Bi-directional Power Converter

解鎖6.6kW SiC 雙向充電器設計

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ARROW

Five Years Out

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6.6kW Bidirectional Power Converter Introduction

Arrow – ST Joint Lab

For details, please visit Arrow Open Lab website

Power & Energy Lab

Bidirectional Charger (250-450V/19.6A, 6600W) for EV, PFC

P/N：2021P004-ST

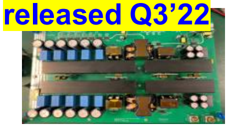
Released

Functions	Qty	Charger for EV
SiC MOS	16	SCTW40N120G2VAG- SCT040W120G3-4AG
SiC MOS Gate Driver- 1-CH	12	STGAP2SiCS
Gate Driver Isolated Power	12	A6986I*
Aux -30W	1	VIPER31*
Isolated DC-DC/10W	6	STL8N10LF3*
MCU	1	STM32G474VBT6

Energy Storage (ESS) bi-directional 80V/82.5A Output, 6600W, PFC & DC-DC

P/N：2021P005-ST, 2021P006-ST

Off-grid PFC Newly released Q3’22



DC-DC Q4’22 release

In Development

Functions	Qty	Energy Storage
SiC MOS	16	SCTWA60N120G2-4 -> SCT040W120G3-4AG
SiC MOS Gate Driver- 1-CH	8	STGAP2SiCS
Gate Driver Isolated Power	12	A6986I
DC-DC low side FET	32	STP75NF20
Aux	1	VIPER319HDTR
Diode	2	STPS1150A
Digital Isolator	2	STISO621WTR
Isolated DC-DC/10W	6	STL8N10LF3*
ESD Suppression	3	HDMIULC6-4SC6Y
ESD Suppression	2	ESDCAN03-2BWY
MCU	2	STM32G474VBT6

11 kW Battery Formation bidirectional-48V

P/N：2022P001

In Development

Functions	15kW PFC	Qty
HV SiC MOS	SCT040W120G3-4AG	6
SiC MOS	SCT018W65G3-4AG	6
MCU	STM32G474VBT6	1
Gate DRV	STGAP2SM	12
AUX	VIPER26HD	1

Automation Lab

IO-link Master

IO-link Slave – Sensors/ Actuators

Released

8-CH Master w/ Arrow MCU

P/N：2021W001

8-CH IO-link Master	Qty
ARW-IOLM4P-STM32L4 STM32L431RBT6	2
M24256-BRDW6TP	2
USBLC6-4SC6	1
L7986ATR	1
LD1117S33TR	1
LD39050PU33R	1
M93C66-RMC6TG	1
IPS161H	8
L6360	8
SPT01-335DEE	8
STM32F746ZGT6	1
STG3693QTR	2

Released

8-CH Digital Input

P/N：2021W002

DI Module	Qty
SM15T33CA	1
SMA4F5.0A	1
STM32G071RBT6	1
STISO621WTR	2
CLT01-38SQ7-TR	1
L7986ATR	1
SPT01-335DEE	1
LD39050PU33R	1
L6364Q	1
STPS140Z	8
STPS3L60UFN	1
STPS340AFN	1

Released

8-CH Master w/ Ethernet IP

P/N：2021W004

8 CH IOLM	Qty
STM32H743ZIT6	1
VN808-32-E	1
L6360	8
M24256-BRDW6TP	1
L7986A	1
SLVU2.8-4A1	2
SMA4F28A	24

Released

8-CH Digital Output

P/N：2021W003

DO Module	Qty
STPS3L60UFN	1
STPS340AFN	1
SM15T33CA	1
SMA4F5.0A	1
L7986ATR	1
SPT01-335DEE	1
LD39050PU33R	1
L6364Q	1
ISO8200AQ	1
STM32G071RBT6	1

Released

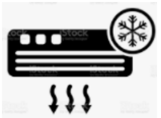
Tower-light CTRL

P/N：2021W005

Tower light	Qty
IPS4260L	1
L6364Q	1
STM32G071	1
M24C08	1
SMB15F24A	2
STG3157CTR	1

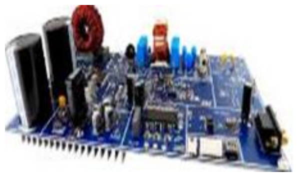
8CH Master w/ Profinet Software version In Development

Motor Control Lab



Air-conditioning Compressor

P/N：2019M002 Customization



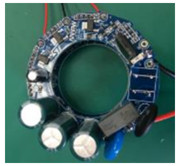
STEVAL-CTM010V1

Released

Func.	HVAC – 2kW	Qty
IPM	STGIB15CH60TS-L	1
MCU	STM32F302RBT6	1
PFC MOS	STP4LN80K5	2
PFC Gate DRV	PM8834	1
PFC Diode	STTH30AC06C	2
TRIAC	T435-800B	1
Valve Stepper Motor CTRL	STSPIN820	1

110 krpm BLDC Motor Driver

P/N：2021M001



Released

Func.	Fast Hair Dryer	Qty
MCU +GATE DRV	STSPIN32F0601Q	1
MOS	STN6N60M2	6
AUX	VIPER222	1
LDO	LD1117S33TR	1
AUX Diode	BAT41ZFILM	1
AUX Pri. Diode	STTH1L06A	2
TRIAC	T1635T-8FP	1

1kW Servo Motor Driver

P/N：2022M001

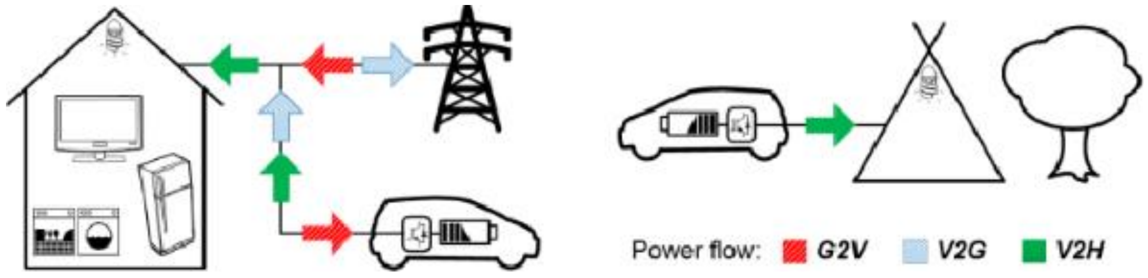
Newly released Q3’22

Func.	Servo	Qty
MCU+GATE DRV	STSPIN32G4	1
MOS	STL110N10F7	6
AUX	VIPER319HDTR	1
AUX Diode	STPS1H100A	3
DC-DC	ST1S40IDR	2
LDO	LD1117S12TR	1
Ethernet Protection	ETP01-1621RL	4
Quad. RS-42X	ETP01-1621RL	2

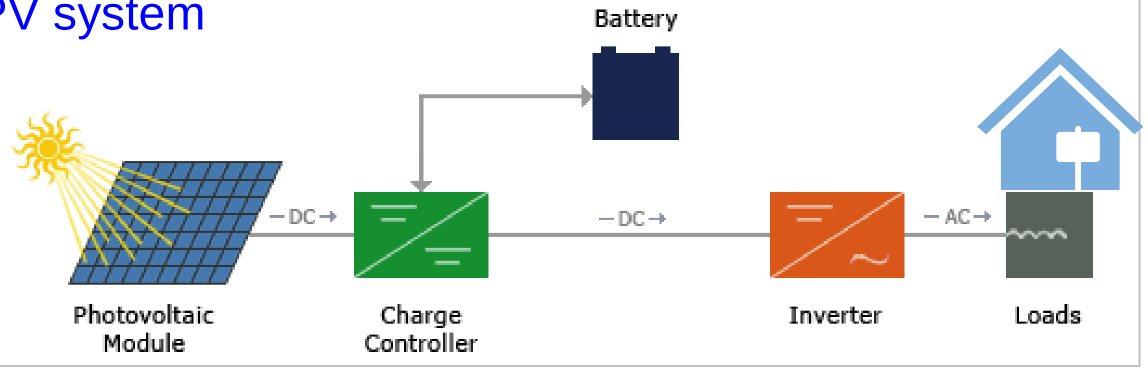
6.6kW Bidirectional Power Converter Introduction

Application examples:

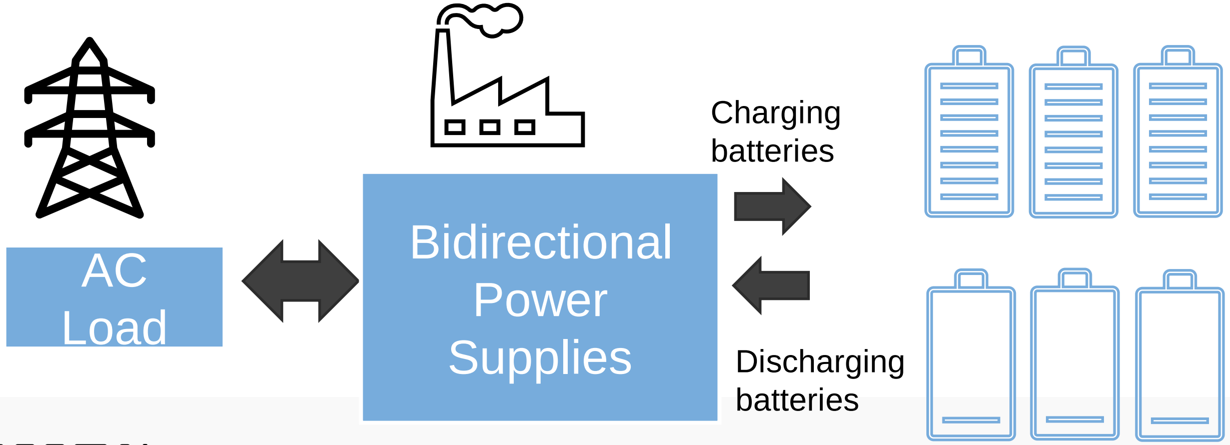
EV system



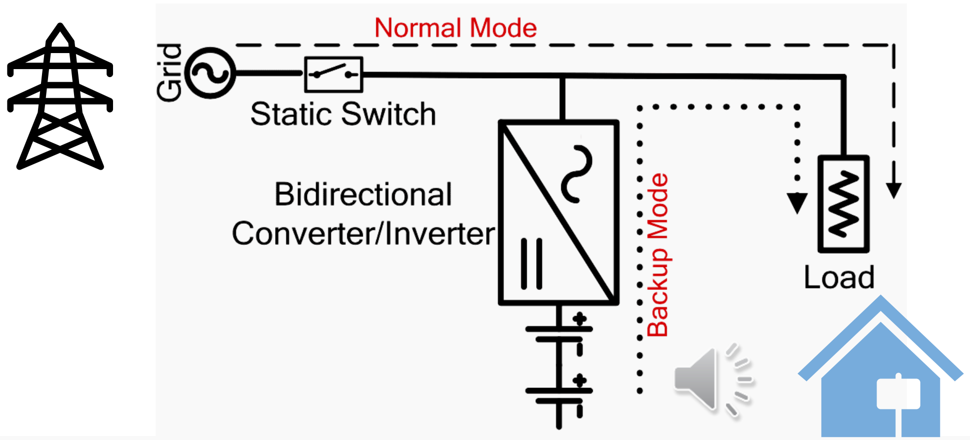
PV system



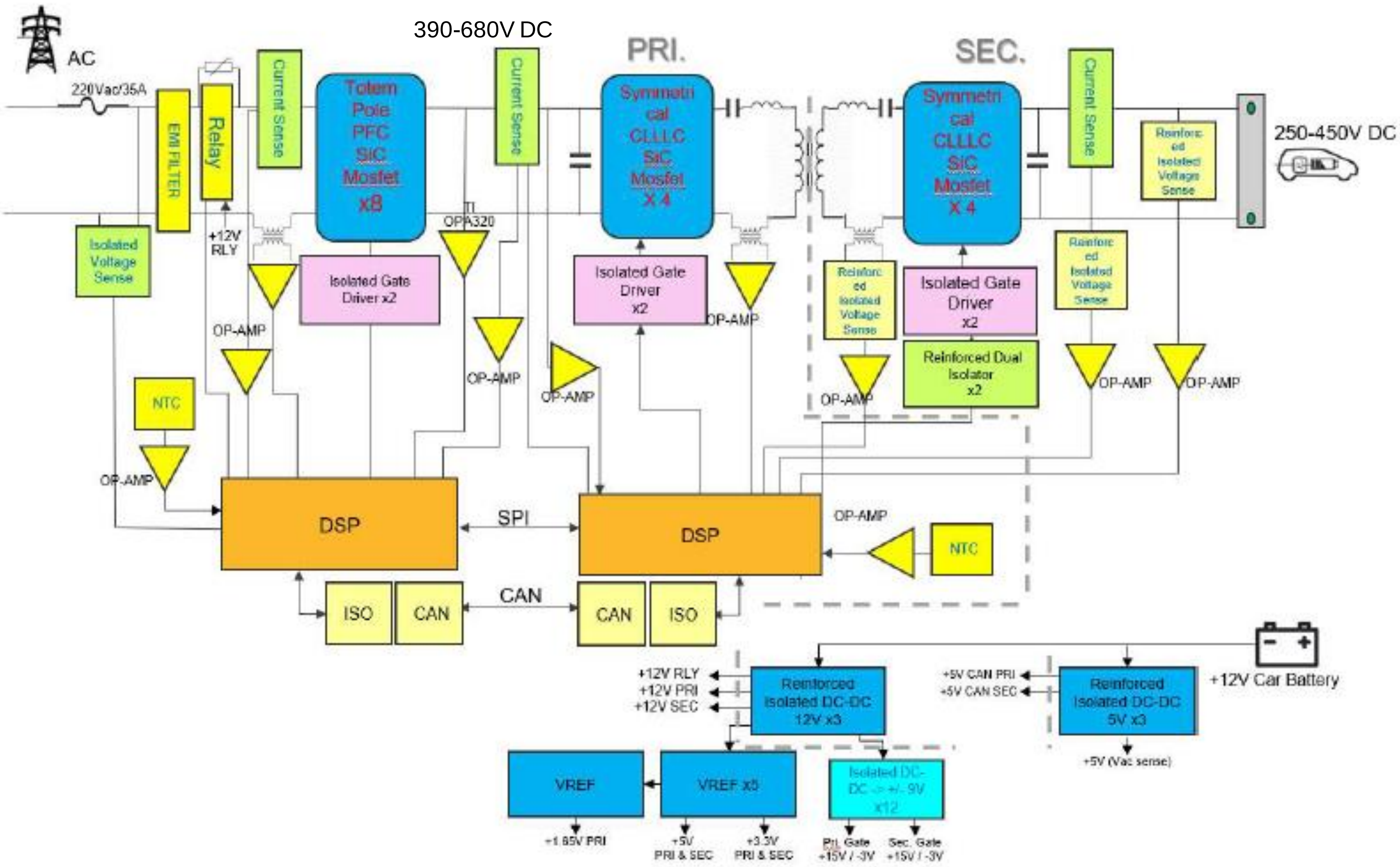
Equipment- e.g. Battery formation, Aging Test Loading

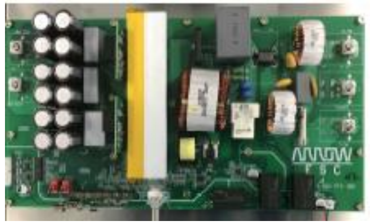


Energy storage system/ Emergency Power Supplies



Block Diagram - Bidirectional charger for EV- 250-450V, 19.6A/ 6600W





AC-DC board

DC-DC board

Specification:

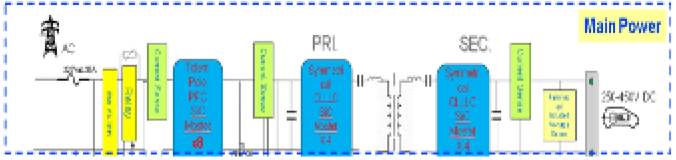
- AC/DC Bidirectional Power Conversion
- Max Charging Power: 6.6kW
- AC Input Voltage: 200-265 VAC
- DC Output Power: 250-450VDC
- Max Inversion Power: 3.3kW
- Inversion Rated Input:336Vdc
- Inversion rated Output: 220Vac 50Hz
- Efficiency >95%
- Totem Pole PFC 67kHz
- CLLLC 200kHz

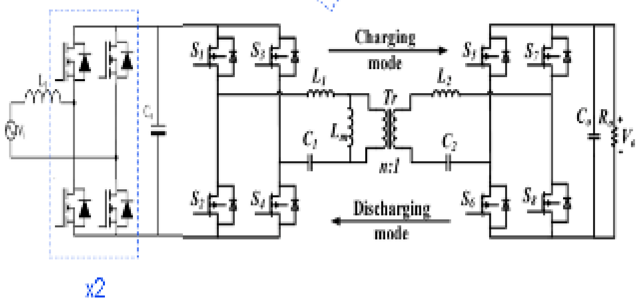
Applications:

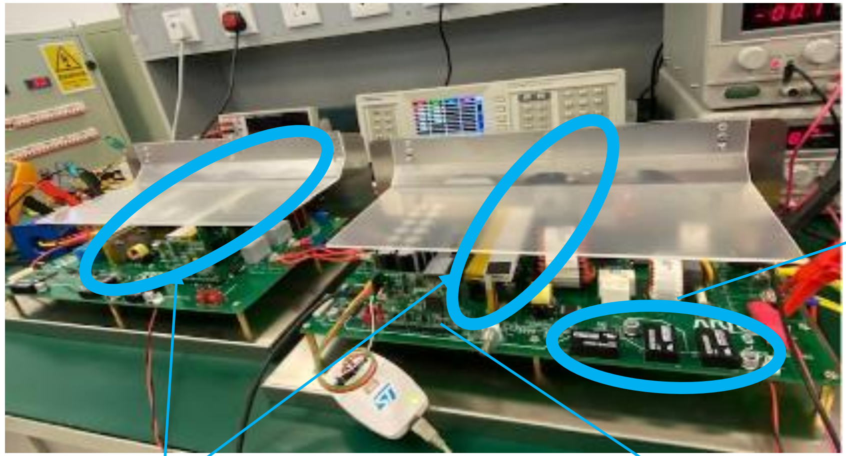
- Onboard charger for EV
- Bidirectional AC-DC equipment
- Energy Storage

1) Power Conversion – Bidirectional charger - 250-450V, 19.6A/ 6600W

Released

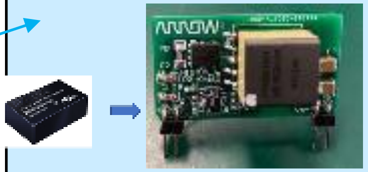


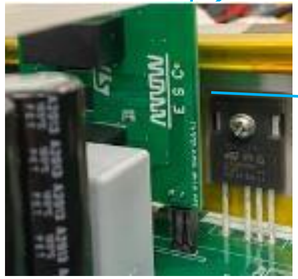




Isolated power supply with **STL8N10LF3 (2021)**
Specification:

- Vin =12Vdc
- Vout = 12V, 1.1A (Max)





ST SiC MOS & Gate Driver Board

SiC MOS Gate Driver

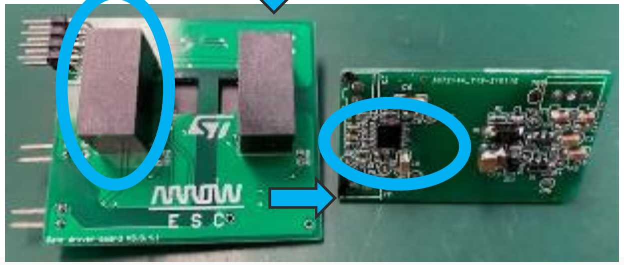
ST MCU Board

- Key ST Parts

Functions at p	Qty	Devices
SiC MOS	16	SCTW40N120G2VAG
SiC MOS Gate Driver-1-CH	12	STGAP2SiCS
Gate Driver Isolated Power	12	A6986I*
Aux -30W	1	VIPER31*
Isolated DC-DC/10W	6	STL8N10LF3*
MCU at PFC Bd.	1	STM32G474VBT6

Demo Video

YouTube   YOUKU 优酷



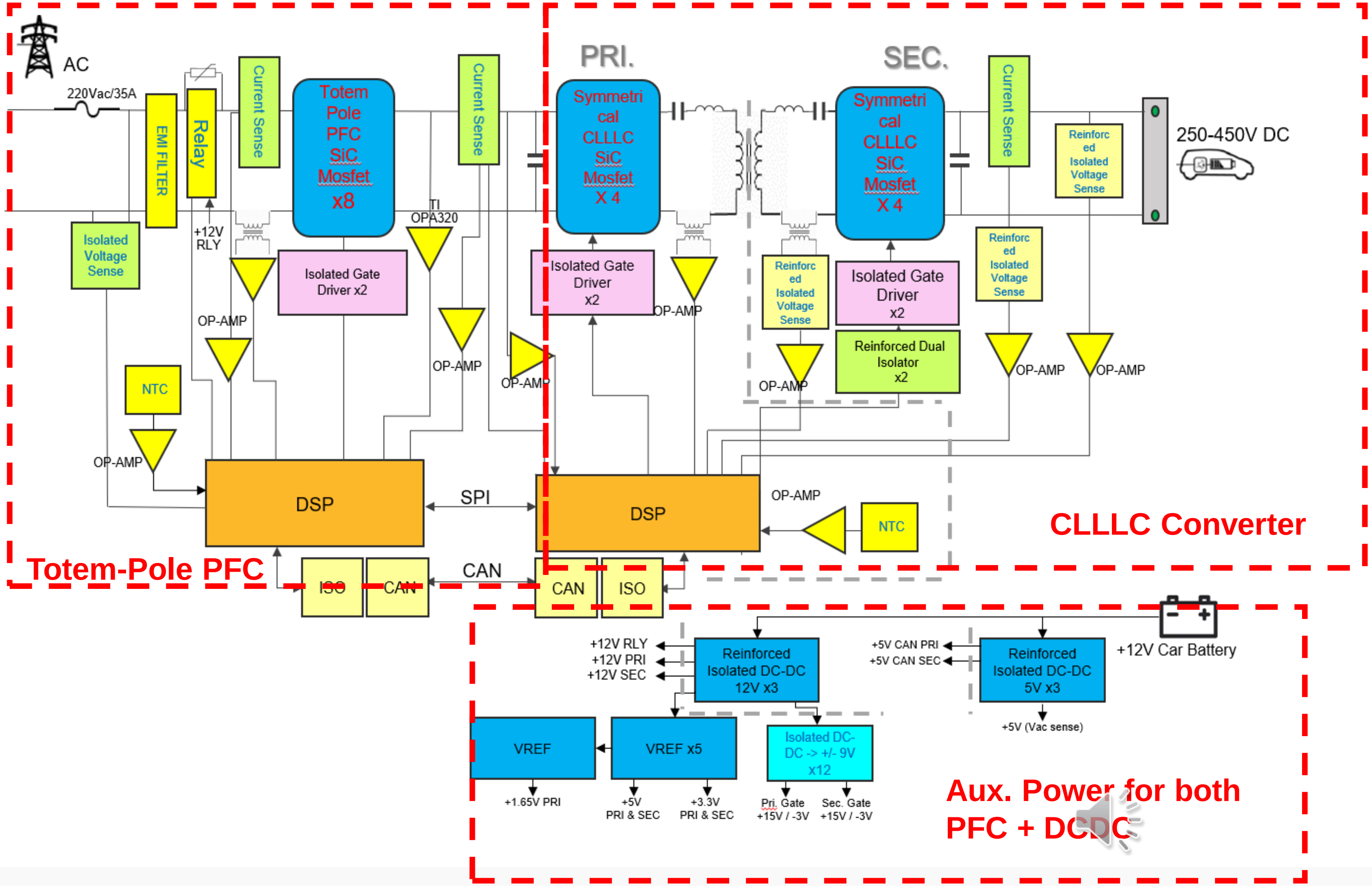
Gate Driver Isolated Power Module
Discrete Alternatives by ST-A6986I

ST Aux Power -30W-ST- VIPER31

6.6kW Bidirectional Power Converter Block Diagram

Challenges

1. Noise at SiC MOSFET gate driving
2. PFC current spike issue at zero-crossing
3. Vac drop (Under-voltage control)
4. CLLLC secondary synchronous rectifier control

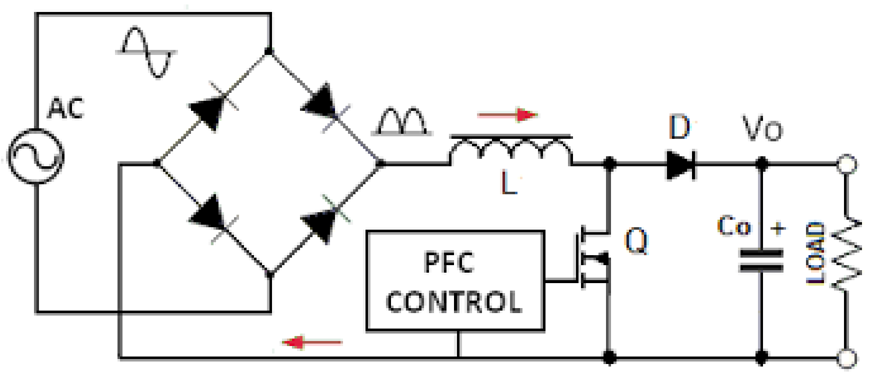


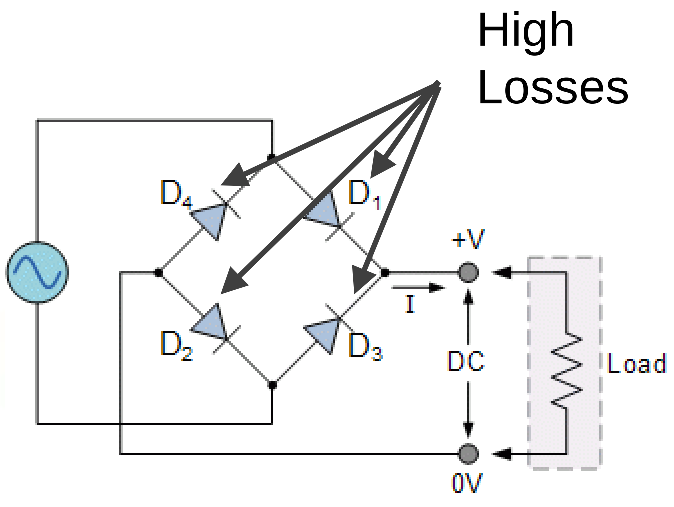
Totem-Pole PFC Bidirectional Power Converter

Why Totem Pole PFC?

Disadvantages of Traditional PFC :

- Larger sized passive components are used
- Higher conduction losses at bridge rectifiers and passive components

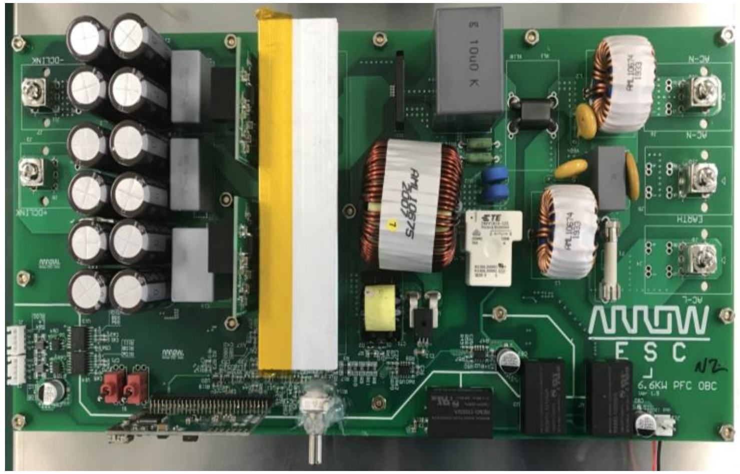




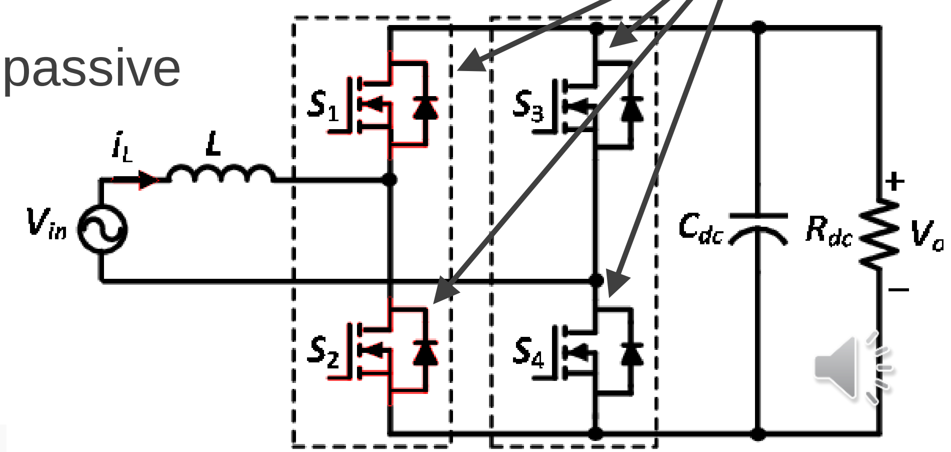
Totem-Pole PFC Bidirectional Power Converter

- Totem-Pole PFC is always called Bridgeless Totem-Pole PFC or Bridgeless PFC

  - Advantage:
    - ✓ Capability of bidirectional power transfer
    - ✓ MOSFET substituted the bridge rectifier, R_{DSON} losses is lower than the bridge rectifier forward voltage drop
    - ✓ SiC MOSFET used, lower power loss
    - ✓ Higher frequency, smaller ripple, smaller size of passive components can be used
    - ✓ Higher power density



Lower Losses with Less SiC MOSFET R_{DSON}

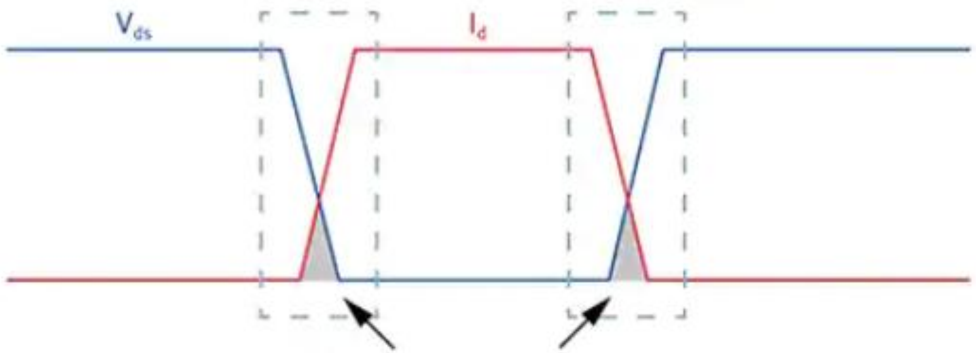


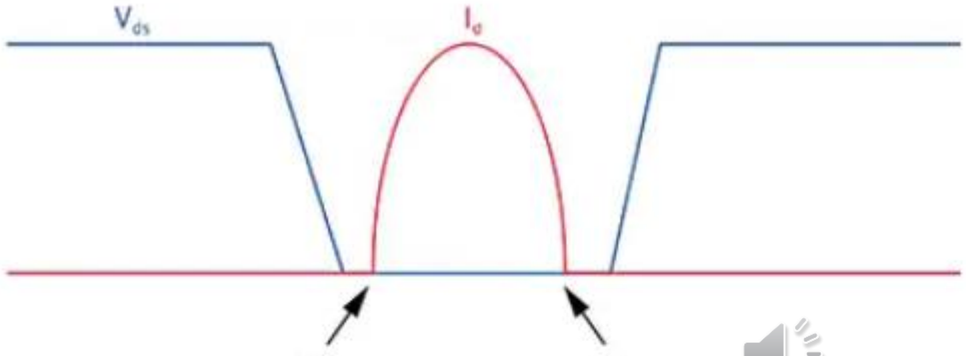
CLLLC Full Bridge Bidirectional Power Converter

CLLLC Full Bridge Bidirectional Power Converter

Why CLLLC?

