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

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Power Discrete Group – Technical Marketing
1. Introduction: Industrial On-Board Chargers
2. Typical Architecture
3. Topologies & ST Evaluation Boards
How to charge an electrical vehicle?

**DC Charger**

**On-Board Charger + “AC Charger”**

- Battery Pack
- Inductive pick-up
- Charging inductor
- OBC

**Wireless Charging**

**On Board Charger**

Advantages:
+ Battery Compatible
+ Ease of use

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

SiC!
EVs: Many more applications beyond cars

Industrial Vehicles

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.
Industrial On-Board Charger

System Concept

Parameter | Value
---|---
Input voltage | $L_x-L_y \rightarrow 400 \, V_{DC}$
 | $L_x-N \rightarrow 230 \, V_{AC}$
DC Link Voltage | 400..1000 V
Nominal Power | 11..22 kW
Output Voltage | 200..500 $V_{DC}$ for 400 $V_{DC}$ Batteries
 | 500..900 $V_{DC}$ for 800 $V_{DC}$ Batteries
AC/DC concepts

3-Level 3-Phase

Example: Modified Vienna Type 1

Phase 1

Phase 2

Phase 3

D1+

D1-

D2+

D2-

T1+

T1-

400V

800V

+ 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.
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

**Modified Vienna Type 1**

- **Phase 1**
  - T1
  - D1
  - D2
- **Phase 2**
  - T1
  - D1
  - D2
- **Phase 3**
  - T1
  - D1
  - D2

**Required Semiconductor** | **ST Solution**
--- | ---
D1 | Rectifier SCR
T1 | 650V IGBT 650V SJ POWER MOSFET 650V SiC POWER MOSFET
D2 | 600V FRD 650V SiC Diodes
GD | Isolated driver
Control | STM32 (Digital) STNRGPF0x (Mixed mode)

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**Modified Vienna Type 2**

- **Phase 1**
  - T1
  - D1
  - D2
- **Phase 2**
  - T1
  - D1
  - D2
- **Phase 3**
  - T1
  - D1
  - D2

**Required Semiconductor** | **ST Solution**
--- | ---
T1/D1 | 650V IGBT 650V SJ POWER MOSFET 650V SiC POWER MOSFET
D2 | 1200V SiC Diode
GD | Isolated driver
Control | STM32 (Digital) STNRGPF0x (Mixed mode)

xx → Current class
x → Family name
Topology efficiency comparison @ $P_{\text{out}} = 20$ kW

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

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

Documentation Available!
AC/DC concepts

3-Level 3-Phase

Example: Modified Vienna Type 1

- 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.

+ 650V Si Switches.
3x 1-Phase Topologies: Standard PFC

Booster PFC

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<td>Rectifier SCR</td>
<td>STBRxx12W, TNxx50H-12WY</td>
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<tr>
<td>1200V SiC POWER MOSFET</td>
<td>SCTxxN120</td>
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<tr>
<td>1200V SiC Diodes</td>
<td>STPSCxxH12C</td>
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1200V SiC MOSFET
Due to high DC link voltage.

xx ➔ Current class
x ➔ Family name
SiC MOSFET mandatory due high DC Voltage and body diode robustness.

### Bridge-less topologies: Totem Pole PFC

**Var. 1 – Cost – Diode Leg**

**Phase 1**
- S1
- D1
- S2
- D2

**Phase 2**
- Grid
- Grid

**Phase 3**
- S1
- D1
- S2
- D2

**Var. 2 – Performance – SiC MOS Leg**

**Phase 1**
- S1
- S3

**Phase 2**
- S2
- S4

**Phase 3**
- S1
- S3
- D1
- Grid
- Grid

**Var. 3 – Relay-less – SCR Leg**

**Phase 1**
- S1
- T3

**Phase 2**
- S2
- T4

**Phase 3**
- S1
- T3
- Grid
- Grid

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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

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**: STTHxRQ06 (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
  - **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)

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**Notes:**

- Only in LLC
- Bi-directionality when needed.
Evaluation Board 3
3x 7 kW On-Board Charger

Available Q2/20

Single solution 7 kW

21 kW solution, stacked modules with bus bars

DC-DC converter
Interleaved FB LLC

PFC
Interleaved Totem Pole

Semiconductor
Automotive version | Industrial Version
--- | ---
Rectifier | STTH30L06GY | STTH30L06C
650V SiC POWER MOSFET | SCTH35N65G2V-7AG | SCTH35N65G2V-7
Thyristors | TN3050H-12GY | TN3050H-12GY
Isolated driver | STGAP1AS | STGAP2S
650V SJ MOSFET | STB47N60DM6AG | SCTH35N65G2V-7
650V SiC Diode | STPSC20065GY | STPSC20065
Microcontroller | SPC58NN84E7 (x 2) | STM32G474
OBC First Platform Overview

Single Module 7 kW

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

Dimensions
- 9 cm
- 25 cm
- 40 cm

Control Board
- STEVAL-DPSC58C1 Bernina
- IMS substrate LLC
- Drivers A6387 board
- STGAP1AS
- Current Transformers
- DC-DC Transformers
- DC-DC resonant inductors

 life augmented
Evaluation board 4: 100 W Auxiliary Power Supply

Available Q1/20

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
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