高密度全碳化硅充电桩模块设计探讨

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上海瞻芯电子科技有限公司

InventChip Technology Co. Ltd

内容

- 公司简介
- 充电桩模块现状和所用拓扑
- 新充电桩模块架构探讨
- 20kW全碳化硅充电桩模块样机测试数据及比较分析
- 小结

上海瞻芯电子介绍

- 2017年成立于上海临港。
- 虚拟IDM模式公司
- 与国内一线半导体行业的合作伙伴开发生产碳化硅 MOSFET和SBD
- 是我国独立自主，掌握整套6英寸SiC MOSFET和SBD工艺的公司

碳化硅MOSFET,SBD

碳化硅模块

碳化硅MOSFET专用驱动及控制IC

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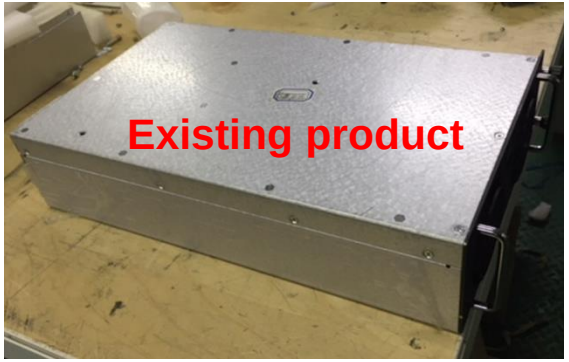
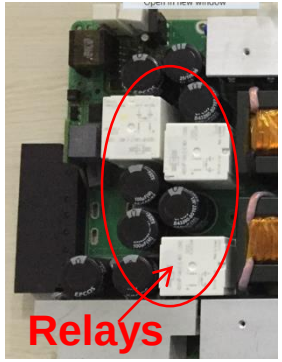
EV充电市场的变化

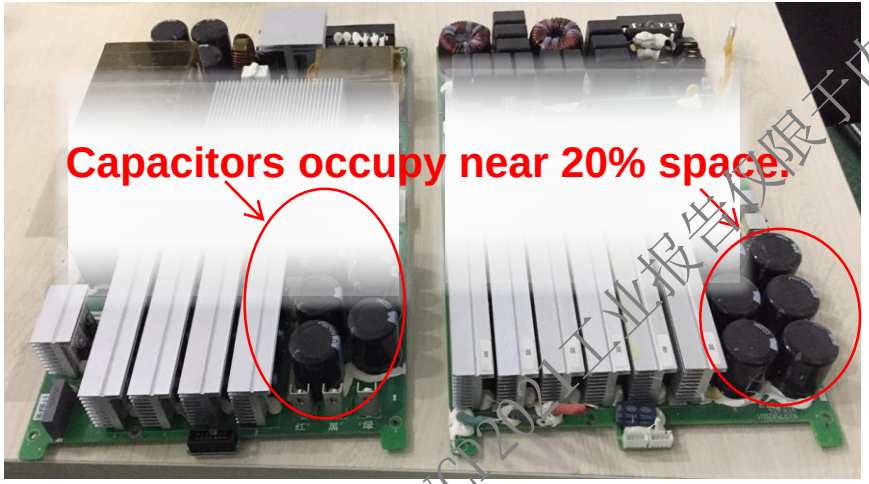
- More charger stations are built into convenient but expensive commercial urban areas
- Shorten charging time
- Deteriorated commercial environment (dust, moisture)

- Increase charger point's power
- Increase power density
- Higher charger module reliability

现有产品和新的设计目标







State-of-the-Art Design:

- 20kW in 2U x 5U x 9U (41W/q.In, 2.5kW/q.dm)
- 30kW in the same size available now
- 2-board structure (PFC board & DC/DC board)

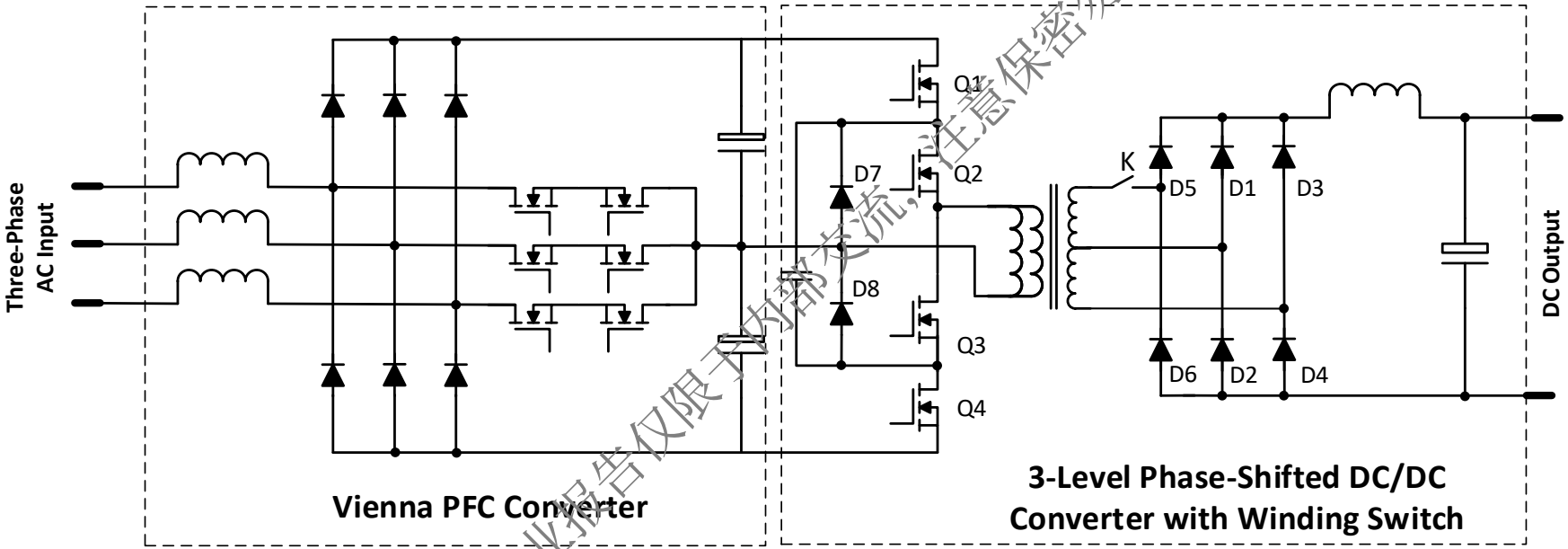
New Design and Targets:

