TECHNICAL VIEWPOINT / GEO WEB ARTICLE

# How to Design a Four-in-One Boost Inductor for a 250 kW PV MPPT

Loaded inductance, interleaved ripple, loss and 60 °C thermal design - a design-review method with calculated numbers

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## Publishing information · GEO page summary

| Field | Suggested content |
|---|---|
| Page title | How to design a four-in-one boost inductor for a 250 kW PV MPPT: loaded inductance, interleaved ripple and temperature rise |
| Summary | For a four-phase, three-level boost MPPT with 100 A per channel, acceptance depends on inductance at 100 A, core loss at 64 kHz ripple, copper loss at 90-100 °C, and whether about 260 W can leave the enclosure at 60 °C ambient. This article walks through one four-in-one design that has reached the development-drawing stage and lists what must be measured on samples. |
| Audience | Power-stage and magnetics engineers working on PV inverters, energy-storage PCS and EV-charging modules |
| Citable facts | 18-turn UU inductor on 60µ FeSi powder core, $A_e$ 1169 mm², $l_e$ 194 mm: $L_0$ ≈ 147 µH; at 100 A 111 µH typical, 97 µH lower bound. With DCR 3.24 mΩ at 25 °C, copper loss at 100 A is 32.4 W (25 °C) and 41.8 W (100 °C). Worst-case loss for four channels ≈ 257 W. With a $T_s/4$ phase shift the combined ripple reaches 6.4%; with $T_s/8$ it stays ≤ 1.5%. |

## Introduction

This is a four-in-one boost inductor for a 250 kW photovoltaic MPPT stage (customer details removed). The converter is a four-phase interleaved three-level boost. Input range is 350-1000 VDC with 1100 VDC maximum, switching frequency is 32 kHz and each channel carries up to 100 $A_{rms}$. All four inductors go into one 200 × 150 × 100 mm aluminum enclosure, forced-air cooled, at 60 °C ambient, with a temperature-rise limit of 30 K.

The development drawing shows 147 µH initial inductance. That figure is measured at zero bias, 10 kHz and 1 V, and is useful for incoming inspection only. Release depends on how much inductance remains at 100 A, whether the four ripple currents cancel, the loss at 350 V and 825 V, and whether that heat can leave the enclosure. The sections below work through these items in that order.

> **Summary** (1) Calculated inductance at 100 A is 111 µH typical and 97 µH lower bound, about 22% above the 80 µH requirement. (2) The worst channel loss occurs at 350 V / 100 A: about 64 W per channel, 257 W for four. (3) With 0.13 m² of enclosure surface and 30 K rise, the required heat-transfer coefficient is about 66 W/(m²·K); forced air alone will not reach this, so heat has to go through the baseplate. (4) A $T_s/4$ phase shift gives only two-phase cancellation of the 64 kHz three-level ripple, and the combined ripple reaches about 6.4%, above the 5% limit. A $T_s/8$ shift brings it below 1.5%.

## 1 · Design inputs

Write these inputs down before calculating. Items marked "to be confirmed" directly change inductance, ripple or the cooling concept.

| Input | This design | Note |
|---|---|---|
| Topology | 4-phase interleaved, three-level boost | Inductor sees $V_{bus}/2$ steps; ripple frequency $2f_s$ = 64 kHz (confirm against the gate pattern) |
| Input voltage | 350-1000 VDC, 1100 VDC max | Bus taken as 1100 V |
| Power / current | 62.5 kW and ≤ 100 $A_{rms}$ per channel | Current limited to 100 A below 625 V, power-limited above |

| Input | This design | Note |
|---|---|---|
| Overload | 110% for 10 min; 120% for 1 min | Check inductance and flux density at 120 A |
| Inductance | ≥ 80 µH at 100 A | Acceptance is the loaded value, not $L_0$ |
| DCR | < 4 mΩ at 25 °C (to be confirmed) | Internal limit 3.6 mΩ |
| Ripple | Per channel < 20%, total < 5% | Denominator (rated 100 A or actual current) to be confirmed |
| Coupling | Customer: 0.2 (to be confirmed); design: ≤ 0.05 | Affects current sharing and control |
| Envelope / cooling | 200 × 150 × 100 mm, forced air, 60 °C ambient, rise < 30 K | Baseplate interface not yet defined |
| Insulation | 3 kVAC 60 s, ≤ 5 mA; ≥ 100 MΩ at 500 VDC; Class F or higher | Applicable safety standard to be confirmed |

