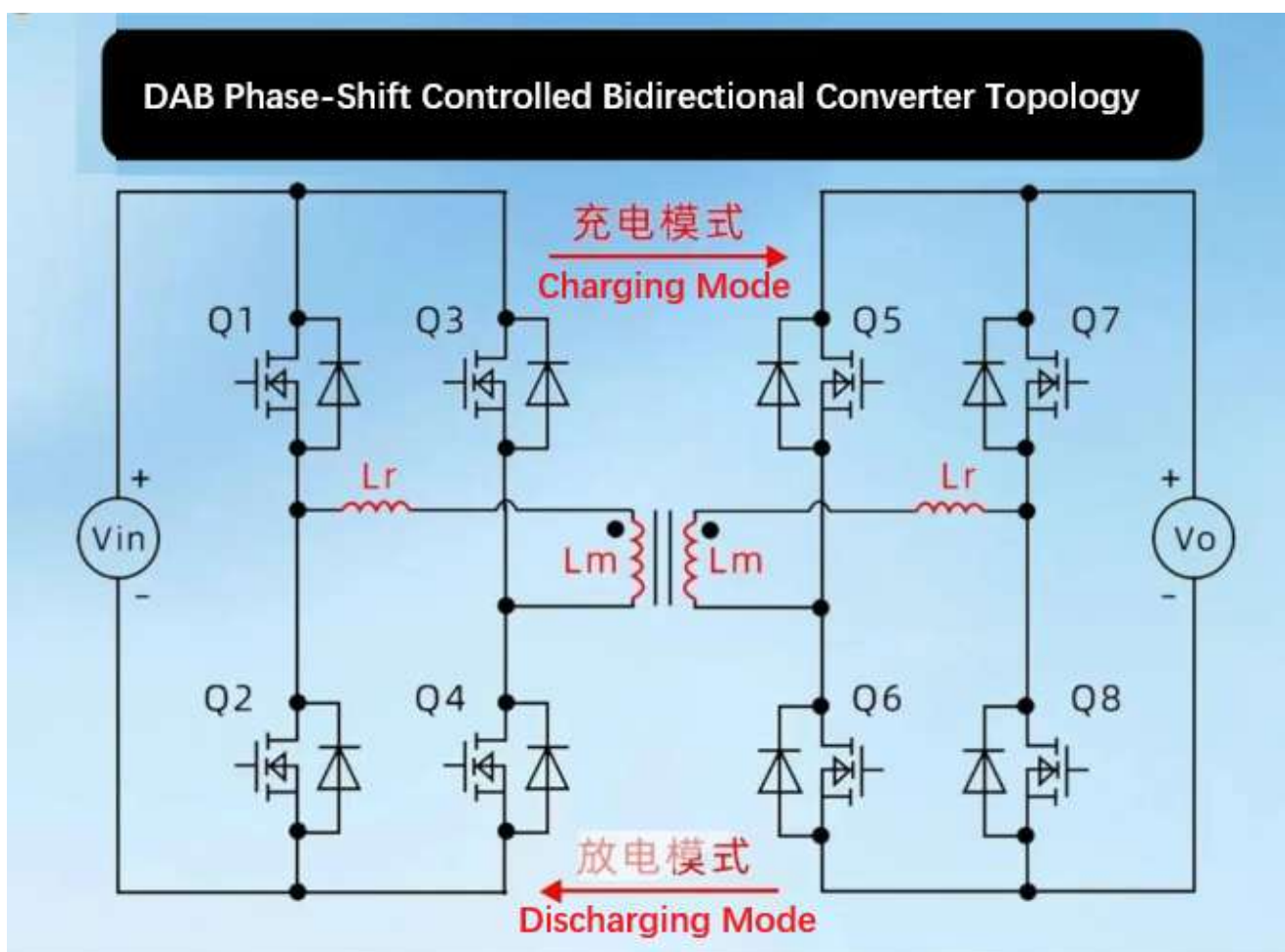
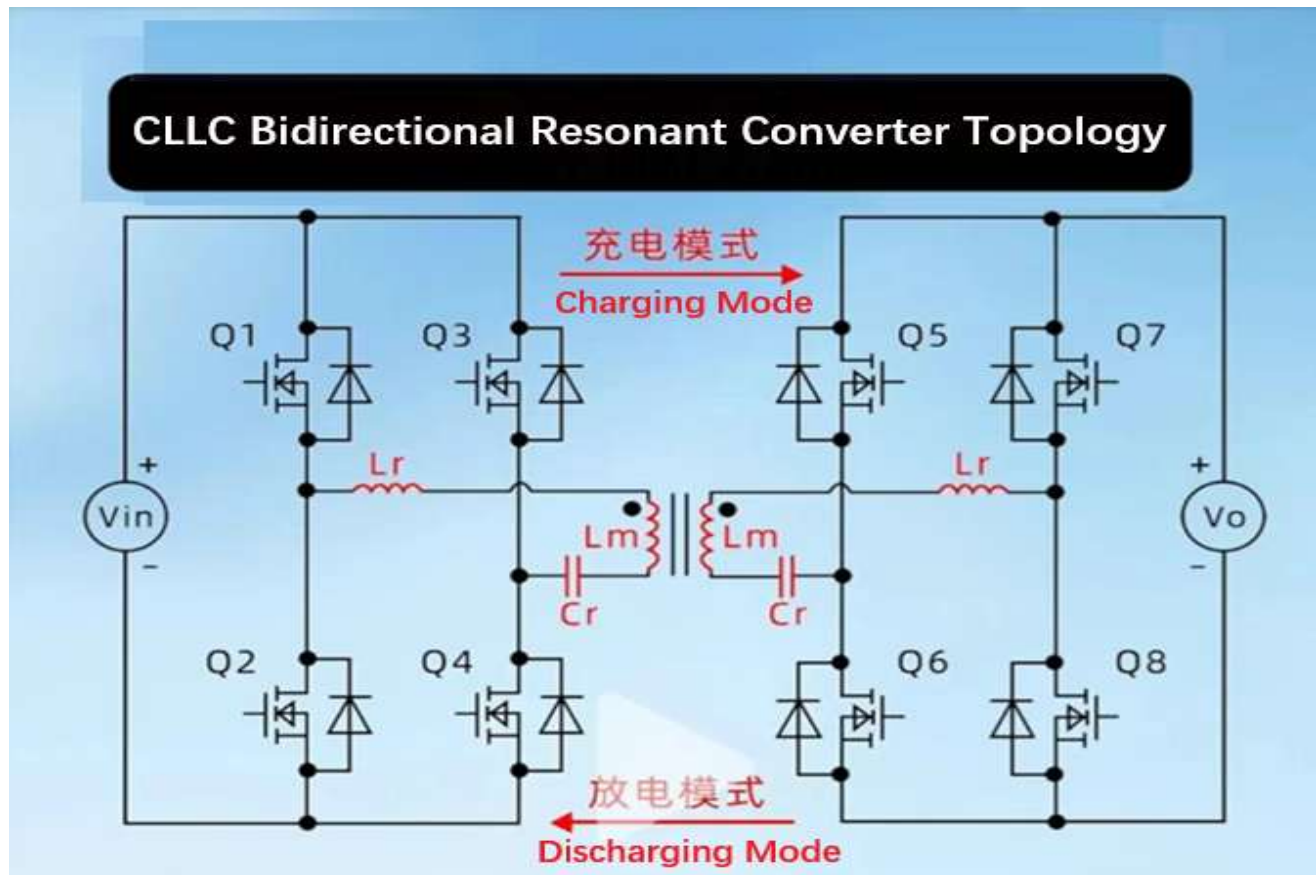