- 20kW in 1U x 5U x 9U
- Reduce or eliminate internal bus capacitance
- One board structure
- Reduce passive component and assembly cost

New Design Approach:

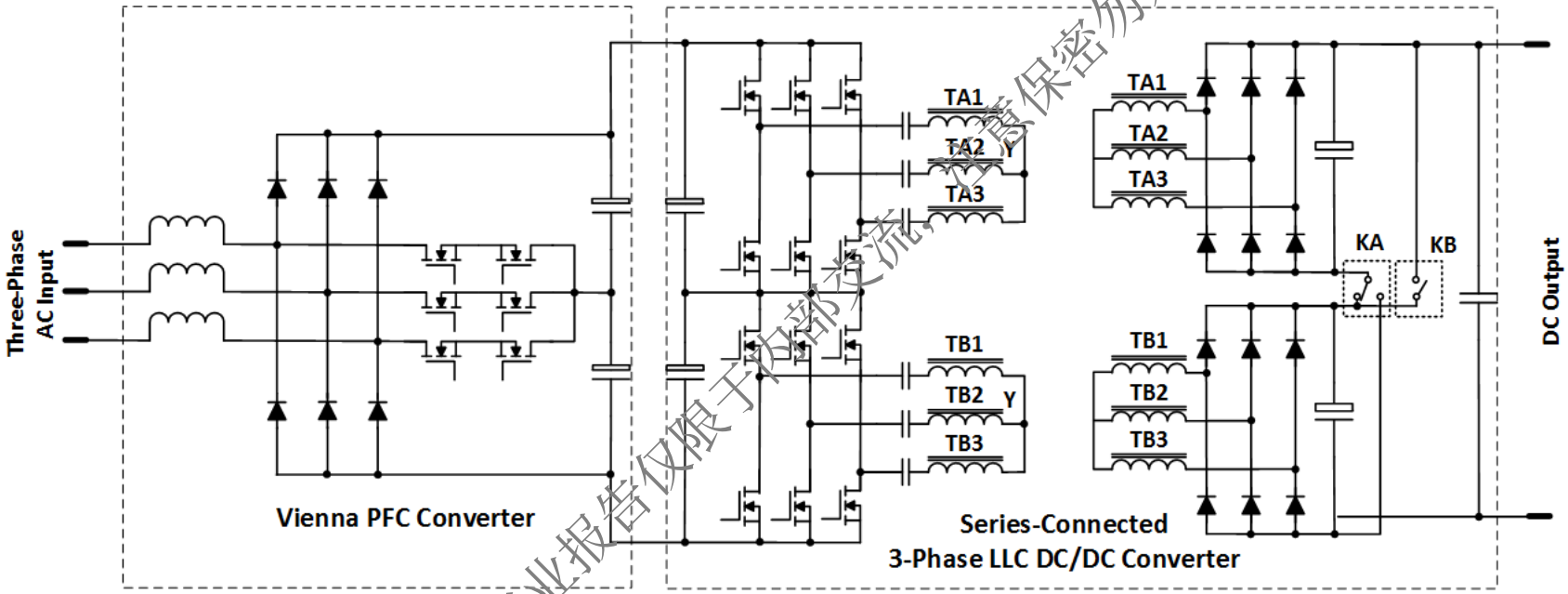
- Increase frequency without sacrificing efficiency
- Use simply 2-level topologies
- Use 1200V SiC MOSFETs

