Artificial Intelligent Techniques for Electric and Hybrid Electric Vehicles

Edited by Chitra A. S. Padmanaban, Jens Bo Holm-Nielsen, S. Himavathi

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Artificial Intelligent Techniques for Electric and Hybrid Electric Vehicles
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An emission-free mobility system is the only way to save the world from the greenhouse effect and other ecological issues. This belief has led to a tremendous growth in the demand for electric vehicles (EV) and hybrid electric vehicles (HEV), which are predicted to have a promising future based on the goals fixed by the European Commission’s Horizon 2020 program. Consequently, progress can be seen as a result of the huge amount of ongoing research currently being conducted in the emerging EV/HEV sector. Hence, the technology needs to be supported by bringing an academic perspective to industrial demands in order to aid the development of proper documentation to direct this progress.

With this goal in mind, this book brings together the research that has been carried out in the EV/HEV sector and the leading role of advanced optimization techniques with artificial intelligence (AI). This is achieved by compiling the findings of various studies in the electrical, electronics, computer, and mechanical domains for the EV/HEV system. In addition to acting as a hub for information on these research findings, this book also addresses the challenges in the EV/HEV sector and provides proven solutions that involve the most promising AI techniques.

Since the commercialization of EVs/HEVs still remains a challenge in industries in terms of performance and cost, these are the two tradeoffs which need to be researched in order to arrive at an optimal solution. Therefore, this book focuses on the convergence of various technologies involved in EVs/HEVs. Since all countries will gradually shift from conventional internal combustion (IC) engine-based vehicles to EVs/HEVs in the near future, it also serves as a useful reliable resource for multidisciplinary researchers and industry teams.

Among the contributors to this book are those from various esteemed national and international institutions; namely, Tanta University, Egypt; NIT Mizoram, NIT Meghalaya and NIT Pondicherry, India; Anna University Chennai, India; Thiagarajar College of Engineering, Madurai, India; and Vellore Institute of Technology, Vellore, India. I would like to
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IoT-Based Battery Management System for Hybrid Electric Vehicle

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Abstract
The basic function of the BMS are to monitoring and control the battery process such as charging and discharging cycle, ensure the healthy condition of the battery, minimizing the risk of battery damaging by ensuring optimized energy is being delivered from the battery to power the vehicle. The use of monitoring circuit in BMS will monitor the key parameters of the battery like voltage, current, temperature during both charging and discharging situation. It estimates the power, State of Charge (SoC), State of Health (SoH) and ensures the healthiness based on the measurement. Balancing the cell is one of the important features of the BMS system. It will monitor the individual cells/group of cells connected in parallel and balancing the cells online. It also conducts the diagnostics of the battery to ensure the safe operation. If, BMS identified any one cell is weak, it will give intimation or alarm for cell replacement. It also provides the protection against overcharging, undercharging, overcurrent, under voltage, short circuit and temperature variations (low and high temperature). In recent years, Internet of Things (IoT) plays a major role in monitoring and control, also it enables the remote data logging facility for battery parameters, conditions, etc.

Keywords: Electric vehicles, hybrid electric vehicles, batteries, internet of things, battery management system, Li-ion batteries, SoC, SoH

1.1 Introduction
Lithium-Ion batteries are widely used in Electric Vehicle (EV) and Hybrid Electric Vehicles (HEV) due to its various advantages over other types of
batteries. It has the unique feature which requires a Battery Management System (BMS) to actively monitor its parameters and also to ensure the reliable, control and safe operation of battery during their charging/discharging cycle [1, 16].

The basic function of the BMS is to monitor and control the battery process such as charging and discharging cycles, ensure the health condition of the battery, minimizing the risk of battery damaging by ensuring optimized energy is being delivered from the battery to power the vehicle. The monitoring circuit in BMS is used to monitor the key parameters of the battery like voltage, current, temperature at both charging and discharging situations in order to ensure the safe operation. It estimates the power, SoC, SoH and ensures the healthiness based on the measurement [17]. The typical two-wheeler battery SoC status indication is shown in Figure 1.1.

