Research Status of the National Key Laboratory of Power Electronics

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Location of Zhejiang University

China

Zhejiang is Province name
Located in **Hangzhou** city: beautiful city in China
200km from Shanghai

Zhejiang University

Found in 1897
Key national university, Ranks the 3rd in China
The most comprehensive university in China

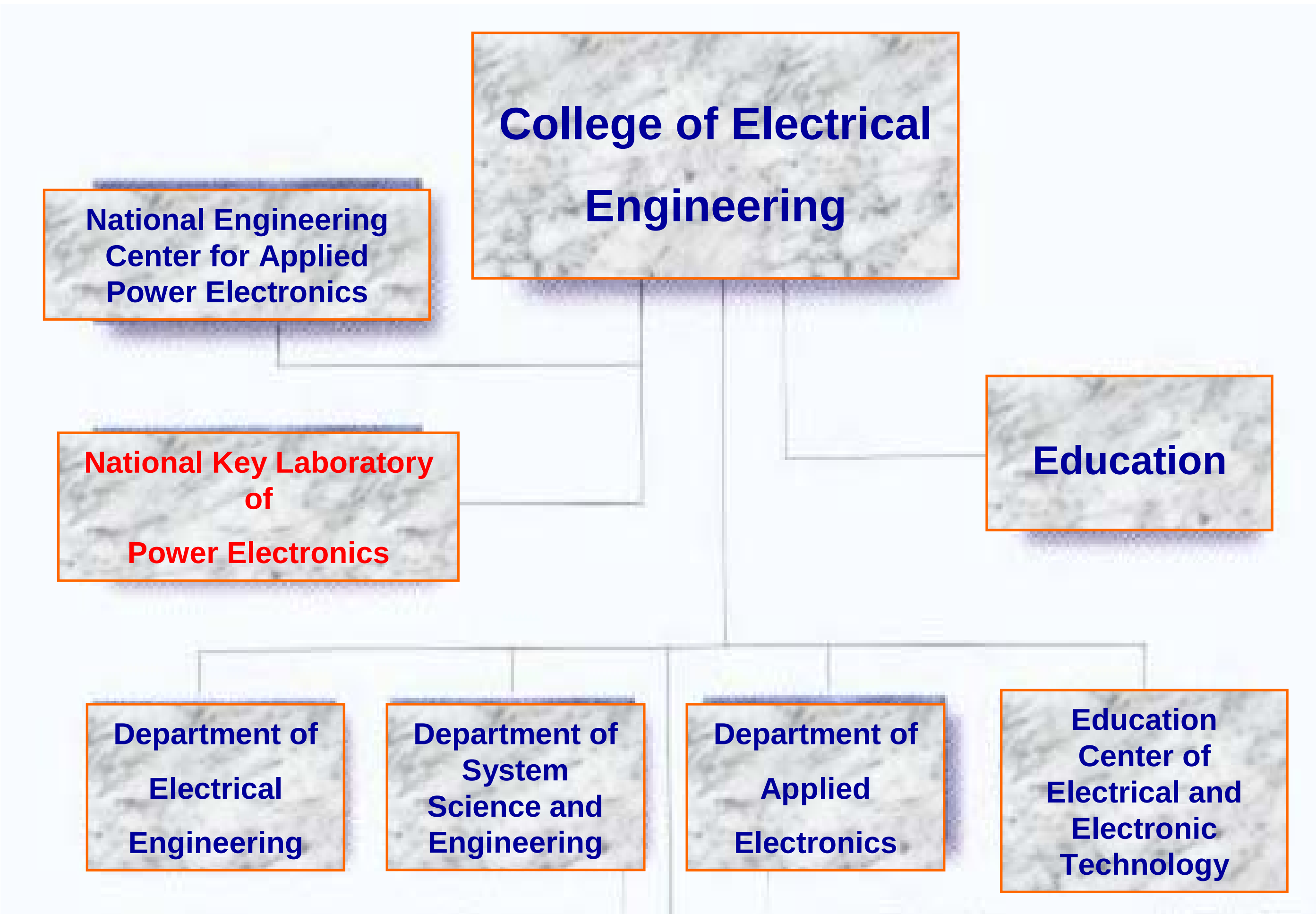
Statistics of 2004
Undergraduates: 24983
Master students :11883
Doctor students:6050
Oversee student:1235

Research Funds	1.02 billion yuan
Papers Included in SCI (2004)	1917
Papers Included in EI (2004)	1551
Granted Patents (2004)	330

Agriculture and
Biotechnology
Animal Sciences
Biomedical Engineering and Instrument Science
Computer Science (Software Technology)
Civil Engineering and Architecture
Economics
Education
Electrical Engineering
Environmental and Resource Sciences
School of International Studies
Humanities
Information Science and Engineering
Law
Life Sciences
Mechanical and Energy Engineering
Materials Science and Chemical Engineering
Medicine
Management
Pharmaceutical Sciences
Science
Public Administration

The college of Electrical Engineering

Established in 1920



Brief information

- The first SCR media-frequency induction-heating power supply (100kW/1kHz) in 1971 in China,
- 1981 began recruit graduates for postgraduates
- 1988, 2002,National key discipline
- 1989 become National Key Laboratory of Power Electronics

Staff:

One member of China Academics of Engineering
Professors:8
Associate professors:4
Assistant professors:7

Students:
Master students: accept 50/year
Ph. D students: accept 25/year

Lab facilities

Software:
Saber, Ansoft(SIMPLORER, Maxwell, PExprt, RMxprt), Matlab, Mathcad, dspace

Instrument:
Network analyzer, device test equipments, power analyzer, logic analyzer ,EMC test equipments, so on

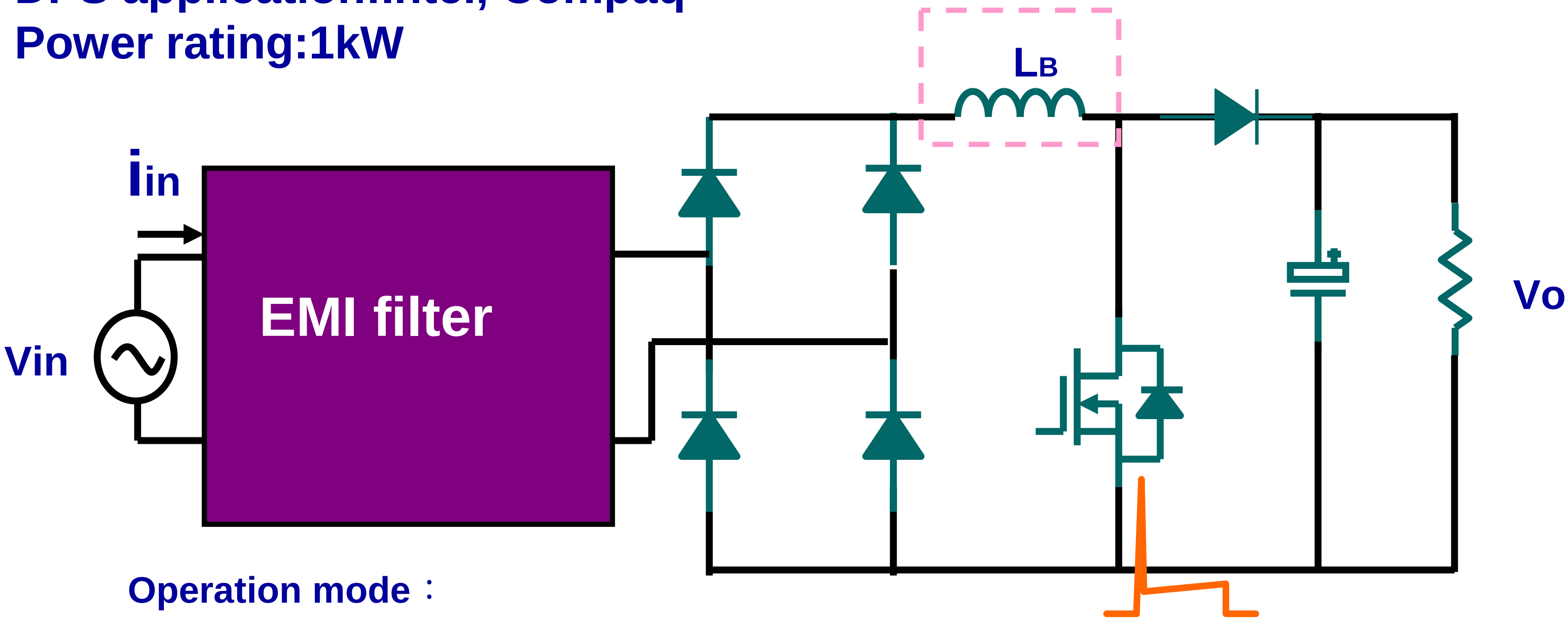
Package equipments:
QualMark FALT &HASS System, SMT equipments

Research directions

- Soft switching technology
- Inverter and UPS control
- Power Electronics for Power system
- Renewable power generation system
- Inverters for induction heating and HV processing equip.
- Integrated power electronics
- Drive
- EMI/EMC

