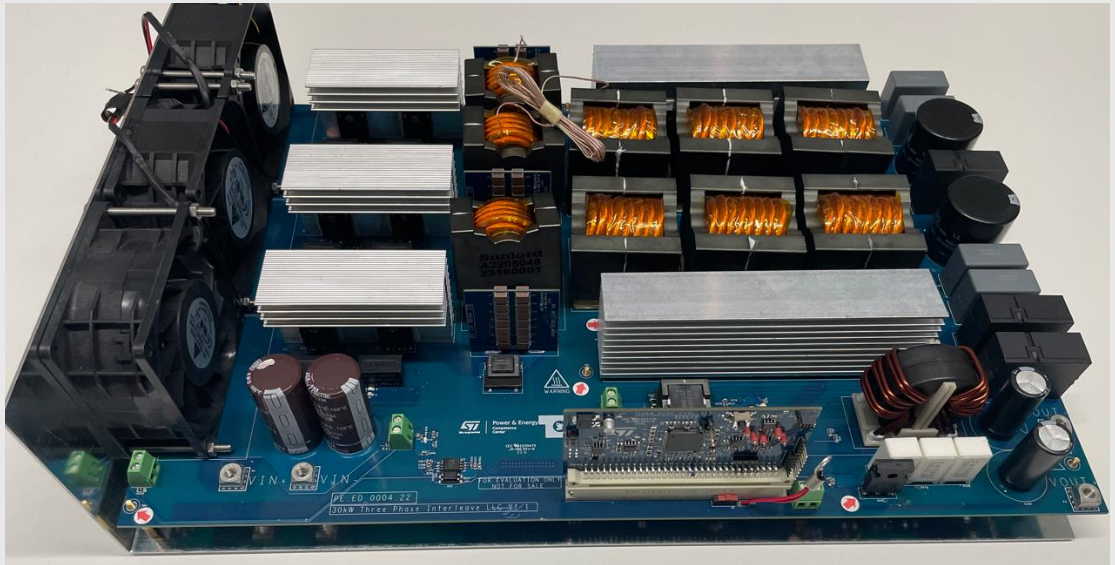
INDUSTRIAL SUMMIT 2023
SHENZHEN, CHINA | 28 SEPTEMBER
POWERING YOUR SUSTAINABLE INNOVATION



30 kW SiC MOSFET DC-DC with STM32G4 for EV chargers

Jianjun Ni

Power & Energy Competence Center

STMicroelectronics

Power & Energy
Competence
Center

Power and energy application segments

Power supply

Energy generation and distribution

Smart lighting (low power)

Smart home lighting, smart street lighting, TV backlighting, plant lighting

Consumer power (low power)

Smart charger, adapter, wireless charger, USB-PD, TV & gaming

System power (medium power)

Server, 5G power, telecom, DCDC networking, POE

Smart metering & wireless charging

Wireless charging & wireless power transfer system, smart metering PLC, sub-GHz, smart solar system

Energy generation & distribution

Solar, commercial battery storage, charging station, UPS, inverter/DC-AC)

STPMIC STUSB STSPIN MasterGaN STPOWER STM32

Products
STNRG011, M2, M6, DM6, K5, F7, STM32, FERD, SiC MOSFET/Rectifiers Protections, USB-PD, STWBC, STWLC, STCOMET, STCOM, STMET STPM01, STPM33/34

STWLC STWBC STCHARGE ST Op Amps BlueNRG VIPerPlus ST PROTECT

Agenda

1 EV charger background

2 30 kW DC-DC digital solution

3 30 kW DC-DC board performance

4 Summary

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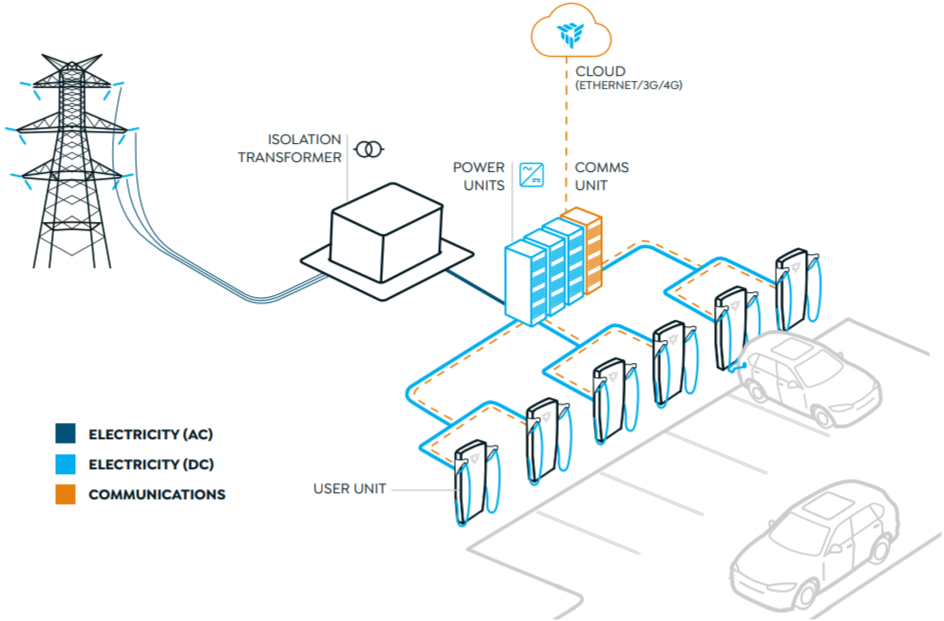
Background

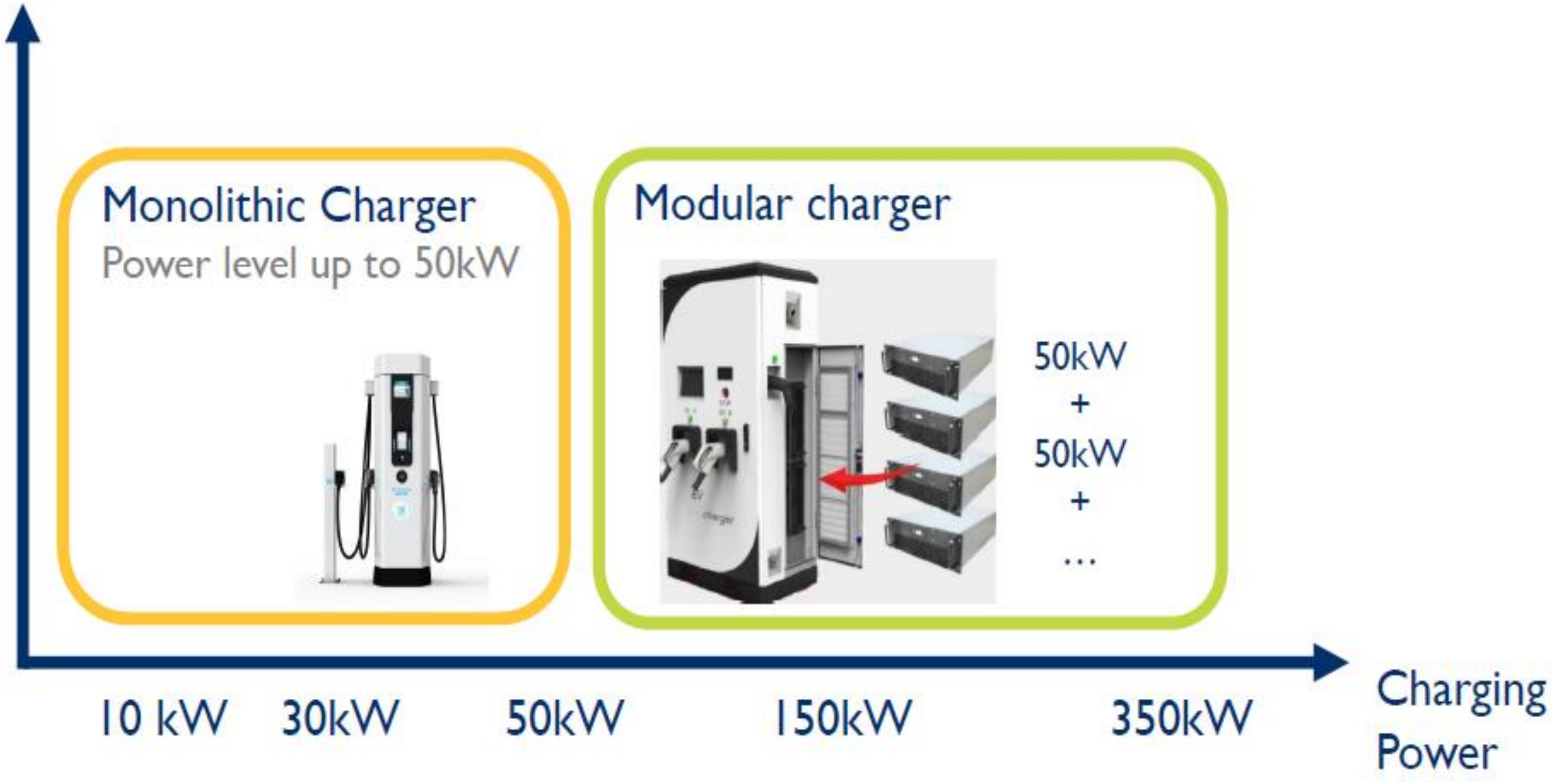
DC charging stations

DC charging comes in different forms of stations, wall boxes, mobile equipment, V2G, liquids, etc



DC charging trends

DC charging comes in higher power and higher voltage



Monolithic Charger

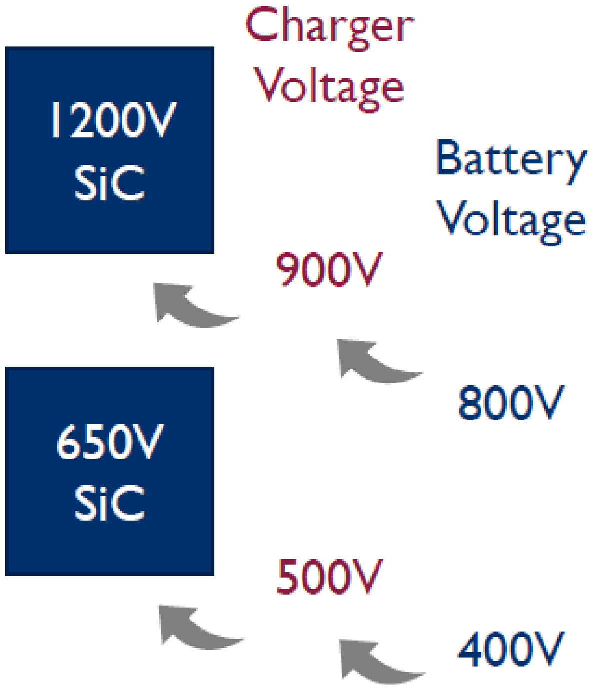
Power level up to 50kW

Modular charger

50kW
+
50kW
+
…

10 kW, 30kW, 50kW, 150kW, 350kW

Charging Power

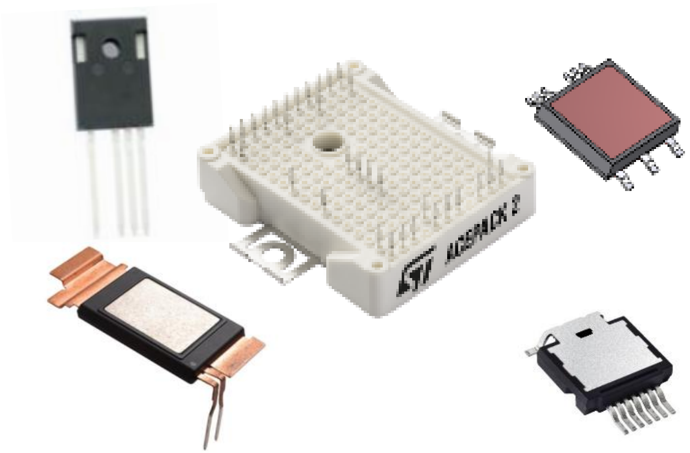


1200V SiC

650V SiC

Charger Voltage: 500V, 900V

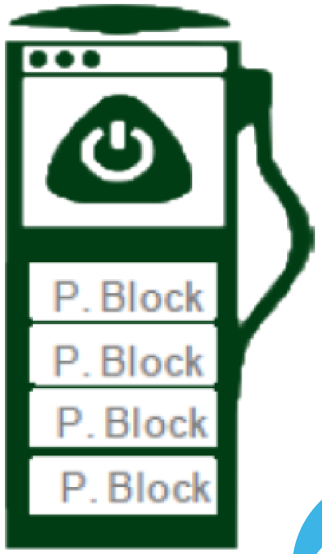
Battery Voltage: 400V, 800V



DC charging module

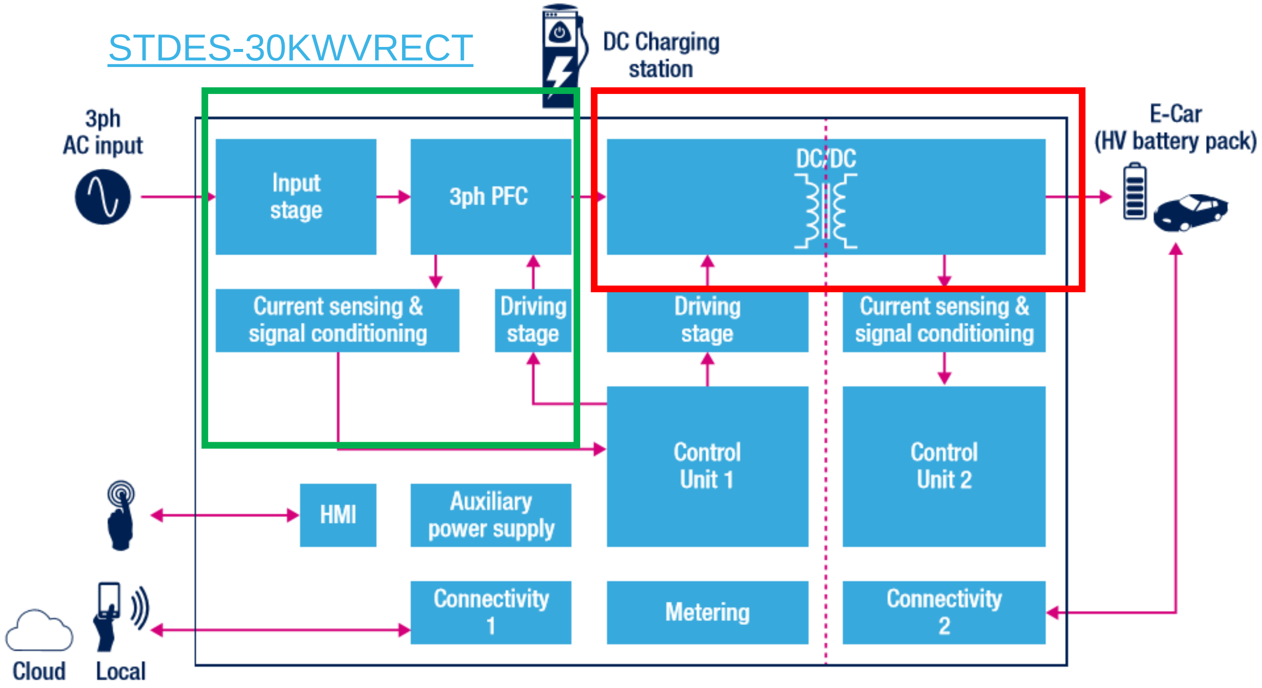
30 kW three-phase LLC reference design with digital control (STDES-30KWLLC)

