Integrated Solid State Transformer (I-SST) Concepts for Utility Interface of Power Conversion Systems

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Electrical & Computer Engineering

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Introduction to Texas A&M Engineering

- Founded 1876
- Total 65,000 Students
- Engineering Students ~ 20,000
- 14 Departments
- 21 Degrees
- Top 10
- Growth Plan 25,000 engineering students by 2025

College of Engineering

Largest college at Texas A&M

More than **20,000** students in **14** departments

Nationally Recognized Programs

Undergraduate Program **8th**

Departments Ranked in Top 10 **7**

Research Expenditures **3rd**

SOURCES

Student enrollment includes undergraduate and graduate students from TAMU College Station, Galveston and Qatar campuses, and Engineering Academies

2017 U.S. News & World Report Rankings of Public Universities

American Society for Engineering Education (2016 report)

Texas A&M Electrical & Computer Engineering

Research Areas

Analog and Mixed Signals
- Active and Passive Filter Design
- Biomedical Applications
- Broadband Communications
- Data Converters
- High-Speed Electronic Systems
- Integrated Circuit Design
- Low-Noise Front-End Electronics
- Low-Voltage Low-Power Electronics
- Millimeter-Wave Integrated System Design
- Power Management
- RF IC and System Design

Biomedical Imaging and Genomic Signal Processing
- Bioinformatics and Computational Biology
- BioMEMs and Lab-on-a Chip
- Biosensing and Bioanalysis Systems
- Dynamic Imaging, Thermal Imaging and Magnetic Resonance Microscopy
- Genomic Signal Processing
- Image Analysis Techniques and Algorithms
- Magnetic Resonance Imaging and Spectroscopy
- Morphological Analysis
- Optical Tomographic Imaging Techniques
- Sensor Arrays in Medical Imaging
- Ultrasound and Elasticity Imaging

Computer Engineering
- Computer Networks and Internet
- Computer Systems
- Digital VLSI Design and Test
- Electronic Design Automation
- Fault Tolerance, Security and Reliability
- Mobile Wireless Networking
- Multimedia Infrastructure
- Network Coding
- Network Security and Reliability
- Storage Systems

Control Systems
- Homomorphic Digital Filtering
- Linear Multivariable Control Systems
- Nonlinear Control Systems
- Robust Control and Adaptive Control

Electric Power and Power Electronics
- Alternative Energy Systems
- Condition Monitoring and Fault Diagnostics of Electric Machines
- DSP-Based Power Electronc Systems
- Dynamic Analysis
- Electric Ship Power and Power Electronics Systems
- Electromechanical Energy Storage Systems
- Monitoring, Control and Protection
- Novel Electric Motors and Generators for Special Applications
- Power Converters for Windmills and Hybrid Vehicles
- Power Electronics and Motor Drives
- Reliability Evaluation
- Substation Automation
- Switching Power Supplies

Electromagnetics and Microwaves
- Antennas
- CMOS RFIC and Systems
- Electromagnetic Theory
- Electromagnetic Wave Propagation
- Guided-Wave Structures
- Microstrip Antennas
- Microwave Solid-state Circuits and Devices
- Microwave Systems
- Millimeter-Wave Circuits
- Sensing and Imaging
- Surface Penetrating Radar

Solid-state Electronics Photonics and Nano-Engineering
- Fiber Optics Devices
- Functional Thin Film Processing
- Integrated Optics
- Micro Electromechanical System (MEMS)
- Nanolithography
- Nanotechnology
- Noise in Electronic Systems
- Optical Communication
- Optical Filters
- Quantum Optics

Telecommunications and Signal Processing
- Advanced Channel Coding Techniques
- Data Compression
- Digital Communications Systems
- Digital Signal Processing
- Estimation and Detection Theory
- Information Security
- Information Theory
- Multirate Signal Processing
- Sensor Networks
- Time-frequency Analysis
- Wireless Networks
- Wireless Systems

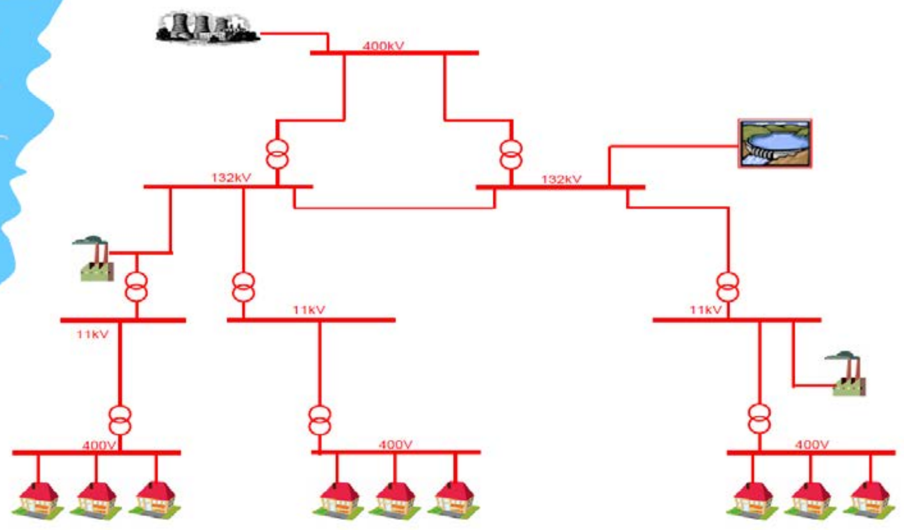
Integrated Solid State Transformer (I-SST)

Technology for the Grid of the Future

1) Brief overview of SST / Smart Transformer approaches
2) Smart Transformers in smart-grid – advantages
3) Smart Transformers for Interconnected Microgrids
4) I-SST for EV Charging Stations
5) I-SST for ASDs / Compact MV-ASDs / MV Power Distribution
6) I-SST for Grid Interconnected Renewables: PV / Wind / Battery

7) Conclusion

Today



Today we have a radial power distribution system with 3 major objectives:

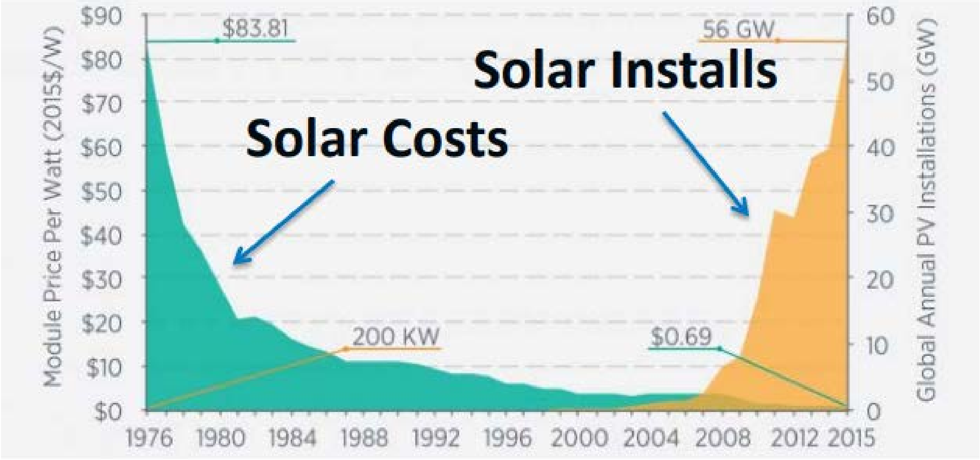
1. Improve reliability i.e. faults are isolated rapidly
2. Minimize the delivery losses (not paid by the customer)
3. Deliver high quality electricity – especially voltage magnitude

- These objectives are typically achieved via distribution management systems (DMS). One of the function of DMS is FISR, fault isolation and service restoration. FISR controls the opening and closing of circuit breaker to increase reliability.

- The other function of DMS is VVC, volt var control. VVC controls voltage control devices, such as load tap changer, voltage regulators and capacitors bank to minimize the delivery losses while maintaining a good voltage profile along feeders.

Renewables on the Rise

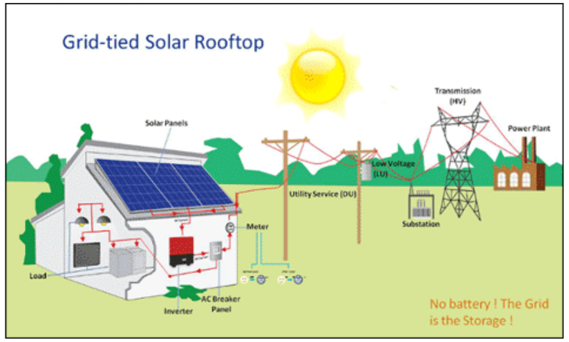
- Solar PV generation is one of the fastest growing sources of renewables



NREL: Integrating High Levels of Variable Renewable Energy into Electric Power Systems

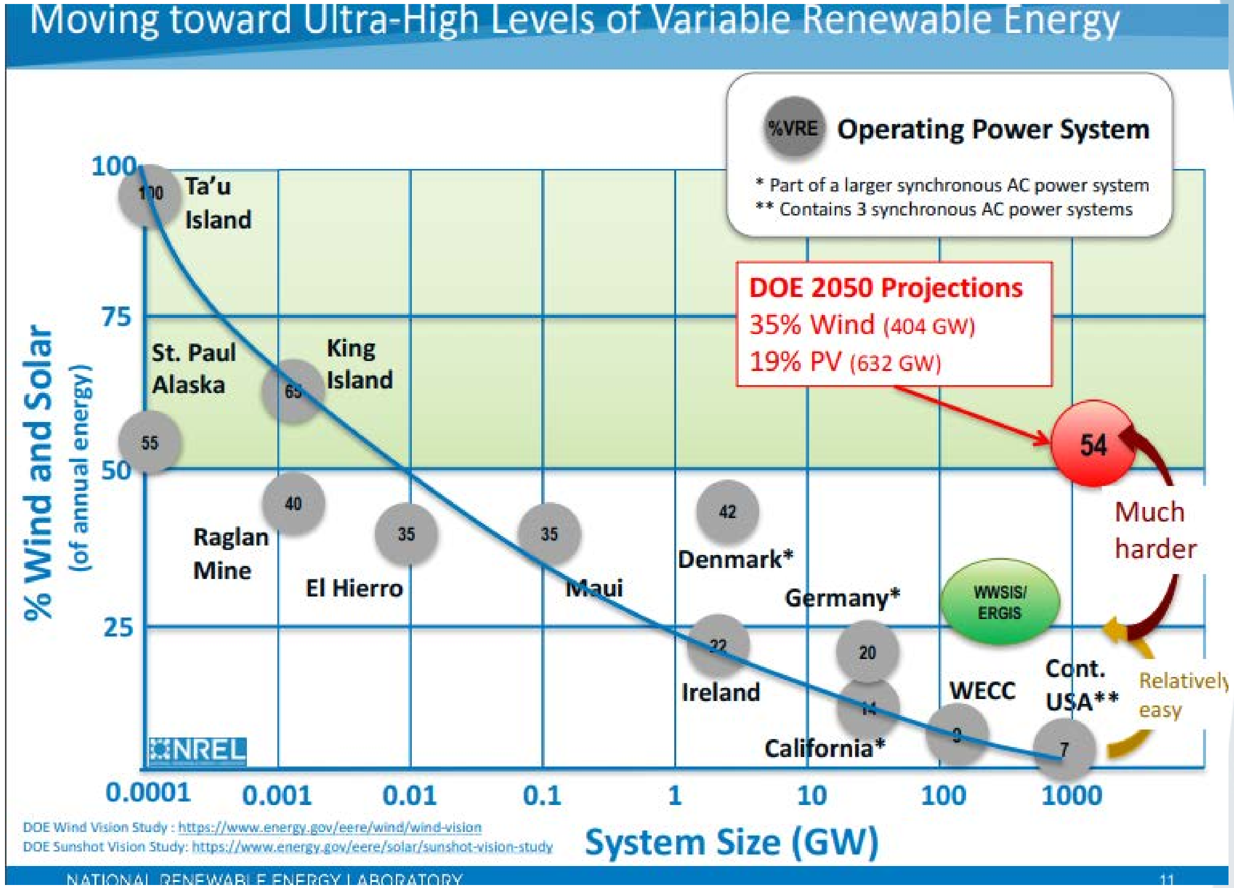
- Majority of new solar installations are being done at distribution level

Berkeley Lab: Installed Cost of Solar Photovoltaic Systems in the U.S. Declined Significantly in 2010 and 2011



Southern light solar

- 30% renewable energy penetration is possible with minimal changes*



What is needed for higher levels of penetration?

* NREL Power Systems Engineering Center

Tomorrow - Increased Renewable Energy Integration

Solid State Transformer Market Forecast 2017 to 2022

RESEARCH AND MARKETS
THE WORLD'S LARGEST MARKET RESEARCH STORE

24/7 1-800-526-8630 U.S. (TOLL FREE) +353-1-416-8900 REST OF WORLD

- Solid State Transformer Market is projected to witness a compound annual growth rate of 32.09% to reach to total market value of US $487.474 million by 2022
- With an increase in the use of distributed energy sources, SSTs are expected to offer better control / Enable Energy Saving / Smart Grid Functionalities

Transformer Basics

- Advantages

• Relatively Inexpensive
• Highly Robust / Reliable
• Highly Efficient (98.5%...99.5% Dep. on Power Rating)

- Weaknesses

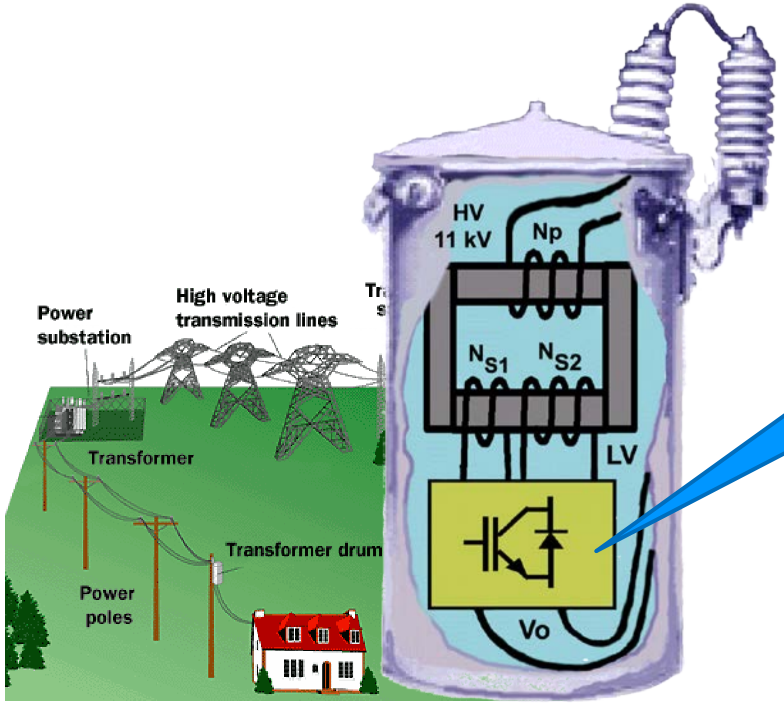
• Voltage Drop Under Load
• Sensitivity to Harmonics
• Sensitivity to DC Offset Load Imbalances
• Provides No Overload Protection
• Possible Fire Hazard
• Environmental Concerns

→ Construction Volume $$A_E A_W = \frac{\sqrt{2}}{\pi} \frac{P_t}{k_W J_{rms} \hat{B}_{max} f}$$

P_t .... Rated Power
k_W .... Window Utilization Factor (Insulation)
B_{max} .. Flux Density Amplitude
J_{rms}... Winding Current Density (Cooling)
f ..... Frequency

• Low Mains Frequency Results in Large Weight / Volume

Smart Transformer – 60Hz

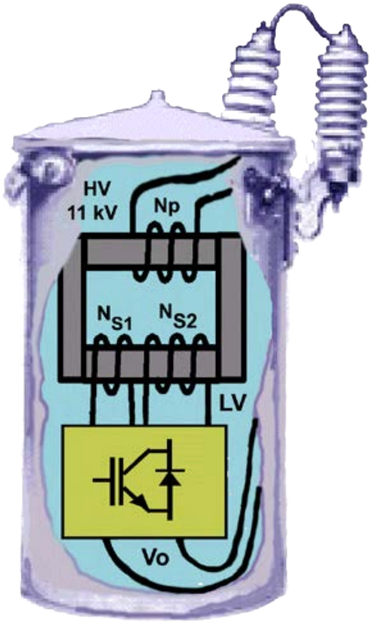


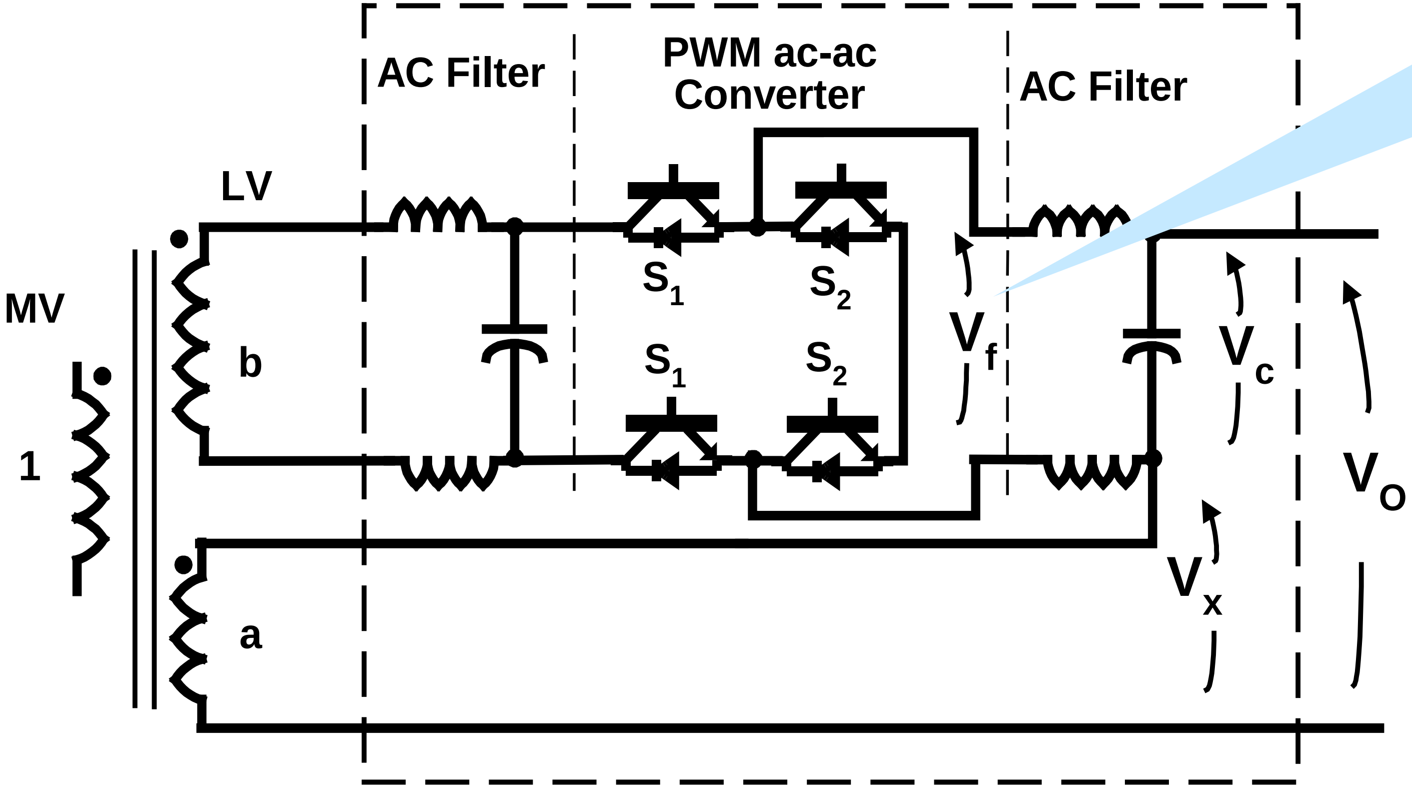
Power Electronics on LV Side

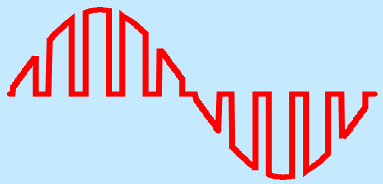
60Hz smart transformer is a low hanging fruit

- Smart Transformer can respond to fluctuations within the power grid instantly acting as voltage regulators and thereby reducing energy consumption by providing optimized voltage at the point of common coupling (PCC)
- At PCC, they can control the active power exchange between the microgrid and utility
- Enhance power quality and reduce grid losses

Smart Transformer – 60Hz







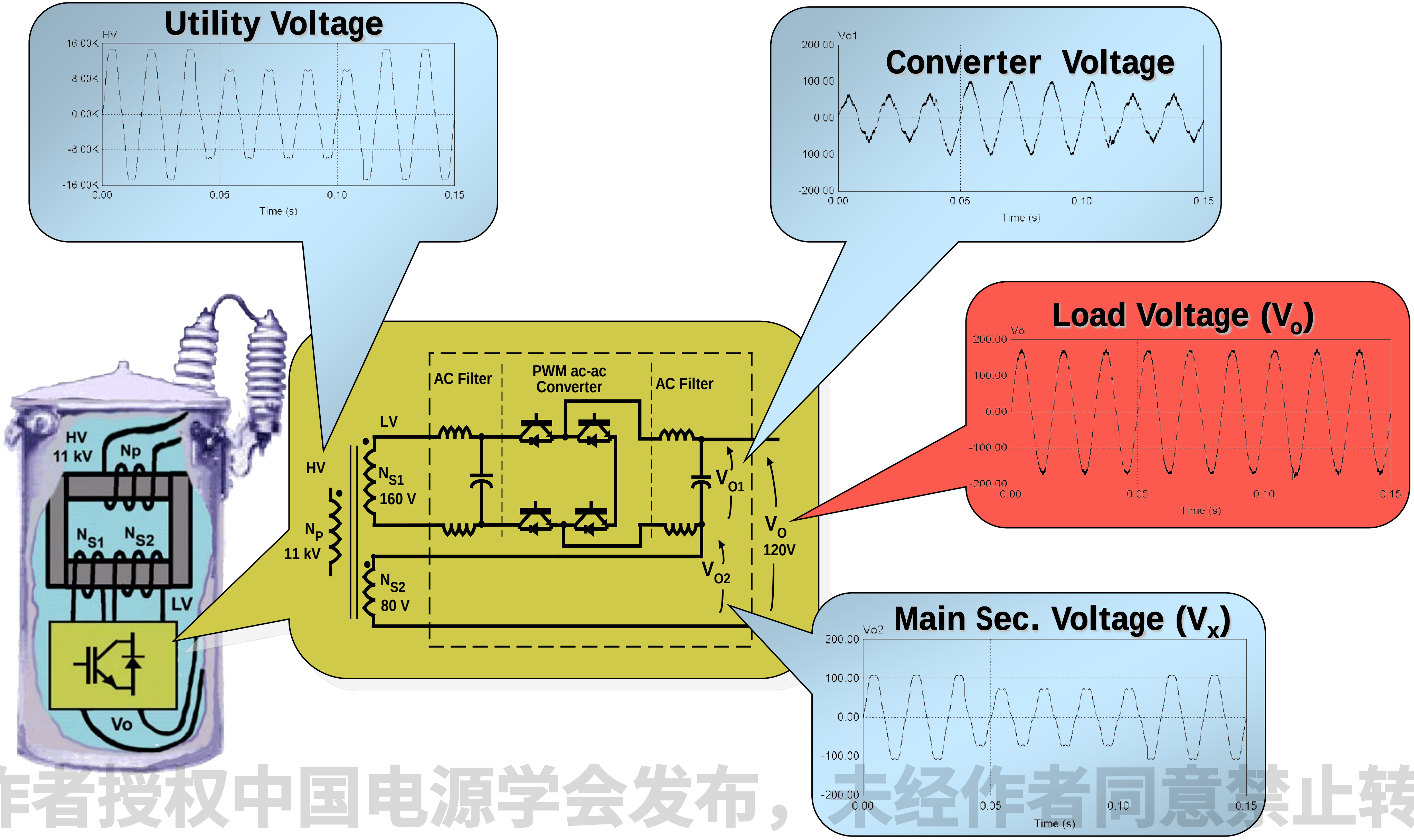
$V_o = V_x + V_c$

$V_o = V_x + D\ V_y$

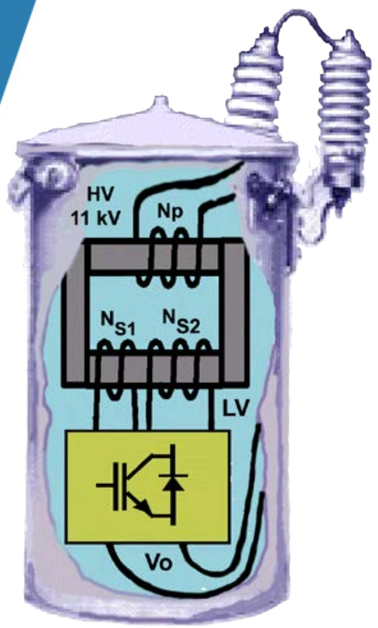
D = Duty Cycle
$0 < D < 1$

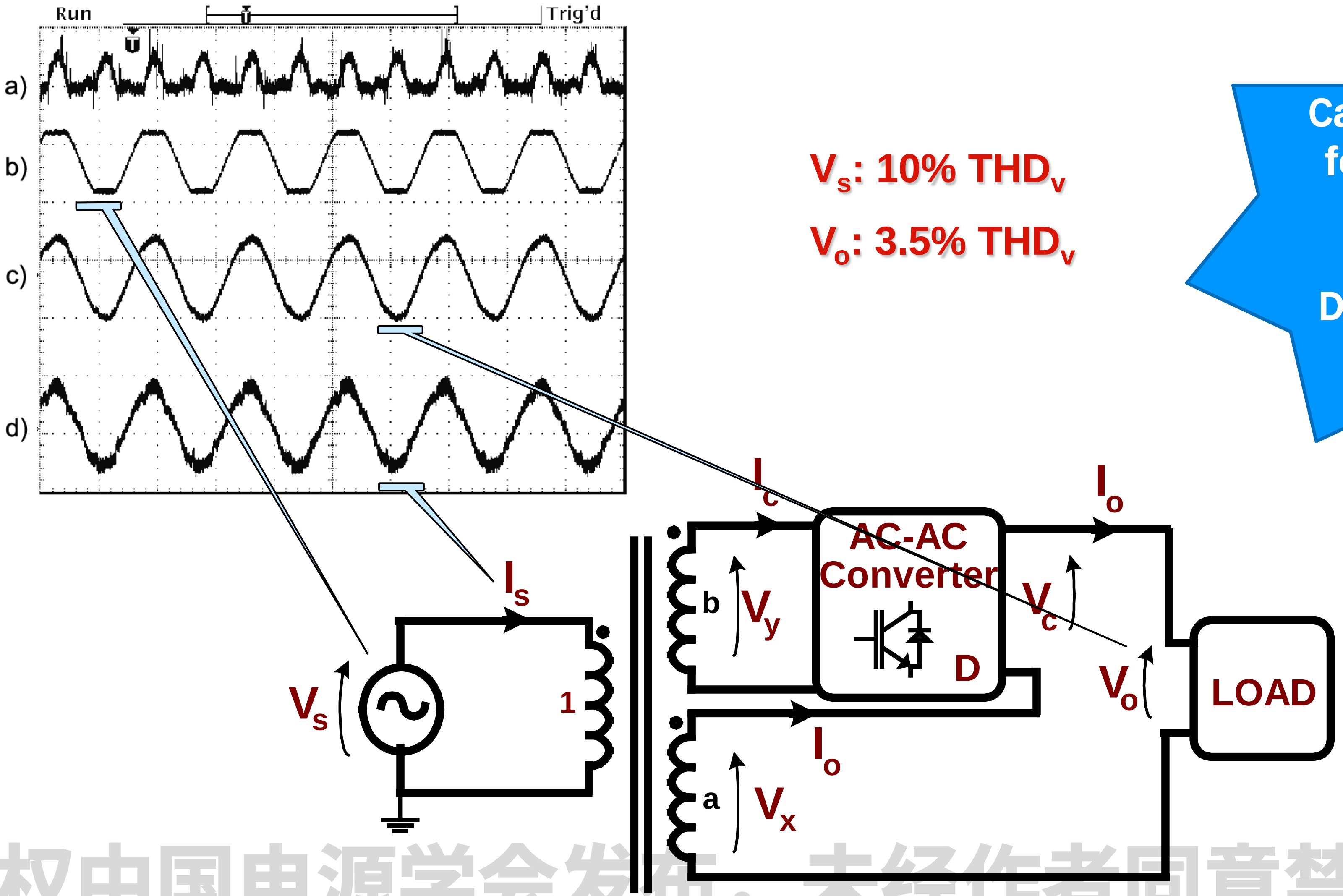
- The output voltage (V_o) is regulated by adjusting the duty ratio (D) of the AC-AC Converter
- Voltage sag & voltage swell can be compensated

Smart Transformer – 60Hz



Smart Transformer – 60Hz



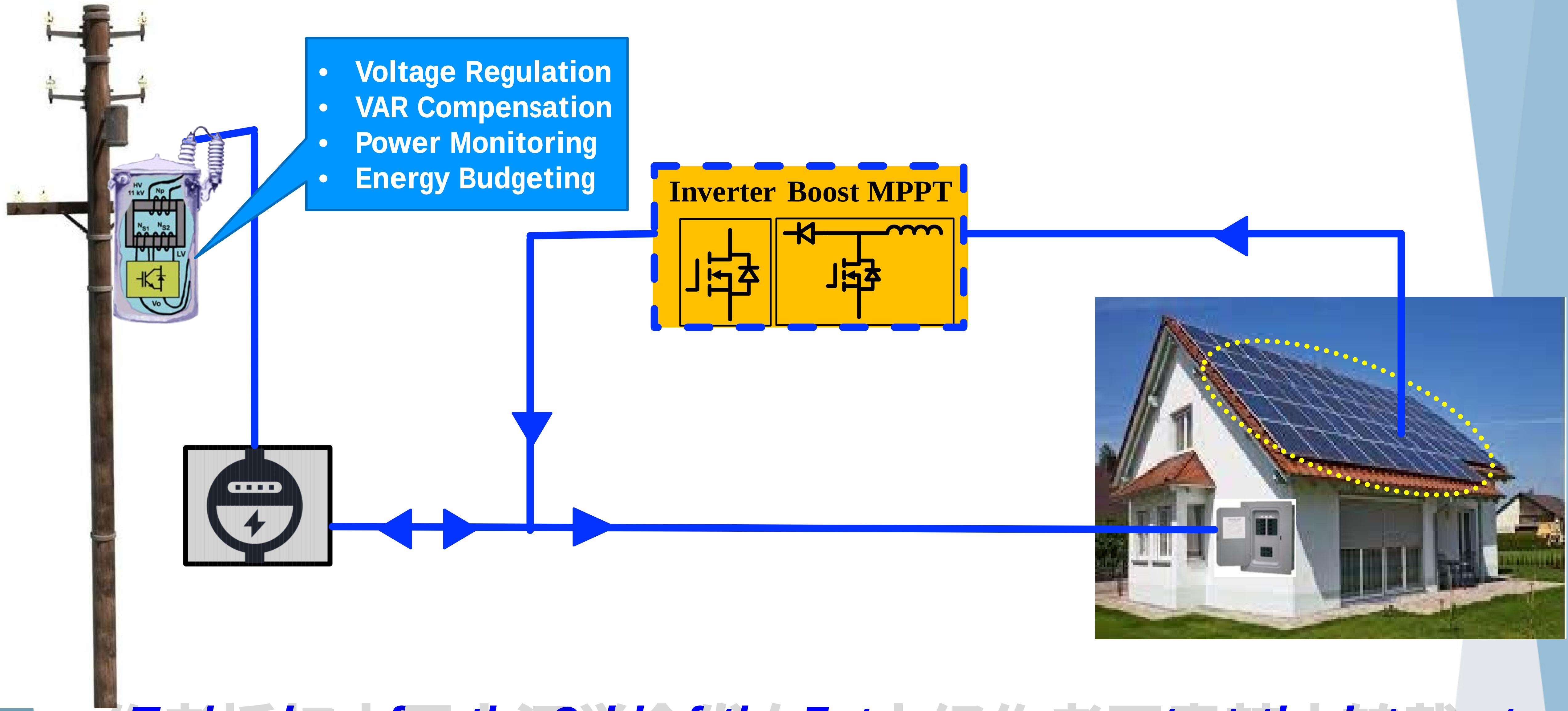


V_s: 10% THD_v

V_o: 3.5% THD_v

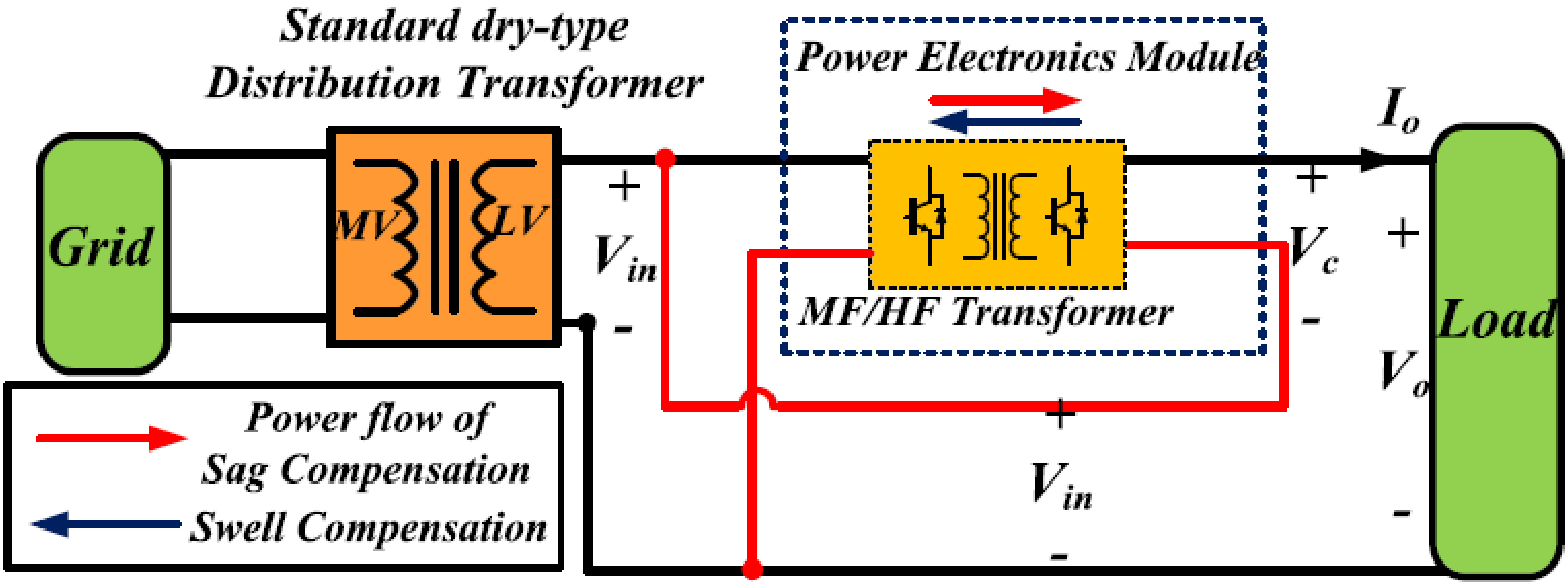
Can Correct for Steady State Voltage Distortions

