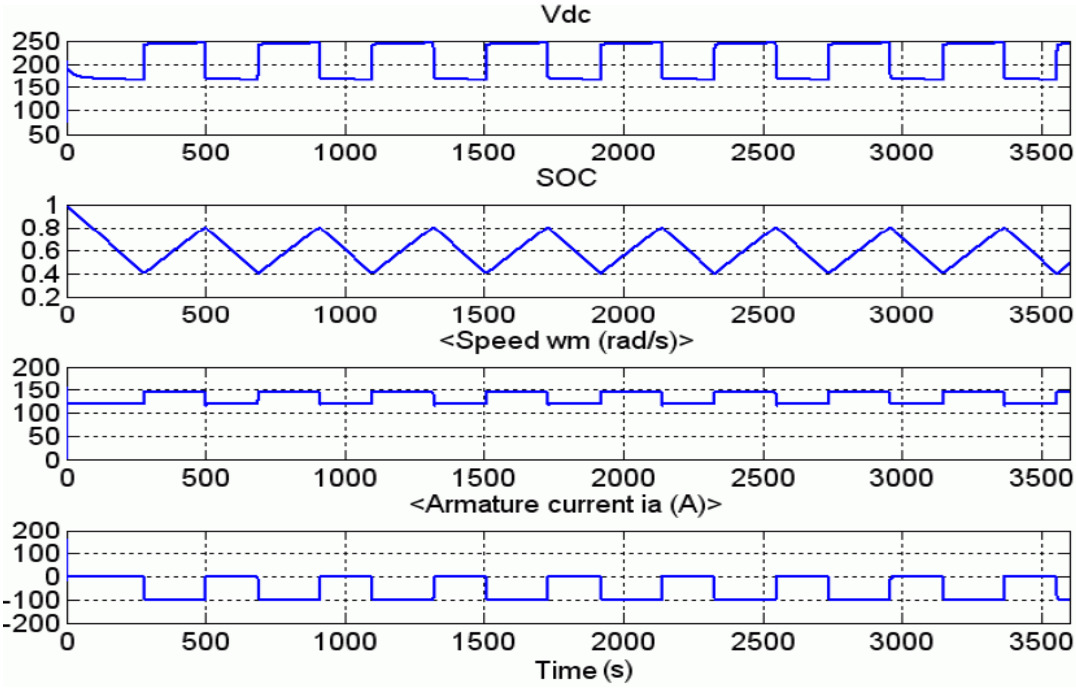

Figure 9. The simulation results

5.2. Simulation

At t = 0 s, the DC machine is started with the battery power. The speed increases to 120 rad/s. The battery is also discharged by the constant DC load of 50 amps. At t = 280 s, the SOC drops under 40%. A mechanical torque of -200 Nm is applied to the machine so it acts as a generator and provides a current of 100 amps. Hence, 50 amps goes to the load and 50 amps goes to recharge the battery. At t = 500 s, the SOC goes over 80%. The mechanical torque is removed and the machine operates free. And the cycle restarts.

6. Battery Monitoring System Using Microcontroller

In this paper, the dynamic battery model that was used will be introduced and explored.