Boost power factor correction （PFC） converter

DPS application:Intel, Compaq
Power rating:1kW



Operation mode：

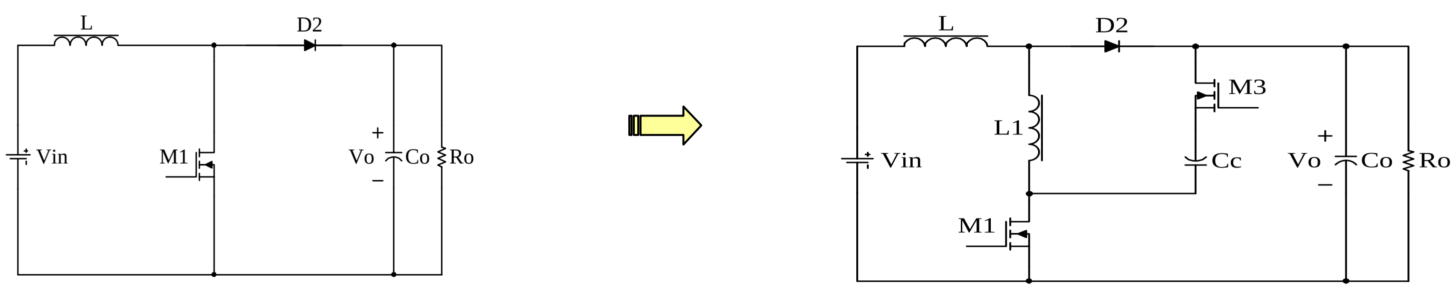
Current continuous mode （CCM） is prefered instead to DCM

- lower current stress, lower conducting loss
- small magnetic component size and its loss（LB+EMI）
- Higher reverse recovery loss

Diode reverse recovery resulting loss suppression

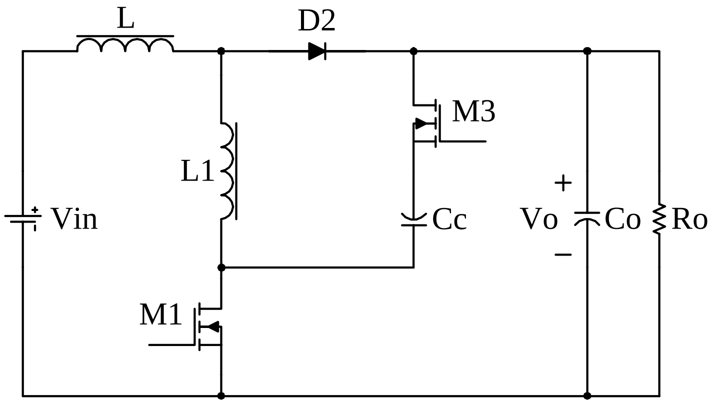
- Lossless snubber
- ZCS or ZVS quasi resonance (DCM)
- ZVT switching
- Active clamping
- SiC diode

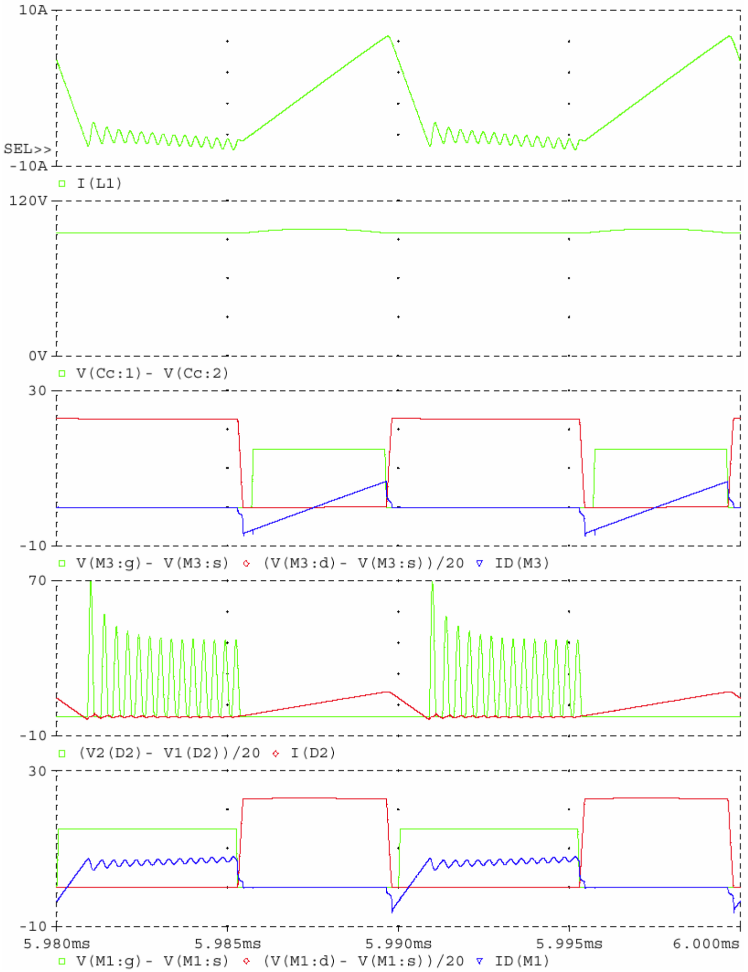
Active clamping



Both the main switch and auxiliary switch are ZVS

Parasitic resonance in active clamping





Ｍ１ in on-state, resonance between Ｌ１ and Ｄ２

⇩

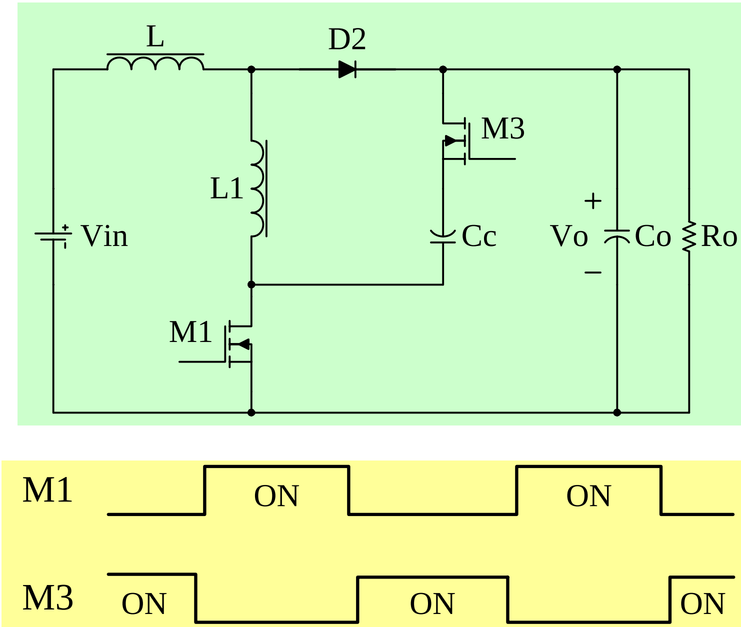
Ｄ２ voltage stress＝２Ｖo

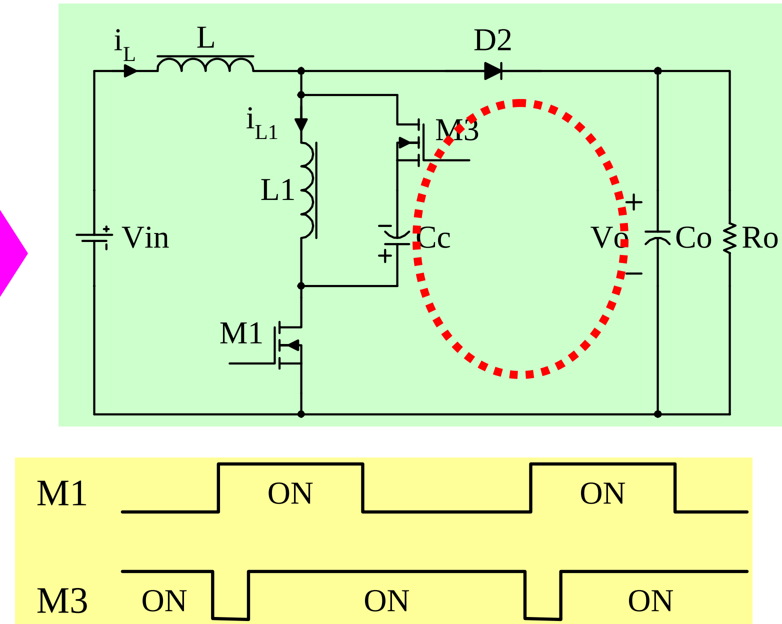
Ｍ１ and Ｍ３ gate signal are complimentary

⇩

Terminal voltage of Ｄ２ in off-state is not clamped

Compound-Active-Clamping (CAC) Boost Converter





Conventional active-clamping boost converter

(M1, M3) in complimentary mode

Compound-Active-Clamping (CAC) boost converter

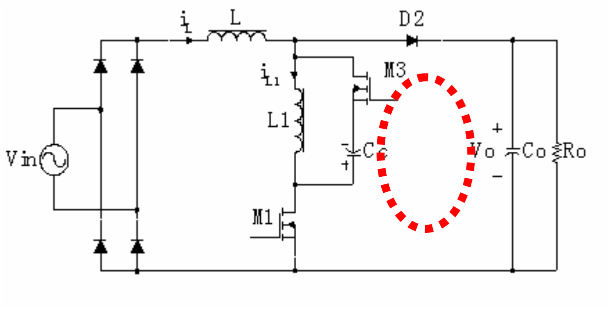
2 of the 3 devices in conducting

(M1, M3 and D2)