- Soft-switching by Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS)
- Without ZVS and ZCS, the large switching losses when current and voltage are overlapped at switching
- With ZVS and ZCS, no current and voltage overlapping at switching

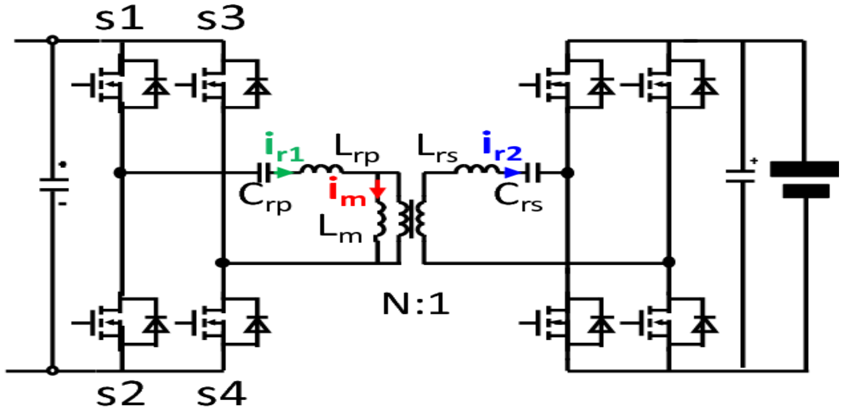




Soft-switching MOSFET current and voltage waveform

CLLLC Full Bridge Bidirectional Power Converter

- CLLLC is a Resonant, Soft-switching Power converter topology
- Advantages:
  - ✓ Capability of bidirectional power transfer
  - ✓ ZVS / ZCS soft switching technologies to achieve lower power loss
  - ✓ Higher switching frequency, smaller ripple
  - ✓ SiC MOSFET used, lower Rdson, lower power loss
  - ✓ Smaller size passive components can be used
  - ✓ Higher power density
  - ✓ Symmetrical, easier to control

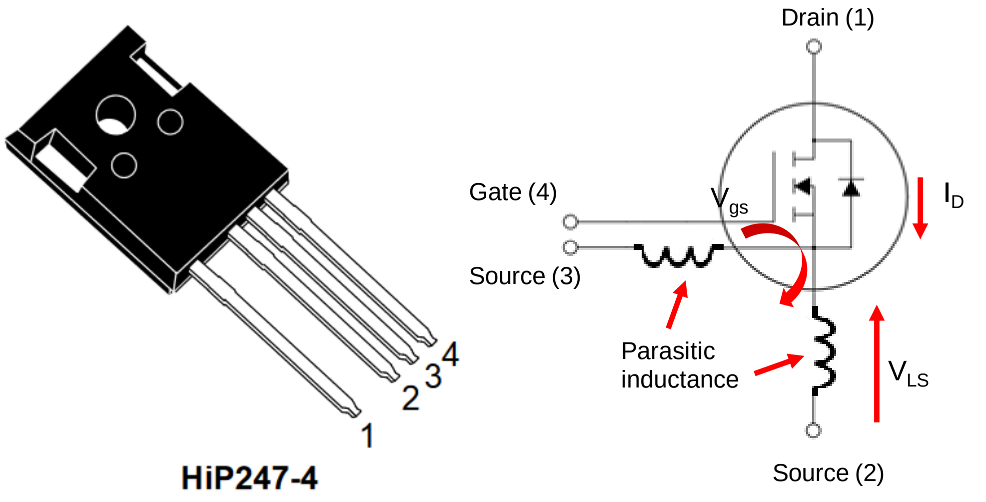


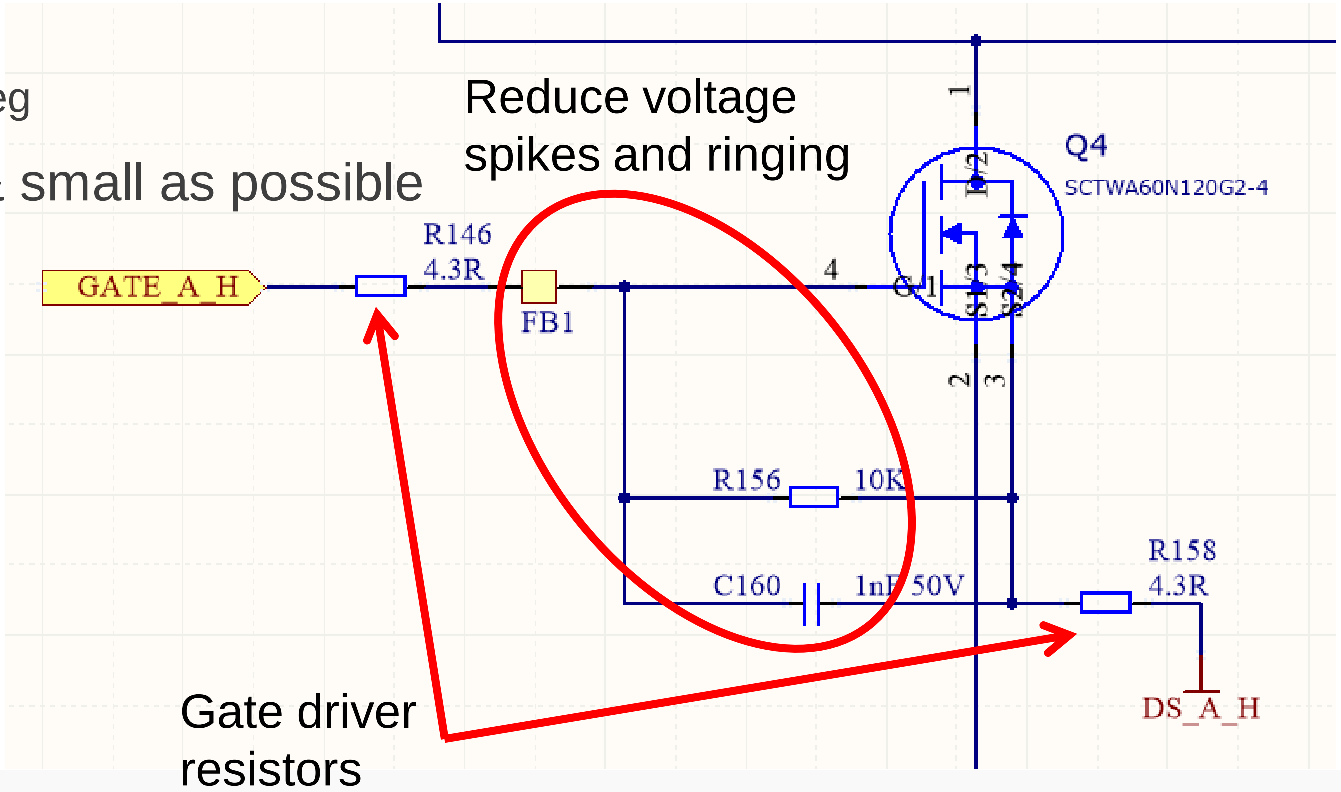
- CLLLC vs LLC
  - LLC has less components, but more complex in control for Gain/Q-point control, especially in reverse direction (inverter mode)
    - LLC in reverse direction (inverter mode) at primary, not ZVS, it’s hard-switching, as there is no resonant tank

SiC MOSFET & Gate Driver Design

Design challenge: Noise at SiC MOS Gate Driving

- SiC MOSFET: SCTWA60N120G2-4 (1200V; 35mΩ typ.; 60A; **HiP247-4**;)
  - **Two** separate Source to separate Gate-Source (G-S) Control Loop and (Drain-Source) Power Loop
- Optimized Gate driver circuit for SiC MOSFET to prevent gate oscillation and reduce voltage spikes and ringing
  - Ferrite Bead at Gate, but not at the Gate Leg
- PCB wiring- G-S & D-S loop as short & small as possible





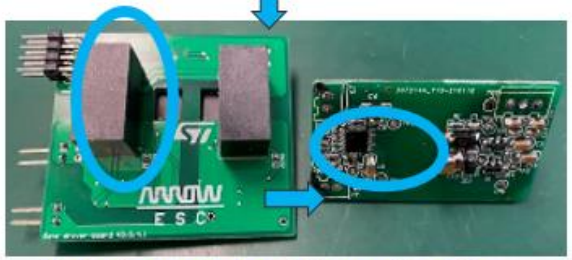
SiC MOSFET & Gate Driver

- SiC MOSFET needs positive & negative voltage driving supply e.g. +20/ -5V

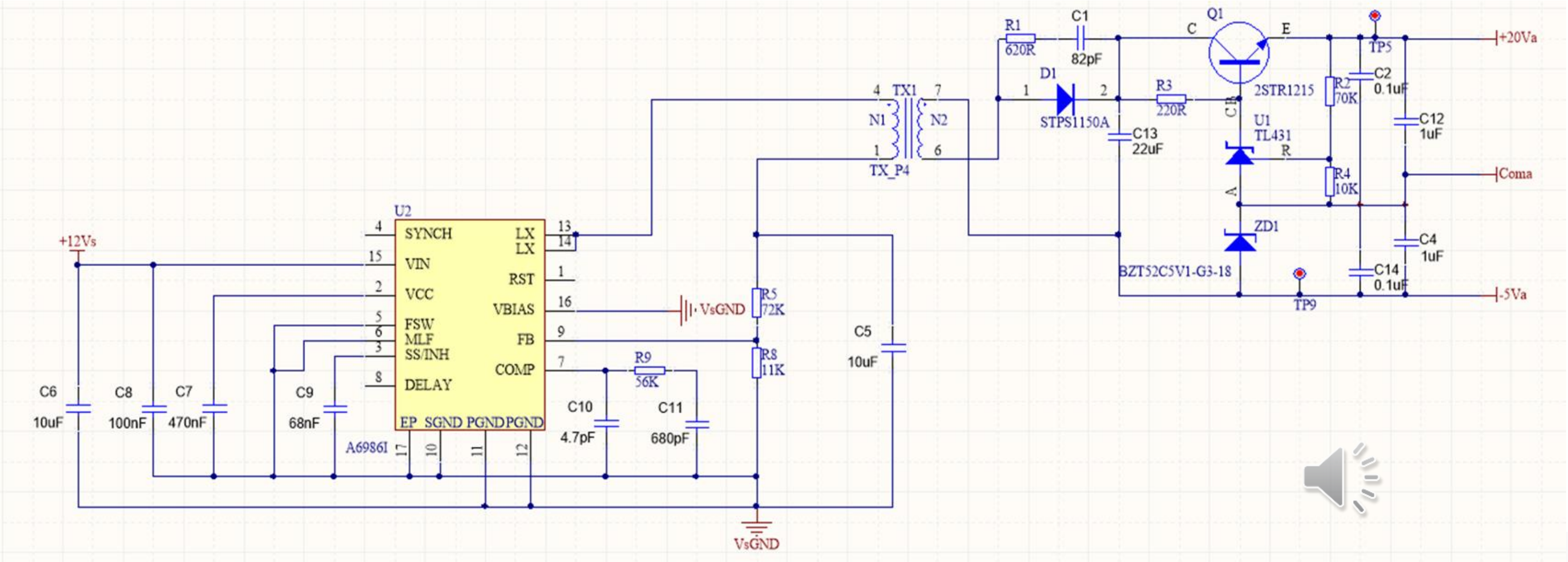
  - Discrete design- ST A6986I
    - ✓ Simple circuit; Size optimized; Fully isolated
    - ✓ No special feedback circuit is needed
    - ✓ +12Vdc input voltage; +20Vdc / -5Vdc output voltage
    - ✓ Max. output power 2.5W
    - ✓ Discrete solution is more cost effective

ST SiC MOS & Gate Driver Board

SiC MOS Gate Driver



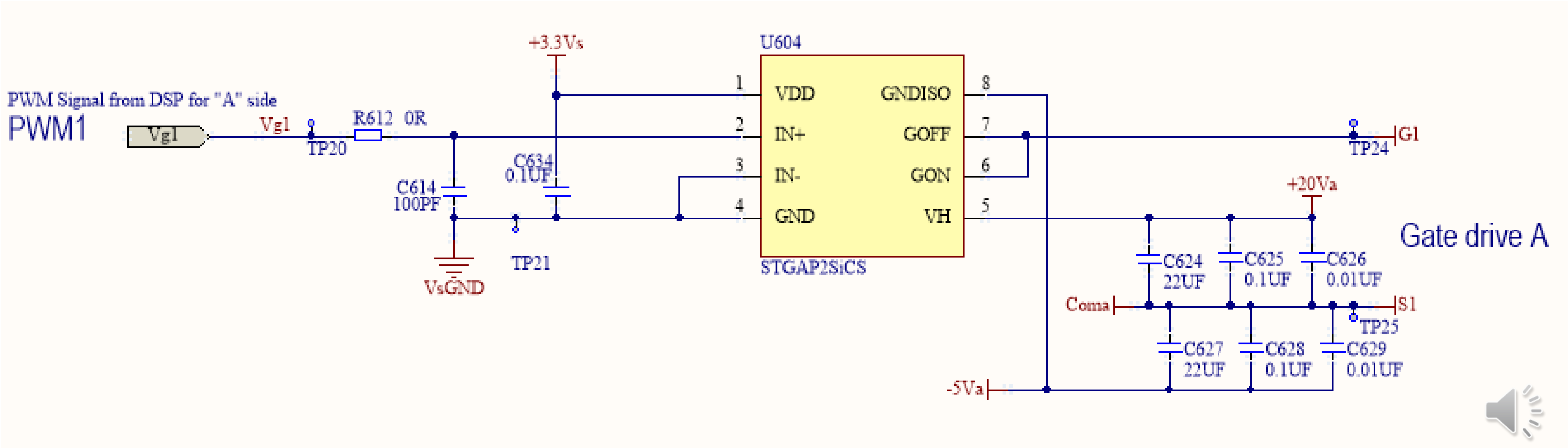
Gate Driver Isolated Power Module
Discrete Alternatives by ST-A6986I



SiC MOSFET & Gate Driver

Gate driver – ST STGAP2SiCS

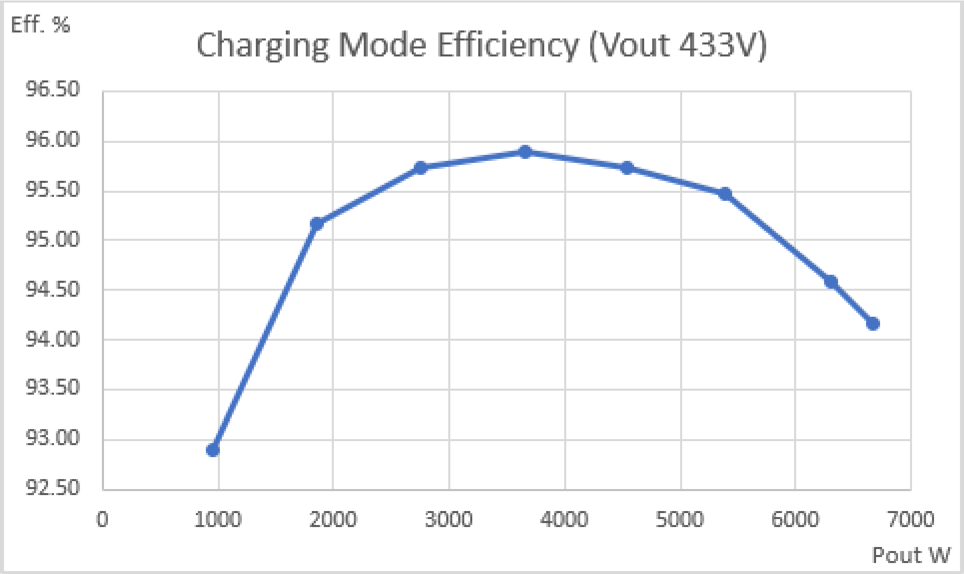
- 4 A driving capability
- Miller CLAMP function prevents gate driver spikes during fast switching operation
- Integrated protection: UVLO & Thermal shut down
- Input to output propagation delay less than 75 ns



Test Results

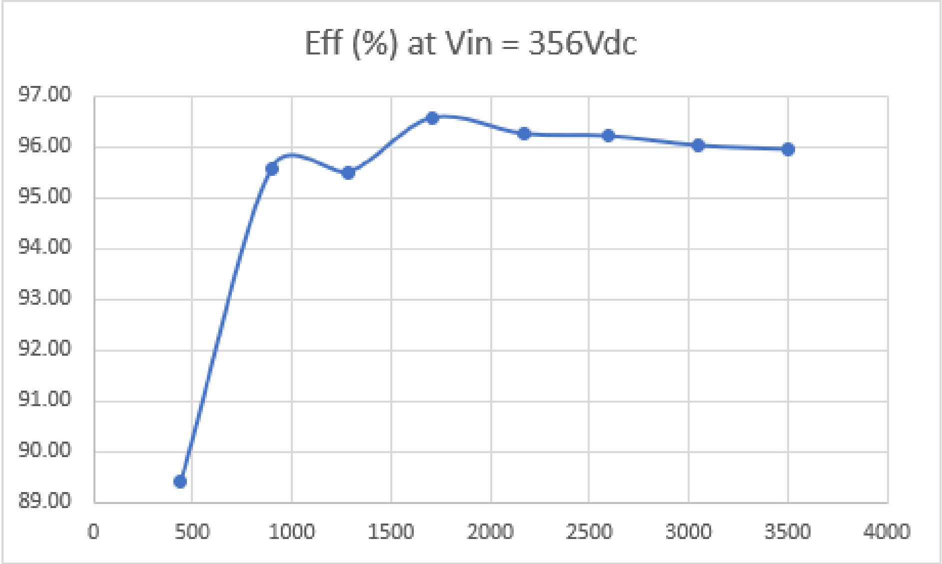
Bidirectional Charger for EV- 250-450V, 19.6A/ 6600W Test Results

Charging Mode:



Vin (V)	230	230	229	229	229	229	228	228
Pin (W)	1028	1950	2885	3818	4741	5646	6675	7076
Vout (V)	433	432	431	430	429	427	426	425
Pout (W)	955	1856	2762	3661	4539	5390	6314	6663
PF	0.986	0.995	0.996	0.997	0.998	0.998	0.998	0.998
Eff (%)	92.9	95.18	95.74	95.89	95.74	95.47	94.59	94.16

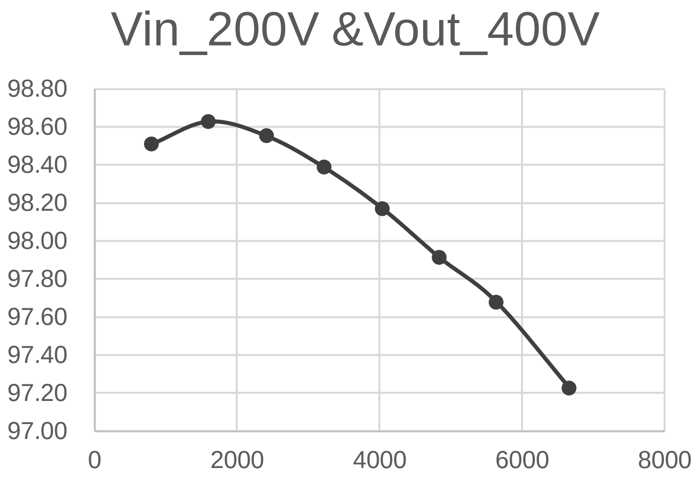
Inversion Mode:

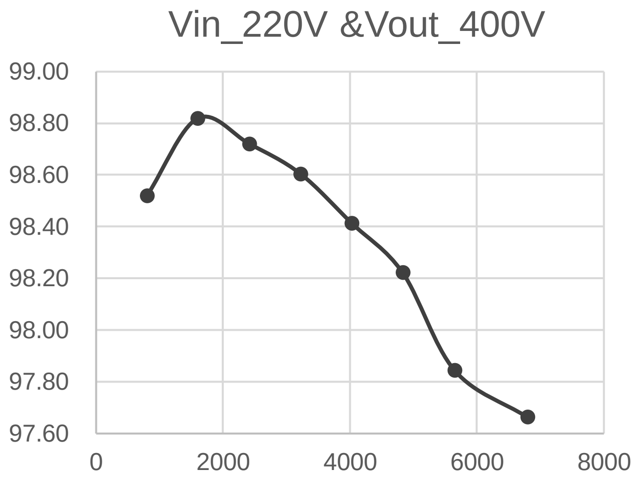


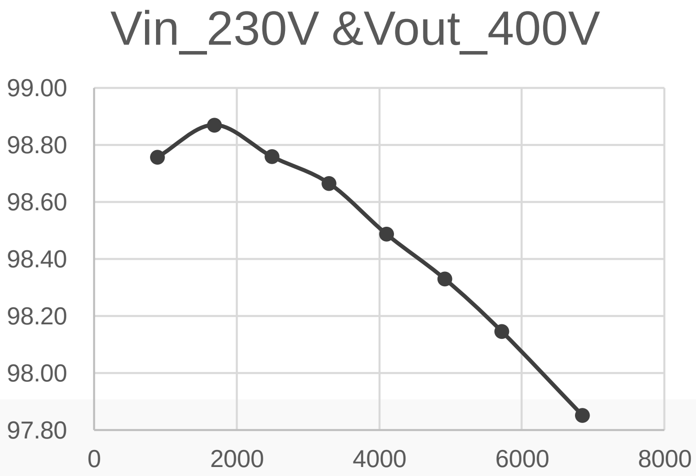
Vin (V)	**355.92**	**355.85**	**355.72**	**355.72**	**355.69**	**355.49**	**355.47**	**355.28**
Pin (W)	**493.86**	**938.19**	**1347.30**	**1767.10**	**2251.30**	**2697.00**	**3175.00**	**3643.60**
Vout (Vac)	**222.85**	**218.30**	**217.85**	**217.00**	**216.81**	**216.95**	**216.61**	**215.97**
Pout (W)	**441.58**	**896.74**	**1286.90**	**1706.70**	**2167.30**	**2595.20**	**3049.00**	**3496.40**
PF	**0.9565**	**0.9896**	**0.9948**	**0.997**	**0.9981**	**0.9983**	**0.9988**	**0.9989**
Eff (%)	**89.41**	**95.58**	**95.51**	**96.58**	**96.27**	**96.22**	**96.03**	**95.96**

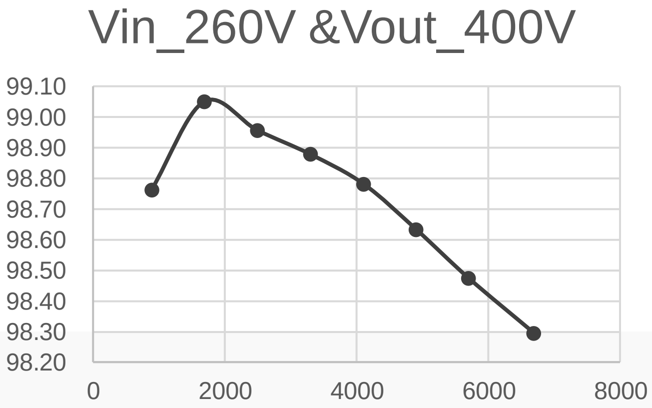
Bidirectional Charger for EV- 6600W (PFC board only) Test Results

- Efficiency of PFC at Vin= 200/220/230/260Vac and Vout = 400Vdc



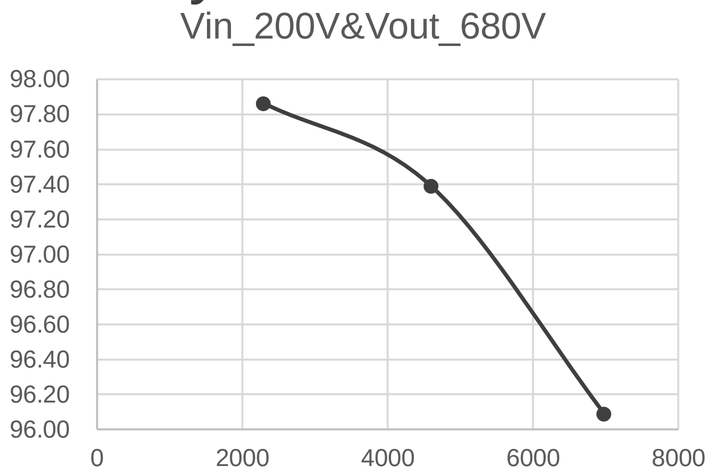


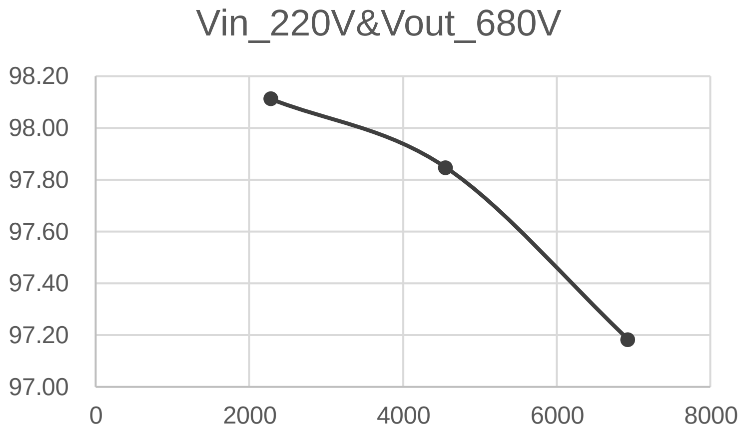


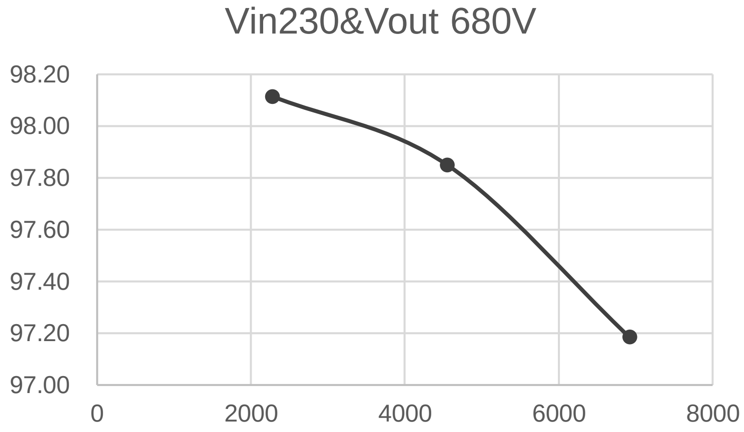


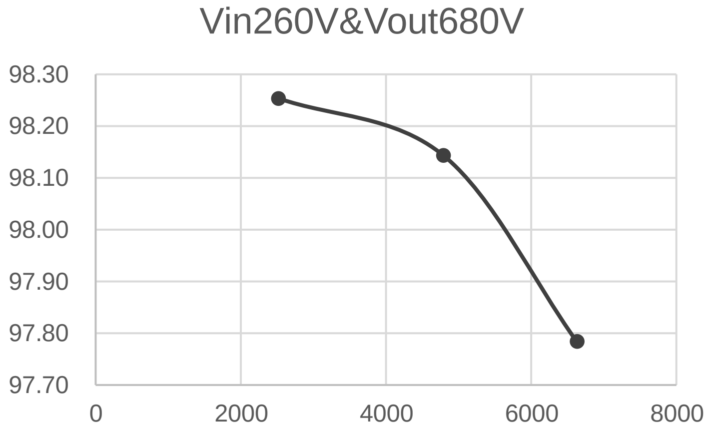
Bidirectional Charger for EV- 6600W (PFC board only) Test Results

- Efficiency of PFC at Vin= 200/220/230/260Vac and Vout = 680Vdc

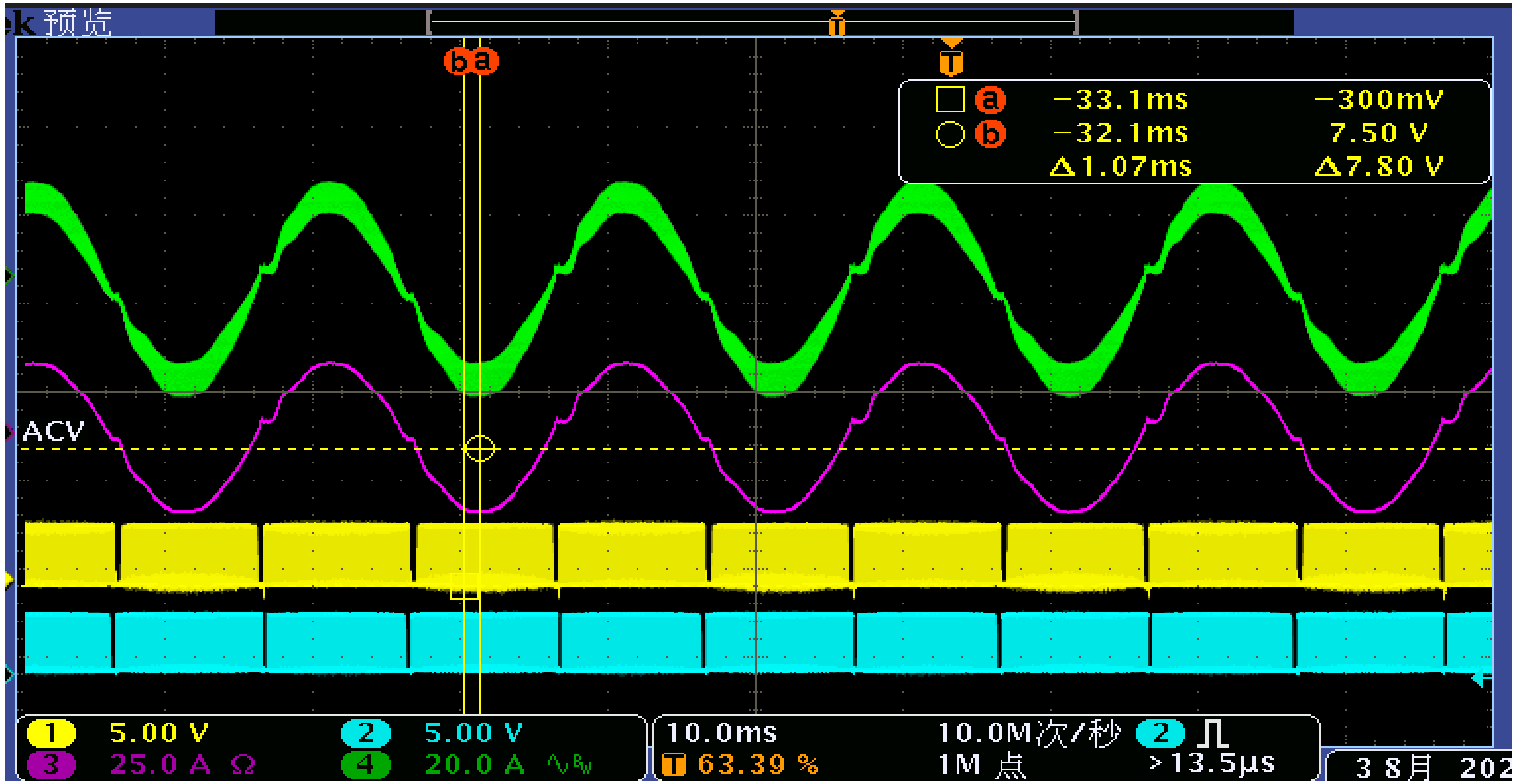


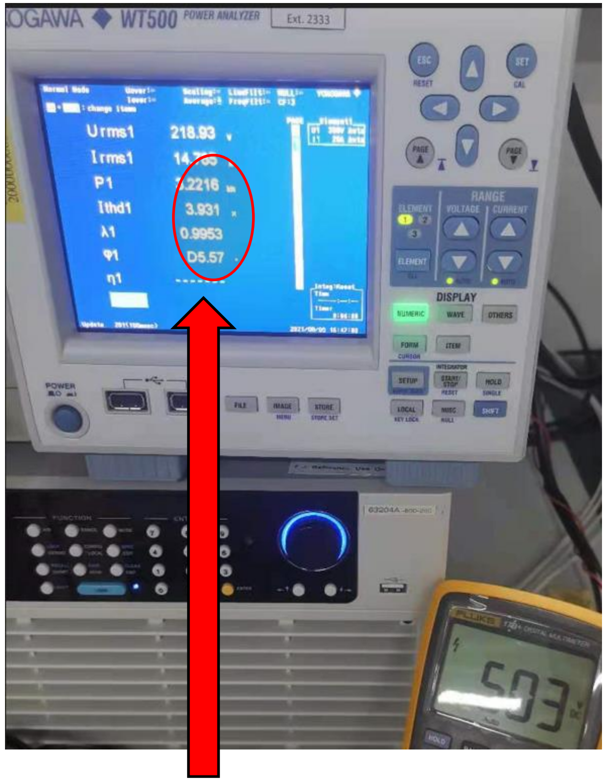






EMC





AC Current (Pink), Inductor Current (Green), Switching PWM (Yellow&Blue)

Test condition

Vin	**220Vac**
Vout	**430Vdc**
P out	**6600W**

* THDi 3.931 %

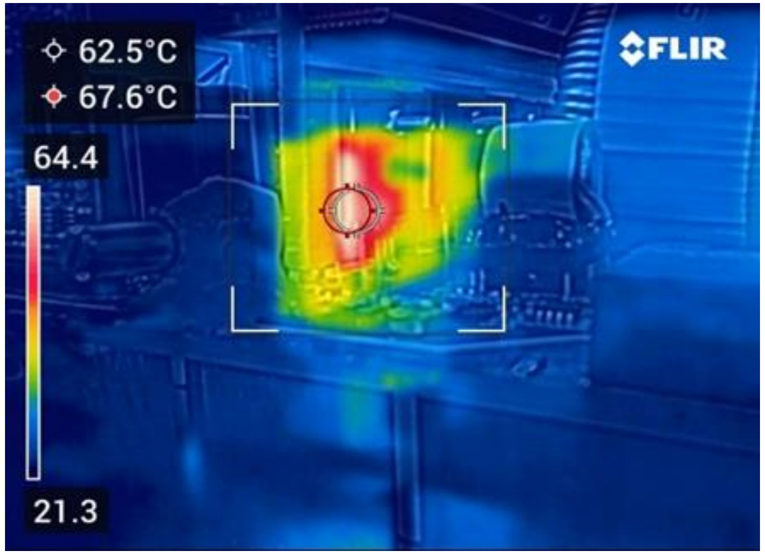
* PF >0.99

Thermal

Test condition

Vin	**220Vac**
Vout	**430Vdc**
P out	**6600W**

Ambient Temp.: 25°C
Delta PFB0812DHE Fan x3pcs –
(at least 132 CFM requested)



SiC Mosfet

CLLLC Transformer

OBC – 6.6kW Bi-directional power conversion (released)

Key components

Function (Main Power)	Supplier	Part Number
SiC MOS	ST	SCTW40N120G2VAG
Gate Driver	ST	STGAP2SICS (1 Ch)
Resonant SMT Cap.	Murata	GCM43D7U3A472JX01L (New)
Main E-cap	Lelon	RQL221M2GBKF1846KEGA
Film cap.	Vishay	MKP1848530094K2
X-cap	Kemet	F863 series
MOV	TDK	B72220S3321K101
Fuse	Littelfuse	01220093Z/0HEV030ZXBD

Function (Aux Power)	Supplier	Part Number
LDO 3.3V	ST	LDK130M33RY
ISO DC-DC 12-12V	RECOM	REM10-1212S/A*
ISO DC-DC 12-5V	RECOM Murata	REM3-1205S/A* NCS3S4805SC*
Gate DRV ISO DC-DC 12- +/- 9V	RECOM Murata	R12P209D* NMK1209SC*

Function (DSP control)	Supplier	Part Number
MCU	ST	STM32G474RE
Crystal	Abracon	ABM3C-20.000MHz-D4Y-T
CAN Choke	Murata Bourns	DLW43SH510XK2L SRF4530A-510Y
Current Sense	Allegro	ACS770LCB-050U-PFF-T
OP-AMP	ST	TSZ181IYLY
NTC	Vishay	NTCALUG01A103F161
Ferrite Bead	Murata	BLM21PG221SH1D
Ceramic SMT Cap	Murata TDK Kemet	GRT, GRM series CGA series CXXXXXXXAUTO
E-cap	Kemet	EDH477M025S9PAADH
Sig. Inductor	Murata	LQM2HPZ2R2MG0L
SMT Resistor	Vishay	CRCWXXXXXXXXXJNED