Charging Pile
60 - 350 kW



Charging module
15 - 60 kW

STDES-30KWVRECT



30 kW DC-DC digital solution

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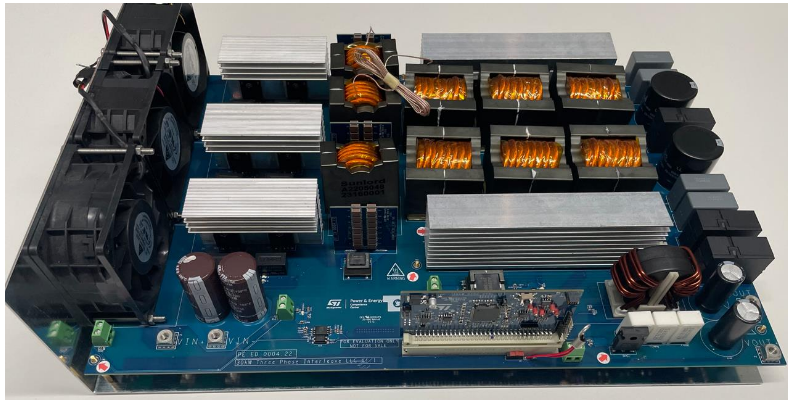
30 kW three-phase LLC converter STDES-30KWLLC



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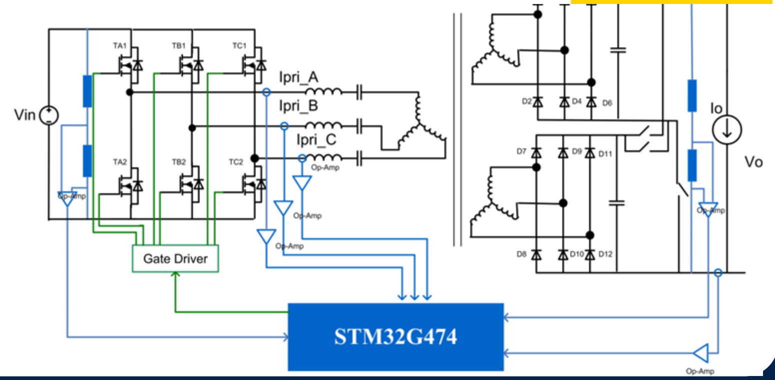
Power & Energy Competence Center



Application key specification:

- Rated output power: 30 kW, switching frequency 100-300 kHz
- DC input voltage: 650 VDC – 850 VDC
- DC output: 200 VDC – 1000 VDC
- Peak efficiency: >98%
- STM32G474: High performance 32-bit MCU

Key products

MCU: STM32G474VET6,
SiC MOSFET: SCT025W120G3-4AG
Ultrafast diode: STTH60RQ06W
ASP product: STGAP2SICS, L6565
Schottky diodes: STTH1L06A, STPS1150A, STPS2H100A, STPS2L60A
GPA: LM393DT, LD29080DT50R, LD29080DT33R, TSV9121DT

STPOWER STGAP STM32

Key benefits

- Higher efficiency achieved based on 1200 V SiC device and high switching frequency
- Less SiC MOSFET to achieve higher power with single LLC converter
- Wide range and high output voltage

Promotion slide

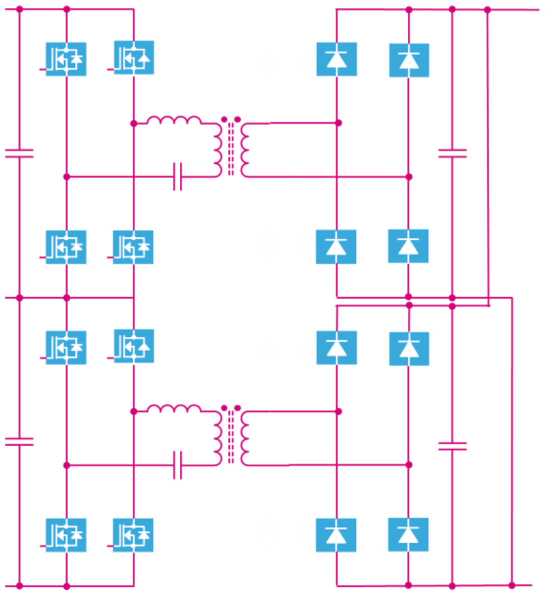
Testing report

Design material

Demo video

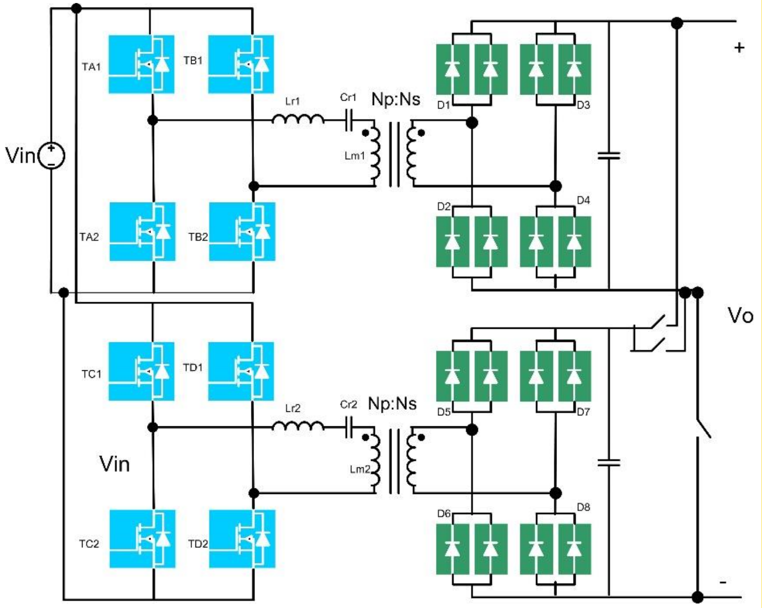
Topology comparison

Full bridge Series LLC



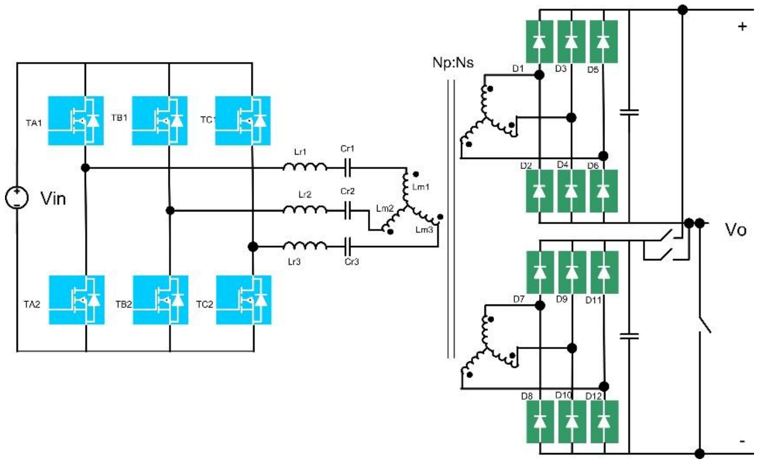
- Control complexity: high
- Component count: high
  8 pcs 650 V Si Mos + 16 pcs Si diode
- Need control methods for current/ voltage sharing
- Low efficiency
- High challenges on resonate devices design and cooling

Full bridge Parallel LLC



- Control complexity: high
- Component count: high
  8 pcs 1200 V SiC Mos + 16 pcs Si diode
- Need control methods for current/ voltage sharing
+ High efficiency
+ Middle challenges on resonate devices design and cooling

Three-phase interleaved LLC ✓



+ Control complexity: low
+ Component count: low
  6 pcs SiC Mos + 12 pcs Si diode
+ Natural current/voltage sharing
+ Low output ripple current
+ Middle efficiency
- Little challenges on resonate devices design and cooling

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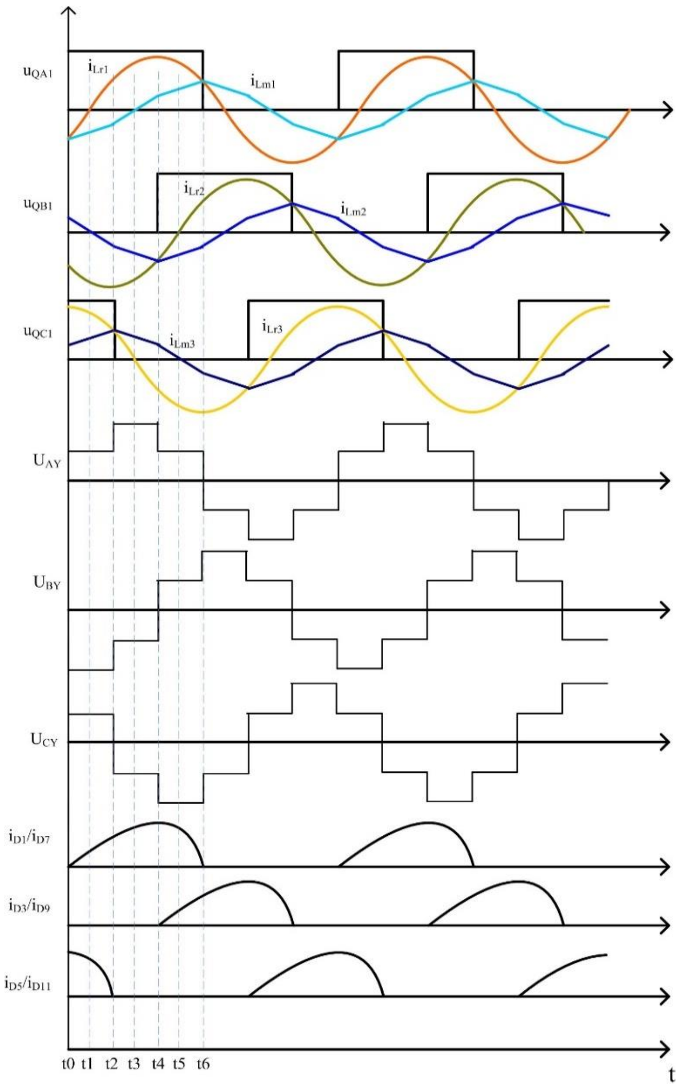
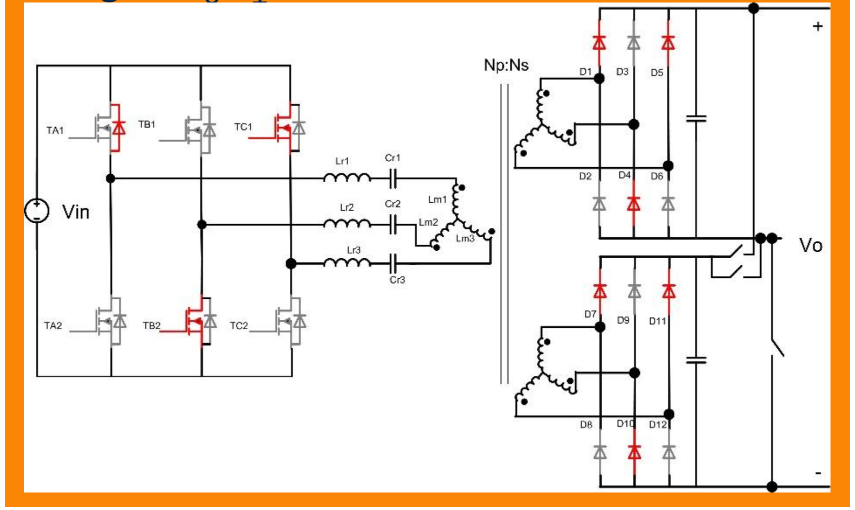
Operation principle



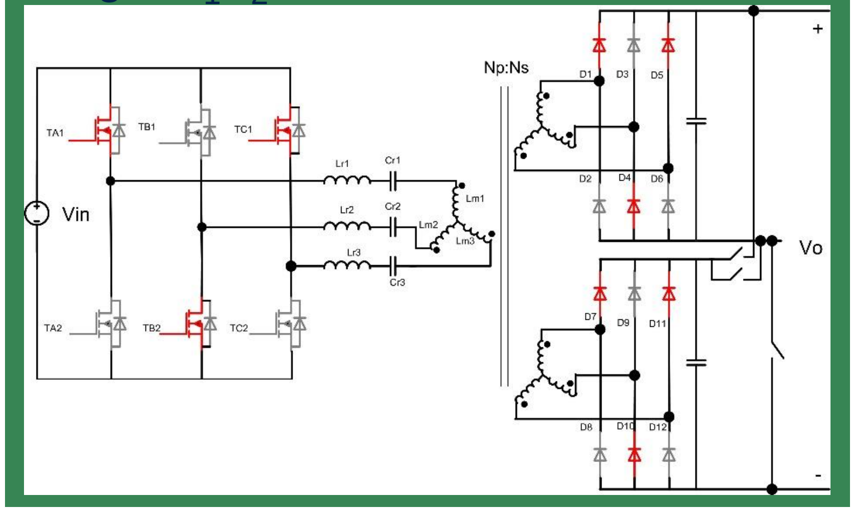
Stage1 t_0-t_1



- ☐ Primary side:
  - D_{A1} Q_{B2} Q_{C1} ON
  - $i_{Lr1}<0$, $i_{Lr2}<0$, $i_{Lr3}>0$
  - $U_{AY} = V_{in}/3$, $U_{BY} = -2V_{in}/3$, $U_{CY} = V_{in}/3$