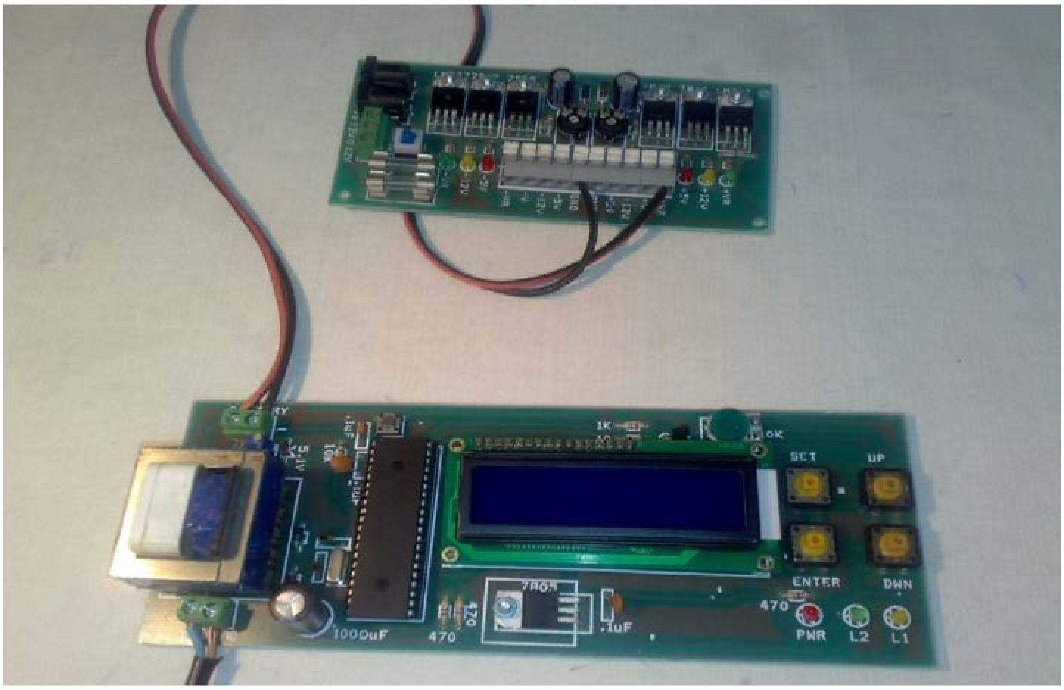

Figure 10. Measurement device and Voltage simulator

The methodology utilized in modeling 12V lead-acid batteries will then be detailed. As all practitioners of battery engineering know, the equations and values provided by models have great variability. Data obtained from one battery test will yield parameters that may differ greatly from data obtained from a slightly different test.

Therefore, exact methodology is very important to give end-users of battery models sufficient insight into the domain of their models and when they may no longer apply, and to compare variations in models. There are many models available for battery modeling, and a few of them are mentioned here in this section.

6.1. Experimental Methodology

The proposed model can therefore represent several types of discharge curves. It is now important to validate whether the obtained parameters properly represent the real behavior of a battery. There are several methods which can be used to validate the model. Of course, it is possible to validate the model by using other simulation models but the software containing these models is very rare and the parameters they require are sometimes difficult to obtain. The suggested validation approach consists of comparing directly (by superposition) the obtained discharge curves using the model with those of the manufacturers.

The experimental tasks for battery modeling involve placing current profiles upon the battery, and measuring voltage responses. The designed system as shown in Figure 9, Figure 10, Figure 11 and Figure 12 developed and it consists of Transformer, Micro controller, regulator, capacitor, LED, Monitor and power supply connected to each 12v battery unit. This unit collects all data regarding battery and sends it serially to microcontroller.