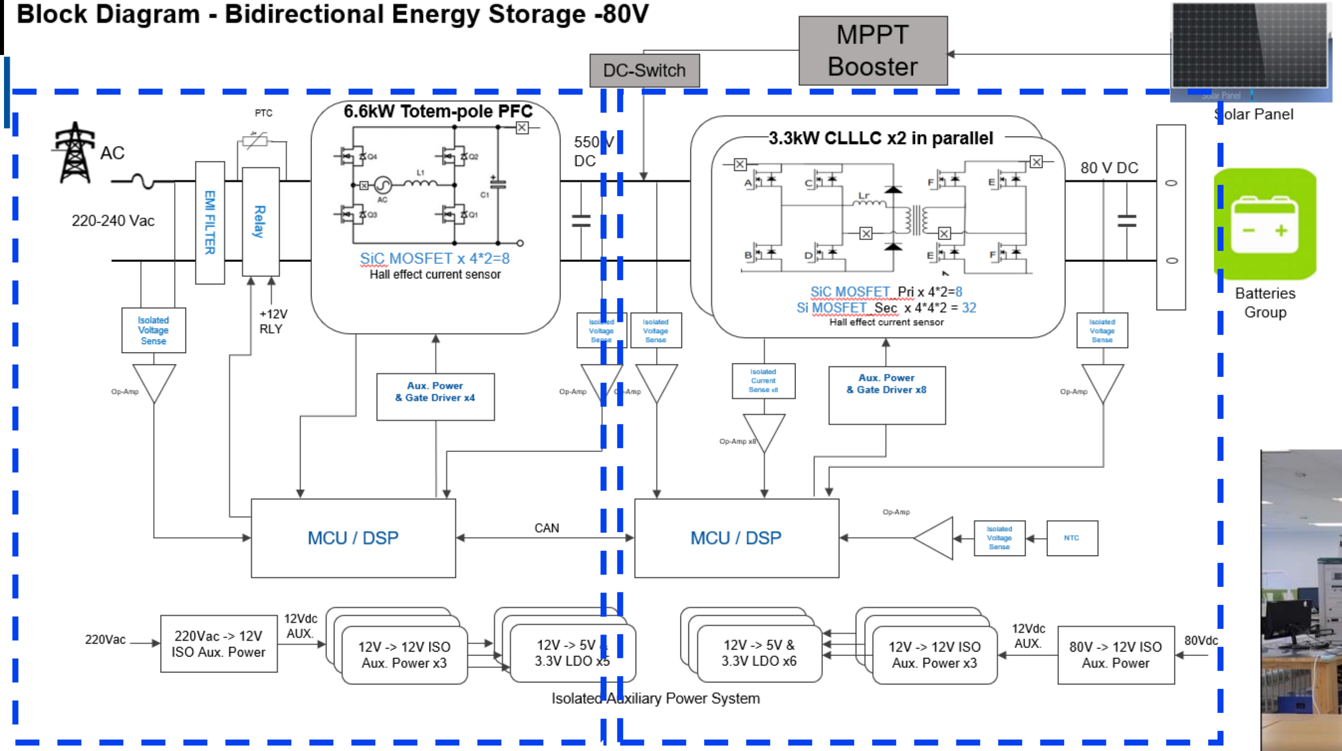
Note
*: Non-automotive parts

Extension to EV charger for E-bike, Energy Storage……

Bidirectional Energy Storage – 80V, 82.5A/ 6600W

In Development

Block Diagram - Bidirectional Energy Storage -80V



PFC: Lx Wx H= 450mm x 150mmx 100 mm

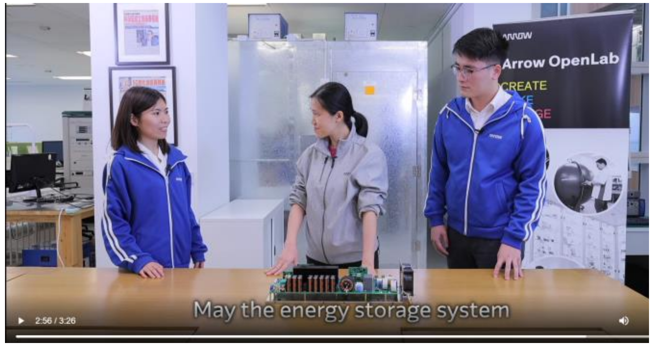
Bidirectional PFC
(Released)

DC-DC Lx Wx H= 450mm x 330mmx 100 mm

Bidirectional DC-DC
(Release by Q4'22)

Demo video

https://www.arrowopenlab.com/hk/solution_video_article/2021P005_en.html



Specification:

- AC/DC Bidirectional Power Conversion
- Max Charging Power: 6.6kW
- AC Input Voltage: 180-265 VAC
- DC Output Power: 60-90VDC
- Max Inversion Power: 6.6kW
- Inversion Rated Input: 80Vdc
- Inversion rated Output: 220Vac 50Hz
- Efficiency >95%
- Totem Pole PFC 120 kHz
- CLLLC 200kHz
- Forced Cooling

Applications:

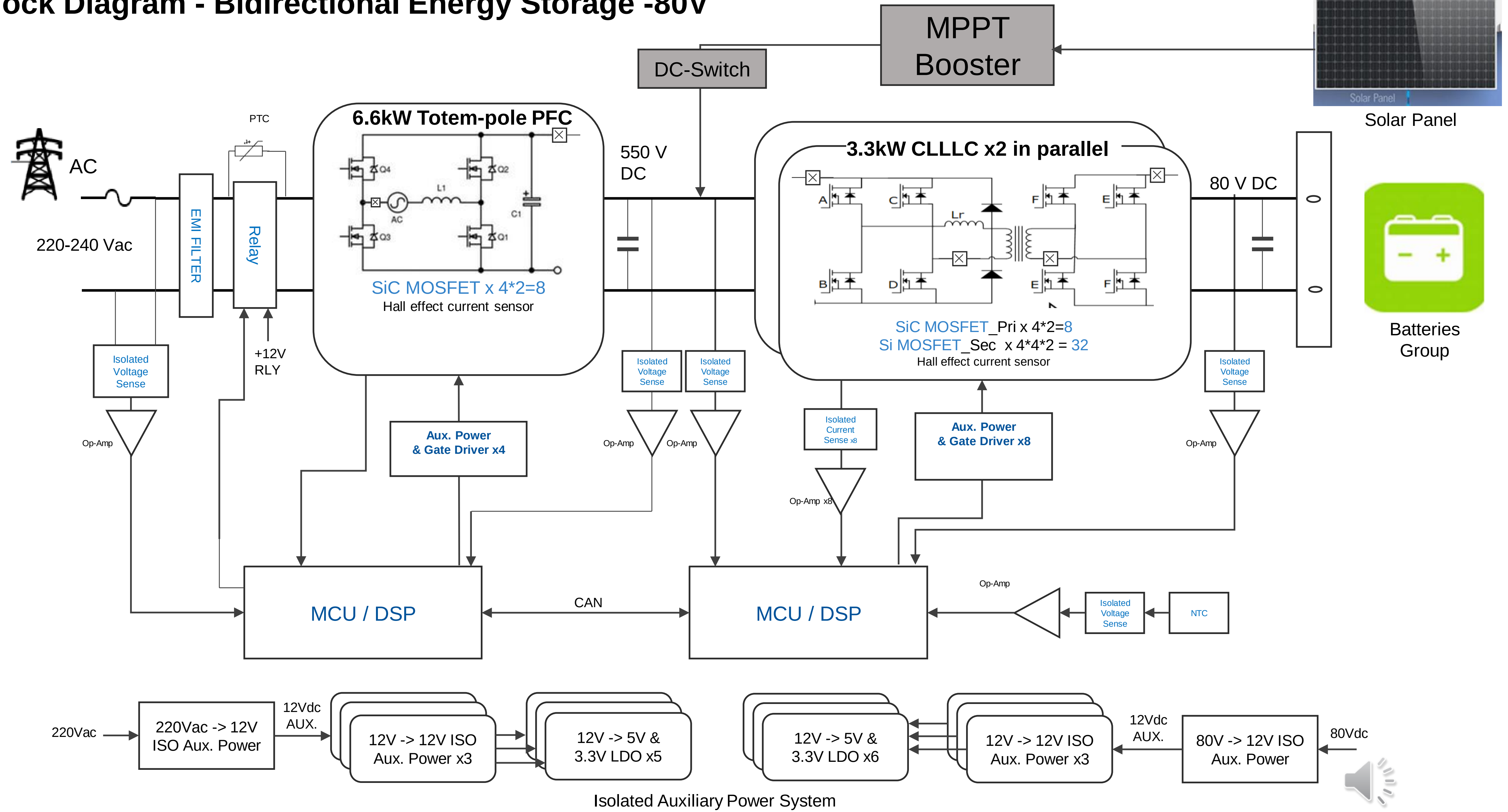
- Energy Storage
- Solar inverter with energy storage
- Forklift Charger
- AC-DC loading equipment

- Key ST Parts

Functions	Qty	Devices
SiC MOS	16	SCTWA60N120G2-4
SiC MOS Gate Driver- 1-CH	8	STGAP2SiCS
Gate Driver Isolated Power	12	L6986I
DC-DC low side FET	32	STP75NF20
Diode	2	STPS1150A
Isolated DC-DC/10W	6	STL8N10LF3*
MCU	2	STM32G474VBT6

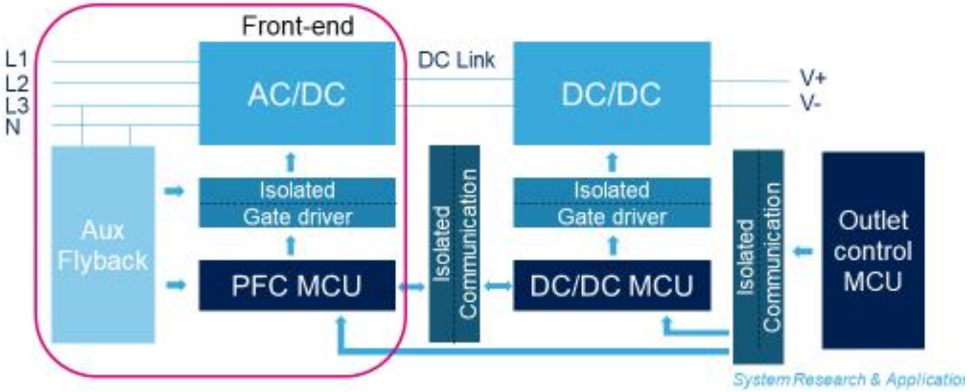
Functions	Qty	Devices
Aux	1	VIPER319HDTR
ESD Suppression	3	HDMIULC6-4SC6Y
ESD Suppression	2	ESDCAN03-2BWY
Hi-Precision OP-AMP	1	TSZ181ILT
Processor Supervisor	1	STM6825TWY6F
Digital Isolator	2	STISO621WTR

Block Diagram - Bidirectional Energy Storage -80V



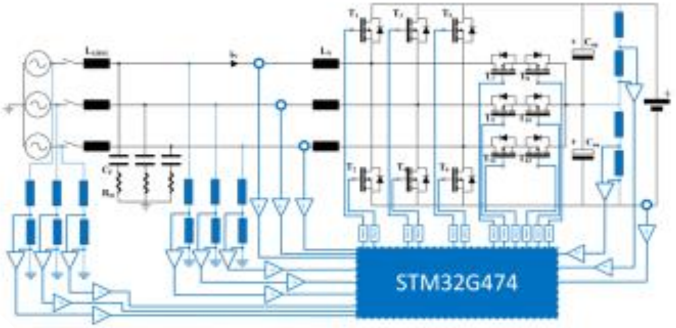
15kW Bidirectional PFC

Front-end Power Converters

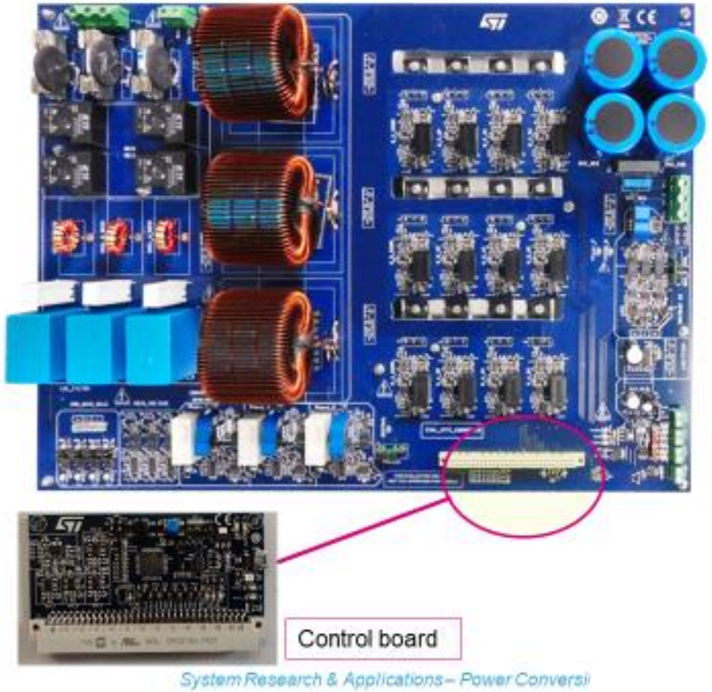


specifications

V_{AC}	400 Vac
V_{DC}	800 Vdc
P_{Out_max}	15 kW
F_s	70 kHz
I_{ripple}	2.5A
V_{out_ripple}	10 Vpp
PF	> 0.9
THD	< 5%



STDES-PFCBIDIR Demoboard



Digital Power Control - MCU

MCU STM32G474

> Accelerator-- Cordic

- STM32G4 Cordic 支持以下的函数:
  - 余弦Cosine (cos θ)
  - 正弦Sine (sin θ)
  - 相位Phase (atan2 y,x)
  - 取模Modulus ($\sqrt{x^2 + y^2}$)
  - 反正切Arctangent ($\tan^{-1}$ x)
  - 双曲正弦Hyperbolic sin (sinh x)
  - 双曲余弦Hyperbolic cosine (cosh x)
  - 双曲反正切Hyperbolic arctangent ($\tanh^{-1}$ x)
  - 自然对数Natural logarithm (ln x)
  - 平方根Square root ($\sqrt{x}$)

q1.15 fixed point: (precision = 4)

ARM fast math arm_sin_q15()	Cordic: zero-overhead mode	Cordic: DMA in/out mode
36 cycles/sample	7 cycles/sample	11 cycles/sample
-	x5 acceleration	x3 acceleration
100%CPU	100% CPU	0% CPU
Max error: 0.00012	Max error: 0.00004	Max error: 0.00004
-	x3 precision	x3 precision

q1.31 fixed point: (precision = 6)

ARM fast math arm_sin_q31()	Cordic: zero-overhead mode	Cordic: DMA in/out mode
41 cycles/sample	8 cycles/sample	12 cycles/sample
-	x5 acceleration	x3 acceleration
100%CPU	100% CPU	0% CPU
Max error: 0.00002	Max error: 0.000002	Max error: 0.000002
-	x10 precision	x10 precision

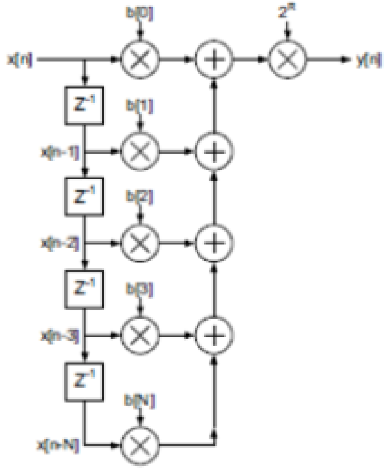
MCU STM32G474

> Accelerator-- FMAC

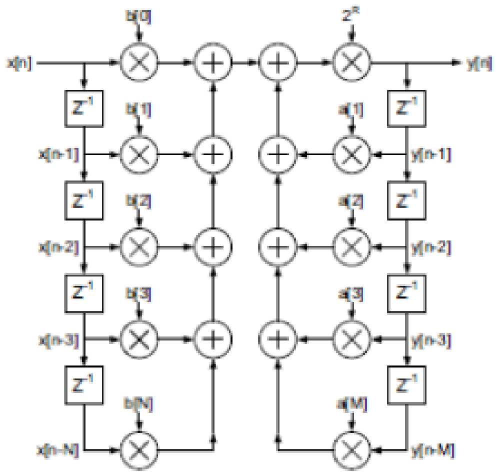
数字滤波加速器(FMAC)