- ☐ Secondary side:
  - D_1 D_4 D_5 ON
  - D_7 D_{10} D_{11} ON

Stage2 t_1-t_2

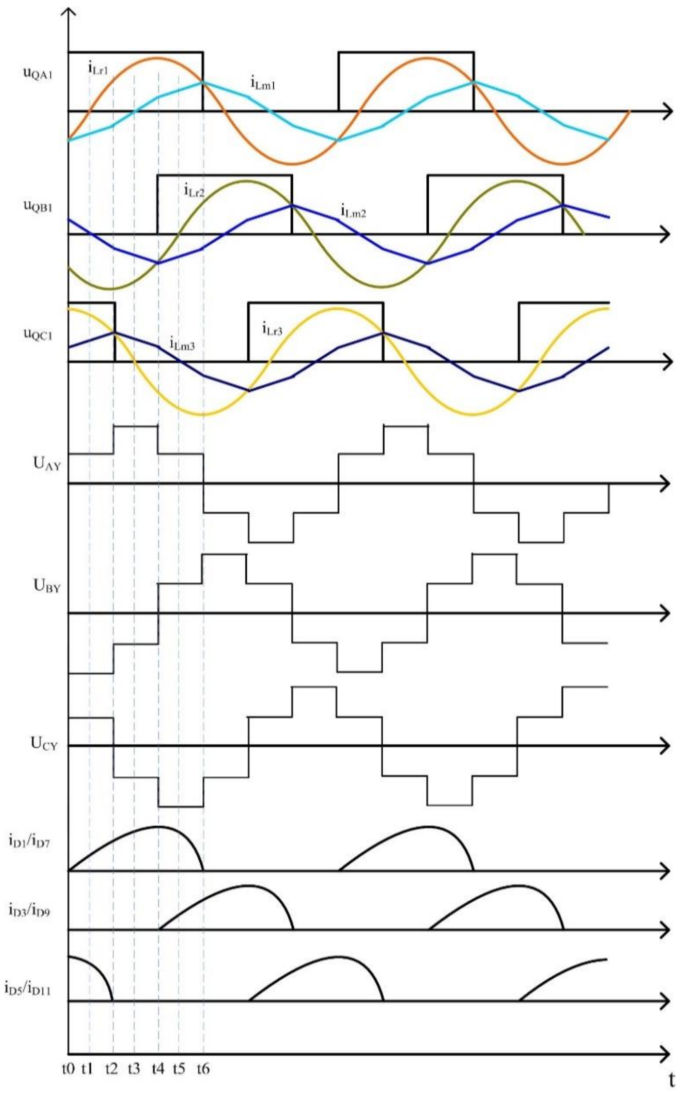


- ☐ Primary side:
  - Q_{A1} Q_{B2} Q_{C1} ON
  - $i_{Lr1}>0$, $i_{Lr2}<0$, $i_{Lr3}>0$
  - $U_{AY} = V_{in}/3$, $U_{BY} = -2V_{in}/3$, $U_{CY} = V_{in}/3$

- ☐ Secondary side:
  - D_1 D_4 D_5 ON
  - D_7 D_{10} D_{11} ON

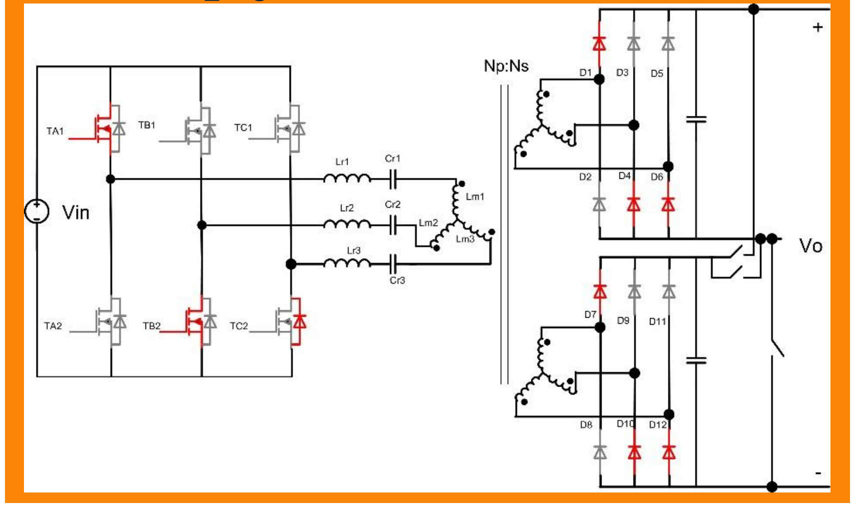
$f_s = f_r$

Operation principle



$$f_s = f_r$$

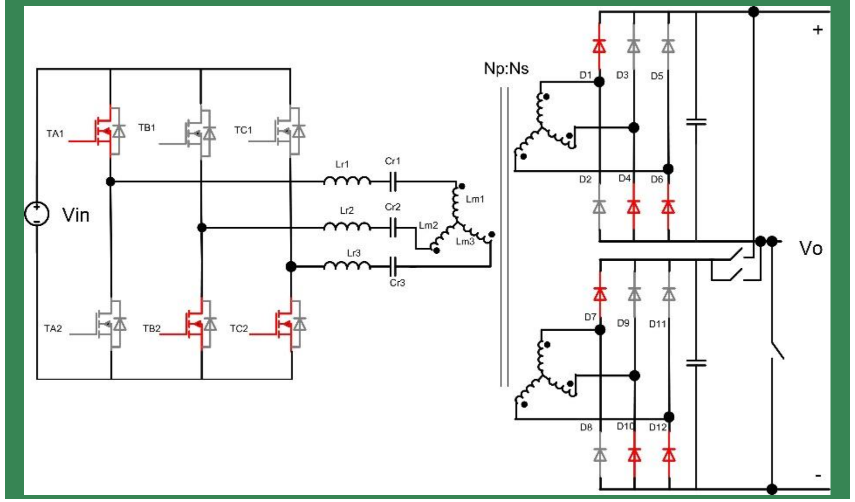
Stage3 t_2-t_3



- ☐ Primary side:
- Q_{A1} Q_{B2} D_{C2} ON
- $i_{Lr1}>0$, $i_{Lr2}<0$, $i_{Lr3}>0$
- $U_{AY} = 2V_{in}/3$, $U_{BY} = -V_{in}/3$, $U_{CY} = -V_{in}/3$

- ☐ Secondary side:
- D_1 D_4 D_6 ON
- D_7 D_{10} D_{12} ON

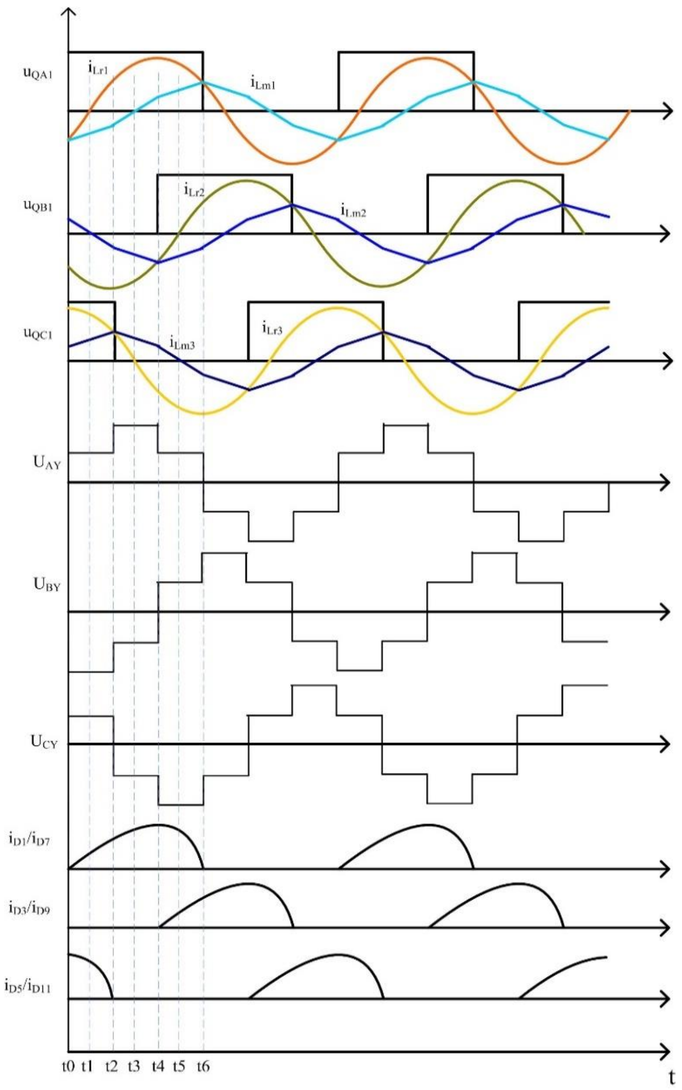
Stage4 t_3-t_4



- ☐ Primary side:
- Q_{A1} Q_{B2} Q_{C2} ON
- $i_{Lr1}>0$, $i_{Lr2}<0$, $i_{Lr3}<0$
- $U_{AY} = 2V_{in}/3$, $U_{BY} = -V_{in}/3$, $U_{CY} = -V_{in}/3$

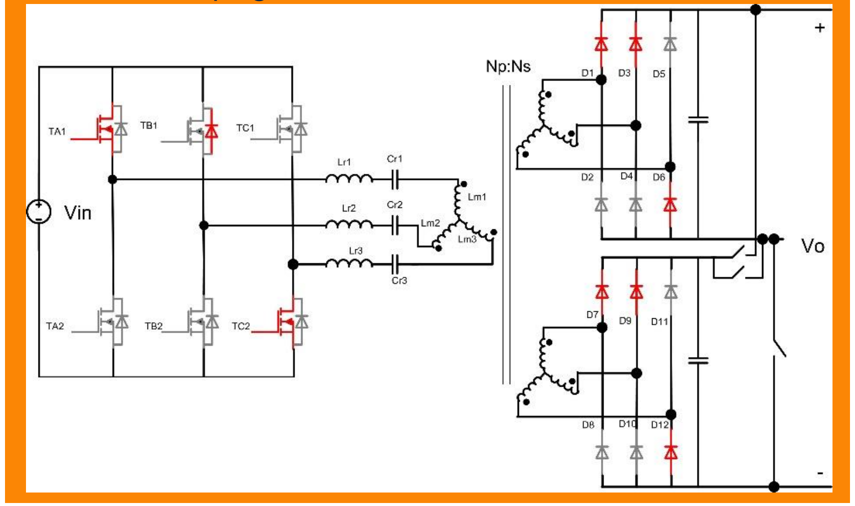
- ☐ Secondary side:
- D_1 D_4 D_6 ON
- D_7 D_{10} D_{12} ON

Operation principle



$f_s = f_r$

Stage5 t_4-t_5



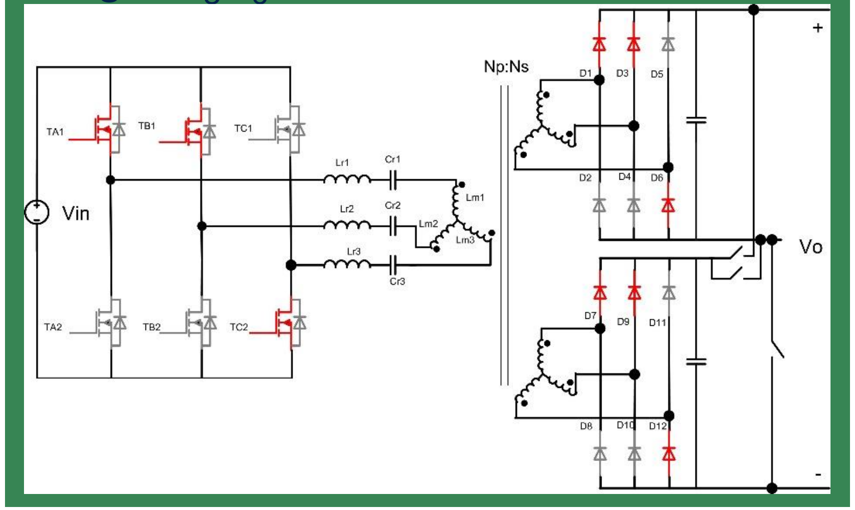
❑ Primary side:

- Q_{A1} D_{B1} Q_{C2} ON
- $i_{Lr1}>0$, $i_{Lr2}<0$, $i_{Lr3}<0$
- $U_{AY} = V_{in}/3$, $U_{BY} = V_{in}/3$, $U_{CY} = -2V_{in}/3$

❑ Secondary side:

- D_1 D_3 D_6 ON
- D_7 D_9 D_{12} ON

Stage6 t_5-t_6



❑ Primary side:

- Q_{A1} Q_{B1} Q_{C2} ON
- $i_{Lr1}>0$, $i_{Lr2}>0$, $i_{Lr3}<0$
- $U_{AY} = V_{in}/3$, $U_{BY} = V_{in}/3$, $U_{CY} = -2V_{in}/3$

❑ Secondary side:

- D_1 D_3 D_6 ON
- D_7 D_9 D_{12} ON

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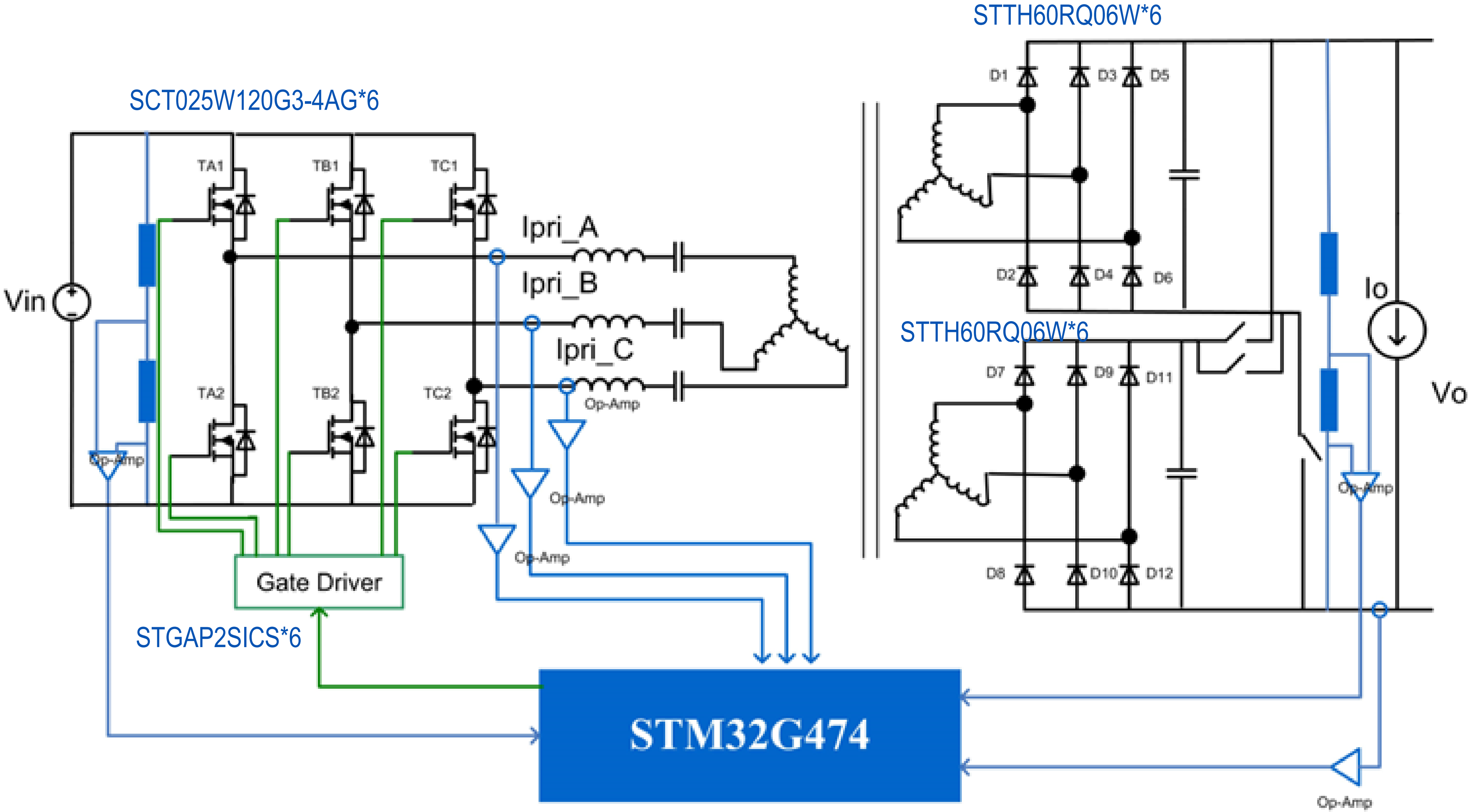
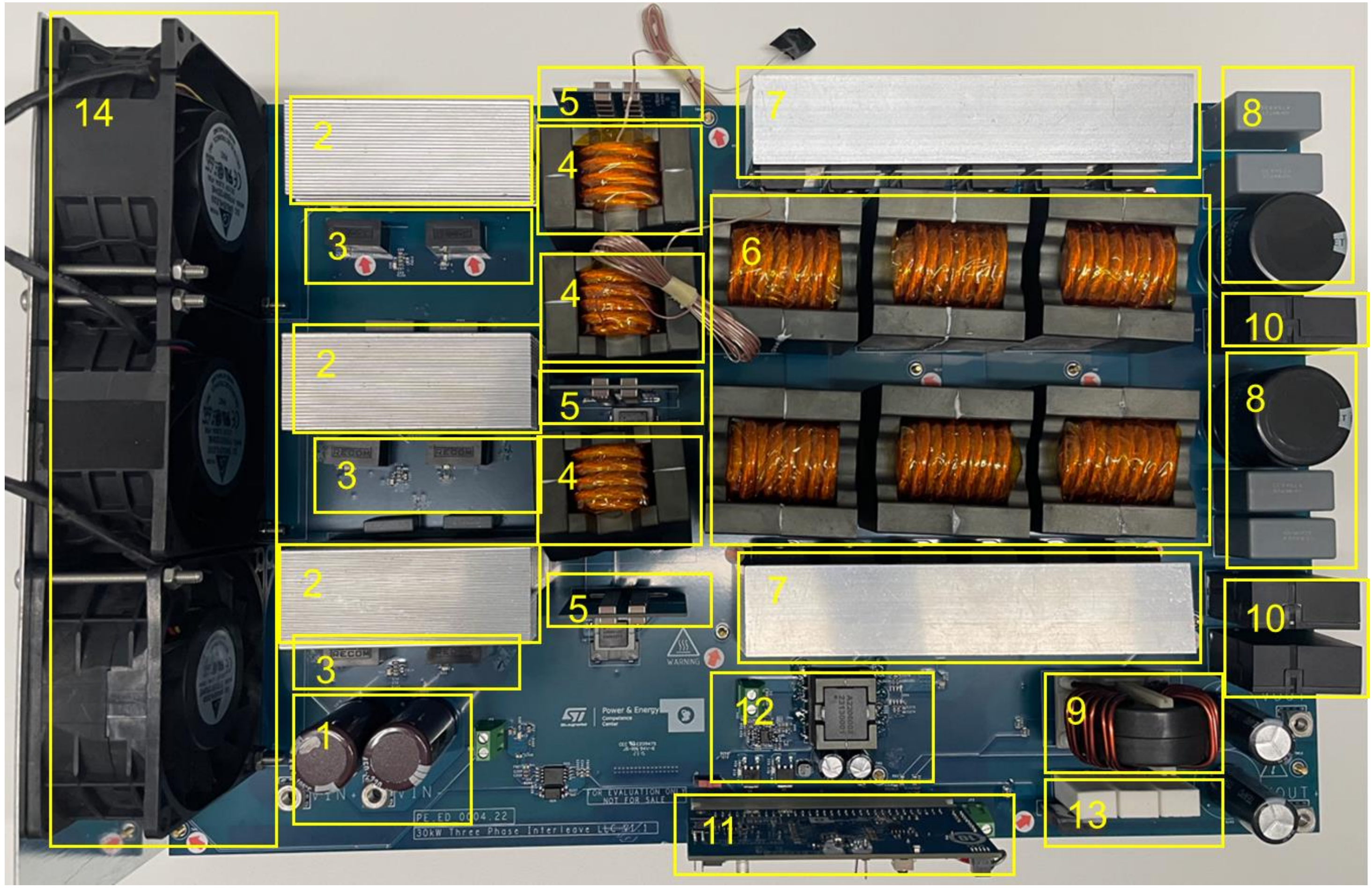
Simplified block diagram



Board assembly overview

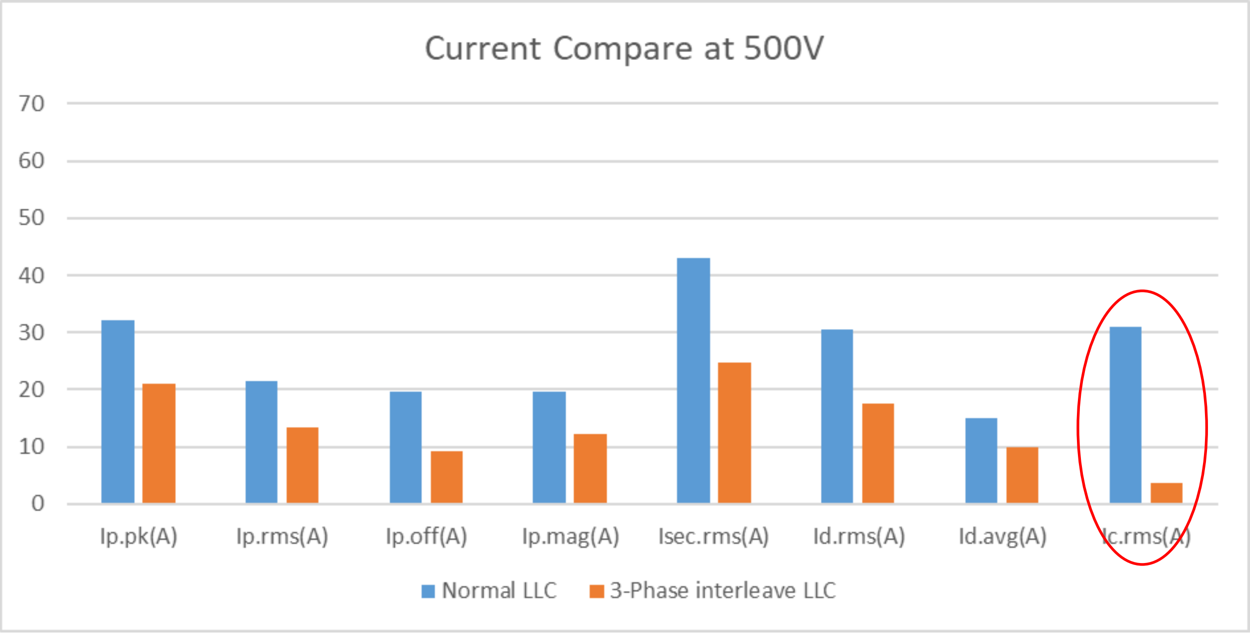
1. DC input connector
2. SiC MOSFET and heatsink
3. Drive circuit
4. Resonant inductor
5. Resonant capacitor board
6. Transformers
7. Rectifiers and heatsink
8. Output capacitors
9. Output CM inductor
10. Mode switch relays
11. Control board
12. Auxiliary power supply
13. Discharge circuit
14. Fans

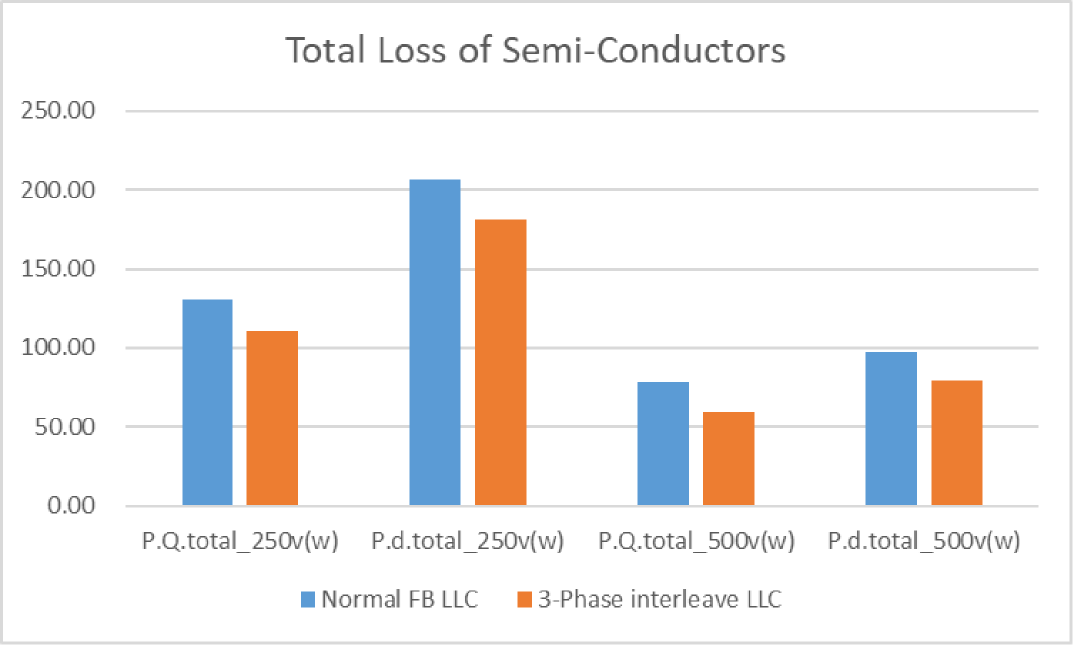


W*L*H: 285 mm*415 mm*70 mm

Full bridge vs three-phase

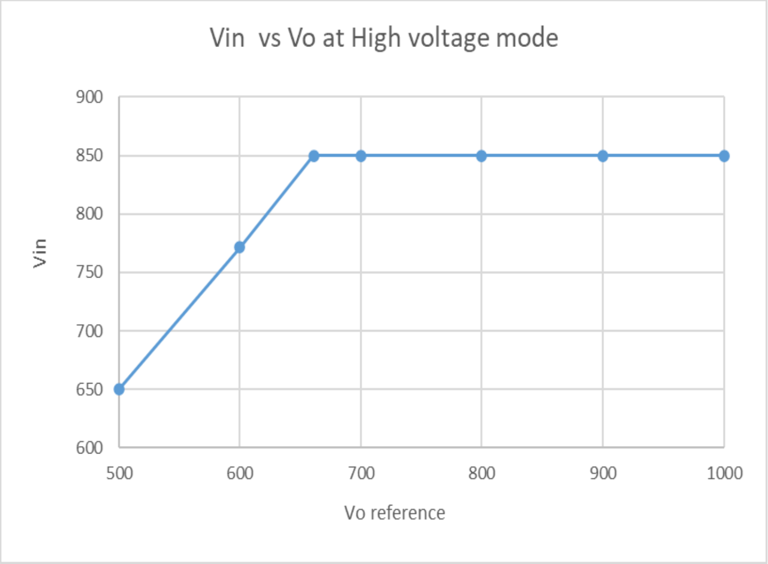
- Normal FB LLC and 3-Phase Interleaved LLC parallel use the same device
- Primary: SCT025W120G3-4AG Secondary: STTH60RQ06W

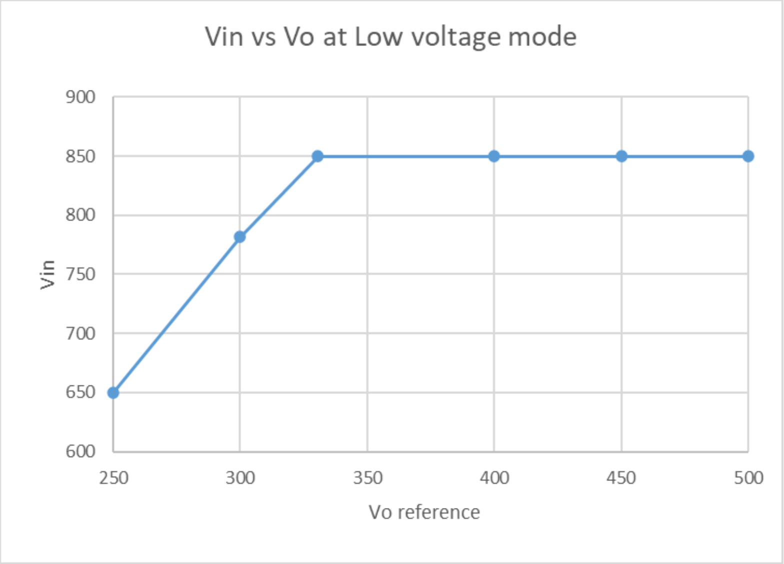


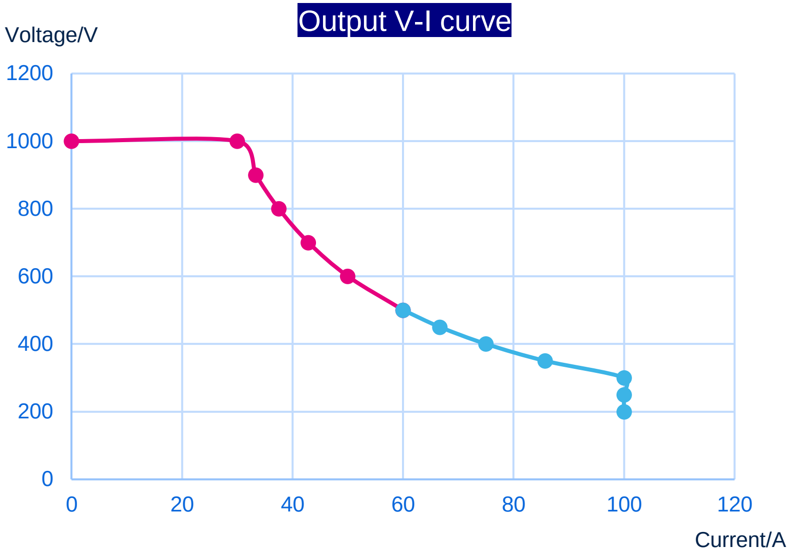


- Output current in cap is much less than full bridge LLC
- 0.3% efficiency higher than full bridge LLC (only consider semiconductor)

