

A High-Power Step-Up DC Transformer for Renewable Energy Distribution Systems

Jiahui He, Ning Wang, Binbin Li, Yingzong Jiao,
Dianguo Xu, Harbin Institute of Technology

Speaker: Jiahui HE



Education:

2020-2024 B.S. Jilin University, Changchun, China

2024-Present M.S. Harbin Institute of Technology, Harbin, China

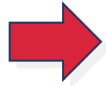
Research direction:

high-power isolated DC/DC converter & MVDC Grid

Email: jiahui_he@stu.hit.edu.cn



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— Introduction

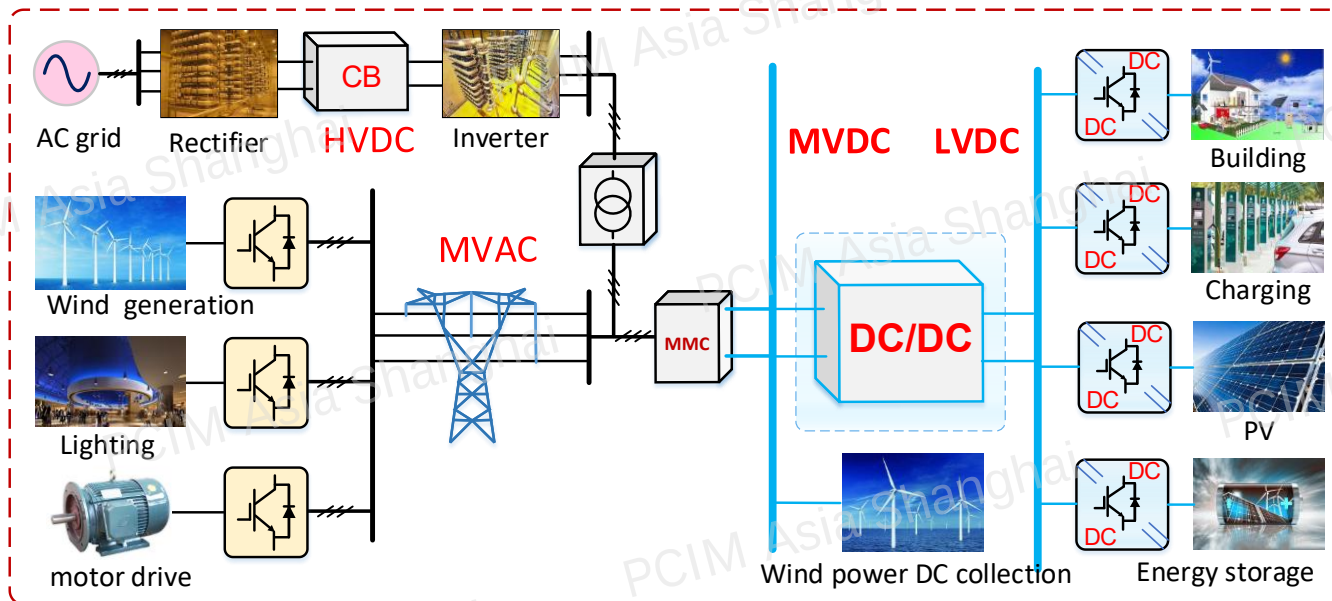
— Proposed Topology and Operating Principle

— Control Strategy

— Simulation Verification

— Conclusion

- With the access of many types of DC electrical equipment, there is an urgent need to build a DC power distribution system !
- **MVDC-LVDC DC/DC** converter is the key technology of medium voltage and low voltage DC bus interconnection !



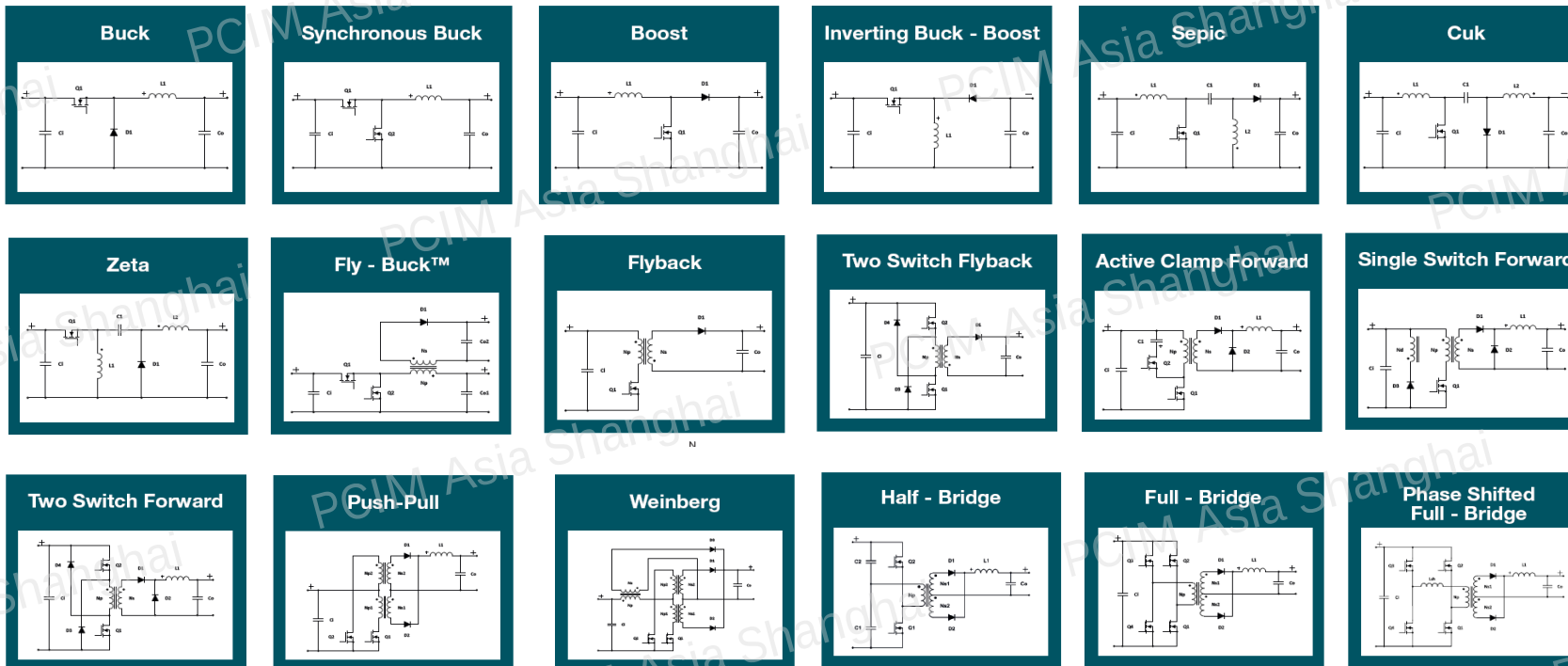
- high step-down ratio
- galvanic isolation
- wide input voltage range operation
- provide ports or interfaces to connect distributed power generators or energy storage device

Voltage/Power:

<3kV

■ Classical low voltage DC-DC converter

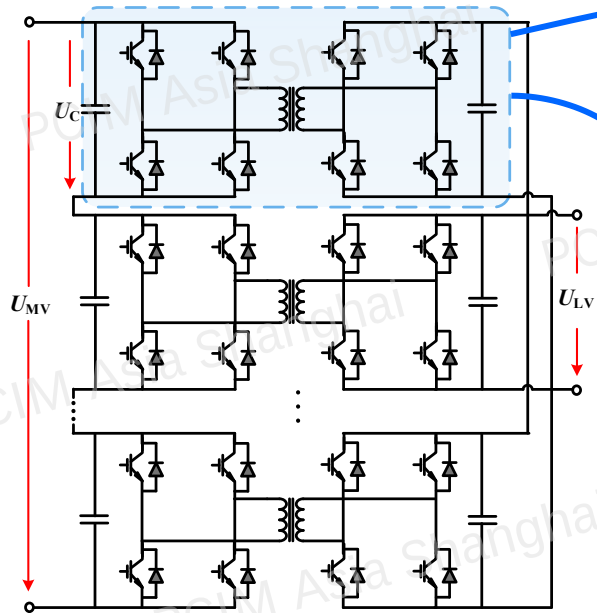
- Power supply applications under **low voltage and low power**
- Can't readily be scaled up to hundreds of kilovolts and megawatt power ranges due to **the limitations of losses, cost, dv/dt, filter and voltage ratings of the semiconductors**



Voltage/Power:

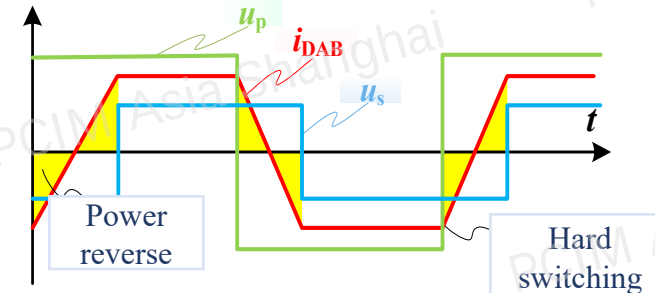
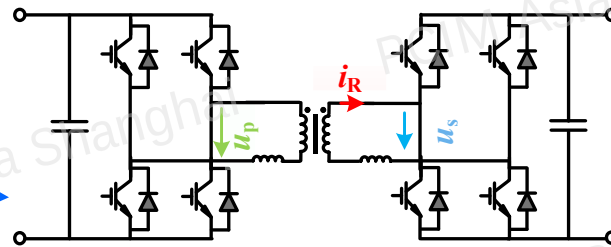
3~50kV

Input-parallel output-series configuration



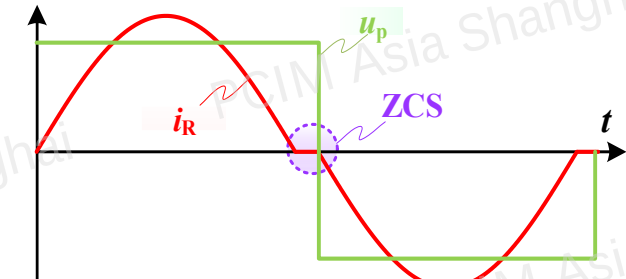
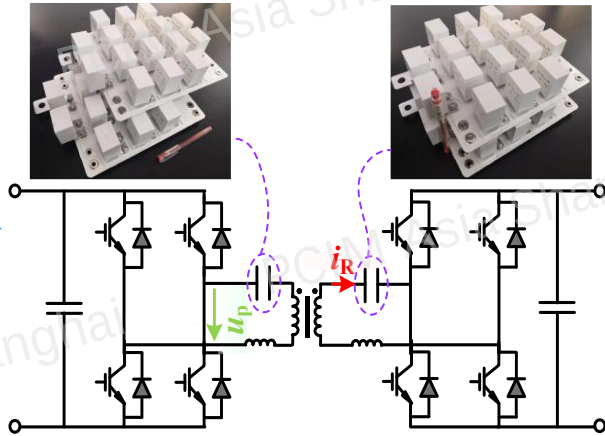
ISOP

- Two main power modules



①Dual active bridge (DAB)

- The circulating current
- Hard switching, high switching loss



②Series resonant converter (SRC)

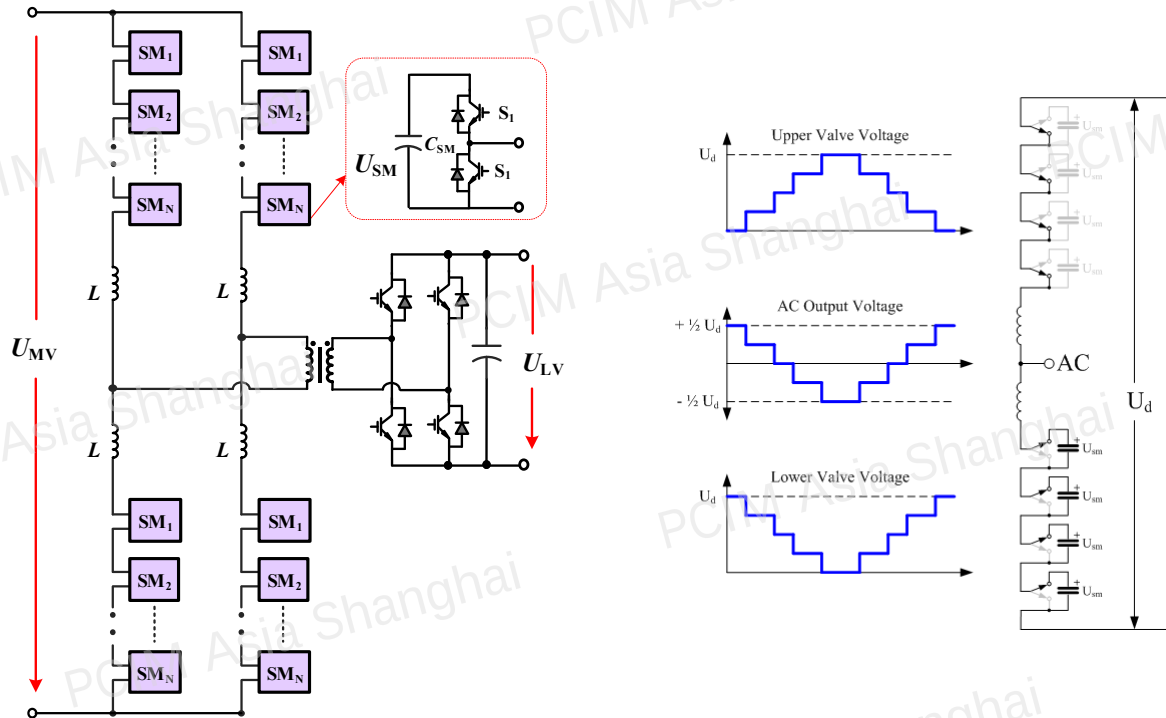
- Wide voltage regulation is not allowed
- Large number of high-voltage capacitors