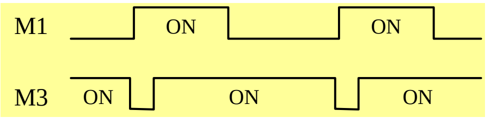
- **Key piont: $V_{s1}+V_{s3}+V_{d2}=V_o+V_{Cc}$**
- Only 2 of 3 device are conducting
- Terminal voltage of the turn-off device is clamped and parasitic oscillation is eliminated
- Suppress reverse recovery process
- Both main and aux. switch are ZVS

Soft switching DC/DC converter and PFC converter

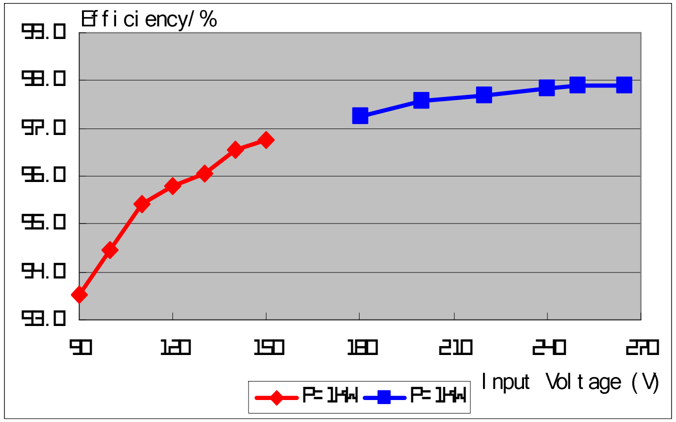
Compound-Active-Clamping (CAC) ZVS PFC



- Diode reverse recovery is relieved. No voltage ringing occurs on the diode.
- Both the main switch and the auxiliary switch are ZVS.
- Higher efficiency is achieved for 1kW CAC PFC converter

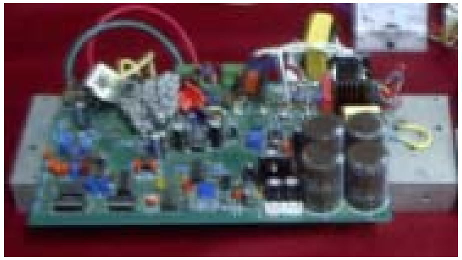


The main switch and the auxiliary switch do not operate in complimentary mode. **There are always two of the three devices (M1, M3 and D2) in conducting, which results in clamping the terminal voltage of the turn-off device.**



Efficiency vs. input voltage *Vin*
(*Po=1000W*, *Vo=380Vdc*)

Input voltage *Vin*=90V~265Vac
Output voltage *Vo*=380Vdc
Rated power *Po*=1kW
Switching frequency *fs*=100kHz



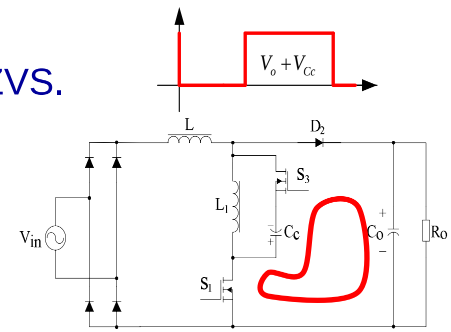
- S1 and S3: IRFP460×2
- D2: MUR1560
- C2: 4000pF/1kV
- Cc: 2.2uF/250V
- L1: 8uH
- L: 600uH

Minimum-Voltage Active-Clamping(MVAC) PFC Converter

- Diode reverse recovery relieved.
- No voltage ringing on the diode.
- Both the main switch and the auxiliary switch are ZVS.
- Higher efficiency
- Voltage stress equal to hard-switching circuit

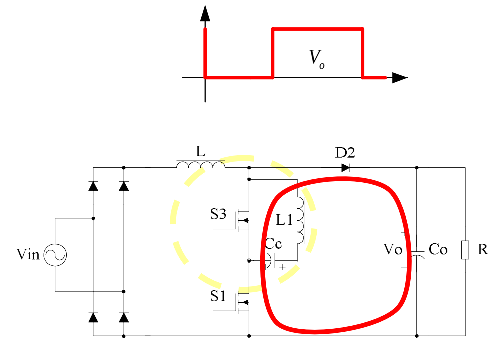
PWM control is the same as CAC ZVS PFC converter

CAC

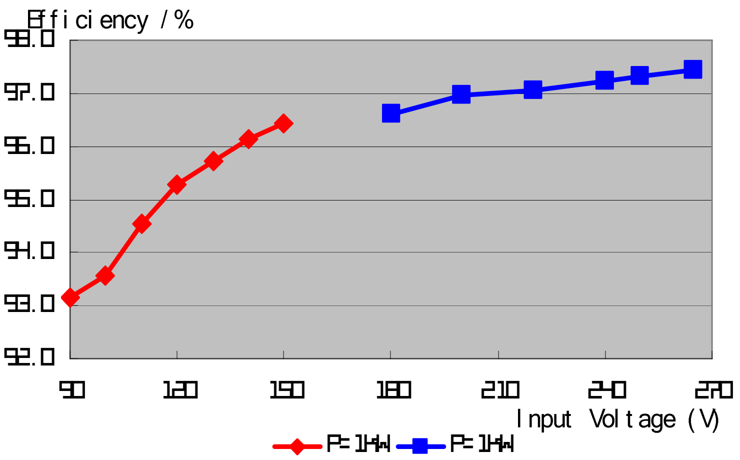


$V_{s1}+V_{s3}+V_{d2}=V_o+V_{Cc}$

Minimum Voltage Active Clamp



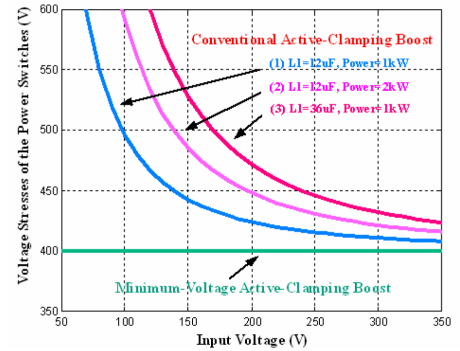
$V_{s1}+V_{s3}+V_{d2}=V_o$



Efficiency vs. input voltage *Vin*
(*Po=1000W*, *Vo=380Vdc*)

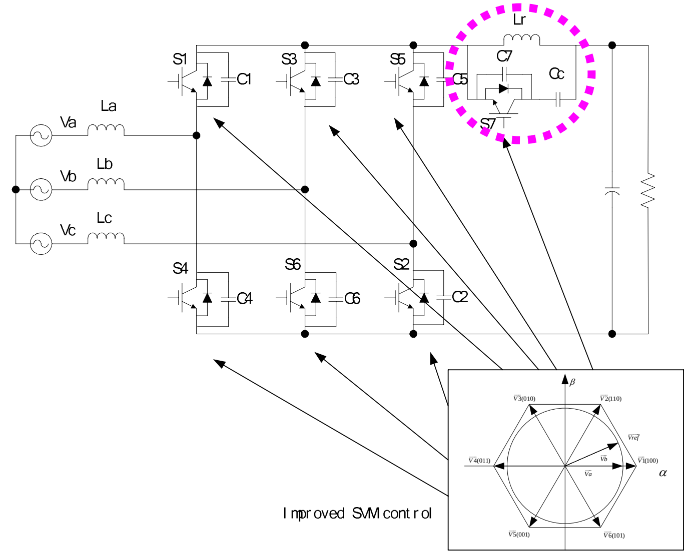
Input voltage *Vin*=90V~265Vac
Output voltage *Vo*=380Vdc
Rated power *Po*=1kW
Switching frequency *fs*=100kHz

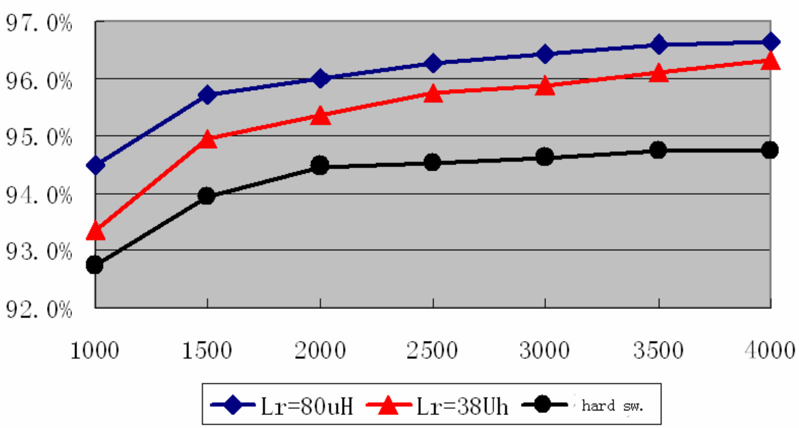
- *S1, S3*：IRFP460×2(IR)
- *D2*：MUR1560
- *L*：0.6mH（EE55）
- *C2*:1680pF/1000V
- C_o：1320µF/450V
- *L1*：12µH
- *Cc*：4.7µF/250V



CAC 3-phase PFC converter

- Add one auxiliary branch
- ZVS for all the switches
- Improved SVM control
- Suppress diode reverse recovery
- Fixed frequency control for both the main switch and the auxiliary switch
- low voltage stress on the switches
- Higher efficiency
- Lower EMI



