High Efficiency, Compact On-Board Chargers for Industrial Electric Vehicles

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STMicroelectronics

Thomas Höffken
Innolectric AG
• Introduction: Industrial On Board Chargers
• Typical Architecture
• Topologies & ST Evaluation Boards
• Customer’s Example: Innolectric AG
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How to Charge an Electrical Vehicle?

DC Charger

On-Board Charger + “AC Charger”

Wireless Charging

Advantages:
+ Battery Compatible
+ Ease of use

Challenges:
* Cooling concept
* Mechanical Robustness
* Grid Configuration
* Reduced volume and weight

SiC!
EVs: Many More Applications Beyond Cars

Transition to greener platforms everywhere:

- Locally **CO2 neutral**;
- **Less noise** from EVs than combustion engines.

Shift from lead-acid to lithium-ion batteries:

- Larger storage capacity → ** Longer Autonomy**;
- Higher voltages → **Shorter charging time**.
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**Industrial On-board Charger System Concept**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>$L_x - L_y \rightarrow 400 , V_{AC}$</td>
</tr>
<tr>
<td></td>
<td>$L_x - N \rightarrow 230 , V_{AC}$</td>
</tr>
<tr>
<td>DC Link Voltage</td>
<td>400..1000 V</td>
</tr>
<tr>
<td>Nominal Power</td>
<td>11..22 kW</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>200..500 $V_{DC}$ for 400 $V_{DC}$ Batteries</td>
</tr>
<tr>
<td></td>
<td>500..900 $V_{DC}$ for 800 $V_{DC}$ Batteries</td>
</tr>
</tbody>
</table>
• Introduction: Industrial On Board Chargers
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AC/DC Concepts

3-Level 3-Phase

Example: Mod. Vienna Type 1

- 6 devices / phase.

+ 650V Si Switches.

3x Independent 1-phase

Example: 3x PFC Booster

+ 4 devices / phase
+ Flexible grid configuration

- May need of 1200V SiC switches*

* In order to accomplish battery voltage requirements.
Modified Vienna Rectifier

Topology Comparison

**Mod. Vienna Type 1**

- All 650V rated devices
  - lower cost

- 2 devices in the main current path (D1&D2)
  - lower efficiency

**Mod. Vienna Type 2**

+ 1 devices in the main current path (D2)
  - Higher efficiency

- Need 1200V diodes (D2), typically SiC.
  - Higher cost
Modified Vienna Rectifier

Device Proposal

<table>
<thead>
<tr>
<th>Required Semiconductor</th>
<th>ST Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1 Rectifier SCR</td>
<td>STBRxx12W</td>
</tr>
<tr>
<td></td>
<td>STBRxx12W</td>
</tr>
<tr>
<td></td>
<td>TNxx50H-12WY</td>
</tr>
<tr>
<td>T1 650V IGBT</td>
<td>STGWxxH65DFB2</td>
</tr>
<tr>
<td></td>
<td>STGWxxH65DFB2</td>
</tr>
<tr>
<td></td>
<td>STWxxN65M5</td>
</tr>
<tr>
<td></td>
<td>STWxxN65M5</td>
</tr>
<tr>
<td></td>
<td>SCTWxxN65G2V</td>
</tr>
<tr>
<td></td>
<td>SCTWxxN65G2V</td>
</tr>
<tr>
<td>D2 600V FRD 650V SiC Diodes</td>
<td>STTHxxRQ06</td>
</tr>
<tr>
<td></td>
<td>STTHxxRQ06</td>
</tr>
<tr>
<td></td>
<td>STPSCxx065C</td>
</tr>
<tr>
<td>GD Isolated driver</td>
<td>STGAP2S</td>
</tr>
<tr>
<td>Control</td>
<td>STM32 (Digital)</td>
</tr>
<tr>
<td></td>
<td>STN RGPF0x (Mixed mode)</td>
</tr>
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<tr>
<td>T1/D1 650V IGBT</td>
<td>STGWxxH65DFB2</td>
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<tr>
<td></td>
<td>STGWxxH65DFB2</td>
</tr>
<tr>
<td></td>
<td>STWxxN65M5</td>
</tr>
<tr>
<td></td>
<td>STWxxN65M5</td>
</tr>
<tr>
<td></td>
<td>SCTWxxN65G2V</td>
</tr>
<tr>
<td></td>
<td>SCTWxxN65G2V</td>
</tr>
<tr>
<td>D2 1200V SiC Diode</td>
<td>STPSC40H12C</td>
</tr>
<tr>
<td>GD Isolated driver</td>
<td>STGAP2S</td>
</tr>
<tr>
<td>Control</td>
<td>STM32 (Digital)</td>
</tr>
<tr>
<td></td>
<td>STN RGPF0x (Mixed mode)</td>
</tr>
</tbody>
</table>

xx → Current class  
x → Family name
Topography Comparison

Efficiency Comparison @ $P_{\text{out}}=20$ kW

<table>
<thead>
<tr>
<th>Mod. Vienna Type 1</th>
<th>Mod. Vienna Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>STBR6012W</td>
</tr>
<tr>
<td>T1</td>
<td>STGW40H65DFB-4</td>
</tr>
<tr>
<td></td>
<td>STW88N65M5-4</td>
</tr>
<tr>
<td>D2</td>
<td>STPSC40065C</td>
</tr>
</tbody>
</table>

