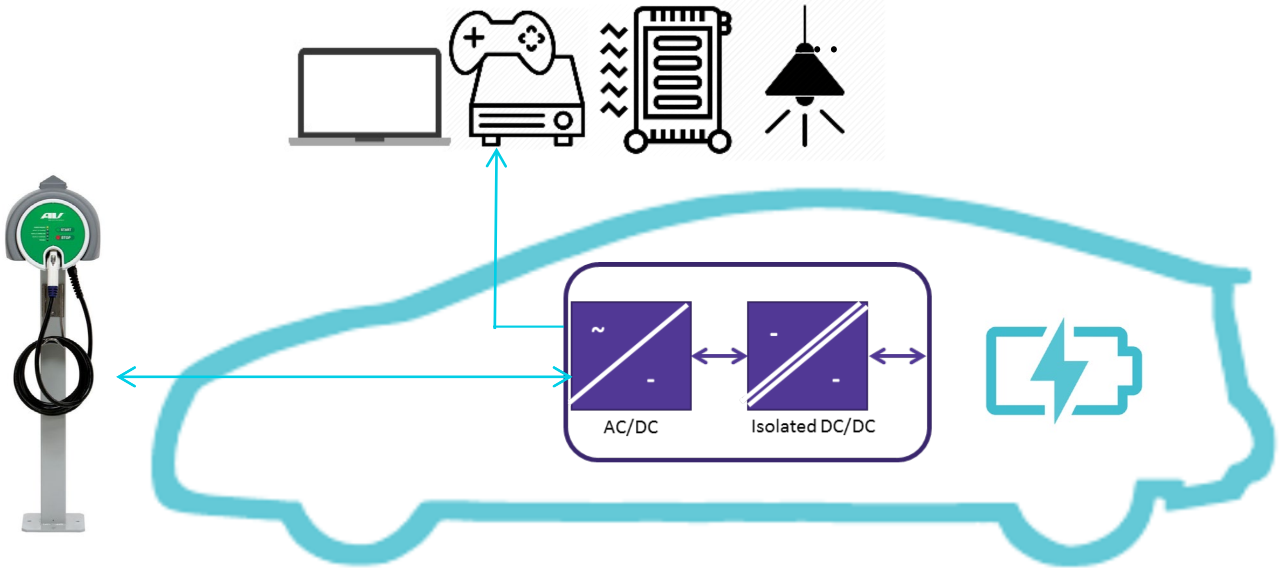
22kW High Efficiency Bi-directional AC-DC Converter

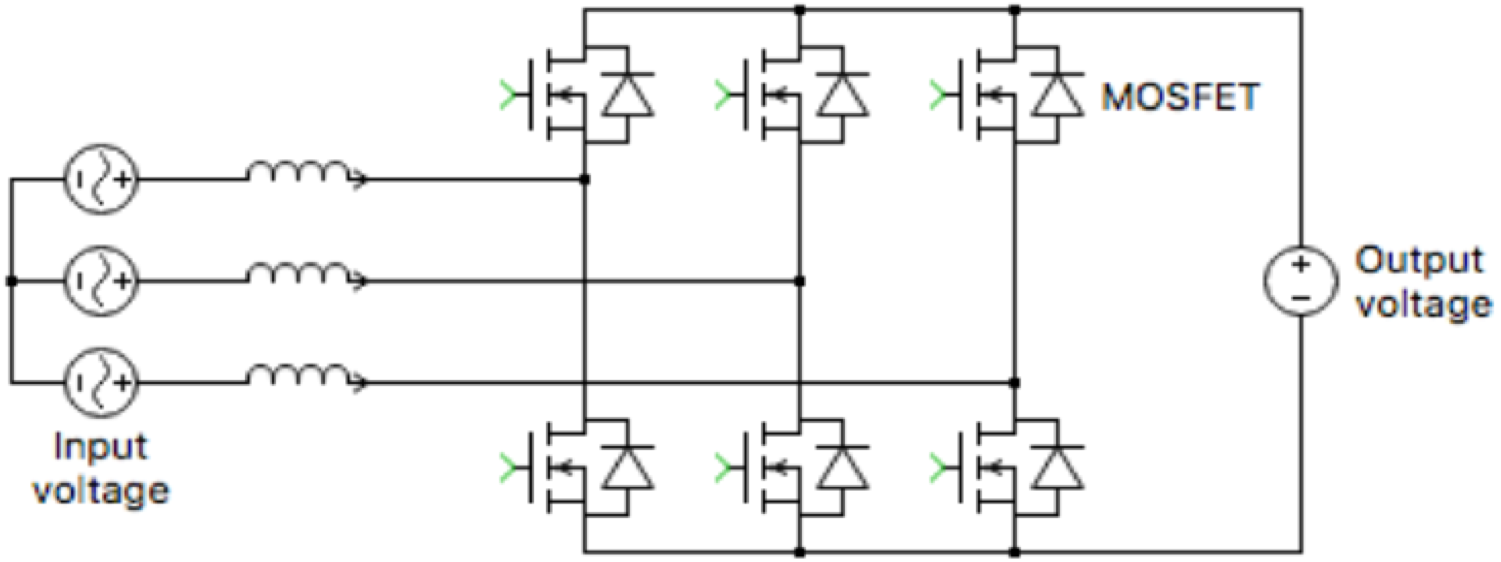
22KW BI-DIRECTIONAL OBC SPECIFICATIONS

Description	3phase AC input Charging	1phase AC input Charging	Discharging Mode
Input Voltage	304Vac~456Vac	180Vac~264Vac	300Vdc-800Vdc
Output Voltage	200-800Vdc	200-800Vdc	220Vac
Rated Power	22kW 36A max	6.6kW	6.6kW
OBC peak Efficiency	>96%	>96%	>96%
DCDC peak Efficiency	>98.5%	>98.5%	>98.5%
DC Bus Voltage	650V-900V	380V-900V	360V-760V