Smart Transformer – 60Hz

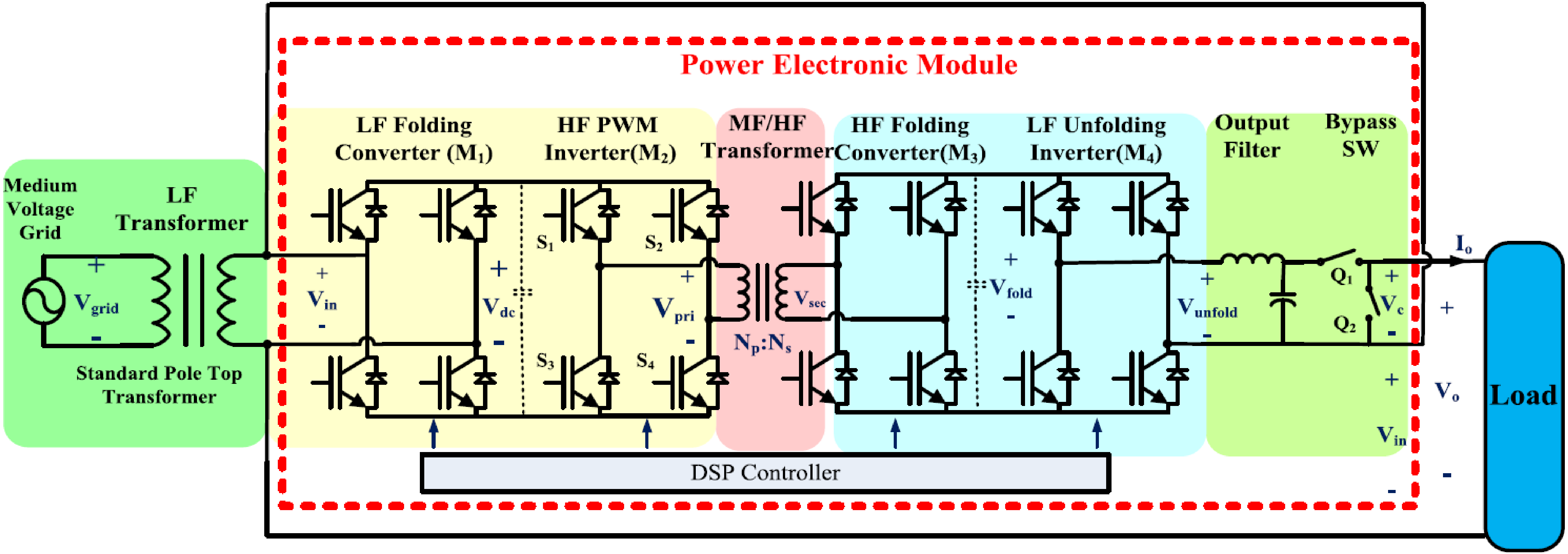


Technology for the Grid of the Future – as smart at the internet

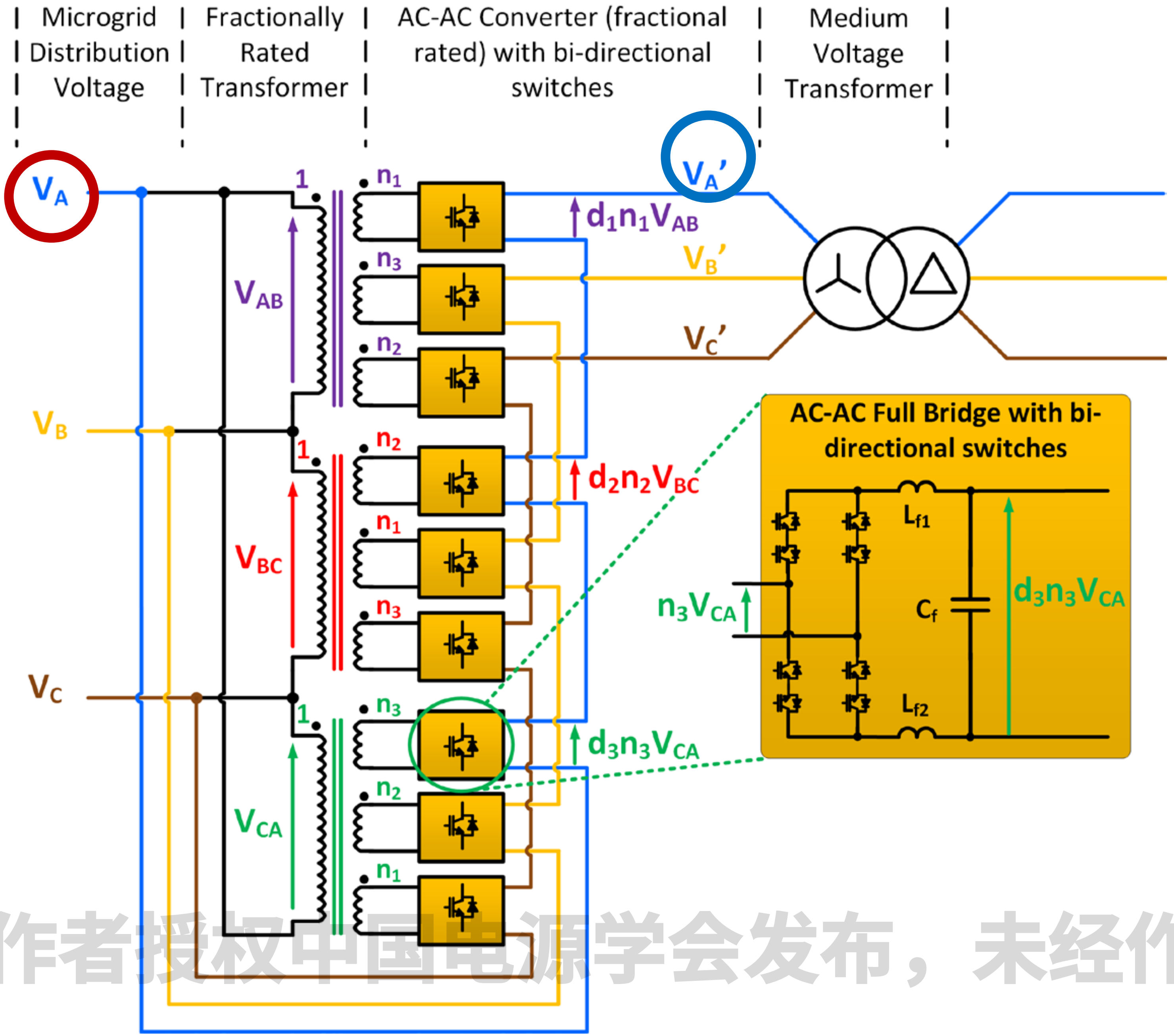
Smart Transformer – High Frequency

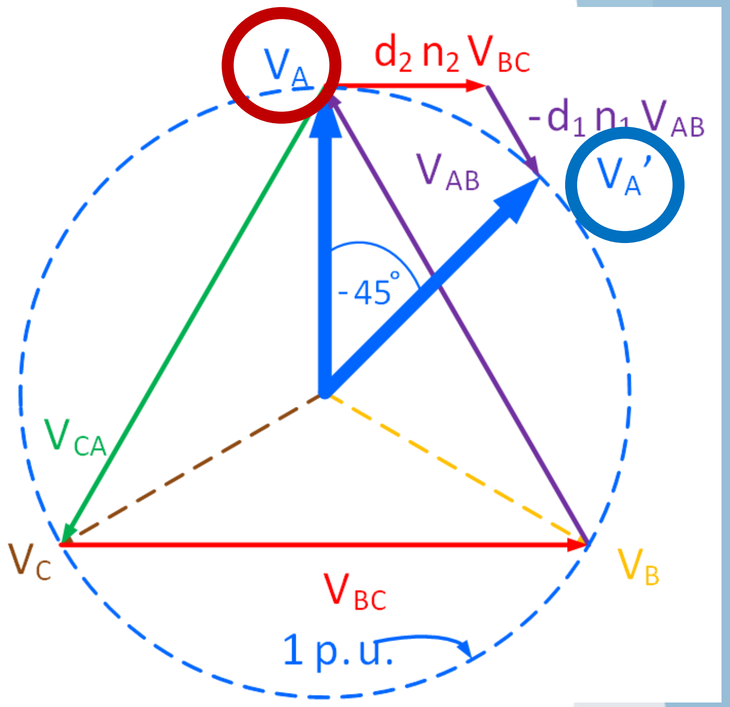


Smart Transformer – High Frequency

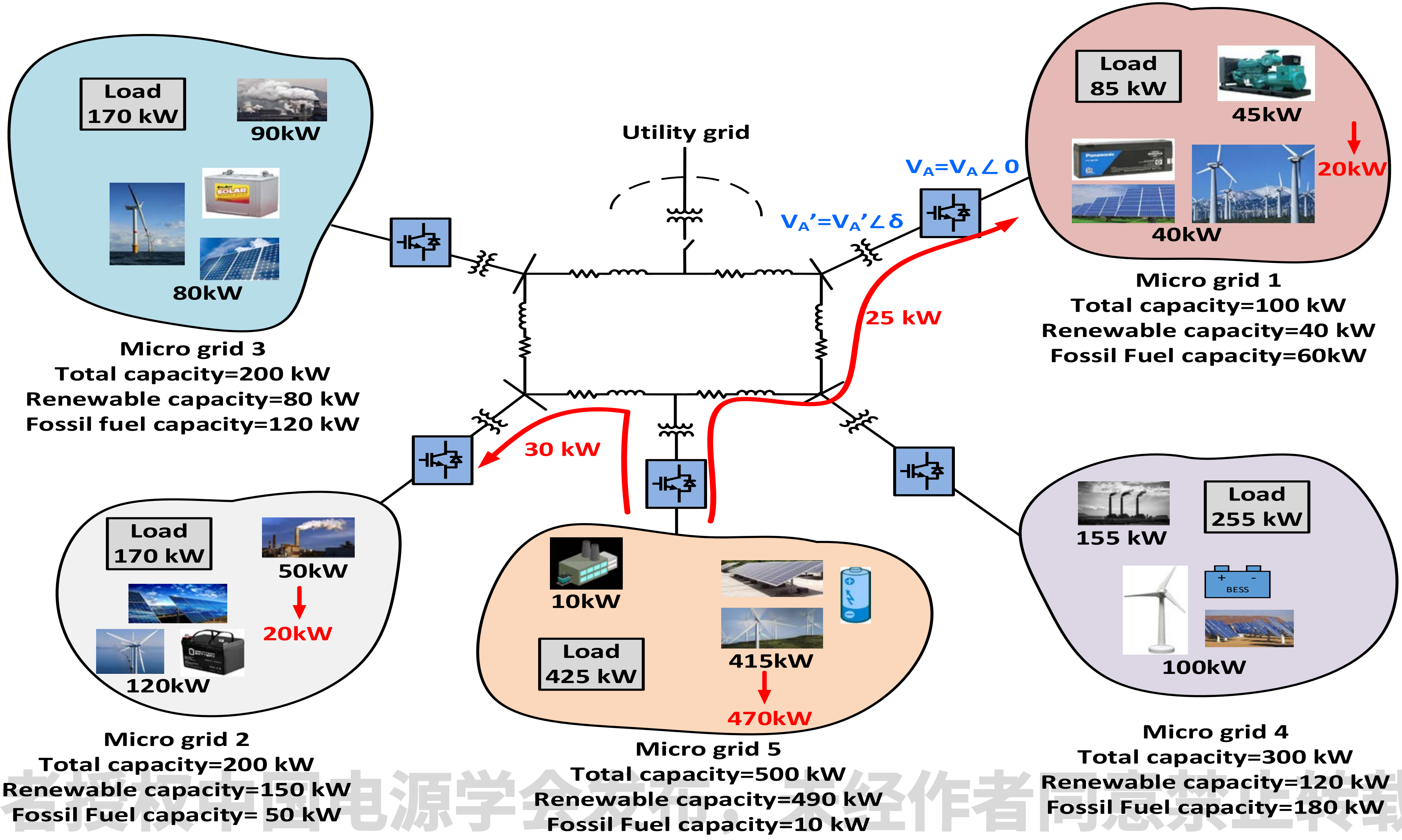


Smart Transformers in Microgrids



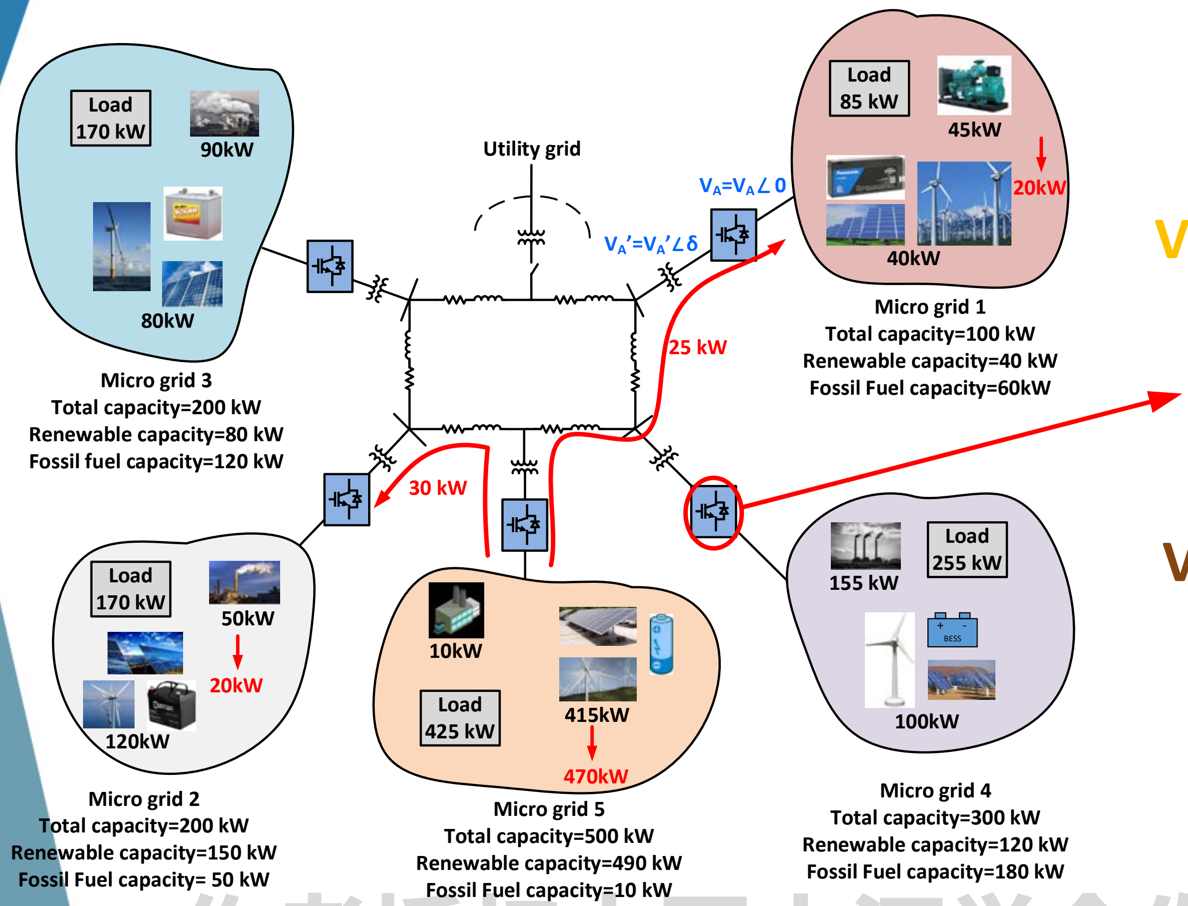


Smart Transformers in Microgrids

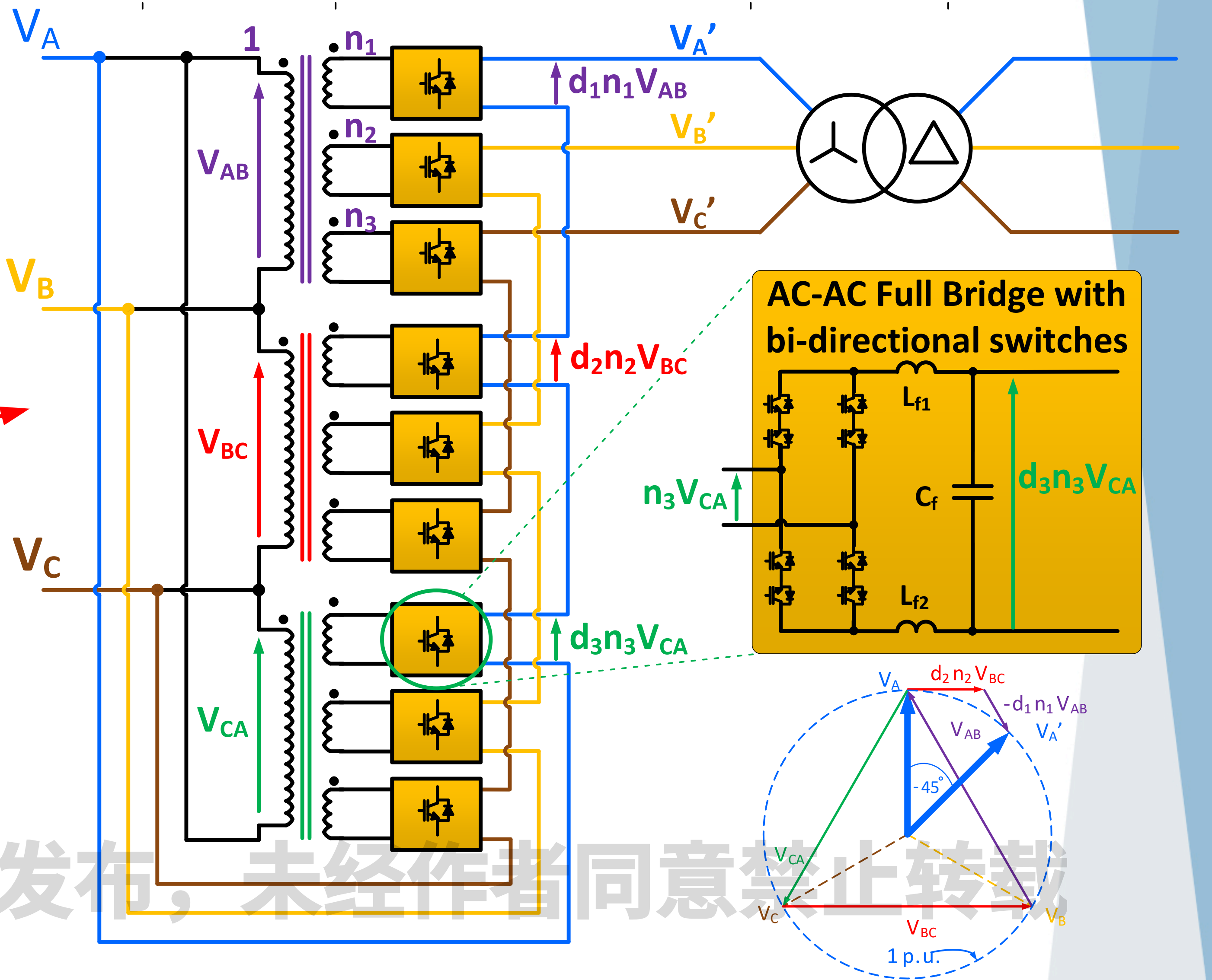


Smart Transformers in Microgrids

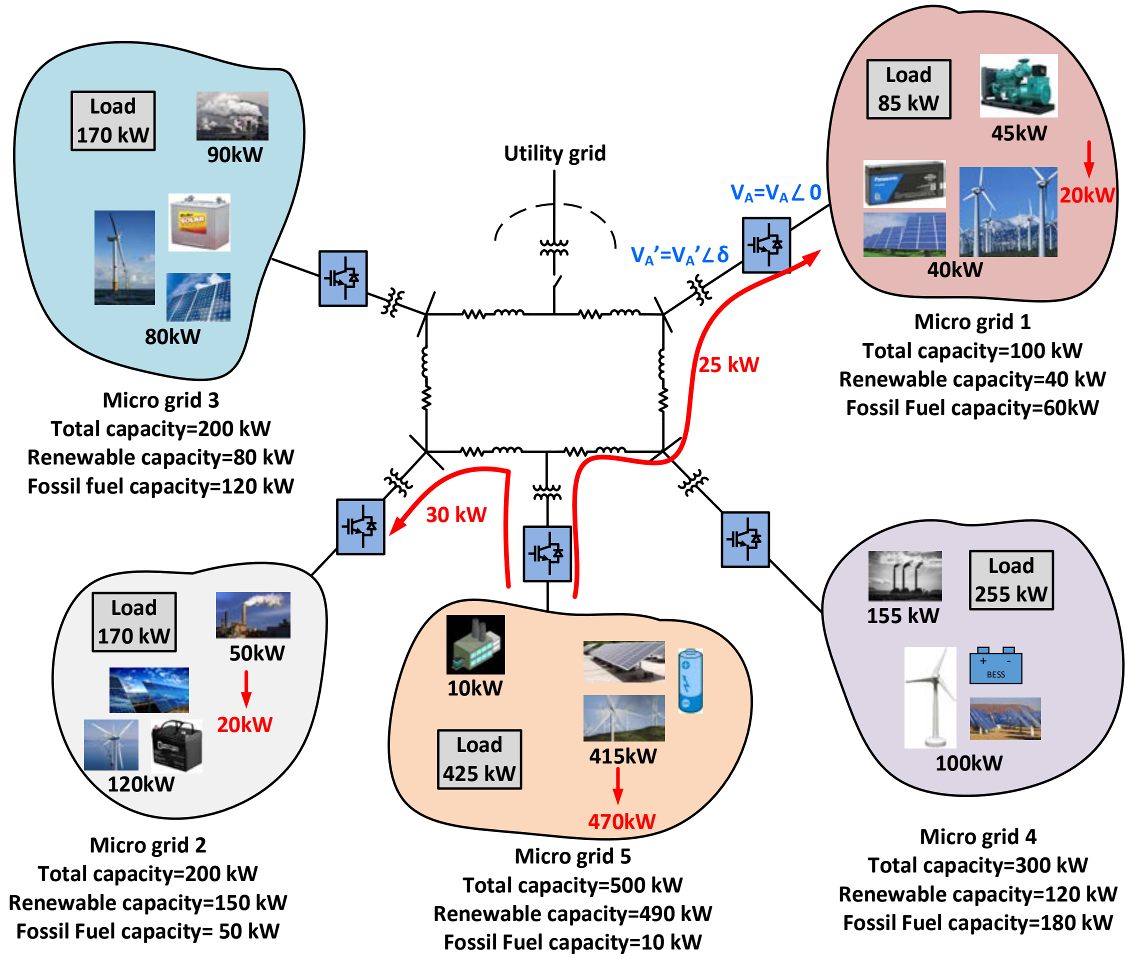
Proposed five microgrid configuration with Modified Angle Droop Control

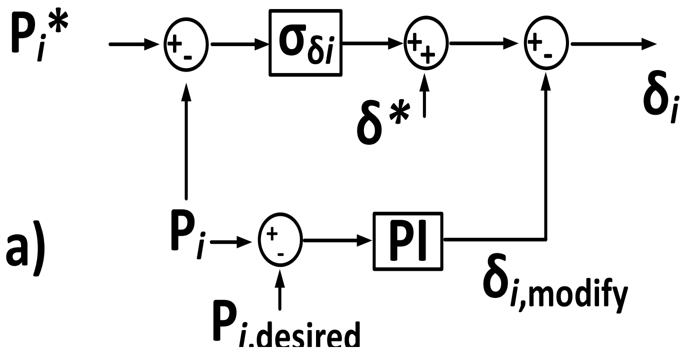


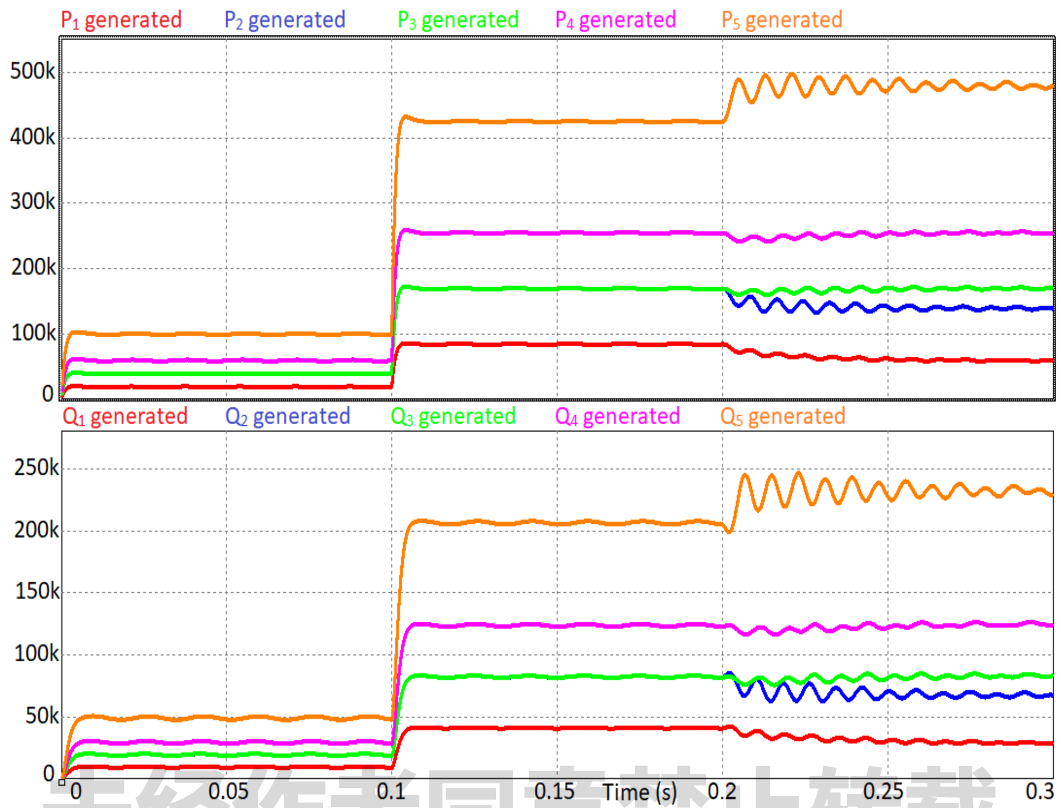
Microgrid Distribution Voltage	Fractionally Rated Transformer	AC-AC Converter (fractional rated) with bi-directional switches	Medium Voltage Transformer	Medium Voltage Microgrid Interface Point of Common Coupling



Smart Transformers in Microgrids







At t=0.1sec, the system load changes from 25% to 85%, after t=0.2 sec, μG_5 provides 25kW, 12.1 kVAR to μG_1 and 30 kW, 14.5 kVAR to μG_2.

Electronic Transformer
Medium Frequency / High Frequency

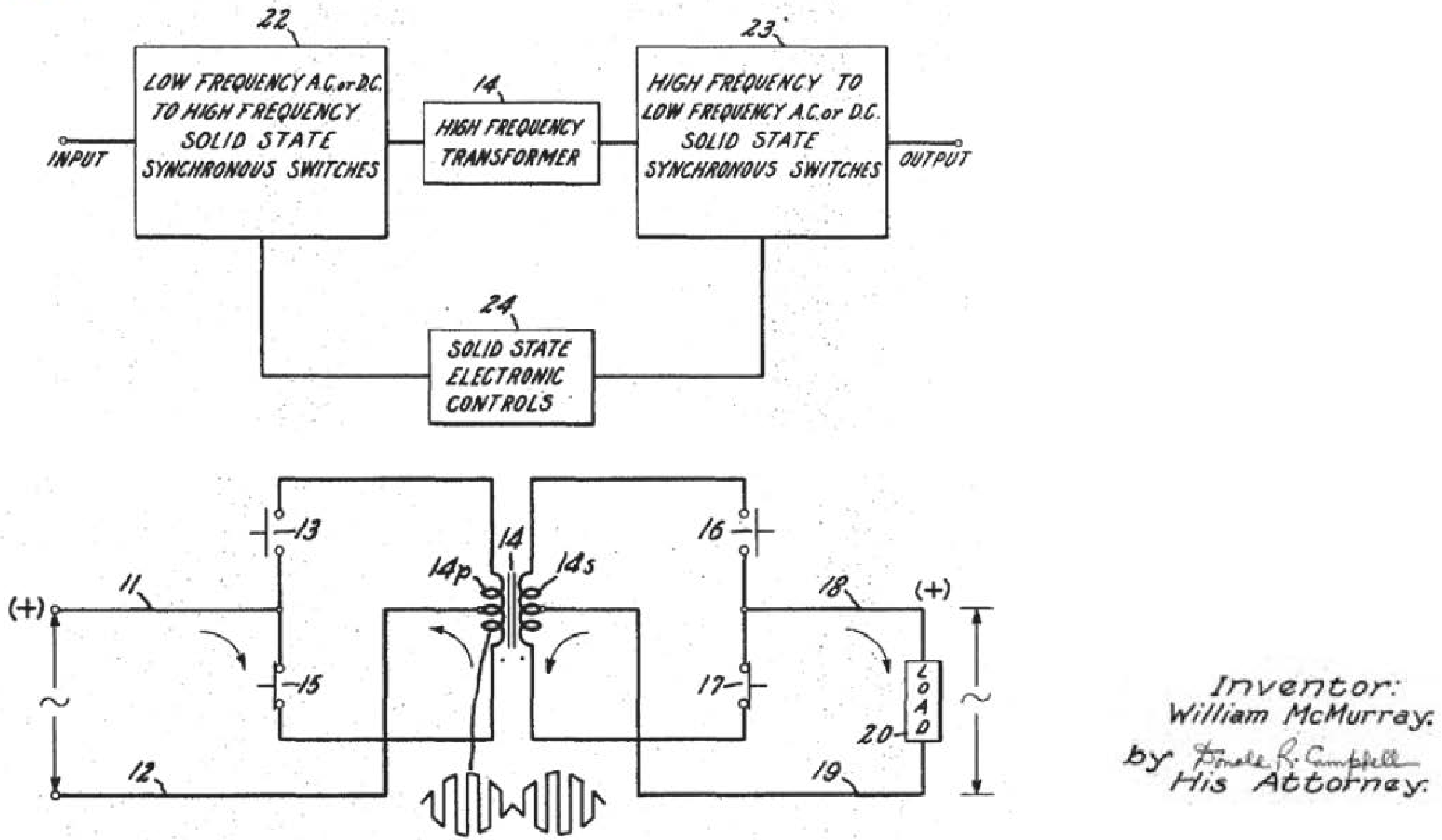
Transformer Size is a Concern

- Volume and weight of the transformer are important in high density urban settings with low available space.
- Size is also a concern in underground installations, moving power systems such as ships, factories, etc.