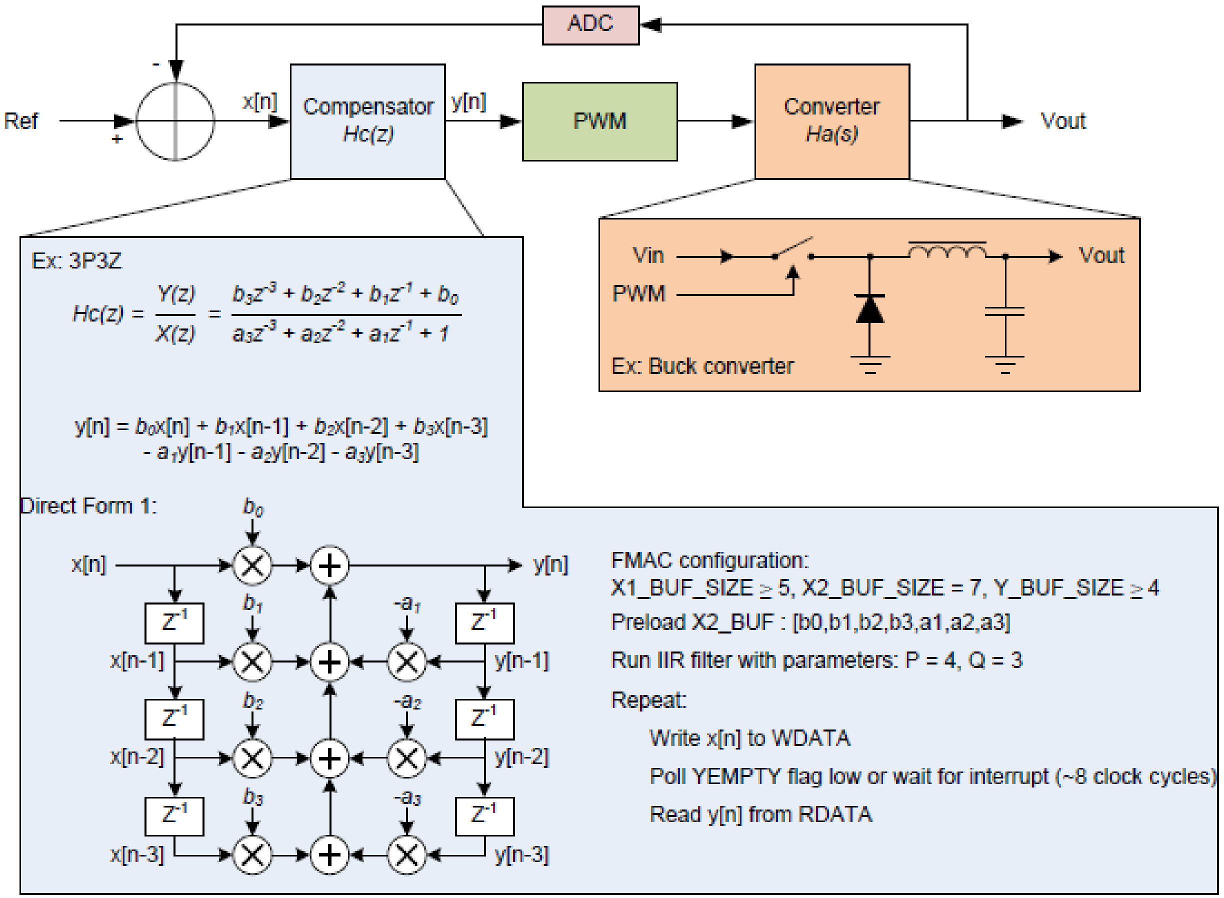
- 可被用于生成
  - FIR，IIR
  - 补偿器 (数字电源三极点三零点3p3z)

FIR 滤波器



IIR滤波器

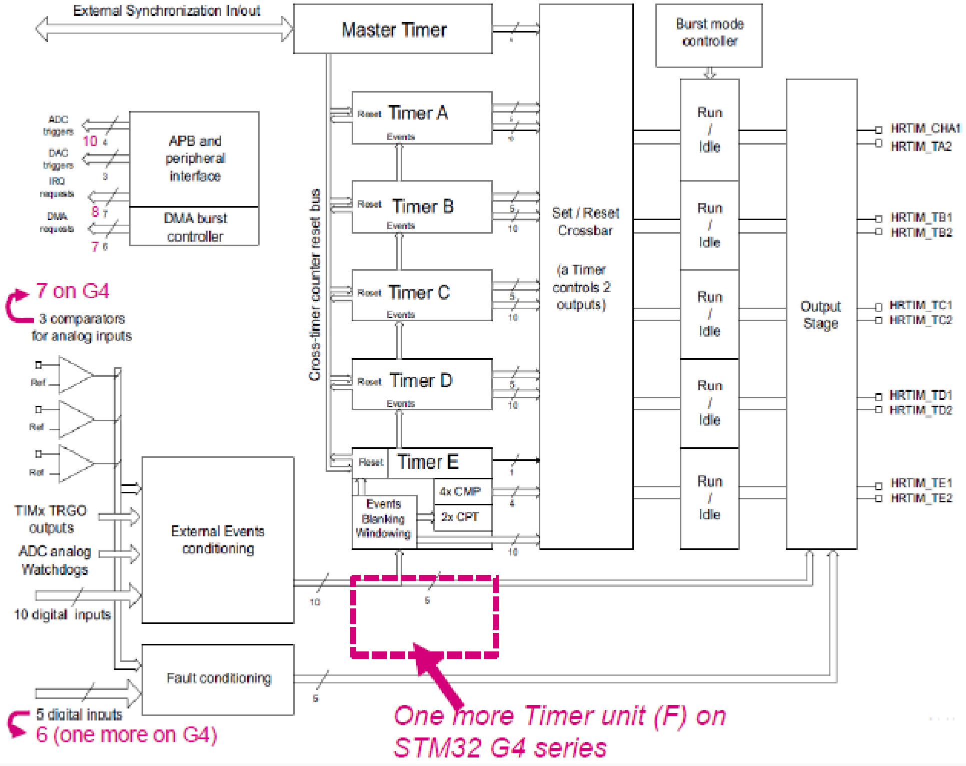




MCU STM32G474

> HRPWM

- 模块架构: 主定时器+ 6 x 子定时器，交叉同步
- 主频:170MHz， DLL 32x to 5.4G
- 高精度
  - 184ps 所有PWM输出
- 自动校准
  - 无温漂/电压偏移
- 高达12 路PWM输出
- 多种故障/事件输入
- 减少软件开销
- 复合事件处理机制
  - 消隐/窗口/超时



In courtesy to st.com

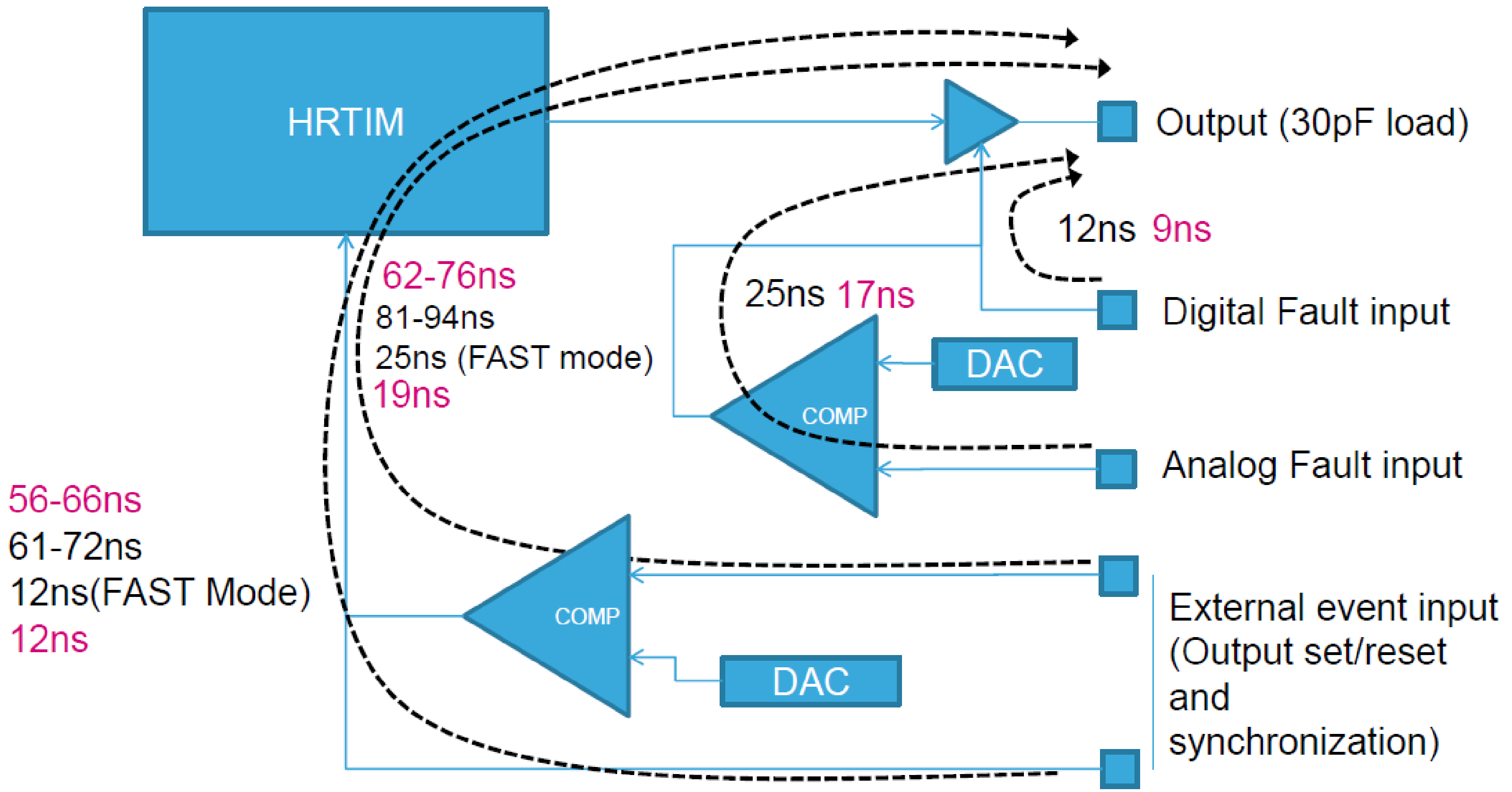
MCU STM32G474

> ADC

ADC 单元	5 (only 2 for G431)
输入通道	高达42路输入，单端/差分模式 (only 18 for G431)
转换技术	12-bit 逐次逼近
转换时间	250 nS, 4 Msamples/s (when f_{ADC_CLK} = 60 MHz)
转换模式	单次(singal)、连续(continuous)、扫描(scan)、不连续(discontinuous)、注入(injected)
触发启动	软件启动或是外部事件触发启动(定时器或是IO)
特殊功能	硬件过采样，模拟看门狗 (+滤波), 数据预处理 (偏置和增益补偿), 多种采样时间设定
数据处理	中断, DMA 请求
低功耗模式	Deep power-down, auto delay, 功耗取决于转换速度