CANDIDATE A FOR AC-DC CONVERTER

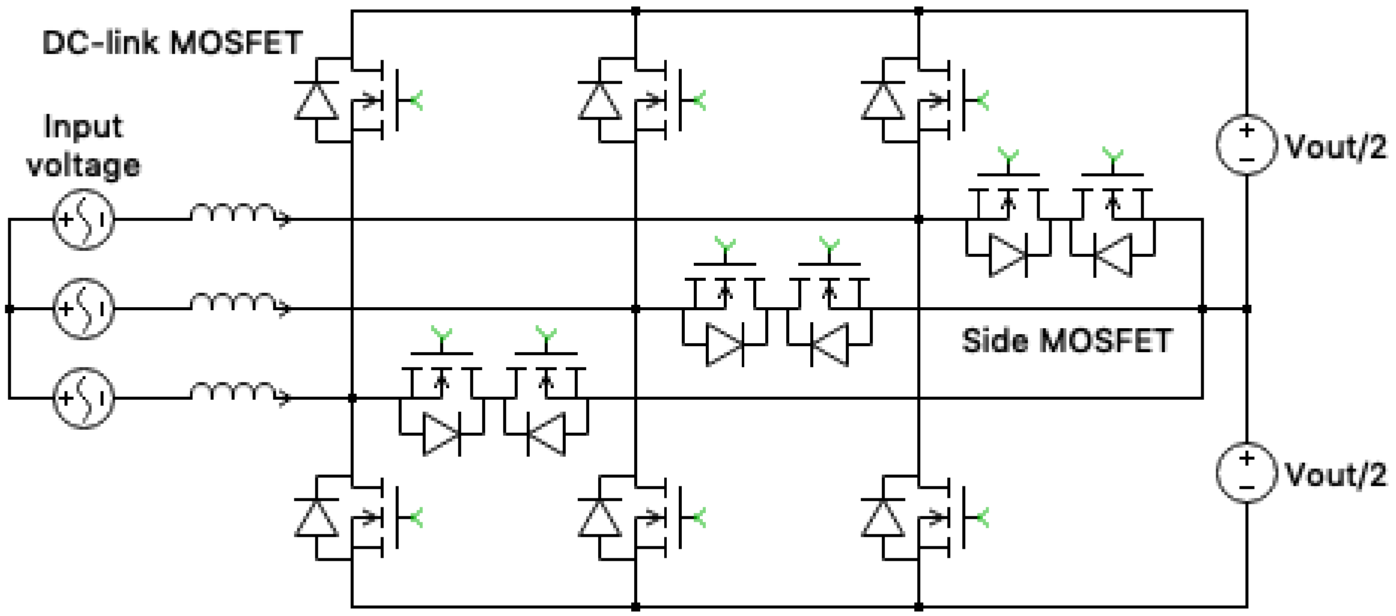
Six Switches Active Front End Converter



- ✓ Bi-directional Operation
- ✓ Single & 3 phase AC input Compatible
- ✓ Low Parts Counts
- ✓ Simple Control/ Simple Drive/ Low Cost

CANDIDATE B FOR AC-DC CONVERTER

T-type ACDC Converter



- ✓ Bi-directional Operation
- ✓ Low Switching Loss/ Smaller Inductor
- ✓ Higher Parts Counts
- ✓ More Gate Drive/ Higher Cost

TOPOLOGY SELECTION

Six Switches Active Front End Converter		T-type ACDC Converter	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Single & 3 phase AC input Compatible →Totem pole PFC with single phase AC input	Larger Choke	3level Converter →Lower switching loss, smaller choke, higher efficiency	More parts counts, → Larger Size, lower power density and higher cost
Lower parts counts, → Smaller Size, higher power density and lower cost	Hard switching 2 level converter → EMI concerns	3level → EMI friendly	Complex control for 6 DC-link MOSFETs + 6 Side MOSFETs
Easy to control at both 3ph and 1ph charging mode; also in discharging mode			

✓ For high Power Density and lower cost, Six Switches Active Front End Converter is selected.

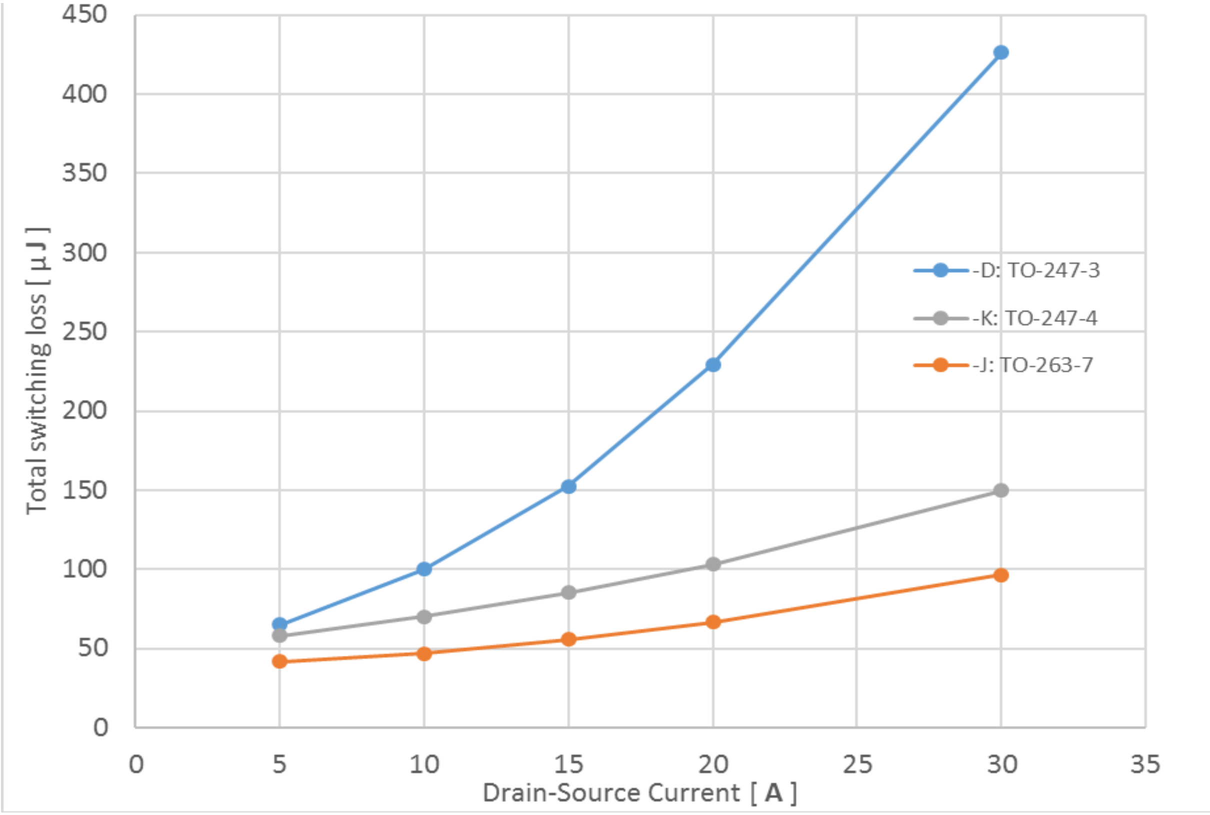
WHY SILICON CARBIDE?