➤ A massive number of transformers with onerous requirement for high insulation

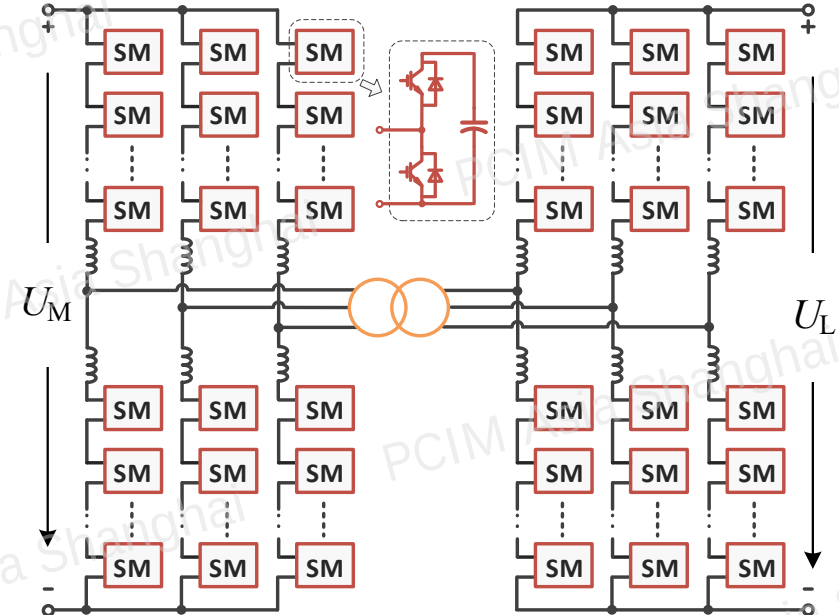
Voltage/Power:

>50kV

■ DC-DC converter based on MMC



■ FTF-MMC

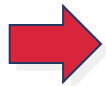


- **Many power devices and large losses:** half of the SMs are always bypassed at any time
- **A large capacitance and volume:** SM capacitors are charged or discharged by significant arm current for a long time
- **The step-down ratio is dependent on the transformer:** unsuited to wide voltage regulation



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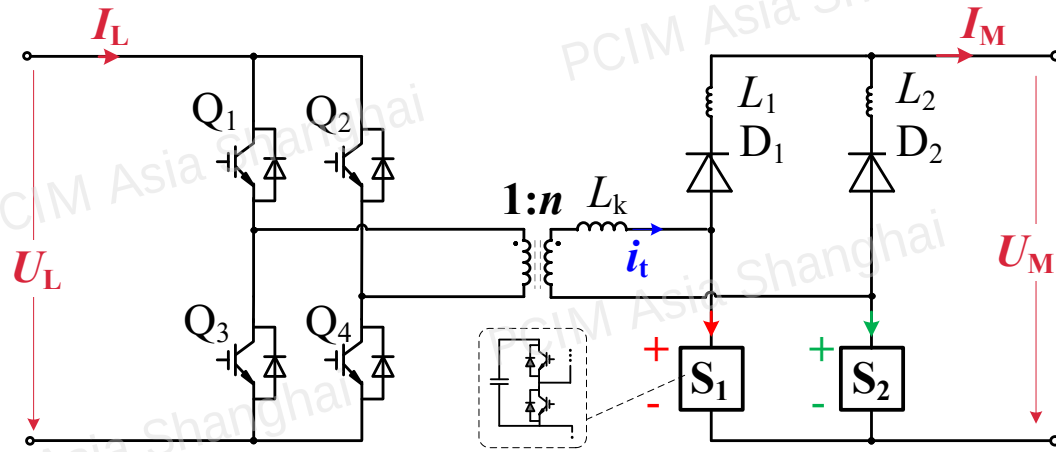
– **Proposed Topology and Operating Principle**

– Control Strategy

– Simulation Verification

– Conclusion

■ The proposed High-Power Step-Up DC Transformer topology



- LVDC side: IGBT rectifier
- Transformer: around 500Hz
- MVDC side: Diode valves + Arms (cascaded by half bridge SMs)

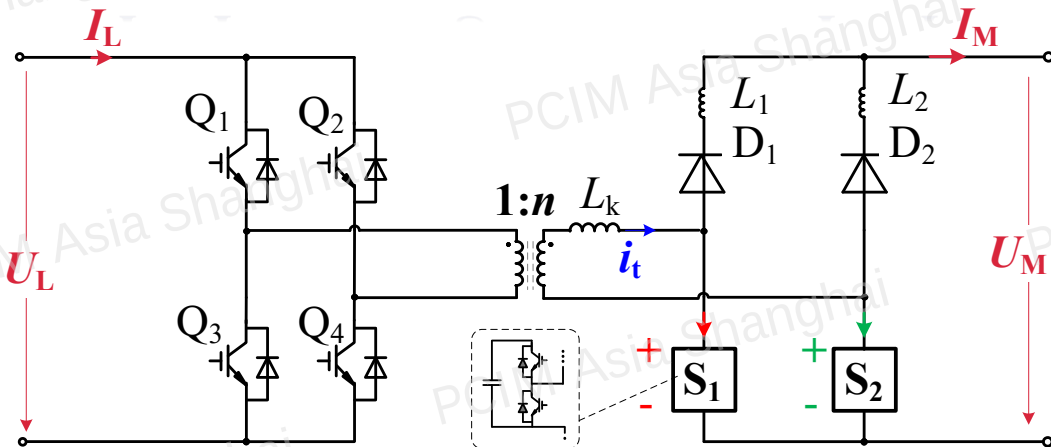
● Diode

- ✓ low conduction loss
- ✓ high-power density
- ✓ high current rating

● Arm:

- ✓ high controllability of the voltage and current waveforms
- ✓ ZCS-enabled IGBT operation
- IGBT rectifier:
 - ✓ Eliminates tail current losses
 - ✓ Reduces switching stress

■ The proposed High-Power Step-Up DC Transformer topology



■ Output Current waveforms design:

