Technology Enablers for Decarbonizing the Off-Road Segment

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NREL Off-Road Workshop March 23rd 2022
Eaton is solving industry’s toughest power management challenges around the world.
We make delivering your best work.*
Vehicle Group Product Portfolio
Serving multiple customers & markets globally; focused on emissions reduction

Light Duty Technologies
- Valves
- Variable Valve Actuation (VVL/CDA)
- eVactive
- TVS Supercharger
- Fuel Emission Controls
- Gears & shafts
- Light Duty Transmissions
- Differentials

Commercial Vehicle Technologies
- Engine Brake
- TVS Fuel Cell
- Clutches
- Aftermarket
- Automated Transmissions
- Gearing Systems
- EGR control
- Exhaust thermal management

eMobility
- Power Electronics
- Distribution, safety
- Charging, Hydrogen

HV power electronics
- On-board charging
- Power distribution and protection
- Connectors
- Fuel Cells
- MD & HD EV transmissions
Agenda / Key points
Opportunities to accelerate and amplify deployment

1. Value of energy efficiency
   ✓ The economic value of efficiency - smaller batteries, less charge time and lower energy costs - may be secondary
   ✓ 20-30% inefficiency gaps creates barriers to a-scale deployment: loading of the grid and the capital costs of charging infrastructure

2. Paradigm shift in EV safety
   ✓ Higher power applications are not well served by fuses and contactors: detection, contactor welding, re-settability
   ✓ DC microgrids protection concepts applied to Evs
   ✓ Flexible PDU for engineering a low volume / high mix

3. Scalable EV charging infrastructure
   ✓ Site upgrade is a limiting factor: expensive ($1-$2M) and long-time for design/homologation installation (2-3 years)
   ✓ Reducing installation and commissioning time and costs, adding scalability for PV/storage expansions, will amplify and accelerate GHG reductions
Efficiency is critical to at-scale EV deployment

Industry and operator incentives for efficiency are not aligned

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>0.27 kWh/mile</th>
<th>0.37 kWh/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>325 miles</td>
<td>Same</td>
</tr>
<tr>
<td>Battery charge</td>
<td>87.75 kWh</td>
<td>120.25 kWh</td>
</tr>
</tbody>
</table>

- Both vehicles are zero-emissions
- Inefficient vehicle **adds 36% load to grid**
- OEM incentive: more range for same cost

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>81%</th>
<th>+ 20% cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>100 miles</td>
<td>Same</td>
</tr>
<tr>
<td>Battery charge</td>
<td>160 kWh</td>
<td>128 kWh</td>
</tr>
</tbody>
</table>

- Inefficient e-powertrain **adds ~25% load to grid**
- End-user benefit / bus: $500 - 1,200 / year
- Capital benefit of 20% less charge: $200,000

<table>
<thead>
<tr>
<th>Performance</th>
<th>No-shift</th>
<th>Multi-speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start grade</td>
<td>5.3%</td>
<td>21.0%</td>
</tr>
<tr>
<td>Perf. 0 – 30 mph</td>
<td>15.0 - 21.3 s</td>
<td>12.9 s</td>
</tr>
<tr>
<td>Powertrain weight</td>
<td>660 lbs</td>
<td>396 lbs</td>
</tr>
<tr>
<td>Powertrain cost</td>
<td>$16,000</td>
<td>$10,000</td>
</tr>
</tbody>
</table>

- 20% better efficiency through multispeed transmissions: cost neutral, better performance, but more sophistication vs Gen 1 products
- Further 5%: Si-C power electronics at significant cost

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Paradigm shift in protection
Challenges can build on DC microgrid experience

Applications need higher DC power on vehicle...

Fast charging
Maximizing regen power
High power accel / load

Challenges: new to vehicles, but known in kV DC microgrids

Overload vs Short
Contactor welding
Resetting

Fuse
✓ Passive protection, no sensors
× Sensitivity, coordination, fatigue

Pyro
✓ Active protection, accurate
× External sensors, failure modes

Breaktor™
✓ Single device, both active and passive
✓ Coordinates switching and protection
✓ No contactor welding: battery fire
✓ Resettable: no stranded buses

Flexible PD rapid and robust EV electrical system engineering in high mix / low volume

Programmable
Rightsizing modules
Coordinated protection and distribution
EVCI deployment is a significant barrier

Rapid installation, better efficiency, lower cost and footprint

- 40% footprint reduction
- 60% weight reduction
- Higher Efficiency (up to 98%)
- 50% lower total deployment cost
- Much faster, all-in-one deployment
- Future-proofed: Scaling, Storage & Solar
- Key technologies: Solid-State Transformers and 1,000 V DC microgrids

~ $1M/MW
~ 2 years
Limited flexibility