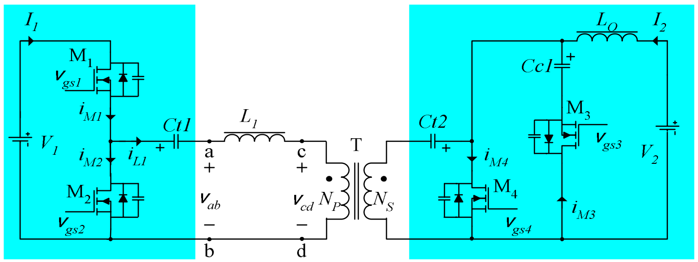


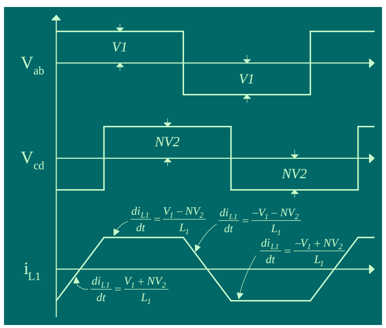
Vin: 3*380Vrms Vdc=620V Pout=4kW switching freq. 12.8kHz

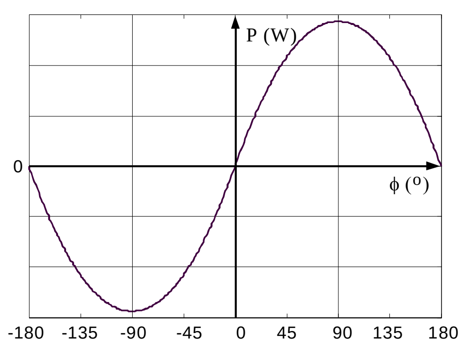
Sector	angle	Vector1	Zero vector	Vector2	Vector1
1	-30° ~ 0°	1 0 0	1 1 1	1 0 1	1 0 0
2	0° ~ 30°	1 0 0	1 1 1	1 1 0	1 0 0
3	30° ~ 60°	1 1 0	0 0 0	1 0 0	1 1 0
4	60° ~ 90°	1 1 0	0 0 0	0 1 0	1 1 0
5	90° ~ 120°	0 1 0	1 1 1	1 1 0	0 1 0
6	120° ~ 150°	0 1 0	1 1 1	0 1 1	0 1 0
7	150° ~ 180°	0 1 1	0 0 0	0 1 0	0 1 1
8	180° ~ 210°	0 1 1	0 0 0	0 0 1	0 1 1
9	210° ~ 240°	0 0 1	1 1 1	0 1 1	0 0 1
10	240° ~ 270°	0 0 1	1 1 1	1 0 1	0 0 1
11	270° ~ 300°	1 0 1	0 0 0	0 0 1	1 0 1
12	300° ~ 330°	1 0 1	0 0 0	1 0 0	1 0 1

☹ **Hard switching** ☺ **ZVS** ☺ **ZVS**

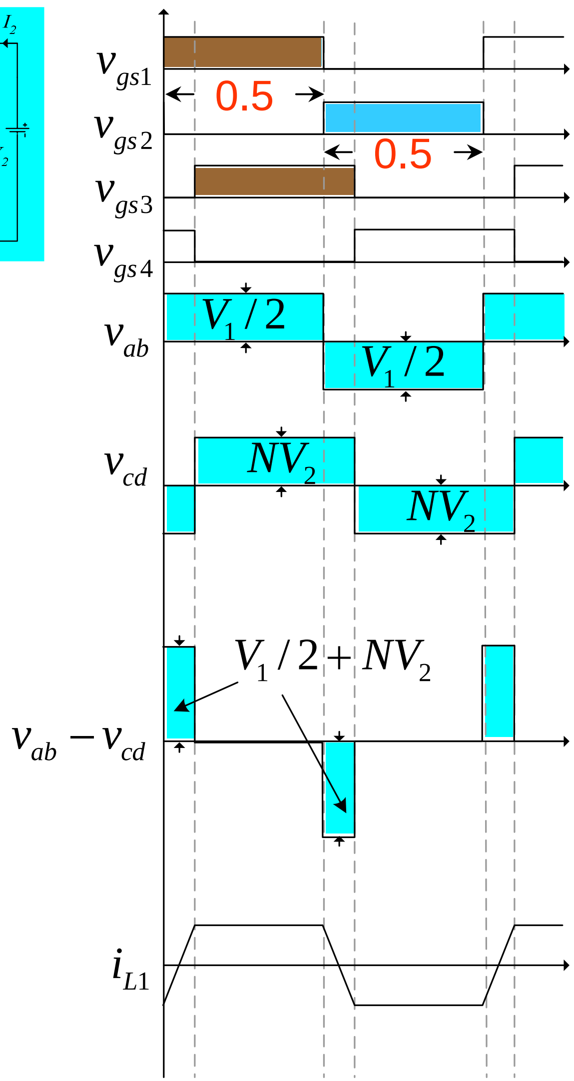
Phase shift (PS) controlled bidirectional DC/DC converter



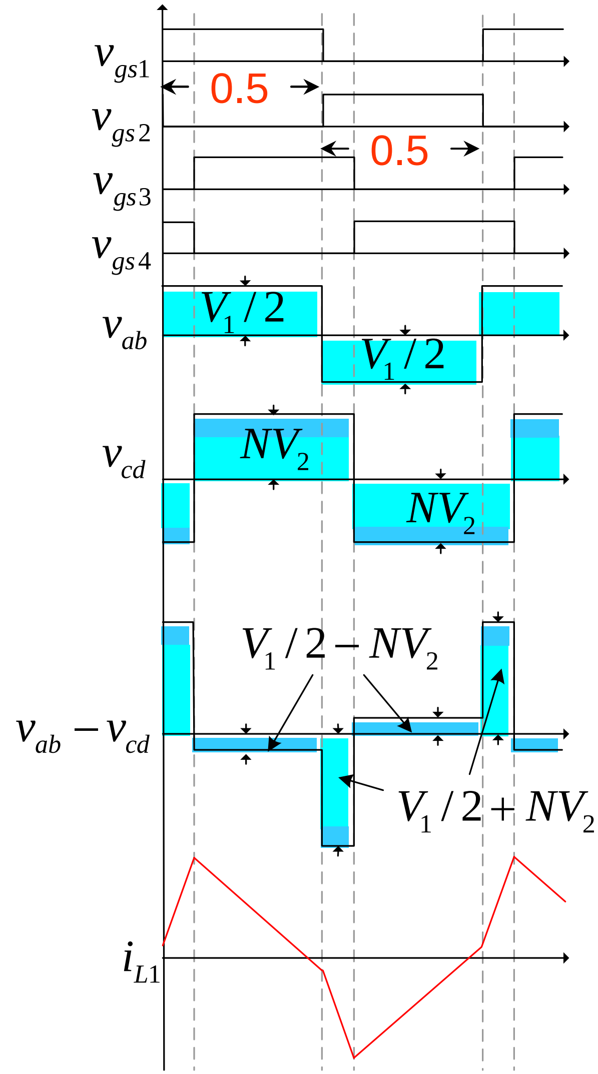




Power vs. phase-shift



PS control when $V_1/2=NV_2$



PS control when $V_1/2<NV_2$

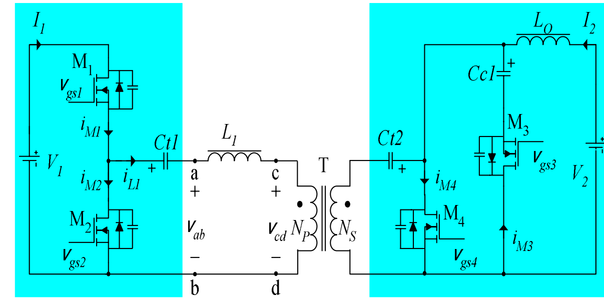
PWM+phase shift (PPS) control

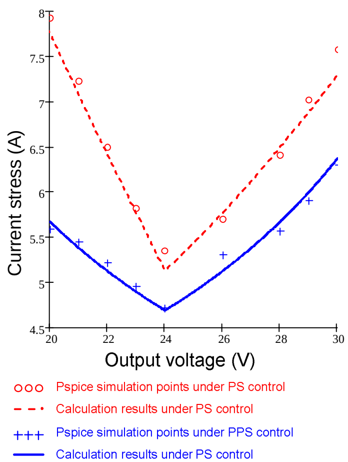
PPS control, duty ratio of M1 AND M3:

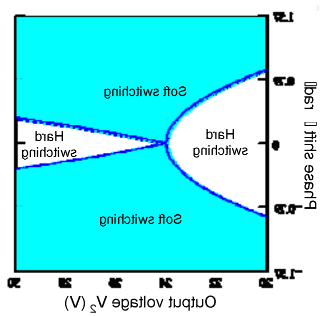
$$D = \frac{NV_2}{V_1}$$

N: turn ratio of the transformer

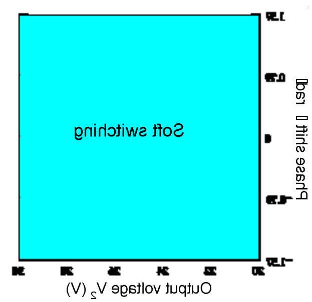
Duty ratio of M2 and M4 : *1-D*



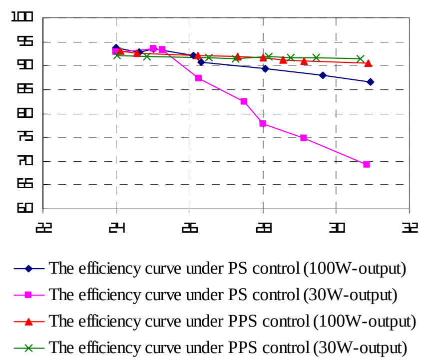


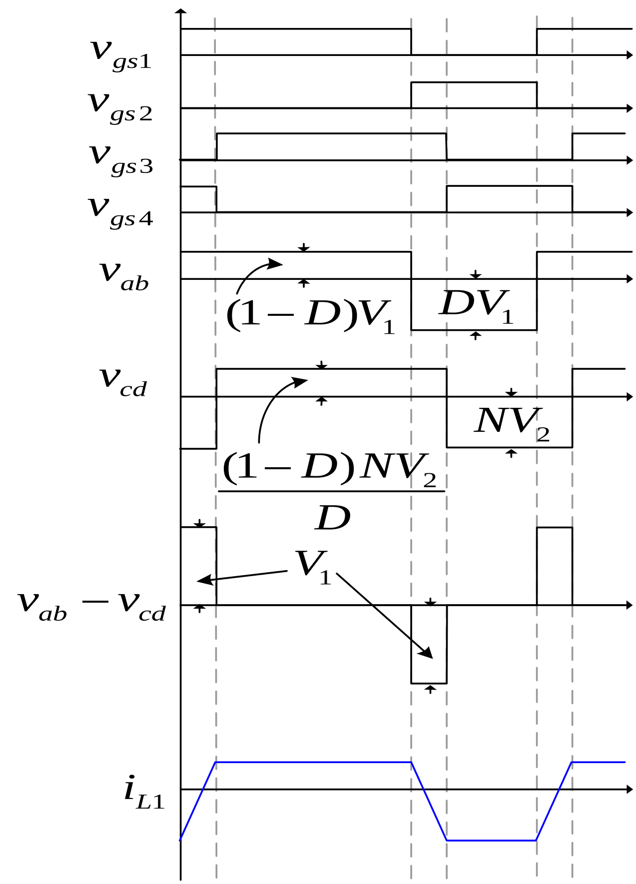


PS control



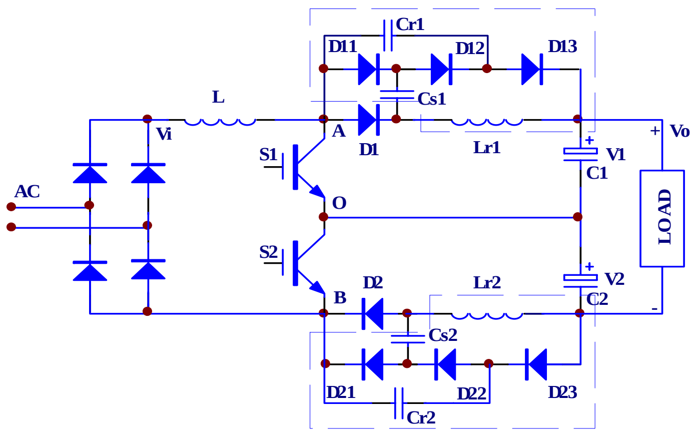
PPS control

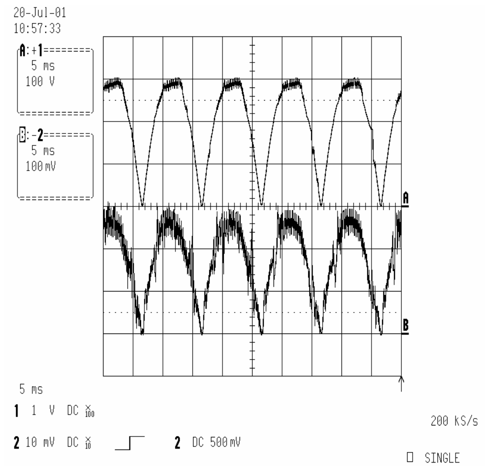


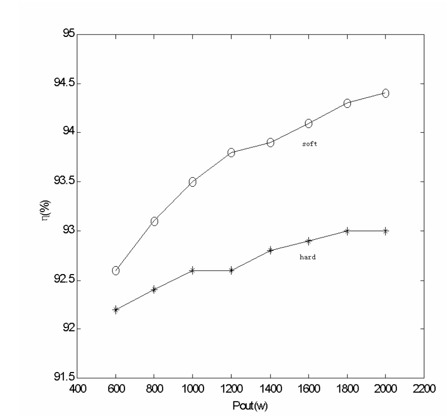


- Current peak is reduced
- switching loss and conduction loss reduced
- Current stress of the switches are reduced
- ZVS range is widen

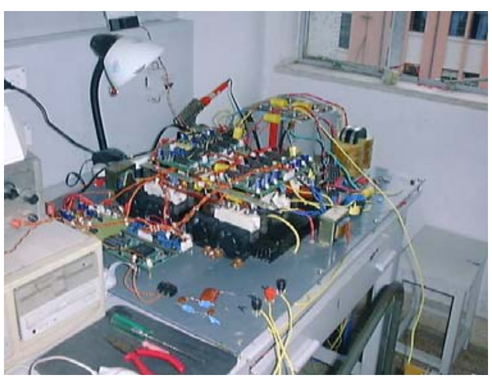
Three-level Power Factor Correction with Passive Lossless Snubber

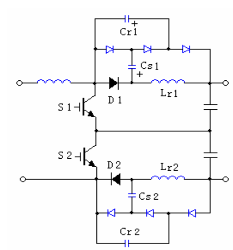


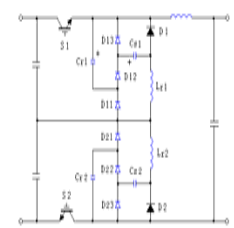


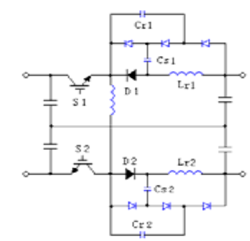


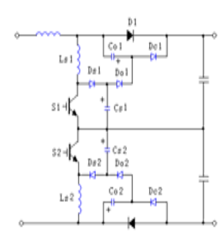
- efficiency is increased
- Less over-voltage stress on main power switches.

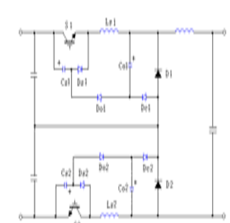


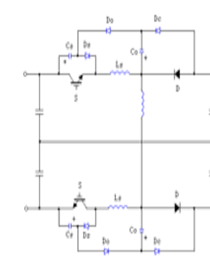












Chargers

- Input voltage 220Vac±15%
- Output voltage 180V-275V，output current 15A
- PFC operate frequency 33KHz， DC/DC operate frequency 70KHz
- One module output power 4kW，efficiency>90%

- Three phase input voltage 380Vac±20%
- Output voltage 175V-330V，output current 25A
- PF：0.92， Efficiency：90%

Power supply

100VA DC/DC Converter

2-Phase 25Hz/3kVA ACSource (Parallel and Play and Plug in Available)

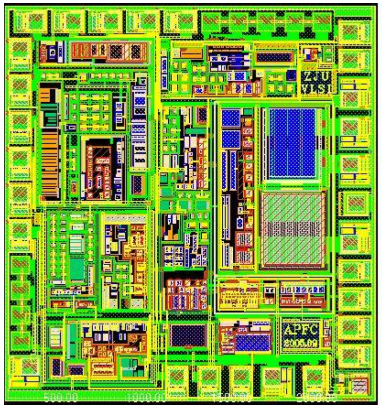
500VA DC/DC Converter

3kVA/50Hz AC/DC/AC Inverter

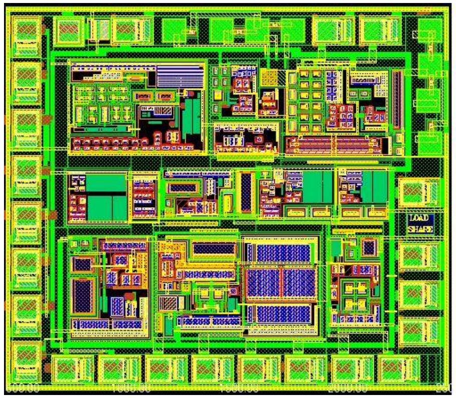
Integrated power electronics

- Planar transformer design
- Integrating passives design
- packaging
- Power management IC design

