Future Hybrids
-Reduced cost and increased efficiency
May 14, 2014
Main targets for Kollmorgen in the HCV Project

- Reduce Driveline component cost with 40%
  - Deliver a DC/DC converter in WP 4420 (600 / 28 VDC)
  - Deliver a Drive (Inverter) in WP 4420
- Participate in the specification of the components for the Hybrid driveline, WP4210
- Participate in creating simulation models for the components, WP4410
- Participate in the integration of the hybrid driveline, WP 4530
Main challenges for Kollmorgen and how they are solved

- Reduce cost with 40%
  - Topology with resonant DC/DC converter
    - Higher switching frequency
      - Smaller (lower cost) electromagnetic components
  - Use of multiple sourced standard components
    - High volume components (lower cost)
Parallel Discrete IGBT vs Modules

- Discrete transistors: Paralleling of multiple discrete packages with one transistor each.
- Power Module: One package with multiple transistors paralleled inside.

Due to the shorter supply chain and larger production quantities, the cost for a discrete power stage is approximately 50% of the cost for a module solution with the same current rating.
## Modules Vs Discrete IGBT

### Comparison ACH -- Modules at 700VDC - Total losses

<table>
<thead>
<tr>
<th>Output current (Arms)</th>
<th>200A</th>
<th>300A</th>
<th>400A</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 kHz</td>
<td>293</td>
<td>337</td>
<td>483</td>
</tr>
<tr>
<td>4 kHz</td>
<td>577</td>
<td>719</td>
<td>888</td>
</tr>
<tr>
<td>8 kHz</td>
<td>1147</td>
<td>1480</td>
<td>1685</td>
</tr>
</tbody>
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**Reduction in losses (W)**
Assumptions

• 100kW Peak system-performance

• Duty cycle giving 50kW Continuous

• 1% improvement of highly efficient system (95% → 96%)

• 50% of usage is braking and 50% is acceleration

• All losses in acceleration is waste

• 50% of losses in retardation/re-gen is waste (When braking above Peak power, all losses are not waste)
Improved efficiency

• Acceleration

5% losses and 25kW cont  \( \Rightarrow \frac{25}{1-0.05} - 25 = 1.32\text{kW losses} \)
4% losses and 25kW cont  \( \Rightarrow \frac{25}{1-0.04} - 25 = 1.04\text{kW losses} \)
This gives 0.27kW less losses
If used in average 5000h/year this gives 1370kWh/year in less losses
With a diesel engine efficiency of 35% this means 3900kWh or 14000MJ
Energy content in diesel is about 37MJ/l
14000MJ=381l diesel/year

• Braking

5% losses and 25kW cont  \( \Rightarrow \frac{25}{1-0.05} - 25 = 1.32\text{kW losses} \)
4% losses and 25kW cont  \( \Rightarrow \frac{25}{1-0.04} - 25 = 1.04\text{kW losses} \)
This gives 0.27kW less losses of which 50% is seen as waste  \( \Rightarrow 0.14\text{kW} \)
If used in average 5000h/year this gives 685kWh/year in less losses
With a diesel engine efficiency of 35% this means 1950kWh or 7000MJ
Energy content in diesel is about 37MJ/l
7000MJ=190l diesel/year

Total savings of \(~570l\) diesel/year
SiC Power transistors

Losses in electronics show up as heat

Thermal imaging measurements below shows the result when running 60Arms at 600VDC and 7.6 kHz in air for a few seconds.

SiC MOSFETs are the eight devices to the left, the other 16 devices are the Si-IGBTs.
System level benefits

System benefits
• Lower switching losses → Higher system efficiency

• Higher → Lower demand on cooling → Simpler heat sink or even air cooling instead of WEG cooling

• Increased frequency of operation -> Smaller passive components like inductors and transformers

ACH 6550 SiC, Complete inverter assembled. DC/AC converter, Air cooled, 750 VDC, 400 ARMS peak

ACH 6550 Si, DC/AC converter, WEG cooled, 750 VDC, 550 ARMS peak