- ➢ Smaller capacitance, Fast switching and low switching losses
- ➢ Less temperature dependence of Rdson and low conduction loss at high temperature
- ➢ Low reverse recovery body diode enables reliability in case of hard-commutation

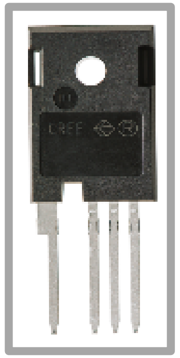
  - ✓ Enabling higher switching frequency
  - ✓ Increasing power density and reducing weight
  - ✓ High efficiency
  - ✓ Bi-directional operation

PACKAGE SELECTION

SWITCHING LOSS COMPARISON @ EXACTLY SAME TEST CONDITIONS



TO-247-3
NO - Kelvin Pin
2.6mm Creepage
8nH Inductance



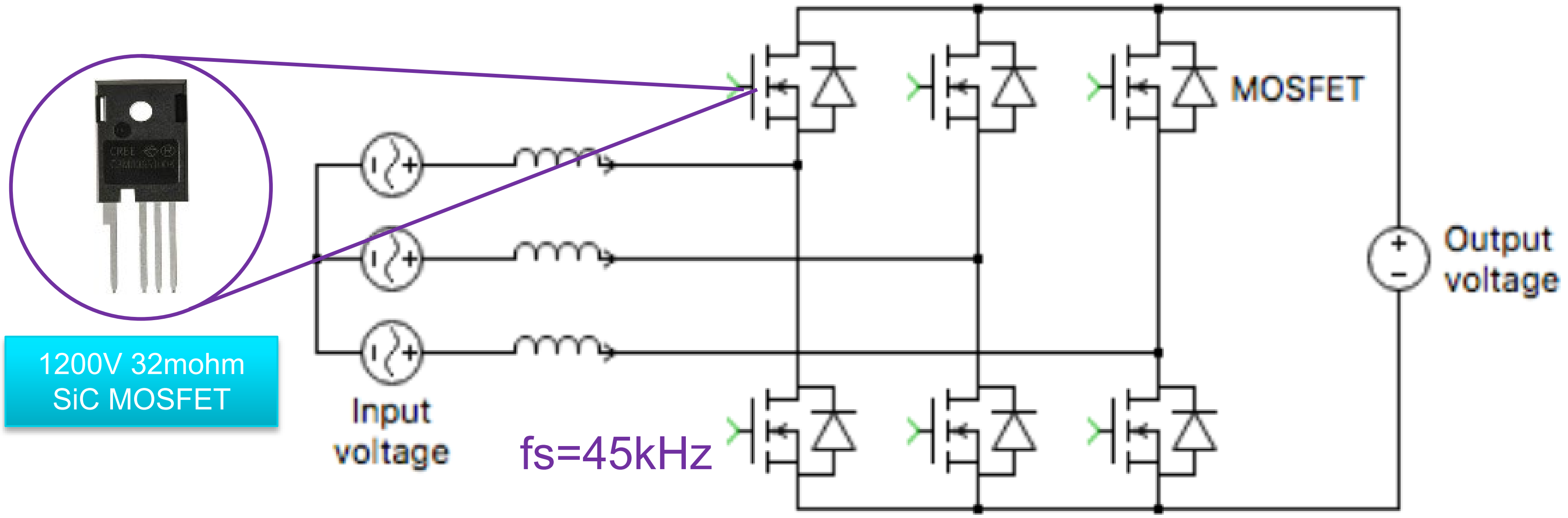
TO-247-4
Kelvin Pin
8mm Creepage
8nH Inductance

TO-263-7
Kelvin Pin
7mm Creepage
2nH Inductance

✓ TO-247-4 package is selected for efficiency, reliability and thermal management.

POWER COMPONENTS SELECTION

The DC link voltage is up to 900V. Battery voltage is up to 800V.



C3M0032120K 1200V 32mohm SiC MOSFET is selected for AFE and CLLC converters based on electrical stress and thermal design.