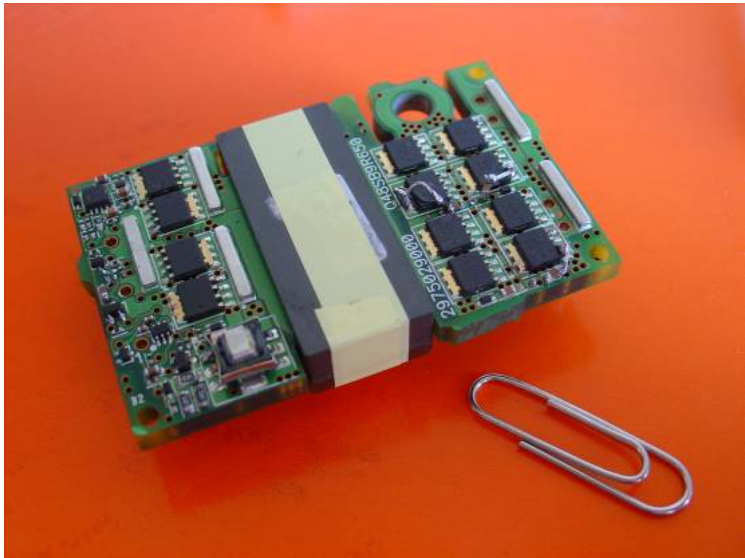
Current sharing



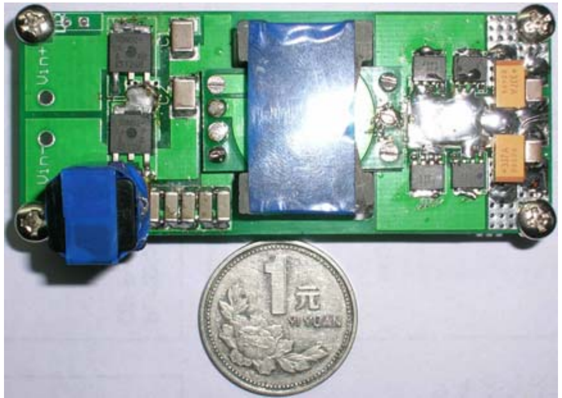
PFC controller



DC/DC Module: 1/4 Brick,   480VA,   48/9V

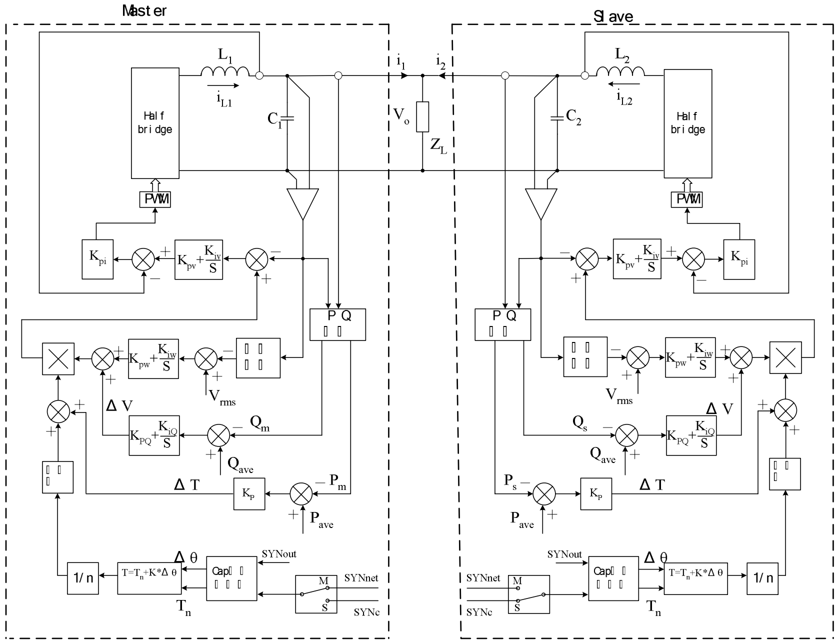


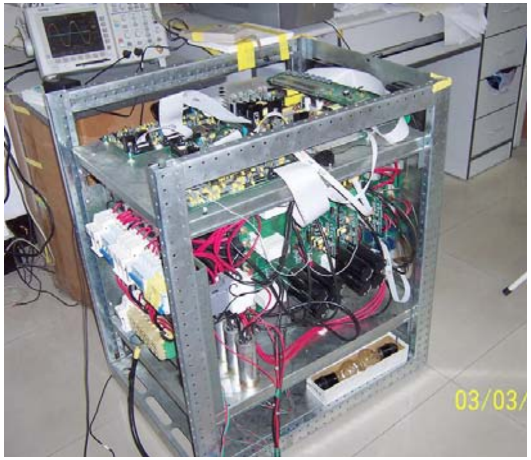
0.9V/50A VRM



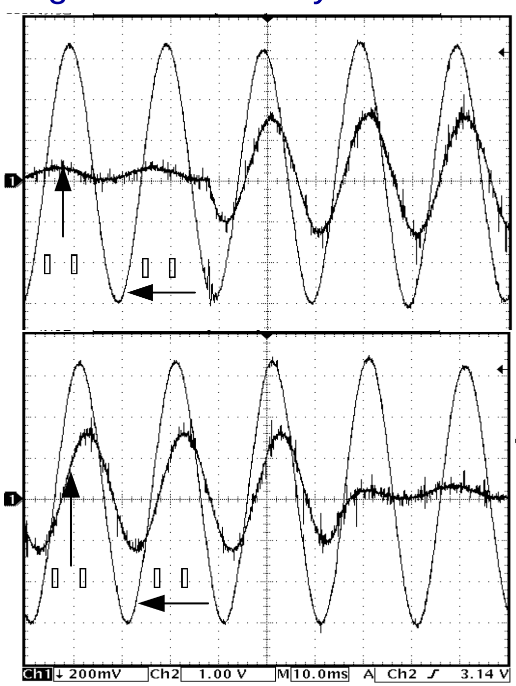
30kW UPS with DSP control

- DSP control
- 3in-3out without transformer
- Front end PFC
- Current sharing for multi-UPS





Light load to heavy load



Current sharing control

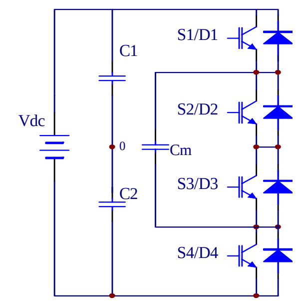
Heavy to light

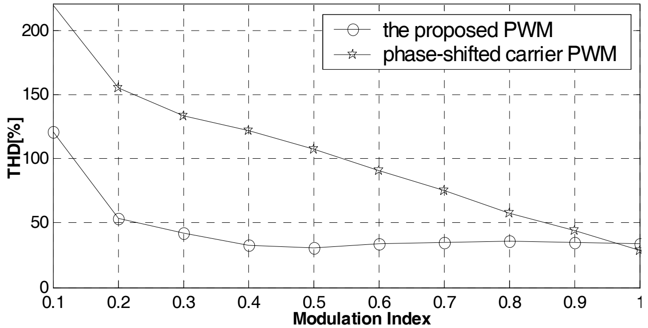
V:100V/div, Current:11A/div, time:10mS/div

Novel PWM Method for Flying Capacitor Multilevel Inverters

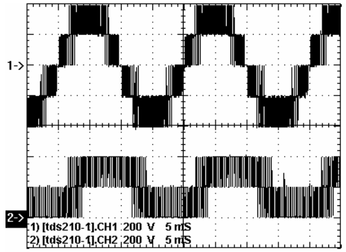
- good performances under both high and low modulation index regions.

- balances the flying capacitor voltage in a carrier period.

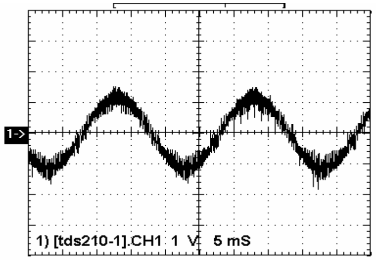




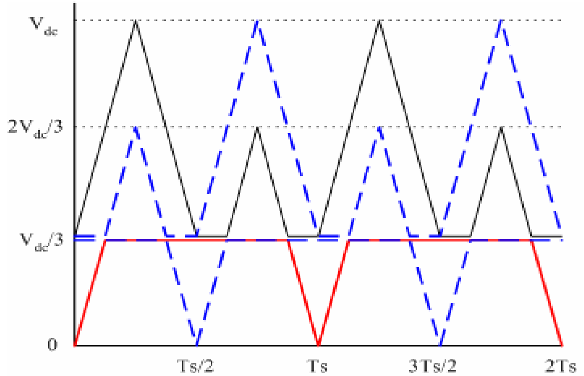
THD vs. modulation index (below 150th harmonics)