Simulated efficiency @ $T_j = 125^\circ\text{C}$, considering only semiconductor losses.
Evaluation Board 1
Mod. Vienna Type 2

15 kW 3-ph PFC Converter

ST Solutions:
- SCTW35N65G2V (SiC MOSFET);
- STPSC20H12 (SiC Diode);
- STNRGPF0x (mixed mode controller, in development);
- STM32G474 (microcontroller);
- STGAP2S (Gate Driver).

Documentation Available!
3-Level 3-Phase

Example: Mod. Vienna Type 1
+ 650V Si Switches.
- 6 devices / phase.

3x Independent 1-phase

Example: 3x PFC Booster
+ 4 devices / phase
+ Flexible grid configuration
- May need of 1200V SiC switches*

* In order to accomplish battery voltage requirements.
### Required Semiconductor ST Solution

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<tr>
<td>Rectifier SCR</td>
<td>STBRxx12W</td>
</tr>
<tr>
<td></td>
<td>TNxx50H-12WY</td>
</tr>
<tr>
<td>1200V SiC POWER MOSFET</td>
<td>SCTxxN120</td>
</tr>
<tr>
<td>1200V SiC Diodes</td>
<td>STPSCxxH12C</td>
</tr>
<tr>
<td>Isolated driver</td>
<td>STGAP2S</td>
</tr>
<tr>
<td>Control</td>
<td>STM32 (Digital)</td>
</tr>
<tr>
<td></td>
<td>STNRGPF0x (Mixed mode)</td>
</tr>
</tbody>
</table>

*xx* → Current class

*x* → Family name

**1200V SiC MOSFET**

Due to high DC link voltage.
SiC MOSFET mandatory due high DC Voltage and body diode robustness.
Main Features

- Input AC voltage: 85VAC up to 264VAC
- DC output voltage: 400VDC
- Switching frequency: 72 kHz
- Maximum input current: 16 A RMS (POUT = 3.6KW)
- Efficiency: > 97.5%
- THD < 10%
- Remove two bulky relays and an NTC resistor thanks to SCRs progressive start-up

Available Q2/20

Evaluation Board 2
3.6 kW Totem Pole PFC

Key Products

- TN3050H-12WY → SCR in the Bridge
- SCTW35N65G2V → 650V SiC MOSFET
- STGAP2S → Isolated Gate Driver
- STM32 → 32-bit Microcontroller
- VIPER26LD → HV Converter Controller

Compliant to:
- EN 55015 and IEC 61000-4-11 and IEC 61000-3-3
- IEC 61000-4-5 surge: 4kV
- IEC 61000-4-4 EFTY burst: criteria A @ 4kV min
- Design for operation with DC/DC converter
- Peak inrush current tuning
DC/DC Stage Topologies

Resonant LLC / ZVS or DAB

1200V SiC MOSFET due to robust diode, low $R_{ds,on}$.

Resonant LLC / Zero Voltage Switching

- **Device**: T2
  - **Technology**: 1200V SiC POWER MOSFET
  - **ST Solution**: SCTxxN120

- **Device**: D3
  - **Technology**: 600V FRD 1200V SiC Diodes
  - **ST Solution**: STTHxxRQ06 (LLC) STPSCxxH12C (ZVS)

- **Device**: GD
  - **Technology**: Isolated Driver
  - **ST Solution**: STGAP2S/D

- **Device**: Control
  - **Technology**: Microcontroller
  - **ST Solution**: STM32 (Digital)

Bi-directionality when needed.

Dual Active Bridge (DAB) / Bi-directional LLC

- **Device**: T2
  - **Technology**: 1200V SiC POWER MOSFET
  - **ST Solution**: SCTxxN120

- **Device**: T3
  - **Technology**: 650V SiC POWER MOSFET 1200V SiC POWER MOSFET
  - **ST Solution**: SCTxxN65G2V [400V Batt.] SCTxxN120 [800V Batt.]