Interleaved trapezoidal waveform → **smooth DC currents**

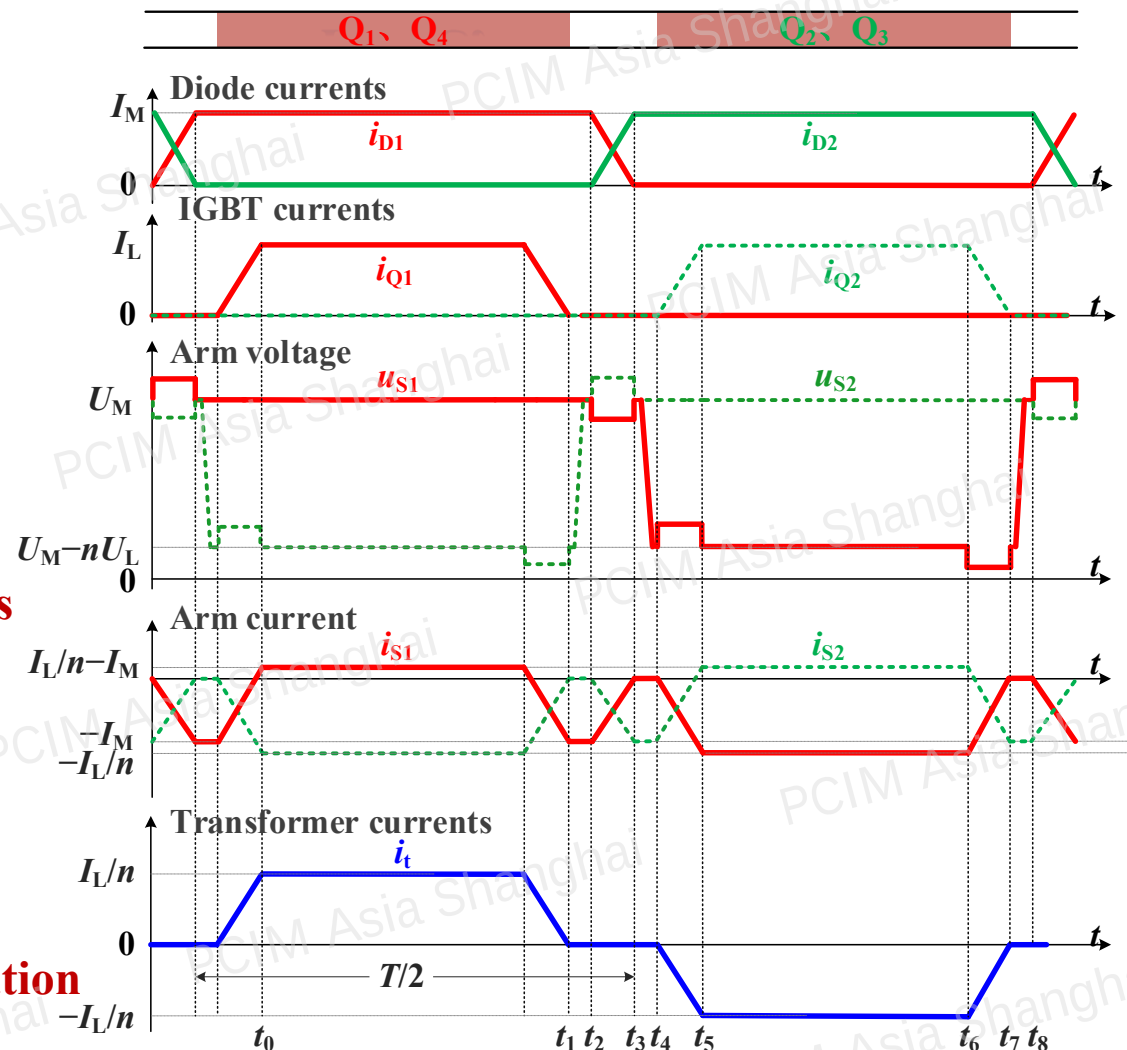
■ Voltage modulation:

Similar to two-level modulation → **lower capacitance**

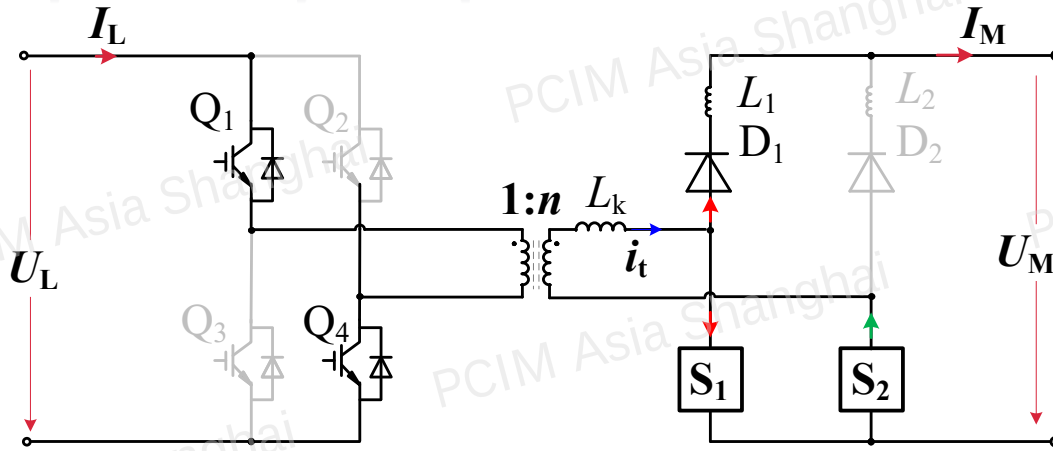
■ High controllability of the arms

Arm coordinated commutation → **IGBTs ZCS**

Adjust the duty cycle of SMs → **wide voltage range regulation**



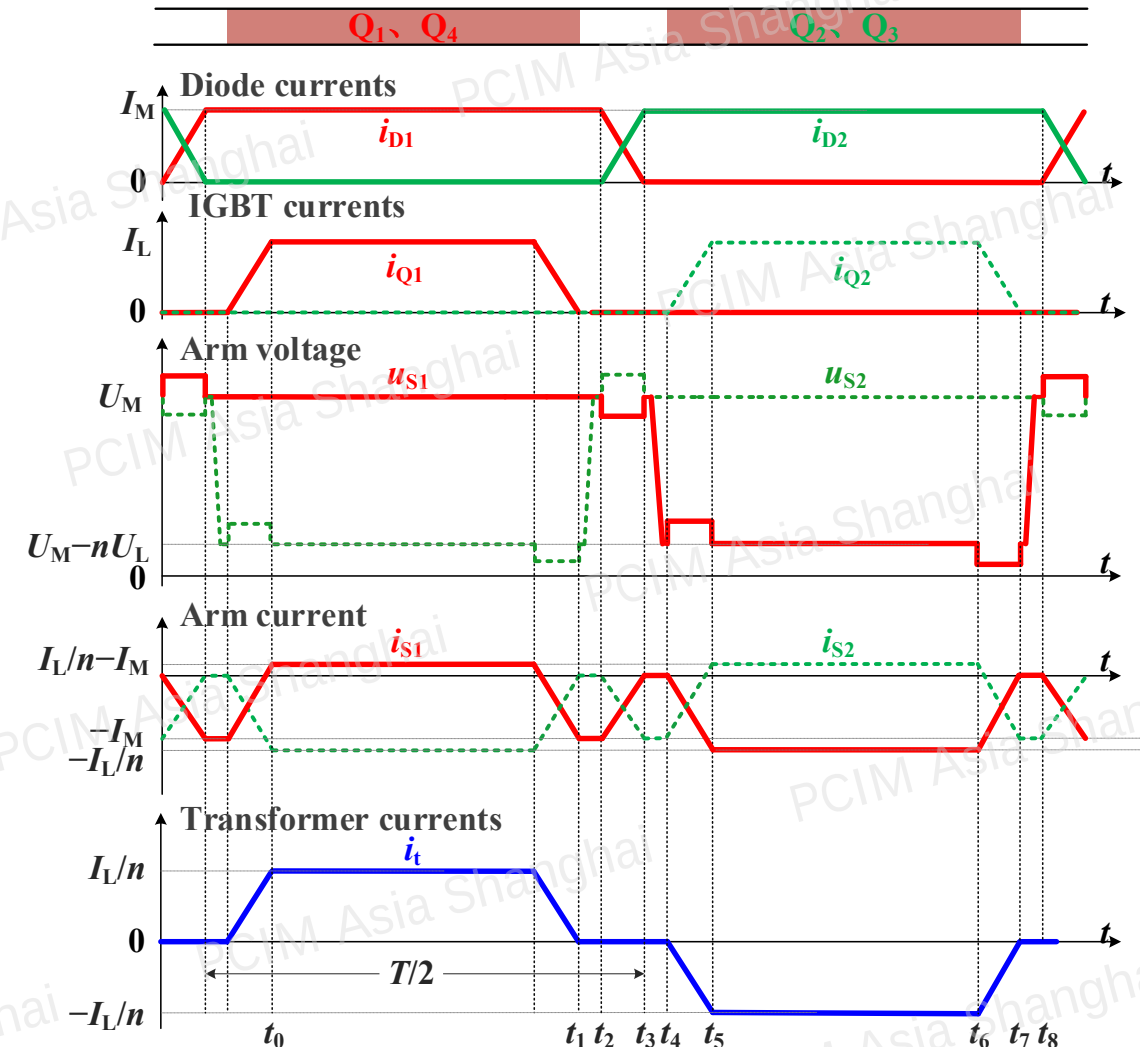
Operation principle



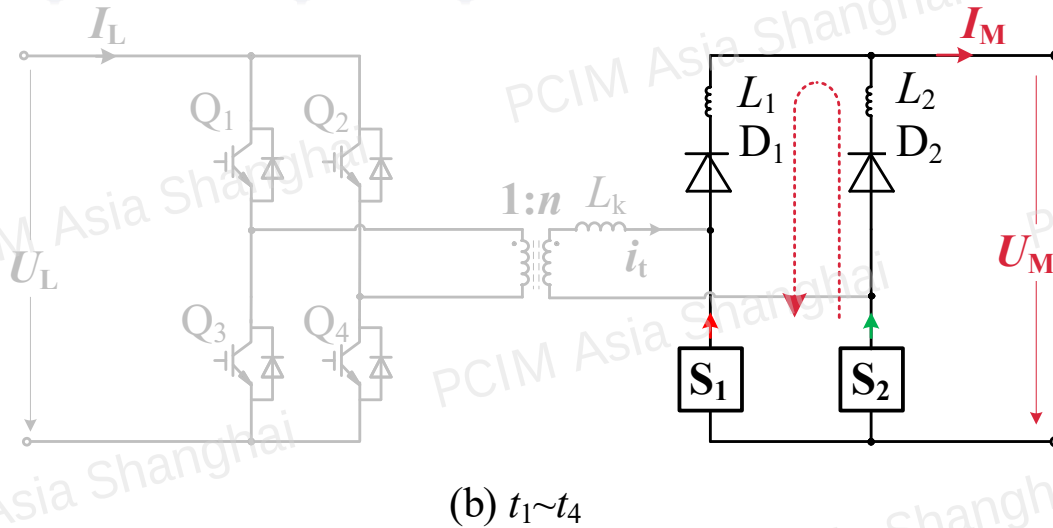
(a) $t_0 \sim t_1$

Constant current stage:

- Two IGBTs Q_1 & Q_4 ($i_{Q1}=I_L$), and one diode D_1 are in on-state ($i_{D1}=I_M$)
- One arm S_1 needs to support the MV-side voltage ($u_{S1}=U_M$)
- Another arm S_2 needs to control transformer current, sustains the voltage difference ($u_{S2}=U_M-nU_L>0$)