It also monitors the EV and HEV ancillary systems like charger operations, protection and safety devices (fuses and circuit breakers), thermal management, etc. Balancing the cell is one of the important features of the BMS system. It will monitor the individual cells and/or group of cells connected in parallel and balancing the cells online. The diagnostics of the battery is conducted to ensure the safe operation. If BMS identified any one cell is weak, then it will give intimation or alarm for cell replacement. It will also provide the protection against overcharging, undercharging, overcurrent, under voltage, short circuit and temperature variations (both low and high temperatures) [20, 21], i.e. it will provide the signals to protection devices if any

---

**Figure 1.1** Typical-two wheeler SoC status indication.
parameter monitoring value exceeds the pre-set value or threshold value and will give the notification alarm [3, 4, 15]. It will control the charging, power down, power up and it communicates all the parameters to the vehicle [2].

The BMS acts as the interface with other systems of the vehicle like vehicle controller, motor controller, safety system, communication system and climate controller [5, 6]. The two or more numbers of battery strings are connected in parallel to a common DC bus. The BMS shall aggregate the string monitored data and communicate it with the main host system (vehicle master control system) [7, 8]. In recent years, Internet of Things (IoT) plays a major role in monitoring and control of the equipment for reliable and safe operation. IoT also enables the remote data logging facility for battery parameters, battery conditions, etc. [10, 16, 17].

This chapter explains the concept of IoT-based battery management system for EV and HEV.

### 1.2 Battery Configurations

The battery packs are designed to deliver the higher voltage, higher current or both. The number of cells to be connected in series and number of cells to be connected in parallel is based on the voltage and current requirements to powering the electric motor in the vehicle [13]. The multiple individual cells are connected in series for higher voltage requirement. The battery pack voltage is the product of number of cells connected in series and cell voltage. The typical name plate details of Li-Ion cell are listed in Table 1.1.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specifications</th>
<th>Value</th>
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<tr>
<td>1</td>
<td>Nominal voltage (V)</td>
<td>3.7</td>
</tr>
<tr>
<td>2</td>
<td>Maximum charge voltage (V)</td>
<td>4.2</td>
</tr>
<tr>
<td>3</td>
<td>Nominal capacity (mAh)</td>
<td>3,200</td>
</tr>
<tr>
<td>4</td>
<td>Maximum charge current (mA)</td>
<td>3,100</td>
</tr>
<tr>
<td>5</td>
<td>Maximum charge current C rating</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Standard discharge current (mA)</td>
<td>620</td>
</tr>
<tr>
<td>7</td>
<td>Standard discharge current C rating</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>Maximum discharge current (A)</td>
<td>10</td>
</tr>
</tbody>
</table>
The expression for voltage of the battery pack is given in Equation 1.1.

\[ V_{\text{battery pack}} = N_s \times V_{\text{cell}} \quad (1.1) \]

Where

- \( V_{\text{battery pack}} \) is voltage of the battery pack
- \( N_s \) is number of cell connected in series
- \( V_{\text{cell}} \) is cell voltage

Example 1: Calculate the battery pack voltage for 3.7 V, 3,100 mAh, 40 numbers of series connected cells.

The cell voltage is 3.7 V.
No. of cells is 40.
Applying the number of cells and cell voltage in Equation 1.1, the battery pack voltage is 148 V.

The series connection of individual cells is called as Series Cell Modules (SCM) and is shown in Figure 1.2.

For higher current requirement multiple individual cells are connected in parallel. The battery pack current is the product of number of cells connected in parallel and cell current. The expression for current of the battery pack is given in Equation 1.2.

\[ I_{\text{battery pack}} = N_p \times I_{\text{cell}} \quad (1.2) \]

Where

- \( I_{\text{battery pack}} \) is current of the battery pack
- \( N_p \) is number of cell connected in parallel
- \( I_{\text{cell}} \) is cell current

Figure 1.2 Series cell connection.
Example 2: Calculate the battery pack voltage for 3.7 V, 3,100 mA, 10 numbers of parallel connected cells.

The cell current is 3,100 mA.
No. of cells is 10.

Applying the number of cells and cell current in Equation 1.2, the battery pack current is 31,000 mA or 31 A.

The parallel connection of individual cells is called as Parallel Cell Modules (PCM) is shown in Figure 1.3.

The series and parallel connection of multiple number of cells is used to achieve the desired voltage and/or current. For an example, 2P5S module has the total number of 10 cells with 2 cells in parallel and 5 cells in series. Figure 1.4 shows the series and parallel configuration of 2P5S module.

1.3 Types of Batteries for HEV and EV

The types of battery has to be chosen by considering technical requirements such as power and energy requirements, commercials involved in it [18, 19]. The different types of batteries for HEV and EV are listed below
AI Techniques for Electric and Hybrid Electric Vehicles

1. Energy battery
2. Power battery
3. Hybrid battery
   - The energy battery is low C rating and economical.
   - The power battery is higher C rating and expensive.
   - Hybrid battery is a combination of small power battery with active or passive coupling, energy battery with ultra-capacitor.