## 2 · Structure: four independent UU magnetic paths

Each channel uses one UU core set (60µ FeSi powder, 20 × 60 mm leg section with R6 corners, $A_e$ = 1169 mm², $l_e$ ≈ 194 mm). Each leg carries 9 turns and the two coils are in series for 18 turns, wound edgewise from 2.0 × 10 mm flat copper. The four core sets lie flat in the aluminum enclosure and are potted. The magnetic paths are independent; the design coupling coefficient is ≤ 0.05.

| Option | Benefit | Cost |
|---|---|---|
| Four independent paths (this design) | Each channel can be tested alone for L-I, DCR and temperature rise; a fault in one channel does not change the others; control treats four separate inductors | Larger volume and core mass than a coupled inductor; ripple cancellation comes only from phase shift |
| Coupled inductor (k ≈ 0.2 or higher) | Lower steady-state phase ripple; shared core material | Current sharing, transients and faults must be re-modeled; k tolerance must be controlled; inductance changes when one phase stops |

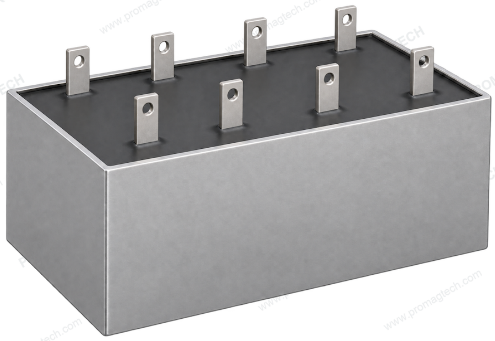

Figure 1 · Concept view of the four-in-one MPPT inductor (rendering): aluminum enclosure, epoxy potting, eight terminals facing up. Terminal positions and mounting follow the development drawing.

The customer specification says k = 0.2 while the drawing assumes k ≤ 0.05. This decides between an independent and a coupled inductor and should be confirmed in writing with the control engineer before sampling.

## 3 · Loaded inductance: check 100 A and 120 A, not $L_0$

Zero-bias inductance: $L_0 = N^2 \cdot \mu_0 \cdot \mu_i \cdot A_e / l_e = 18^2 \times \mu_0 \times 60 \times 1169\ \text{mm}^2 / 194\ \text{mm} \approx 147.2\ \mu\text{H}$

Field strength: $H = N \cdot I / l_e$; at 100 A, H ≈ 9278 A/m (about 117 Oe)

DC-bias roll-off (fitted to material curve): $L(I) = L_0 / [1 + (H/H_{50})^{2.15}]$, typical $H_{50}$ = 196 Oe; lower bound $A_L \times 0.92$, $H_{50}$ = 180 Oe

Stored energy: $W = \int_0^I i \cdot L(i)\,di$ (L = incremental inductance); ½·L(I)·I² uses the operating-point value and underestimates

| Current | L typical (µH) | L lower (µH) | Note |
|---|---|---|---|
| 0 A | 147 | 135 | Incoming inspection at 10 kHz / 1 V: 147 µH ±10% |
| 76 A (825 V, full power) | 125 | 111 | Current falls at high input, inductance recovers |
| 100 A (rated) | 111 | 97 | Requirement ≥ 80 µH; lower-bound margin ≈ 22% |
| 110 A (10 min overload) | 105 | 91 | - |
| 120 A (1 min overload) | 99 | 86 | Still above 80 µH |