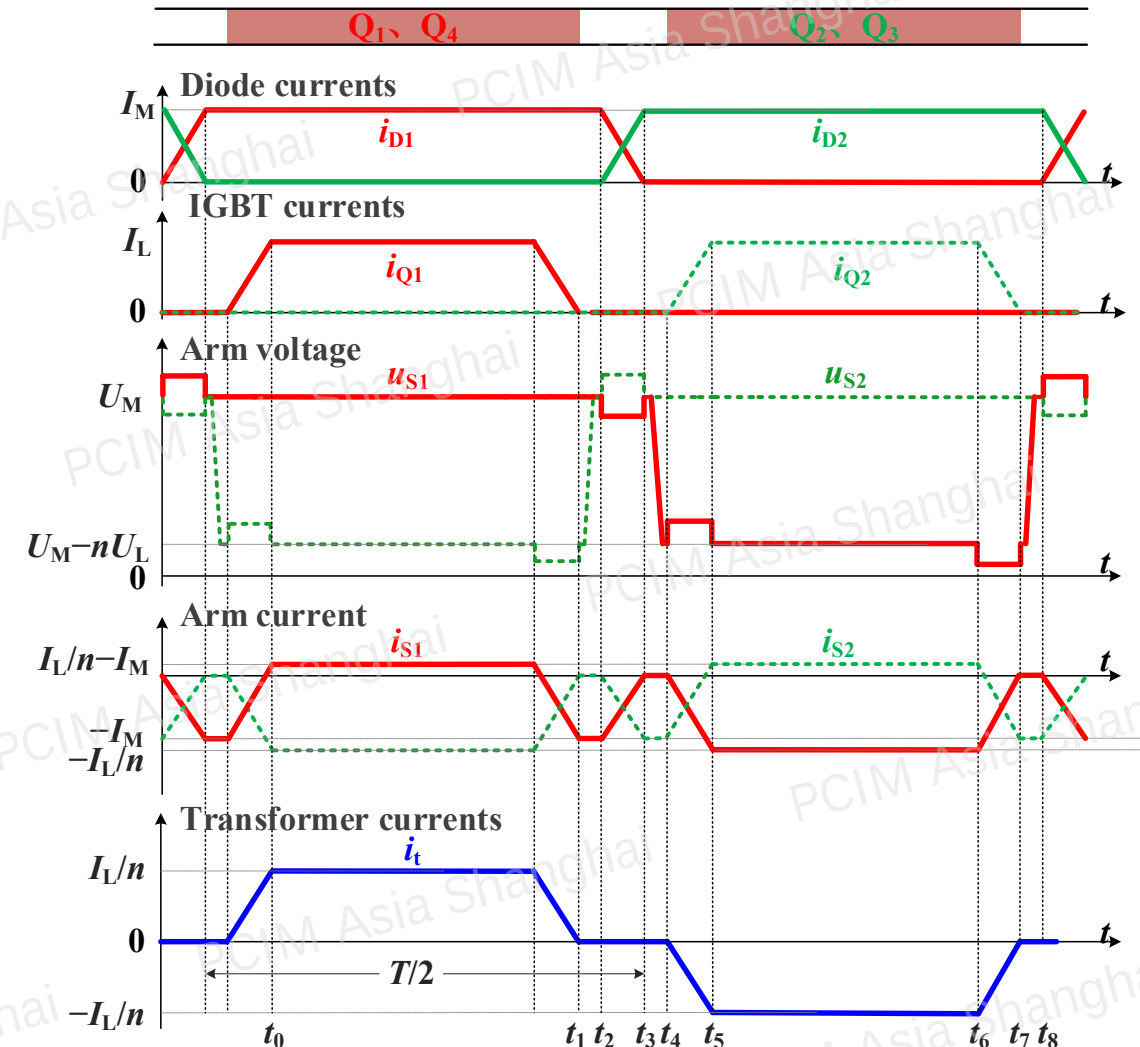


■ Operation principle

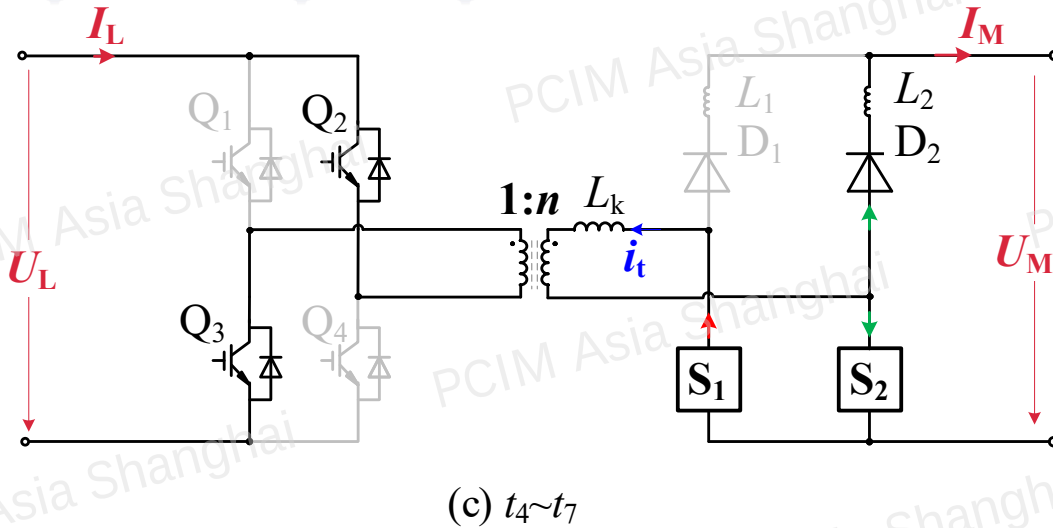


■ Diode Commutation Stage:

- Arms produce opposite voltage (U_D) across corresponding diode. Inductors L_j of the two phases → **linear commutation**
- One diode D_2 current rises from 0 to I_M , where the other diode D_1 falls from I_M to 0 with the same rate



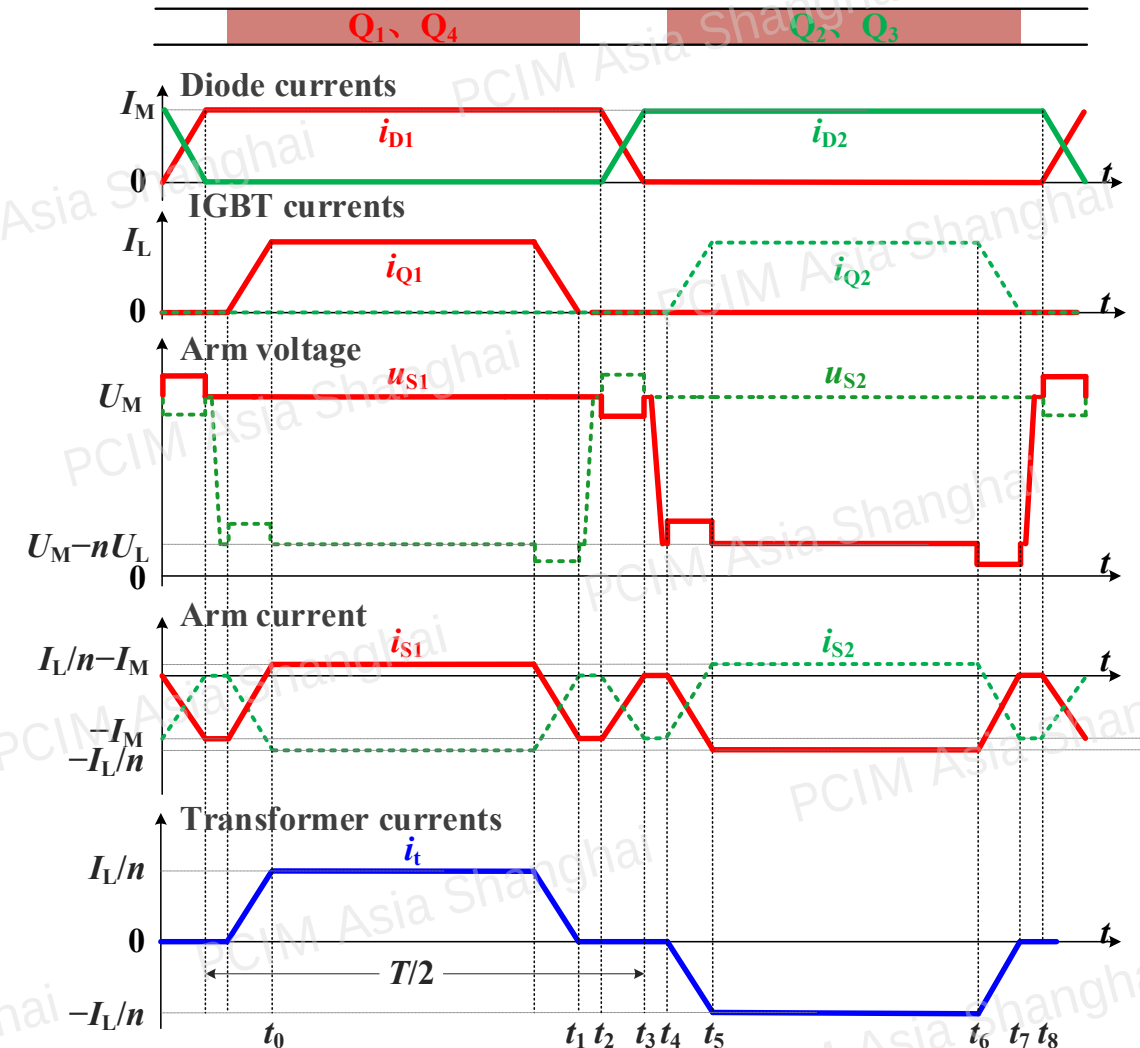
■ Operation principle



■ IGBT Commutation Stage:

- Arms produce opposite voltage (U_Q) across corresponding IGBT leakage inductors L_k
- IGBT Q_2 & Q_4 current rises from 0 to I_M
- IGBT conduction duty cycle determines the operating frequency

