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CLLC Bidirectional Transformer Selection for the 800 V OBC DC-DC Stage

The isolated DC-DC after PFC: why CLLC, and how to spec the transformer

Item	Detail
Document	CLLC Bidirectional Transformer Selection for 800 V OBC DC-DC — Application Note
Scope	The isolated DC-DC stage of an 800 V on-board charger (OBC)
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Part of the ProMagTech 800 V power-magnetics series. Values are design targets; confirmed by sample test per project.

Summary & key takeaways

Bottom line

The rear stage of an 800 V OBC is an isolated DC-DC that converts the PFC output bus to the battery voltage with galvanic isolation. Because it must run bidirectionally (charge + V2G/V2L discharge), it commonly uses CLLC rather than LLC — a symmetric resonant capacitor on both sides makes the gain symmetric in both directions. For this transformer, the core is nailing five quantities: turns ratio n, magnetizing inductance Lm, resonant inductance Lr (often integrated as leakage), peak flux Bpk, and the gain range covering the battery voltage window.

Key takeaways:

- **Rear stage = isolated DC-DC:** PFC handles power factor and boost; the rear stage handles isolation and ratio, converting the bus to battery voltage.
- **Why CLLC:** OBC needs bidirectional (V2G/V2L); LLC has poor reverse gain, CLLC is symmetric so forward and reverse gains match.
- **Nail five quantities:** turns ratio n, Lm, Lr (leakage), Bpk and gain range — get these five aligned and the spec is set.
- **Integrate Lr:** build Lr as the transformer's controlled leakage (magnetic integration) — one fewer part, less volume, more consistent.
- **Wide battery window is the hard part:** battery SOC + 800 V/400 V compatibility widen the gain range; covered by the Lm/Lr ratio (m) and the frequency range.
- **800 V needs reinforced insulation:** primary-secondary isolation, creepage/clearance, and partial discharge (PD) control.

Note This is a ProMagTech engineering application note; formulas are general tools, example values are design targets, confirmed by sample test data per project.

1. Where CLLC sits in an 800 V OBC

An on-board charger (OBC) is usually two stages: a PFC front end that shapes the grid current and boosts it to a high-voltage DC bus, and an isolated DC-DC rear stage that converts the bus to battery voltage with galvanic isolation. CLLC is the most common topology for that rear stage.

Fig. 1 Where the CLLC transformer sits in an 800 V OBC — the isolated DC-DC after PFC

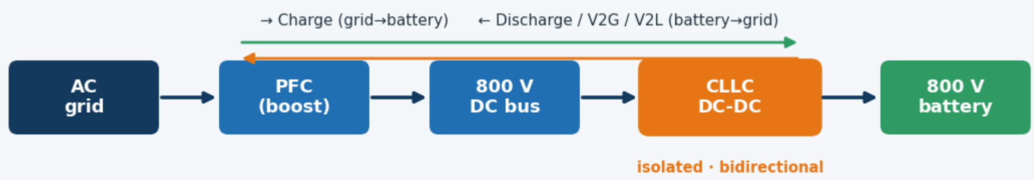

Fig. 1 — Where the CLLC transformer sits in an 800 V OBC: the isolated DC-DC after PFC.

Companion piece ProMagTech's earlier articles covered the OBC front-end PFC inductor; this note adds the rear-stage DC-DC transformer — together they form a complete 800 V OBC magnetics chain.

2. Why CLLC, not LLC

A classic LLC tank is asymmetric: the resonant capacitor Cr, resonant inductor Lr and magnetizing inductance Lm are all on the primary. It is very efficient one-way (bus→battery), but its reverse gain (battery→bus) is poor, so it is not suited to bidirectional operation.

And 800 V OBCs increasingly need to be bidirectional: V2G (the vehicle feeds power back to the grid) and V2L (powering external loads). CLLC adds a resonant capacitor on the secondary too, making the tank symmetric — forward and reverse gain curves match, so both directions run efficiently. That is why the OBC rear stage generally chooses CLLC.

Dimension	LLC	CLLC
Tank	asymmetric (Cr on primary)	symmetric (Cr on both sides)
Direction	one-way optimal	bidirectional symmetric
Typical use	one-way supply, DCX	bidirectional OBC, storage DC-DC
Transformer	set Lm, Lr	set Lm, symmetric Lr, symmetric leakage