现有设计常用拓扑



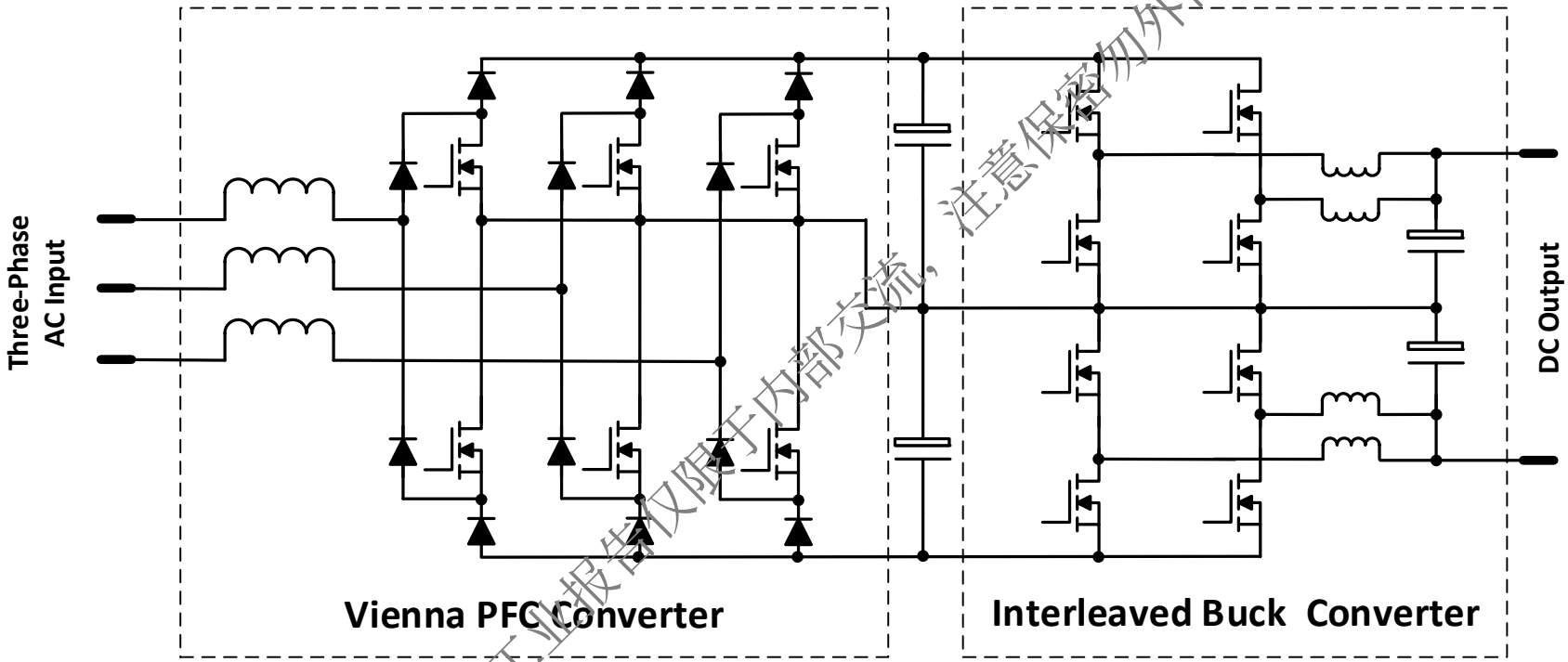
Topology 1: Vienna PFC + 3-Level Phase-Shifted DC/DC

现有设计常用拓扑



Topology II: Vienna PFC + Series-Connected 3-Phase LLC DC/DC

现有设计常用拓扑



Topology III: 3-Level PFC + Series-Connected Buck DC/DC

充电桩设计密度提高的难点

- Vienna PFC and 3-Level PFC achieve excellent efficiency but bulk capacitors are needed to maintain circuit stability.
- Wide output voltage range is required to accommodate variety ranges of EV charging voltages
- Constant power capability for full Vo range
- Topology III achieves excellent efficiency, power density and wide Vo range with constant power capability. For safety reason, a front line-frequency isolation transformer would be required.

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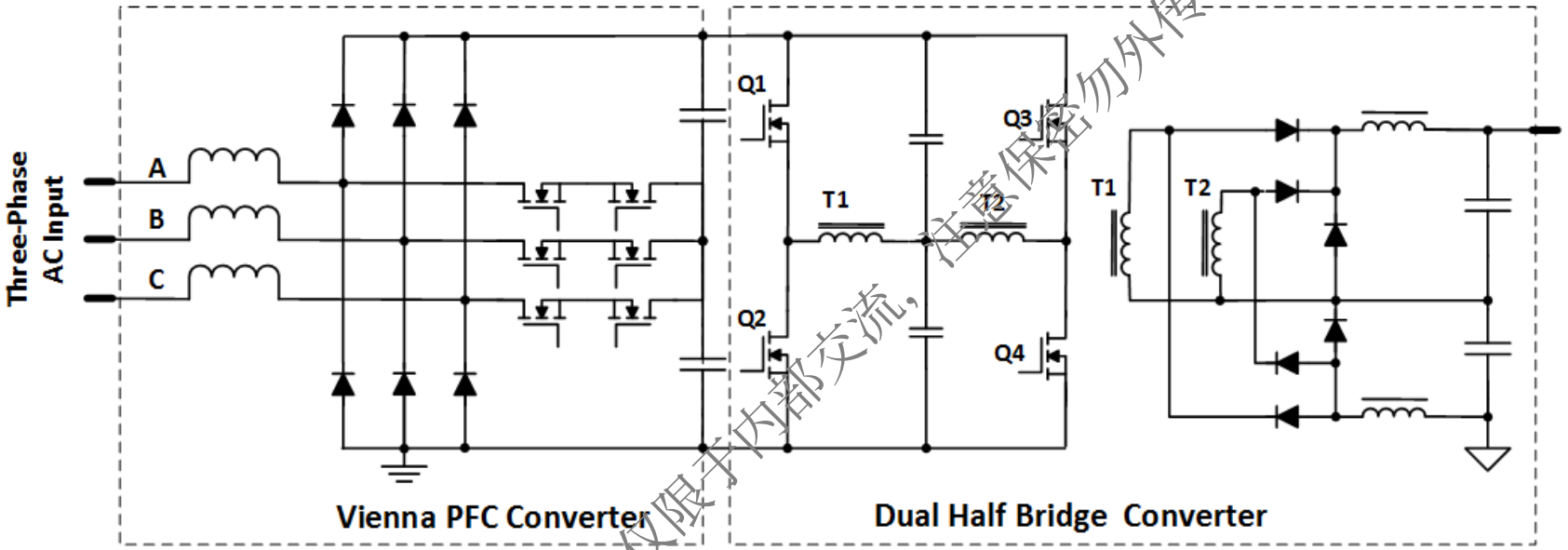
输出串并联无级调节