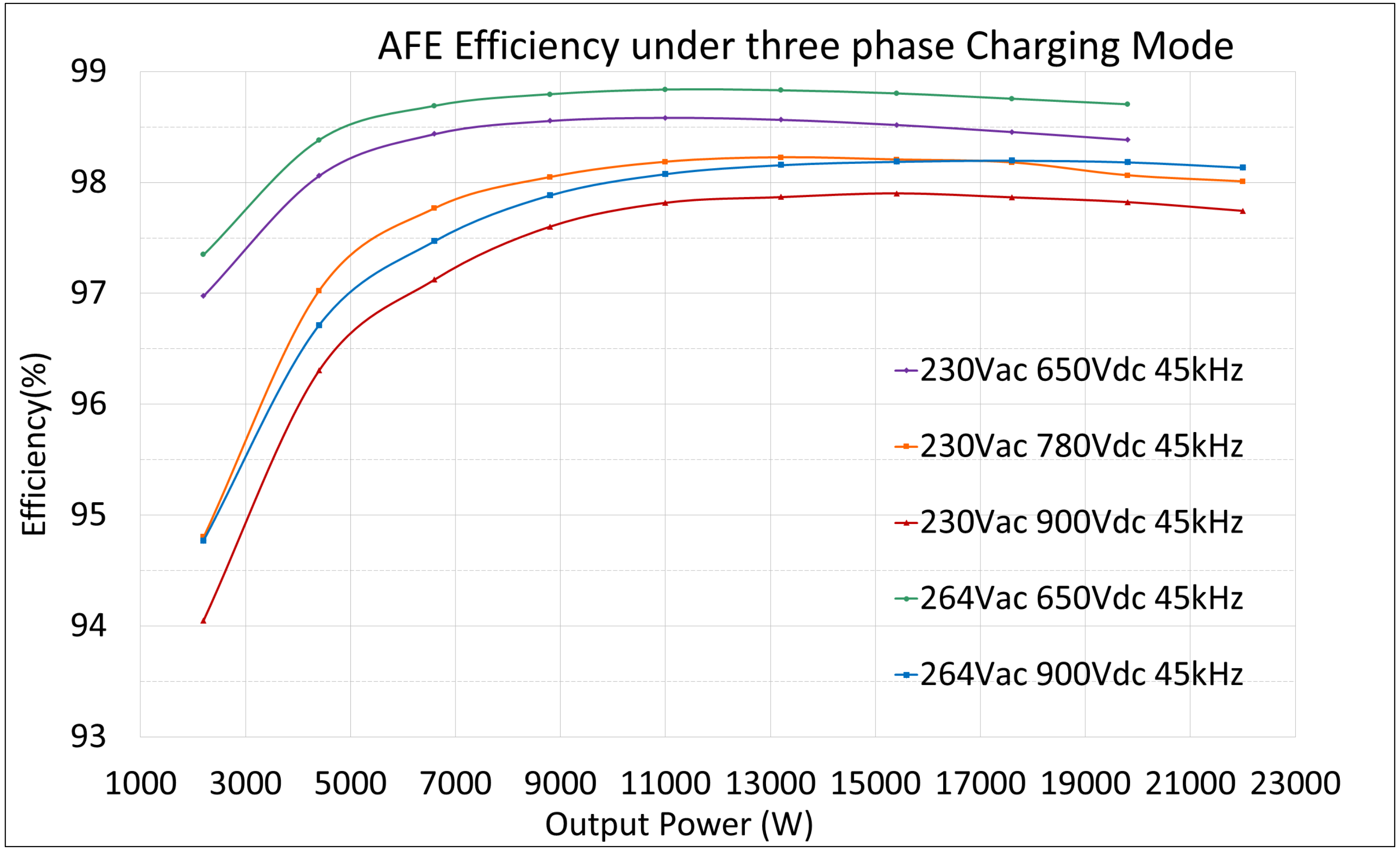
- ❑Best figure of merit (FOM)
- ❑New K-Source package reduces switching loss and reduce cross talk
- ❑Easy to drive (V_{gs} = +15V)

THERMAL ANALYSIS

Description	Rth (j-c) (c/w)	Calculated Power Loss (watts)	Case Temp.	Calculated Junction Temp.	Max. Operating Junction Temp.	Comments
Input 380Vac Output = 900Vdc 22kW						
PFC MOSFET	0.45	52	89.4	112.4	175 °C	**PASS**
Input 215Vac Output = 900Vdc 6.6kW						
PFC MOSFET HF	0.45	42	84.9	103.9	175 °C	**PASS**
PFC MOSFET LF	0.45	20	69.1	78.1	175 °C	**PASS**
Input 760Vdc Output 220Vac 6.6kW						
PFC MOSFET	0.45	36	79.8	96.1	175 °C	**PASS**

- $T_{base\ plate}=65^oC$

TEST RESULT EFFICIENCY @ 3 PHASE AC CHARGING



SUMMARY

Thanks to the low power loss of C3M 1200 V Silicon Carbide MOSFET and the flexible control scheme, all the design targets are achieved.

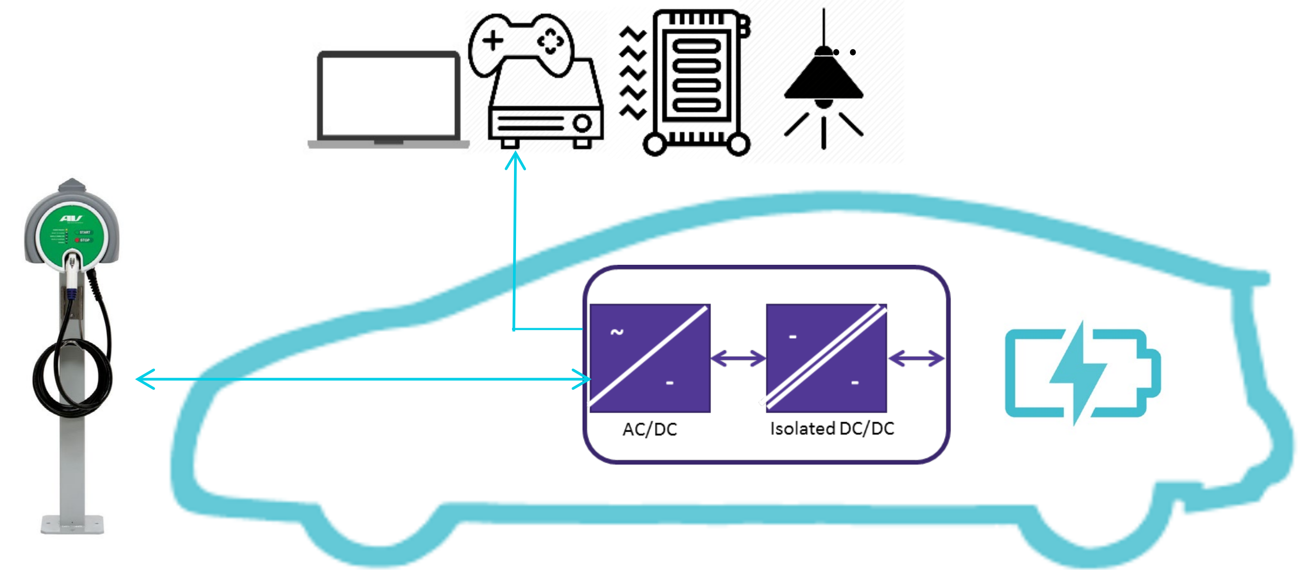
- ✓ High Efficiency > 98.5% in charging and discharging mode
- ✓ Bi-directional Operation
- ✓ Support both 3phase AC and single AC input
- ✓ Support 380Vdc-900Vdc wide DC-link voltage range