V_{in} Adjusted according to V_{out}



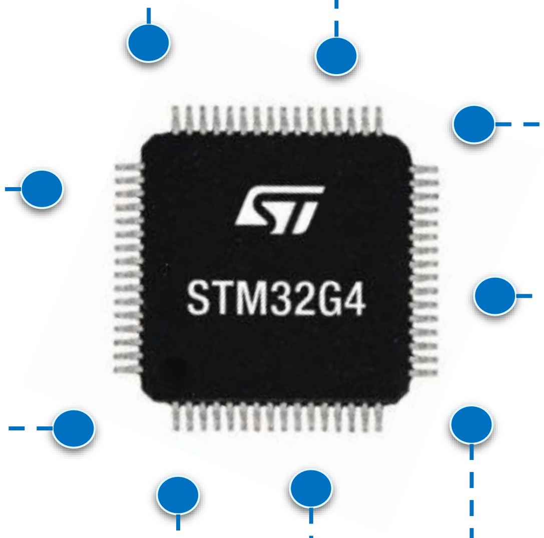




- The input voltage would be adjusted according to output voltage reference
- Make the LLC operating at a relatively high efficiency state from 200-1000Vo

STM32G474 digital platform

Configurations of key MCU functions



Arm® Cortex® -M4 up to 170 MHz

Floating-point unit (FPU)

- Control loop computation (reserved for future use)

32-Kbyte **CCM-SRAM**

- Zero wait-state for critical code execution

CORDIC for trigonometric functions acceleration

- Software phase-locked loop (reserved for future use)

FMAC filter mathematical accelerator

- Hardware digital filter (CPU off-load) for loop computation (reserved for future use)

Hi-Resolution PWM Timer (184 ps)

- For MOSFET control at 100-350 kHz switching frequency

Multiple **ADCs (4 Msps)** up to 5

- 3Ø AC voltage/current, DC voltage/current, and hotspot temperature sensing

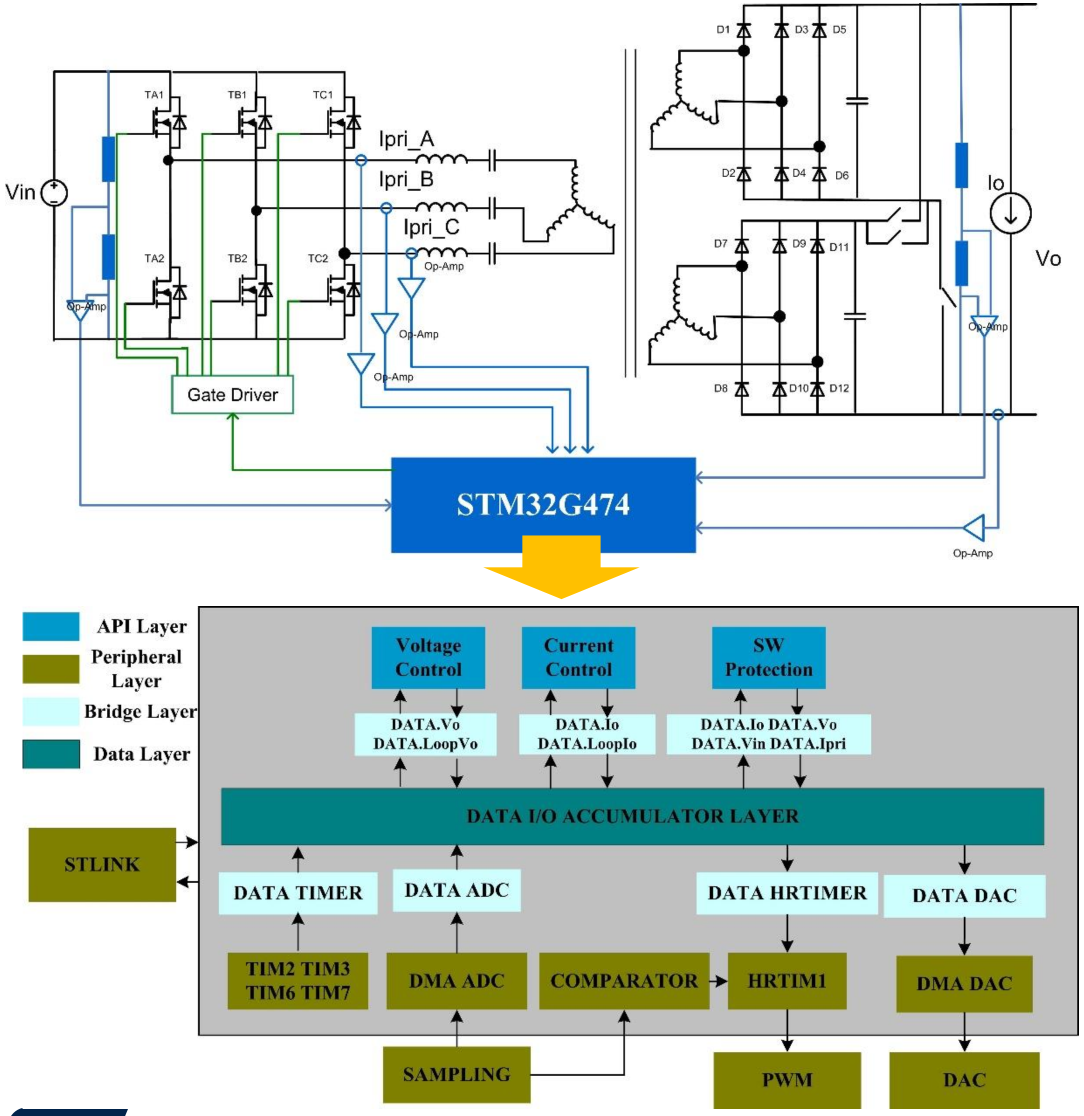
Comparators and **DACs** up to 7

- Reducing the number of components

UART, **SPI**, **CAN** and **USB**

- UART for communication

Functional diagram



API Layer
Peripheral Layer
Bridge Layer
Data Layer

Voltage Control
Current Control
SW Protection
DATA.Vo DATA.LoopVo
DATA.Io DATA.LoopIo
DATA.Io DATA.Vo DATA.Vin DATA.Ipri
DATA I/O ACCUMULATOR LAYER
STLINK
DATA TIMER
DATA ADC
DATA HRTIMER
DATA DAC
TIM2 TIM3 TIM6 TIM7
DMA ADC
COMPARATOR
HRTIM1
DMA DAC
SAMPLING
PWM
DAC

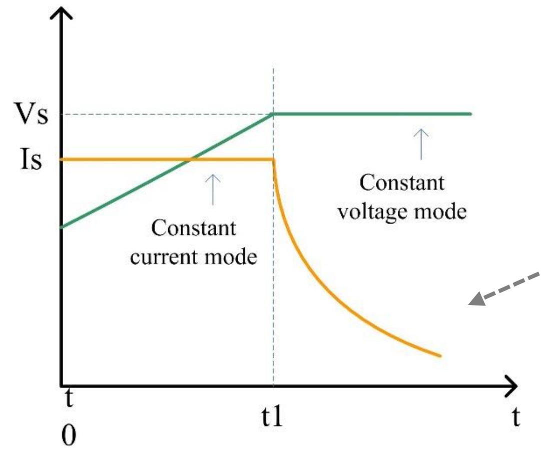
Key features based on digital control

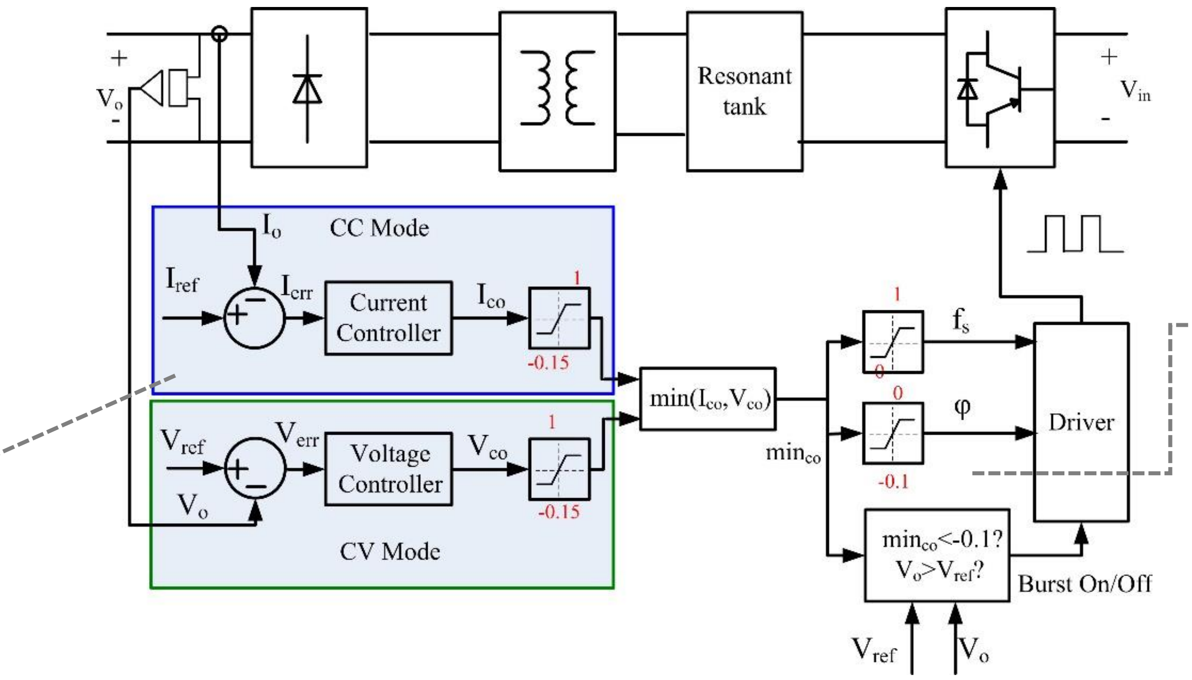
- Soft start control （Patent by phase-shift ）
- Parallel double closed loop control - CV/CC
- DC gain control to obtain lower output voltage and reduce output voltage ripple
- Relay control to extend the range of output voltage and current
- Software protection
- Hardware protection using on-chip comparator, DAC, and analog watchdog

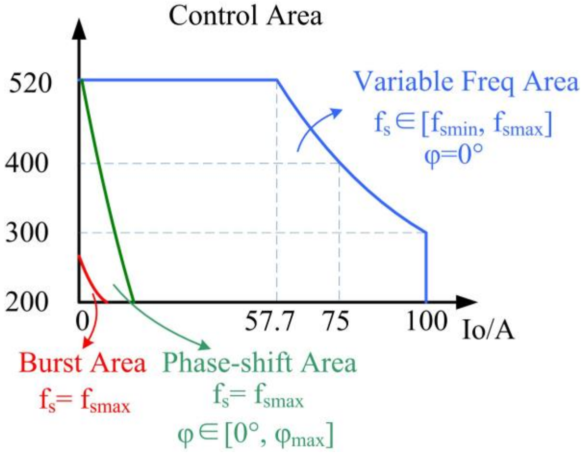
Control strategy of power loop

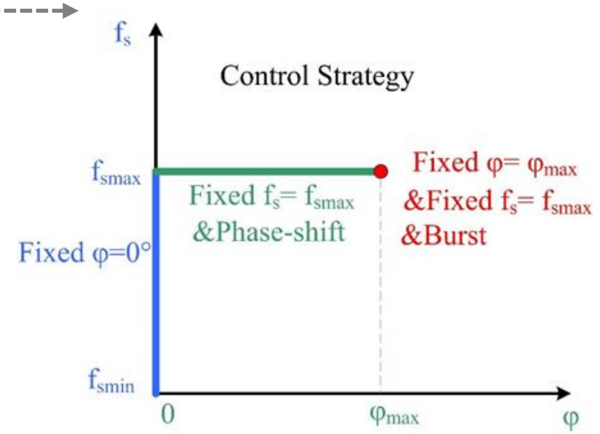
Parallel double closed loop control

- Consists of CC charging mode and CV charging mode
- DC gain control to obtain lower output voltage and reduce output voltage ripple







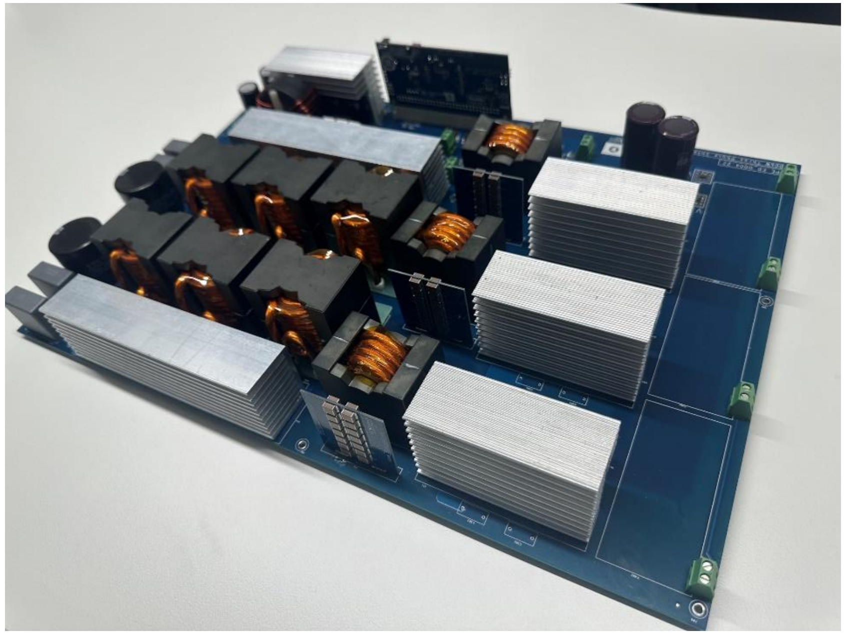


30 kW DC/DC board performance

Performance and features

Input & output

- Input DC voltage: 650-850 VDC
- Output voltage range: **200-1000 VDC**
- Output power: **30 kW maximum**
- Maximum input current: 46A RMS
- Maximum output current: 100A RMS