Electronic Transformer – McMurray 1968

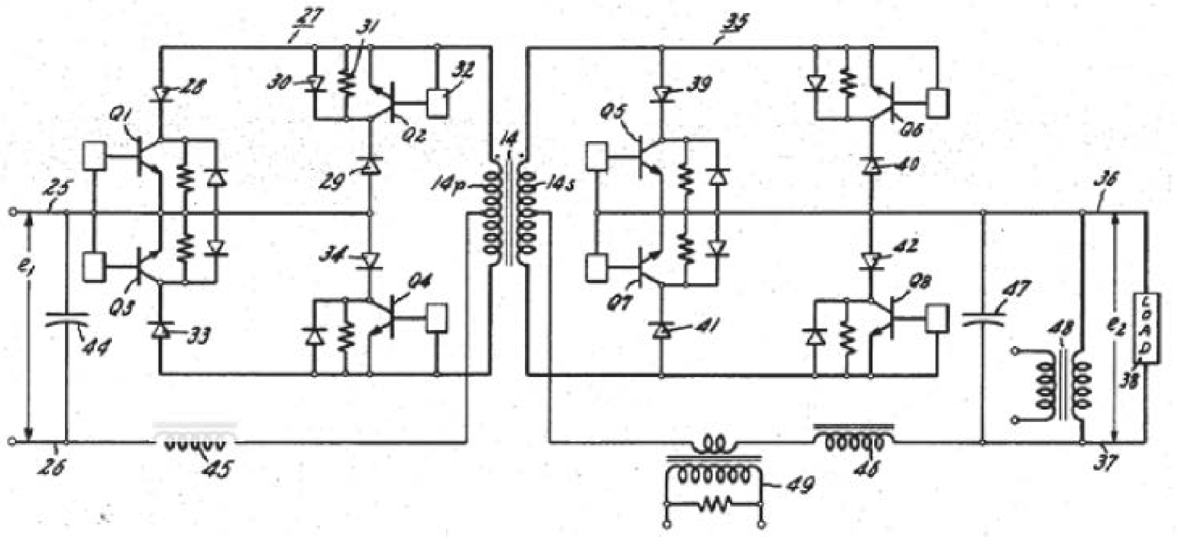
- Matrix-Type $f_1=f_2$

US Patent 3,517,300 June 23, 1970

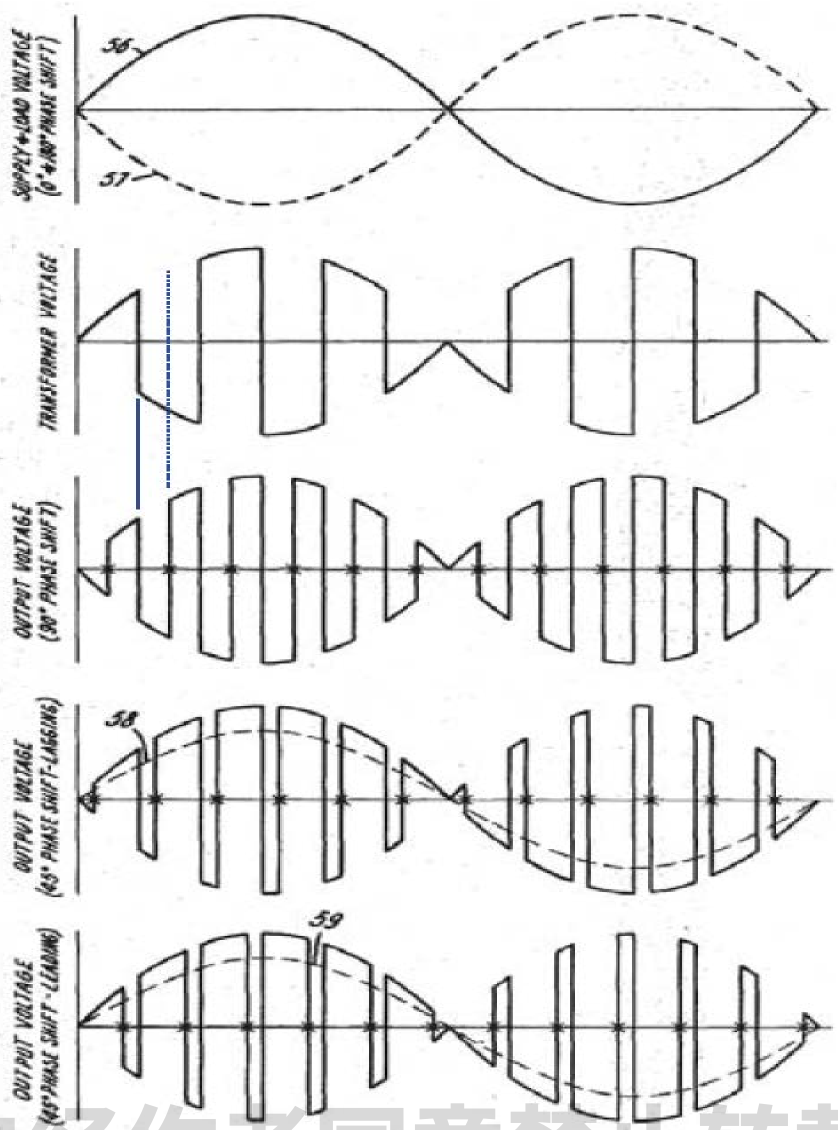


- Electronic Transformer = HF Transf. Link & Input and Output Sold State Switching Circuits
- AC or DC Voltage Regulation / Current Regulation/Limitation/Interruption

Electronic Transformer – McMurray 1968



US Patent 3,517,300 June 23, 1970



- ➢**Fully bidirectional power flow**
- ➢**Output voltage regulation**

Transformer Cores – Price Comparison

Grain Oriented Silicon Steel Sheets

*Price ~= USD **850** per Metric Ton*

Type:	Oriented Silicon Steel
Thickness:	0.23 - 0.30 mm
Standard:	AISI,ASTM,GB,JIS,AISI, ASTM, BS, DIN
Grade:	m4 27Q130,30Q120,30Q130,30Q120 30Q130
Special Use:	Silicon Steel

Amorphous Core Material

Price ~= USD **2000** per Metric Ton

Capacity(KVA)	Dimension (A×B×C×D×E)(mm)	Net Weight (kg)	Core Loss (W/kg)	Exciting power (VA)
30	220×70×41.5×146	26	6	26
	220×120×41.5×146	30	6	30

Ferrite Core Material

Price ~= USD **4000** per Metric Ton

Nanocrystalline Core Material

Price ~= USD **10000** per Metric Ton

Medium Frequency Transformer

Transformer Design	M19 Core 60 Hz	M19 Core 600 Hz	Metglass 600 Hz
Operating Frequency (Hz)	60	600	600
Max. Flux Density (T)	1.25	0.55	1.1
Core Dimensions (cm)	62 X 4 X 7.5	54 X 5 X 2.5	60 X 4.5 X 2.5
Number of turns (#)	250	140	180
Core Volume (L)	1.9	0.67	**0.62**
Core Weight (kg)	14.8	5.3	**5.0**
Core Loss/Mass (W/kg)	1.7	7.5	1.8
Net Core Loss (W)	25	40	9
Winding Loss (W)	20	6	8
Total Transformer Loss (W)	45	46	**17**
Efficiency at 1.6 kVA (%)	97.3	97.2	**99.0**
Cost of Core (p.u.)	1.0	0.35	1.0
Cost of Winding (p.u.)	0.4	0.13	0.2
Total Cost (p.u.)	1.4 (1pu)	**0.48 (0.34)**	1.2 (0.86)

Use the Cost Savings 0.66 pu to Pay for Power Converter / Controls / Protection

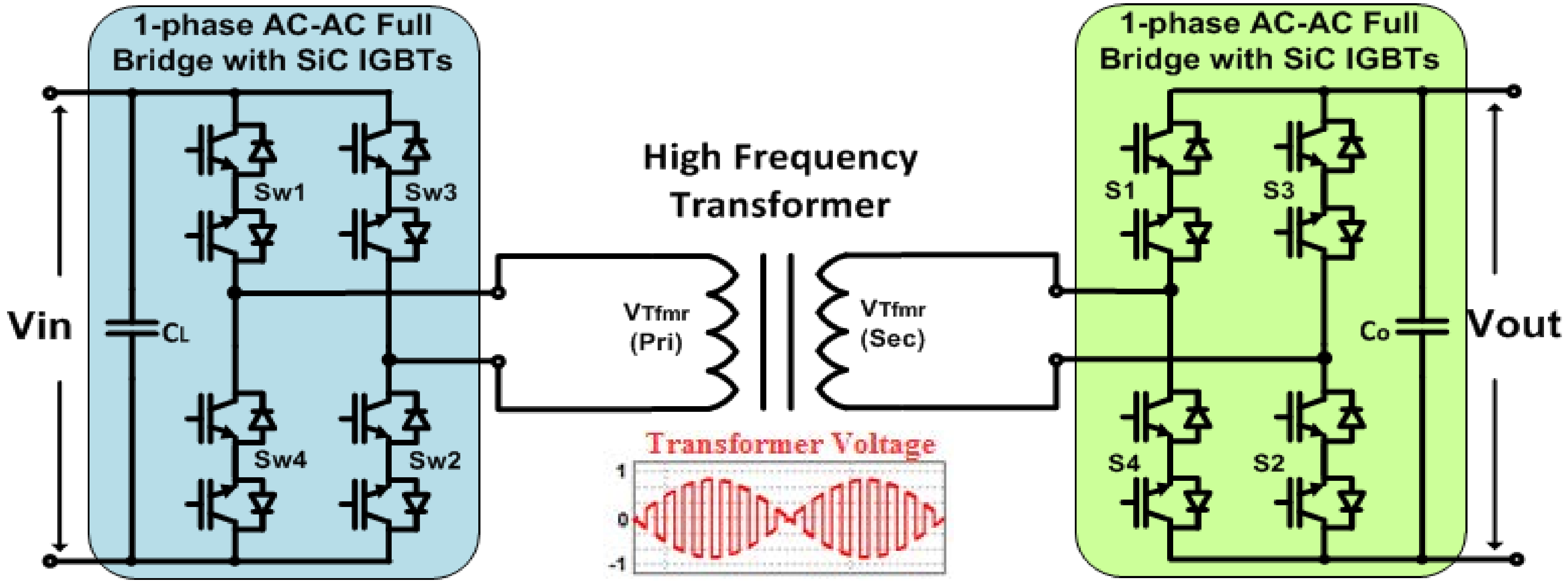
Medium Frequency Transformer

PARAMETER	1000 HZ DESIGN	NORM 60 HZ DESIGN	UNIT
KVA RATING	142.2	142.2	KVA
FLUX DENSITY	3700.0	15000.0	GAUSS
CORE LOSS/LB	2.0	1.0	W/LB
CORE LOSS	480.0	986.4	W
WIRE LOSS	632.4	2018.7	W
CORE WEIGHT	240.0	986.4	LB
WIRE WEIGHT	65.8	270.5	LB
NORMALIZED SIZE	1.00	4.11	
EFFICIENCY	0.99	0.98	
CORE COST	$316.80	$1,301.99	
WIRE COST	$128.55	$528.32	
CORE + WIRE COST	$445.35	$1,830.31	

- **1 kHz transformer is about ¼ the size of its 60Hz counterpart**
- **The difference in cost can possibly fund power electronics**

Medium Frequency Transformer

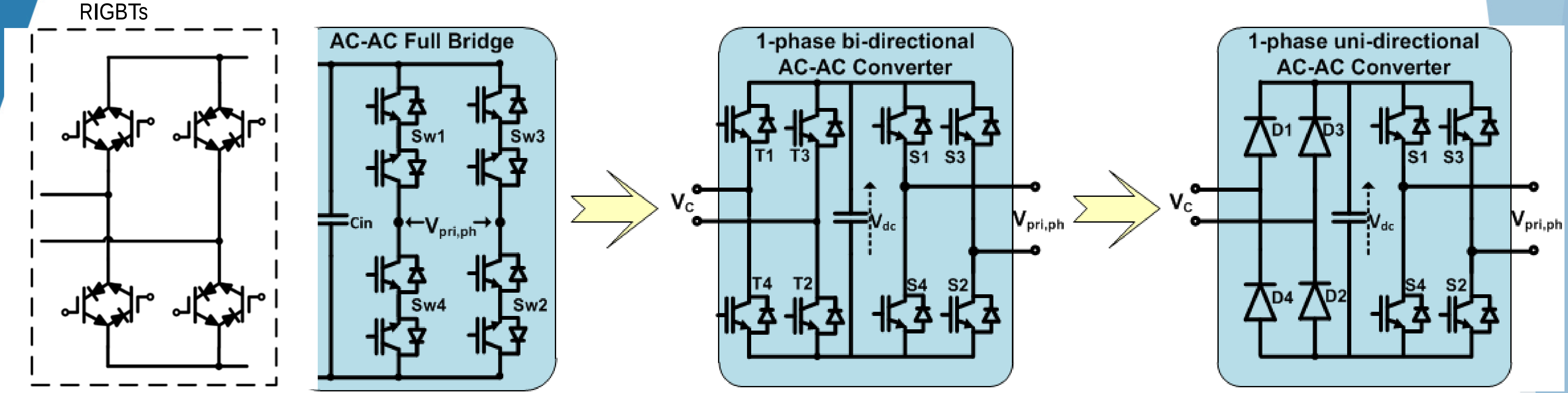
Add Enjeti / Kang / Pitel paper – from conference – 1997??

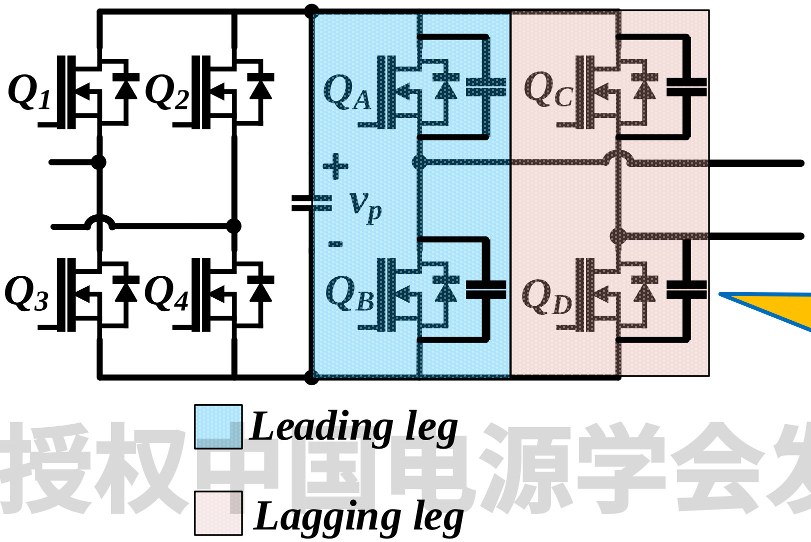


- **Modulated with a MF square wave (switching frequency f_{sw})**
- **AC-AC converter modulates the line frequency (f_s) sine wave into '$f_{sw} \pm f_s$' Hz and higher frequency components**

- **No line frequency components in the transformer voltage**

Medium Frequency Transformer





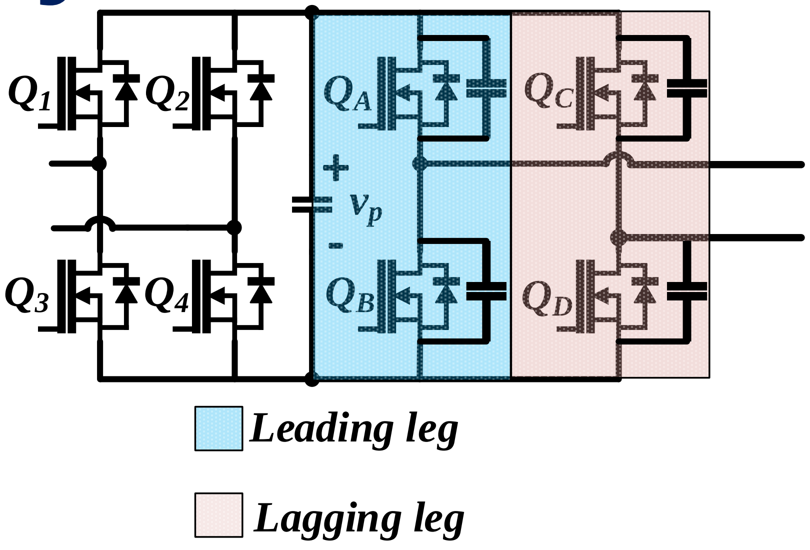
ZVS with phase-shift Modulation

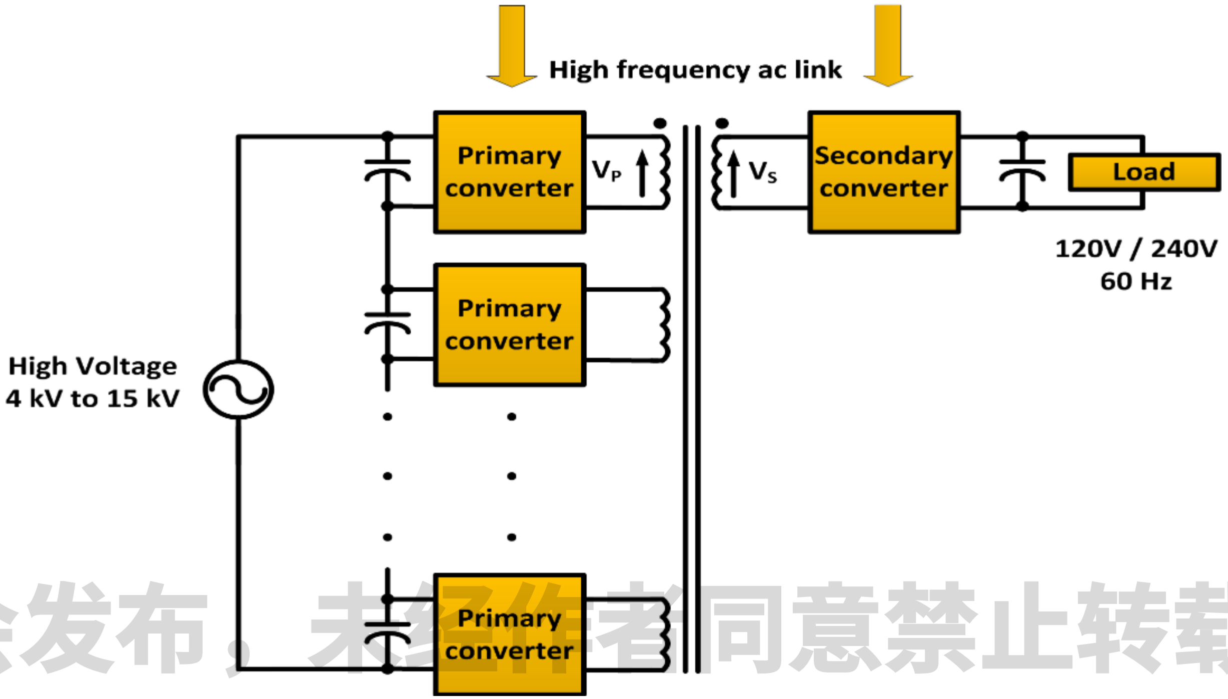
- **For unidirectional power flow - Replace 4 IGBTs with 4 diodes - as shown**
- **No energy storage components**

Medium/High Frequency Transformer

Modular Concept with WBG Devices

- On the primary side several low voltage converters are staked
- All primary converter outputs are coupled to common core
- Voltage sharing on series connected converters is guaranteed
- No bulky energy storage components
- ZVS contributes to high efficiency



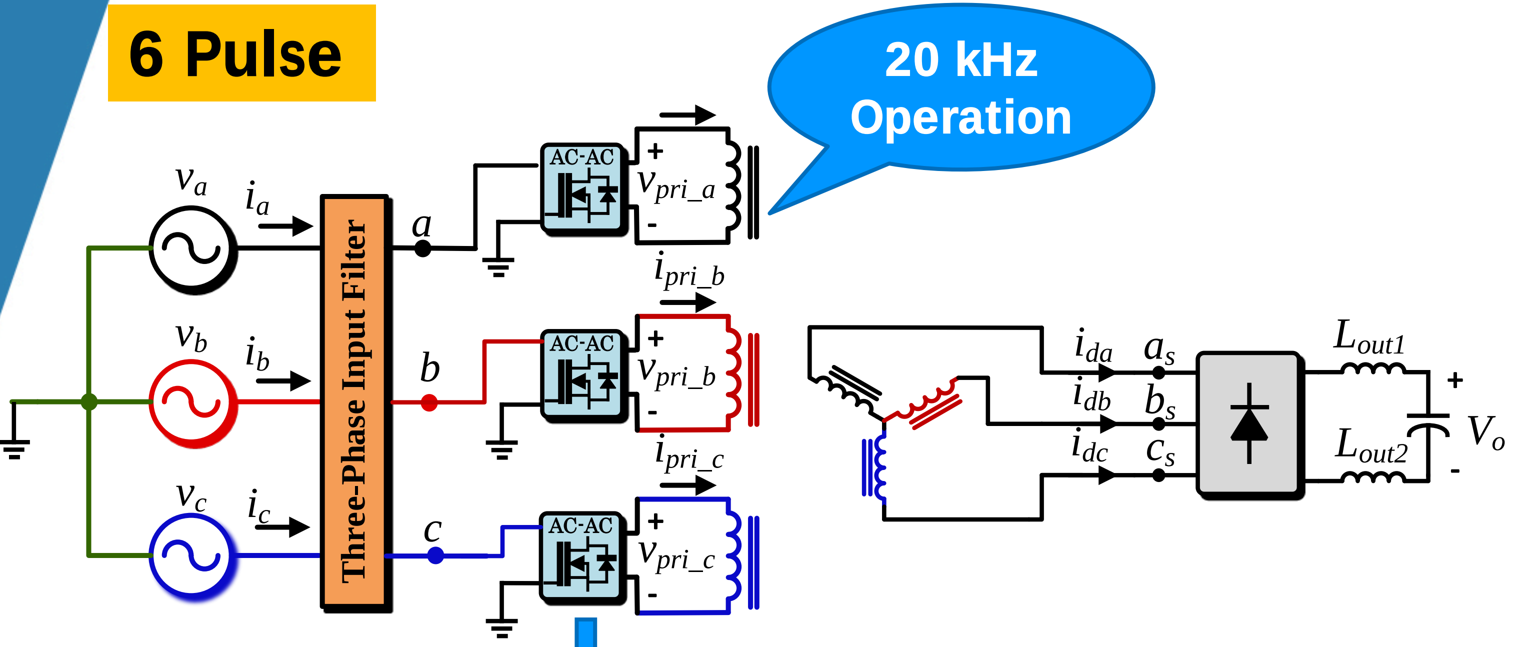


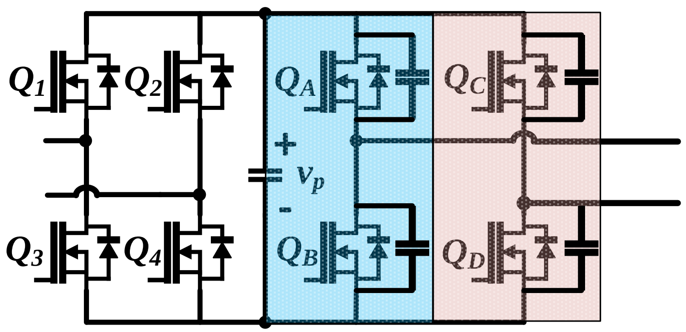
Industrial Applications that can benefit from Integrated – Solid State Transformer (I-SST)

Integrated Solid State Transformer (I-SST)

6 Pulse

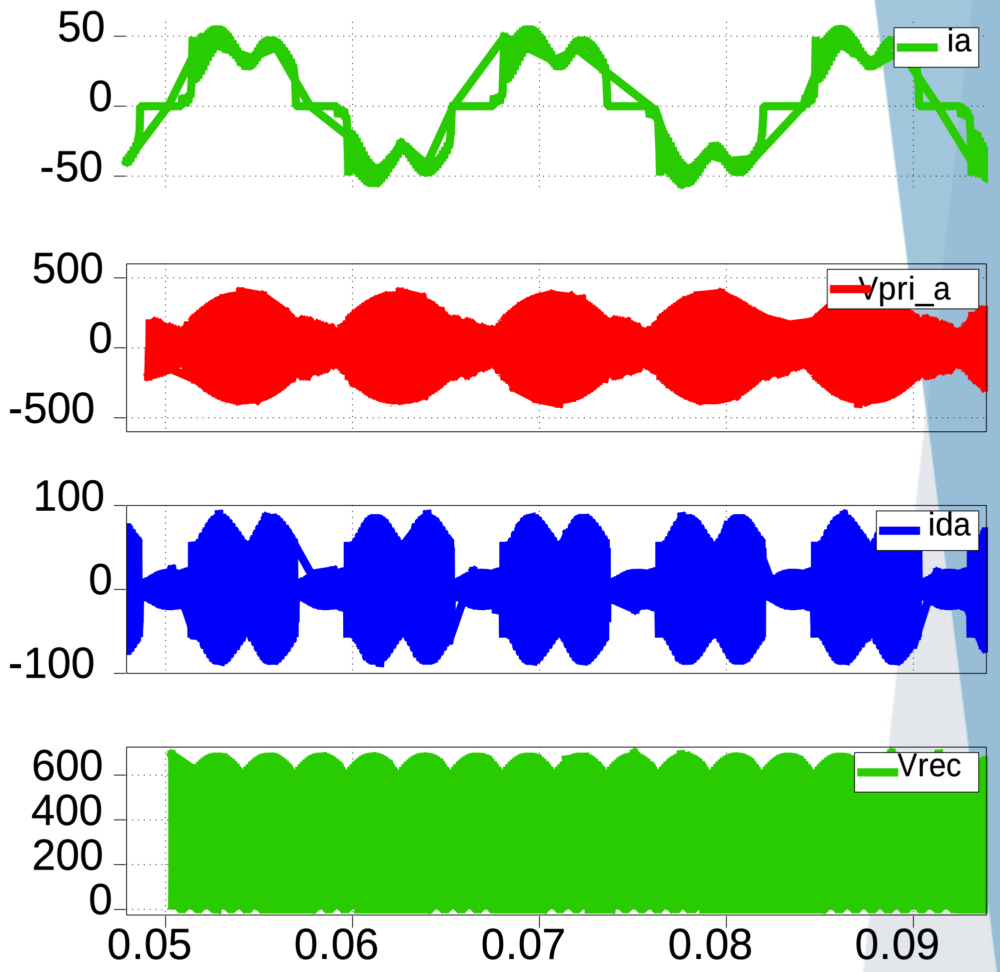
Input current quality is poor





Leading leg

Lagging leg

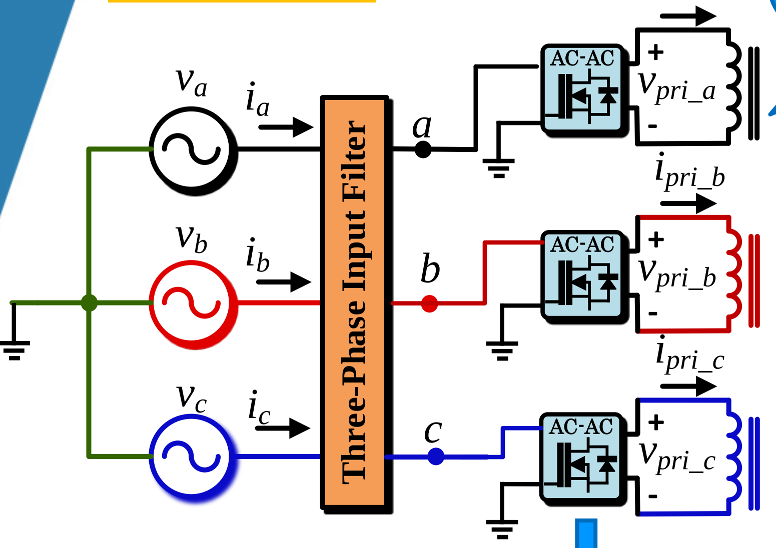


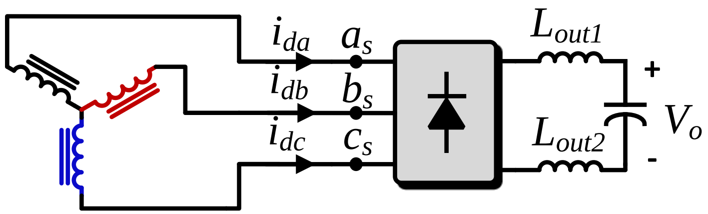
Integrated Solid State Transformer (I-SST)

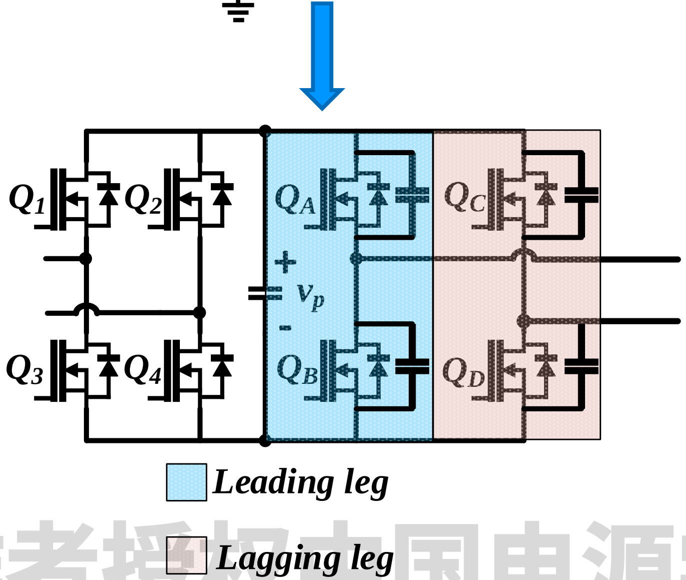
6 Pulse

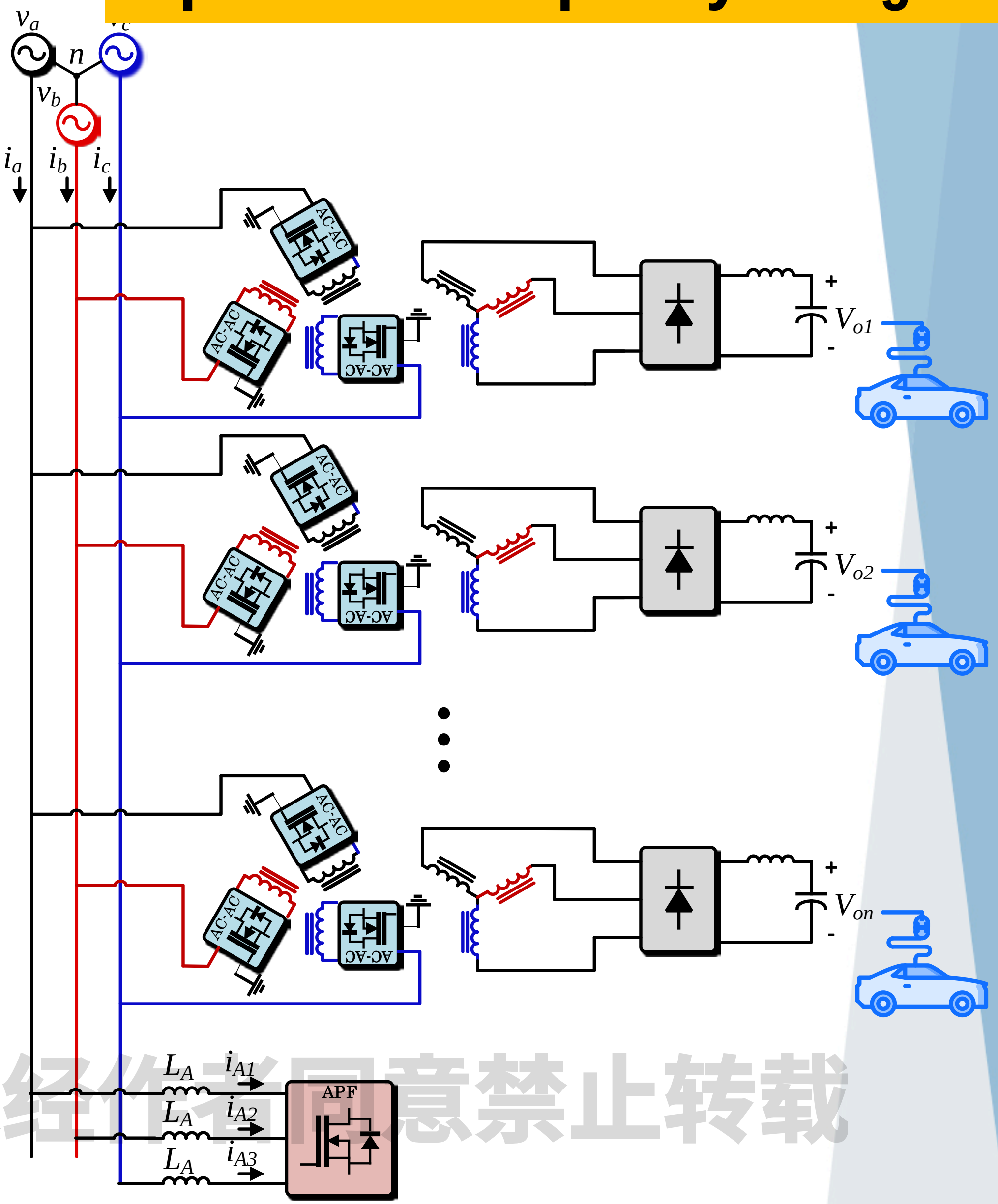
20 kHz Operation

Input current quality is high





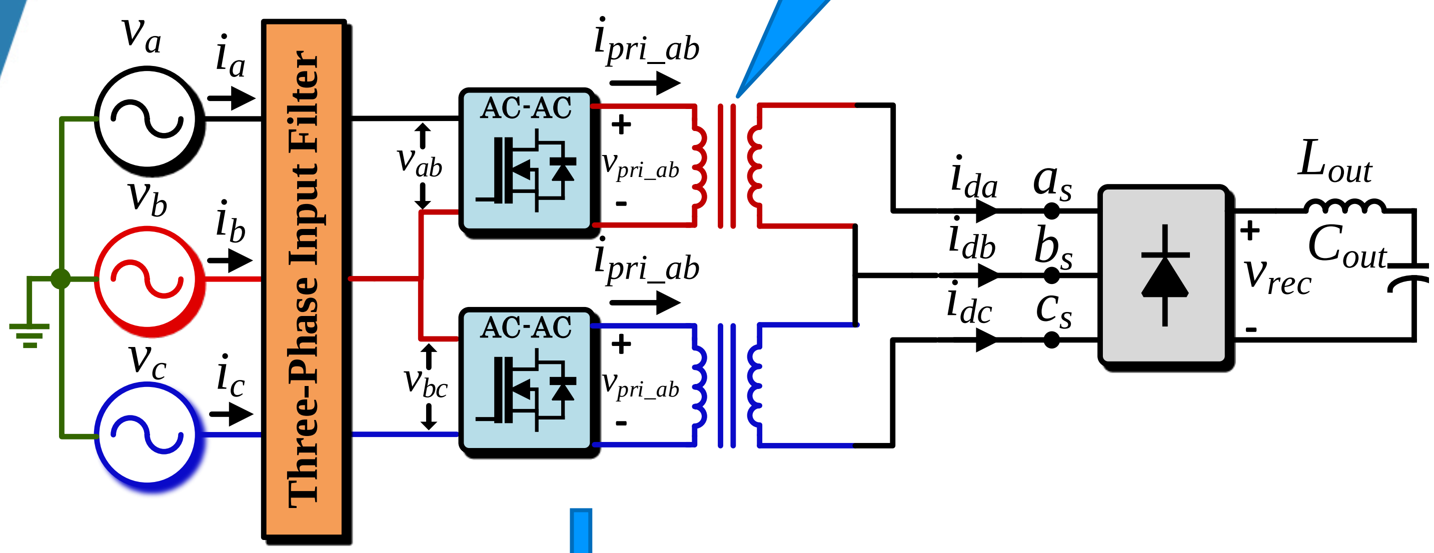


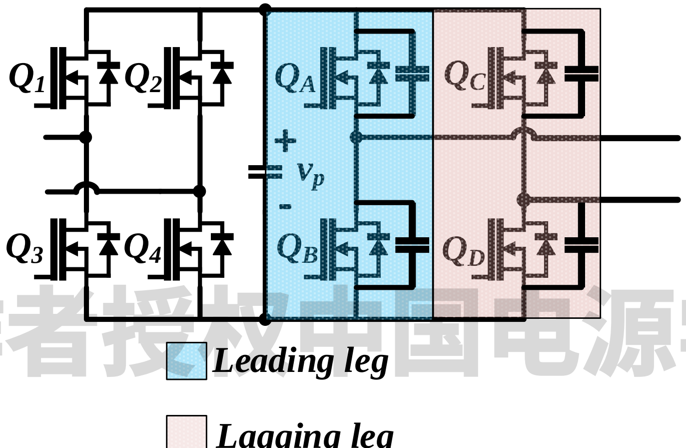


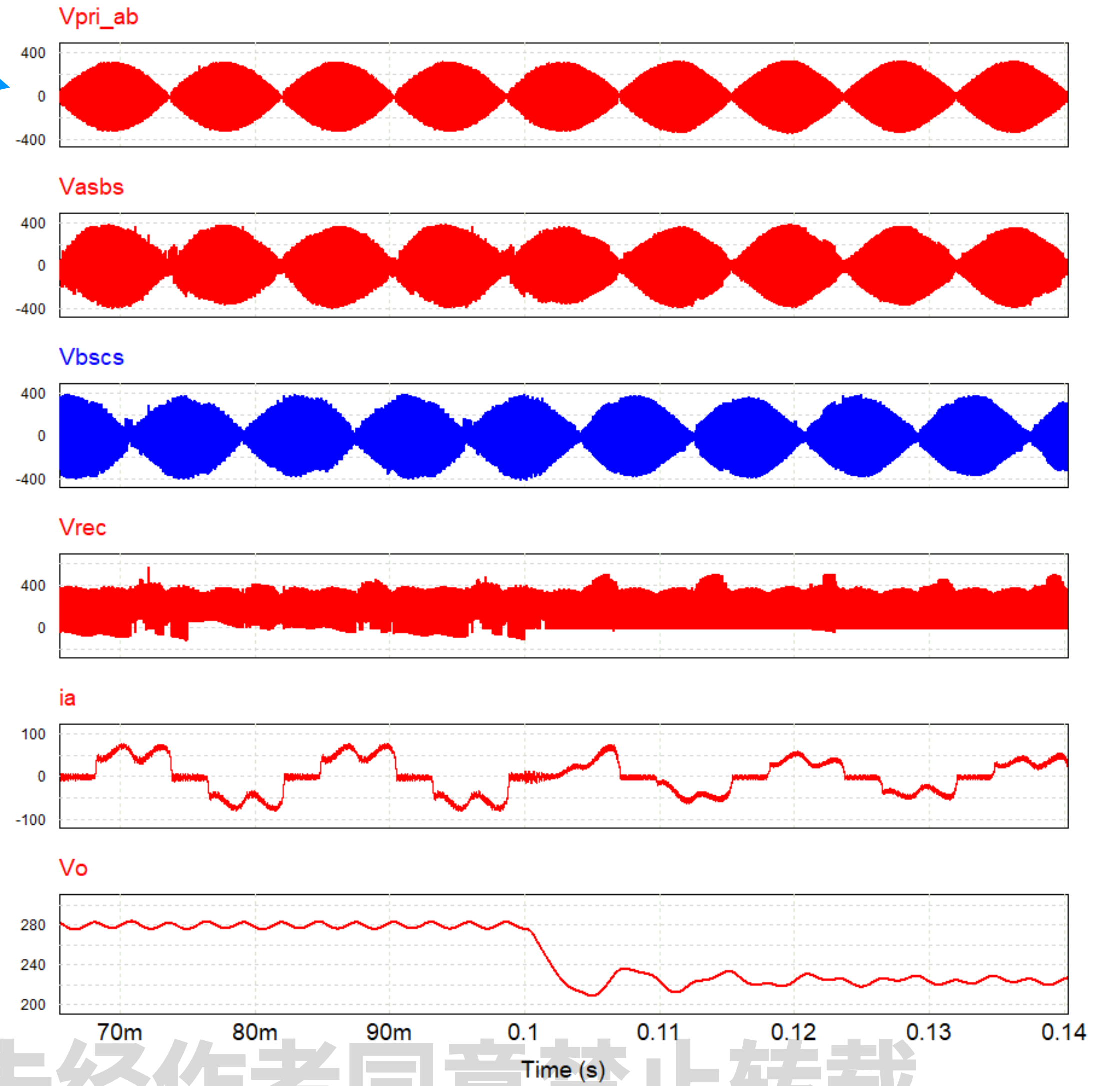
Integrated Solid State Transformer (I-SST)