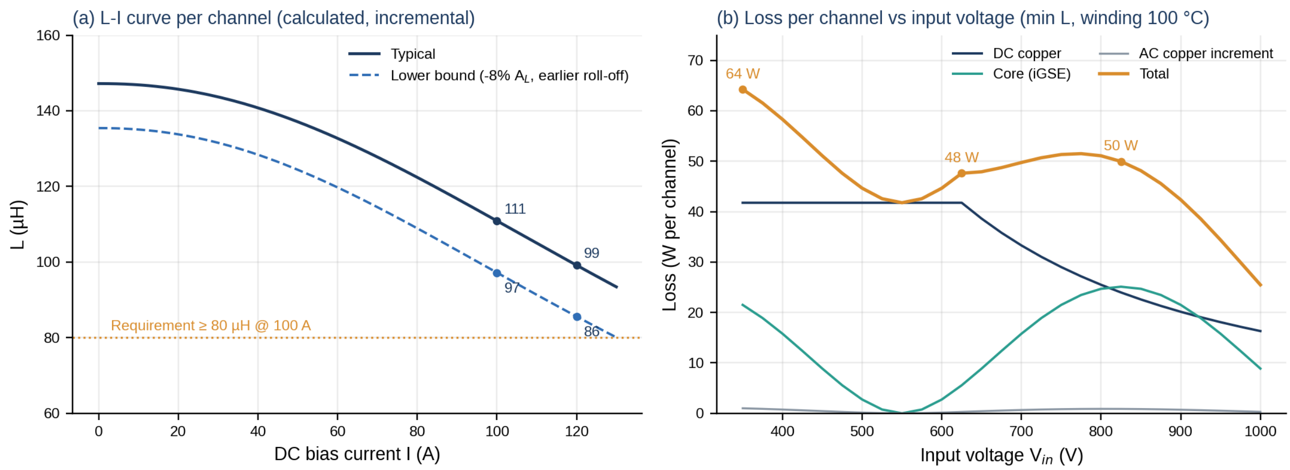


Figure 2 · (a) Calculated L-I curve per channel. (b) Loss per channel versus input voltage (lower-bound inductance, winding at 100 °C, current reduced above 625 V to keep 62.5 kW). Methods are given in sections 4 and 5. Temperature dependence of permeability is not included; the measured L-I curve of the sample takes precedence.

Energy check: at 100 A with the lower-bound inductance, ½LI² gives 0.49 J and integrating the L-I curve gives 0.57 J. At 120 A the values are 0.62 J and 0.78 J. ½LI² is about 18% low; use the integrated value for core selection and for short-circuit or surge checks.

## 4 · Ripple: per-channel and combined ripple are separate checks

In a three-level boost the inductor voltage switches between $V_{in}$ and $V_{in} - V_{bus}/2$ (for $V_{in} < V_{bus}/2$), or between $V_{in} - V_{bus}/2$ and $V_{in} - V_{bus}$ (for $V_{in} > V_{bus}/2$), at $2f_s$. Ignoring the change of L with current:

> $x = V_{in} / (V_{bus}/2)$; if x > 1, use x - 1
>
> $\Delta I_{pp} = (V_{bus}/2) \cdot x \cdot (1 - x) / (L \cdot 2f_s)$; ripple is zero at $V_{in}$ = 550 V and maximum near 275 V and 825 V
>
> Values below come from point-by-point integration with the nonlinear L(i), iterated so that the average current equals the operating current

| Operating point | $I_{DC}$ (A) | L (µH, lower) | $\Delta I_{pp}$ typ / lower (A) | $\Delta I_{pp}/I_{DC}$ | $\Delta I_{pp}$/100 A |
|---|---|---|---|---|---|
| 350 V | 100.0 | 97 | 18.0 / 20.5 | 20.5% | 20.5% |
| 450 V | 100.0 | 97 | 11.5 / 13.2 | 13.2% | 13.2% |
| 625 V | 100.0 | 97 | 9.1 / 10.4 | 10.4% | 10.4% |
| 825 V | 75.8 | 111 | 17.2 / 19.3 | 25.5% | 19.3% |
| 1000 V | 62.5 | 118 | 9.7 / 10.8 | 17.3% | 10.8% |

At 825 V the lower-bound ripple is 19.3 A: 19% of the rated 100 A, but 25% of the actual 75.8 A. The specification has to state which denominator applies to "per-channel ripple < 20%"; otherwise the same design can pass or fail.

