Philosophy of Topology and Component Selection for Cost and Performance in Automotive Converters.

Alexander Isurin and Alexander Cook
“Engineering is a tool that a company can use to make profit.”
Main Requirements and Conditions for the automotive industry

- Reverse polarity protection
- Load Dump Over voltage from alternator
- Sources: battery and alternator
- Over voltage spikes to 800V
- Jump start stresses
- Electromagnetic Compatibility
- Life time, reliability
Main Requirements and Conditions for the automotive industry

• Mechanical challenges: Water resistance and vibration
• CAN-bus communication capability
• High efficiency under light load and low consumption at idle and key off.
• Development cycle time pressures
• Peak currents up to 2900A at 12V
• Operational temperature -40C to +110C
• Electrical air-conditioning drive instead of belt drive
• Optional sources: Electrical grid
General Relationship Between Cost and Efficiency

Cost is a strong function of efficiency as we move away from the minimum 5%~8% $\Delta \text{Cost} \approx |1\% \Delta \eta|$.
Block Diagram of a Dynamic Inverter

- Alternator
- Transformer
- Field regulator
- DC load
- AC load
- DC-AC converter
Comparison between traditional and modified dynamic inverter
The cost of the modified inverter is 17% lower relative to the cost of the traditional inverter.
Observed in most cars and traditional inverter

![Diagram of Simplified Field Regulator]

- Vref
- VDC
- Alternator Field
- Field Current
- DC Voltage

~100mS

Modified Field Regulator

US Patent 7,106,030

2014
Summary of Benefits

- Reduced electrical stress
- Improved response
- Reduced rating for same performance

- These result in reduced cost for the customer
12kW rating, efficiency ~ 97%

Presented APEC2008
Conventional

Single phase DC-AC inverter with ARCP

12kW rating, Efficiency ~ 97%
Cost comparison Table
For our Described Implementation

<table>
<thead>
<tr>
<th></th>
<th>Inverter with ARCP</th>
<th>New inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>Add 2-3%</td>
<td>Basis</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>equal</td>
<td>equal</td>
</tr>
<tr>
<td><strong>EMI</strong></td>
<td>equal</td>
<td>equal</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Reduced</td>
<td>Basis</td>
</tr>
</tbody>
</table>
Summary

• Modern components require the use of new technology and philosophies for automotive applications of power converters
Motor drive DC-AC Converters without and with LC Filters

System with a filter has higher efficiency under light load,
This point very important for EV vehicle.
The converter and motor should be looked at as one integrated power stage. We need to see the whole picture from the start to the end. Only this way can we get a good cost with optimal performance.
9kW Bi-directional DC-DC converter

- High voltage side: 500VDC-800VDC
- Low voltage side: 20VDC-30VDC @300A
- Operational temperature: -40C to +70C @ full power
- Efficiency 94% excluding reverse polarity protection and pre-charge (93% with)
- Efficiency 84% @ 5% load
- Consumption @ idle 60W
- Life time minimum 20 years
- Cost for customer equivalent to conventional alternator
New Topology

DC-DC Converter in Step-down Mode

Presented APEC2006

Patent US 6,483,731

### Comparisons

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>PHASE-SHIFT</th>
<th>NEW</th>
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<tbody>
<tr>
<td>Max. com. freq.</td>
<td>1x</td>
<td>2x</td>
</tr>
<tr>
<td>Load range</td>
<td>Limited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Commutation</td>
<td>ZVS</td>
<td>ZVS ZCS</td>
</tr>
<tr>
<td>Rectifier recovery</td>
<td>Recovery losses</td>
<td>Simple and soft</td>
</tr>
<tr>
<td>Paralleling of stages</td>
<td>Requires additional control</td>
<td>Simple</td>
</tr>
<tr>
<td>Transformer</td>
<td>Not optimal</td>
<td>Optimal</td>
</tr>
<tr>
<td>DC-bias</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Control</td>
<td>Standard</td>
<td>Special</td>
</tr>
<tr>
<td>Idle losses</td>
<td>1.5%</td>
<td>0.15%</td>
</tr>
<tr>
<td>COST</td>
<td>Basis</td>
<td>Basis minus &gt;10%</td>
</tr>
</tbody>
</table>

The both have the same performance.
Low voltage side power stage with integrated power transformer

Presented without the clamping frame

Patent US 7,123,123
Cost and efficiency of the low-voltage side power stage with two types of transformers

<table>
<thead>
<tr>
<th>Power Stage Incorporating:</th>
<th>Product Cost</th>
<th>System Efficiency</th>
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<tbody>
<tr>
<td>Integrated transformer</td>
<td>1</td>
<td>94%</td>
</tr>
<tr>
<td>Planar transformer</td>
<td>1+20%</td>
<td>92%</td>
</tr>
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</table>

Commutation frequency 110kHz
Low voltage side rating 280A
To use a topology where the transformer works under **optimal conditions**

The transformer itself cannot be useful alone. It can be used only as **part** of the whole power stage
Emitter Switched Bipolar Transistor

ESBT symbol and equivalent circuit, cascade connection

Comparison:

<table>
<thead>
<tr>
<th></th>
<th>ESBT total</th>
<th>SiC</th>
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<tbody>
<tr>
<td>Cost</td>
<td>1</td>
<td>3</td>
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</tbody>
</table>

ESBT-STE70IE120 and SiC-SAS100H12AM1
The both have the same performance.
Commutation Frequency-80kHz Current via Primary winding of transformer is sinusoidal with peak 60A and duty cycle 90-95%
Simplified waveforms of S2:
Gate signals
Current and Voltage
Comparison between different combinations of IGBT and MOSFETs.

IGBT-IXEN60120  MOSFET-IXFN32N120

<table>
<thead>
<tr>
<th></th>
<th>IGBT</th>
<th>IGBT &amp; MOSFET</th>
<th>Two MOSFET’s</th>
<th>Three MOSFET’s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COST</strong></td>
<td>N/A</td>
<td>1</td>
<td>1.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Power losses per switch</td>
<td>N/A</td>
<td>109W</td>
<td>158W</td>
<td>105W</td>
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</table>
During the last 15 years the EMI requirements for electronic units for automotive applications has become more stringent, from CISPR25 class 2 to class 4. The main reason is the demand for **COMPATIBILITY**.

The key for this point are soft-switching and maximum slew-rate 2500V/uS.
Total cost of ownership considerations

• Product cost
• Diagnostic
• Removal and replacement cost
• Availability (stock) cost
• Loss of use

High cost of automotive maintenance calls for high reliability
Resonant topologies with clamp diodes provide passive power limiting.
Conclusion

- Efficiency target: 92-98%  The efficiency itself is not the target, rather the low cost and superior performance
- Use soft-switch technology
- Minimum of active components
- Reduced quantity, and simply constructed, magnetic components
- Use integrated magnetic components
- Use SMA where possible
- Use multi-level topology only when voltage is above 1000VDC
- Limit slew rate to 2500V/μS
- Keep operating frequency high to minimize the filter
Maximize board mounting, minimize chassis mounting
In other words packaging is key to realizing the benefits of the topology
Thank You for Your Attention.