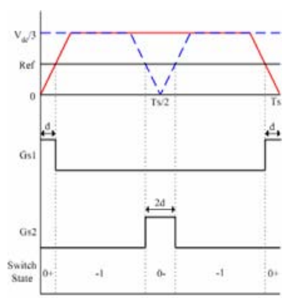


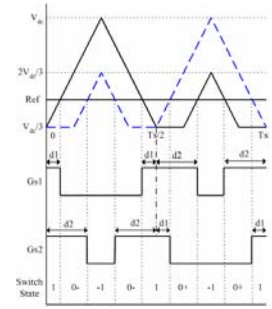
Phase- and line- voltages

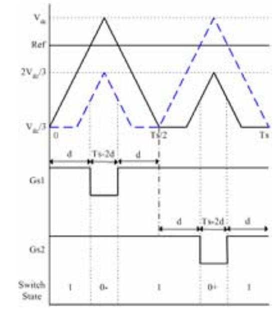


Current waveform



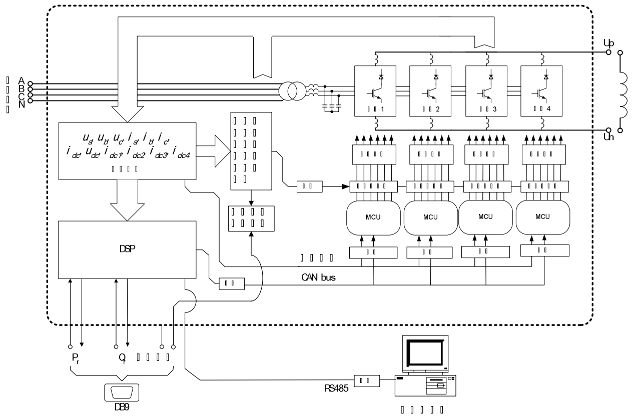




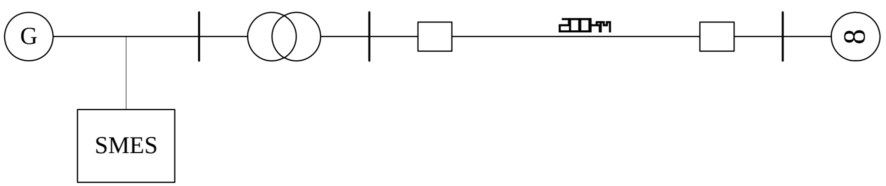


35kJ/7.5kW/200A HTS SMES

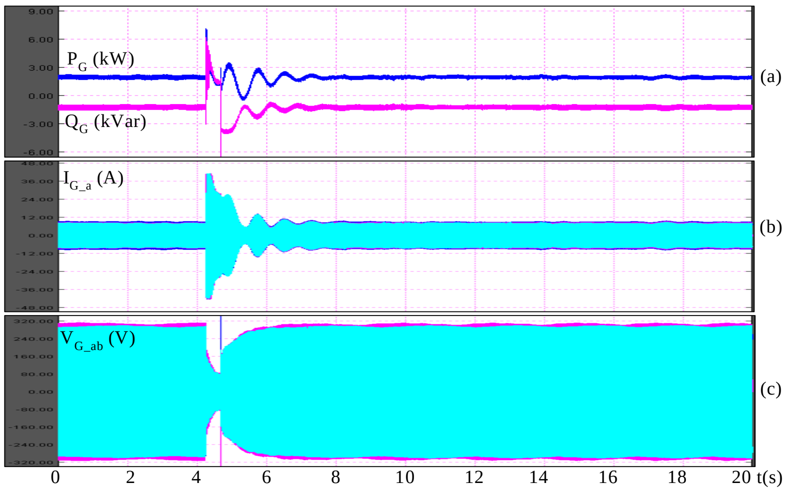
- Current unbalancing in a multi-modular current source converter with Carrier-swapping
- Lower AC side harmonics current
- The response of the converter is fast.



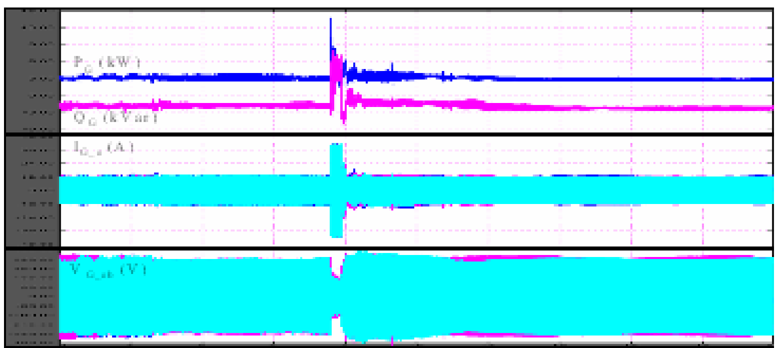
Test setup



Withot SMES



With SMES



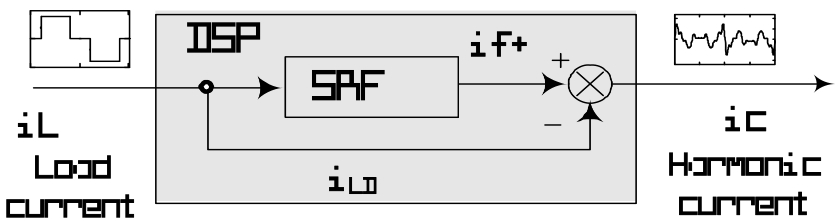
Power System Failure Current Limiter (10kV / 1000A）

Sensors

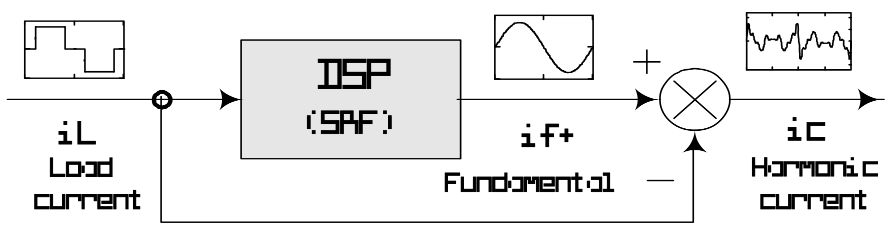
Active Power Filter

Vin:380Vrms Rating： 15KVA

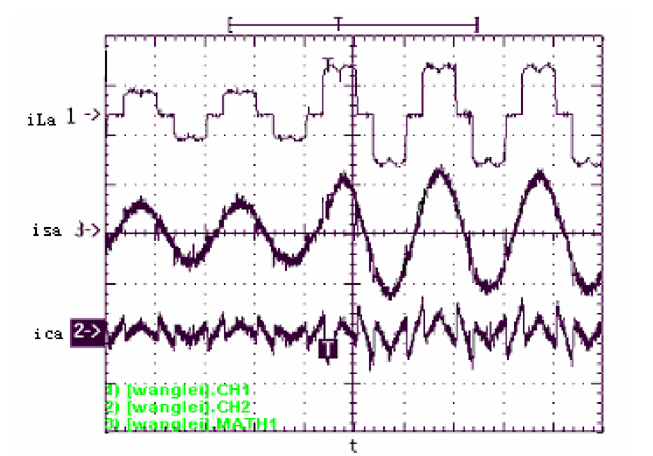
- DSP control
- Accurate compensation method with digit control
- Higher efficiency conversion Tech.
- Inductorless bus bar