Open Delta

20 kHz Operation







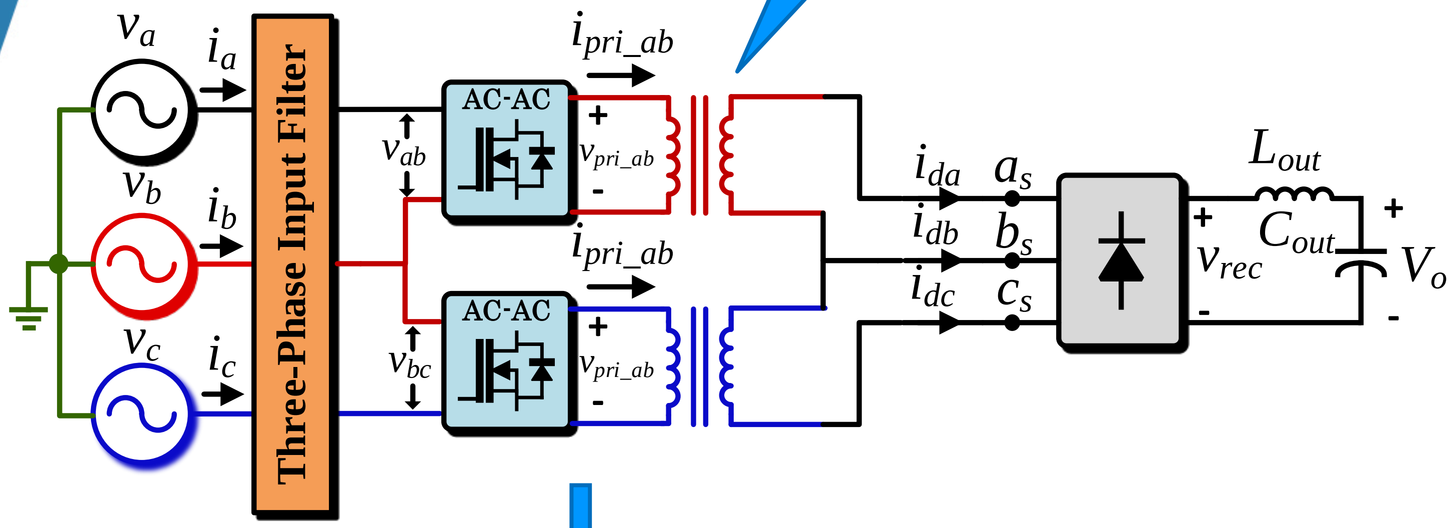
Input current quality is poor

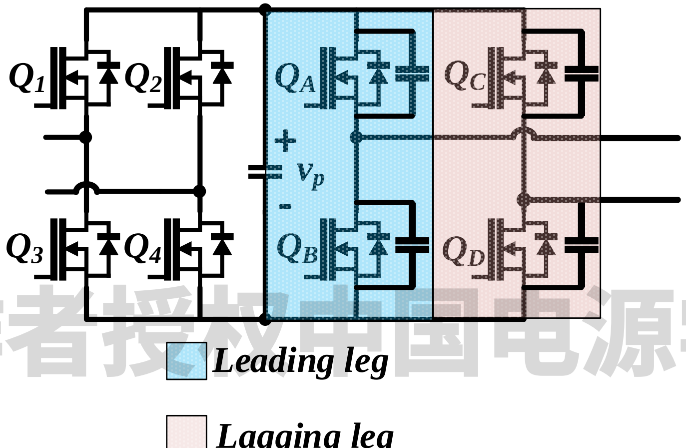
Integrated Solid State Transformer (I-SST)

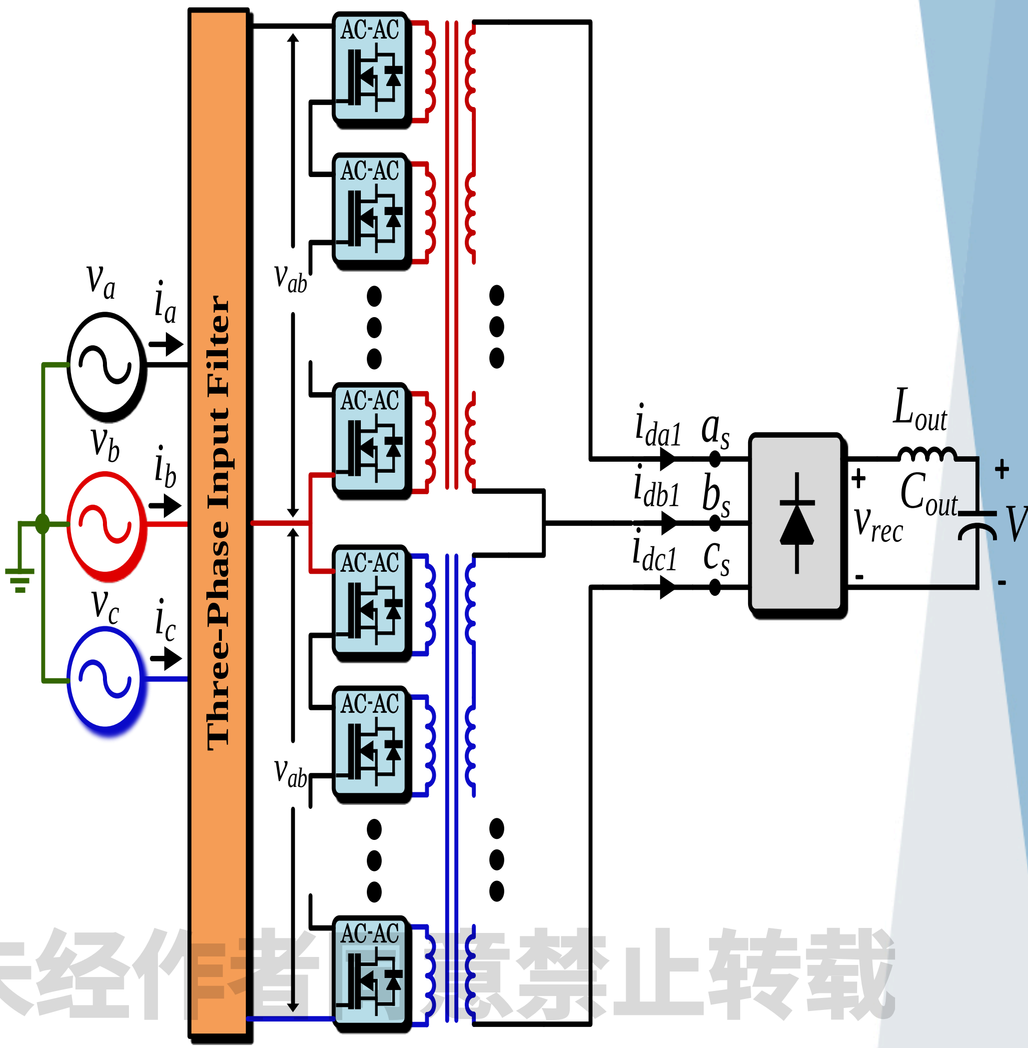
Open Delta

20 kHz Operation

Series Cascade for higher voltage

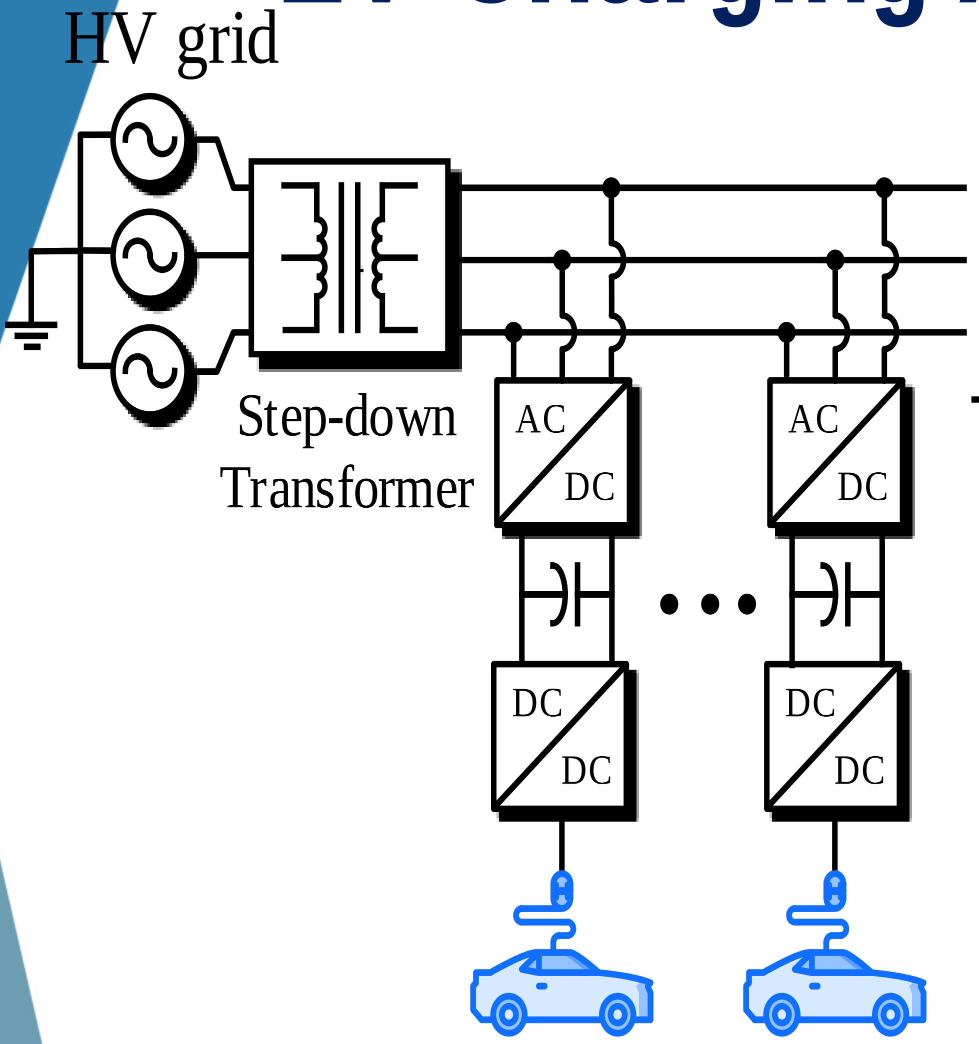


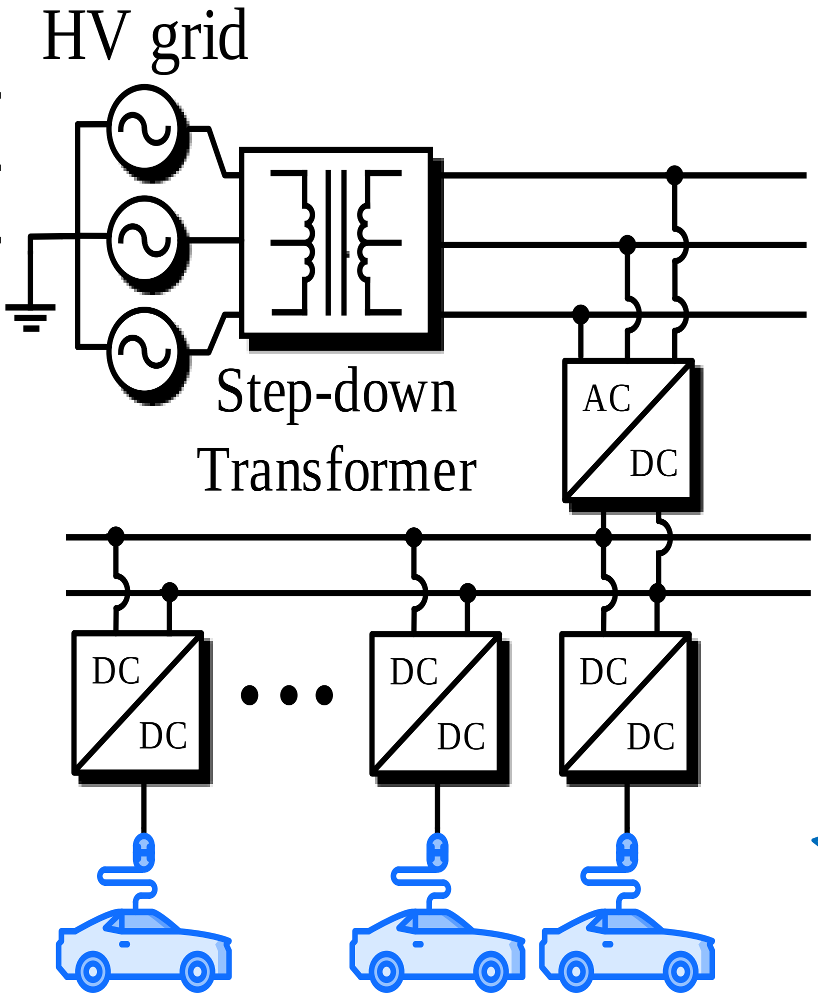




EV Charging Application with Integrated Solid State Transformer

EV Charging Application – with I-SST





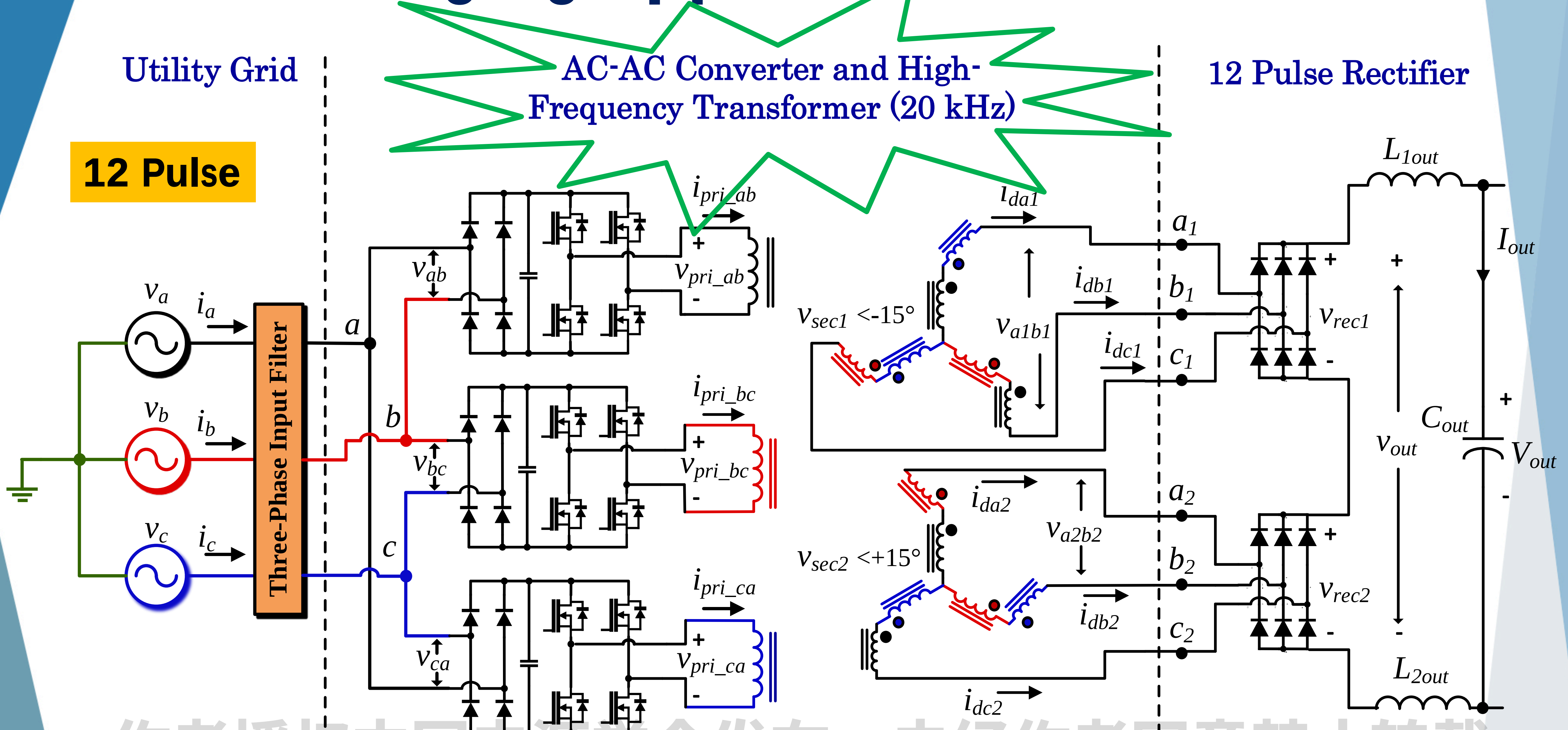
- Level-3 Chargers are rated > 50kW
- Both approaches use line frequency transformer which compromise the size of the Level-3 charging station

How can we improve the power density of the system?

- **AC bus architecture with step-down line frequency transformer [1],[2].**
- **DC bus architecture with line frequency transformer [2],[3].**

EV Charging Application – with I-SST

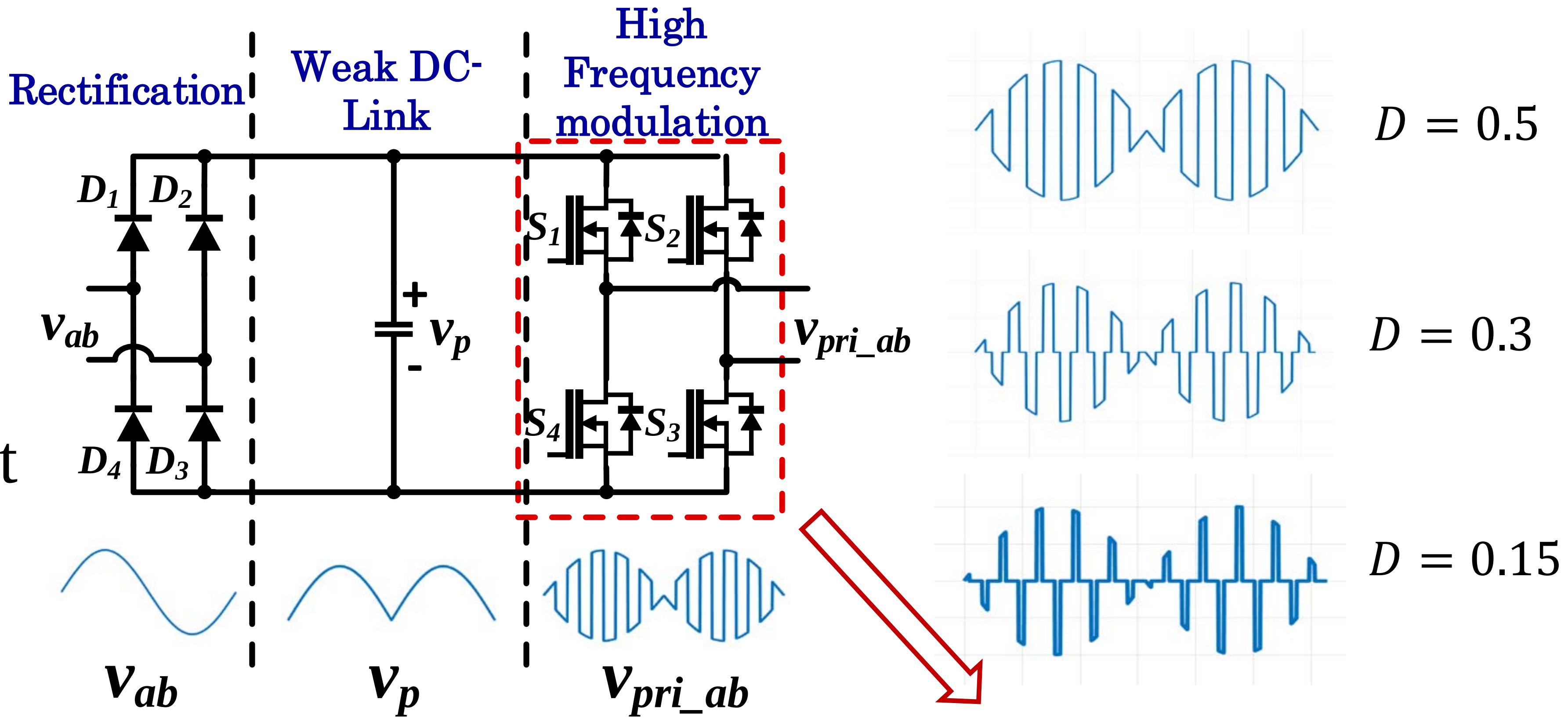
12 Pulse



EV Charging Application – with I-SST

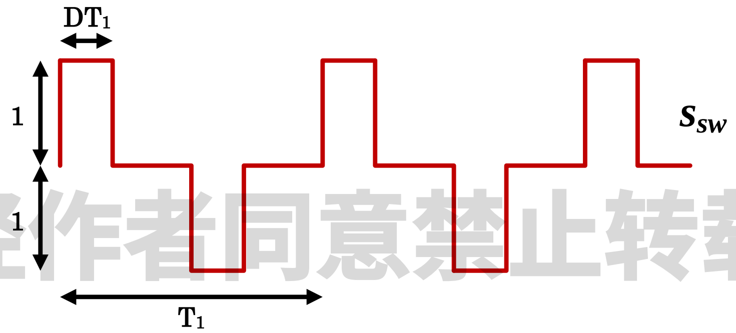
Operation Principle

- 50% duty cycle provides maximum AC link voltage.
- Change of Duty Cycle allows output voltage regulation.

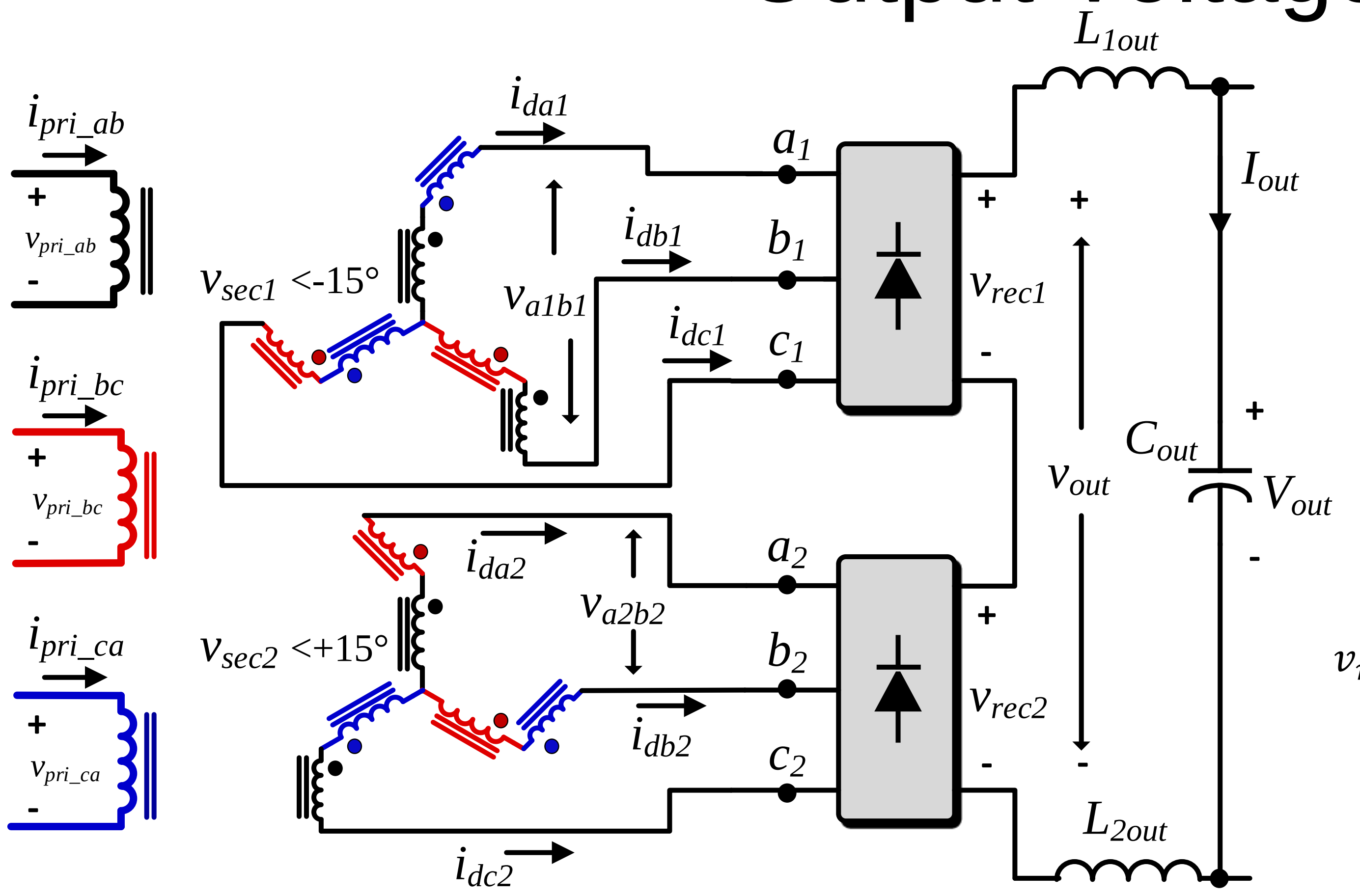


$$s_{sw} = \sum_{k=1}^{\infty} \frac{1}{k\pi}\left[\sin(2\pi kD) - \sin\left(2\pi k\left(\frac{1}{2}+D\right)\right)\right]\sin(k\omega_s t) + \cdots$$

$$\ldots + \frac{1}{2\pi k}\left(1 - \cos(2\pi kD) + \cos\left(k2\pi\left(\frac{1}{2}+D\right)\right) - \cos(k\pi)\right)\cos(k\omega_s t)$$



Output Voltage Analysis



$$s_d(\omega t) = \sum_{n=1,3,5,7\ldots}^{\infty} \left(\frac{4}{n\pi}\cos\left(\frac{n\pi}{6}\right)\right)\cdot \sin(n\omega t)$$

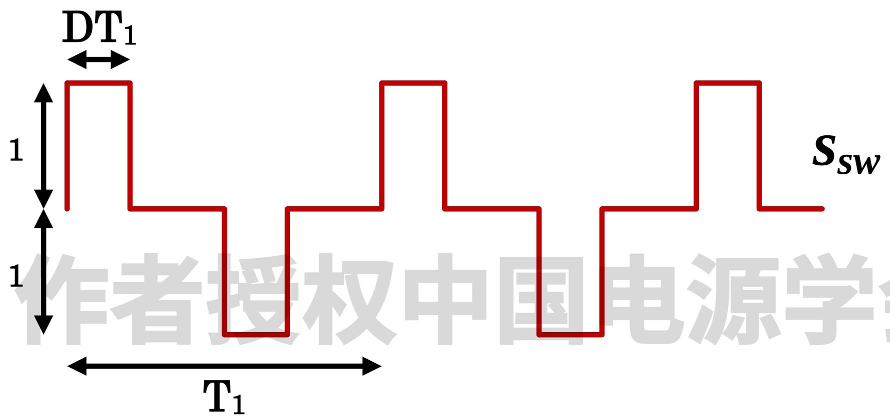
$$s_{dHF} = s_d(\omega t)\cdot s_{sw}$$

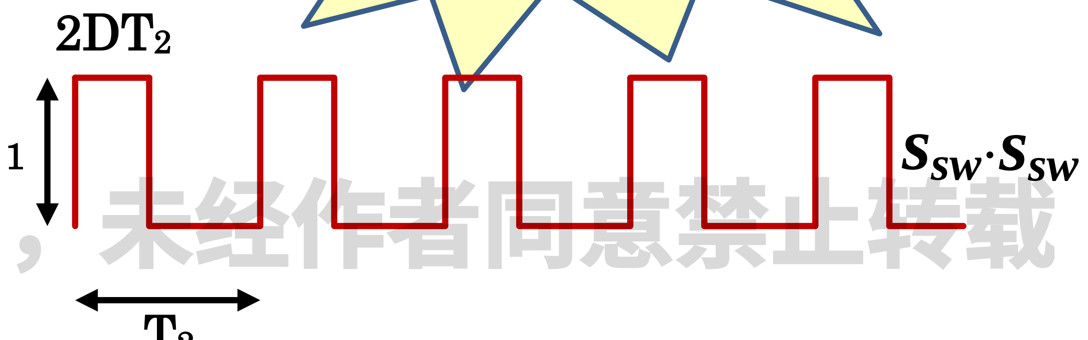
$$v_{a1} = \sqrt{2}V_{LL}\sin\left(\omega t - \frac{\pi}{12}\right)\cdot s_{sw}$$

$$v_{rec1}(\omega_s t) = v_{a1}s_{dHF} + v_{b1}s_{dHF} + v_{c1}s_{dHF}$$

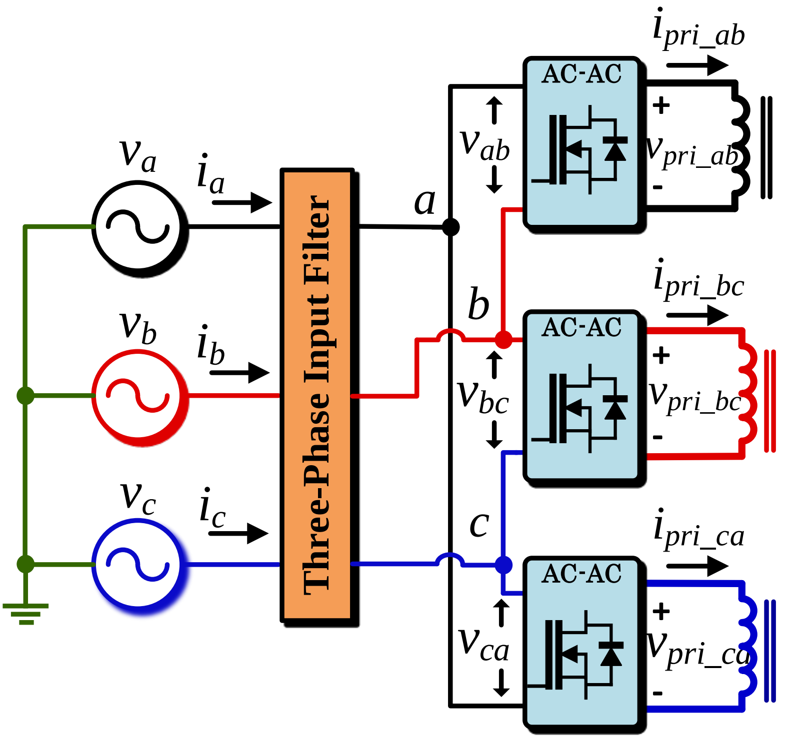
$$v_{rec1} = s_{sw}\cdot s_{sw}\cdot \frac{3\sqrt{2}}{\pi}V_{LL}\left[1 - \sum_{n=1}^{\infty}\frac{2}{36n^2-1}\cos(6n\omega t)\right]$$

$$V_{out} = \frac{12D\sqrt{2}}{\pi}V_{LL}$$

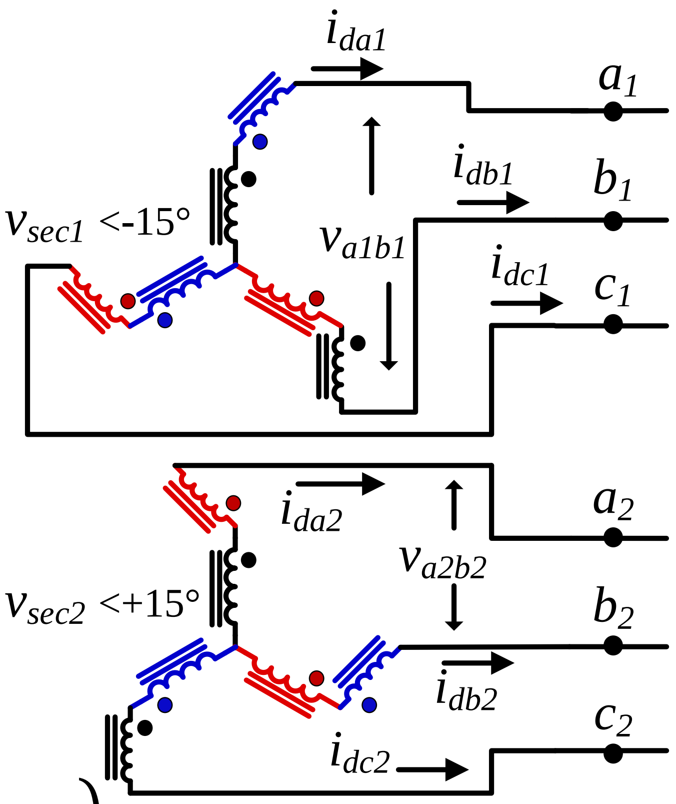




Input Current Analysis



$$i_{pri\_ab} = N_{s1}(i_{da1} + i_{da2}) - N_{s2}(i_{db2} + i_{dc2})$$



$$s_{di} = \sum_{n=1,3,5,7\ldots}^{\infty} \left(\frac{4I_{out}}{n\pi} \cos\left(\frac{n\pi}{6}\right) \right) \sin(n\omega t)$$

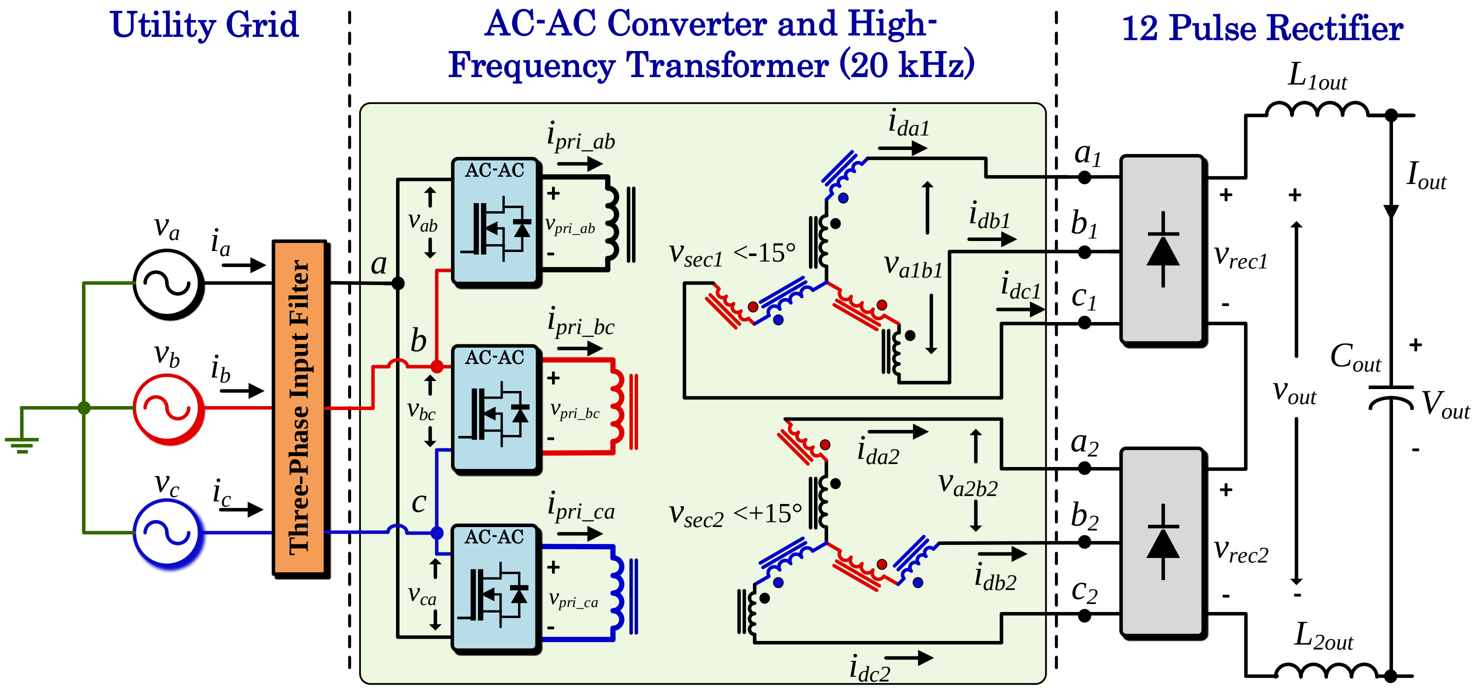
$$i_a = s_{sw} \cdot i_{pri\_ab}$$

$$i_a = s_{sw} \cdot s_{sw} \cdot \frac{4\sqrt{3}I_{out}}{\pi} \left\{ \begin{aligned} &\sin(\omega t) + \frac{1}{11}\sin(11\omega t) + \frac{1}{13}\sin(13\omega t) \\ &+ \frac{1}{23}\sin(23\omega t) + \frac{1}{25}\sin(25\omega t) + \cdots \end{aligned} \right\}$$

Harmonics generated by S_{sw} do not affect input current quality because they are at high frequencies!