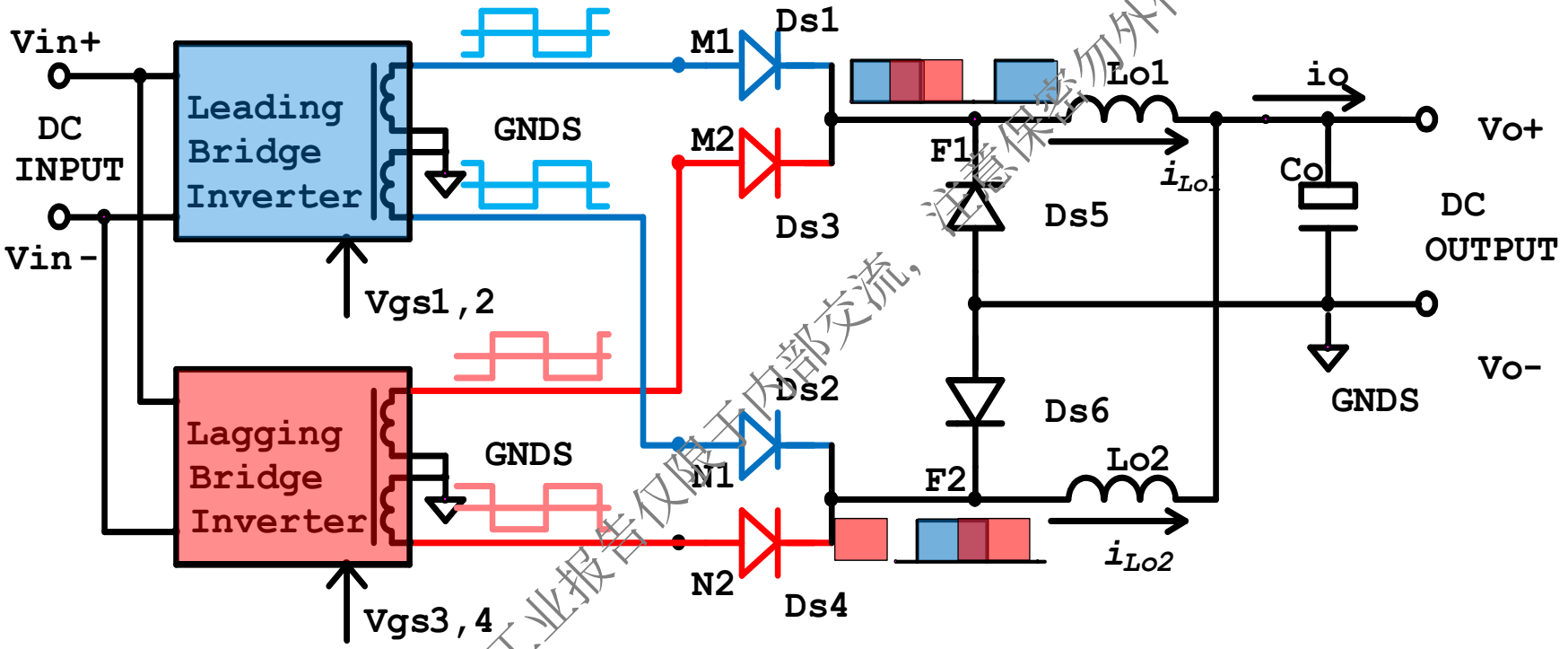
Dual Bridge Advantages:

1. Wide range ZVS with zero circulating current
2. Wide Vo regulation range (100%), No relay needed
3. Seamless output parallel and series connection exchange
4. Simple control

Unsolved issue:

Two bridge current sharing at low output voltage

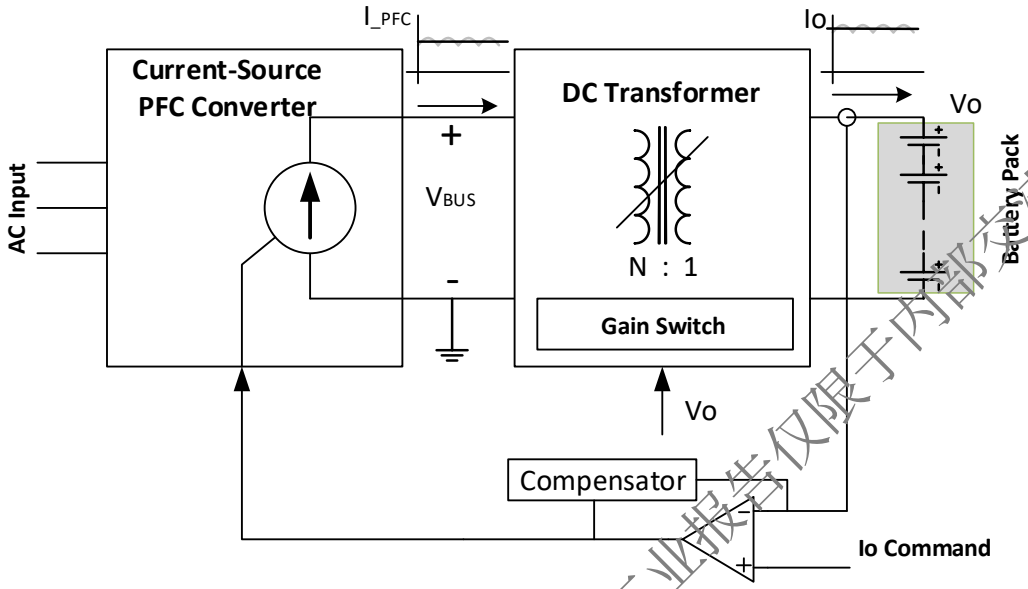
输出串并联无级调节



In Phase = Parallel Connection

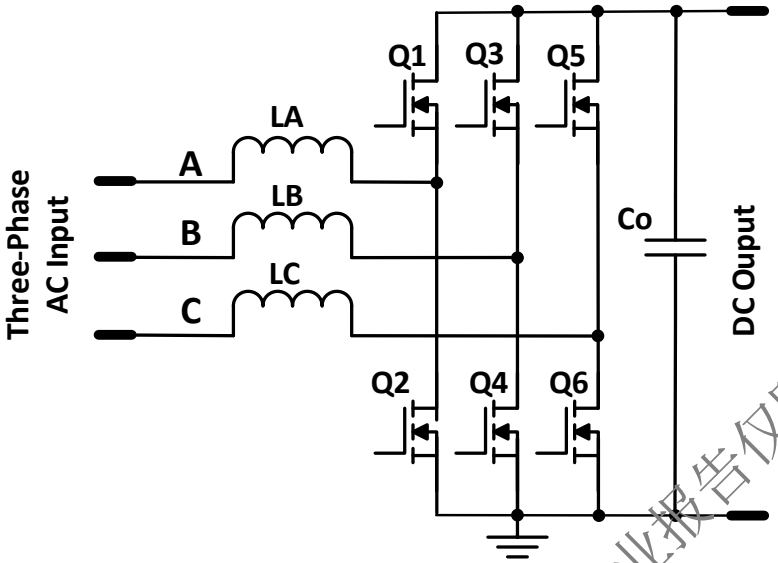
Out of Phase = Series Connection

新充电桩电路架构



- Battery acts as a super capacitor
- DC-X operates at optimal eff point
- PFC operates at current source mode
- PFC current charges battery by DC-X
- PFC output is clamped by reflected battery voltage
- Limited film capacitors needed for PFC output and DC/DC input current ripples

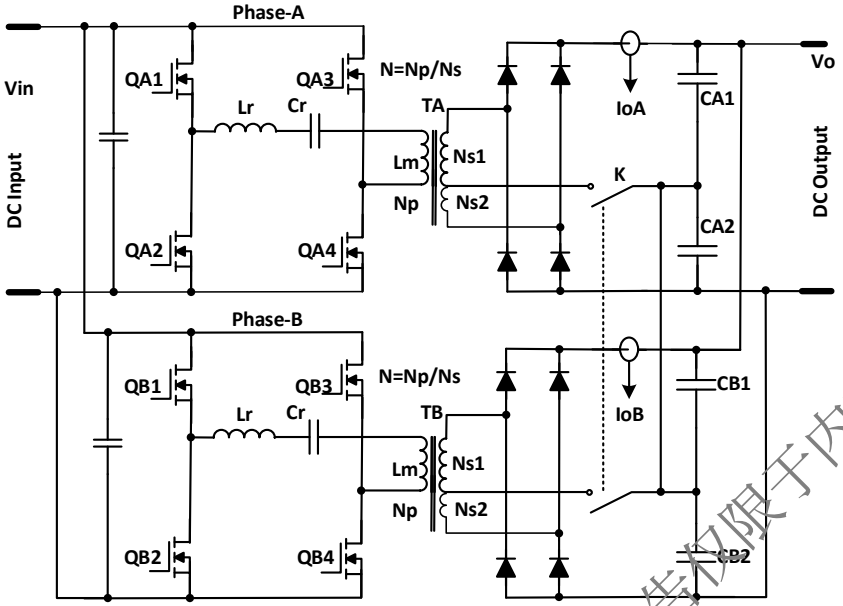
新充电桩电路架构用的PFC

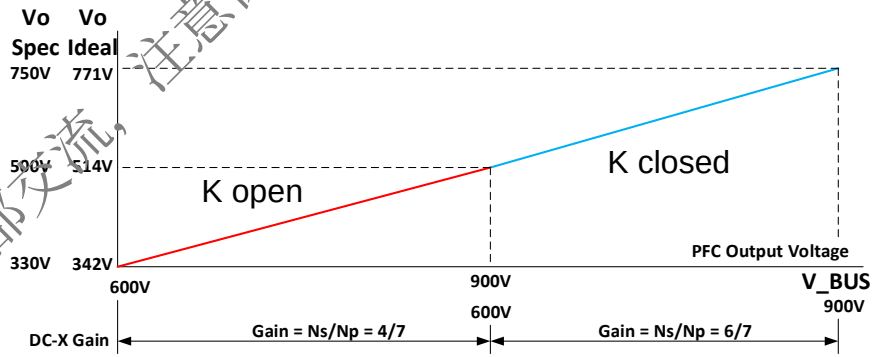


$$Po = 2 \cdot V_{rms} \cdot I_{rms} \left[Sin^2(\omega t) + Sin^2(\omega t + 2\pi/3) + Sin^2(\omega t - 2\pi/3) \right]$$
$$= 3 \cdot V_{rms} \cdot I_{rms}$$