- **Device**: GD
  - **Technology**: Isolated Driver
  - **ST Solution**: STGAP2S/D

- **Device**: Control
  - **Technology**: Microcontroller
  - **ST Solution**: STM32 (Digital)
Evaluation Board 3

3 x 7 kW On-board Charger

Available Q2/20

Single solution 7 kW

21 kW solution, stacked modules with bus bars

Available Q2/20

DC-DC converter
Interleaved FB LLC

PFC
Interleaved Totem Pole

fsw ~70 kHz
2240 µF

85 – 205 Vac

Neutral

Semiconductor

<table>
<thead>
<tr>
<th></th>
<th>Automotive version</th>
<th>Industrial Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectifier</td>
<td>STTH30L06GY</td>
<td>STTH30L06C</td>
</tr>
<tr>
<td>650V SiC POWER MOSFET</td>
<td>SCTH35N65G2V-7AG</td>
<td>SCTH35N65G2V-7</td>
</tr>
<tr>
<td>Thyristors</td>
<td>TN3050H-12GY</td>
<td>TN3050H-12GY</td>
</tr>
<tr>
<td>Isolated driver</td>
<td>STGAP1AS</td>
<td>STGAP2S</td>
</tr>
<tr>
<td>650V SJ MOSFET</td>
<td>STB47N60DM6AG</td>
<td>SCTH35N65G2V-7</td>
</tr>
<tr>
<td>650V SiC Diode</td>
<td>STPSC20065GY</td>
<td>STPSC20065</td>
</tr>
<tr>
<td>Microcontroller</td>
<td>SPC58NN84E7 (x 2)</td>
<td>STM32G474</td>
</tr>
</tbody>
</table>
OBC First Platform Overview

Single Module 7 kW

- PFC Inductors
- Bulk Capacitors
- IMS substrate PFC
- Control Board STEVAL-DPSC58C1 Bernina
- Input Filter
- AC Input Voltage
- Water Inlet
- External 12V supply Voltage
- Water outlet
- Output Voltage
- 64 PIN ST DSMPS connector

Dimensions
- 25 cm
- 9 cm
- 40 cm
Available Q1/20

100 W Auxiliary Power Supply

**Project details**

- **Input voltage**
  - 185 – 640 Vac
  - 150 – 900 Vdc
- **Output power**
  - Up to 100W
- **Topology**
  - Flyback

**ST components**

- L6566BH → Quasi-resonant controller
- STW12N150K5 → 1500V SJ MOSFET
- SCT1000N170 → 1700V SiC MOSFET
- STN1HNK60 → Start-up MOSFET
- STPS10150 → Output Diode

1700V SiC MOSFET due to:
Input Voltage + Reflected voltage + Spikes
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Headquarter in Bochum, Germany

2000’s
Product developments within Scienlab

scienlab

2016
Foundation of the company

2017
Corporate structure & acquisitions

2018

2019
Transformation into stock corporation

2020
SOP MARK 1 OBC

Energy storages

Charging communication

Power electronics

Long-term partnership with STMicroelectronics
22 kW Industrial On-board Charger

Parameters and Performance

- 12 kg Weight
- 15 liters Volume

**Conversion Efficiency**

- Efficiency OBC42.1 > 96%

<table>
<thead>
<tr>
<th>Product name</th>
<th>OBC42</th>
<th>OBC42.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component design</td>
<td>400 V</td>
<td>800 V</td>
</tr>
<tr>
<td>Input power</td>
<td>22 kW</td>
<td></td>
</tr>
<tr>
<td>Input voltage (3-AC)</td>
<td>380 – 480 V (+10%) - 14%</td>
<td></td>
</tr>
<tr>
<td>Input voltage (1-AC)</td>
<td>120 – 240 V (+10%) - 14%</td>
<td></td>
</tr>
<tr>
<td>Input current (AC)</td>
<td>32 A (per phase)</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>50 – 60 Hz (+/- 1%)</td>
<td></td>
</tr>
<tr>
<td>Efficiency [2 – 22 kW]</td>
<td>&gt; 94%</td>
<td></td>
</tr>
<tr>
<td>Efficiency [2 – 10 kW]</td>
<td>&gt; 96%</td>
<td></td>
</tr>
<tr>
<td>Output voltage (DC)</td>
<td>210 – 510 V</td>
<td>400 – 850 V</td>
</tr>
<tr>
<td>Output current (DC)</td>
<td>Up to 70 A</td>
<td>Up to 45 A</td>
</tr>
</tbody>
</table>
• Several **Industrial Vehicles** are now being electrified. A good portion of them will require an **on-board charger**.

• **Industrial OBCs** are typically implemented in a **2-stage** concept: **PFC** followed by isolated **DC/DC**.

• **650V & 1200V Silicon Carbide MOSFETs** provide advantages in both stages. **1700V SiC MOSFETs** can also be used in **Auxiliary power supply**.

• Several **evaluation boards** to approach this application are now ready or in preparation at **STMicroelectronics**.
Thank you for your Attention! Any Question?