Design Example

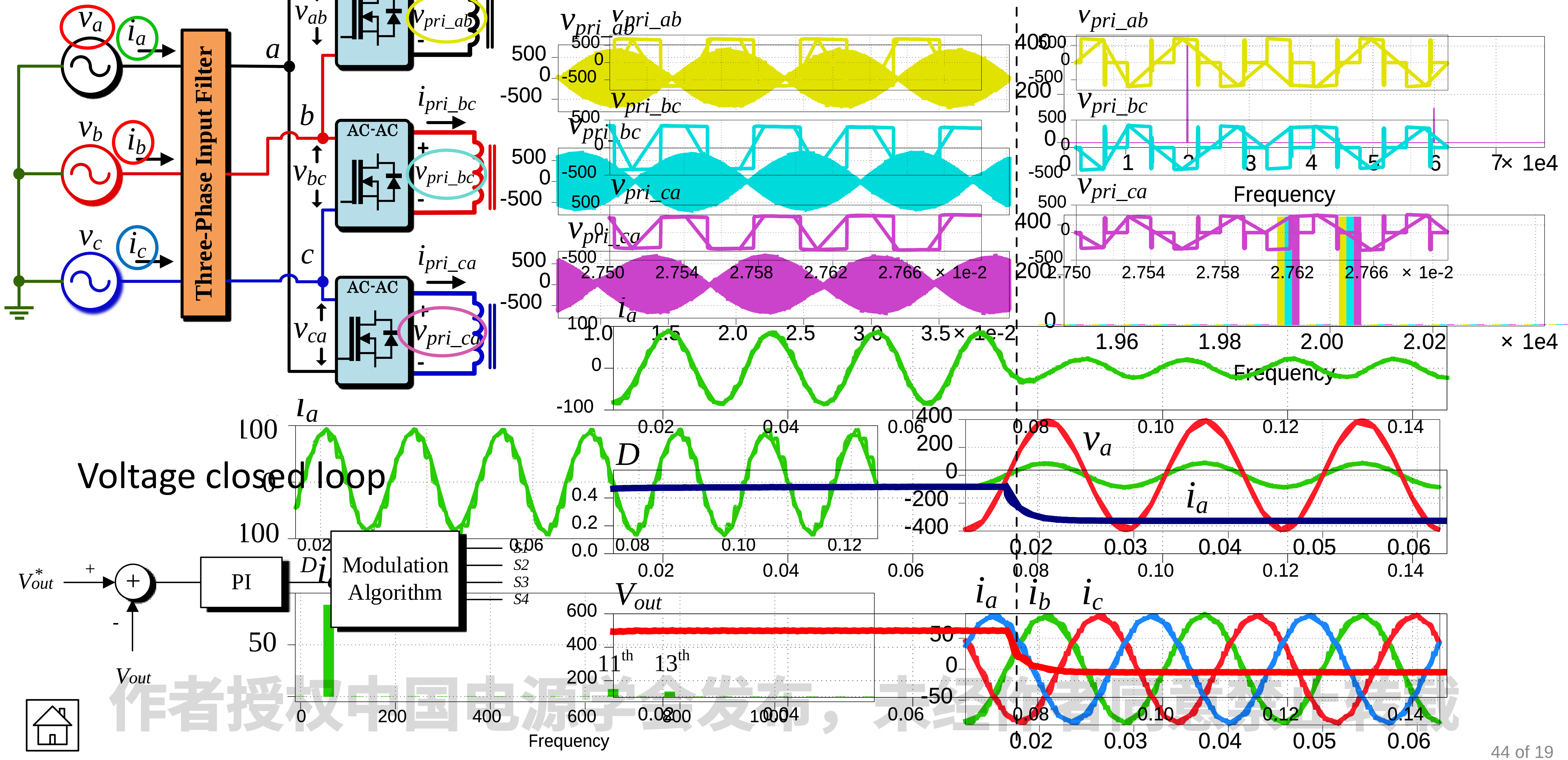
Operating conditions used for simulation in PLECS	
Grid voltage (line-to-line rms)	480 V rms
Grid frequency	60Hz
Output dc voltage	500 V
Rated power	50 kW
Switching Frequency	20kHz
Input Inductor	25 μH
Output Inductor	1 mH
Output Capacitor	200 μF
Transformer K_t	0.44



Transformer's Gain

$$K_t = \frac{\pi \cdot V_{out}}{6\sqrt{2}V_{LL}}$$

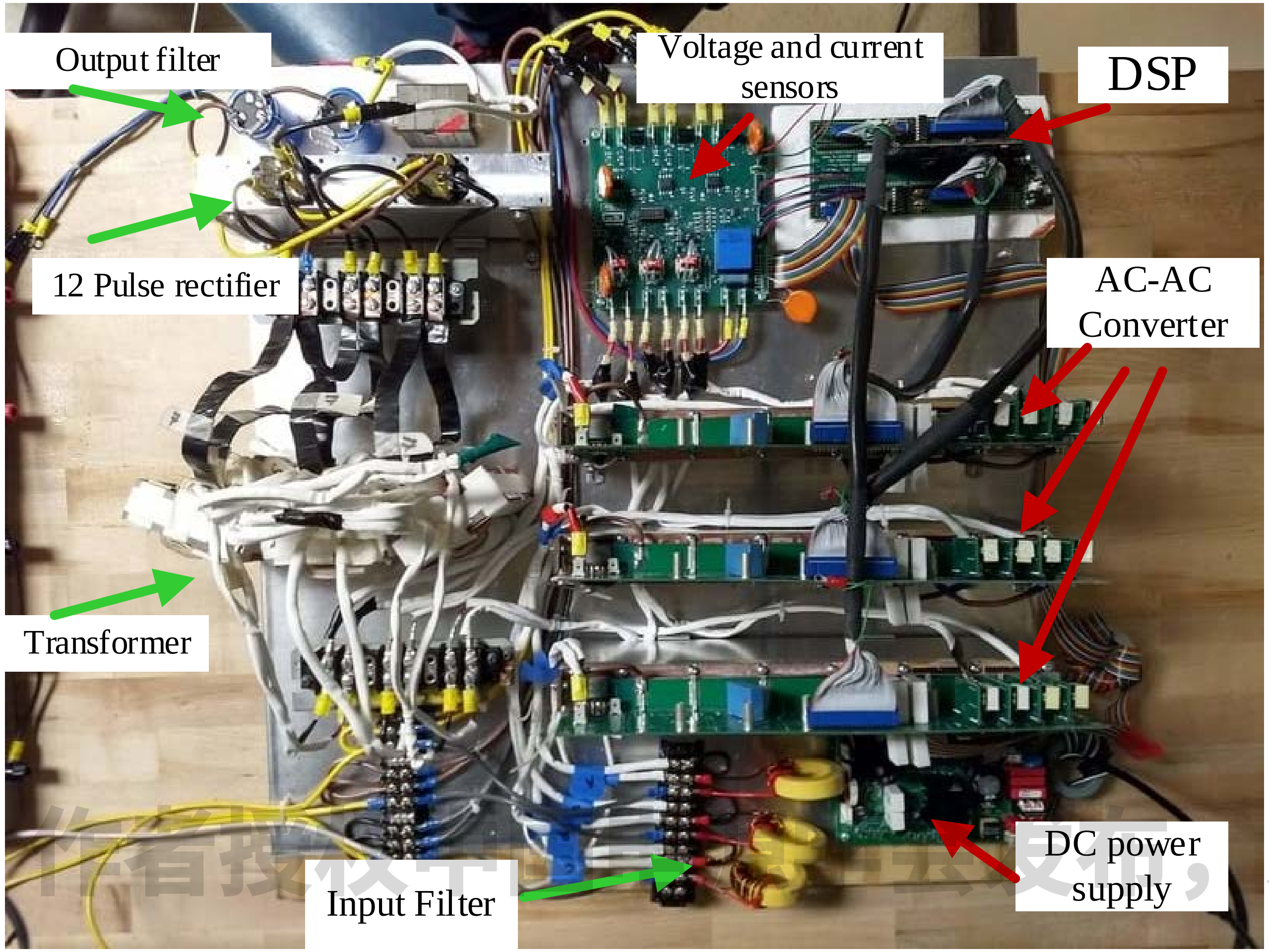
Simulation Results



Voltage closed loop

Experimental Prototype

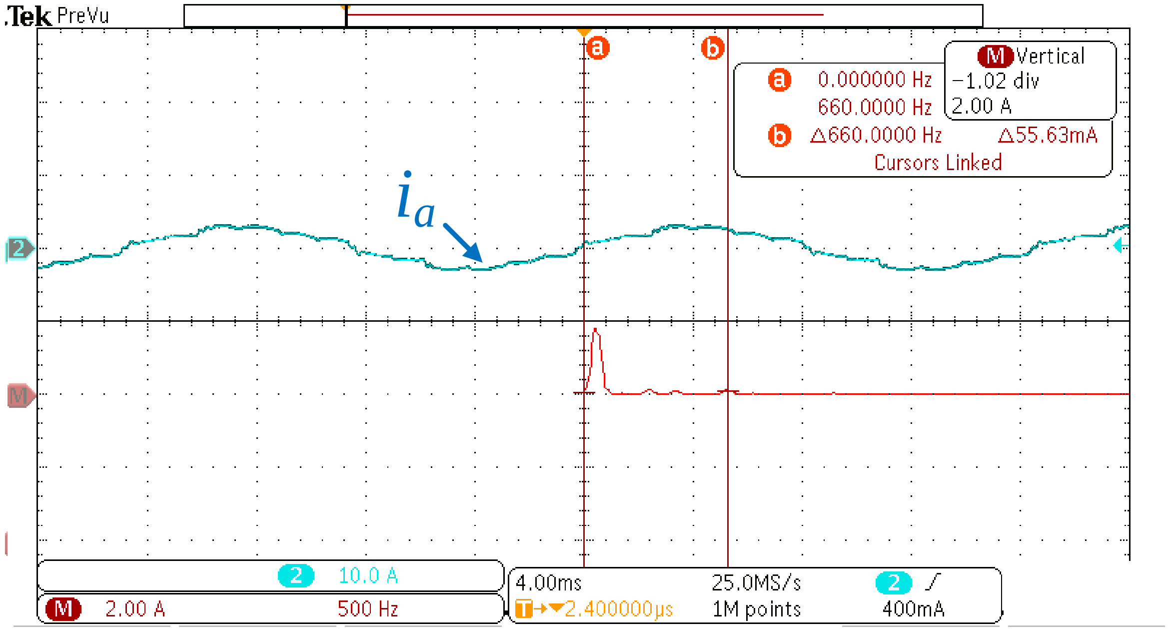
- 2 kW experimental layout.
- 208 VLL RMS
- 500 V DC output
- 20 kHz switching frequency

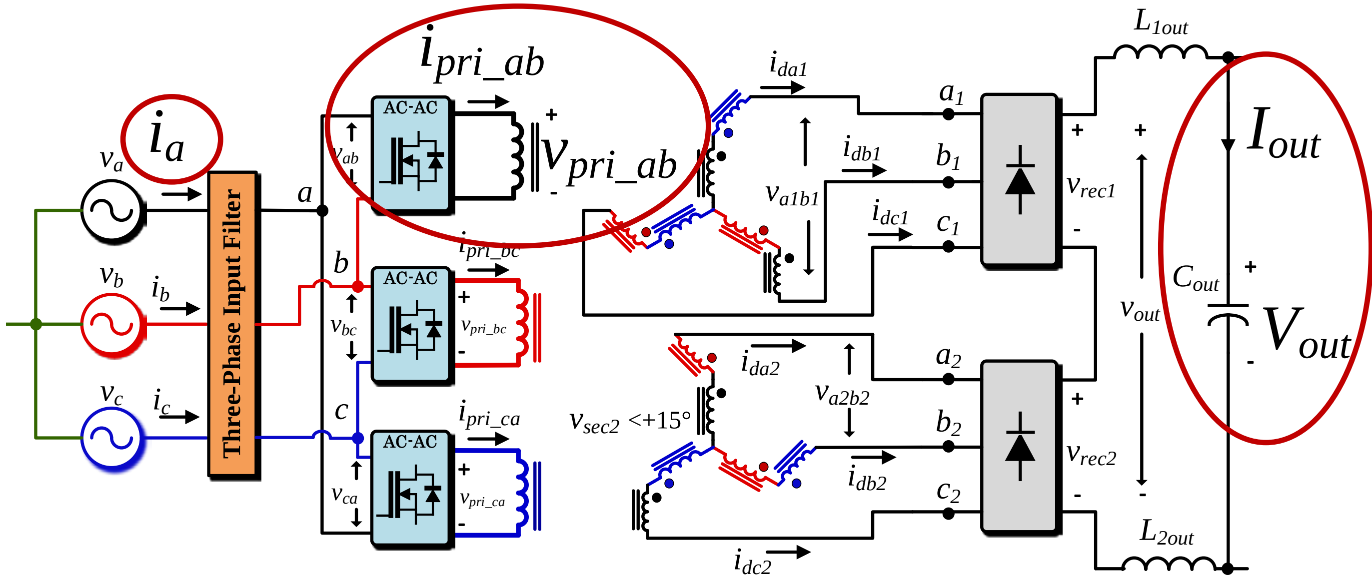


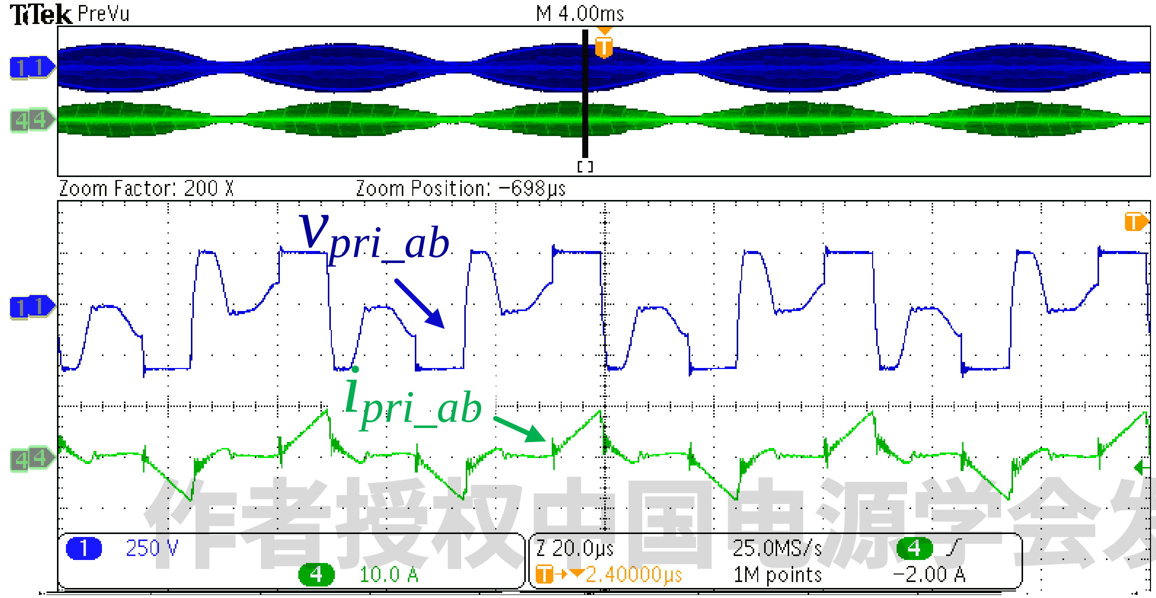
- 20 kHz, 10 kW Ferrite core transformer.
- 3 independent cores. 14 x 5 x 3 cm.

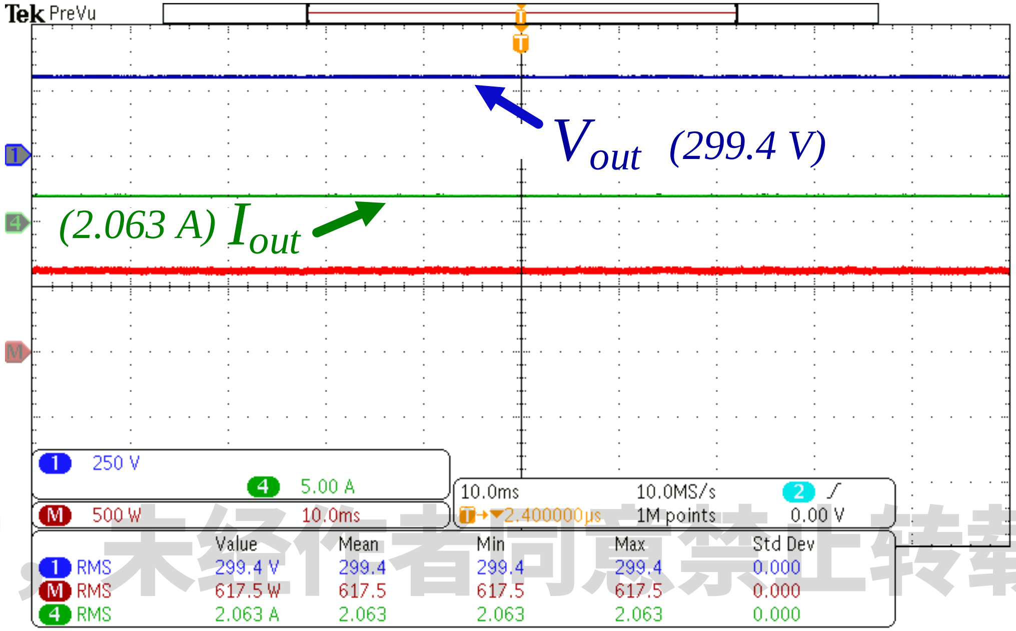
Experimental Results

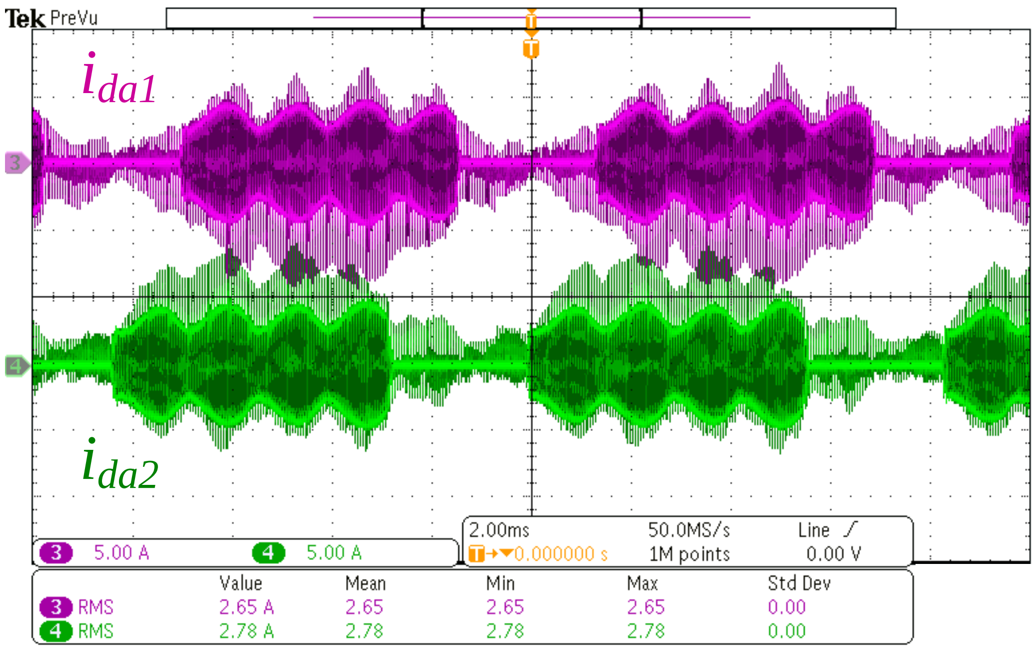
D=0.35

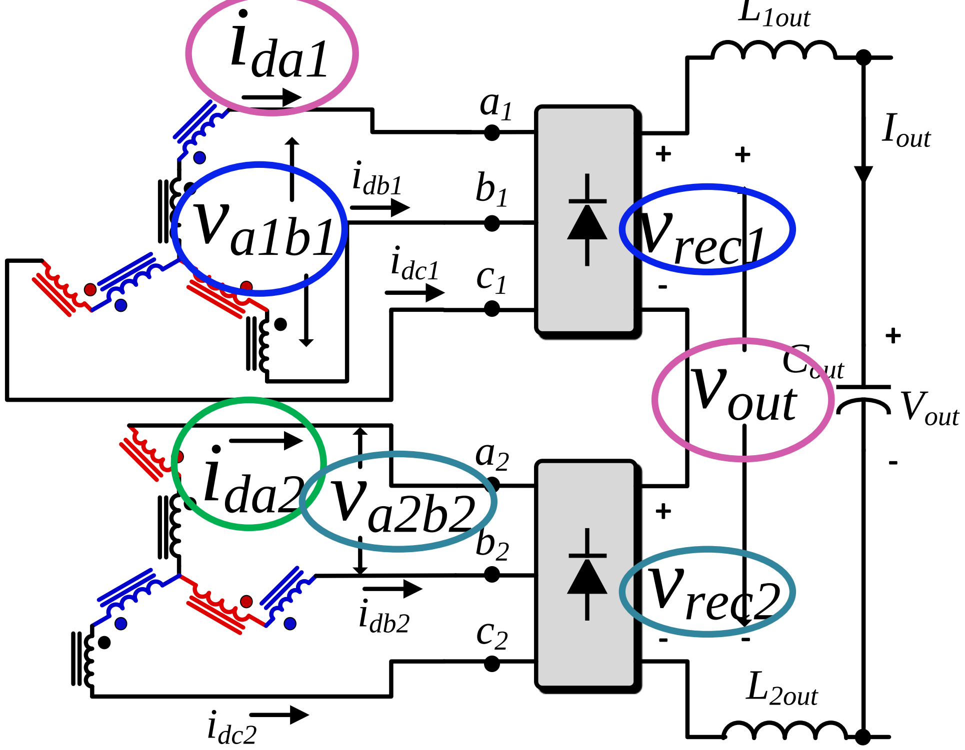


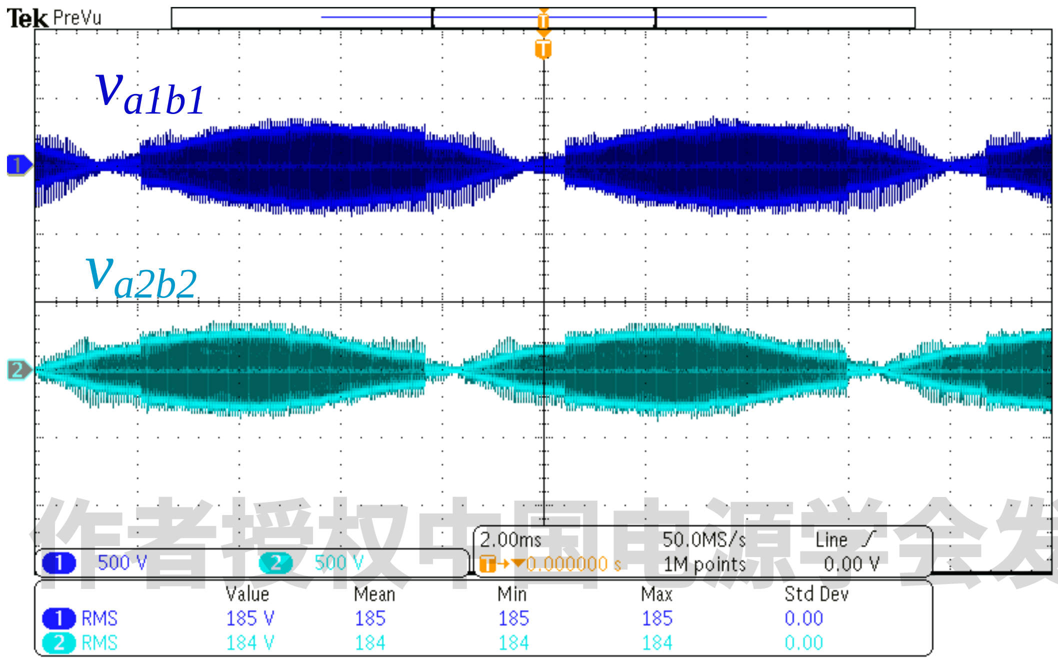


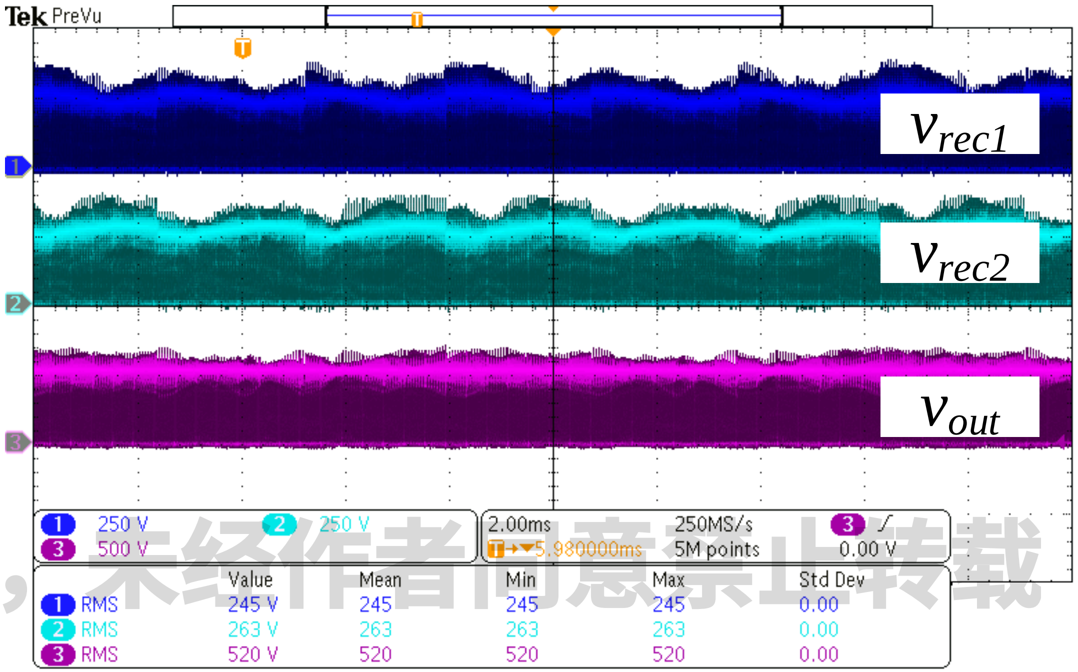





Tek PreVu
i_{da1}
i_{da2}
3 5.00 A
4 5.00 A
2.00ms 50.0MS/s Line
0.000000 s 1M points 0.00 V
Value Mean Min Max Std Dev
3 RMS 2.65 A 2.65 2.65 2.65 0.00
4 RMS 2.78 A 2.78 2.78 2.78 0.00

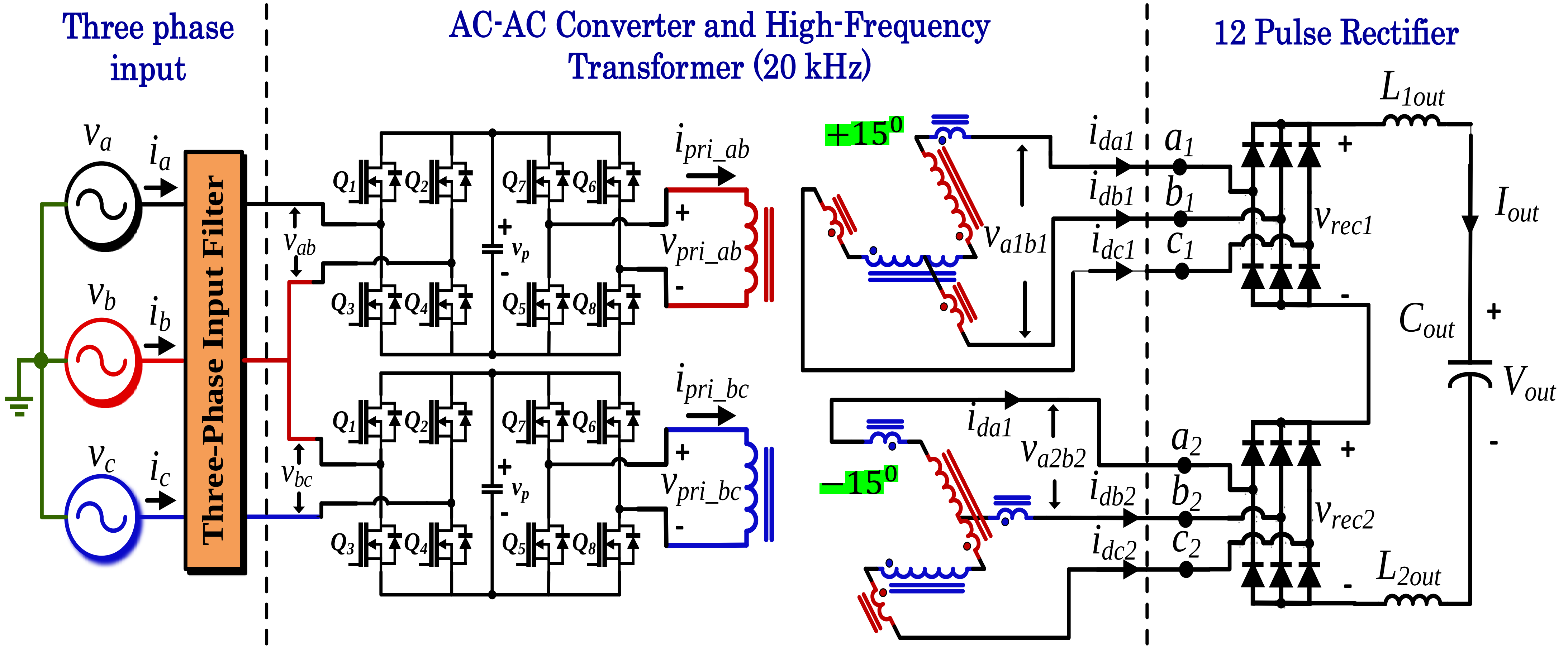

i_{da1}
L_{1out}
a_1
I_{out}
i_{db1}
b_1
v_{a1b1}
v_{rec1}
i_{dc1}
c_1
v_{out}
C_{out}
V_{out}
i_{da2}
v_{a2b2}
a_2
b_2
v_{rec2}
i_{db2}
c_2
L_{2out}
i_{dc2}


Tek PreVu
v_{a1b1}
v_{a2b2}
1 500 V
2 500 V
2.00ms 50.0MS/s Line
0.000000 s 1M points 0.00 V
Value Mean Min Max Std Dev
1 RMS 185 V 185 185 185 0.00
2 RMS 184 V 184 184 184 0.00


Tek PreVu
v_{rec1}
v_{rec2}
v_{out}
1 250 V
2 250 V
3 500 V
2.00ms 250MS/s
5.980000ms 5M points 0.00 V
Value Mean Min Max Std Dev
1 RMS 245 V 245 245 245 0.00
2 RMS 263 V 263 263 263 0.00
3 RMS 520 V 520 520 520 0.00