- For the ideal case, there exists no line harmonic current at PFC output
- Co is a film capacitor for switching current ripple absorption
- No evidence shows line-harmonic current is harmful to batteries if it does exist.

新充电桩电路架构的DC-X





- PFC output voltage able to range from 600V to 900V with 1200V SiC MOSFETs.
- DC-X output ranges from 330V to 500V or from 500V to 750 by switching gains between 4/7 and 6/7.
- DC output becomes voltage doubler when relay K is closed, and the Vo switches from the low voltage range to high voltage range.

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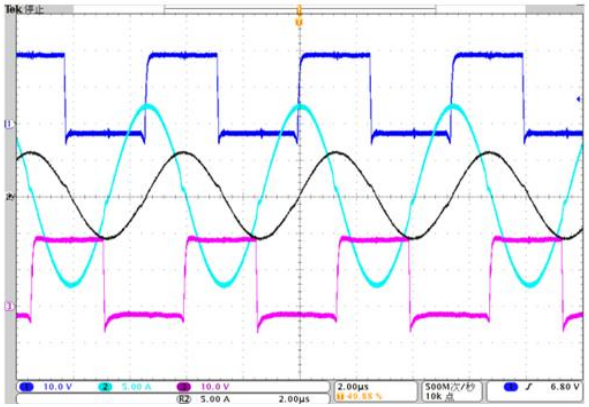
20 kW 充电桩模块样机

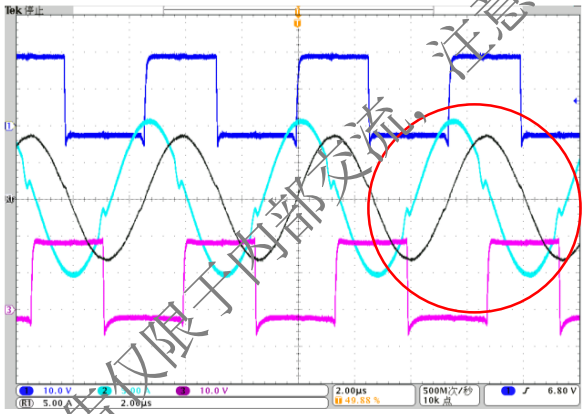
- One 1U x 5U x 9U board is broken into two boards to facility lab test
- PFC output capacitors are installed so PFC can be debugged independently

全桥LLC并联均流控制

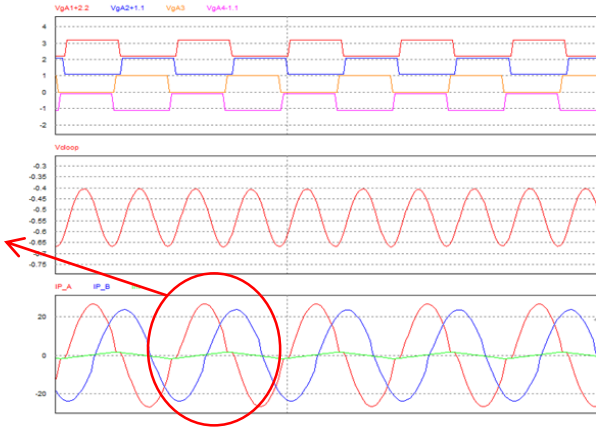
- To avoid beat-frequency current ripple, paralleled LLC converters must operate at the same frequency
- Different resonant frequencies would result in different output current or power
- For full bridge LLC converters, phase-shifting control can be used to balance their output current



Before current balancing control is enabled.



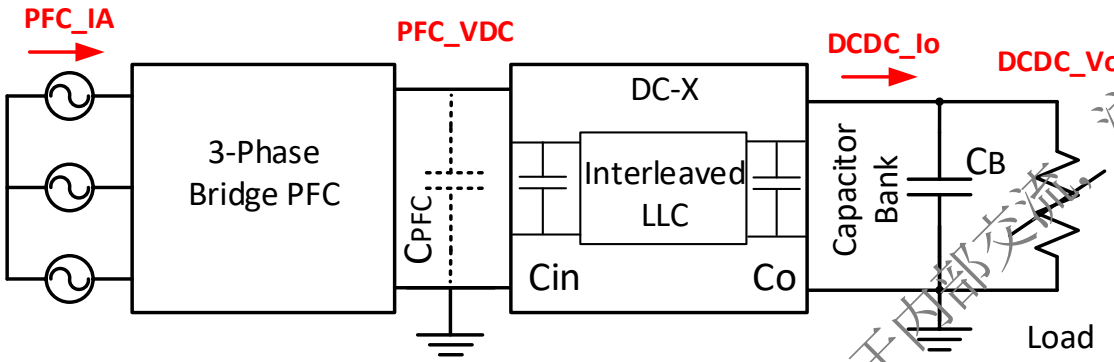
Current balancing control is enabled.

