System Level Simulation Technique for Optimizing Battery Thermal Management System of EV

18/02/2020

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Explains how 1D simulation is used in automotive industry.

Overview of Battery Cooling Circuit
Explains how a generic battery cooling/heating system works.

Modeling of Battery Thermal Management System of EV
Explains how a physical system modelling tool Matlab/Simulink/Simscape is used for battery thermal modeling

Model Validation
1D model results are compared with test data from vehicle thermal trials and validated

Logic Development and Results
Testing of different thermal logics
Uses of 1D Simulation

01
Component Selection
In an early stage of the development cycle, 1D system level simulation can be used for dimensioning or to test different designs.

02
Logic Development
1D models can be used for developing control logics and to improve algorithms.

03
Controller Testing
1D system level simulation is used to test controllers connected to the simulated system instead of the real one (HIL testing).

04
System Optimization
1D simulation can be used to quickly evaluate the effect of component change.
Generic Battery Cooling/Heating Circuit
Battery

- Battery temperature needs to be maintained between 25°C and 45°C.
- $I^2r$ losses will generate heat inside the battery during charging and discharging.
When the battery temperature crosses 30°C, refrigeration system is turned ON, which will cool down the coolant.
If battery temperature drops below 10°C, heater is used to heat the coolant.
Compartment Cooling

- Refrigerant Circuit is shared by battery as well as HVAC system of the vehicle
Battery Thermal Management Functions are handled by BMS ECU

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Battery cooling/heating circuit

**Input to BMS**
- Battery temperature sensor values
- Coolant temperature sensor values
- Heater temperature sensor values
Output from BMS

- Coolant Pump Speed
- Heater On/Off request
- Heater power Required (Watts)
- Chiller On/Off Request
- Chiller power required (Watts)
1D BATTERY THERMAL MODELING

Cell Level

Module Level

Pack Level

System Level
Compressor Power = $m(h_2 - h_1)$
Cooling Power = $m(h_1 - h_4)$
COP = $\frac{h_1 - h_4}{h_2 - h_1}$

$m$ – Refrigerant mass flow rate
Simulink Vehicle Model

- Vehicle Model will predict the instantaneous power demanded from the battery for different drive cycles.
- Drive cycles under consideration: MIDC, MIDC Part1, NEDC, WLTP
- Traction Force is calculated by considering Rolling resistance, Gradient resistance, Inertia resistance and Aerodynamic resistance.
- Motor shaft torque depends on vehicle torque, gear ratio as well as transmission efficiency.
Second order equivalent circuit model

\[
\begin{align*}
\nu_{oc}[k] &= \nu_t[k] + i_t[k] \times R_0[k] + \nu_{c1}[k] + \nu_{c2}[k] \quad \ldots \ldots \quad (1) \\
\nu_{c1}[k] &= \nu_{c1}[k-1] \times e^{-\frac{\Delta t}{\tau_{u1}[k]}} - i_t[k] \times R_1[k] \times \left(1 - e^{-\frac{\Delta t}{\tau_{u1}[k]}}\right) \quad \ldots \ldots \quad (2) \\
\nu_{c2}[k] &= \nu_{c2}[k-1] \times e^{-\frac{\Delta t}{\tau_{u2}[k]}} - i_t[k] \times R_2[k] \times \left(1 - e^{-\frac{\Delta t}{\tau_{u2}[k]}}\right) \quad \ldots \ldots \quad (3)
\end{align*}
\]

**Acronym** | **Meaning**
--- | ---
\(\nu_t\) | Terminal voltage
\(i_t\) | Battery current
\(\nu_{c1}\) | Voltage across capacitor C1
\(\nu_{c2}\) | Voltage across capacitor C2
\(k\) | Time instants

The ease of parametrization and implementation makes it the most widely employed model for real-time battery management applications.

Model Validation
COMPARING TEST AND SIMULATED COOLANT INLET TEMPERATURE

Mean Absolute Percentage Error = 0.70%
COMPARING TEST AND SIMULATED BATTERY MODULE TEMPERATURE – MODULE NO:13

Mean Absolute Percentage Error
Bottom Temperature = 0.68%
Top Temperature = 0.86%
Logic Development and Results
COMPRESSOR ON-OFF LOGIC

Current Compressor Logic

- Compressor cut off logic in the old algorithm was only based on battery temperature
- When the battery temperature reduces to a set value, compressor will cut off

Proposed Compressor Logic

- New compressor operation logic will consider both battery temperature as well as coolant temperature for compressor ON/OFF.
- Once the coolant temperature drops to the set temperature or the battery temperature drops below the set value, compressor will turn OFF
- It will turn back ON again only if the battery temperature is still above the set value and the coolant temperature rises by 3°C

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Charging C rate</td>
<td>1C, 0.3C</td>
</tr>
<tr>
<td>2.</td>
<td>Ambient Temperature</td>
<td>41°C</td>
</tr>
<tr>
<td>3.</td>
<td>Battery Initial Temperature</td>
<td>41°C</td>
</tr>
<tr>
<td>4.</td>
<td>Coolant Initial Temperature</td>
<td>41°C</td>
</tr>
</tbody>
</table>
RESULTS & INFERENCE

Simulation Results 0.3C Charging

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Battery Final Temperature</th>
<th>Energy Consumed by Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Algorithm</td>
<td>34.22°C</td>
<td>1.321 kWh</td>
</tr>
<tr>
<td>New Algorithm</td>
<td>35.76°C</td>
<td>0.832 kWh</td>
</tr>
</tbody>
</table>

Simulation Results 1C Charging

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<thead>
<tr>
<th>Algorithm</th>
<th>Battery Final Temperature</th>
<th>Energy Consumed by Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Algorithm</td>
<td>43.71°C</td>
<td>1.84 kWh</td>
</tr>
<tr>
<td>New Algorithm</td>
<td>44.21°C</td>
<td>0.928 kWh</td>
</tr>
</tbody>
</table>

Inference

Battery final temperature is slightly more with new algorithm but the energy consumed by compressor reduces. In 0.3C charging, battery final temperature is 1.5°C more with the new algorithm but power consumed by compressor is ~37% less. In 1C charging, battery final temperature is 0.5°C more with the new algorithm, but power consumed is ~50% less.
Thank You