$$D = \frac{T - 4(T_u + T_c)}{T}$$





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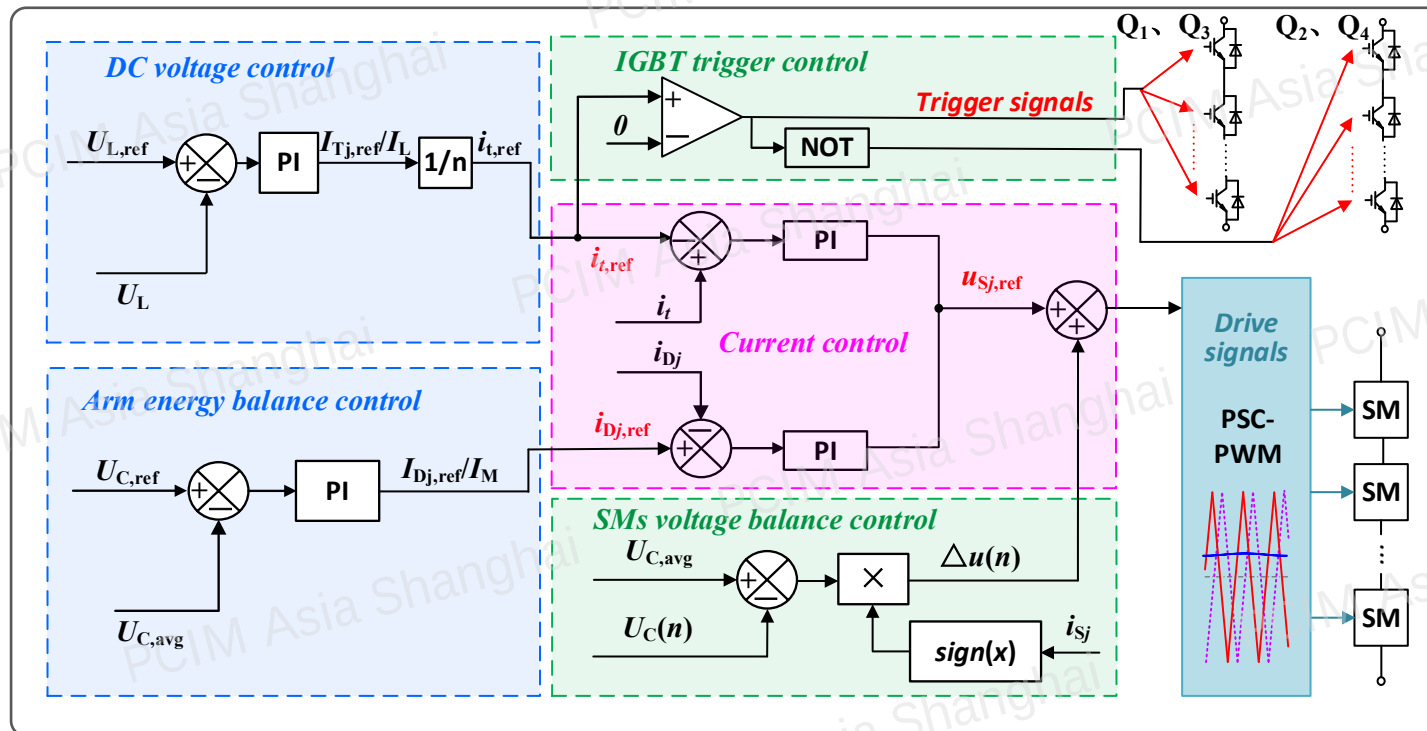


– Control Strategy

– Simulation Verification

– Conclusion

Control strategy



➤ DC voltage control & the arm energy balance control

- Generate transformer current and diode current reference signals $i_{t,ref}$ & $i_{Dj,ref}$

➤ Current control

- $i_{j,ref} - i_{Dj,ref} = i_{Sj,ref}$, perform closed-loop control on the bridge arm current and diode current. Then with the voltage feedforward control, the arm voltage modulation wave is obtained.

➤ SMs and IGBT valves control

- PWM modulation & capacitor voltage balanced control → SMs driving signals & trigger signal of IGBT valves.



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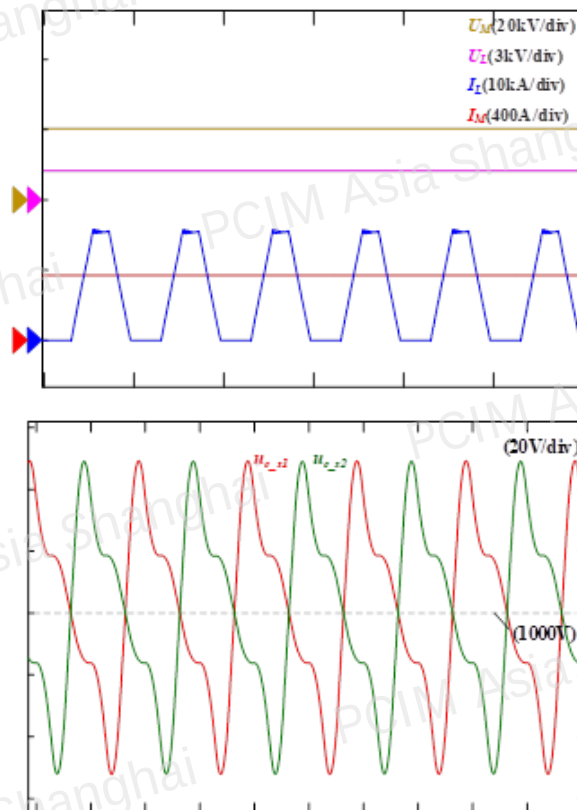
➔ – **Simulation Verification**

– Conclusion

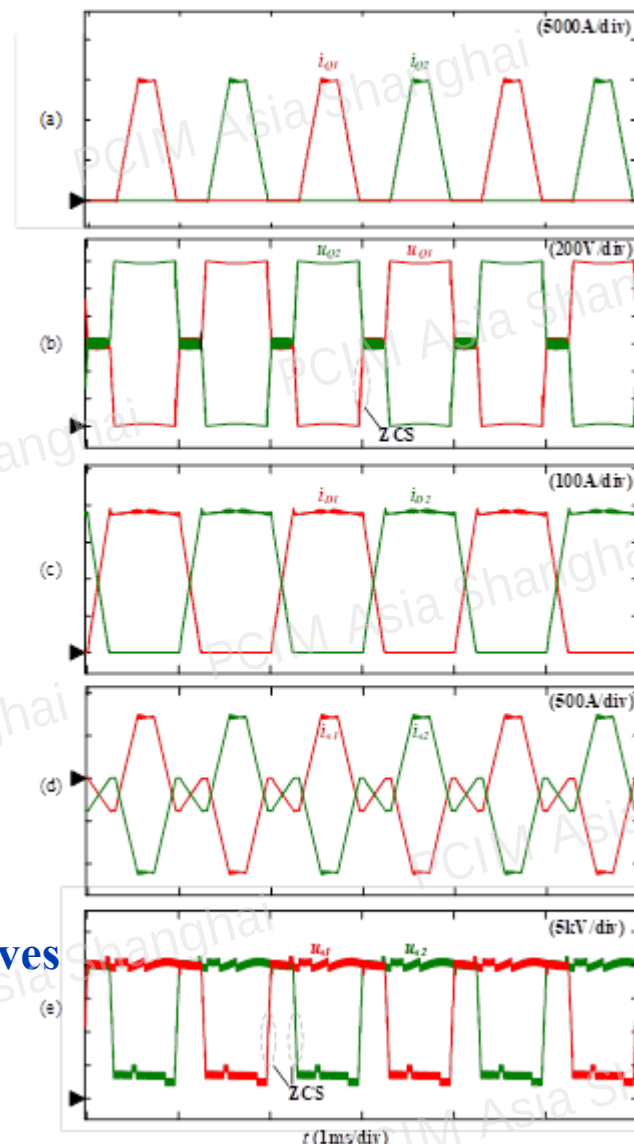
Steady state simulation results

Simulation parameters

Parameters	Simulation
Power rating P	7.8MW
LV-side voltage U_L	1.2kV
MV-side voltage U_M	20kV
Transformer frequency f	500Hz
Transformer turn ratio n	1:14
No. of SMs per arm N	25
Duty cycle of IGBT conduction α	0.42
SM capacitance C_{SM}	1.92mF
Average SM capacitance C voltage U_C	1kV
PWM carrier frequency f_{sw}	2500Hz
Inductance L_j	200uH
Leakage Inductance L_{kj}	100uH
Commutation time T_c	240us
Voltage changing time T_u	50us