MCU STM32G474

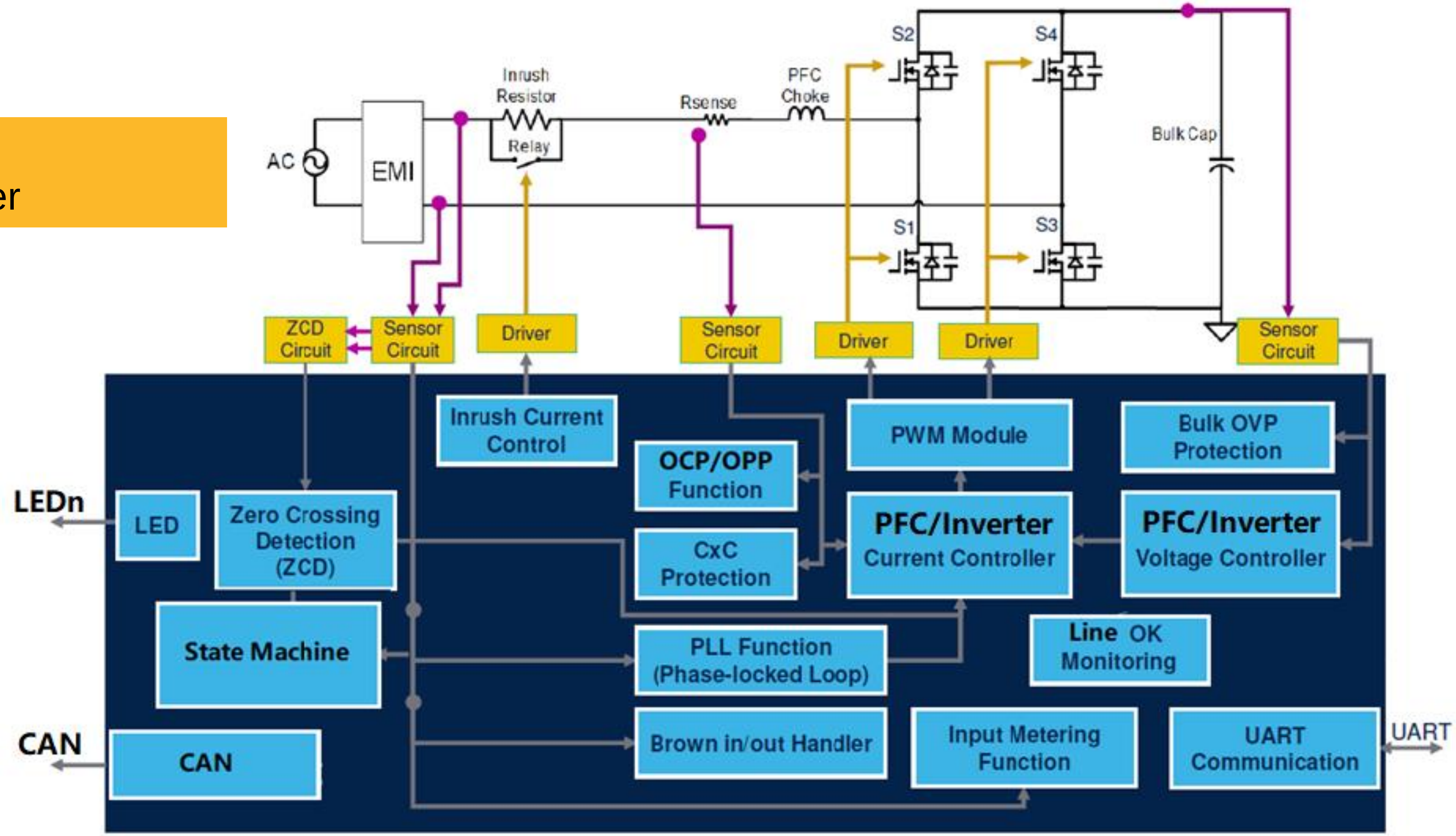
> Fast protection response



Digital Power Control - Firmaware

PFC/Inverter Functional Block Diagram

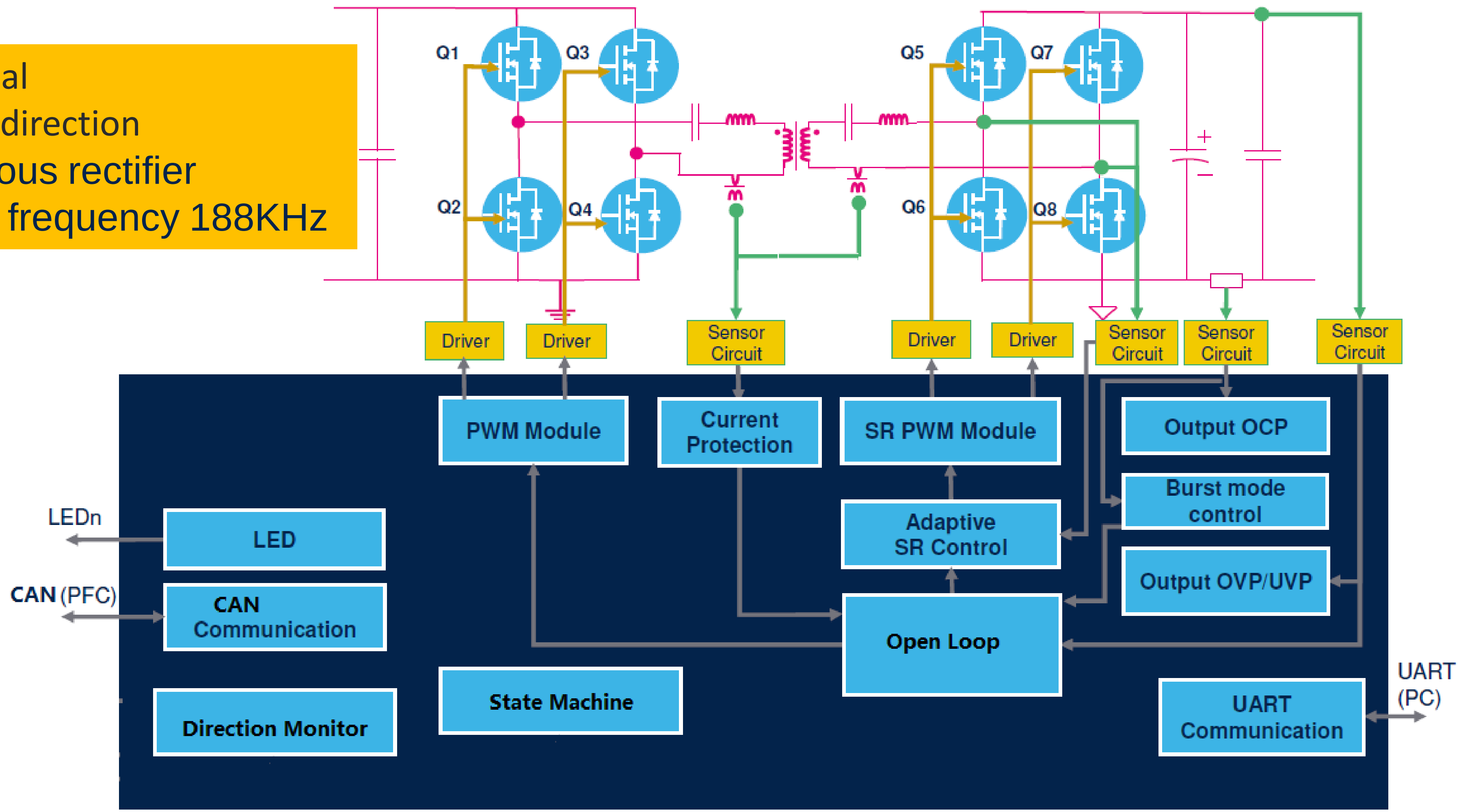
- PFC
- Inverter



In courtesy to st.com

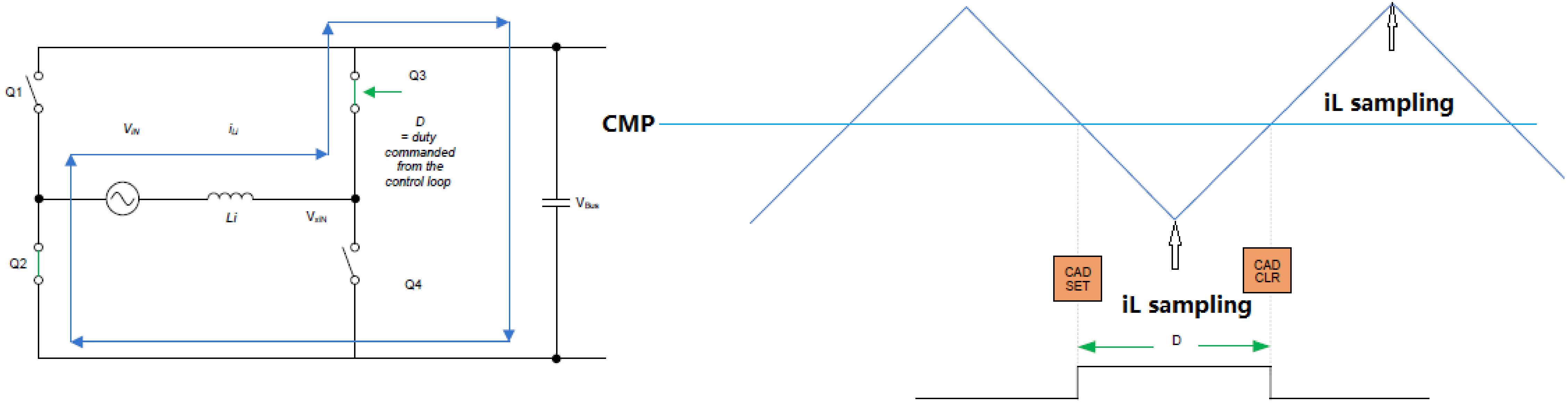
CLLLC Functional Block Diagram

- Bidirectional
- Adaptivity direction
- Synchronous rectifier
- Resonant frequency 188KHz



In courtesy to st.com

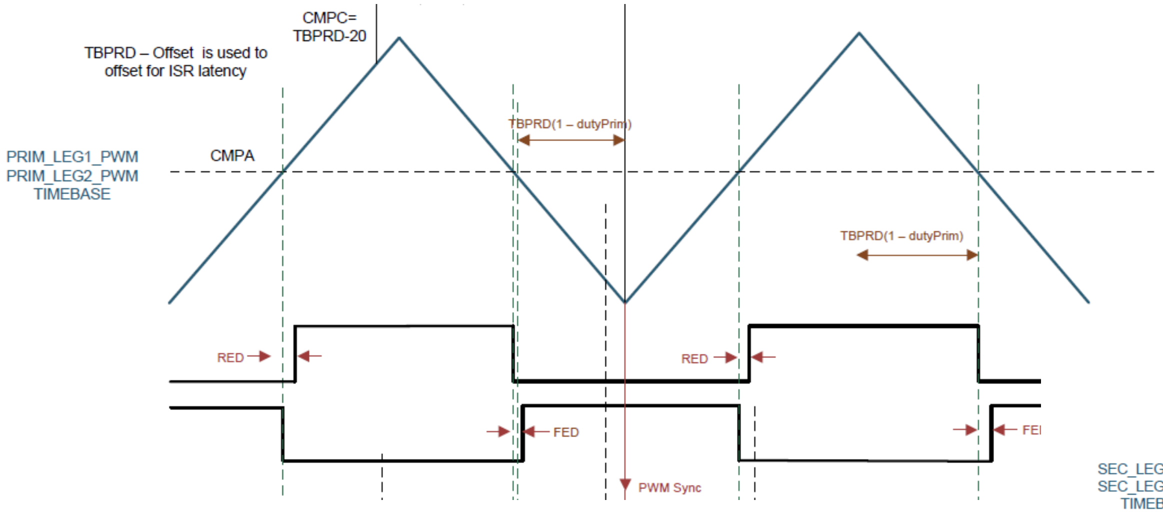
PWM Generate& Current sampling For PFC



Single-Phase Diagram of TTPL PFC

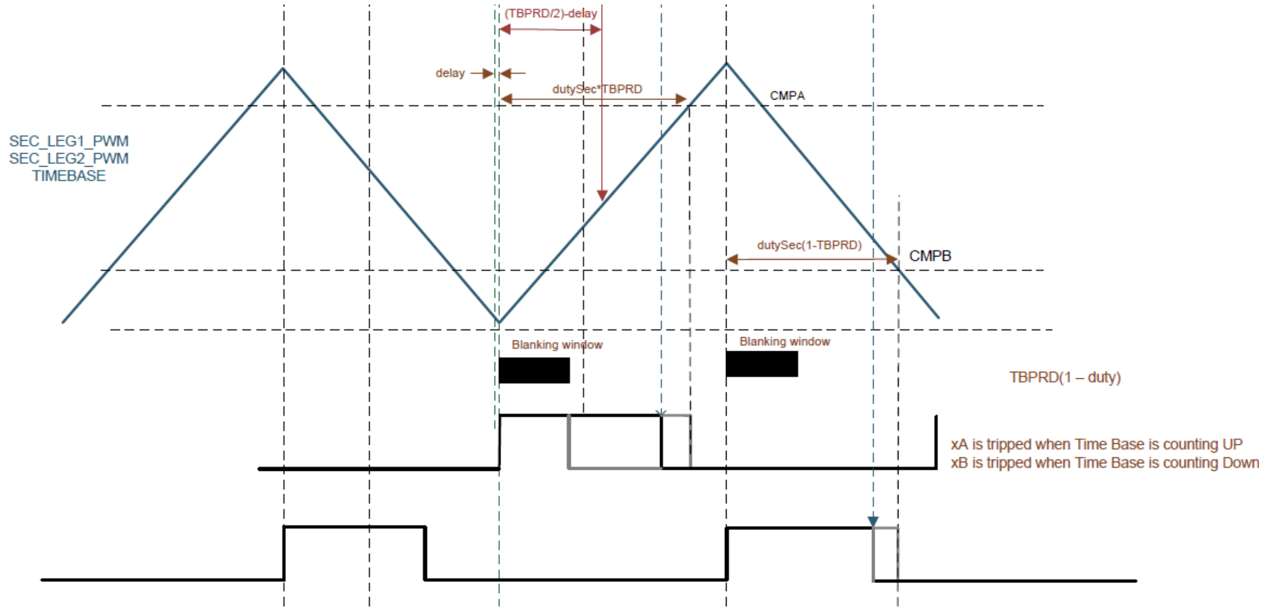
Inductor current is sampled twice per PWM switching cycle，averaged twice before being used as the current loop feedback input. It can mainly reduce the interference during sampling and ensure the balance of positive and negative half cycles.