22kW High Efficiency Bi-directional DC-DC Converter

Wolfspeed

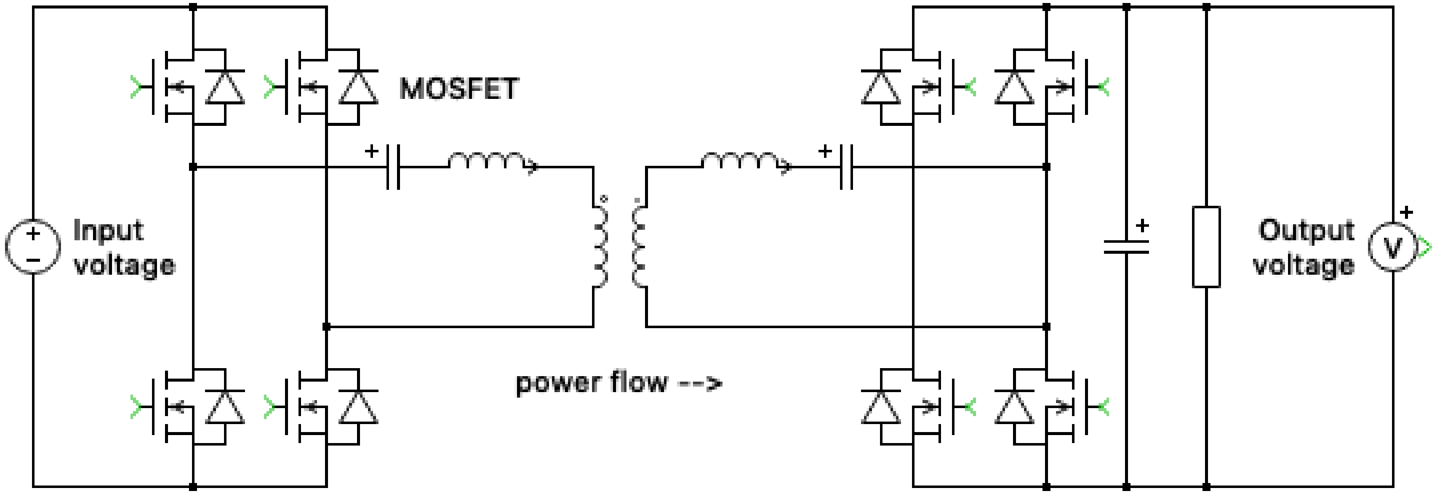
22KW BI-DIRECTIONAL OBC SPECIFICATIONS

Description	3phase AC input Charging	1phase AC input Charging	Discharging Mode
Input Voltage	304Vac~456Vac	90Vac~277Vac	300Vdc-800Vdc
Output Voltage	200-800Vdc	200-800Vdc	220Vac
Rated Power	22kW 36A max	6.6kW	6.6kW
OBC peak Efficiency	>96%	>96%	>96%
DCDC peak Efficiency	>98.5%	>98.5%	>98.5%
DC Bus Voltage	650V-900V	380V-900V	360V-760V



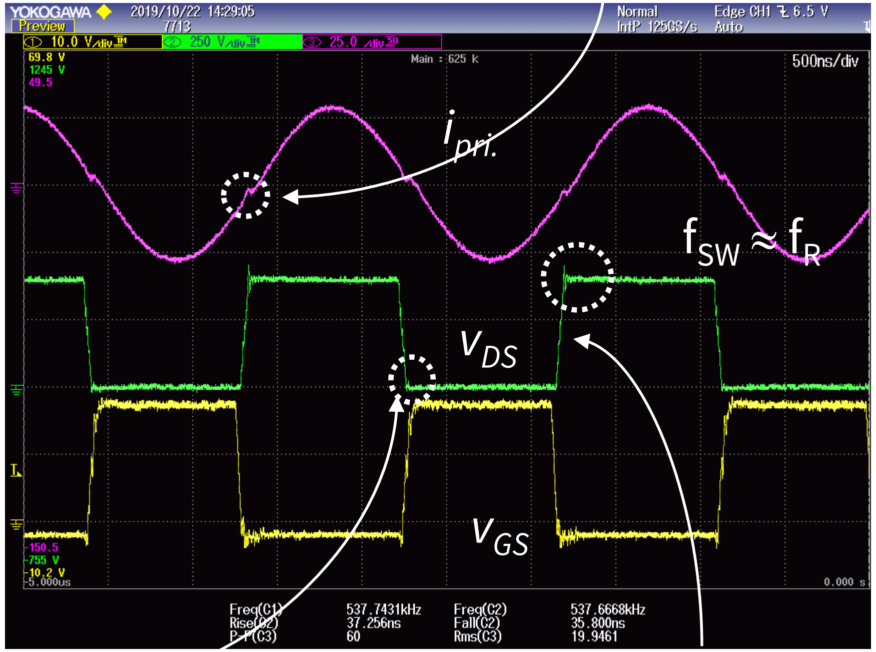
CANDIDATE A FOR DCDC CONVERTER

Full Bridge CLLC Resonant Converter



- ✓ Zero Voltage Turn-On
- ✓ Low Current Turn-off →Low Switching Loss
- ✓ Bi-directional Operation
- ✓ Enable Flexible Control
- ✓ Enable high-frequency switching
- ✓ Low EMI