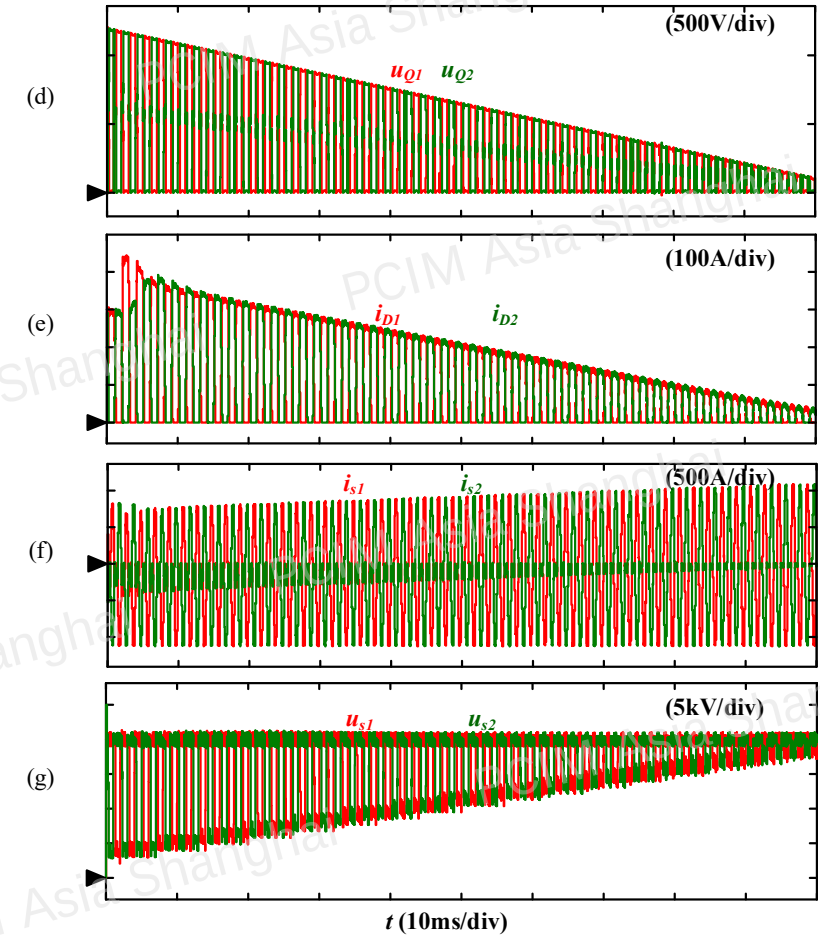
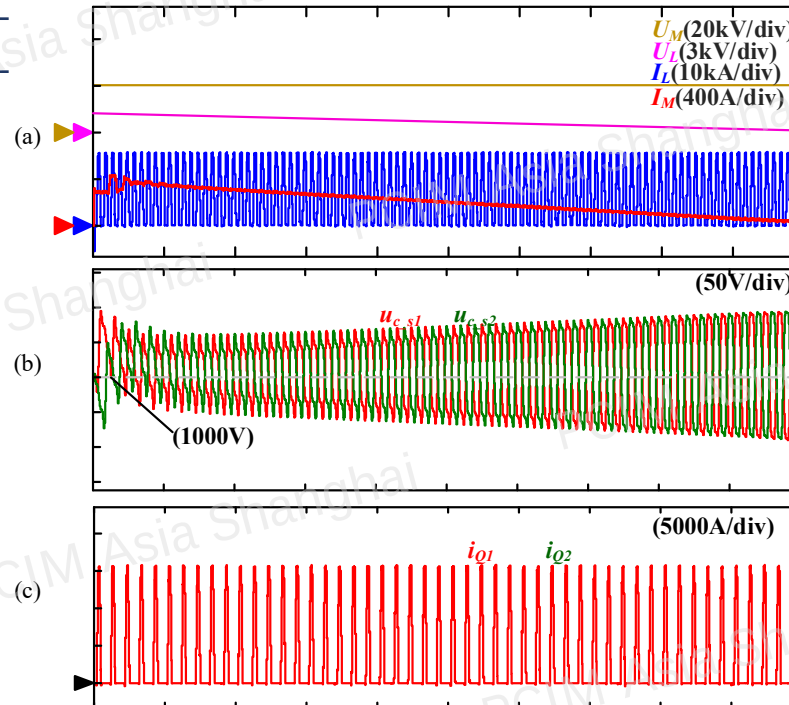
- The current of the transformer and the diode are interleaved trapezoidal waves
→ I_M is continuous and smooth
- The commutation process of IGBT and diode are linear.
- LV side IGBTs and SMs achieve ZCS



Dynamic simulation results

Simulation parameters

Parameters	Simulation
Power rating P	7.8MW
LV-side voltage U_L	1.2 ~ 0kV
MV-side voltage U_M	20kV
Transformer frequency f	500Hz
Transformer turn ratio n	1:14
No. of SMs per arm N	25
Duty cycle of IGBT conduction α	0.42
SM capacitance C_{SM}	1.92mF
Average SM capacitance C voltage U_C	1kV
PWM carrier frequency f_{sw}	2500Hz
Inductance L_j	200uH
Leakage Inductance L_{kj}	100uH
Commutation time T_c	240us
Voltage changing time T_u	50us



- U_L changes in a wide range, U_M is constant
- Linear commutation, ensuring the smooth transition
- As U_L decreases, the capacitance voltage fluctuation of the SM will increase.



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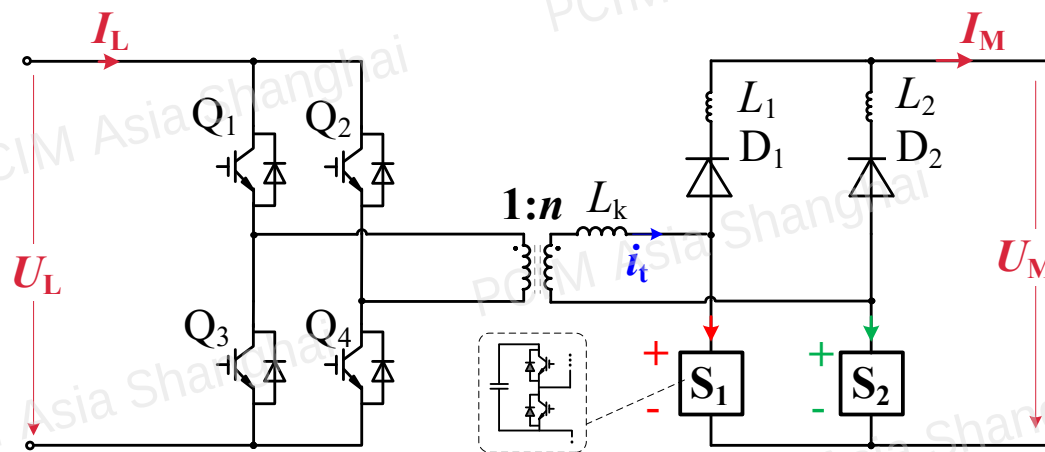
– Proposed Topology and Operating Principle

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- Topology combines the modular multilevel arm, IGBTs and diodes with low cost and high power density, which has the advantages of **high efficiency, low cost and light weight**.
- The IGBTs on the LVDC side achieve zero-current turn-off with a wide soft-switching range, eliminating the drawbacks of high turn-off losses and current stress caused by IGBT tail current, thereby enhancing the **efficiency and reliability** of the DC transformer.
- On the MVDC side, a combination of diodes and submodule arms is adopted, this configuration enables **wide voltage range regulation and high-quality current control**.



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Thanks for your attention!

Jiahui He

24 September 2025