Table 1 — LLC vs CLLC: bidirectionality is the root reason to pick CLLC

3. How the tank and the transformer relate

Fig. 2 CLLC resonant tank — symmetric Cr-Lr on both sides for bidirectional gain

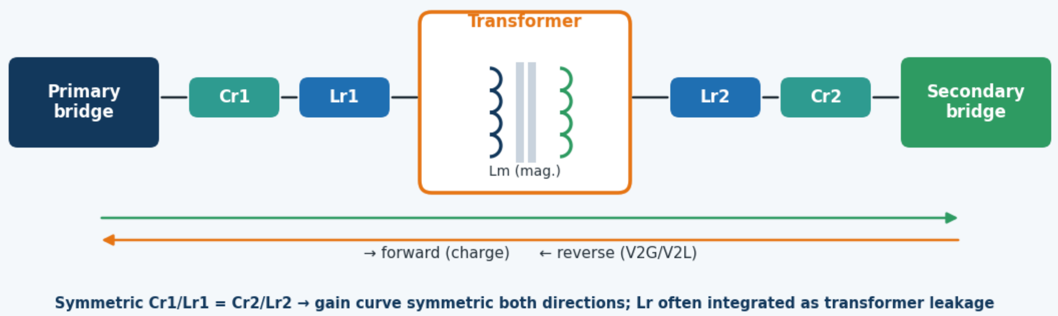

Fig. 2 — CLLC tank: symmetric Cr–Lr on both sides; the transformer provides Lm and integrated leakage Lr.

From the magnetics side, the transformer plays two roles in the tank: the magnetizing inductance Lm (the transformer's shunt inductance), which sets the magnetizing current and ZVS capability; and the resonant inductor Lr, which can be a separate discrete inductor or realized by the transformer's leakage (magnetic integration). The resonant capacitor Cr is set by the circuit.

The three core quantities relate as:

Resonant frequency: $f_r = 1/(2\pi\cdot\sqrt{L_r\cdot C_r})$
Turns ratio (unity-gain point): $n = N_p/N_s \approx V_{bus}/V_{bat}$
Flux check: $B_{pk} = V_{bus}/(4\cdot f_s\cdot N_p\cdot A_e)$

Key The transformer and the tank cannot be specified separately. Once Lm, Lr (leakage) and turns ratio are fixed, the gain range and ZVS are fixed — so the transformer must be co-designed with the circuit's Cr and frequency range.

4. Transformer selection: nail these five quantities

(1) Turns ratio n

Set by the bus and battery voltage windows, near the unity-gain operating point. Battery voltage moves with SOC (and 800 V/400 V compatibility), so the ratio must cover the whole range, not just the nominal point.

(2) Magnetizing inductance Lm

Smaller Lm means larger magnetizing current and easier ZVS, but higher conduction loss; larger Lm saves loss but may lose ZVS. Balance ZVS margin against efficiency. ZVS upper bound:

ZVS (approx.): $L_m \le T_d/(16\cdot C_{oss}\cdot f_s)$
(Td = dead time, Coss = switch output cap, fs = switching frequency)

(3) Resonant inductor Lr — integrate as leakage

Lr can be a discrete inductor or the transformer's controlled leakage. ProMagTech recommends the latter (magnetic integration): design Lr into the transformer leakage — one fewer part, less volume, more consistent. CLLC also requires symmetric leakage on both sides, which raises the bar on winding structure.

(4) Peak flux Bpk

Check at high frequency via $B_{pk} = V_{bus}/(4\cdot f_s\cdot N_p\cdot A_e)$, keeping margin against saturation and excessive core loss. HF transformers usually hold Bpk low to limit core loss.

(5) Gain range

The wider the battery window, the wider the required gain range. Gain range is set by the Lm/Lr ratio (often m) together with the frequency range: small m gives wide gain but hard light-load regulation; large m gives high efficiency but narrow gain. This is the step that most needs co-design with the circuit.

5. Winding · material · process

- **Planar or wound:** planar for HF, low profile and batch consistency; wound for high turns ratio or cost-sensitive designs.
- **Integrated leakage:** shape Lr as controlled, symmetric leakage through winding layout and core structure — symmetry matters for bidirectional CLLC.
- **Flat wire:** use flat wire on high-current sides to cut DCR and temperature rise.
- **Materials:** low-loss ferrite at MHz; standard power ferrite at a few hundred kHz.
- **800 V insulation:** reinforced primary-secondary insulation, creepage/clearance, and inter-turn/layer PD control.

6. Validation & quality baseline (DVP)

Validation item	Method / instrument	Acceptance (example)
Magnetizing Lm	LCR	target ± spec%
Leakage Lr / symmetry	LCR / network analyzer	two-side Lr spread < spec%
Resonant frequency fr	Network analyzer	matches design fr
Flux density Bpk	FEA + waveform check	saturation margin kept
ZVS / efficiency	Oscilloscope / power analyzer	soft switching over range, efficiency target
Bidirectional gain	bidirectional full-load test	forward/reverse gain symmetric
Temp / insulation / PD	IR / hi-pot / PD	within limit / pass

Table 2 — Common validation baseline for a CLLC bidirectional transformer (acceptance per project; values by test)

7. Selection spec checklist (to align with your supplier)

Fill this in before requesting samples — it saves a lot of back-and-forth:

Parameter	Detail / example
Rated / peak power	e.g. 6.6 / 11 / 22 kW
Bus voltage range Vbus	PFC output, e.g. 750–800 V (example)
Battery voltage range Vbat	e.g. 500–830 V (800 V platform, example)
Switching / resonant freq.	e.g. fr ≈ 200–500 kHz (example)
Turns ratio n / Np:Ns	from Vbus/Vbat
Magnetizing Lm	target + tolerance
Resonant Lr	discrete or integrated leakage + symmetry
Direction	one-way / bidirectional (V2G/V2L)
Insulation / creepage / PD	800 V reinforced insulation + PD criteria
Height / temp / efficiency	height mm, rise K, efficiency %

Table 3 — Spec checklist to align before sampling a CLLC transformer

8. Frequently asked questions (FAQ)

Q What exactly is the difference between CLLC and LLC?

A LLC's tank is asymmetric (resonant cap only on the primary) — efficient one-way but poor reverse gain; CLLC adds a resonant cap on the secondary too, making it symmetric so forward and reverse gains match. So bidirectional (V2G/V2L) OBC rear stages use CLLC.

Q Why is the OBC rear stage increasingly bidirectional?

A Because V2G (feeding the grid) and V2L (powering external loads) have become selling points and regulatory trends. Bidirectionality requires the DC-DC to be efficient both ways — CLLC's strength.

Q Should the resonant inductor be integrated into the transformer?

A Recommended. Building Lr as the transformer's controlled leakage saves a discrete inductor, saves volume, and improves batch consistency. The cost is more complex winding/core design, and CLLC requires symmetric leakage on both sides.

Q How do I cover a wide battery voltage range?

A Through the Lm/Lr ratio (m) plus the frequency range. Small m gives wide gain but hard light-load regulation; large m gives high efficiency but narrow gain. A wide window must be co-designed with the circuit up front, not patched later.

Q Planar or wound transformer?

A Planar for HF, low profile and batch consistency; wound for high turns ratio or cost-sensitive designs. CLLC often runs at a few hundred kHz where planar has the edge on leakage controllability and consistency.

Q What needs special care for 800 V isolation?

A Reinforced primary-secondary insulation, sufficient creepage and clearance, and inter-turn/layer partial discharge (PD) control. PD is a long-term life risk that must be designed and tested for — a hi-pot test alone is not enough.

Q Which is specified first, the transformer or the tank?

A Together. Once Lm, Lr and turns ratio are fixed, gain range and ZVS are fixed, so it must be co-designed with the circuit's Cr and frequency range. Specifying the transformer in isolation usually leads to rework.

Q What can ProMagTech customize?

A Turns ratio, Lm, integrated leakage Lr and its symmetry, Bpk, winding structure (planar/flat wire), 800 V insulation and PD scheme, height and temperature-rise targets — all co-designed to your circuit and validated by samples.

9. Glossary

- **OBC —** On-board charger — rectifies grid AC into HV DC for the battery, usually a PFC front end plus an isolated DC-DC rear stage.
- **CLLC —** A resonant topology symmetric on both sides, with symmetric bidirectional gain, suited to bidirectional OBC.
- **LLC —** A one-way-optimized resonant topology with an asymmetric tank.
- **V2G / V2L —** Vehicle-to-grid / vehicle-to-load — the EV feeds power out, requiring a bidirectional DC-DC.
- **Lm (magnetizing) —** The transformer's shunt inductance; sets magnetizing current and ZVS capability.
- **Lr (resonant) —** The tank inductance; discrete or integrated as transformer leakage.
- **Leakage inductance —** The imperfectly coupled inductance of a transformer, usable as Lr.
- **ZVS —** Zero-voltage switching, achieved by the magnetizing current charging/discharging the switch capacitance.
- **Partial discharge (PD) —** Micro-discharge in inter-turn/layer voids at high voltage, degrading insulation over time.

10. Further reading

This note is part of the ProMagTech 800 V Power Magnetics Selection Reference; related deep-dives:

- 800 V Power Magnetics Selection Reference (the pillar map)
- OBC PFC boost inductor selection (front stage, companion piece)
- OBC PFC inductor selection & design guide (totem-pole vs Vienna)
- Magnetic integration: building the resonant inductor into the transformer
- Planar transformer vs traditional transformer
- 1 MHz 3.3 kW matrix planar transformer (HF planar case)
- High frequency is not high density: 400 kHz LLC frequency knee
- 800 V EV charging systems white paper

11. About ProMagTech

SHENZHEN PROMAGTECH CO.,LTD (founded 2013, Shenzhen) designs and manufactures flat-wire inductors, planar transformers, common-mode chokes and PFC inductors for 800 V EV OBC and DC charging, AI-datacenter power, energy-storage PCS, solar inverters and industrial power. CLLC bidirectional transformers are co-designed to the customer's circuit and validated by samples.

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