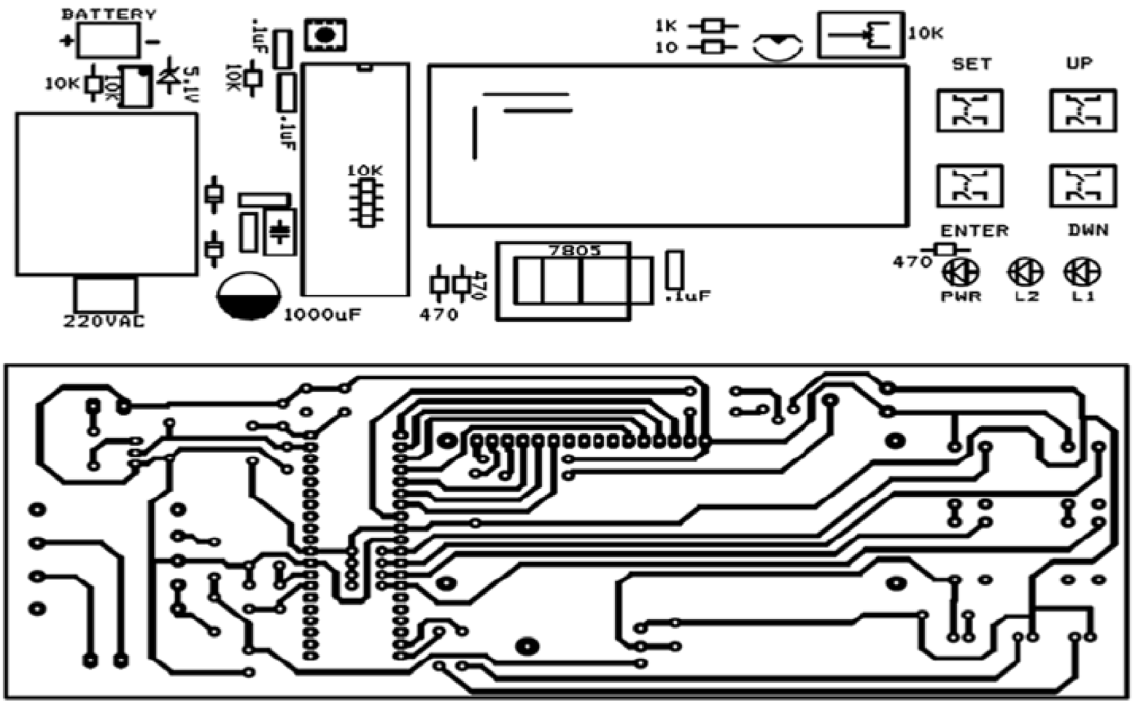

Figure 11. Experimental Hardware

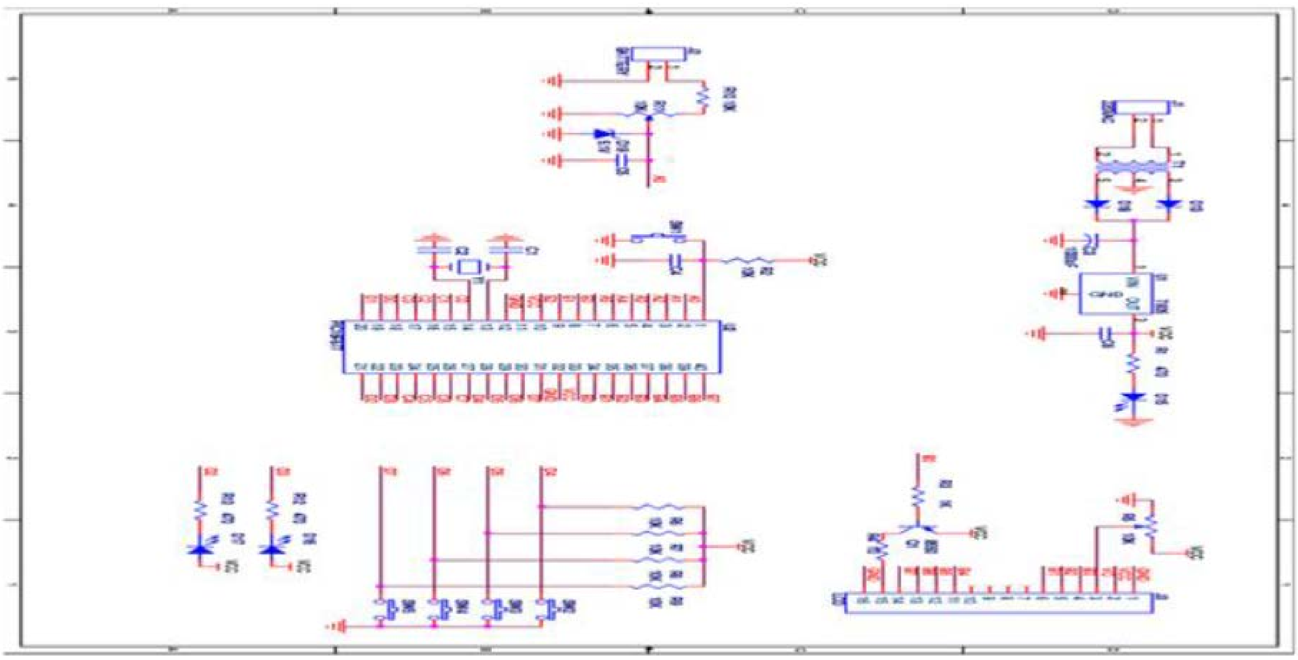

Figure 12. Electrical schematic for experimental setup

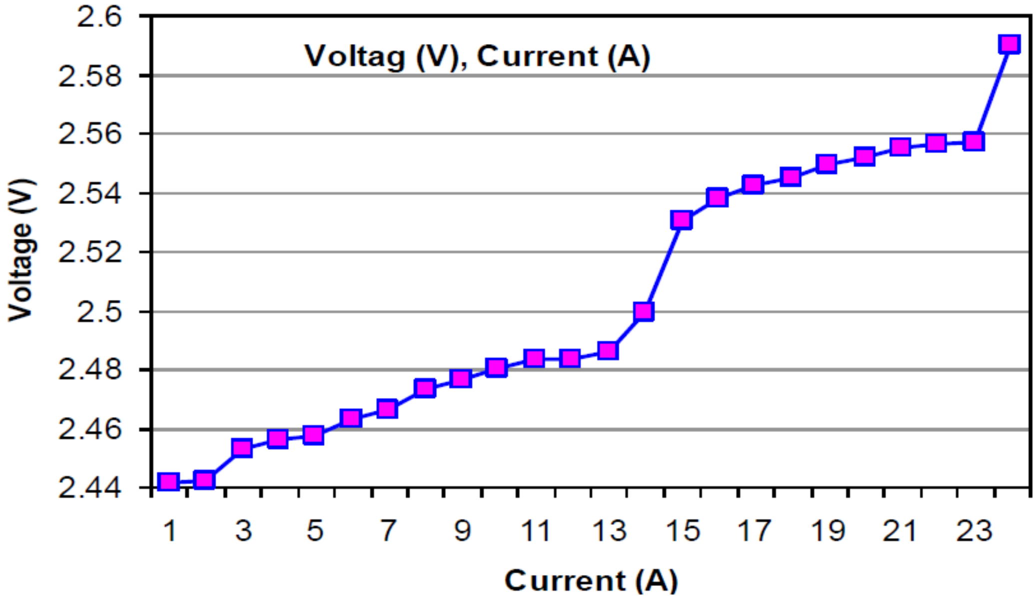

Figure 13. Graph of current Vs Voltage

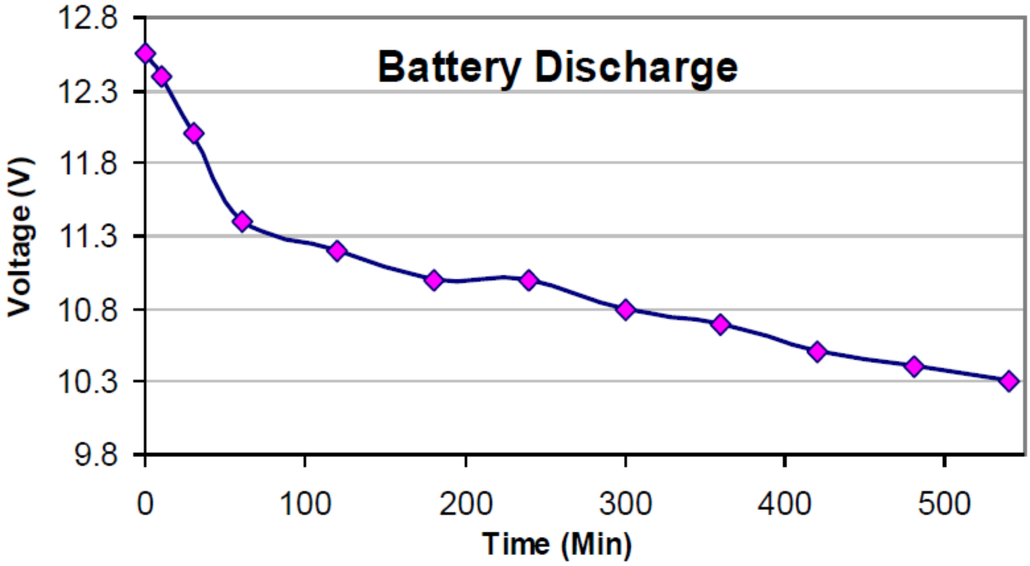

Figure 14. Graph of discharge

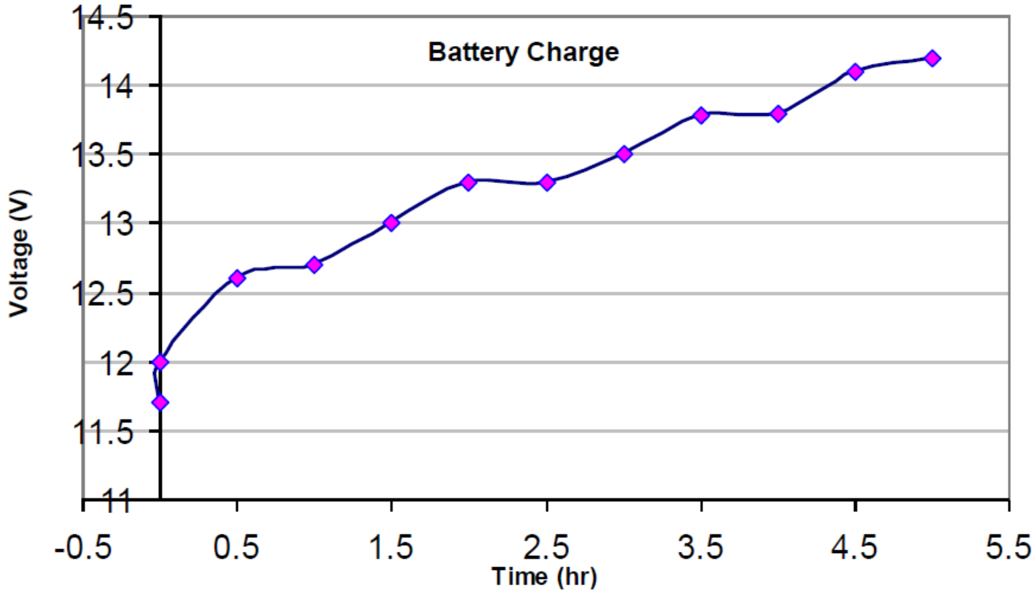

Figure 15. Graph of Charge

We have implemented Battery Monitoring System” which is capable to measure electrolyte temperature, electrolyte level & no. of backup hours given by battery of hybrid vehicle and can record all these parameters with respect to time and display it on LCD as well as on computer as shown in Figure 13, Figure 14 and Figure 15. These figures give graphical representation of important parameters of the battery. This graphical data can be used to know certain parameters of battery like rate of charging, rate of discharging and power corresponding battery volt and battery current drawn by electrical loads. Real time monitoring system provides key information to the user of an electrical car or battery operated systems or electrical power system. In the graphical representation, the graphs are given for ampere hou, state of charge, load current and terminal voltage of the battery.

7. Conclusion

This paper presents a common battery modeling methodology and the results of its application to modeling automotive lead-acid batteries and nickel hydrogen batteries (NiMH) over the range of environmental conditions that it is expected to operate in. The two major portions of this paper, and the biggest contributions, were the experimental methods (excitation currents used) and parameter estimation. Both of these have appeared previously, and were applied successfully to the specific task of automotive battery modeling. The work of this paper presents an incomplete picture of the full process of modeling and fault-diagnosis of these batteries. The modeling cannot be considered complete as it was based only on one battery. A number of improvements could be made to the experimental methodology and analysis techniques presented in this work. We have implemented battery monitoring System” which is capable to measure electrolyte temperature, electrolyte level & no. of backup hours given by battery of hybrid vehicle and can record all these parameters with respect to time and display it on computer. We have tried our level best to make the project as good as possible. The system will help to ensure the efficient working of battery.

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