Low current turn-off

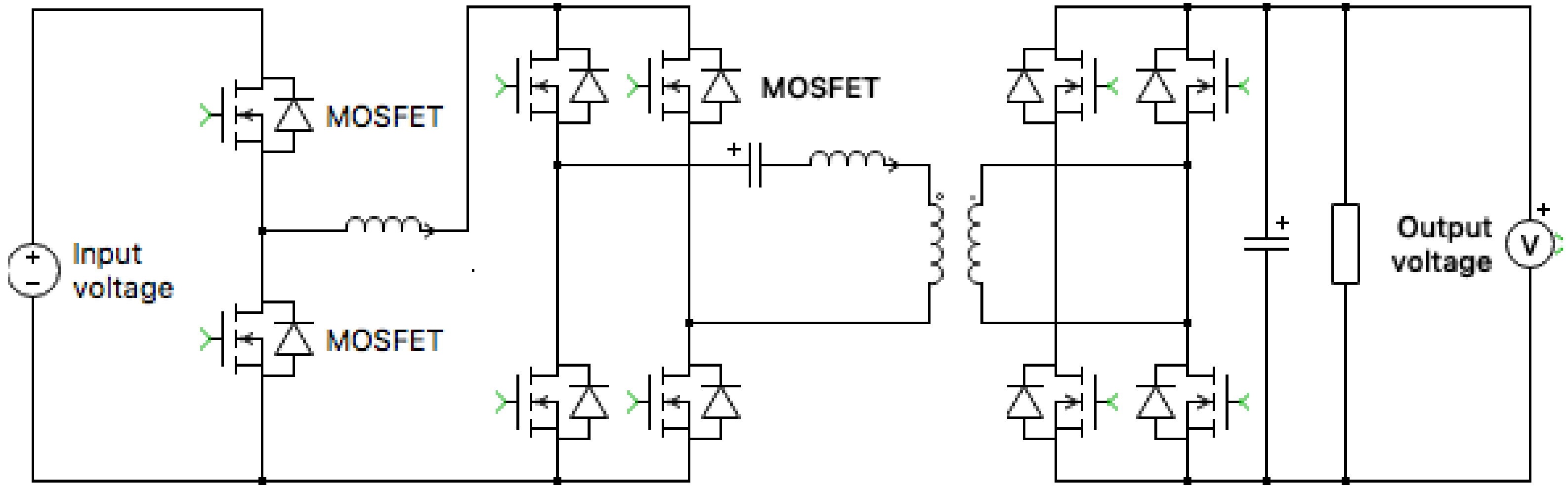


Zero voltage turn-on

Low voltage overshoot

CANDIDATE B FOR DCDC CONVERTER

Buck/Boost +Full Bridge DCX Resonant Converter



Buck/Boost

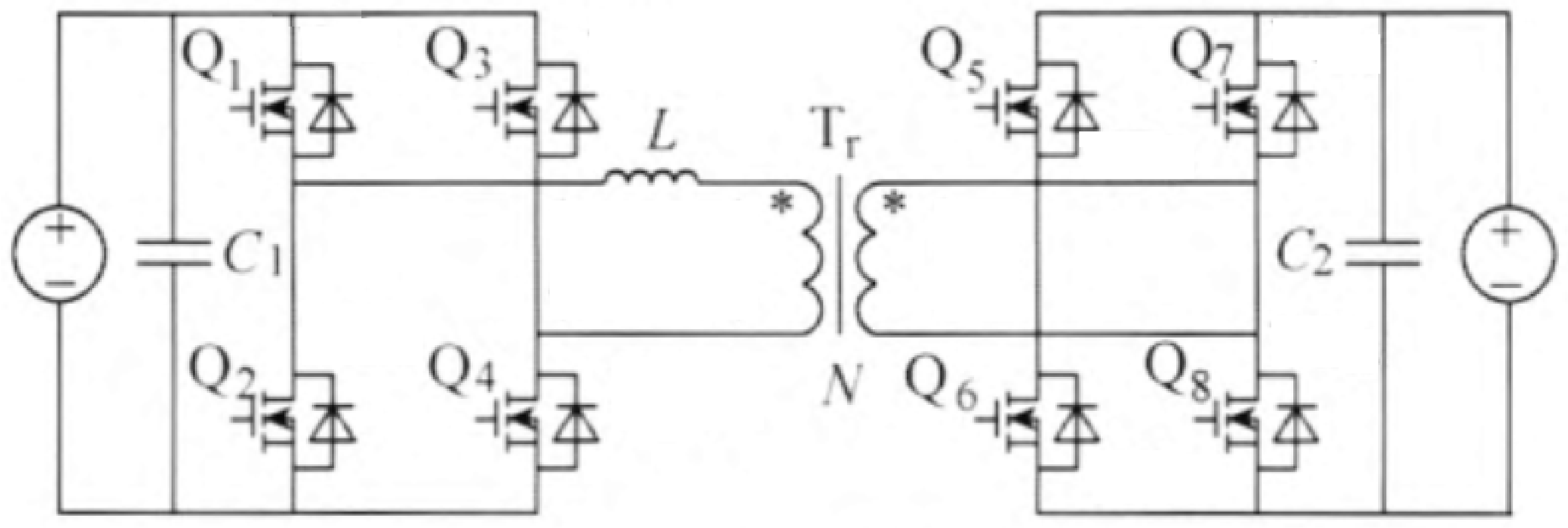
- ✓ Wide Voltage Gain Range by PWM Control
- ✓ Bi-directional Operation
- ✓ High Efficiency

Full Bridge DCX Resonant Converter

- ✓ Zero Voltage Turn-On
- ✓ Low Current Turn-off →Low Switching Loss
- ✓ Bi-directional Operation
- ✓ Simple Fixed Frequency Control
- ✓ Enable high-frequency switching
- ✓ Low EMI

CANDIDATE C FOR DCDC CONVERTER

Dual Active Bridge Converter



- ✓ Wide Voltage Gain Range
- ✓ Bi-directional Operation

- ✓ High Current Turn-off →high switching loss
- ✓ Lower Power density due to Limited switching frequency
- ✓ Limited Load Range for Soft-switching
- ✓ High di/t → EMI concern

TOPOLOGY SELECTION

Dual Active Bridge Converter

Advantages	Disadvantages
Fixed frequency Control	Lower efficiency due to high turn off current
Wide voltage gain range	Lower power density due to limited frequency
	EMI concerns

Full Bridge CLLC Resonant Converter

Advantages	Disadvantages
Wide range ZVS → higher efficiency	To get a wide voltage gain range Hard to optimize the turns ratio, Lm of transformer and Lr
High frequency operation→ Smaller Size, higher power density and lower cost	High frequency operation with high turnoff current in Buck mode → lower efficiency at lower Vout.
ZVS operation, lower turn-off current → EMI friendly	Complex control for primary MOSFETS + adaptive control for SR MOSFET

✓ Full bridge CLLC resonant converter has better performance.

