Circuit Protection on High Reliability Electric Vehicles (EVs)

International Forum on Innovation and Development of Electric Vehicle Electronica Shanghai
14 March 2017
Agenda

- Market for EV / HEV Vehicles
- EV / PHEV Architecture
- EV Sensing Line Protection vs. BMS and Battery Pack Architecture
- Battery Management System and Protection Devices Summary
- EV Charger System (On-Board and Off-Board Charger)
- IGBT/MOSFET Protection
- Summary and Conclusion
The Market for EV / HEV Vehicles
Growth Drivers and Types of EVs

- Market for vehicles with any form of higher voltage (>12 or 24V) electric system is expected to show CAGR of ~15% to ~30% until 2020.

  In addition to the growing number of BEV, PHEV and HEV cars, the new 48V Mild Hybrid or Eco Drive systems will significantly contribute to the growth.

- Key driver is the demand for improved air quality by lower or zero emissions, requiring better efficiency of cars.

  Additional driver is the growing number of electric loads in vehicles, requiring higher voltages and more powerful electric systems.

Source: Navigant Research 2013
Source: CONTINENTAL AG 2013
EV / PHEV Architecture
Main Building Blocks
EV Sensing Line Protection
Increased EV Battery Safety Requirements
Sensing and Balancing Lines

**FMVSS 305**

Described:
Retention of propulsion battery protection during a crash

Added:
Electrical isolation of the chassis from the high-voltage system

**ASIL C or D**
Automotive Safety integrity level

Protection for the signal line harness

**ISO26262**
Functional safety for automotive electronics and electrical safety-related systems

*OC/OV Protection*
BMS “Decentralized Architecture” with High and Medium Voltage Fuses

Module N

~4V

32Vdc to 125Vdc or higher

Long wires interconnecting cells and slave board
⇒ High likelihood to get short circuit under high voltage in case of crash event inside module but also between modules

Littelfuse Solution
⇒ Fuse in wire: 275A/251A Series Pico Fuse /477A Series Cartridge fuse
⇒ SMD Fuse: 477A Series

Battery Pack Voltage

IC Sense/Balancing line “Slave”

CPU “Master”
BMS “Centralized Architecture” with Low Voltage SMD Fuse

Short distance between cells and slave board
⇒ Low likelihood to get short circuit under high voltage in case of crash event. However, short circuit on slave board might occur inside the module due to component failure mechanism (capacitor, resistor … )

Littelfuse Solution
⇒ SMD Fuse: 437A /440A Series
**Littelfuse Sensing Line**  
Auto grade overcurrent protection based on AEC-Q200 standard

### Suitable for Passive and Active Balancing

<table>
<thead>
<tr>
<th>Series</th>
<th>Technology</th>
<th>Form Factor</th>
<th>Package</th>
<th>Breaking capacity</th>
<th>Voltage Rating</th>
<th>Current rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>437A 440A</td>
<td>TFF</td>
<td>1206</td>
<td>SMD</td>
<td>50A</td>
<td>32Vdc – 63Vdc</td>
<td>2A – 8A</td>
</tr>
<tr>
<td>477A</td>
<td>Cartridge</td>
<td>5x 20</td>
<td>SMD</td>
<td>400A-1500A</td>
<td>400Vdc</td>
<td>2A-20A</td>
</tr>
<tr>
<td>477A</td>
<td>Cartridge</td>
<td>5x20</td>
<td>Fuse in cable</td>
<td>400A – 1500A</td>
<td>400Vdc</td>
<td>2A-20A</td>
</tr>
<tr>
<td>251 *</td>
<td>Pico Fuse</td>
<td>7,11x 2,8mm</td>
<td>Fuse in cable</td>
<td>300A</td>
<td>125Vdc</td>
<td>2A-10A</td>
</tr>
</tbody>
</table>

* AEC-Q200 pending for Pico 251 Series and released in March 2017 for 477A Series.
Sensing and Balancing Lines
Voltage rating vs. size and breaking capacity

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Size</th>
<th>Breaking Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>63Vdc</td>
<td>1206</td>
<td>5x 20mm SMD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5x 20mm in line leaded fuse</td>
</tr>
<tr>
<td>125Vdc</td>
<td>2,8 x 7,1mm in line leaded fuse</td>
<td>Suitable for Passive and Active Balancing</td>
</tr>
<tr>
<td>400Vdc</td>
<td>5x 20mm in line leaded fuse</td>
<td></td>
</tr>
</tbody>
</table>