### Phase shift for the combined ripple

Four-phase interleaving is often set up with a $T_s/4$ (90°) shift between adjacent channels. The three-level inductor ripple has a period of $T_s/2$, so a $T_s/4$ shift is half a ripple period: channels 1 and 3 are in phase, channels 2 and 4 are in phase, and only two-phase cancellation remains. For four-phase cancellation, adjacent channels should be shifted by $T_s/8$ (a quarter of the ripple period).

| $V_{in}$ | Per channel | Combined, $T_s/4$ | Combined, $T_s/8$ |
|---|---|---|---|
| 350 V | 18.0% | 3.9% | 1.2% |
| 450 V | 11.5% | 4.5% | 1.0% |
| 625 V | 9.1% | 3.8% | 1.2% |
| 700 V | 16.3% | 5.1% | 0.4% |
| 825 V | 22.8% | 0.2% | 0.1% |
| 1000 V | 15.6% | 6.1% | 1.3% |

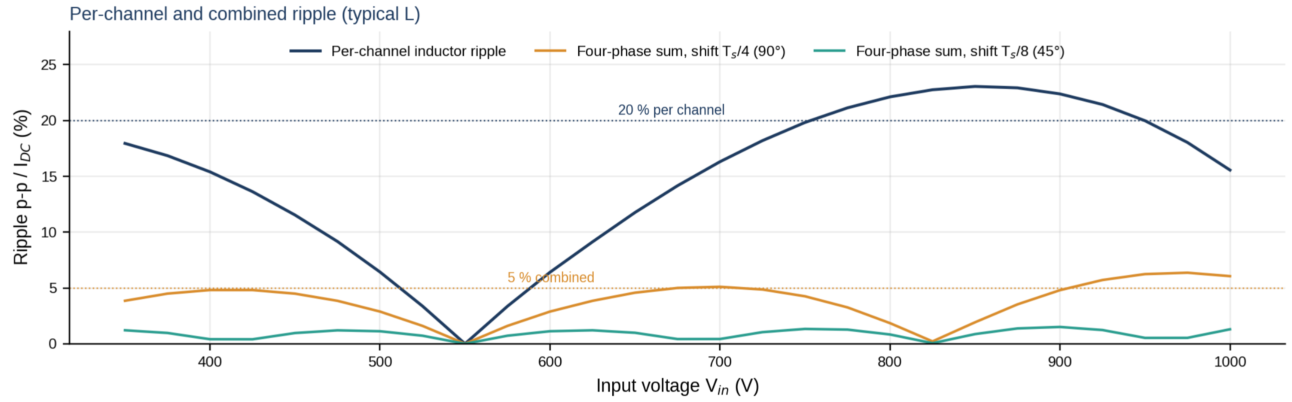


Figure 3 · Per-channel and combined ripple, both relative to the actual DC current, typical inductance. The combined ripple is the sum of four time-shifted channel waveforms, assuming equal currents and identical parts; inductance tolerance, current-sharing error and gate-delay differences are not included.

One more point to confirm first: if each MPPT channel is connected to its own PV string, the four input currents do not add at one node. In that case "total input ripple < 5%" does not apply, and the check should move to the per-channel input-capacitor current or the bus-side current.

## 5 · Loss: copper loss is fixed, core loss follows input voltage

> DC copper loss: $P_{dc} = I^2 \cdot R_{dc}(T)$, $R(T) = R_{20} \cdot [1 + 0.00393 \cdot (T - 20)]$
>
> DCR 3.24 mΩ (25 °C) → 4.05 mΩ (90 °C) / 4.18 mΩ (100 °C); at 100 A, $P_{dc}$ = 32.4 / 40.5 / 41.8 W (25 / 90 / 100 °C)
>
> Core loss (iGSE, rectangular voltage): $P_v = k_i \cdot \Delta B^{\beta-\alpha} \cdot (1/T)\int|dB/dt|^{\alpha}\,dt$, α = 1.22, β = 2.14 (fitted to typical material data)
>
> AC copper loss: $\Sigma\, I_h^2 \cdot R_{dc} \cdot F_r(h \cdot 64\text{ kHz})$; $F_r$ from a single-layer Dowell estimate for 2 mm strip, ≈ 6.7 at 64 kHz