TOPOLOGY SELECTION

Buck/Boost +Full Bridge DCX Resonant Converter		Full Bridge CLLC Resonant Converter	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Almost fixed frequency for DCX converter. → higher efficiency especially for low output voltage	Additional power stage and lower efficiency at system level	Single DCDC power stage →higher efficiency and higher power density	To get a wide voltage gain range Hard to optimize the turns ratio, Lm of transformer and Lr
Easy to optimize Tx to get ZVS→ lower magnetizing current, lower conduction & switching loss	More parts counts, → Larger Size, lower power density and higher cost	Lower parts counts, → Smaller Size, higher power density and lower cost	High frequency operation with high turnoff current in Buck mode → lower efficiency at lower Vout.
Easy to control, both primary and SR MOSFET→ higher reliability	Hard switching Buck/Boost converter → EMI concerns	ZVS operation, lower turn-off current → EMI friendly	Complex control for primary MOSFETS + adaptive control for SR MOSFET

✓ For high Power Density and lower cost, full bridge CLLC resonant converter is selected.

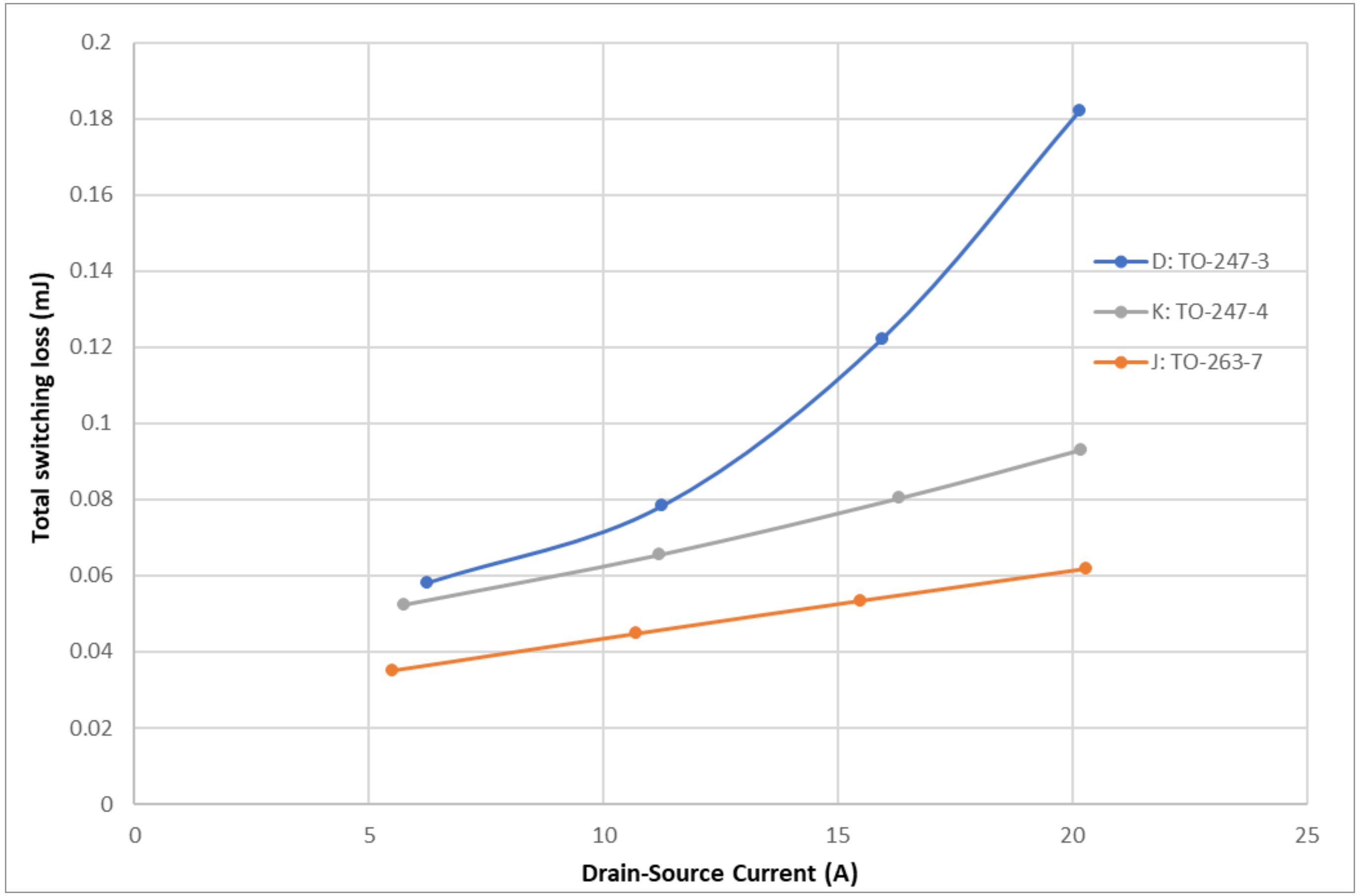
WHY SILICON CARBIDE?