(a) Routine scheme

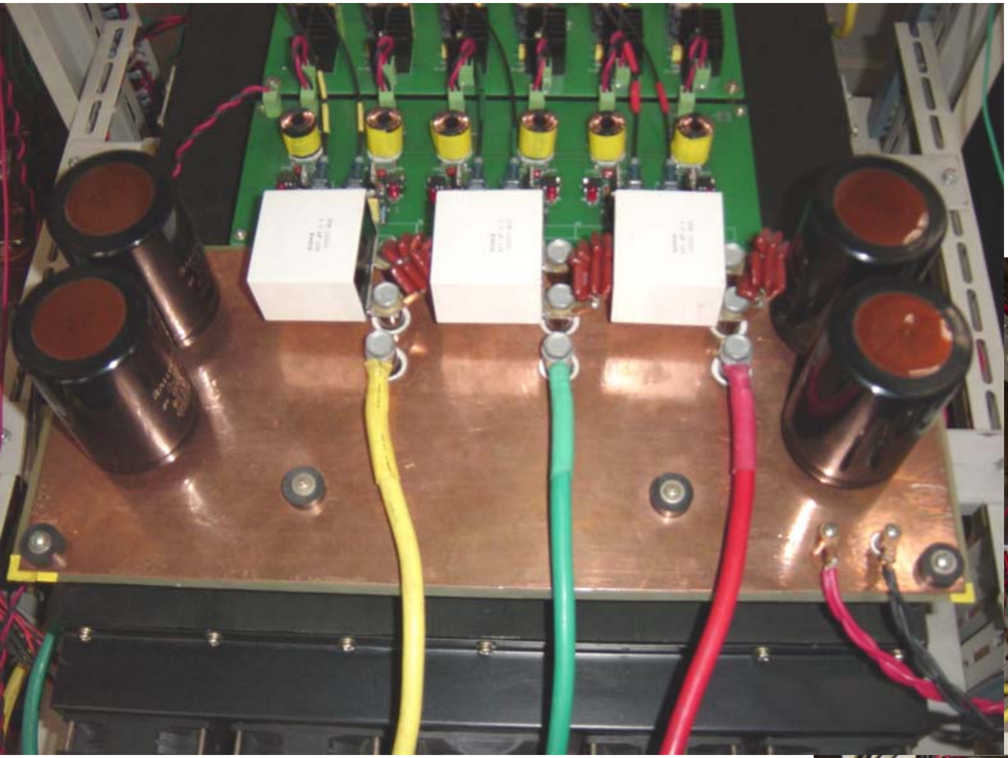


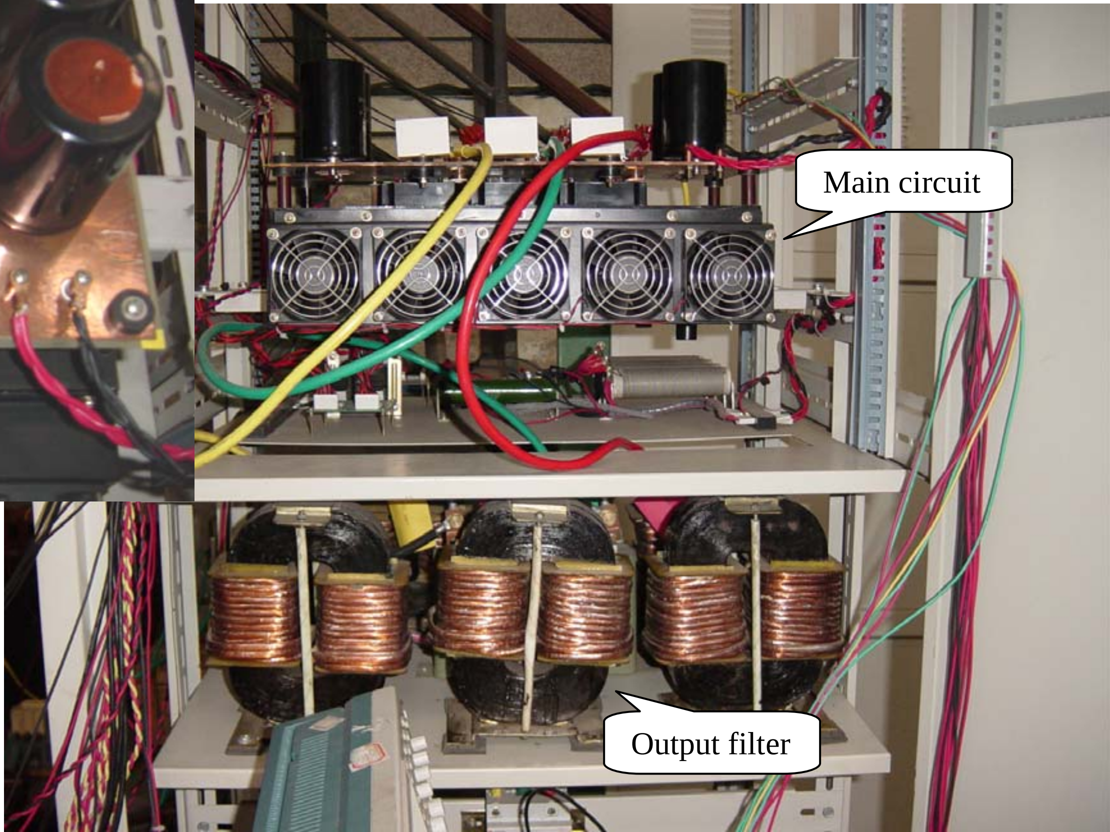
(b) Improved scheme



Dynamic response (32A/div, 10ms/div)

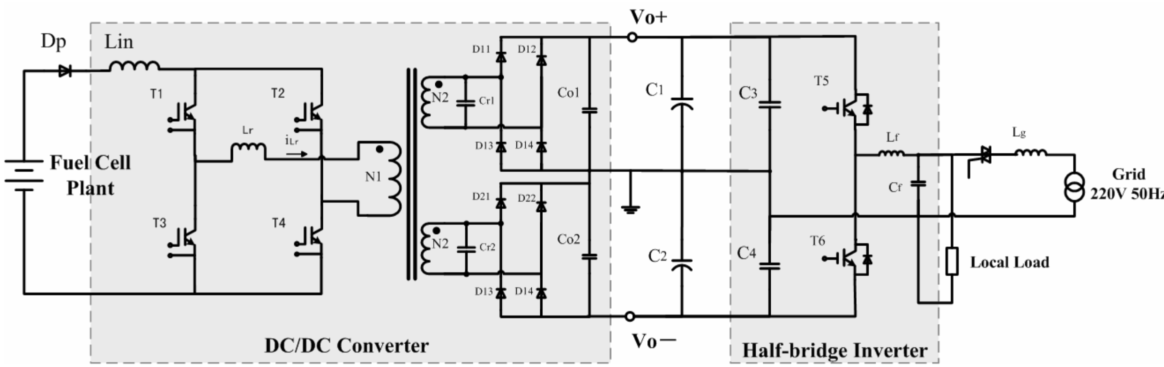
50 kVA active power quality conditioner

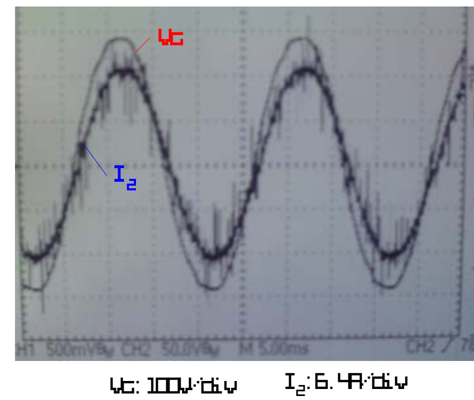


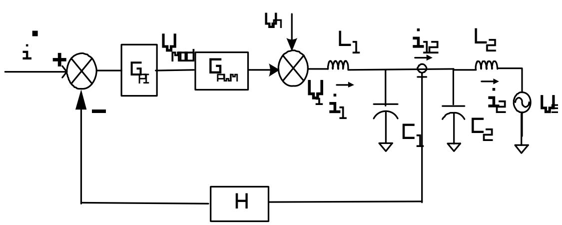


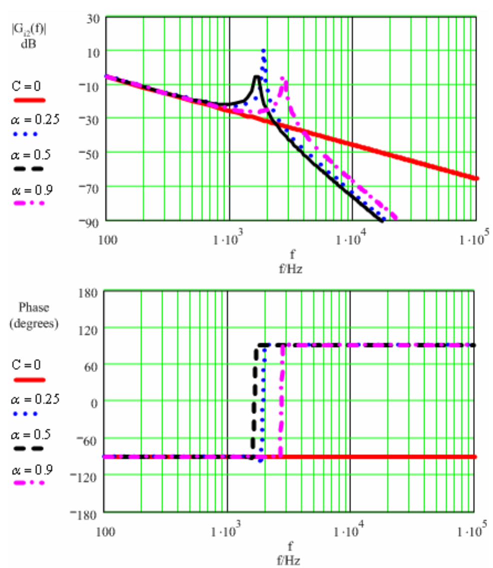
5 kW Fuel cell power generation system

- Frond end current ZCS DC/DC with RB-IGBT suited to FC
- Seamless transition by amplitude adjusting
- LCL filter fed inverter stability improvement by split capacitor mid-point current feedback









Inverter for inducting heating

200kW/50kHz IGBT
inverter for induction heating

5-30kW/100-400KHz MOSFET
inverter for induction heating

Heating process line

High Voltage Ion Generator for plastic film Printing

Motor Drive

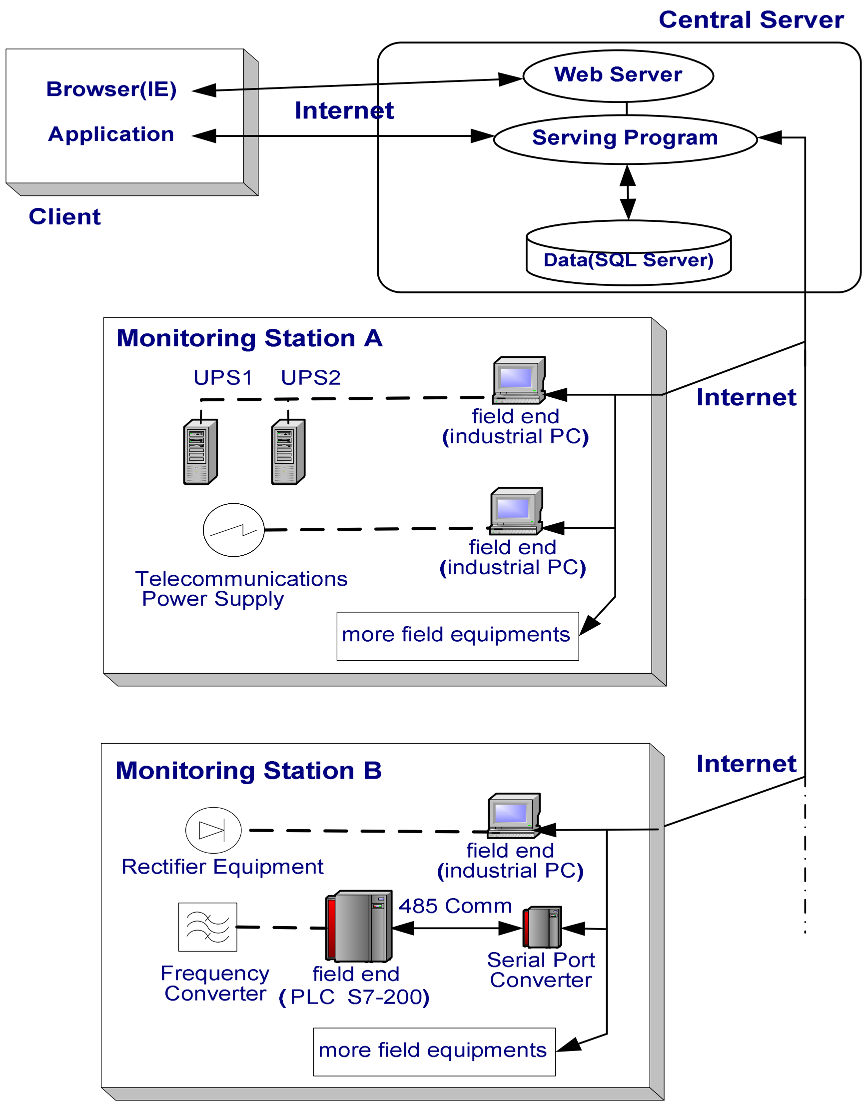
Drive equipment for spaceship

PM brushless DC motor for lockstitch sewing machine

1kVA Matrix Converter

20kVA PM Brushless Inverter

Remote fault diagnosis for power electronics equipment



- Compatibility design of remote fault diagnosis system for different power electronic equipments
- Remote real-time and synchronous data acquisition and transfers method
- On-line and off-line fault diagnosis for power electronic systems

Training Tool:

Digital Control Platform for Power Electronics

Future research focus

Fundamental oriented

- Power electronics Integration technology
- High frequency conversion
- Advanced control in power electronics
- Virtual testing for power electronics
- Thermal design
- EMI filter design

Application oriented

- Power Electronics for renewable and cleaning power generation
- EV and power electronics for transportation
- Power Electronics application in in environment protection and materials' treatment
- FACT devices
- High voltage, large power drives

Thanks!