The important parameters of battery pack selection for HEV are

1. Energy (kWh)
2. Continuous discharge power (kW)
3. Peak discharge power (kW)
4. Continuous charge power (kW)
5. Peak charge power (kW)
6. Storage and ambient temperature
7. No. of charging and discharging cycle
8. Cooling requirements
9. Weight (kg) Safety
10. Disposal/Recycling procedures
11. Mounting direction
12. Dimensions

1.4 Functional Blocks of BMS

The basic function of the BMS is to monitor and control the battery process such as charging and discharging, ensure the health condition of the battery and minimizing the risk of battery from damage. BMS also ensure the optimized energy from the battery is being delivered to power the vehicle.

The monitoring circuit in BMS is used to monitor the key parameters of the battery during both charging and discharging conditions such as

- Voltage
- Current
- Power
- Cell temperature
- Ambient temperature

It estimates the State of Charge (SoC) and Depth of Discharge (DoD) of the battery based on the measurements.
1.4.1 Components of BMS System

The following components are minimum essential for BMS system:

1. Voltage sensor
2. Current sensor
3. Cell temperature sensor
4. Ambient temperature sensor
5. Interface circuits to communicate with vehicle controller
6. Interface circuit to communicate with remote device

A. Voltage Sensor
The battery State of Charge (SoC) and State of Health (SoH) depends on cell voltage. The accuracy of cell voltage measurement plays a major role in estimation of battery SoC and SoH in travel. Inaccurate measurement of every milli voltage has an impact in battery SoC and SoH in travel. The selected/used voltage sensor shall have the better accuracy in cell voltage measurements during charging and discharging time period.

B. Current Sensor
The current sensors are used to measure the current flowing in the circuit i.e., current flow from the charger to battery during the battery charging and current flow from the battery to vehicle electric motor during the discharging. Current measurement of the battery pack is required to ensure the safety during the operation, to log abuse conditions and estimate SoC and SoH. The product of voltage and current is used to find the charging and discharging power in and out to the battery.

The measurement of current by using current sensors is done by two methods which are discussed below:

1. Shunt method
2. Hall effect sensor.

In shunt method, a shunt sensor (high precision resistor) of lower value in milli Ohm is connected in series with battery pack to measure the current flow. The current flow in the circuit is calculated as per Ohms law and given in Equation 1.3.

\[ I = \frac{V_{\text{shunt}}}{R_{\text{shunt}}} \]  

(1.3)
Where

\[ I \text{ is current flow in A} \]
\[ V_{\text{shunt}} \text{ is voltage drop (V) in shunt} \]
\[ R_{\text{shunt}} \text{ is shunt resistance in } \Omega \]

The typical block diagram showing the measurement of current using shunt is represented in Figure 1.5.

The disadvantages of using shunt sensor for current measurement introduced losses and it generates heat during their entire operation. Heat has to be dissipated properly without affecting the other equipment’s performance. The resistance of shunt sensor changing with respect to temperature changes. Shunt resistance has to be calibrated with temperature.

Hall effect sensors or Hall sensors are used to measure the current flow in the circuit by measuring the magnetic field generated by current flowing in a circuit or wire.

The typical block diagram of measurement of current by using hall sensor is shown in Figure 1.6.

**Figure 1.5** Measurement of current by using shunt sensor.

**Figure 1.6** Measurement of current by using hall sensor.
C. Cell Temperature Sensor
The battery pack characteristics and degradations during operation are affected by temperature. Sometimes changes in temperature is leading to cell failure. The cell temperature is measured by cell temperature sensor installed in top of the cell. The BMS is measuring the actual temperature on the cell during the charging and discharging time through this cell temperature sensor. The accuracy of the measurement is important in order to find the healthiness of the battery.

D. Ambient Temperature Sensor
The BMS is measuring the actual ambient temperature during the charging and discharging through ambient temperature sensor installed in the battery stack.

E. Interface Circuits to Communicate With Vehicle Controller
All the measured and estimated parameters by BMS like SoC, SoH, power, temperature, etc., are communicated to vehicle controller for user information. Interface circuits are used between the BMS and vehicle controller to transfer the data. From the vehicle display the users understand the SoC, SoH, expected km of driving, nearest charging station through GPS, problems like over temperature in cell, battery under voltage, etc.