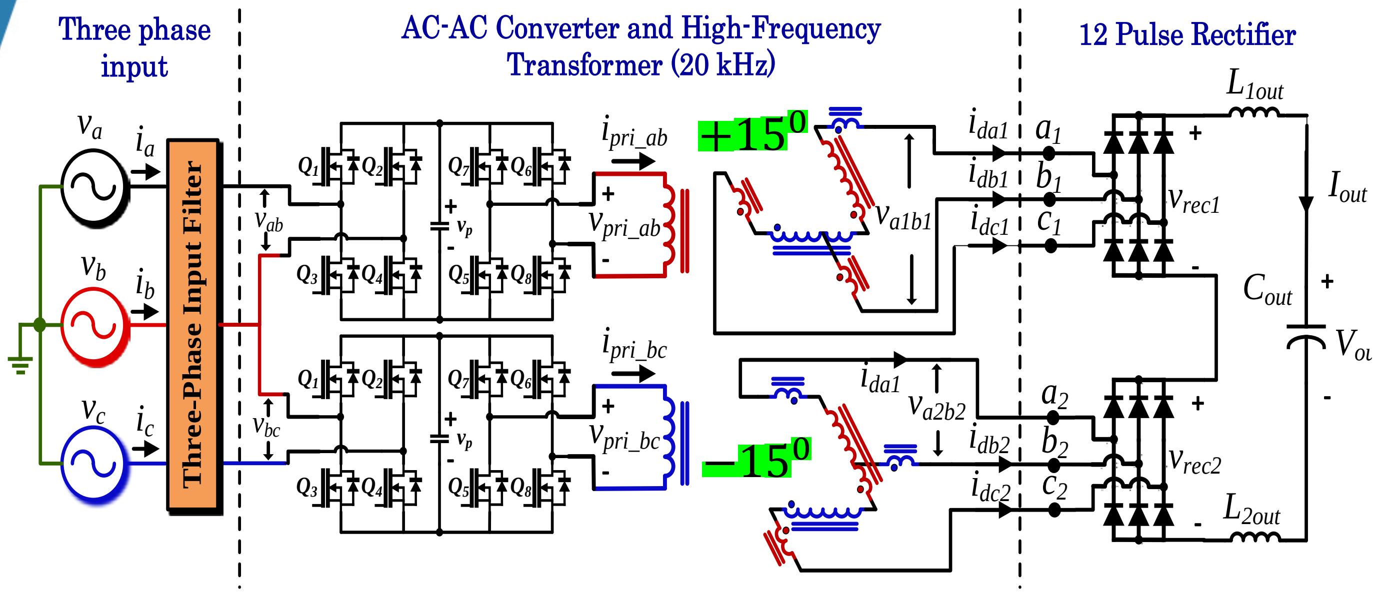
EV Charging Application – with I-SST

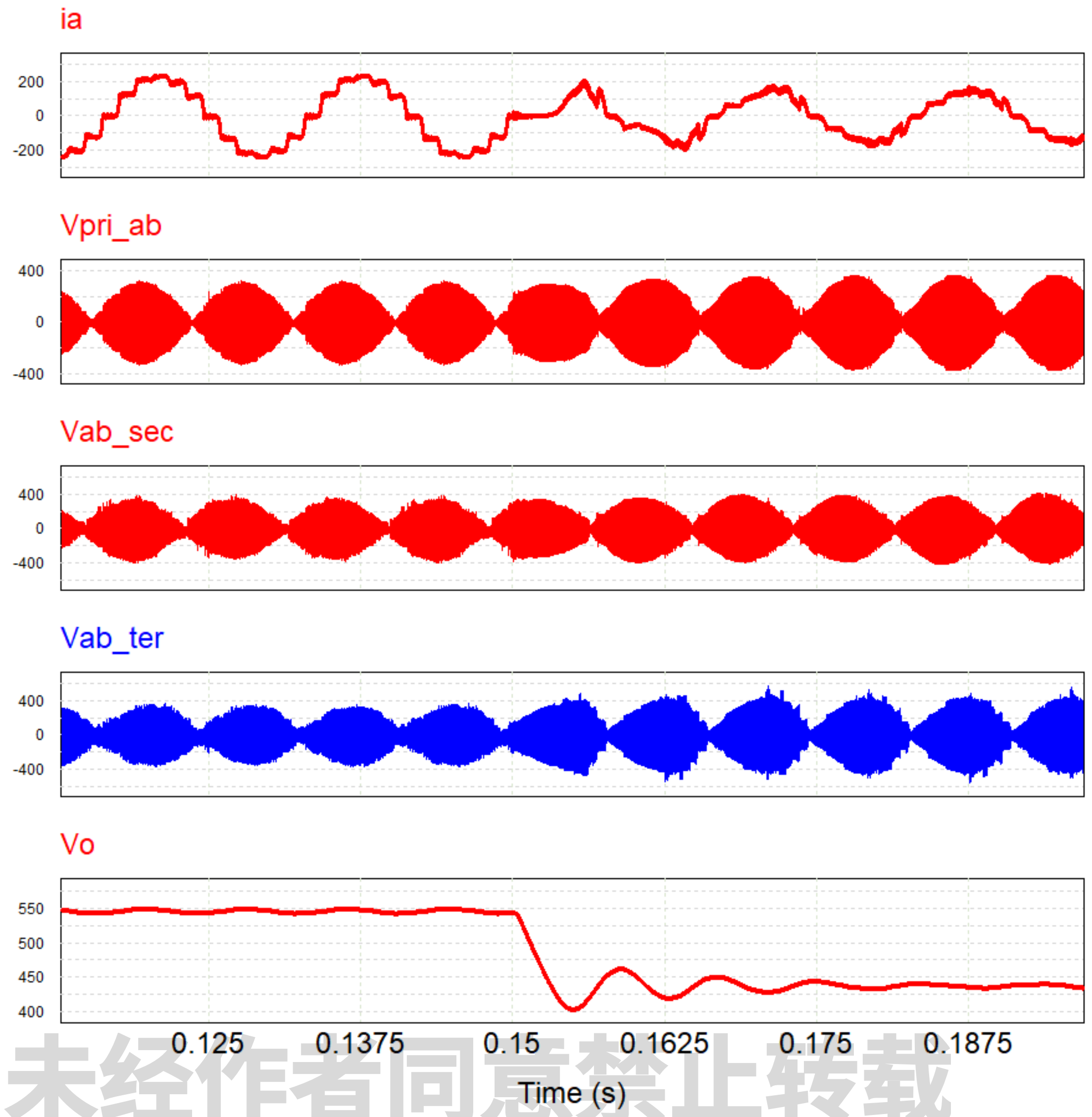
Open Delta 12 pulse



EV Charging Application – with I-SST

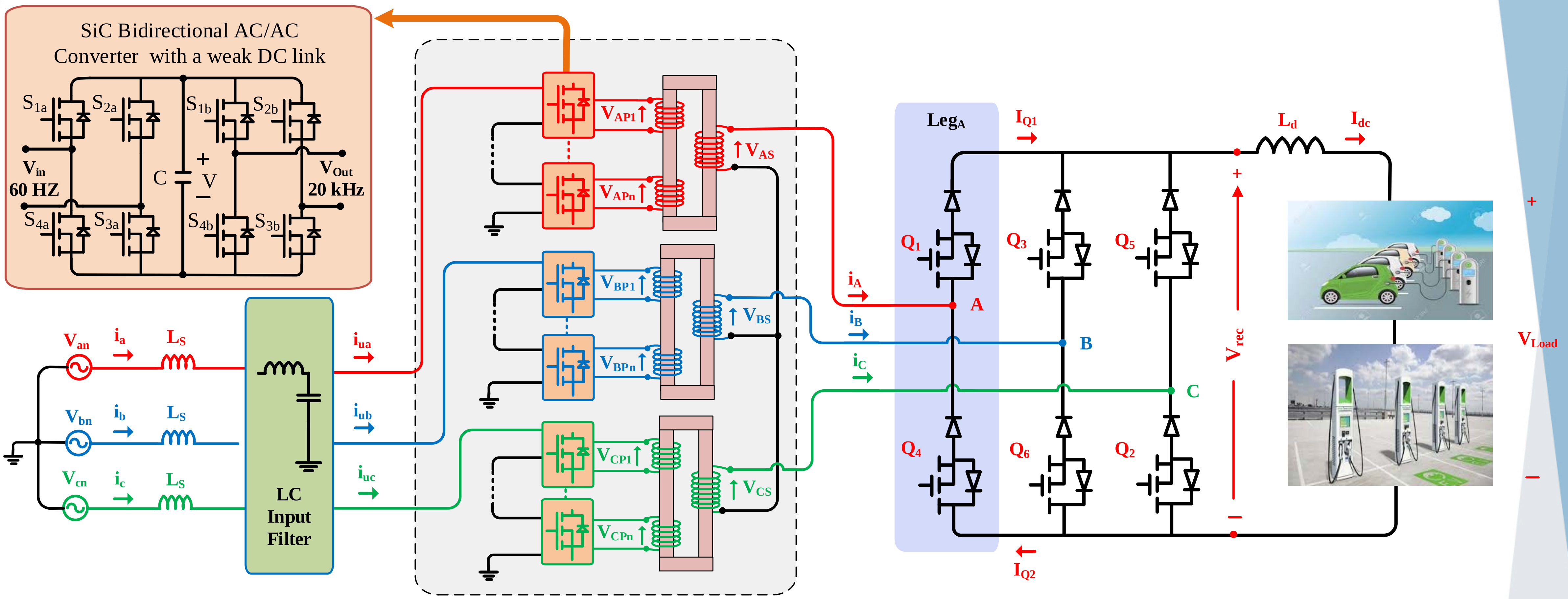
Open Delta 12 pulse





Input current quality is high

EV Charging Application – with I-SST



Medium Voltage

Input Filter

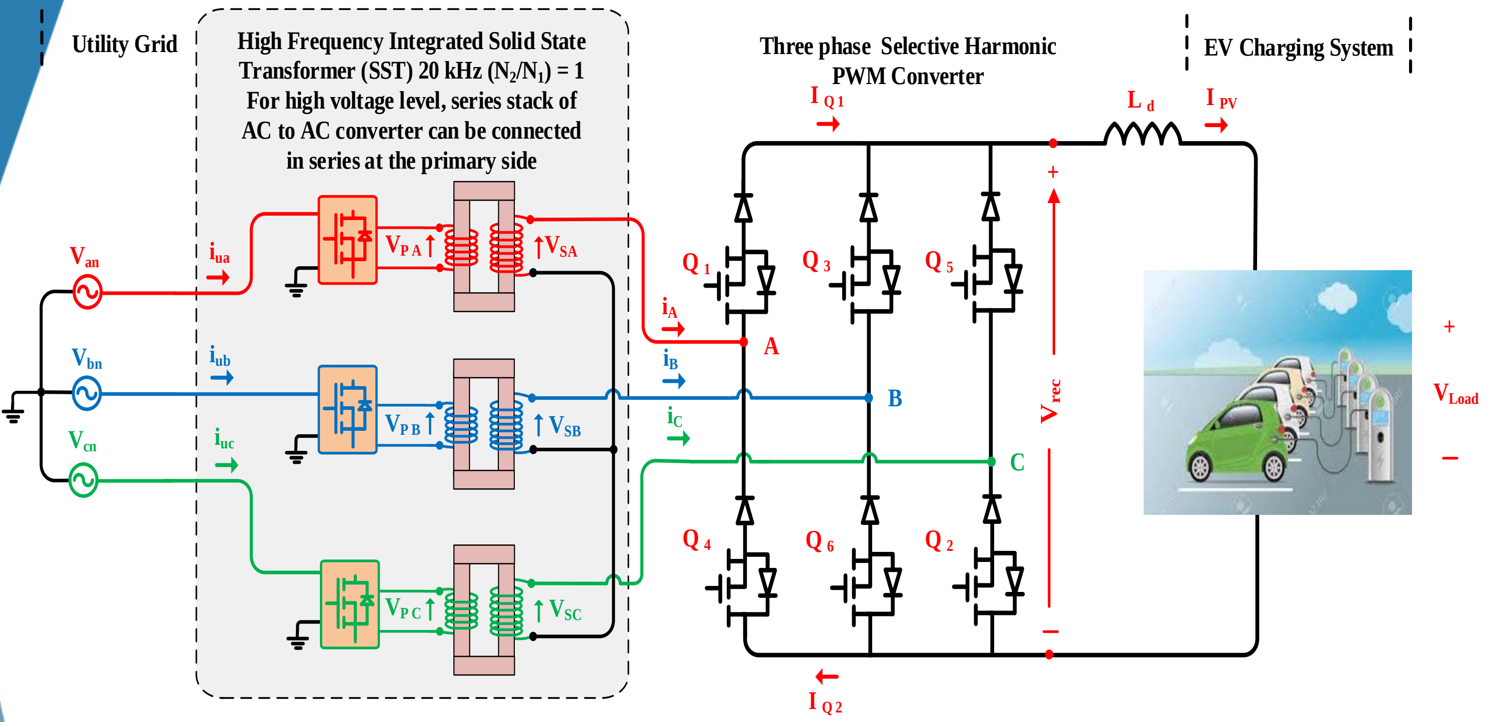
High Frequency Integrated Solid State Transformer (SST) 20 kHz (N_2/N_1) = 1
For high voltage level, series stack of AC to AC converter can be connected in series at the primary side

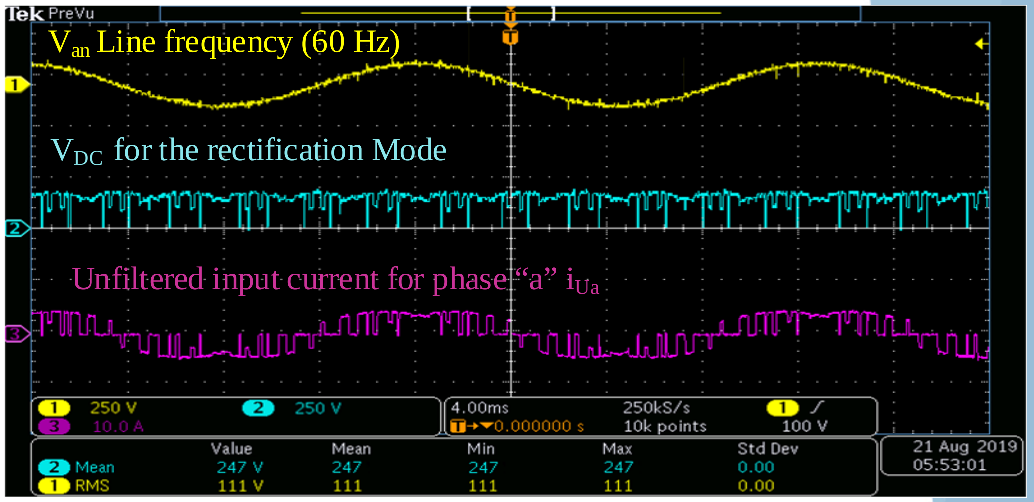
Three phase Selective Harmonic PWM Converter

EV Charging System

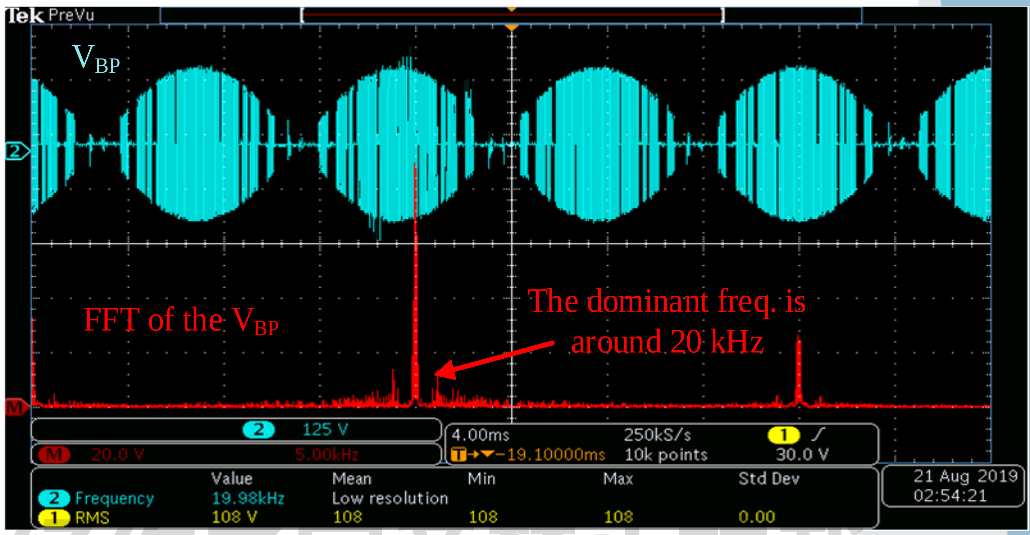
➢ **HF Isolation ; ZVS operation of I-SST ; Scale to high power with WBG technology**

EV Charging Application – with I-SST





Input voltage ; Output voltage and Input current

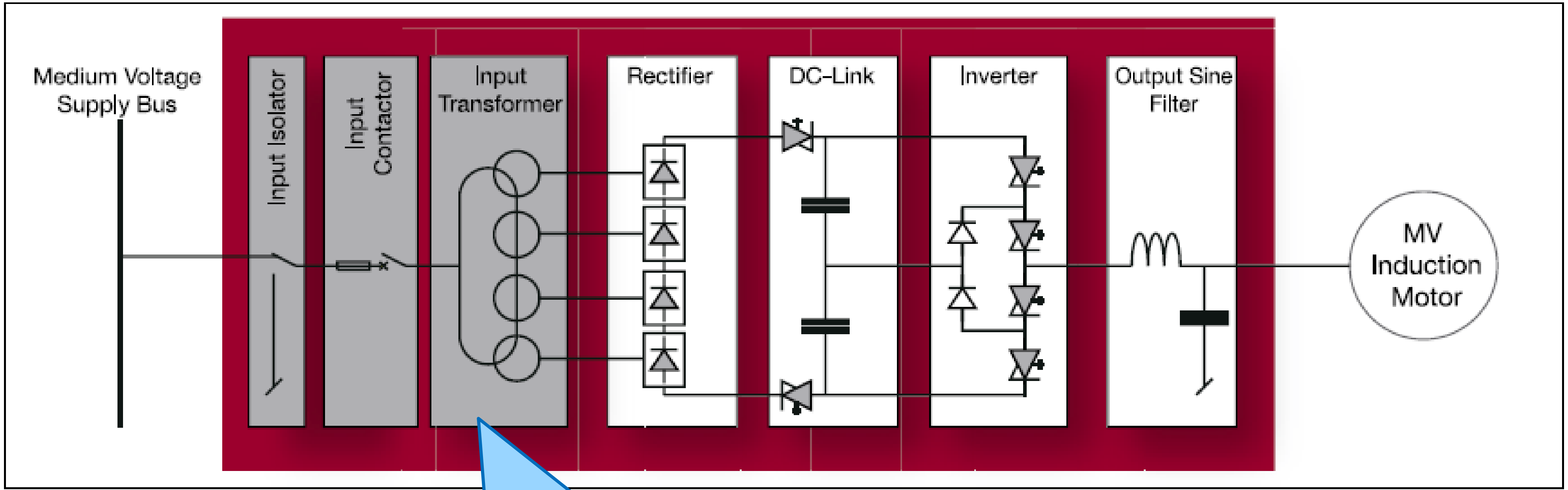


Frequency spectrum for the transformer voltage V_{BP}, The dominant frequency is around (20 kHz)

➢ **HF Isolation ; ZVS operation of I-SST ; Scale to high power with WBG technology**

Adjustable Speed Drive Systems with Integrated Solid State Transformer

MV Adjustable Speed Drive – with I-SST

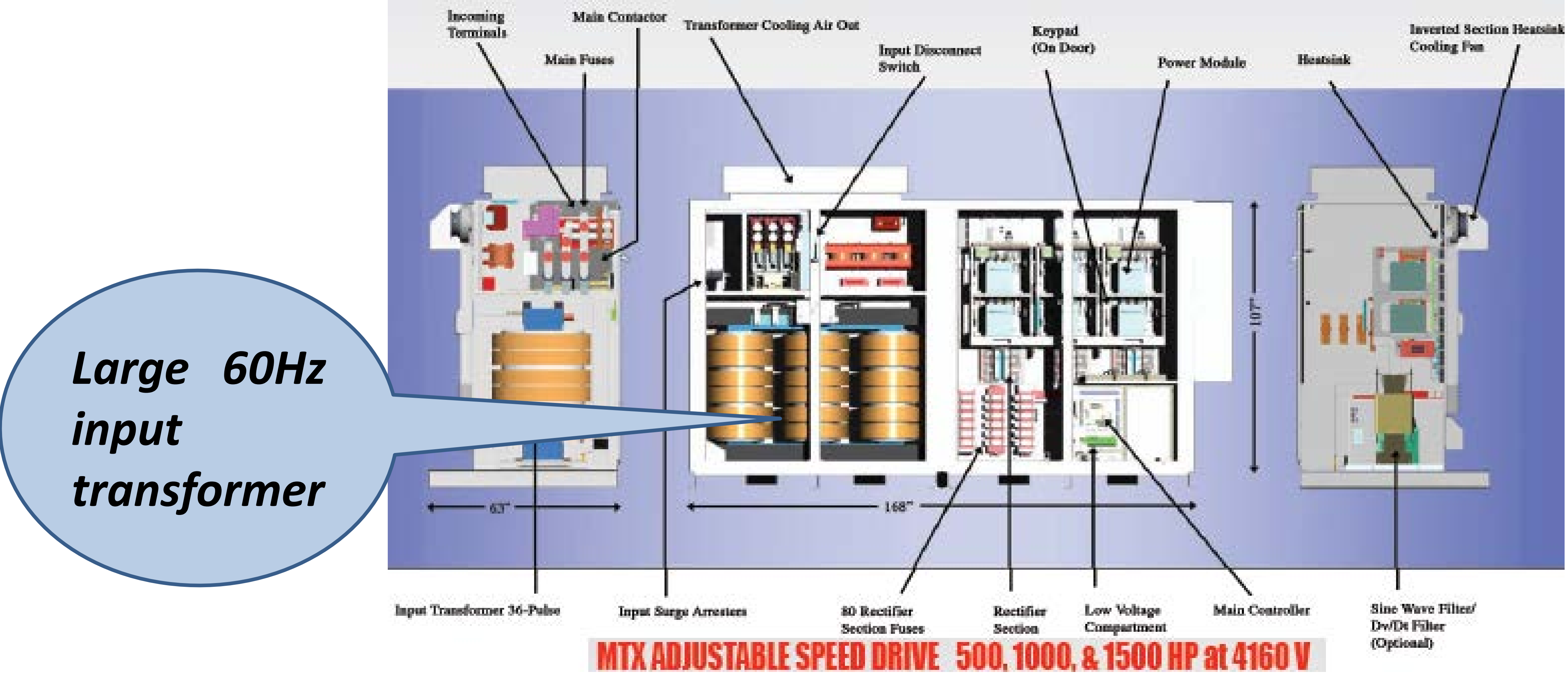


Typical ACS 1000i diagram

Large 60Hz input transformer

- **MV-ASD system (ABB) with 24-pulse diode bridge rectifier configuration and 3-level, 3-phase NPC inverter**

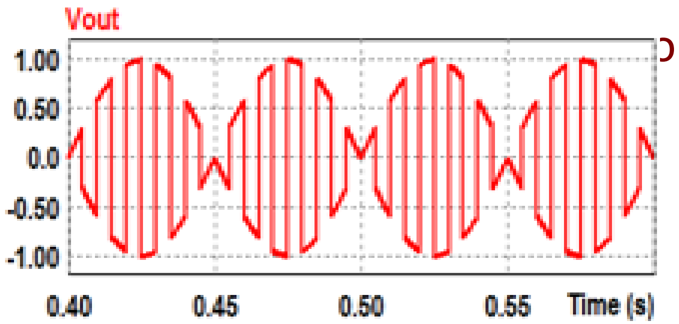
Major Factors Influencing Power Density:



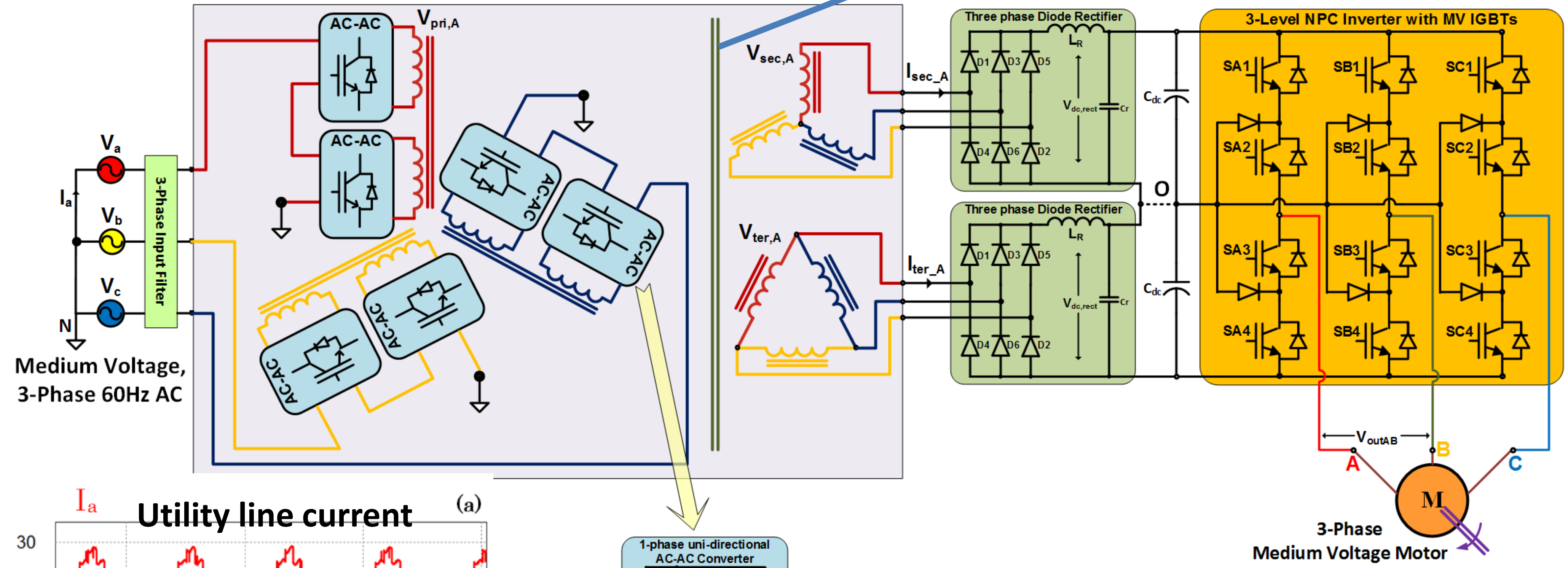
- EMI Filter (~ 2.5 L); DC-Link Capacitors (~ 0.5 L); Heat Sink (~ 0.5 L)

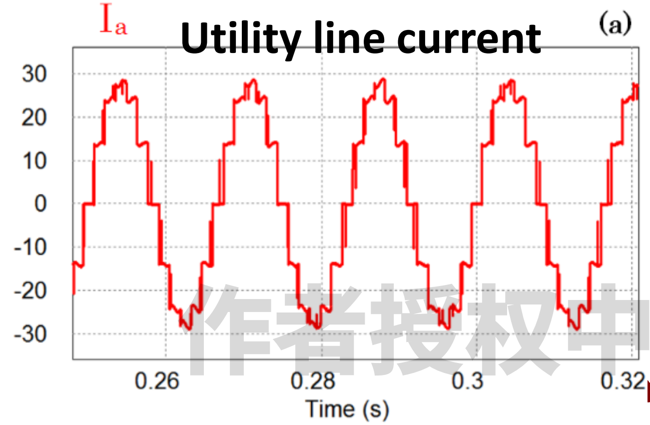
Transformer (~ 14 L) > 70%

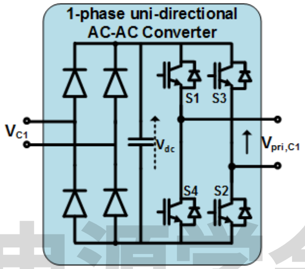
Proposed Medium Frequency Transformer for ASDs



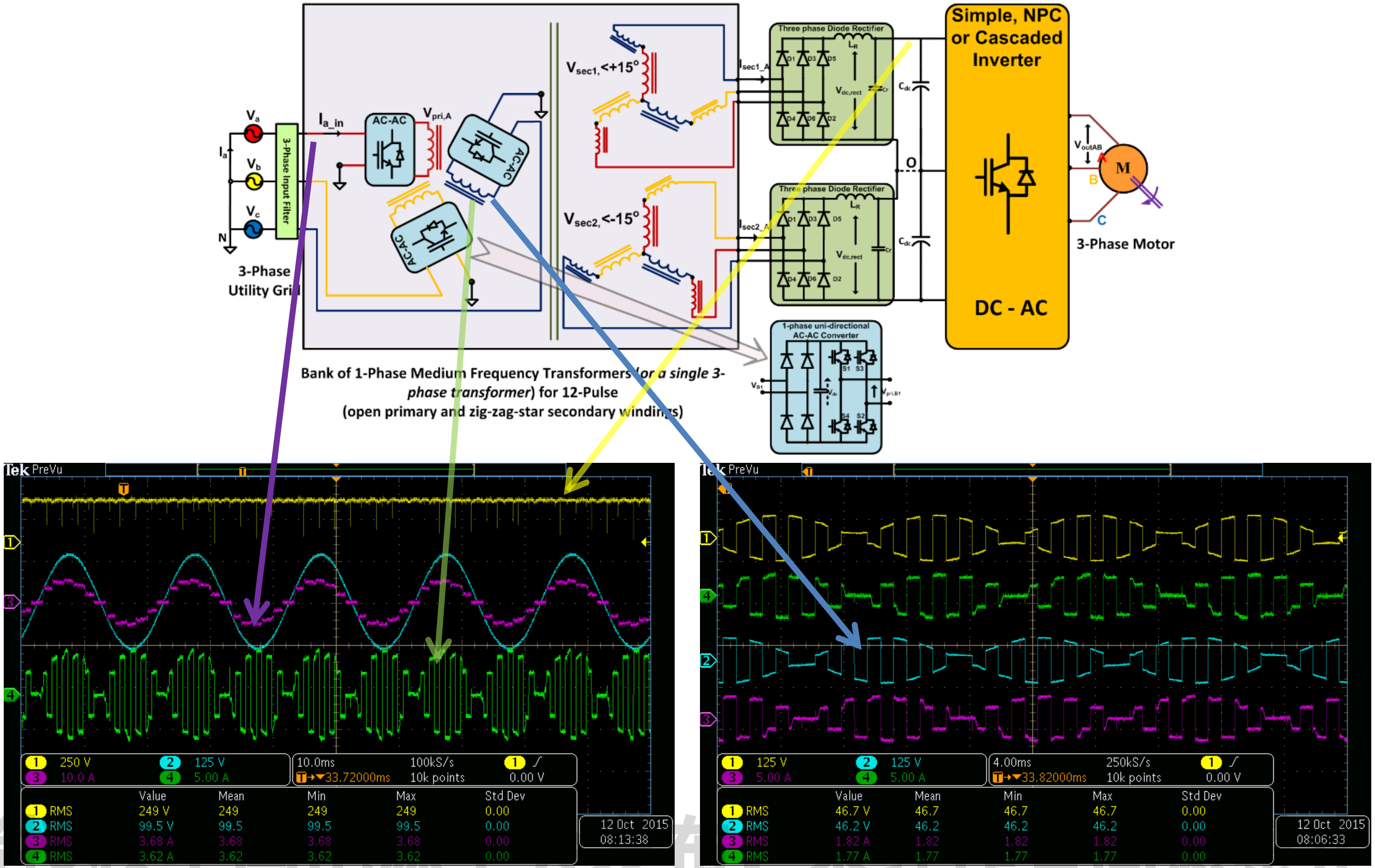
3-Phase Medium / High Frequency SST
(2- winding primary & 2 secondary windings)