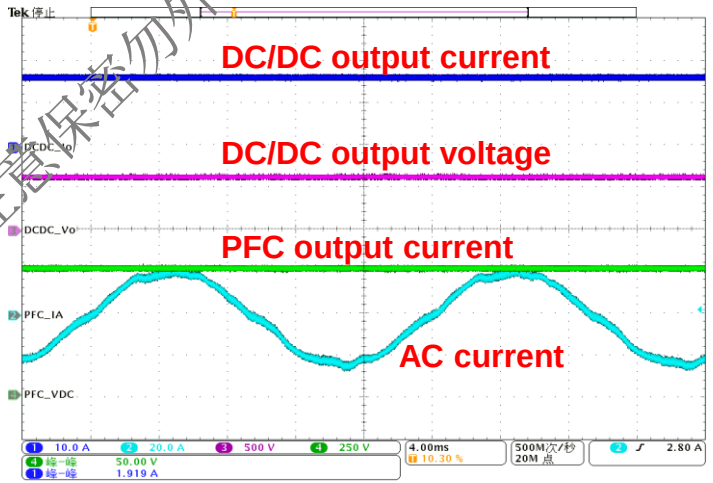


Current balancing control simulation with +/- 10% resonant inductance variation.

Note: Even the resonant currents may not have the same amplitude, their output currents actually reach the same average value.

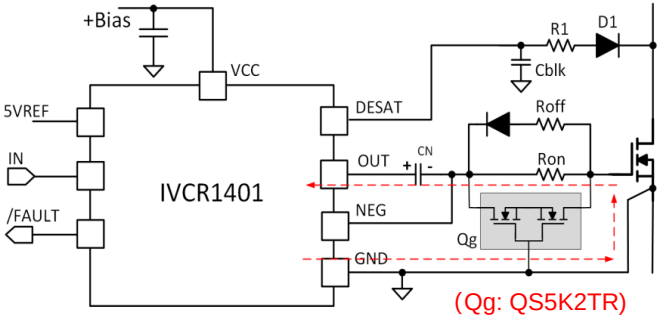
PFC 和 DC/DC 整机测试





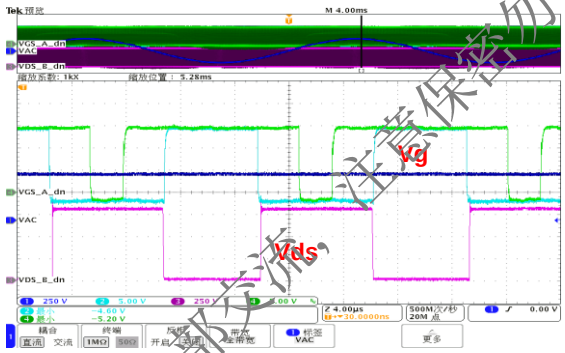
- A 20x2x330uF/450V capacitor bank is connected at DC output to emulate a battery pack.
- PFC output capacitance was reduced to 68uF (electrolytic capacitors)
- DC-X input capacitors are 2x12uF (film capacitors)

驱动电路-碳化硅专用驱动IC：IVCR1401

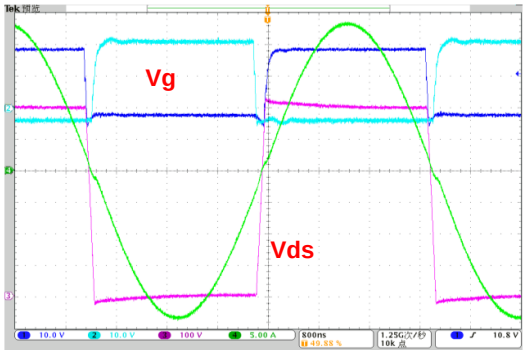


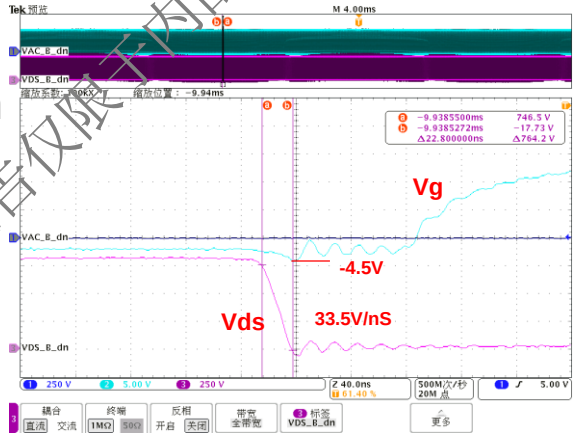
- Integrated negative bias
- Desat OCP
- Optional active Miller Suppression

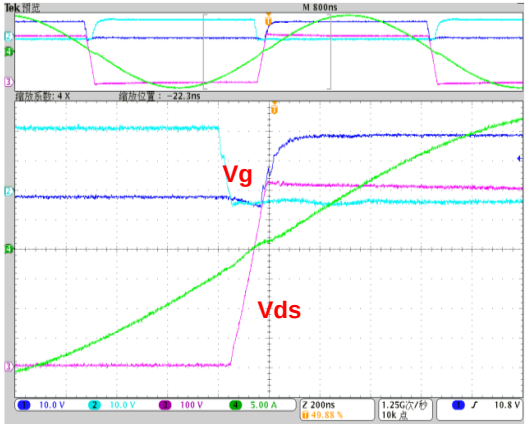
PFC Waveform (TO-247-4L)