F. Interface Circuits to Communicate With Remote Device
This interface circuit enables the monitoring of vehicle parameters such as SoC, SoH, power, battery voltage, cell temperature, etc., from remote location. Various advantages are there for monitoring these parameters in remote devices like storing the history of the vehicle performance, tracking of vehicle location, etc.

G. State of Charge
This State of Charge (SoC) is expressed as the ratio of amount of battery left at measurement time to amount of energy of the battery when it was new. The expression for SoC is given in Equation 1.4.

\[
\text{SoC} = \frac{\text{Amount of energy left at measurement time in the battery}}{\text{Amount of energy of the battery when it was new}} = \frac{\text{Battery residual AH}}{\text{Battery nominal AH capacity}}
\]  

\[(1.4)\]
The SoC of the battery is estimated based on voltage and Coulomb counting. The SoC, determines the usable capacity that is available for the usage and estimate the vehicle mileage.

H. Depth of Discharge
The Depth of Discharge (DoD) of the battery is defined on the amount of capacity that is discharged from its overall capacity [23, 24]. It also indirectly says the SoC of the battery after the discharge. The DoD is the ratio of discharged energy from the battery to overall energy capacity of the battery. The expression for DoD is given in Equation 1.5.

\[
\text{DoD} = \frac{\text{Discharged energy from the battery (kWh)}}{\text{Overall energy capacity of the battery (kWh)}}
\] (1.5)

Example 1: The battery pack overall capacity is 25 kWh of electric energy and 20 kWh energy is discharged. The DoD is 80%. It means, 80% of 25 kWh energy is discharged and 20% of 25kWh energy is available in the battery.

Example 2: The battery pack overall capacity is 50 AH and battery manufacturer recommending 80% of DoD. What capacity of energy is available to discharge while considering the 80% DoD.

Answer: The energy availability for discharge by considering 80% DoD is calculated from Equation 1.6.

\[
\left(\frac{\text{Energy availability}}{\text{from the battery (AH)}}\right) = \left(\frac{\text{Overall energy capacity}}{\text{of the battery (AH)}}\right) \times \text{DoD}
\]

\[
= 50 \times 80\% 
\] (1.6)

Energy availability from the battery (Ah) = 40

The life of the battery depends on charging and discharging cycle of the battery and battery discharge capacity.

I. Cell Diagnostics
During the vehicle operation, any of following things can go wrong and shall lead to performance degradation or failure of equipment:
• Cell over temperature
• Higher current leakage
• Under voltage or over voltage.

The individual cell temperature may exceed the pre-set value during the vehicle operation. In series configurations, voltage variations are widely encountered and in parallel configurations, the leakage current problems are widely encountered. Sometimes these will lead to catastrophic failure of the equipment.

J. Cell Balancing
Li-Ion batteries should not be overcharged for safe operation because overcharging the Li-Ion batteries affects its internal materials. The BMS is monitoring the battery pack voltage actively and cuts off the charger once any one cell reached the threshold value even others cells are not fully charged. Whenever cells are connected in parallel tend to self-balance all the cells that are connected in parallel, i.e., voltage in overcharged cells are balancing the undercharged cells results in self balancing. This cells balancing are classified into two types.

1. Passive cell balancing approach
2. Active cell balancing approach

The passive cell balancing is achieved by depletion of overcharged cells to make the cell Ah capacities to be equal.

The active cell balancing is achieved by diverting the overcharged cells to lesser charged cells to make the cell Ah capacities to be equal.

K. Thermal Management for Battery Pack
The performance of the battery pack is depends on temperature and change in temperature affects the vehicle mileage [22]. The typical operating temperature of the battery pack during on board of the vehicle is 5 to 40°C. If the temperature is high then battery performance is reduced and the temperature is low then battery performance is increased.

1.5 IoT-Based Battery Monitoring System
In general, IoT is a mediator or medium of communication between the various sensors (hardware) and application (software). The important task of IoT is to collect the data from the various hardware using different protocols,
remote location device configuration and its control [9, 11, 12, 14]. The general block diagram of IoT-based system architecture is shown in Figure 1.7.

The voltage sensor, current sensor and temperature sensors are used to measure the battery parameters such as voltage, current, cell temperature and ambient temperature respectively used in the battery management system. The measured parameters are used to estimate the power flow, SoC, SoH, Depth of Discharge (DoD), etc., and communicate to vehicle master controller locally.