Q&A:

Design Differences and Correlations Between DAB and CLLC Topologies



Preface

This document adopts standard power electronics academic & industrial terminology, compiled as a professional Q&A manual for engineering researchers and power converter design specialists, covering fundamental definitions, operating principles, circuit design, soft-switching performance, efficiency, control schemes, application scenarios and technical trends of dual active bridge (DAB) and symmetric CLLC bidirectional resonant converters.

Nomenclature (Standard Glossary)

- DAB: Dual Active Bridge, dual active bridge isolated bidirectional DC-DC converter
- CLLC: Capacitor-Inductor-Inductor-Capacitor symmetric bidirectional resonant converter (also denoted CLLLC)
- ZVS: Zero-Voltage Switching
- ZCS: Zero-Current Switching
- FHA: Fundamental Harmonic Approximation
- PFM: Pulse Frequency Modulation
- PSM: Phase-Shift Modulation
- SPS: Single-Phase-Shift modulation
- DPS: Dual-Phase-Shift modulation
- TPS: Triple-Phase-Shift modulation
- OBC: On-Board Charger for electric vehicles
- ESS: Energy Storage System
- DC microgrid: DC distribution microgrid
- WBG: Wide Bandgap semiconductor devices
- Resonant tank: Resonant cavity network
- Magnetizing inductance (L_m): Transformer magnetizing inductance
- Resonant inductor (L_r): Series resonant inductor
- Resonant capacitor (C_r): Resonant tank capacitor
- Power density: Volumetric power density
- Galvanic isolation: Electrical isolation via high-frequency transformer

Full Expert-Oriented Q&A (20 Questions)

Q1: What are the fundamental definitions of DAB and CLLC topologies?