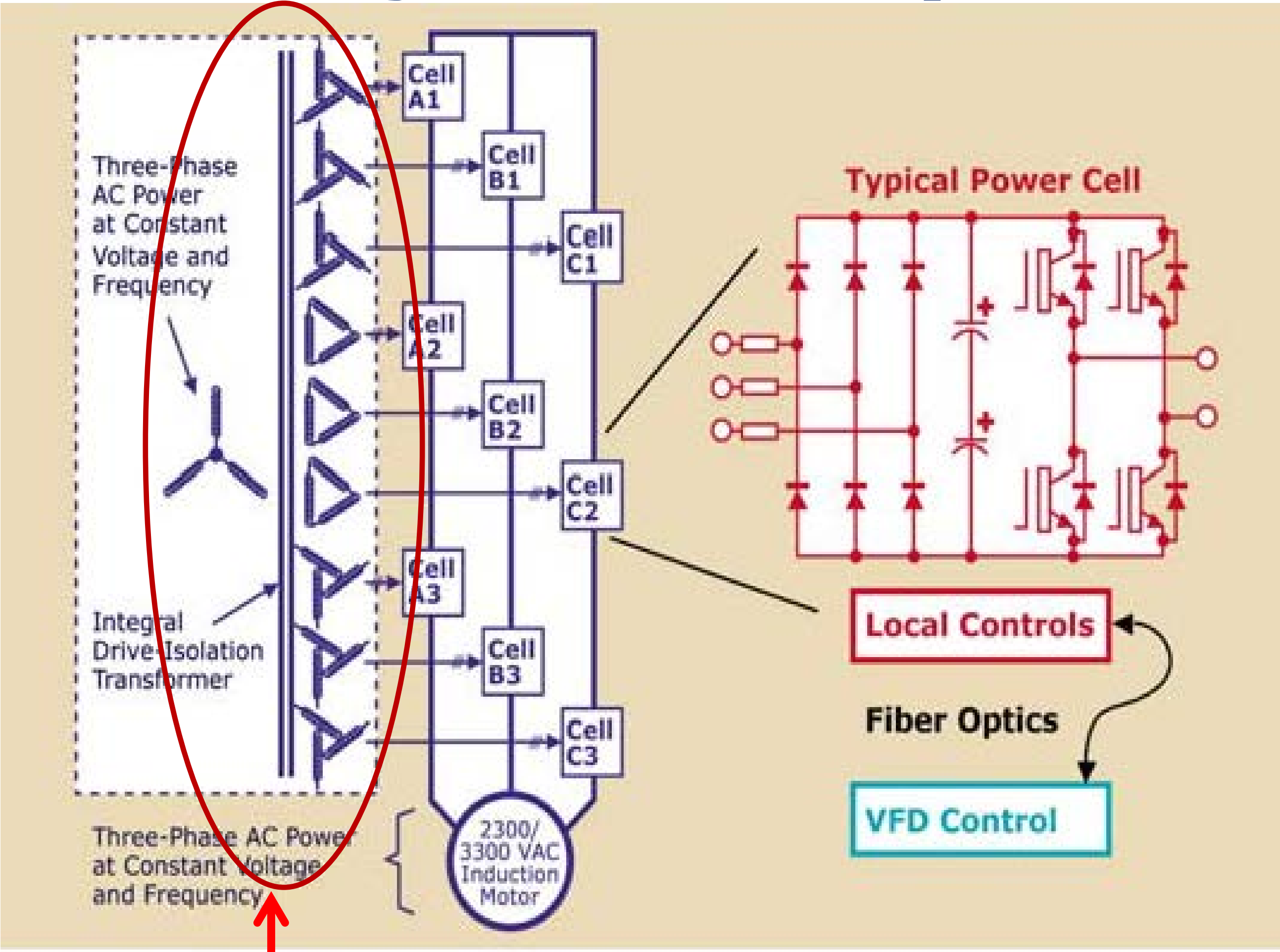




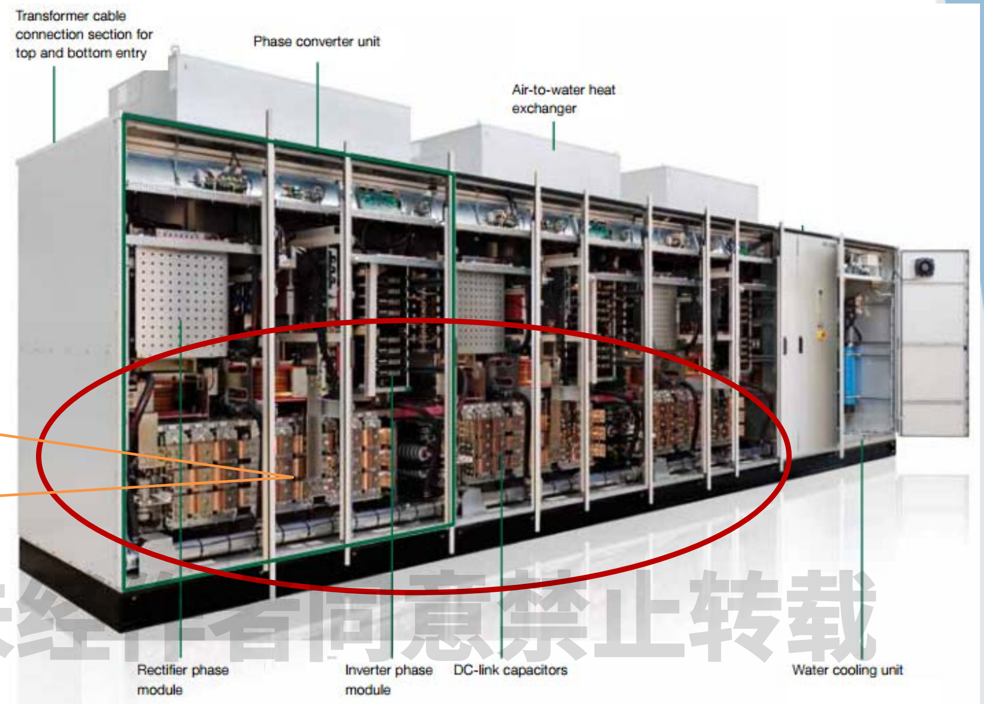
Experimental Results



MV Adjustable Speed Drive – with I-SST



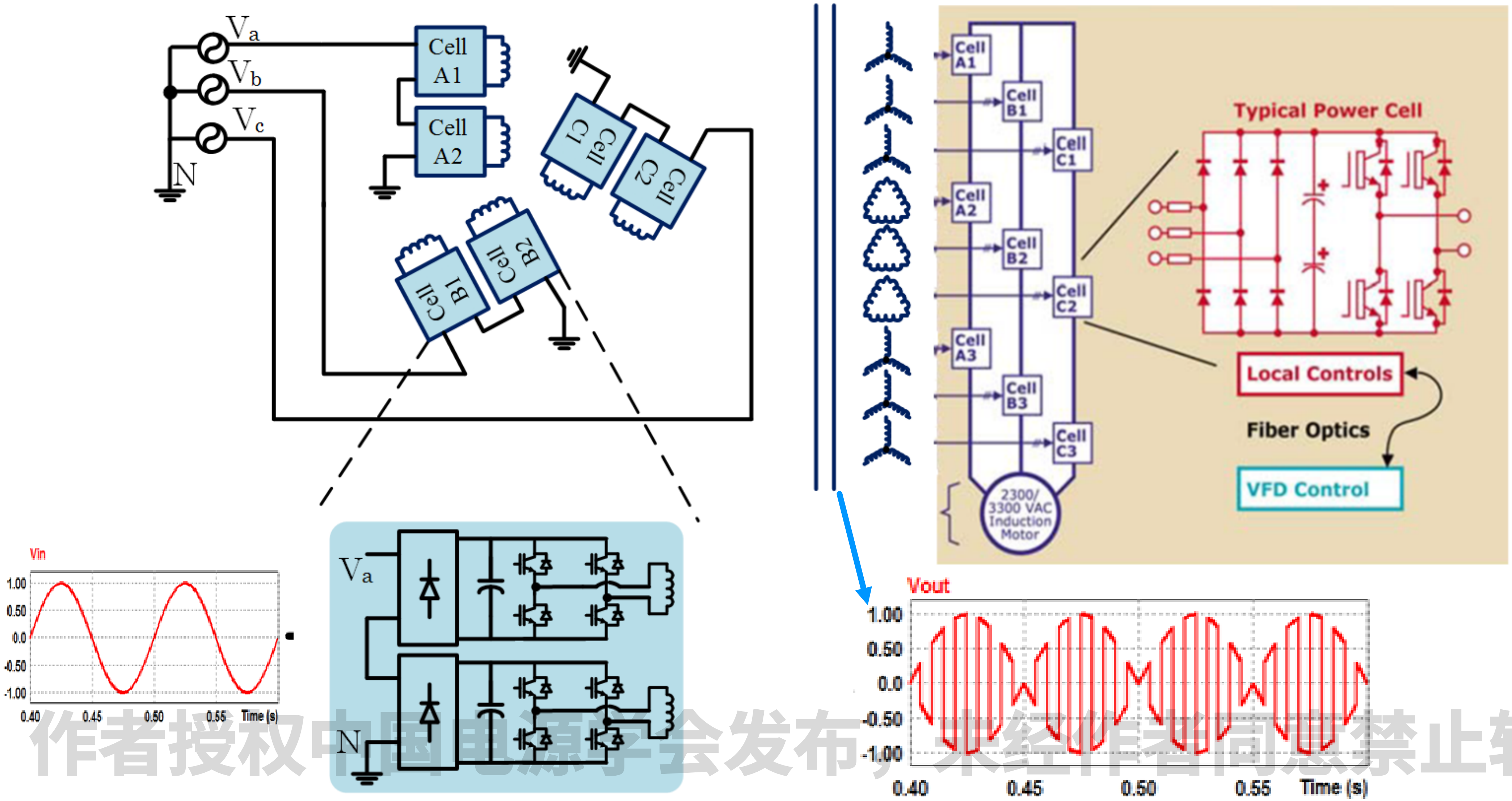
- Modular inverter cells
- Multi phase input transformer
- High quality input/output waveforms
- Large size & weight



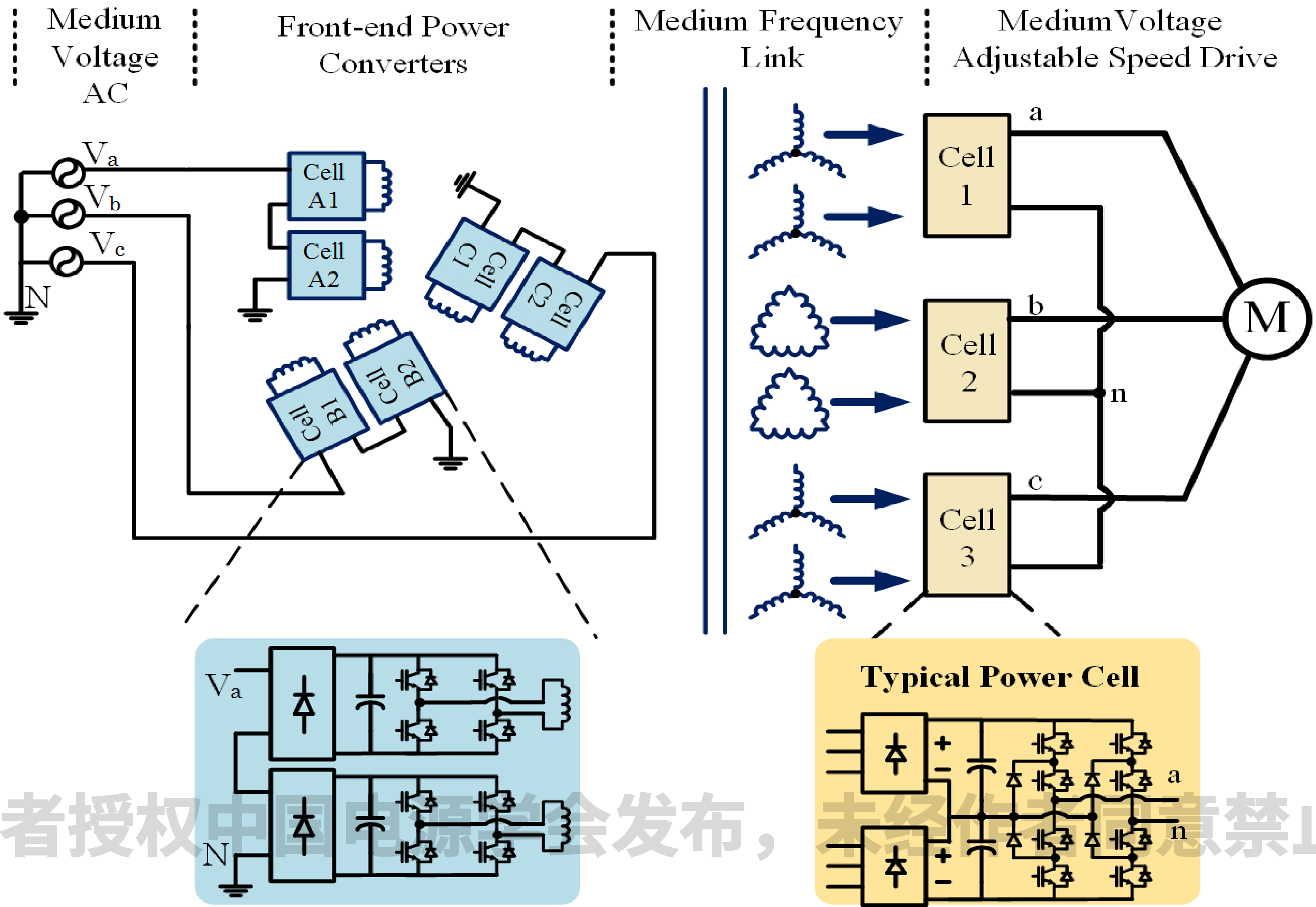
Bulky Line frequency Magnetic Components

MV Adjustable Speed Drive – with I-SST

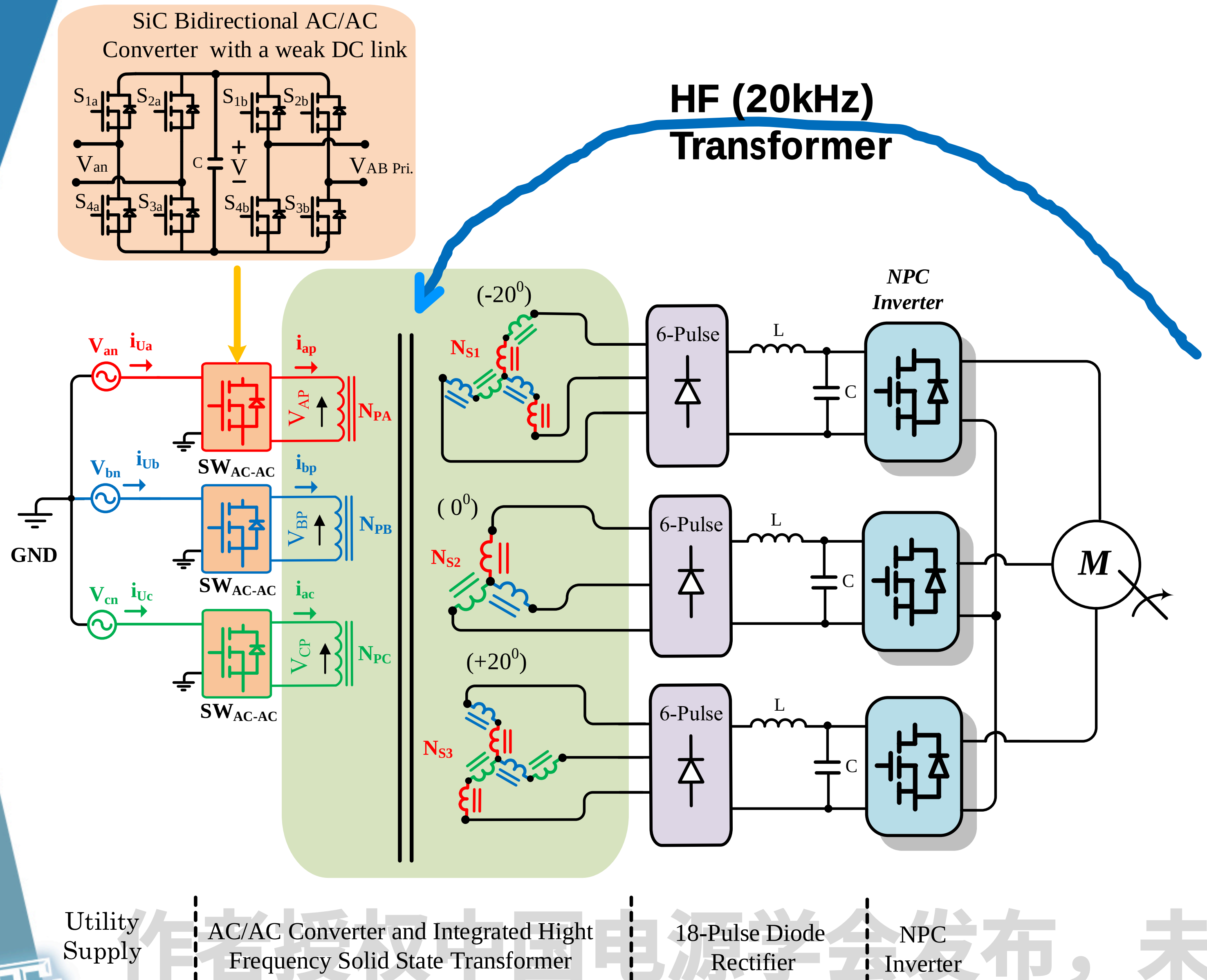
Medium Voltage AC	Front-end Power Converters	Medium Frequency Link	Medium Voltage Adjustable Speed Drive

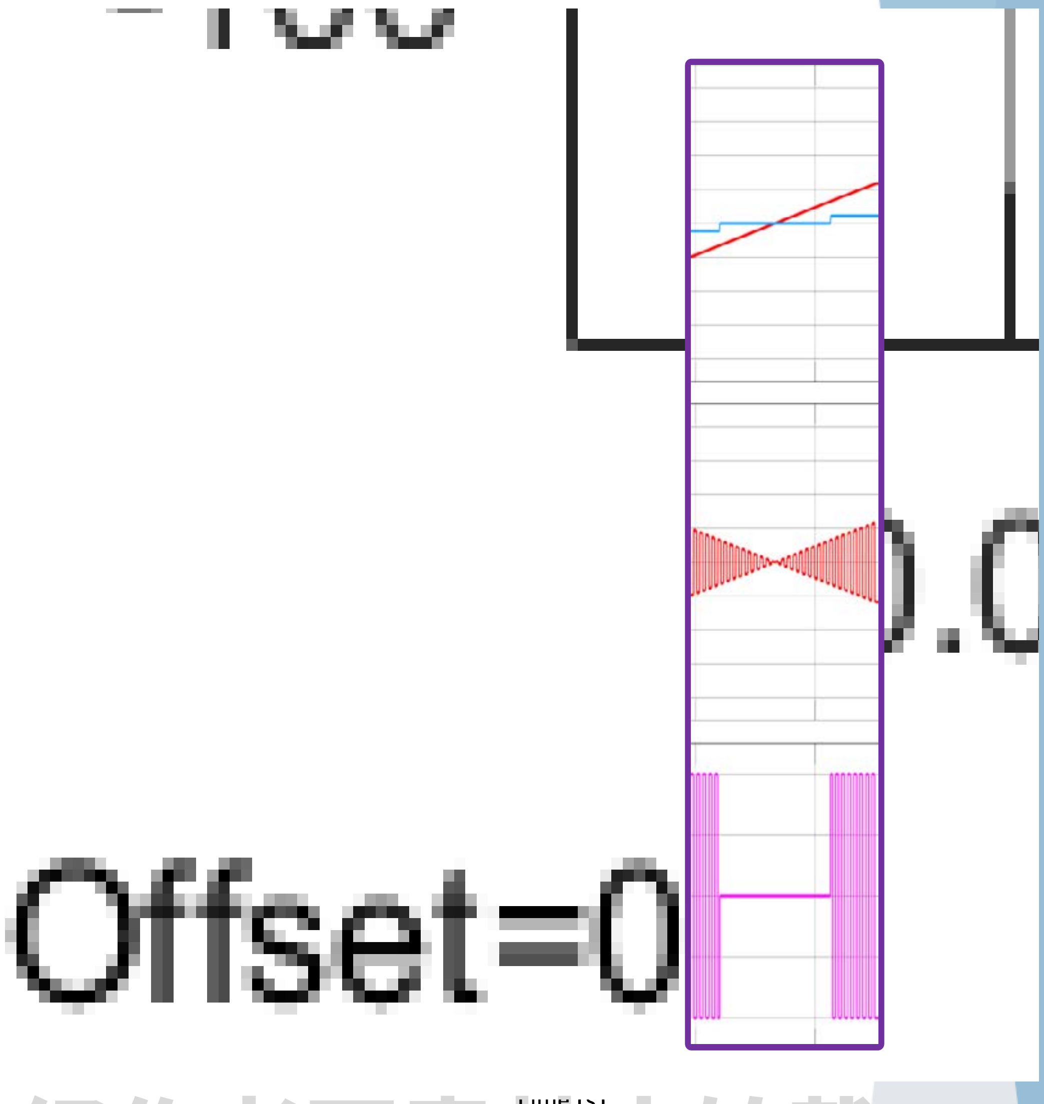


MV Adjustable Speed Drive – with I-SST



MV Adjustable Speed Drive – with I-SST





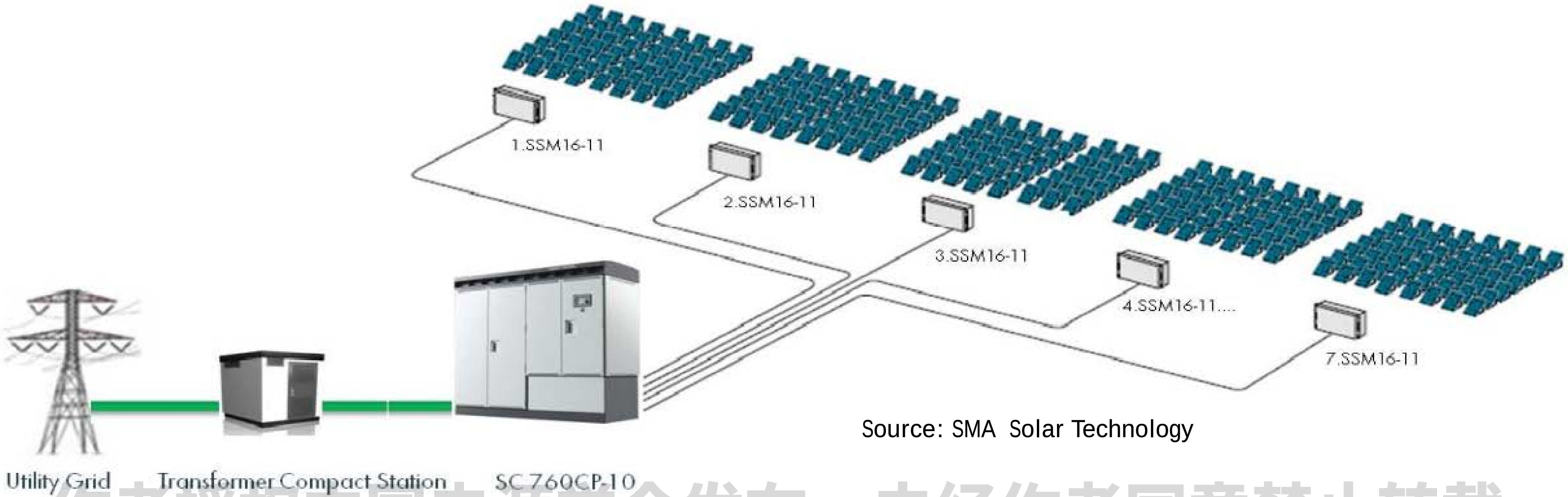
- **HF Isolation ; ZVS operation of I-SST ; Scale to high power with WBG technology**

Grid Connected Renewables with Integrated Solid State Transformer

Large Scale PV Plant – Centralized Inverter

- PV modules wired in series/parallel to 1500V DC
- Central Inverter
- DC coupling of PV panels
- Large size medium voltage transformer interfaces PV plant with the utility grid.

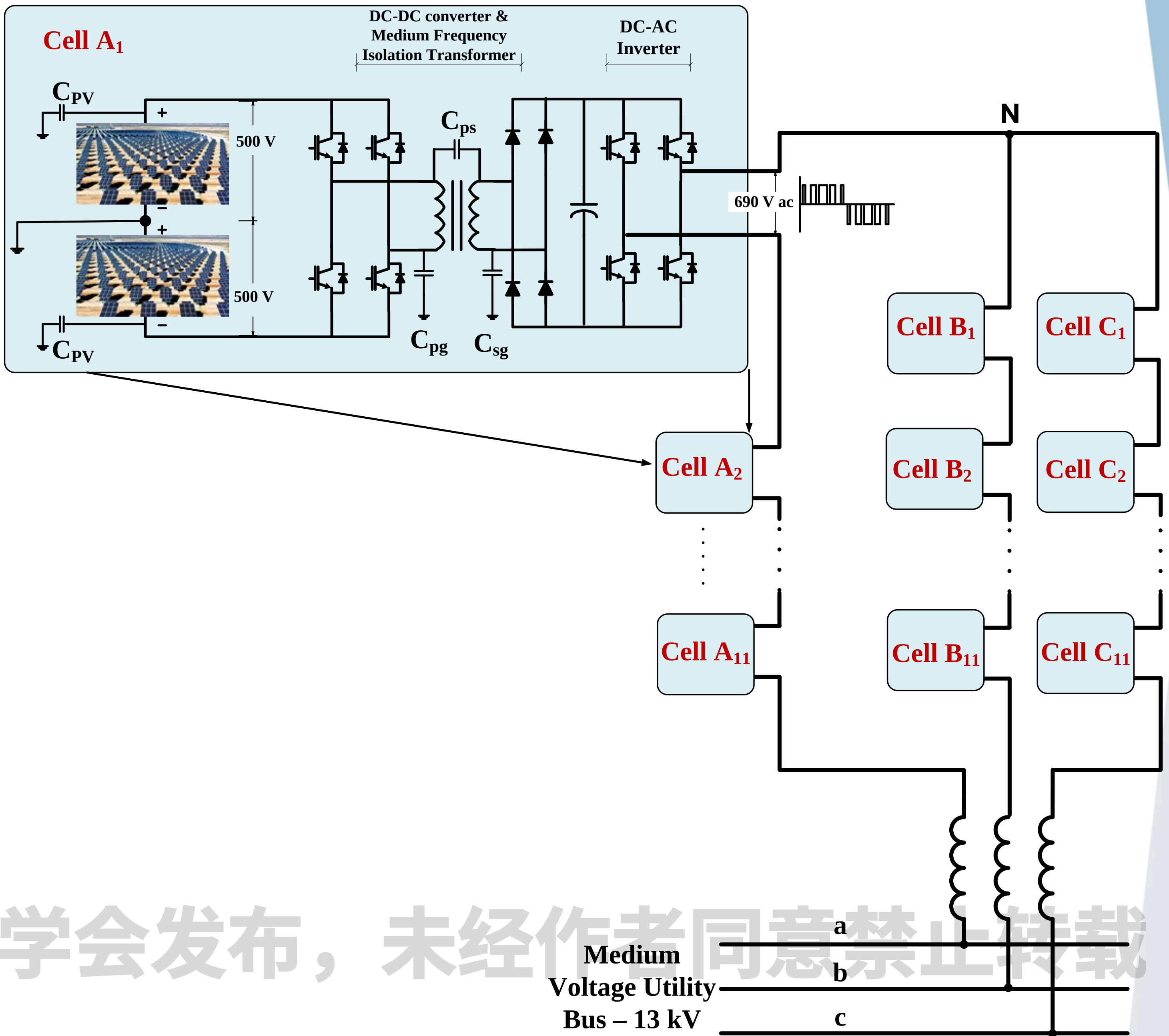
DC Collection



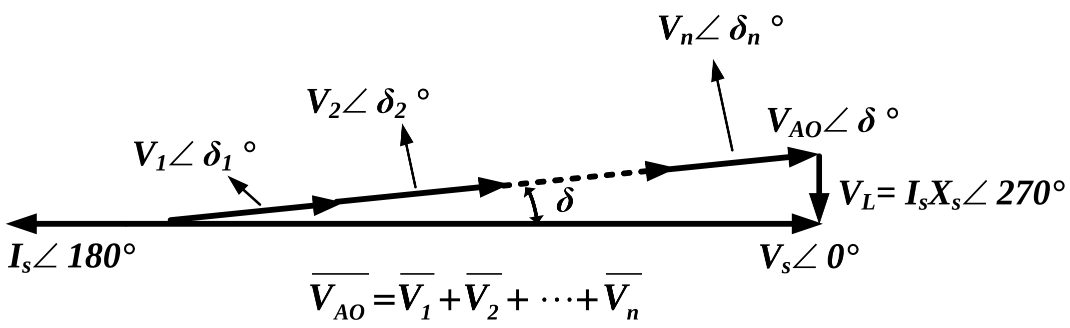
Source: SMA Solar Technology

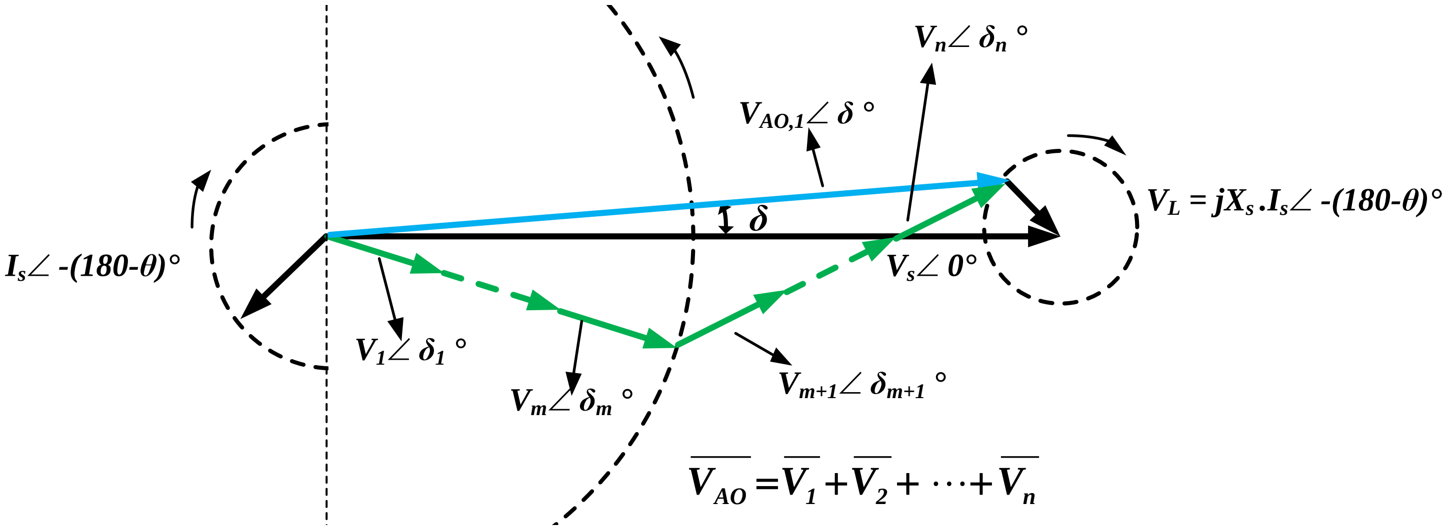
PV Interface – with I-SST

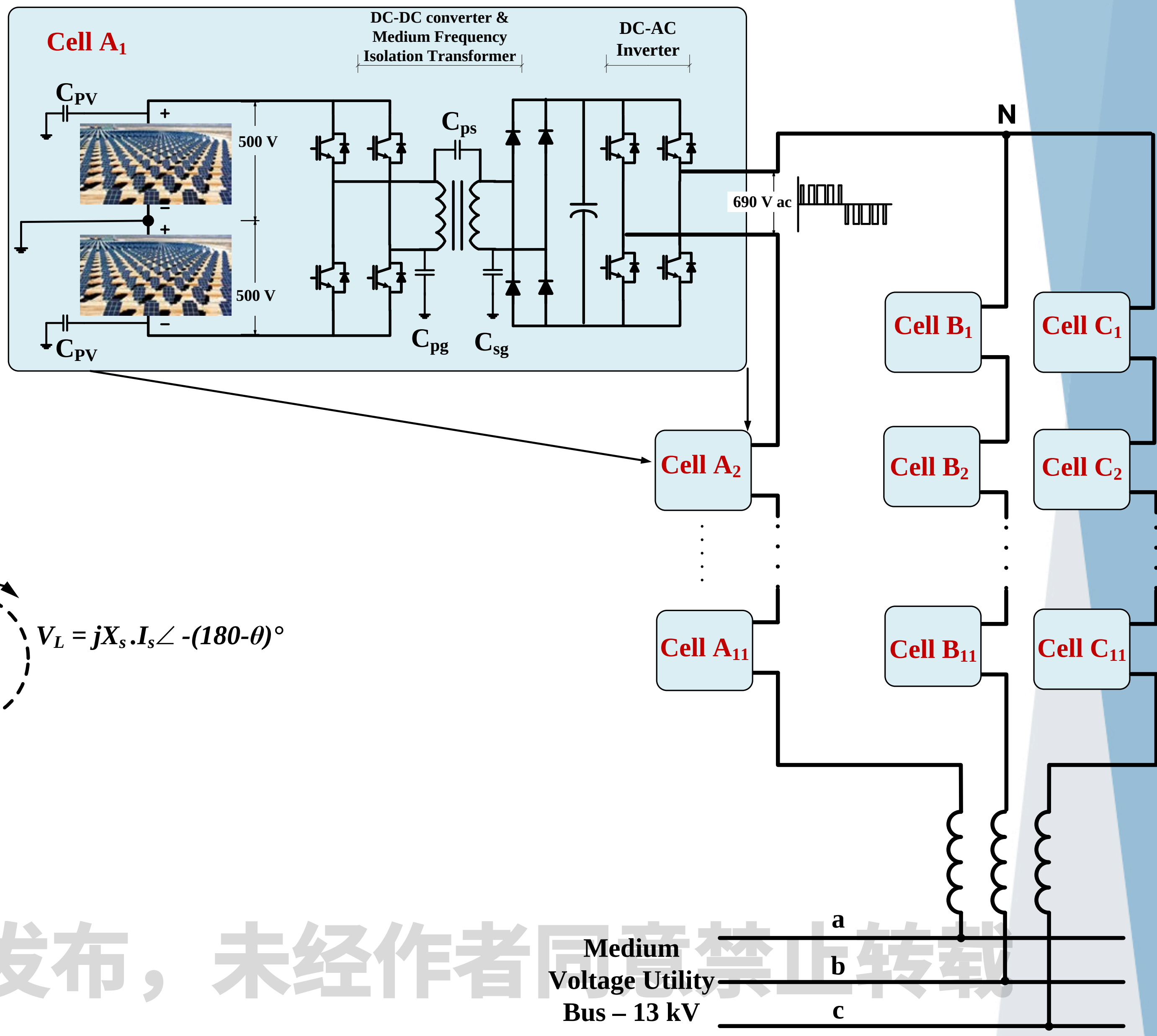
- Series stacked inverter modules.
- High quality multi-level PWM output.
- Line frequency transformer is eliminated.
- Employs standards 690 V inverters with 1700 V IGBTs .
- Suitable for MW scale applications.



PV Interface – with I-SST







AC – Collection Grid for Large Scale PV

2. Eggebek Plant System Overview

Main data	
PV power	83,932 kWp
PV modules	371,089 modules (5 models from 185 Wp to 240 Wp)
Inverters	5061 TLX Pro+ 15k and 257 TLX Pro+ 10k: 78,485 kVA
PV surface	585,472.5 m² of modules
Total surface	1,288,802 m² ground area
Sectors	35, each with its own transformer station: 79,800 kVA (total AC power)
MV description	5 rings connected to a 20 kV/110kV sub-station
Connection point	7 km from the plant sub-station
Plant design and construction	Möhring Energie GmbH
Commissioning	December 2011

Figure 1. Main data of PV power plant in Eggebek

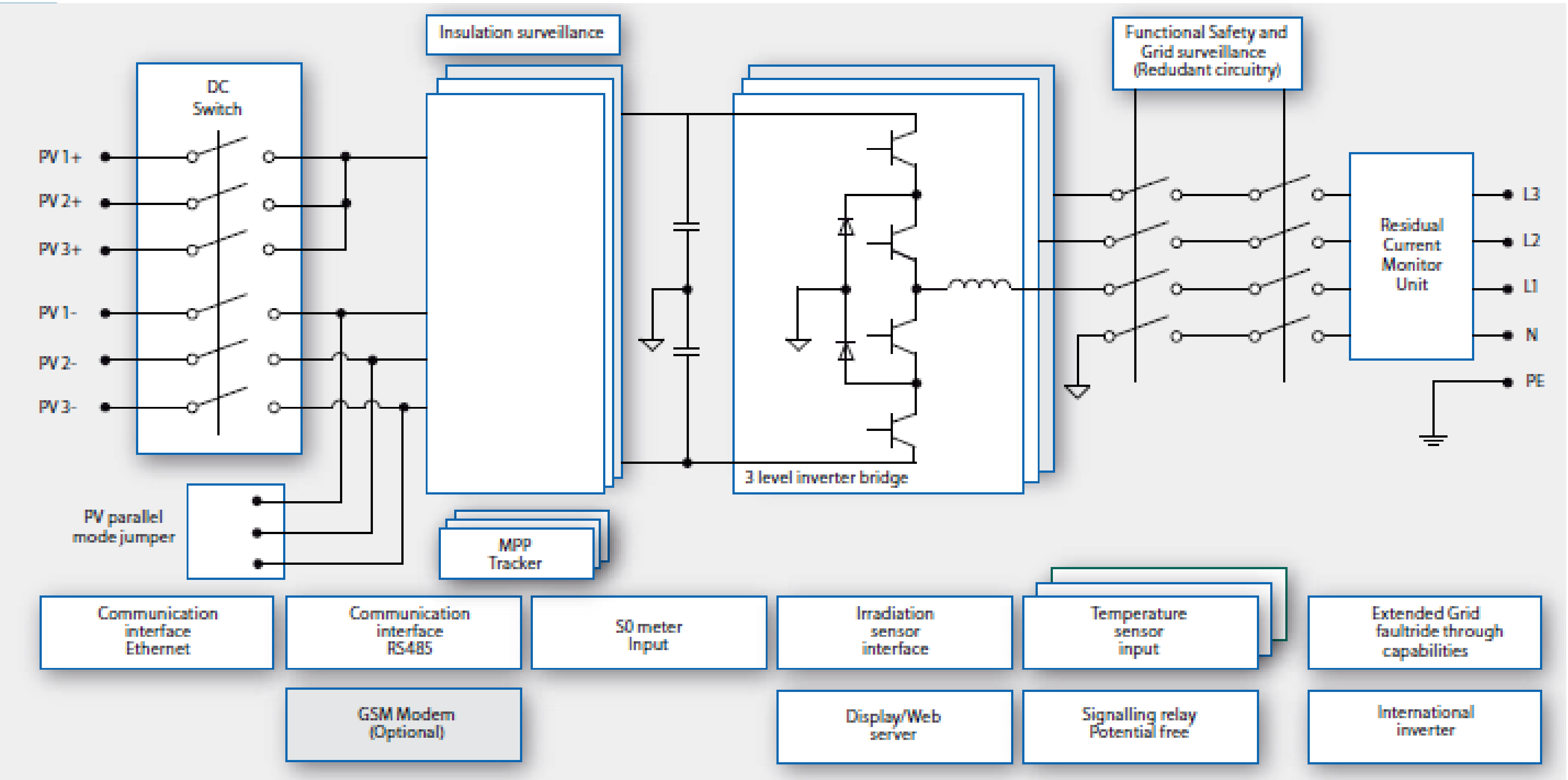
Several hundred 3-phase transformerless inverters are employed

2.1 Location of the plant

The 83.932 kWp PV plant is located at the former NATO airfield in Eggebek, Germany, latitude 54.63, longitude 9.35.