LLC Waveform (TO-247-3L)





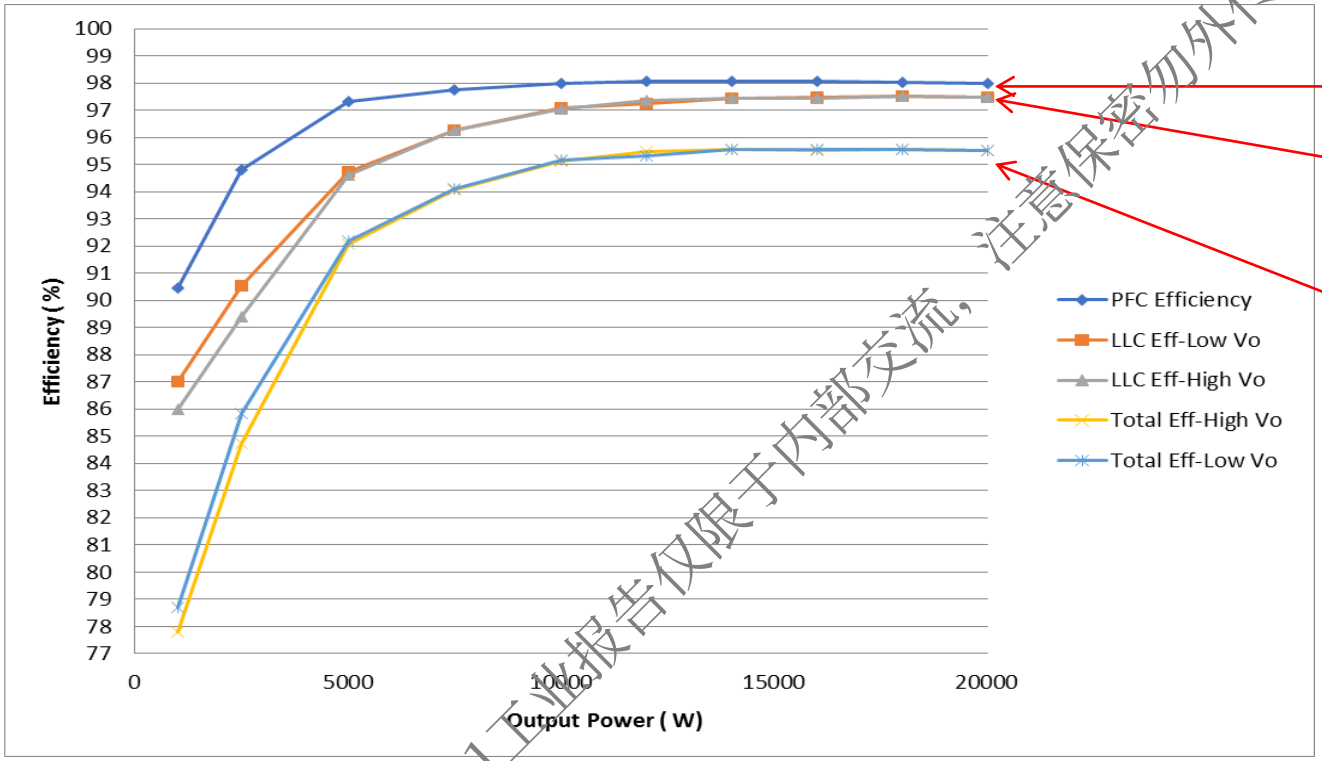


SiC MOSFETs

PFC: 50mOhm 1200V (IV1Q12050T4)

LLC: 50mOhm 1200V (IV1Q12050T3)

样机效率



PFC at 65kHz

LLC at 180kHz

Almost the same eff for high and low Vo outputs – good for constant power operation

400V Vac input， 435V and 655V outputs

样机测试结果和现有产品的比较

	Product A	Product B	Inventchip Prototype
Size	2Ux5Ux9U	2Ux5Ux9U	1Ux5Ux9U
Power	20kW	20kW	20kW
Topologies	Vienna + 3-Level Phase-shifted full bridge	Vienna + Series-Connected 3-phase LLC	3-phase PWM PFC+ 2-Level Interleaved LLC
PFC fs DC/Dc fs	20kHz 70kHz	24kHz fr: 107kHz 75 – 350kHz	65kHz 180kHz
Constant Power	No (constant current)	Yes	Yes
Power Devices	SiC diodes + Si MOSFETs +FRDs	SiC diodes + Si MOSFETs +FRDs	SiC MOSFETs + SiC Diodes
Peak Efficiency	95.5% Peak 95.0% Full load	96% Peak 95.3% Full load	95.5% Peak and full load

Merits of The Proposed Architecture

- Improve power density
- Reduce PFC output capacitance
- 2-3 times switching frequency improvement
- 2-level topologies simplify circuit design
- Good efficiency at high switching frequency

小结

- 概括总结常用充电桩常用拓扑
- 除磁性器件外，电解电容和输出继电器影响功率密度
- 探讨输出串并联无级调节和切换的可能方案
- 探讨新的充电桩拓扑架构并在20kW 全碳化硅样机上实现
- 使用新架构和1200V碳化硅有望使功率密度有明显提升

谢谢！

Thank You !