A1

1. Dual Active Bridge (DAB): A galvanically isolated bidirectional DC-DC converter with fully symmetrical hardware architecture. It adopts full-bridge circuits on both primary and secondary sides separated by a high-frequency transformer. The magnitude and direction of transmitted power are regulated by adjusting the phase-shift angle between square-wave voltages generated by primary and secondary full bridges.
2. CLLC Resonant Converter: A resonant-type bidirectional DC-DC topology evolved from DAB. Symmetrical resonant capacitors (C_r) are deployed on both primary and secondary transformer sides; some variants integrate additional resonant inductors to form fully symmetric CLLC resonant tanks, which is also named CLLLC in literature.

Q2: What are the core distinctions in operating mechanisms between the two topologies?

A2

1. DAB: Power transfer is realized via phase-shift modulation. A phase offset is intentionally introduced between primary and secondary square-wave voltages to build cross-coupled power flow.
2. CLLC: A LC resonant tank filters high-order harmonics of square waves, and power transmission is dominated by fundamental harmonic energy. The voltage gain of the resonant network is tuned by switching frequency modulation (PFM) or auxiliary phase-shift control to regulate output power.

Q3: How is the CLLC topology derived from the conventional DAB structure?

A3

CLLC can be regarded as a DAB variant with symmetric resonant tanks (L_r , C_r) appended to both primary and secondary windings of the high-frequency transformer. This hardware modification transforms the original hard-switching square-wave power transfer of DAB into soft-switching resonant energy transmission.

Q4: What obvious structural differences exist in their main power circuits?

A4

1. DAB: Simplified circuit architecture, consisting merely of two full-bridge switching networks and one high-frequency transformer; transformer leakage inductance inherently serves as the energy transfer inductor without extra passive resonant components.
2. CLLC: Derived from DAB with additional resonant inductors and resonant capacitors installed on both sides. The extra passive components increase component count and overall circuit complexity.

Q5: What are the distinct design priorities for high-frequency transformers in DAB and CLLC?

A5

1. DAB: Transformer leakage inductance acts as the core design parameter, which directly determines the maximum transmittable power and reactive power loss of the converter.
2. CLLC: The resonant frequency is jointly determined by the transformer and external resonant passive components. Transformer parasitic parameters including magnetizing inductance and leakage inductance must be integrated into the resonant tank for collaborative parametric optimization during design.

Q6: What is the standard design methodology for CLLC resonant parameters (L_r , C_r)?

A6

Design is predominantly implemented via the Fundamental Harmonic Approximation (FHA) method. The nonlinear resonant circuit is simplified into an equivalent linear fundamental harmonic model, and resonant component values are selected according to target voltage gain range and operational switching frequency bandwidth.

Q7: What differentiates DAB and CLLC in terms of soft-switching (ZVS/ZCS) realization range?

A7

1. DAB: Only ZVS commutation can be realized, yet the effective soft-switching operating window is narrow. ZVS is prone to failure under light-load conditions or mismatched input/output voltage ratios.

2. CLLC: The current-source characteristic of the resonant tank enables wide-range ZVS operation across full load and wide input/output voltage spectra; secondary-side switches can even achieve complete ZCS turn-off simultaneously.

Q8: How do the two topologies compare in conversion efficiency performance?

A8

1. CLLC: Exhibits superior overall efficiency. In EV OBC applications, peak efficiency reaches 97.2%, while energy storage prototypes can achieve peak efficiency exceeding 98%.
2. DAB: Slightly lower baseline efficiency. Nevertheless, several academic studies demonstrate that optimized DAB prototypes adopting WBG semiconductor devices can attain peak efficiency up to 98.9% under specific operating conditions.

Q9: What fundamental factors lead to the efficiency gap between DAB and CLLC?

A9

1. CLLC: Resonant tank enables power devices to commute under ZVS or ZCS conditions, drastically suppressing switching losses during turn-on and turn-off transients.
2. DAB: Power switches operate under hard-switching or limited-range soft-switching modes; large turn-off current induces significant turn-off switching losses.

Q10: What discrepancies exist in volumetric power density between DAB and CLLC systems?

A10

System-level comparative tests verify that CLLC achieves higher volumetric power density (e.g., 5.94 kW/L), while DAB delivers lower power density (e.g., 3.30 kW/L). The high efficiency of CLLC reduces thermal dissipation hardware requirements and allows downsized magnetic component design.

To Be Continued