Figure 2. Aerial view of Eggebek solar plant. Courtesy of Möhring Energie

Three phase transformerless inverter range from 6-15 kW



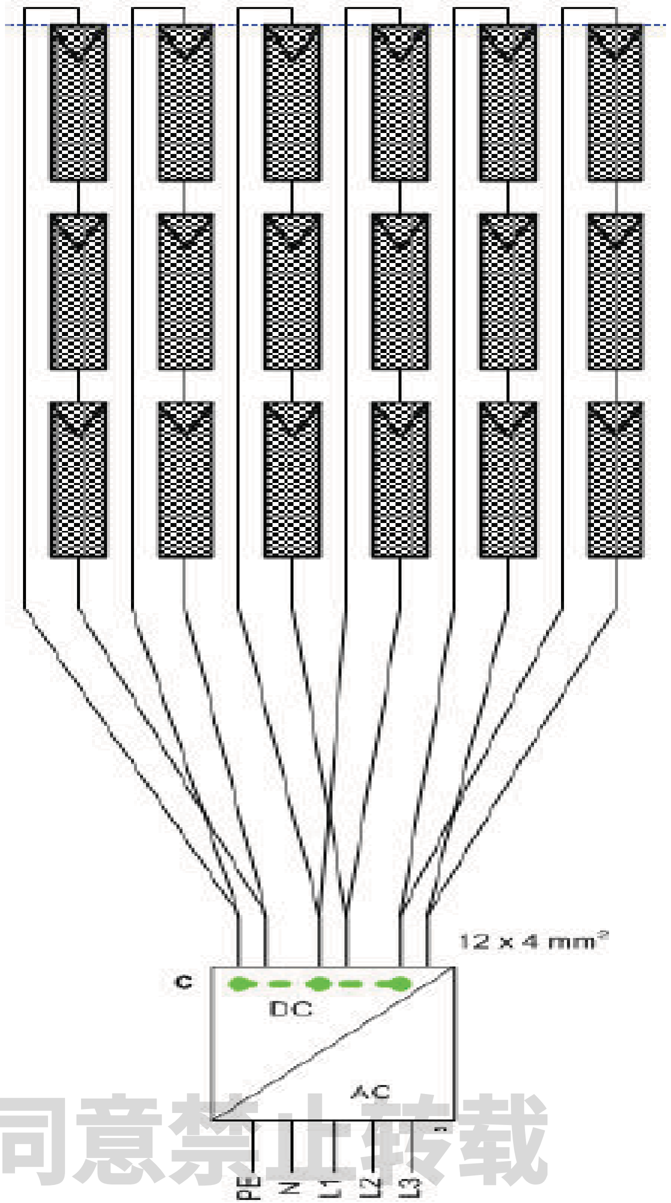
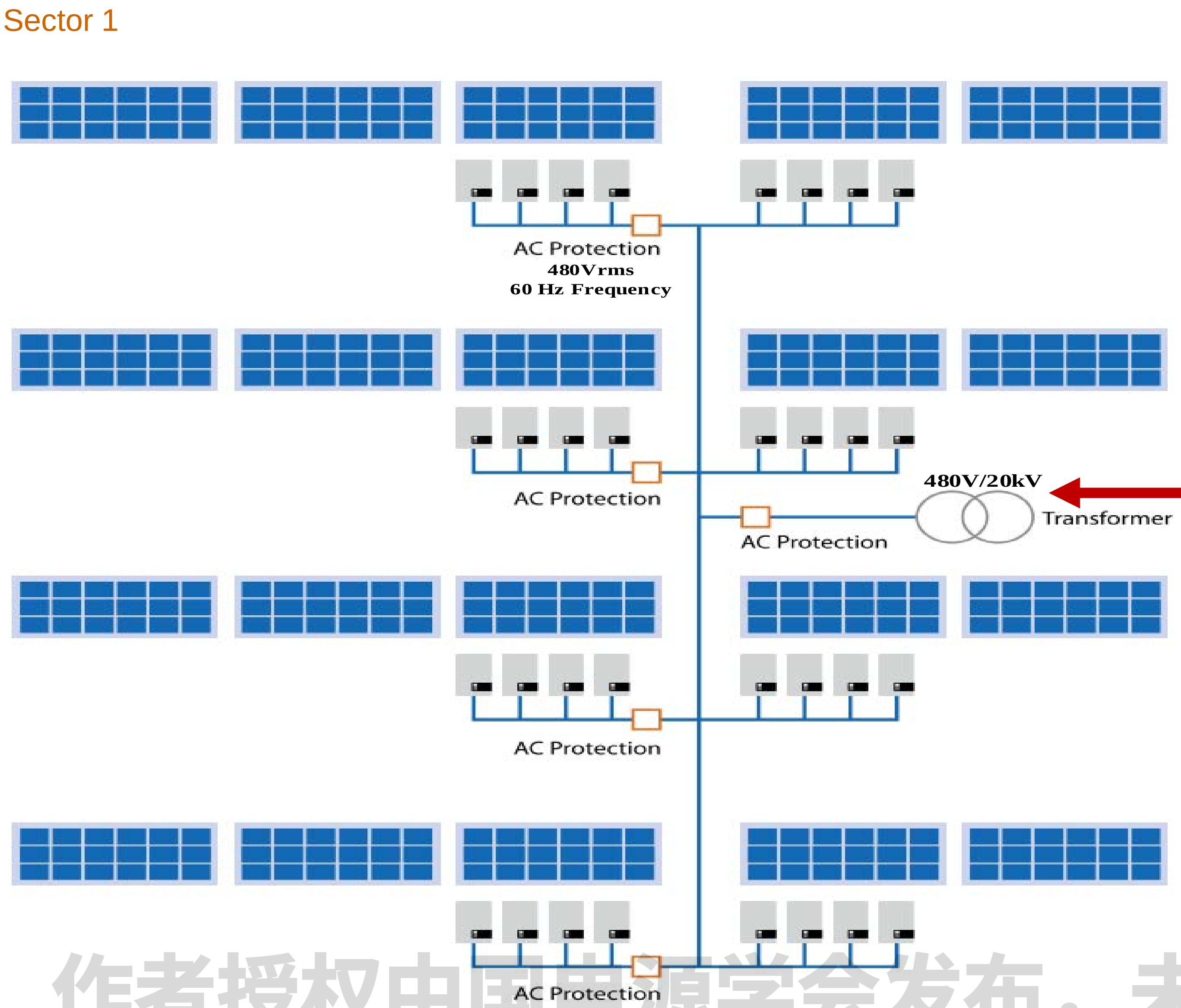


Illustration 5.15: PV System Example 7

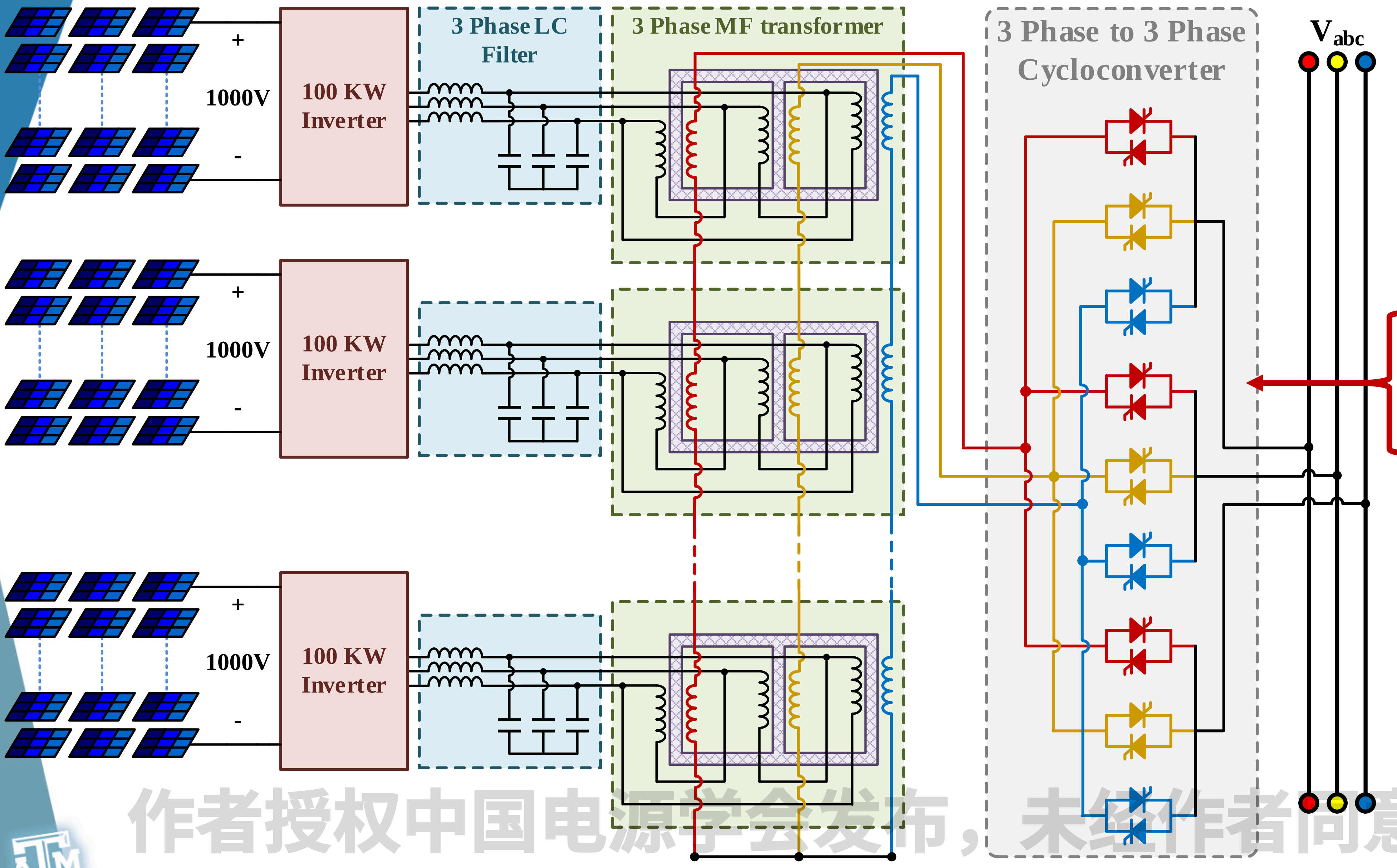
AC – Collection Grid for Large Scale PV



Layout of Eggebek Solar Park

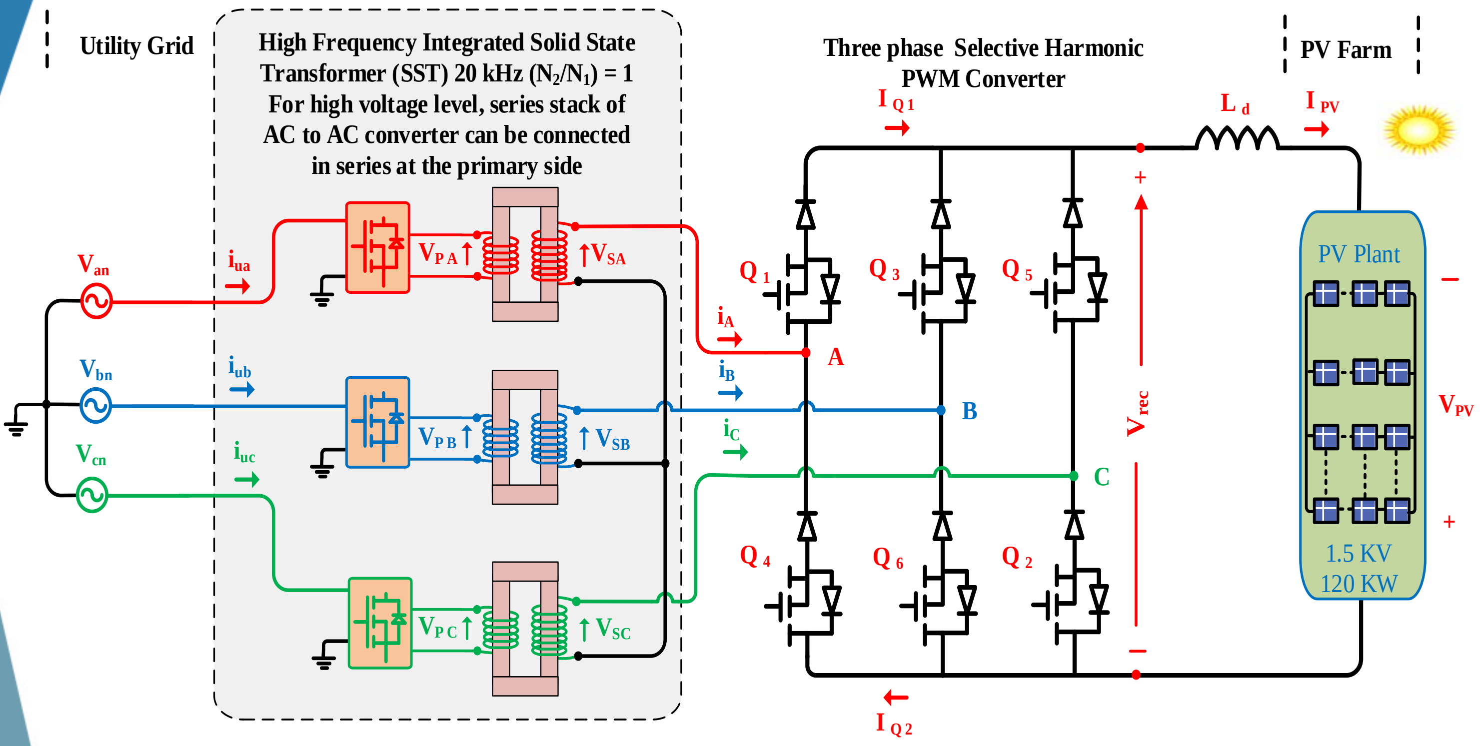
- Danfoss 3-phase 480V AC Inverters are grouped together
- Droop control is employed for power sharing
- 3-phase, 480V, 50Hz AC cables are laid in the field
- A 480V/20kV utility high turns ratio transformer is employed
- Cable size/length/cost are an issue
- No DC-circuit protection

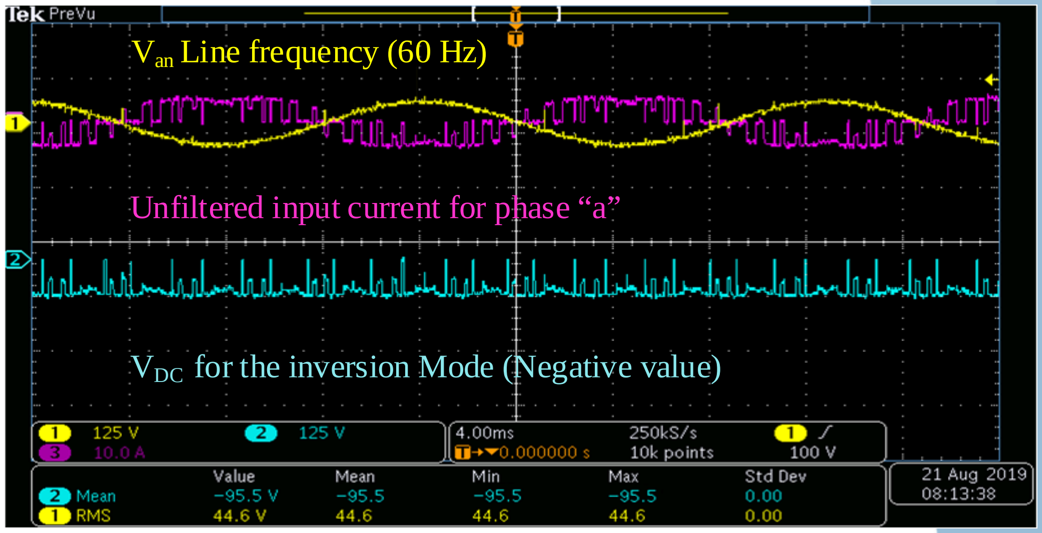
PV Interface – with I-SST



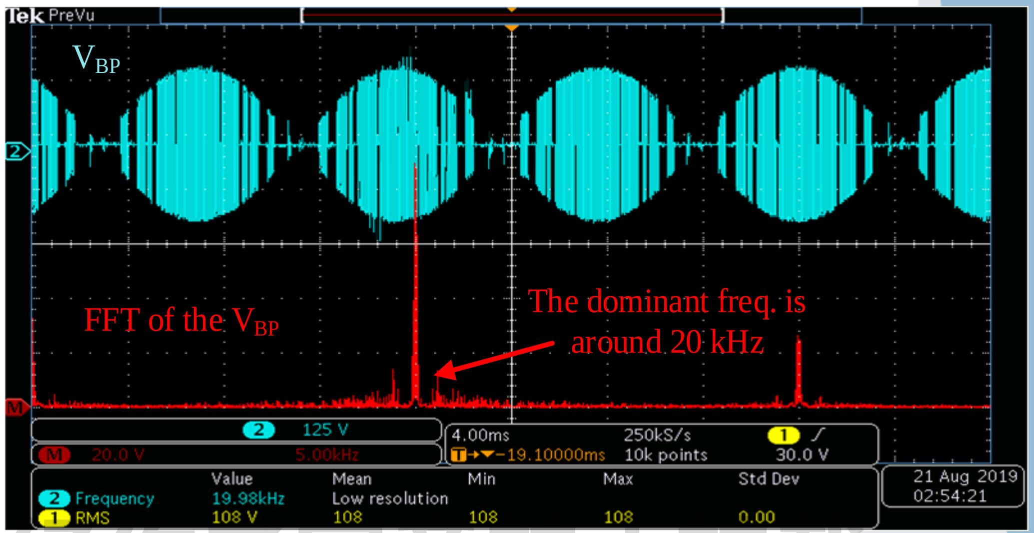
- Medium frequency transformer isolates pv and distribution grid
- AC power collection at higher voltage / frequency
- Reduced cable ohmic losses
- Employs 400Hz to 60Hz 3-phase AC/AC line-commutated cycloconverter.
- Increased overall efficiency by 2%
- Eliminates bulky line frequency transformer; reduces site preparation & allows for more room for pv arrays.

PV / Battery Interface – with I-SST





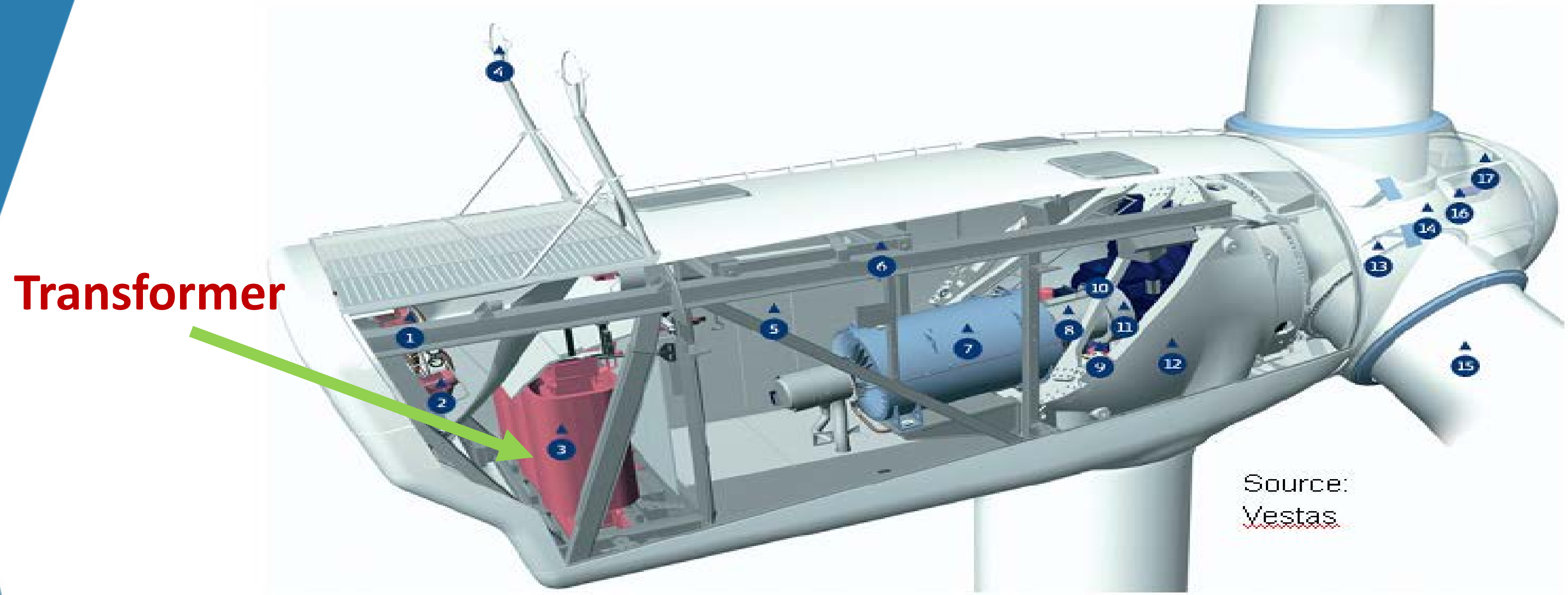
Inversion Mode Operation



Frequency spectrum for the transformer voltage V_{BP}, The dominant frequency is around (20 kHz)

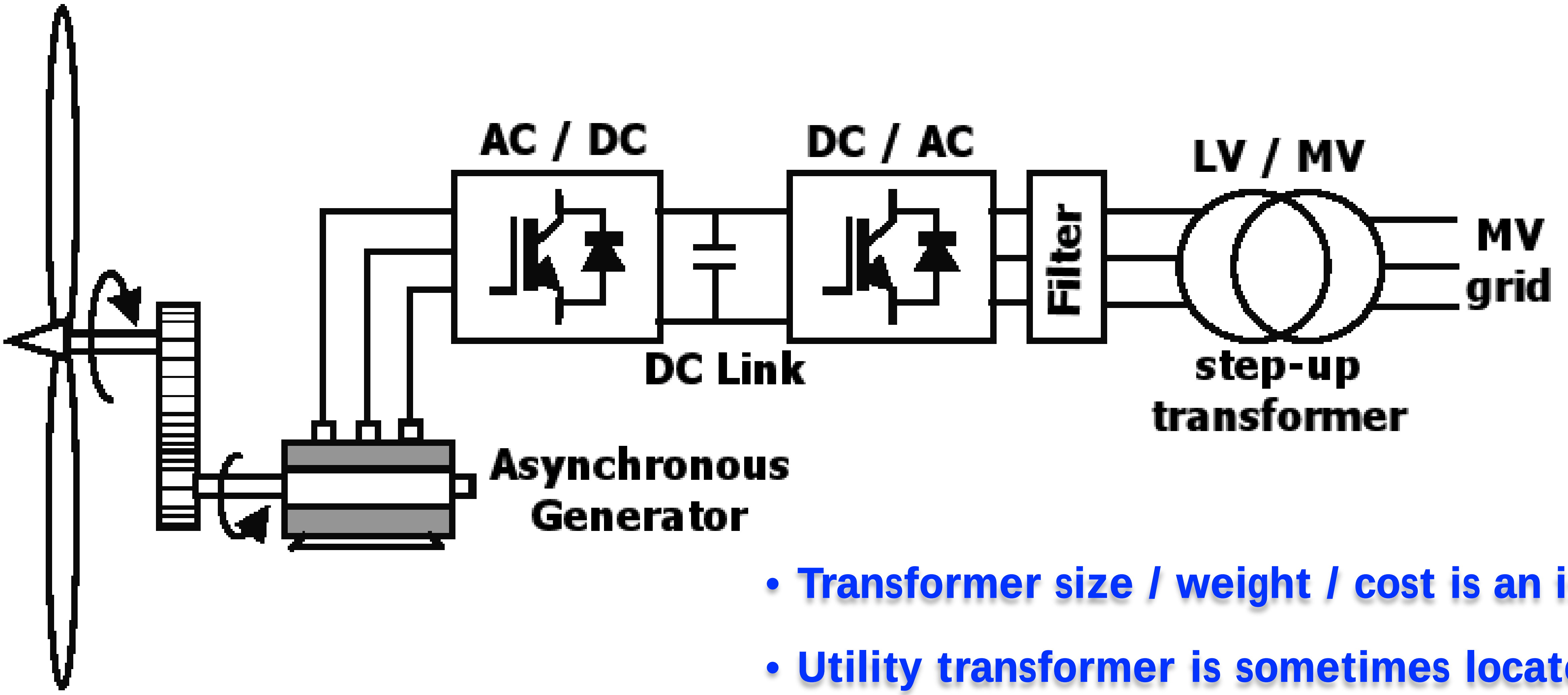
- HF Isolation ; ZVS operation of I-SST ; Scale to high power with WBG technology

Wind Energy Interface – with I-SST



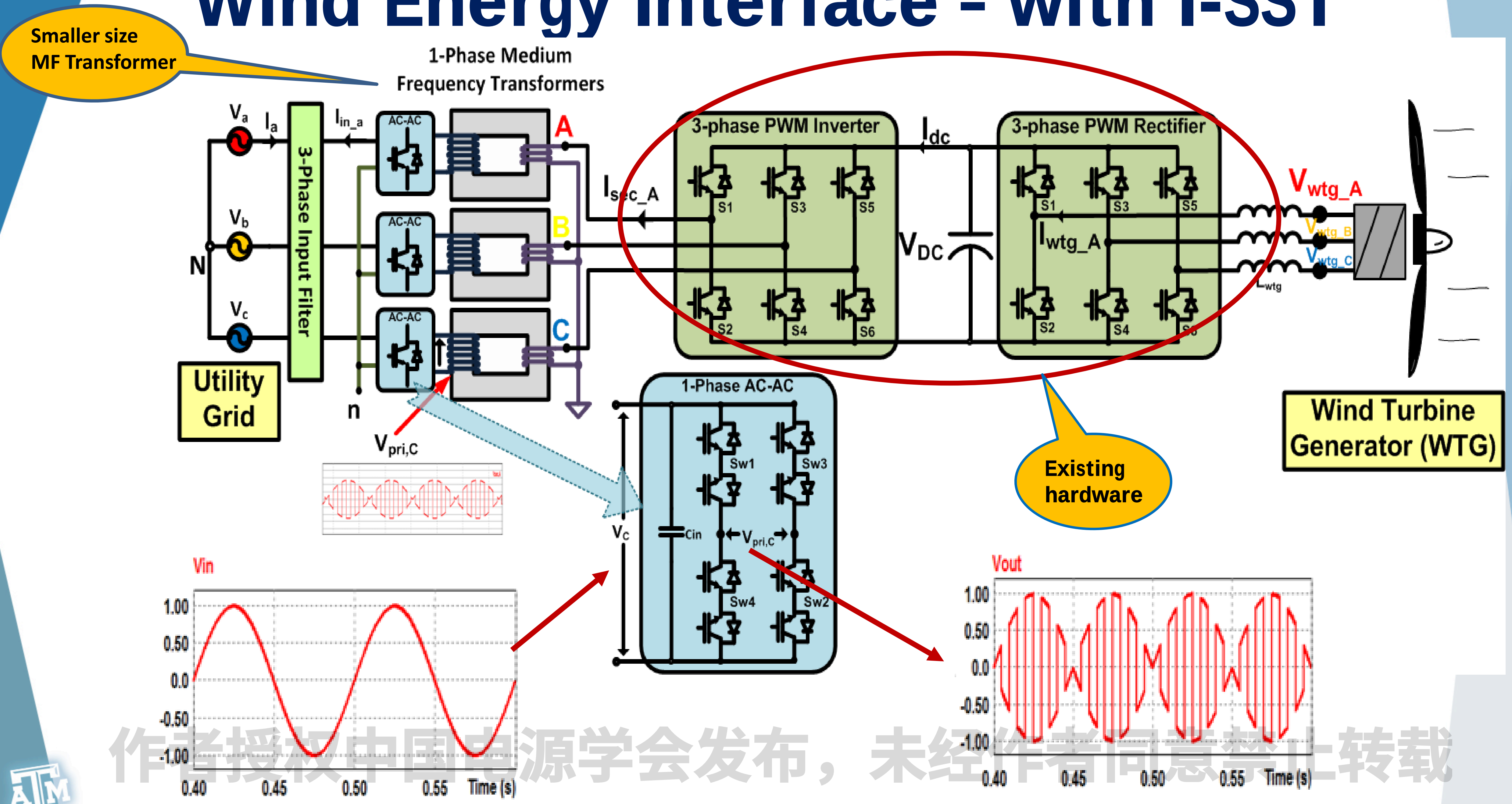
1 Oil cooler
2 Water cooler for generator
3 High voltage transformer
4 Ultrasonic wind sensors
5 VMP-Top controller with converter
6 Service crane
7 OptiSpeed® generator
8 Composite disc coupling
9 Yaw gears
10 Gearbox
11 Mechanical disc brake
12 Machine foundation
13 Blade bearing
14 Blade hub
15 Blade
16 Pitch cylinder
17 Hub controller

Wind Energy Interface – with I-SST

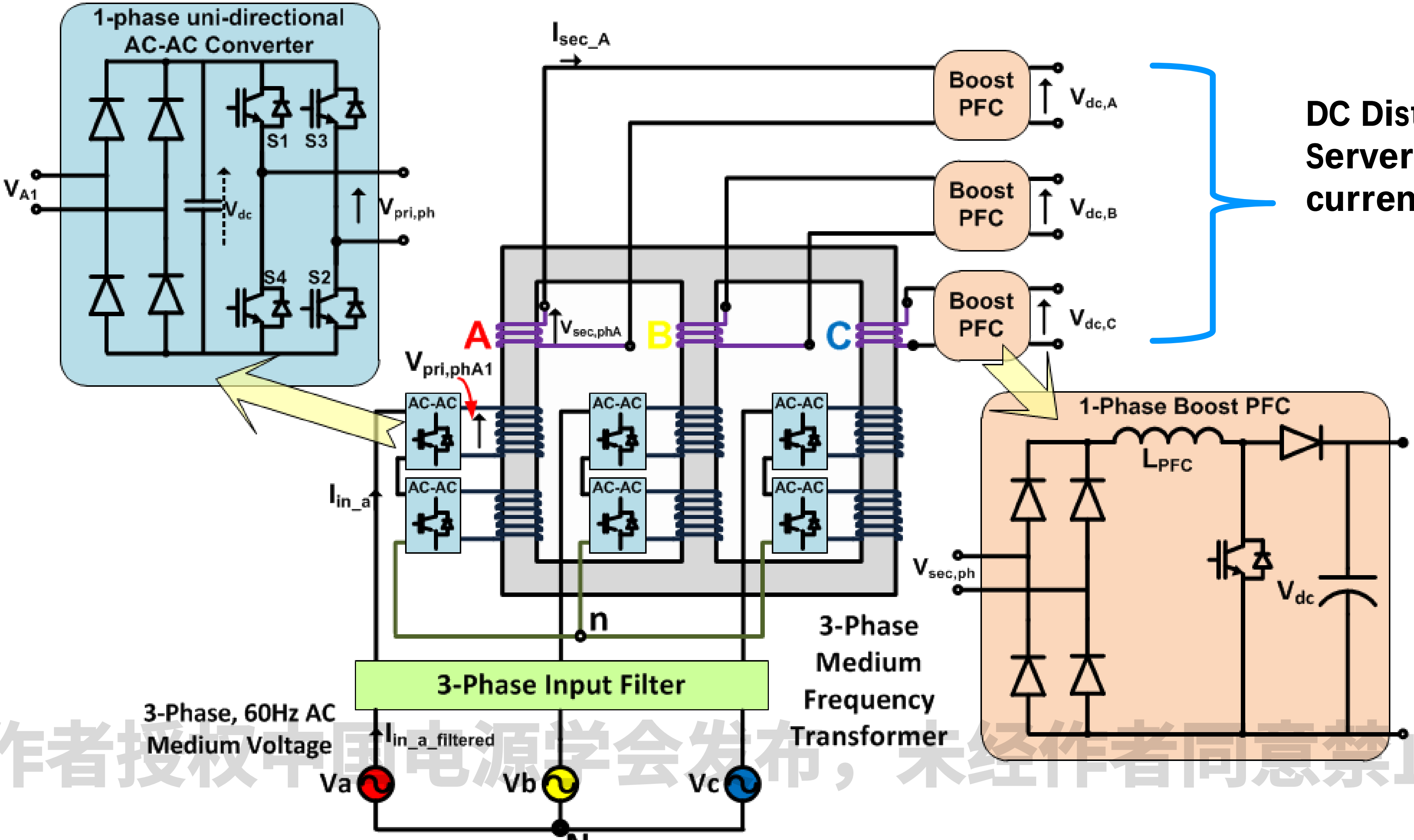


- Transformer size / weight / cost is an issue
- Utility transformer is sometimes located on the top of the tower. Large size adds to the cost of the structure

Wind Energy Interface – with I-SST



MV (13.8 KV) – Power Distribution Systems for Data Centers with transformative performance



DC Distribution for Servers (48V high current)

Thank you!!

Current Ongoing Research

- Micro-grids – PINE – Grid Edge
- HF Converters – GaN / SiC
- Integrated Solid State Transformers
- Cybersecurity of Grid Connected Power Electronics Hardware