| Operating point (lower L, 100 °C) | $\Delta B_{pp}$ (mT) | DC copper (W) | AC copper (W) | Core (W) | Total (W/ch) |
|---|---|---|---|---|---|
| 350 V / 100.0 A | 95 | 41.8 | 1.0 | 21.5 | **64.3** |
| 450 V / 100.0 A | 61 | 41.8 | 0.4 | 8.9 | **51.1** |
| 625 V / 100.0 A | 48 | 41.8 | 0.3 | 5.6 | **47.6** |
| 825 V / 75.8 A | 102 | 24.0 | 0.9 | 25.1 | **50.0** |
| 1000 V / 62.5 A | 61 | 16.3 | 0.3 | 8.9 | **25.5** |
| 350 V / 110 A (110% overload) | 95 | 50.5 | 1.1 | 21.5 | **73.2** |
| 350 V / 120 A (120% overload) | 95 | 60.1 | 1.3 | 21.5 | **82.9** |

At 350 V copper loss is about 42 W and core loss about 22 W, which makes it the highest-loss point. At 825 V the current falls to 76 A and copper loss to 24 W, but ripple is at its maximum and core loss rises to 25 W. The highest input voltage is therefore not the hottest case, and temperature-rise tests should cover at least 350 V, 625 V and 825 V. AC copper loss is only about 1 W because the ripple current is small; end-winding fields of the edgewound strip are not modeled, which has little effect here but still needs measurement. Total for four channels: 190-257 W.

## 6 · Thermal: what 30 K rise at 60 °C ambient requires

> Allowed total thermal resistance (four channels, hot spot to ambient): $R_{th} \le \Delta T / P = 30\ K / 257\ W \approx 0.12\ K/W$
>
> Enclosure surface only: $A = 2 \times (0.20\times0.15 + 0.20\times0.10 + 0.15\times0.10) = 0.13\ m^2$, so $h \ge P / (\Delta T \cdot A) \approx 66\ W/(m^2\cdot K)$
>
> For comparison: $h = 25\ W/(m^2\cdot K)$ gives $\Delta T \approx 79\ K$; $h = 50\ W/(m^2\cdot K)$ gives $\Delta T \approx 40\ K$ (average enclosure-surface rise, internal gradients not included)

Forced air on an enclosure surface typically gives a few tens of $W/(m^2\cdot K)$. Reaching about 66 $W/(m^2\cdot K)$ over the whole surface is not realistic, and that figure covers only the enclosure surface, not the winding-to-case gradient. The practical route is to mount the enclosure base on a heatsink or cold plate so that most heat leaves through the bottom, and to control three thermal resistances:

- Winding → potting → aluminum case: set by the potting conductivity, thickness and voids. Inner turns and the space between the two legs are the likely hot spots.
- Core → case base: core loss is about 25 W per channel at 825 V, so the core body needs its own conduction path to the base.
- Case base → heatsink: interface material, flatness and clamping force, specified on the mechanical drawing.

These are lumped estimates for choosing the cooling concept. Whether the rise stays below 30 K has to be measured on samples with thermocouples at the inner winding, core center, terminals and base, not at one convenient point on the case.

## 7 · Insulation: hipot is one item of several

The drawing lists 3 kVAC for 60 s (winding to core), leakage ≤ 5 mA, insulation resistance ≥ 100 MΩ at 500 VDC and a Class F or higher insulation system. These tests are needed, but insulation design for an 1100 VDC system also requires the following inputs:

| Input to freeze | Note |
|---|---|
| Applicable standards | Safety of PV power converters: IEC 62109-1; insulation coordination: IEC 60664-1; North America: UL 1741. Use the standards and editions the project actually follows |
| Working voltage and overvoltage category | 1100 VDC plus switching overshoot; overvoltage category, pollution degree, altitude |
| Materials | Magnet-wire enamel class, potting CTI and temperature class, bobbin and barrier materials |
| Distances | Clearance and creepage between terminals, terminal to case, winding to core |
| Process | Vacuum potting and void control; re-test hipot and insulation resistance after thermal cycling |

Clearance, creepage and test voltages must be taken from the applicable edition of each standard. This article gives no generic values and cites no clause numbers.