Performance

- Efficiency: Peak 98%
- Vout ripple: less than 1% Vout >300 V; less than 3 V Vout <300 V
- Vout load regulation: 1%
- Vout dynamic regulation: 5%

Features and protection

- Switching frequency: **100-300 kHz**
- Operation mode: PFM
- Input UVP, OVP
- Input OCP
- Output OVP
- Output OCP

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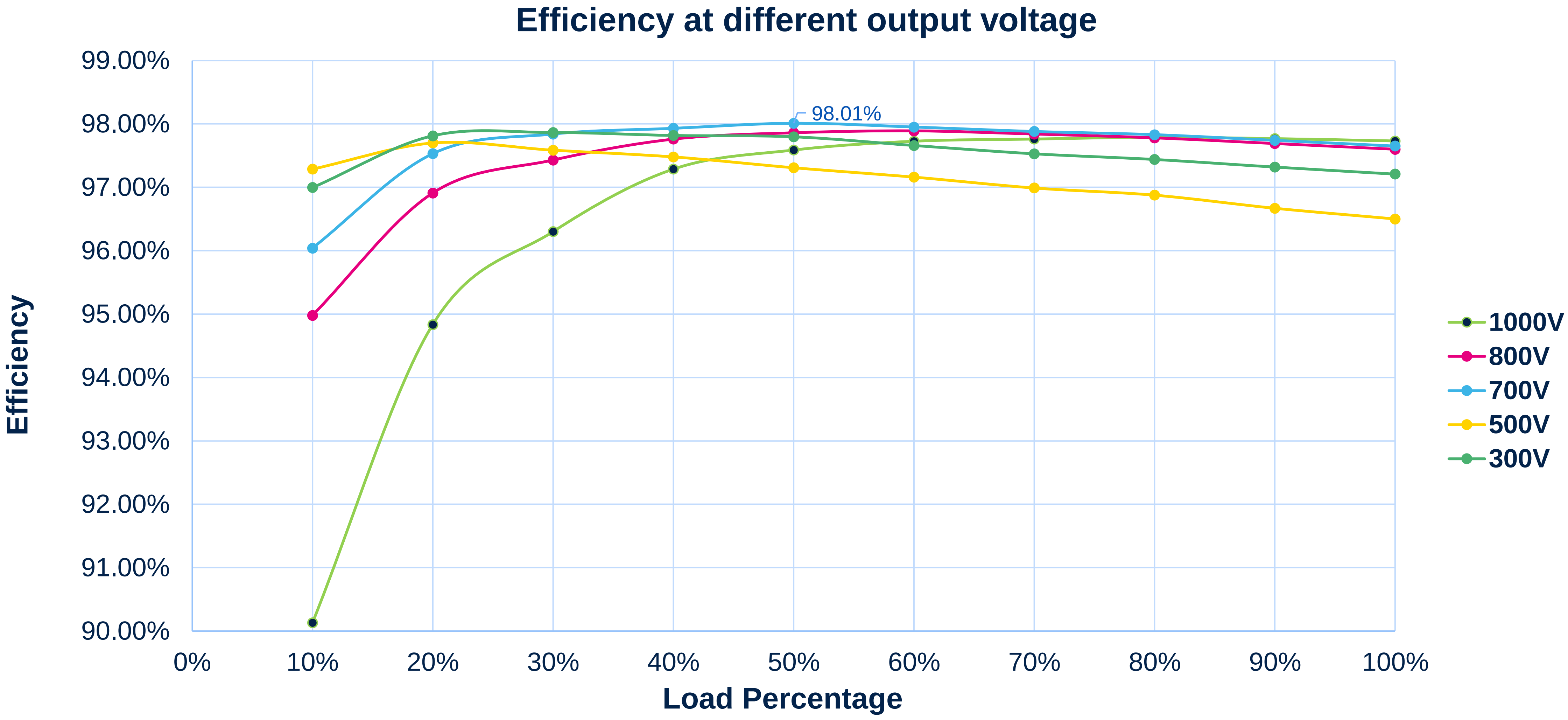
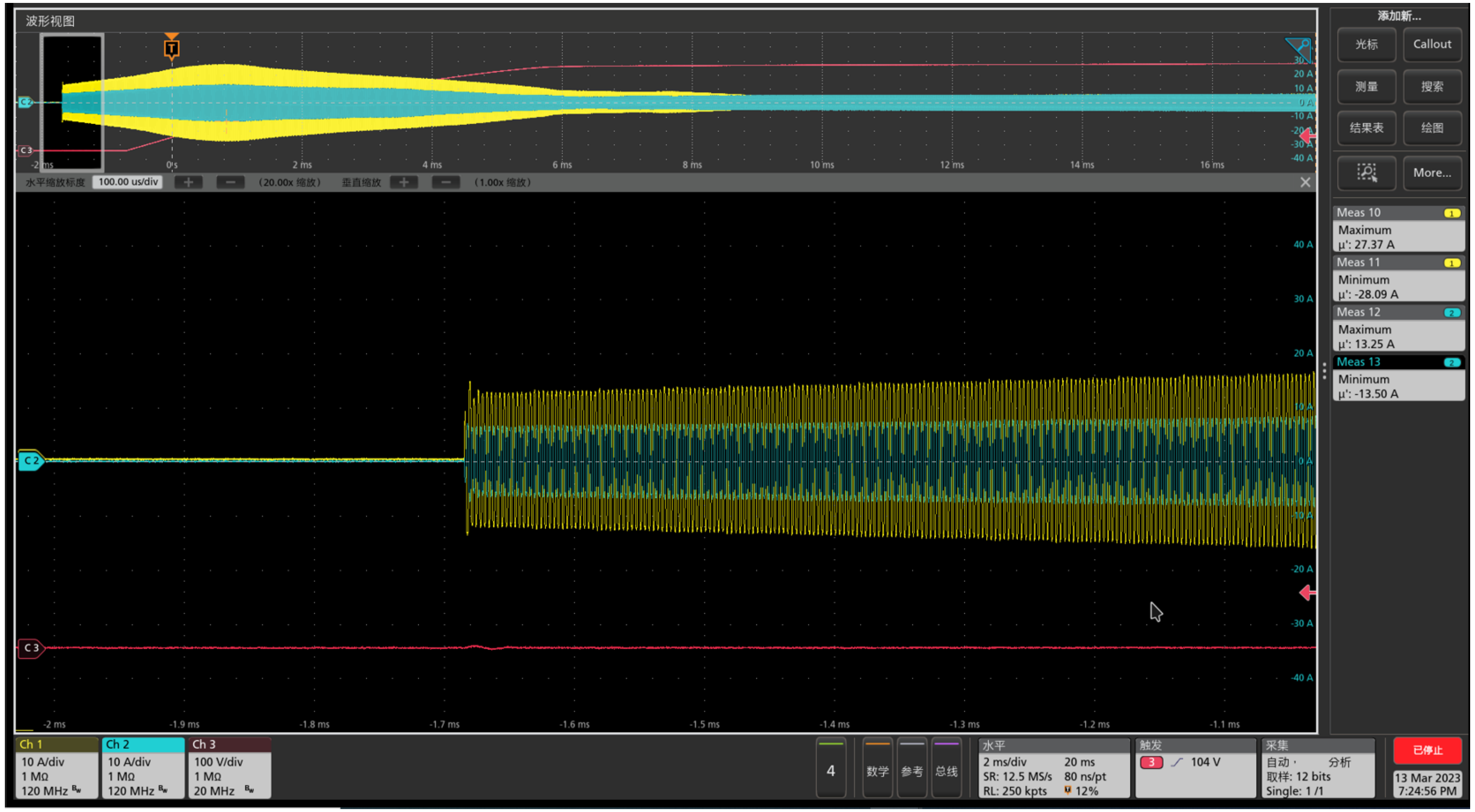
Efficiency



Efficiency at different output voltage
Efficiency
99.00%
98.00%
97.00%
96.00%
95.00%
94.00%
93.00%
92.00%
91.00%
90.00%
98.01%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Load Percentage
1000V
800V
700V
500V
300V

Startup procedure

- 600Vo Start up by phase-shift
- The startup current spike can be limited to under 30 A



Meas 10 (1)
Maximum
μ': 27.37 A

Meas 11 (1)
Minimum
μ': -28.09 A

Meas 12 (2)
Maximum
μ': 13.25 A

Meas 13 (2)
Minimum
μ': -13.50 A

Ch 1
10 A/div
1 MΩ
120 MHz

Ch 2
10 A/div
1 MΩ
120 MHz

Ch 3
100 V/div
1 MΩ
20 MHz

水平
2 ms/div 20 ms
SR: 12.5 MS/s 80 ns/pt
RL: 250 kpts 12%

触发
3 104 V

采集
自动， 分析
取样: 12 bits
Single: 1 /1

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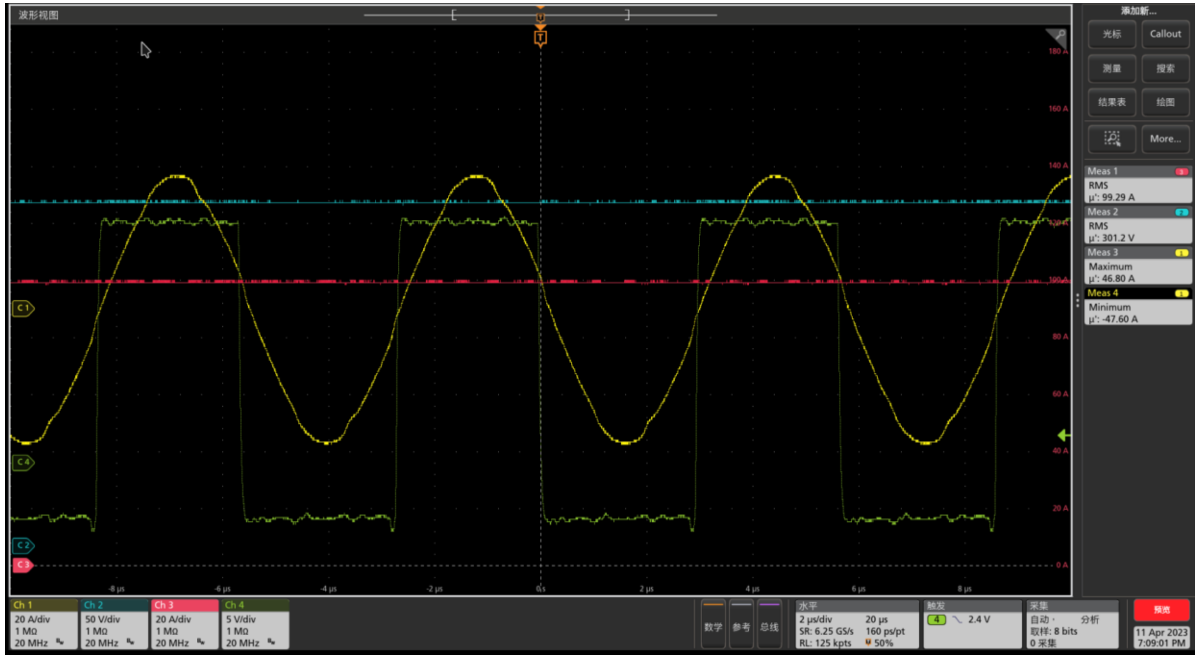
CH1 phase A resonate current CH2 phase B resonate current CH3 Vout

Steady waveform

300Vo 100A full load



Meas 1 RMS µ': 99.29 A
Meas 2 RMS µ': 301.2 V
Meas 3 Maximum µ': 46.80 A
Meas 4 Minimum µ': -47.60 A

Ch 1 20 A/div 1 MΩ 20 MHz
Ch 2 50 V/div 1 MΩ 20 MHz
Ch 3 20 A/div 1 MΩ 20 MHz
Ch 4 5 V/div 1 MΩ 20 MHz
水平 2 µs/div 20 µs SR: 6.25 GS/s 160 ps/pt RL: 125 kpts 50%
触发 4 2.4 V
采集 自动 · 分析 取样: 8 bits 0 采集
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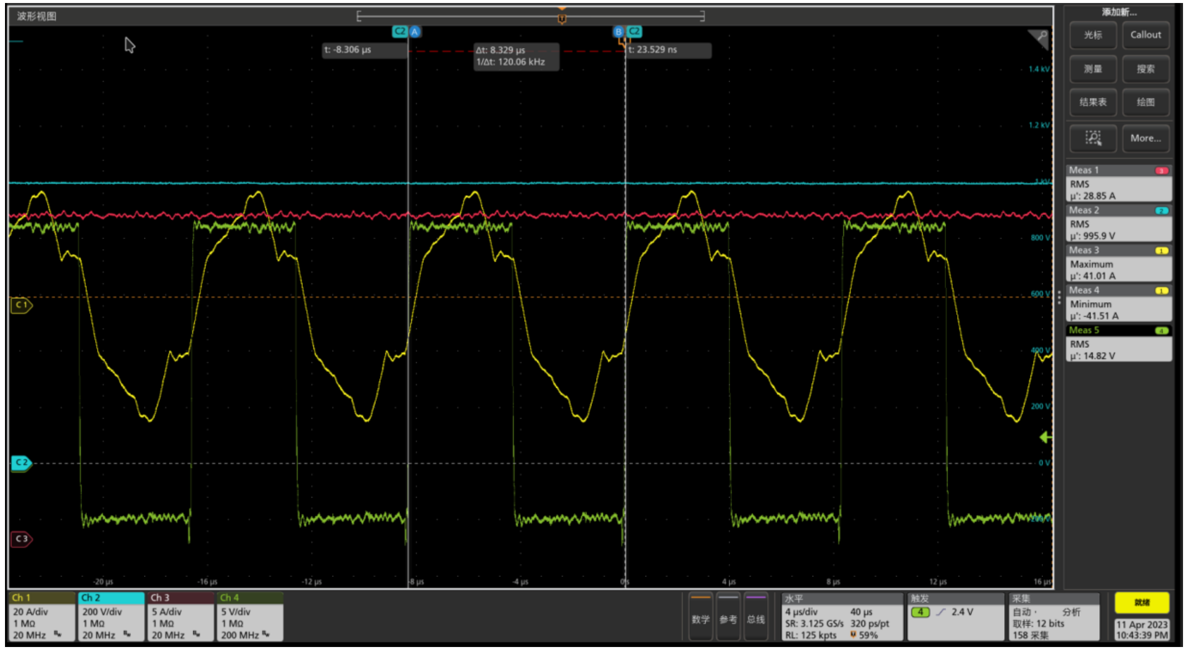
CH1 resonate current CH2 Vout CH3 Iload CH4 upper Vgs