* AEC-Q200 pending for Pico 251 Series
BMS
Protection Devices
Summary
Battery Management System and Protection Devices

- 440A/437A Series
- 251 Pico or 477A Cartridge Series
- TPSMA6L/SD05
- SPHV_C Series
- TPSB Series
- SM24CAN Series
- HC HEV fuses
Battery Management System and Protection Devices
Littelfuse Protection Portfolio

1. Sense Line Fuse Options*
   437A 440A Series (SMD)
   477A Series in line with harness or SMD
   * 251 Pico Fuse Series (in line)

2. Cell Monitor IC Input
   OV Protection
   477A Series in line with harness or SMD

3. High Voltage TVS Transient Protection
   OV / ESD Protection
   SP3030 Series
   TPSMx Series
   SP4021 Series
   SM24CAN Series
   SPHV_C Series

4. Output / ESD Protection
   for Daisy Chain I/F
   450Vdc/~40A- 275Vac/50A
   500Vdc/~125A
   450Vdc/~40A- 275Vac/50A
   500Vdc/~125A
   700Vdc/~250A
   L50QS
   L70QS
   ISO 8820 compliant

5. OV / ESD Protection
   for CAN Bus I/F
   L50QS
   L70QS
   ISO 8820 compliant

6. High Voltage / Current Power Line Fuses
   450Vdc/~40A- 275Vac/50A
   500Vdc/~125A
   700Vdc/~250A

*AEC-Q101 compliant

* Sense Line Fuses:
  Sense Line Short Circuit Protection with electronic fuses can have very different requirements and not all fuses might be suitable. Littelfuse offers a variety of special tested electronic fuses for sense line applications. Please contact your Littelfuse sales or FAE for more details.

* 251 Pico Fuse Series (in line)

* Pending

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# High Voltage Battery System
## Littelfuse Protection Portfolio – Selection Criteria

<table>
<thead>
<tr>
<th></th>
<th>Sense Line Fuse</th>
<th>Cell Monitor IC Input OV Protection</th>
<th>OV / ESD Protection for Daisy Chain</th>
<th>High Voltage TVS Transient Protection</th>
<th>OV / ESD Protection for CAN Bus I/F</th>
<th>High Voltage / Current Power Line Fuses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Voltage range depends on battery configuration, same for interrupt rating</td>
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<td>Voltage range depends on battery configuration</td>
<td>Voltage range depends on battery configuration</td>
<td>Typical operating voltage of CAN Bus protectors is 24V</td>
<td>Operating voltage up to 1000VDC</td>
</tr>
<tr>
<td></td>
<td>High temperature range &gt;105°C</td>
<td>Low leakage current</td>
<td>Low leakage current</td>
<td>Low leakage current</td>
<td>Power rating between 200W to 500W</td>
<td>Low current fuse ratings 10A to 30A, 40A (420/450Vdc VDC)</td>
</tr>
<tr>
<td></td>
<td>Fuse should have a low temperature de-rating</td>
<td>Low capacitance is desirable</td>
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<td>Low capacitance is desirable</td>
<td>ESD Contact Capability of 30kV recommended</td>
<td>Medium current ratings 60A to 125A</td>
</tr>
<tr>
<td></td>
<td>Low tolerance of cold resistance as well as long term stability is required</td>
<td>Low leakage current</td>
<td>Low leakage current</td>
<td>Low leakage current</td>
<td>Low capacitance between 11 to 30pF</td>
<td>High current ratings 150A to 250A</td>
</tr>
<tr>
<td></td>
<td>Fuse should be able to cope with temperature cycles and vibrations</td>
<td>Silicon Diode Arrays provide fastest protection and lowest clamp voltages</td>
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<td>Silicon Diode Arrays provide fastest protection and lowest clamp voltages</td>
<td>AEC-Q101 qualified</td>
<td>Form Factors 10x38, 42x20, 52x30</td>
</tr>
<tr>
<td></td>
<td>Small Form factor for centralized architecture</td>
<td>Small Form factors of 0402 to 0603</td>
<td>Small Form factors of 0402 to 0603</td>
<td>Small Form factors of 0402 to 0603</td>
<td>AEC-Q101 qualified</td>
<td>High Interrupt Rating of 10kA</td>
</tr>
<tr>
<td></td>
<td>Ideally fulfills AEC-Q test conditions</td>
<td>Power Capability several 10 to several 100W (8/20µs)</td>
<td>Power Capability several 10 to several 100W (8/20µs)</td>
<td>Power Capability several 10 to several 100W (8/20µs)</td>
<td>LF offers 600W up to 3000W Diodes</td>
<td>Various mounting options: board mount, bolt down, blade, inline cable</td>
</tr>
<tr>
<td></td>
<td>LF recommended: 440A Series, 437A Series, 477A Series, Pico 251 Series *)</td>
<td>AEC-Q101 qualified</td>
<td>AEC-Q101 qualified</td>
<td>AEC-Q101 qualified</td>
<td>LF offers 600W up to 3000W Diodes</td>
<td>LF recommended: 0HEV/L50QS and L70QS Series (available) Medium / High Current Versions under development</td>
</tr>
<tr>
<td></td>
<td>Package: SMD, in line, Radial leaded</td>
<td>LF recommended: TPSMA6L, TPSMB with stand off voltage range up to 550V</td>
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<td>LF recommended: TPSMA6L, TPSMB with stand off voltage range up to 550V</td>
<td>LF recommended: SM24CANA, SM24CANB, SPHV-C Series</td>
</tr>
</tbody>
</table>