- Smaller capacitance, Fast switching and low switching losses
- Less temperature dependence of Rdson and low conduction loss at high temperature
- Low reverse recovery body diode enables reliability in case of hard-commutation

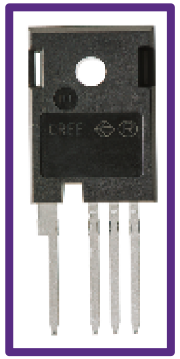
  - ✓ Enabling higher switching frequency
  - ✓ Increasing power density and reducing weight
  - ✓ High efficiency
  - ✓ Bi-directional operation

SWITCHING LOSS COMPARISON FOR DIFFERENT PACKAGE

C3M0060060D/K/J @ RG=2.5Ω, VDS=400V



TO-247-3
NO - Kelvin Pin
2.6mm Creepage
9.14nH Inductance

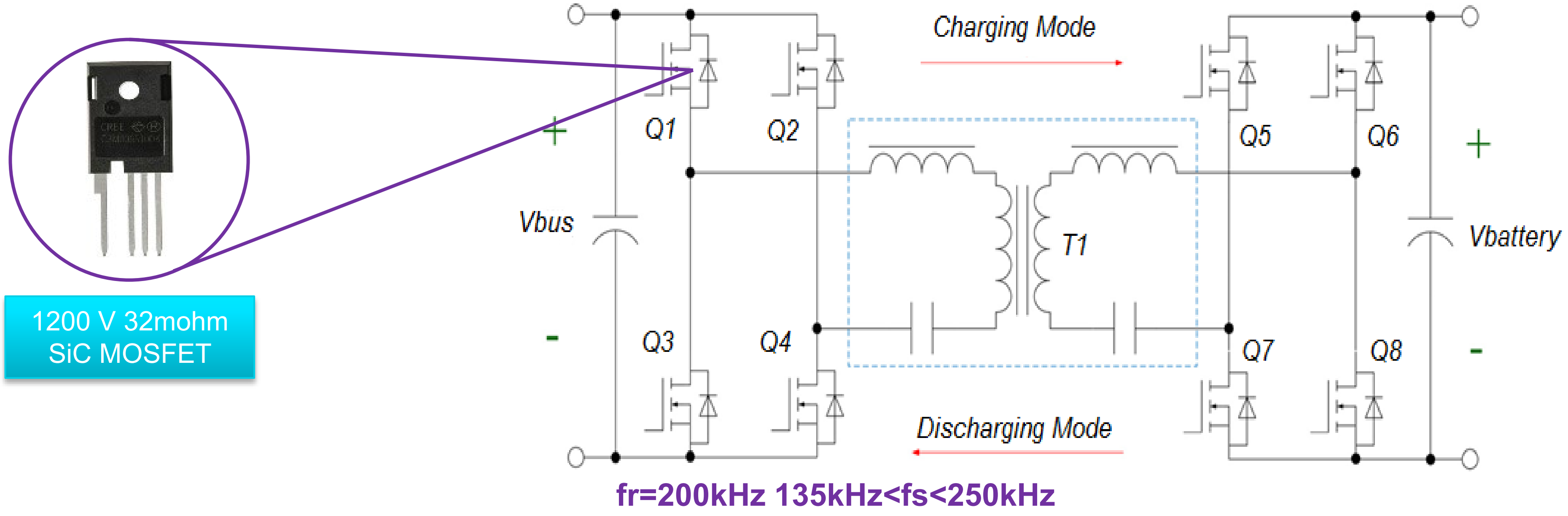


TO-247-4
Kelvin Pin
8mm Creepage
7.36nH Inductance

TO-263-7
Kelvin Pin
7mm Creepage
2.7nH Inductance

POWER COMPONENTS SELECTION

The DC link voltage is up to 900V. Battery voltage is up to 800V.
22.6A rms current for DC link side full bridge MOSFETs.
28.5A rms current for battery side full bridge MOSFETs.



C3M0032120K 1200V 32mohm SiC MOSFET is selected for both primary and secondary of CLLC converters based on electrical stress and thermal design.

- ❑Best figure of merit (FOM)
- ❑New K-Source package reduces switching loss and reduce cross talk
- ❑Easy to drive (V_{gs} = +15V)

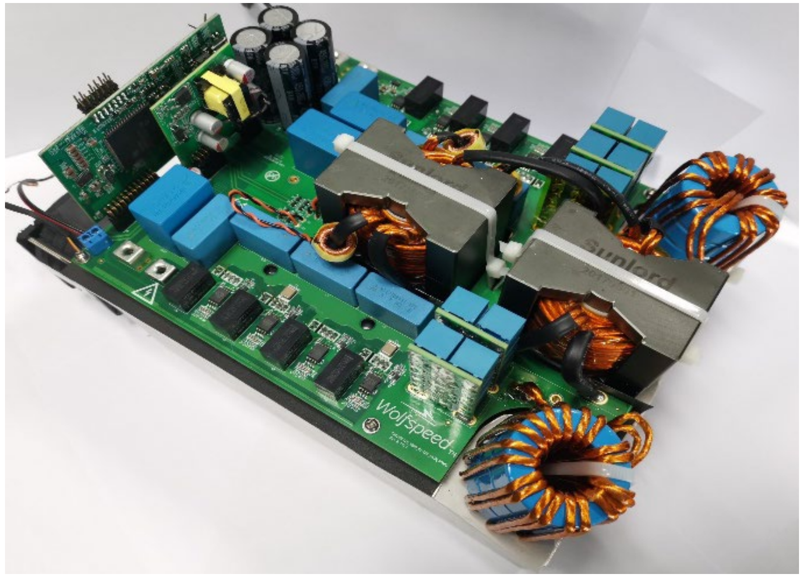
THERMAL RESULTS

Description	Rth (j-c) (c/w)	Calculated Power Loss (watts)	Case Temp.	Calculated Junction Temp.	Max. Operating Junction Temp.	Comments
Output = 611Vdc 22kW						
CLLC MOSFET	0.45	32.5	87.6	102.2	175 °C	**PASS**
CLLC SR MOSFET	0.45	38	91.7	108.8	175 °C	**PASS**
Output = 480Vdc 17.28kW						
CLLC MOSFET	0.45	42	97.8	116.7	175 °C	**PASS**
CLLC SR MOSFET	0.45	38	92.1	109.2	175 °C	**PASS**

- $T_{base\ plate}$=65°C

SUMMARY

The C3M0032120K Silicon Carbide MOSFET and the flexible control scheme enable high efficiency, high power density bi-directional OBC:



- ✓ High Power Density 8kW/L
- ✓ High Efficiency > 98.5% in charging and discharging mode
- ✓ Bi-directional Operation
- ✓ Support the DC link from both 3phase AC and single AC input
- ✓ Support 200Vdc-800Vdc wide battery voltage range

THANK YOU