1000Vo 30A full load



t: -8.306 µs
Δt: 8.329 µs
1/Δt: 120.06 kHz
t: 23.529 ns

Meas 1 RMS µ': 28.85 A
Meas 2 RMS µ': 995.9 V
Meas 3 Maximum µ': 41.01 A
Meas 4 Minimum µ': -41.51 A
Meas 5 RMS µ': 14.82 V

Ch 1 20 A/div 1 MΩ 20 MHz
Ch 2 200 V/div 1 MΩ 20 MHz
Ch 3 5 A/div 1 MΩ 20 MHz
Ch 4 5 V/div 1 MΩ 200 MHz
水平 4 µs/div 40 µs SR: 3.125 GS/s 320 ps/pt RL: 125 kpts 59%
触发 4 2.4 V
采集 自动 · 分析 取样: 12 bits 158 采集
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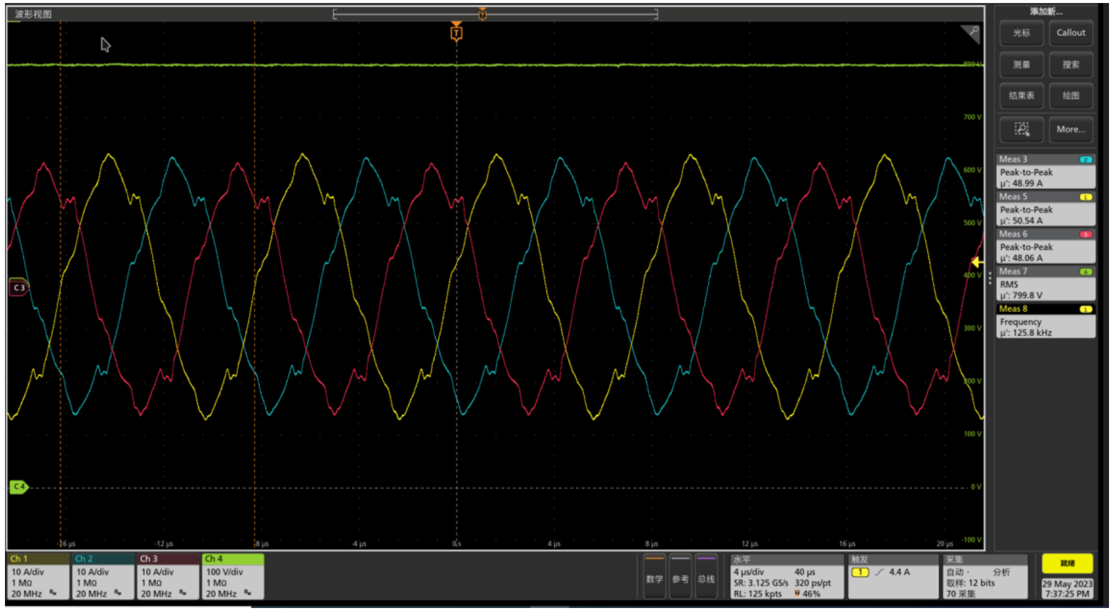
CH1 resonate current CH2 Vout CH3 Iload CH4 upper Vgs

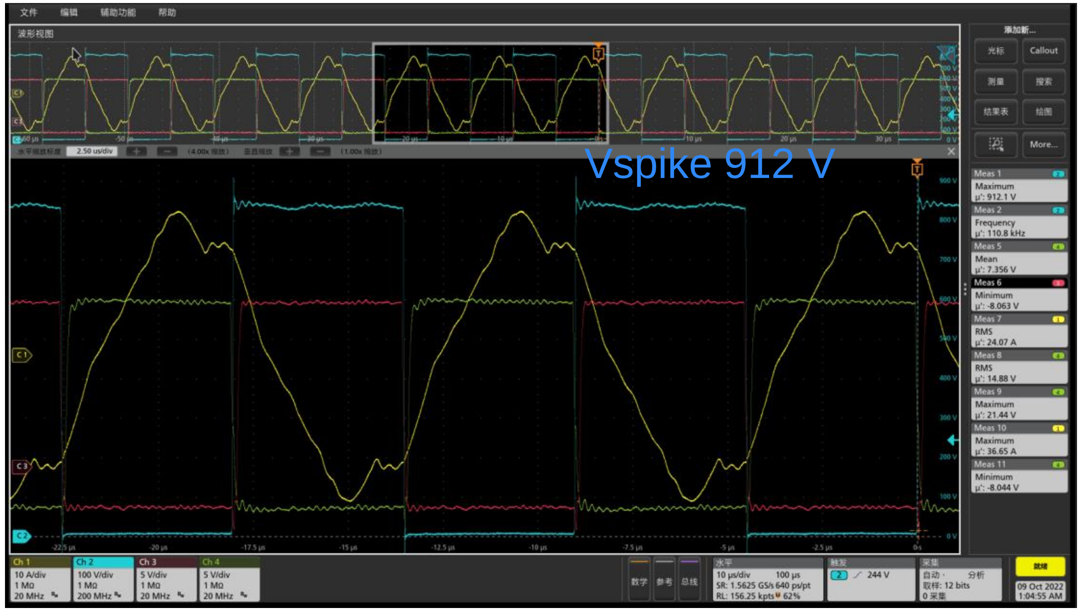
Steady waveform

800Vo half load



CH1 A resonate current
CH2 B resonate current
CH3 C resonate current
CH4 Vout

1000Vo half load



CH1 resonate current
CH2 upper Vds
CH3 Lower Vgs
CH4 upper Vgs

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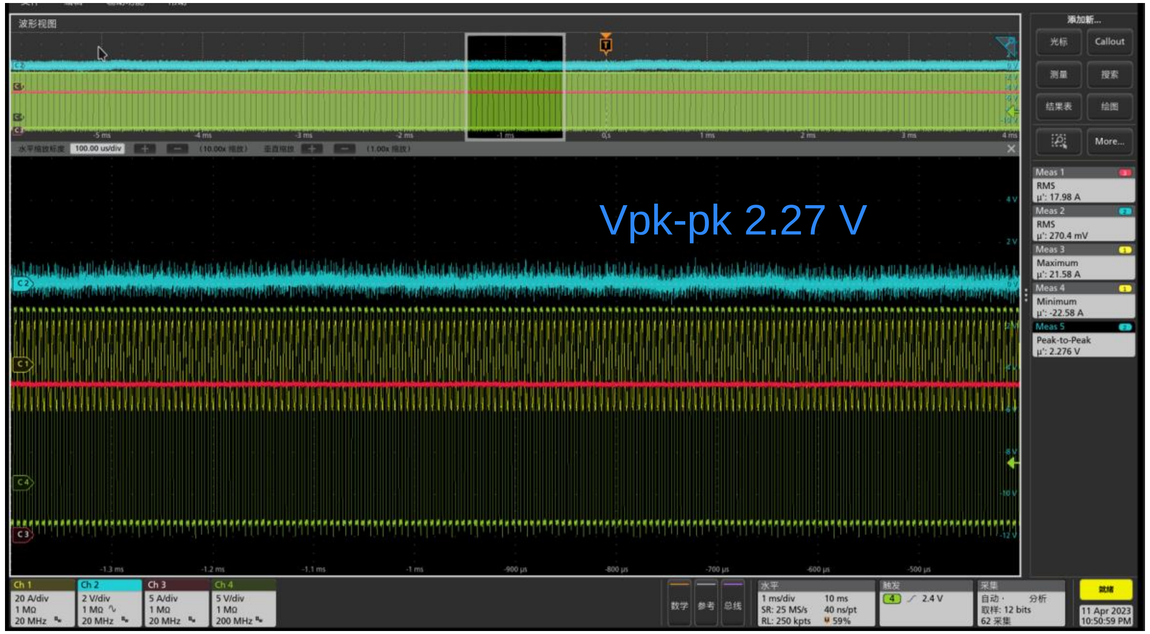
Steady waveform

800Vo half load


Vpk-pk 2.27 V

Meas 1 RMS μ': 17.98 A
Meas 2 RMS μ': 270.4 mV
Meas 3 Maximum μ': 21.58 A
Meas 4 Minimum μ': -22.58 A
Meas 5 Peak-to-Peak μ': 2.276 V

Ch 1 20 A/div 1 MΩ 20 MHz
Ch 2 2 V/div 1 MΩ 20 MHz
Ch 3 5 A/div 1 MΩ 20 MHz
Ch 4 5 V/div 1 MΩ 200 MHz
水平 1 ms/div 10 ms SR: 25 MS/s 40 ns/pt RL: 250 kpts 59%
触发 4 2.4 V
采集 自动 · 分析 取样: 12 bits 62 采集
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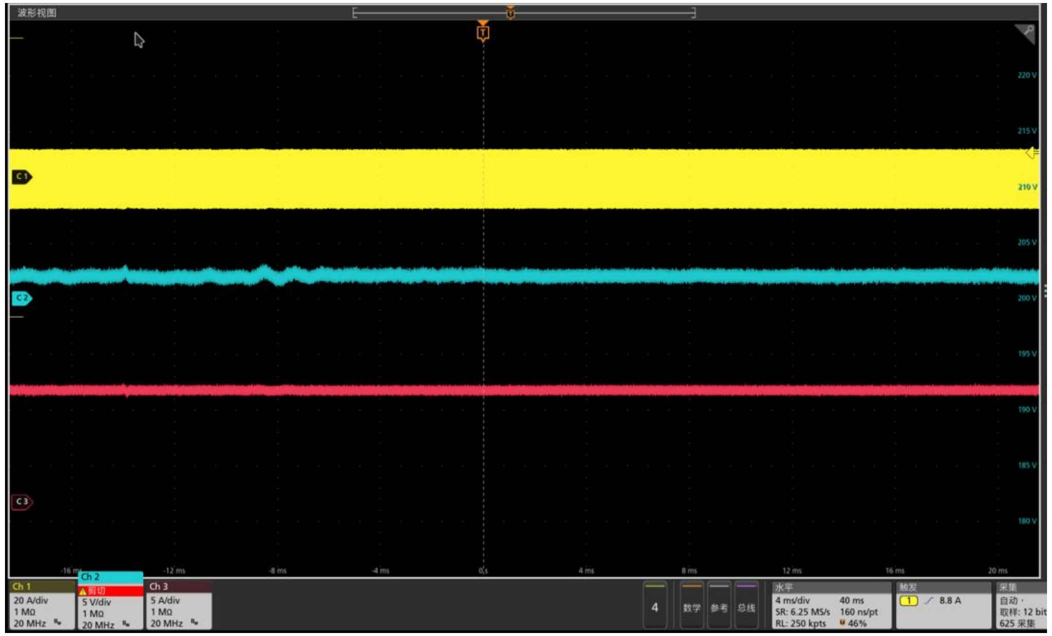
CH1 A resonate current
CH2 Vout ripple
CH3 Iload
CH4 upper Vgs

200Vo 10 A with phase-shift control

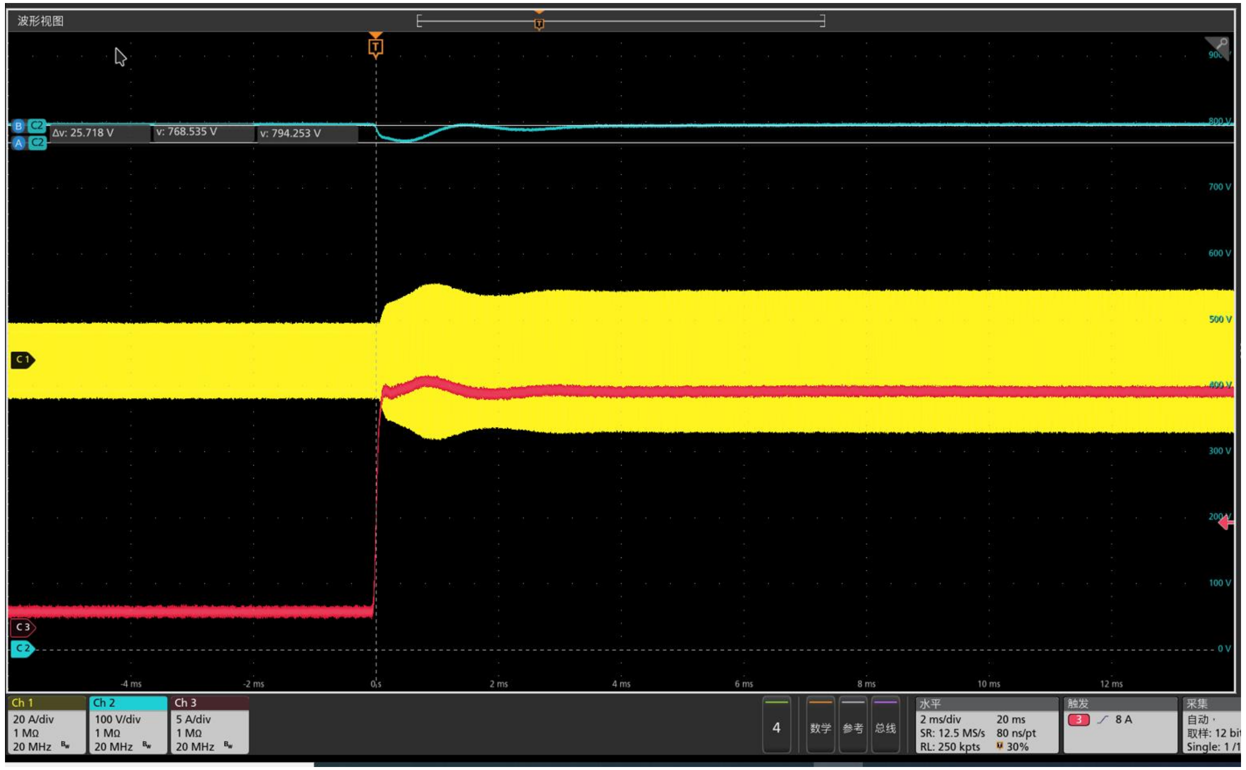

Ch 1 20 A/div 1 MΩ 20 MHz
Ch 2 剪切 5 V/div 1 MΩ 20 MHz
Ch 3 5 A/div 1 MΩ 20 MHz
水平 4 ms/div 40 ms SR: 6.25 MS/s 160 ns/pt RL: 250 kpts 46%
触发 1 8.8 A
采集 自动 · 取样: 12 bit 625 采集