### *Sense Line Fuses:*
*Sense Line Short Circuit Protection with electronic fuses can have very different requirements and not all fuses might be suitable. Littelfuse offers a variety of special tested electronic fuses for sense line applications. Please contact your Littelfuse sales or FAE for more details*
EV Chargers Protection
EV Chargers and WW Standards

Littelfuse experts provide guidance and support customers’ designs in accordance with worldwide automotive safety standards.
EVSE to the Grid

- **AC Charging (Slow charge):**
  - Level 1: 120V, Single phase 2kW and below
    - Typically takes 8-12 hours to charge fully depleted battery
  - Level 2: 208-250V, Single phase (3.3kW ~20kW)
    - Requires a 40A circuit; takes 4-6 hours typically to charge up fully depleted battery
  - Level 3: 380V~440V, 3-phase (~20kW)
    - Requires a 30A circuit; takes 4-6 hours typically to charge up fully depleted battery

- **DC Charging: (Quick charge)**
  - INPUT: 480VAC, 3-phase
  - OUTPUT: 500VDC~1000VDC, 80A~250A, 100kW +
  - Typically provides 80% charge within 30 minutes
On-Board vs. Off-Board Charger

<table>
<thead>
<tr>
<th>On-Board Charger</th>
<th>Off-Board Charger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery charge is managed by BMS</td>
<td>High power transfer</td>
</tr>
<tr>
<td>Low power transfer</td>
<td>More complex BMS to ensure battery thermal management</td>
</tr>
<tr>
<td>Less concern on Battery thermal management</td>
<td>Removes weight from vehicle</td>
</tr>
<tr>
<td>Adds weight to vehicle</td>
<td>Fast charge</td>
</tr>
<tr>
<td>Slow charge</td>
<td></td>
</tr>
</tbody>
</table>

AC/AC Charging Station

AC/DC Converter

AC/DC Charging Station

~2kW ~7,7kW ~20kW ~100kW
AC Charger Level – On-Board (Single-Phase)

120Vac/220Vac 500Vdc

Overvoltage:
Varistor: AUMOV Series (AEC-Q200 March 2017), GDT: CG3 Series

Overcurrent:
0HEV (ISO8820-1), 525A Series*

* AEC-Q200 pending. Please contact your Littelfuse sales or FAE for more details.
AC Charger Level – On-Board (3 phase)

Overvoltage:
Varistor: AUMOV Series (AEC-Q200 March 2017), GDT: CG3 Series

Overcurrent:
0HEV (ISO8820-1), 525A Series*

* AEC-Q200 pending. Please contact your Littelfuse sales or FAE for more details.
**DC Charger – Off-Board (~ 100kW + / 3 Phases)**

Single 1x 100kW and modular structure 4x 25kW

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**Input Voltage**

P1

P2

P3

N

PE

**380Vac -480Vac**

**Output Voltage**

500Vdc

700Vdc

**OC/OV**

**Overvoltage:**

MOV: AUMOV Series (AEC-Q200 March 2017) and TMOV, GDT: CG3 Series

**Overcurrent:**

Charger with Monolithic structure: L50QS and L70QS Series

Charger with Modular structure: 504 Series, 505 Series

Please contact your Littelfuse sales or FAE for more details.
IGBT/MOSFET Protection
DC/DC Converter Protection

Single TVS or Stack of TVSs for IGBT active clamping voltage feature

Overvoltage:
TVS: TPSMx Series (AEC-Q101 qualified)
Please contact your Littelfuse sales or FAE for more details.
IGBT/ MOSFET Driver Protection