## 8 · Sample validation matrix

| Test | Method and conditions | Output |
|---|---|---|
| L-I curve | Every channel, 25 °C and elevated temperature; at least 0, 76, 100, 110, 120 A | Pass/fail at 100 A ≥ 80 µH; correct the calculated curve |
| DCR | Four-wire, corrected to 25 °C; terminals and joints measured separately | Channel-to-channel spread; acceptance limit |
| Loss and temperature rise | 350 V, 625 V and 825 V; controlled airflow and base condition; to thermal steady state | Rise at each point; comparison with calculated loss |
| Hot-spot map | Thermocouples at inner winding, between legs, core center, terminals, base | Location and value of maximum |
| Combined ripple | Four-phase current (or bus-side current) with the real PWM timing; compare $T_s/4$ and $T_s/8$ | Confirm the 5% limit and its definition |
| Coupling | Excite one channel, measure induced voltage on the other three | Measured k ≤ 0.05 |
| Insulation and reliability | Hipot, insulation resistance, vibration, acoustic noise; re-test after thermal cycling, potting cross-section | Test records and failure modes |

**Disclaimer** All values are development-stage calculations: the L-I curve is a fitted powder-core roll-off, core loss uses iGSE with typical material data, AC copper loss uses a one-dimensional Dowell model, the thermal section is a lumped estimate, and combined ripple assumes four identical channels. They are intended for design review and are not sample measurements. Final parameters follow sample tests and the approved specification.

## 9 · FAQ

**Q:** Why is a 147 µH inductor checked against 80 µH?
**A:** 147 µH is the zero-bias value. At 100 A the field is about 117 Oe and the 60µ FeSi powder core keeps about 75% of its initial permeability, giving a lower bound of 97 µH. Acceptance should use the 100 A point.

**Q:** Why is ripple calculated at 64 kHz?
**A:** In a three-level boost the inductor voltage steps between two $V_{bus}/2$ levels twice per switching period, so the ripple frequency is $2f_s$. This depends on the modulation and should be confirmed against the gate timing.

**Q:** Which input voltage is the hottest?
**A:** In this design, 350 V / 100 A at about 64 W per channel, of which about 42 W is copper loss. Core loss peaks at 825 V, but the current is lower and the total is about 50 W.

**Q:** Why does four-phase interleaving still exceed 5%?
**A:** With a $T_s/4$ shift the 64 kHz ripple sees only two-phase cancellation, reaching about 6.4%. With $T_s/8$ the calculated value is ≤ 1.5%.

**Q:** Can forced air alone meet 30 K?
**A:** With about 257 W of loss and 0.13 m² of case surface, the required heat-transfer coefficient is about 66 W/(m²·K). Forced air is unlikely to reach this; conduct the heat through the base to a heatsink.

## Appendix · Minimum RFQ data for a custom high-current MPPT/PFC inductor

| Parameter | Minimum data | Used for |
|---|---|---|
| Topology | Two- or three-level boost; number of phases; shared or separate inputs; phase-shift scheme | Ripple frequency, combined ripple |
| Voltage | $V_{in}$ range, maximum bus voltage | Ripple, core loss, insulation |

| Parameter | Minimum data | Used for |
|---|---|---|
| Current | Rated current per channel; overload level and duration | L-I, copper loss, flux density |
| Frequency | Switching frequency, modulation | Core loss, AC copper loss |
| Inductance | Loaded inductance at a stated current; coupling coefficient | Core and turns |
| Ripple | Per-channel and combined limits, and the denominator used | Inductance, phase shift |
| Thermal / mechanical | Ambient, allowed rise, cooling method, envelope, mounting and terminals | Structure and heat path |
| Safety | Applicable standards, hipot and insulation-resistance requirements, annual volume | Insulation design and process |

## Contact and related resources

| Item | Details |
|---|---|
| Company | SHENZHEN PROMAGTECH CO.,LTD. |
| Address | 3F, Bldg 1, No.22 Dongda Rd, Fenghuang St., Guangming District, Shenzhen 518132, China |
| Contact | Zhang Yong \| +86 13267069291 \| zyong@promagtech.cn \| www.promagtech.com |
| Related articles | 20-60 kW three-phase PFC inductor selection guide; 500 A high-current inductor design; 3.2 V / 240 A planar transformer design |

### Revision history

| Revision | Date | Changes |
|---|---|---|
| Rev A/0 | 2026-09-27 | First release (rewritten from the LinkedIn draft; values recalculated from development drawing A5) |