CH1 phase A resonate current
CH1 output voltage
CH3 output current

Voripple p-p 2.05 V

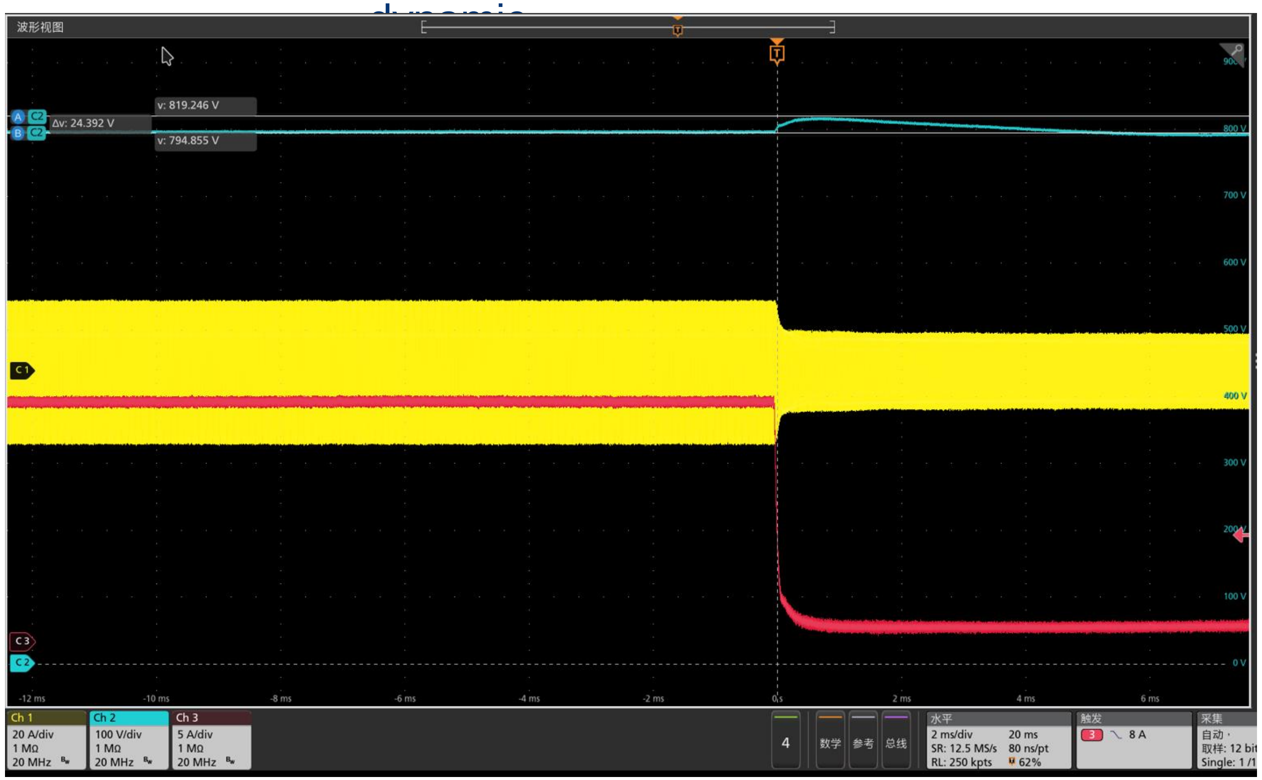
Half load dynamic

800 V 1A-18.75A dynamic



CH1 resonate current CH2 Vout CH3 load Current

800 V 18.75A-1A dynamic



CH1 resonate current CH2 Vout CH3 load Current

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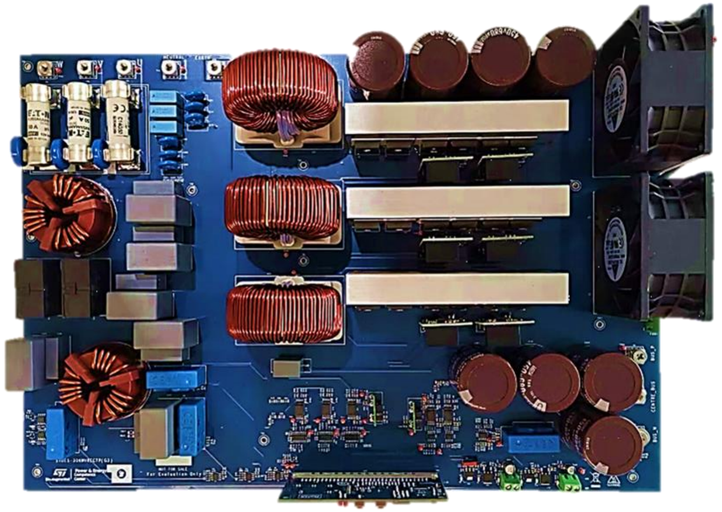
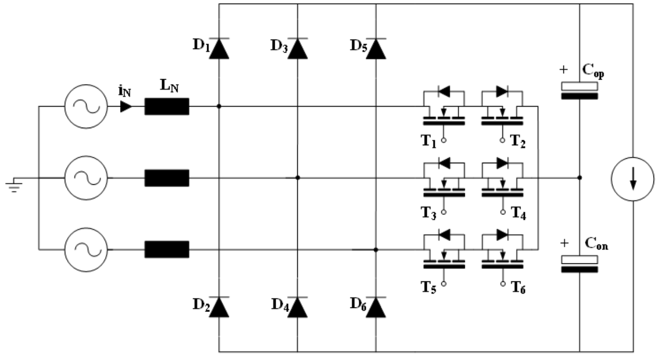
30 kW three-phase Vienna rectifier for EVCS





Application key specification:

- Input AC voltage: three-phase 345 VAC up to 460 VAC with 47 Hz up to 63 Hz
- Maximum input current: 55 ARMS
- DC output voltage 800 VDC, rated output power 30 kW, switching frequency 70 kHz
- Peak efficiency: >98.7%
- 0.99 power factor with lower than 5% THD @ full load operation
- STM32G474: High performance 32-bit MCU

Key products

MCU: STM32G474RET3
SiC MOSFET: SCT018W65G3-4AG
SiC diode: STPSC40H12C
Gate driver: STGAP2SICS
Schottky diodes: STTH1L06A, STPS1150A, STPS2H100A, STPS2L60A
GPA: LD29080S33R, LD29080DT50R, TSV912IDT, TSV912IDT

Key benefits

- Solution based on SiC device; higher efficiency achieved
- Very low THD (total harmonic distortion)
- Higher reliability
- Low design complexity

Promotion slide

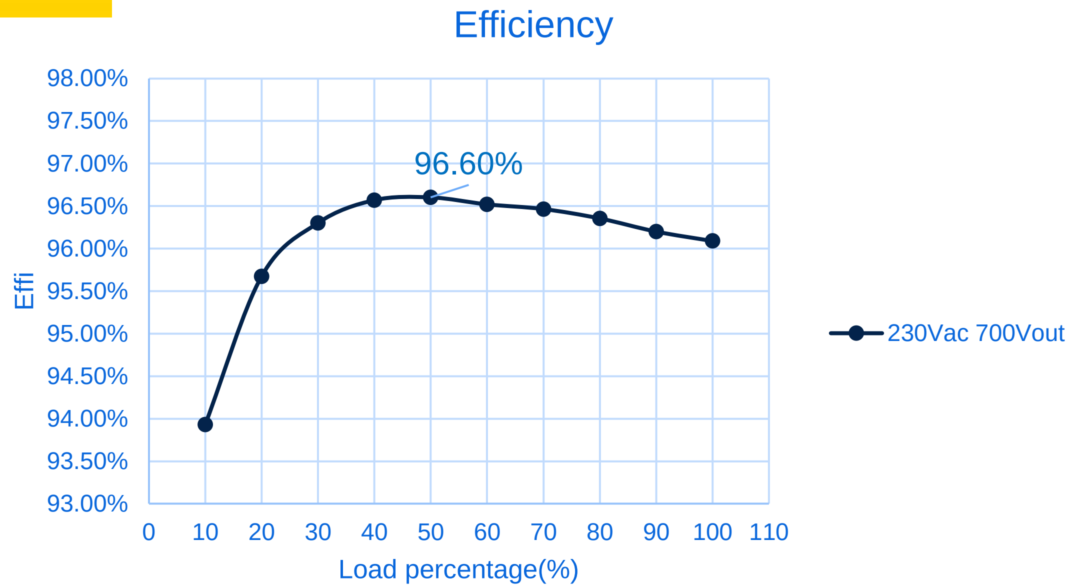
Test report

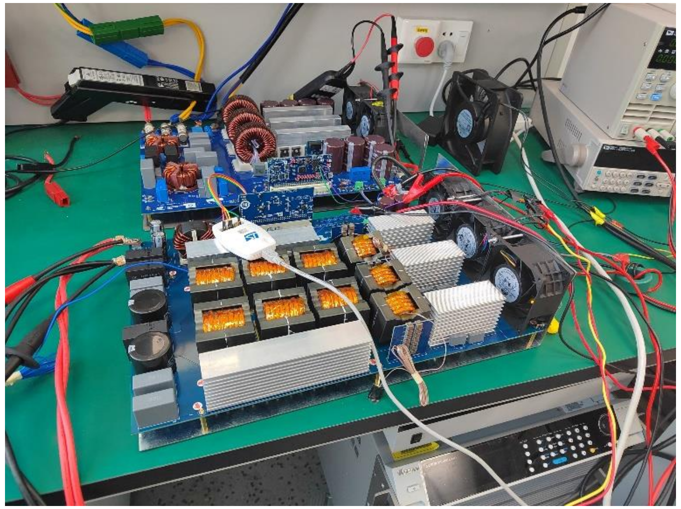
Design material

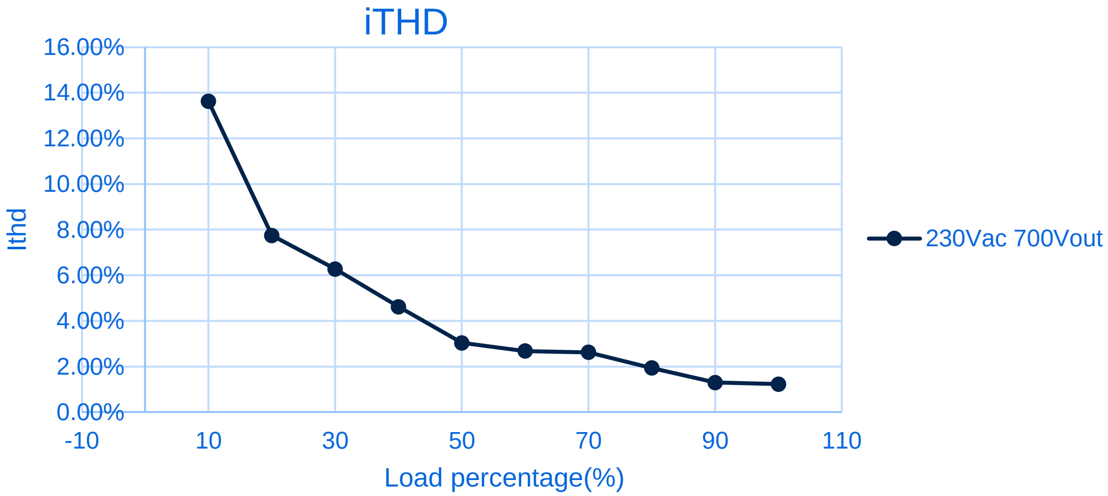
Demo video

Power & Energy
Competence
Center

ST 30 kW total solution







- 96.6% peak efficiency and 96% high efficiency in full load

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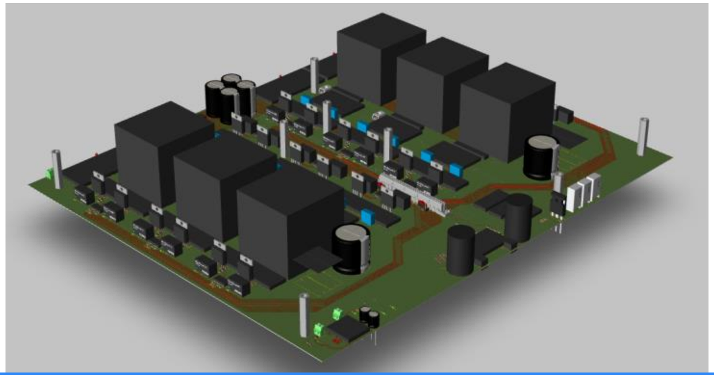
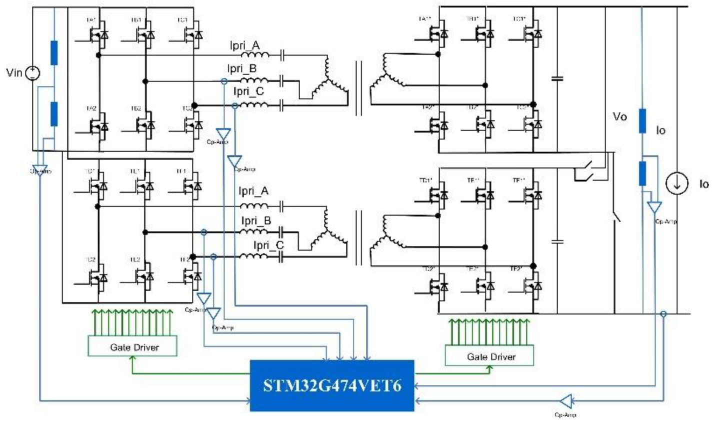
60 kW Three Phase Parallel LLC with digital control
Warm up



Three Phase LLC parallel converter



Application key features:

- DC input voltage: 650 VDC – 850 VDC
- DC output: 200 VDC – 1000 VDC
- Rated output power: 60 kW
- Peak efficiency: >98%
- STM32G474: High performance 32-bit MCU

Key products	MCU: STM32G4, SiC MOSFET: SCT025W120G3-4AG, SCT012W90G3-4AG Ultrafast diode: STTH60RQ06W ASP product: STGAP2SICD, L6565, Schottky diodes: STTH1L06A, STPS1150A, STPS2H100A, STPS2L60A
Key benefits	• Solution based on SiC device; higher efficiency achieved • Parallel LLC with less SiC MOSFET to achieve higher power • Wide range and high output voltage

Summary

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Summary

STM32G4 and ST SiC based solution help achieve high performance EV charger

ST achieved the total solution PFC+DCDC in high power EV charger

ST provides advanced total components to customer (SiC MOSFETs/SiC diode/STGAP/STM32)

ST 30 kW three-phase solution can achieve peak efficiency 98% @160 KHz 700 Vout half load

User manual and detailed design files refer to the link STDES-30KWLLC on ST.COM soon

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Power & SPIN Microsite

Our technology starts with You

Find out more at www.st.com

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