PWM Generate For CLLLC

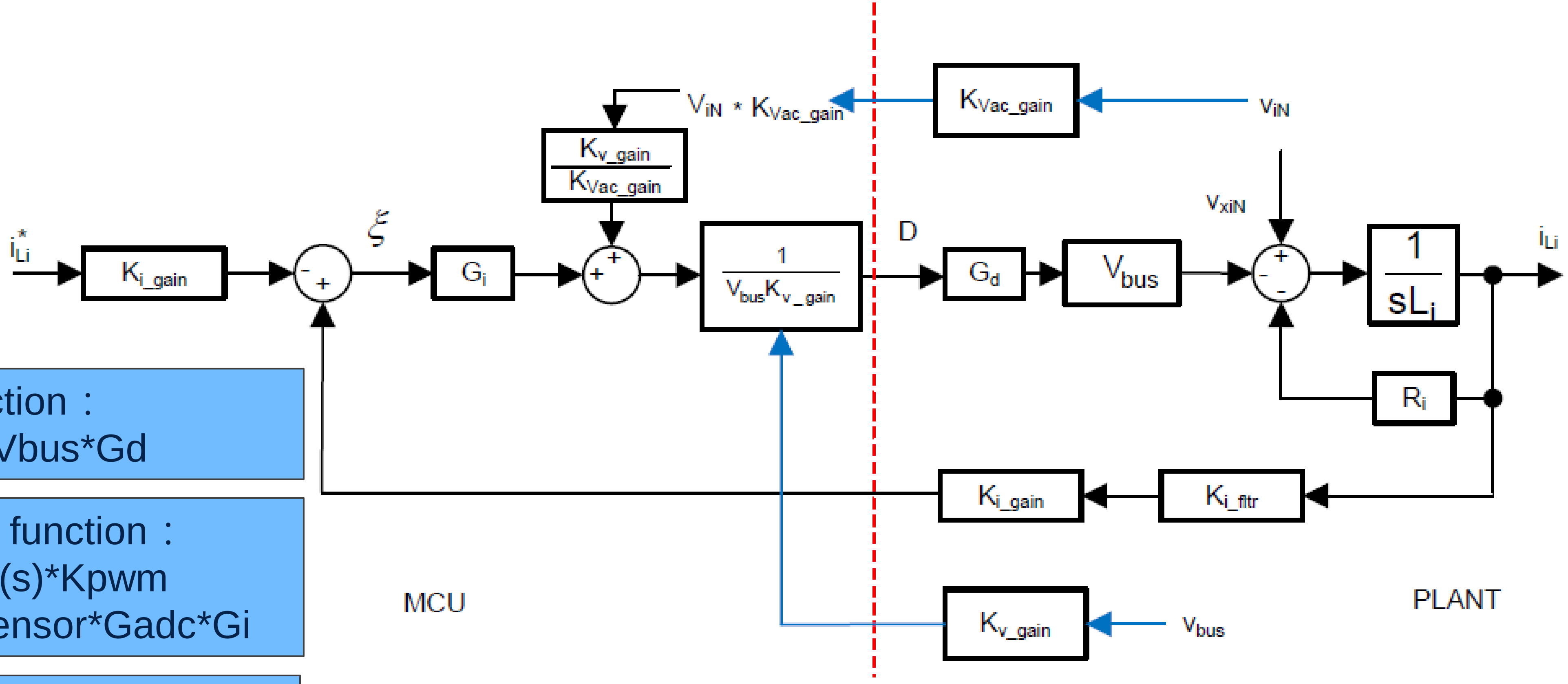


Primary Side PWM

Second Side PWM



Current Loop Block Diagram For PFC

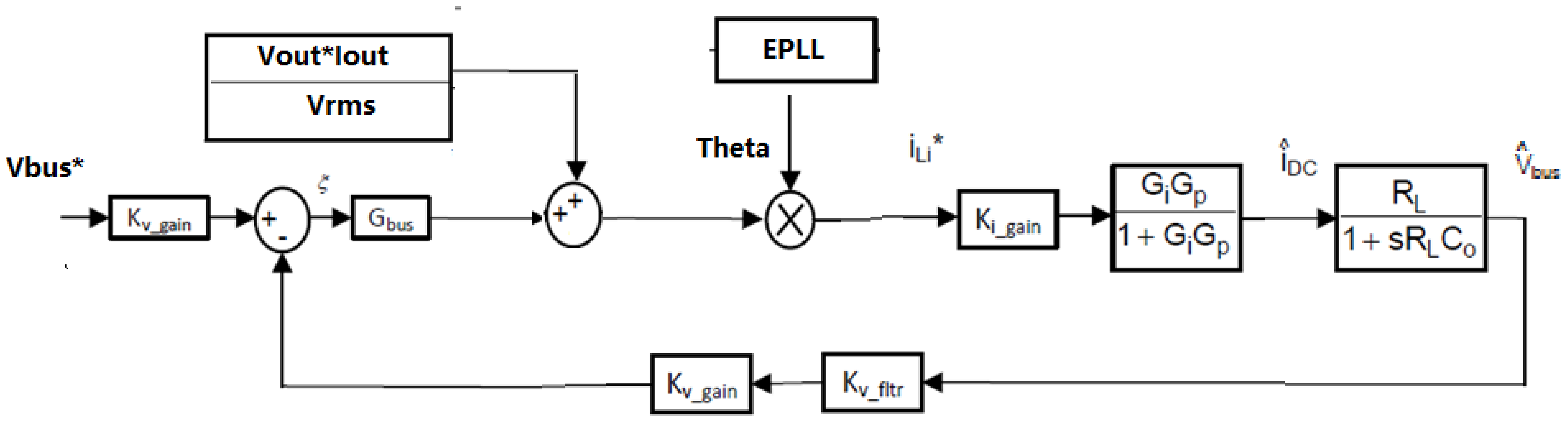


Plant transfer function：
Plant(s)=(1/sLi)*Vbus*Gd

Open loop transfer function：
I_Plant(s)= Plant(s)*Kpwm
*Gi_sensor*Gadc*Gi

Control algorithm: PI

Voltage Loop Block Diagram for PFC

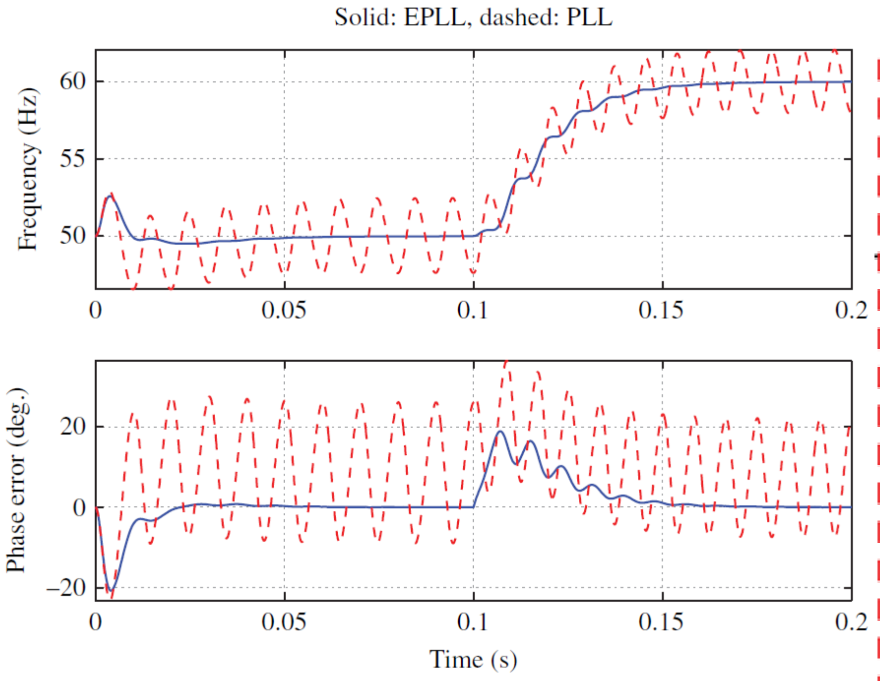


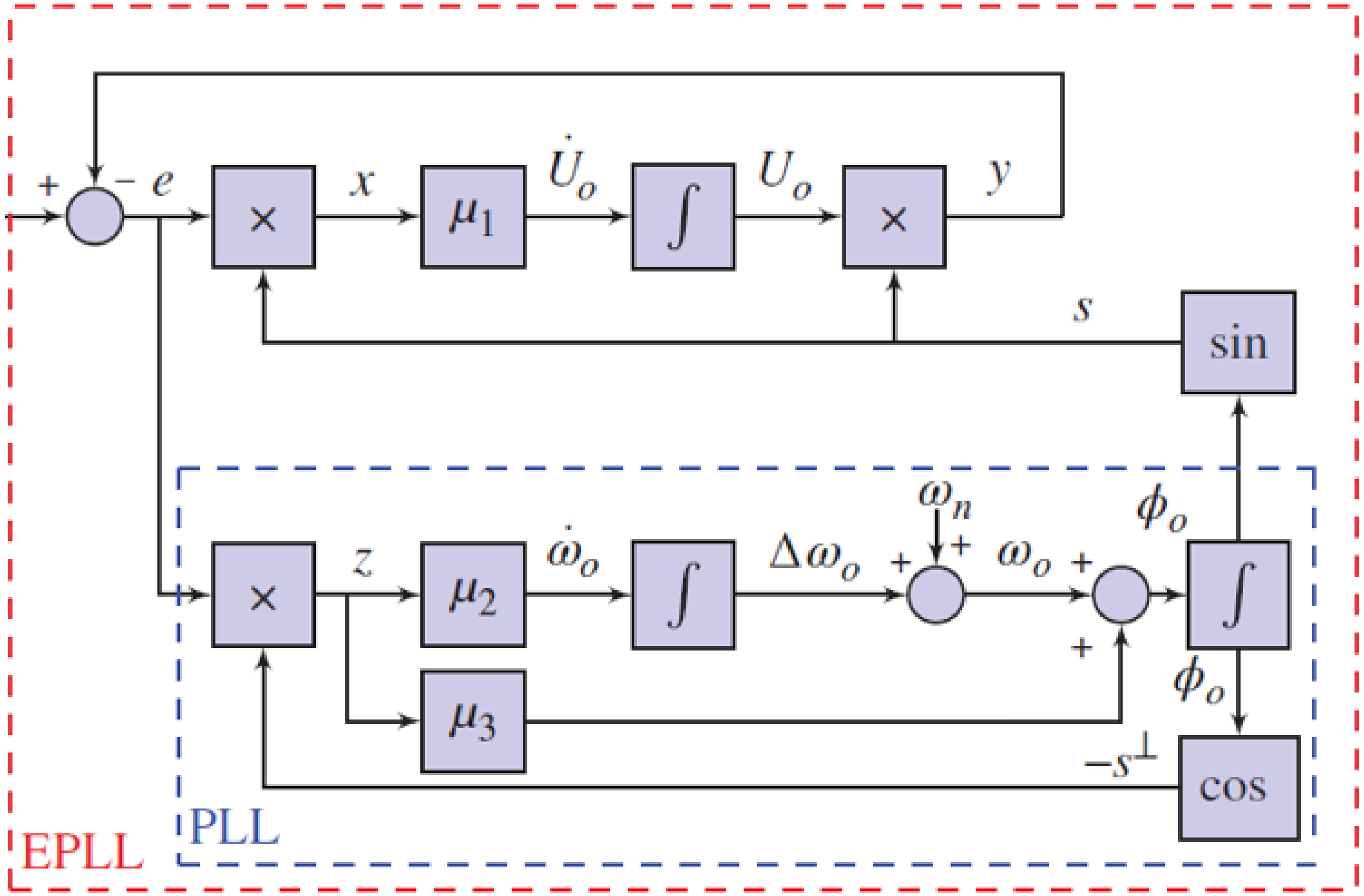
Control algorithm: PI

- Voltage loop: performed at 10kHz
- Current loop: performed at 67kHz

In courtesy to st.com

EPLL Block Diagram for PFC

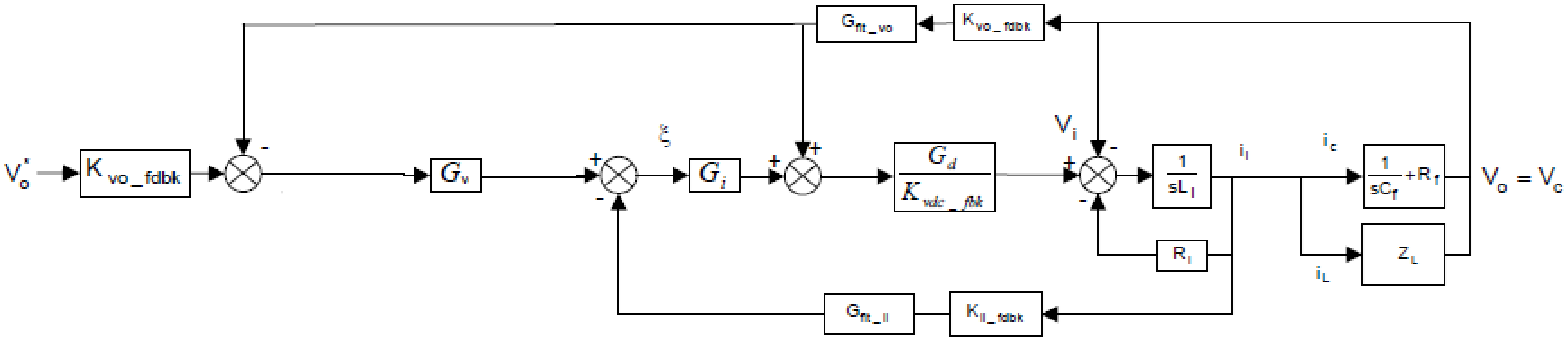




$$x = e\sin\phi_o = (U_i\sin\phi_i - U_o\sin\phi_o)\sin\phi_o$$

$$= \frac{U_i}{2}\cos(\phi_i - \phi_o) - \frac{U_o}{2} + \underbrace{\frac{U_o}{2}\cos(2\phi_o) - \frac{U_i}{2}\cos(\phi_i + \phi_o)}_{\text{double frequency}}$$

Voltage&Current Loop Block Diagram for Inverter

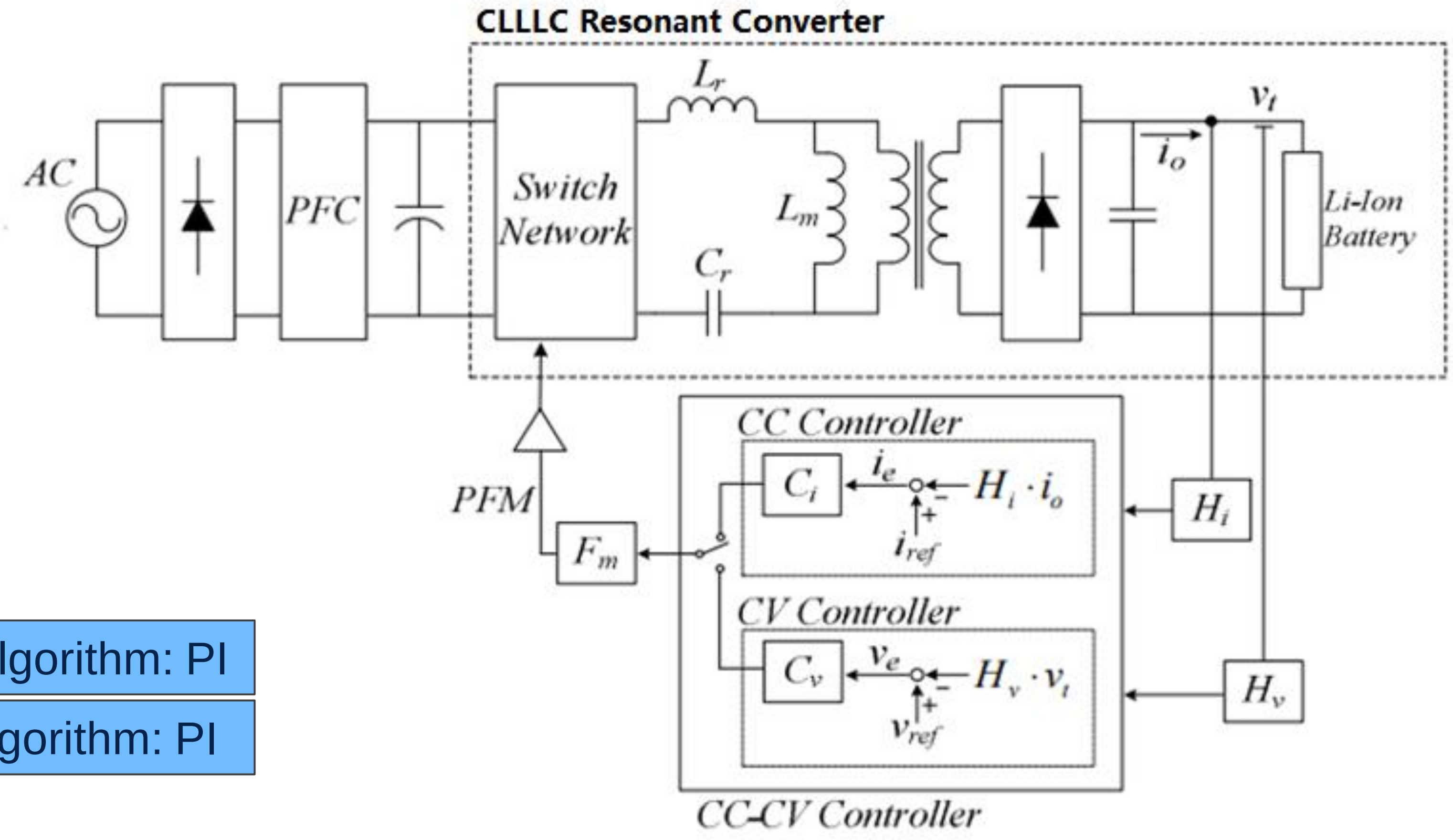


Current Loop Control algorithm: PI

Voltage Loop Control algorithm: PI

- Voltage loop: performed at 67kHz
- Current loop: performed at 67kHz

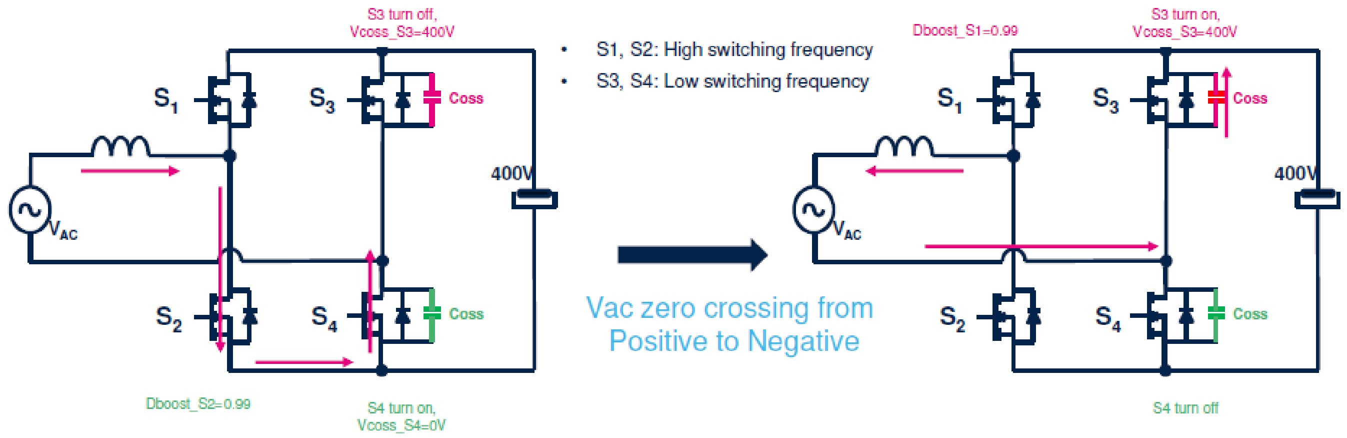
CC&CV Controller for CLLLC

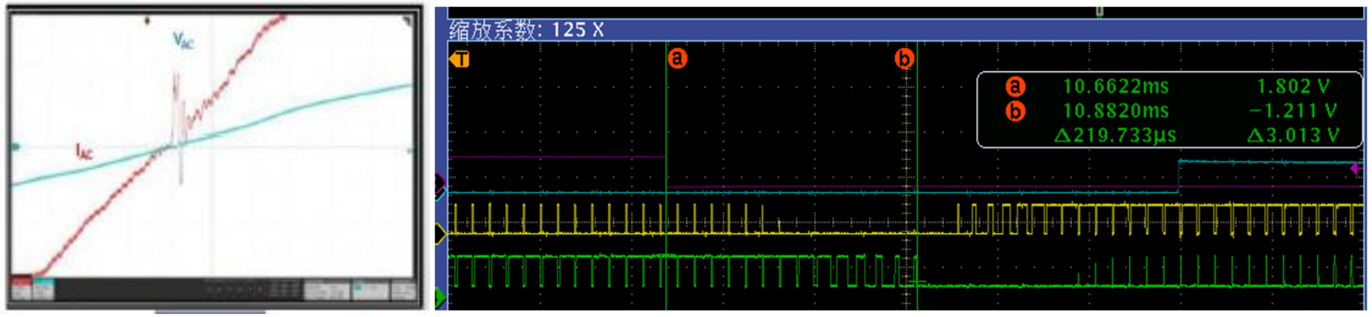


Current Loop Control algorithm: PI

Voltage Loop Control algorithm: PI

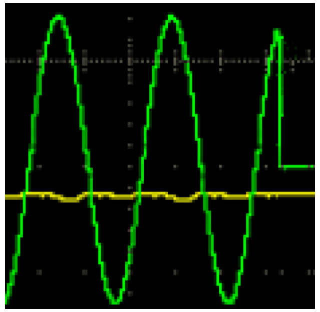
Design challenge 2 : Current spike at AC zero crossing





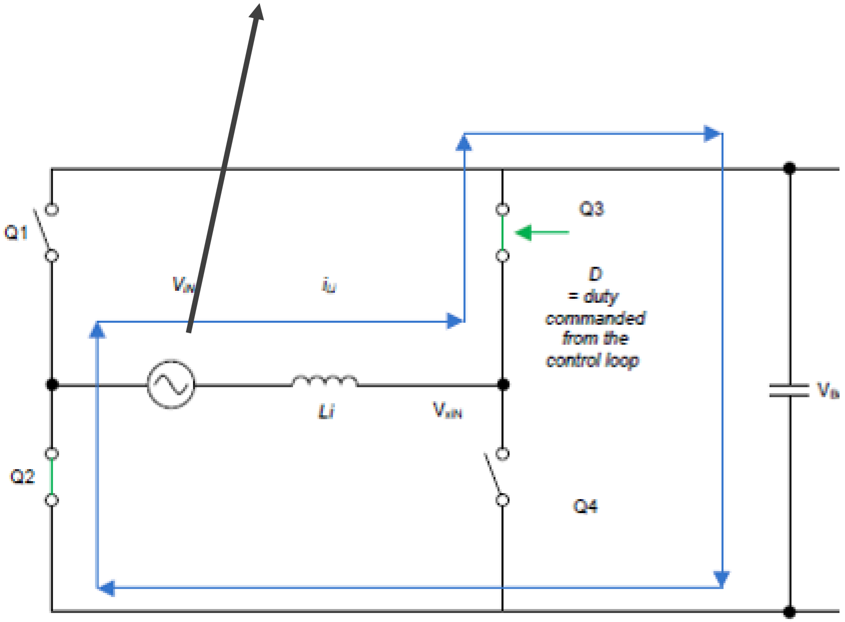
- The control loop should freeze during the blanking time, in order to avoid the integrator of the current loop to generate a large PWM pulse, which will cause a large current spike
- PWM soft-start at zero crossing
- All MOSFETs are turned OFF to ensure a safe permutation of the power switches control and to avoid short-circuit of the output DC capacitor

Design challenge 3 : Vac Drop (Under-voltage) Control



In PFC Charging mode, if the voltage of line drop to zero from higher voltage positions, what will happen?

If the mains drops from high voltage to Zero in PFC mode, the working state is changed from PFC to Inverter mode. At this moment, it is equivalent to the short circuit of the inverter output.

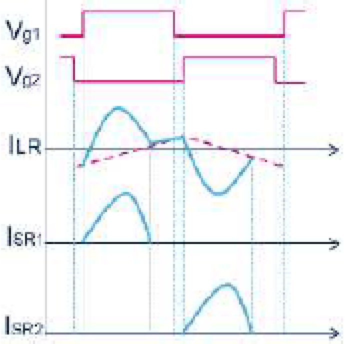


Solution:

- Add Grid Voltage drop Monitoring in Software
- Add Over-current Protection Detection at AC input side

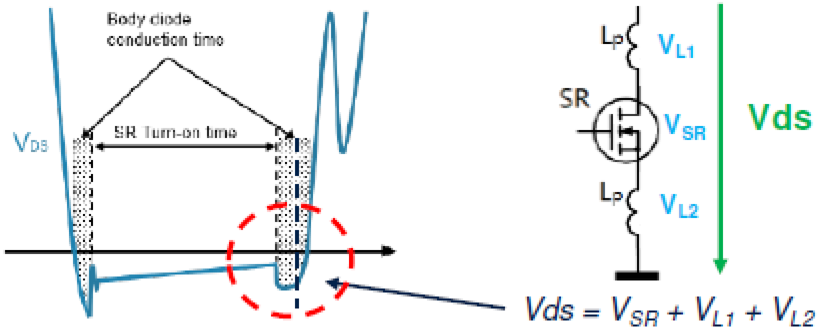
Design challenge 4 : Synchronous rectifier(SR) control

- Negative current caused by late SR MOSFET turn-off



- At heavy load (below resonant frequency), late SR turn off will force MOSFET conduct and cause a negative current from output capacitor
- This negative current could damage the power MOSFETs and resulting unit failure

- Premature SR MOSFET turn-off



- Due to the stray inductance in series with the SR MOSFET, the sensed drain-source signal (Vds) is not really the voltage drop across the SR MOSFET (V_{SR})
- So it will prematurely turn-off SR MOSFET and cause low efficiency

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Thank You !

Q & A