Input Logic: Diode Array SPx Series (AEC-Q101 qualified)
Power Supply: MLA & AUML Series (AEC-Q200 qualified), TVS TPSMx Series (AEC-Q101 qualified)
Gate Protection, Negative bias voltage: TVS TPSMx Series (AEC-Q101 qualified)
High Voltage EV Charger Littelfuse Protection Portfolio

Overcurrent Protection

- **L50HS Series**
  - 500Vdc/Vac ~800A
  - 700Vdc/Vac ~800A

- **L70HS Series**
  - 500Vdc/Vac ~800A

- **504A Series**
  - 500Vac/420Vdc ~ 30A

- **505A Series**
  - 500Vac/500Vdc ~ 30A

**Off-Board Charger**

- **L50QSM Series**
  - Medium Current
  - 500Vdc/125A

- **L70QS Series**
  - High Current
  - 700Vdc/250A

**On-Board Charger**

- **0HEV Series**
  - Low Current
  - 450Vdc/40A- 275Vac/50A

- **525A Series**
  - 450Vdc ~ 30A

- **L70Q Series**
  - 500Vac ~ 30A

**ISO 8820 compliant**

- **AEC-Q pending**

*Please contact your Littelfuse sales or FAE for more details.

Overvoltage Protection

- **ESD**
  - SP Series
  - SM24CAN Series

- **Varistor**
  - AUMOV Series
  - TMOV Series*

- **TVS**
  - TPSMxx Series

- **MLV**
  - AUML Series

- **AEC-Q101 qualified**

- **AEC-Q200**
  - (March 2017)

- **AEC-Q200 qualified**

*Only Off-Board Charger

*GDT

CG3 Series

* Please contact your Littelfuse sales or FAE for more details.
Summary and Conclusion

- The market for vehicles using any kind of electric, battery-powered drive system with voltages equal to or higher than 48V is expected to grow by double digits in the coming years.

- Lithium-based battery technology will be the basis for any kind of xEV vehicles; in addition to its advantages of power density and charging cycle life, it requires major efforts in monitoring and protection.

- Battery Management Systems in xEV vehicles are highly complex and mission-critical systems that need to be properly placed and selected protection components for overvoltage and short circuit protection.

- Electronic fuses for usage in vehicle systems like BMS Sense Line Protection need to be selected carefully and should be able to pass reliability testing following the AEC-Q guidelines; consultation with fuse experts from Littelfuse is essential.

- On-Board Charging Systems link closely with the BMS system of a vehicle and also require a high level of short circuit and overvoltage protection for AC and DC power systems, meeting automotive grade Reliability Expectations in terms of temperature, vibration and transient robustness.

- Littelfuse provides guidance and support customers design according to worldwide automotive safety standards – Please contact your Littelfuse local expert!
Global Footprint – R&D, Manufacturing & Support

Americas
1. Chicago, Illinois, USA (S)
2. Bellingham, Washington, USA (S)
3. Boston, Massachusetts, USA (S, RD)
4. Champaign, Illinois, USA (RD)
5. Lake Mills, Wisconsin, USA (S, RD)
6. Mount Prospect, Illinois, USA (RD)
7. Rapid City, South Dakota, USA (S, RD, M)
8. Fremont, California, USA (RD)
9. Troy, Michigan, USA (S)
10. Manaus, Brazil (S)
11. São Paulo, Brazil (S)
12. Saskatoon, Canada (S, RD, M)
13. Matamoros, Mexico (M)
14. Muzquiz, Mexico (M)
15. Piedras Negras, Mexico (RD, M)

Europe
16. Bremen, Germany (S, RD)
17. Essen, Germany (S)
18. Lauf, Germany (S)
19. Legnago, Italy (RD, M)
20. Ozegna, Italy (RD, M)
21. Kaunas, Lithuania (RD, M)
22. Amsterdam, Netherlands (S)
23. Deventer, Netherlands (S)

Asia
24. Beijing, China (S)
25. Dongguan, China (RD, M)
26. Hong Kong, China (S)
27. Kunshan, China (S, M)
28. Shanghai, China (S, RD, M)
29. Suzhou, China (S, RD, M)
30. Wuxi, China (RD, M)
31. Tokyo, Japan (S)
32. Tsukuba, Japan (RD, M)
33. Seoul, Korea (S)
34. Lipa City, Philippines (RD, M)
35. Singapore (S)
36. Chu-Pei, Taiwan (RD)
37. Taipei, Taiwan (S)

S—International Sales
RD—Research & Design
M—Manufacturing