DESIGN CALCULATION · TECHNICAL ARTICLE

20–60 kW PFC Inductor:

Selection & Design Guide

Three-phase PFC inductor design for EV charging stations, energy storage converters, and industrial power supplies — inductance calculation, core selection, thermal design, and insulation requirements

Applications: EV DC Charging (20–120 kW) · Energy Storage PCS · Industrial Power · UPS

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1. Key Finding

> **Key Finding:** A 20 kW three-phase PFC inductor typically sits near 200–350 μH per phase at 16 kHz, while 60 kW designs require a separate current path, core window, and thermal scale-up. These cannot share one design family.

2. Three-Phase PFC Circuit Overview

Three-phase PFC (Power Factor Correction) is widely used in high-power EV charging stations, energy storage converters (PCS), and industrial power supplies. The 20–60 kW power band is the mainstream segment for DC fast chargers and grid-tied storage systems, requiring careful PFC inductor design to meet high efficiency, low THD, and long-service-life reliability simultaneously.

2.1 Functions of the PFC Inductor

- Energy storage: balance the instantaneous difference between input and output power during each switching cycle
- Current ripple limiting: control the peak-to-peak ripple ΔI to meet grid harmonic (THD) requirements
- Filtering: attenuate switching-frequency harmonics before they propagate into the AC grid

2.2 Circuit Topology Context

A three-phase PFC typically uses a Vienna rectifier or two-level boost topology. Each phase has one boost inductor. The three inductors should be matched in inductance and DCR to avoid inter-phase current imbalance that can increase total harmonic distortion and asymmetric thermal loading.

3. Inductor Design Parameter Calculation

3.1 Reference Design: 30 kW Three-Phase PFC

Parameter	Value	Notes
Input voltage	380 V AC (line-to-line); phase voltage 220 V	Universal three-phase grid
Output voltage	800 V DC	High-voltage bus for EV fast charger
Switching frequency	50 kHz	SiC or IGBT-based converter
Power level	30 kW (10 kW per phase)	Three-phase balanced
Current ripple ratio	0.3 × I_pk	Typical for 15–30% ripple target

3.2 Inductance Calculation

Step 1 — Phase current peak:

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I_pk = √2 × P / (3 × V_phase) = √2 × 30,000 / (3 × 220) ≈ 64 A
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Step 2 — Ripple current target (30% of peak):

$$\Delta I = 0.3 \times 64 \approx 19\ \text{A (peak-to-peak)}$$

Step 3 — Minimum inductance (D = duty cycle ≈ 0.46 at 380 V input / 800 V output):

$$L_{min} = (V_{phase} \times D) / (f_s \times \Delta I) = (220 \times 0.46) / (50{,}000 \times 19) \approx 107\ \mu\text{H}$$

Adding 30% design margin and rounding: select L = 350 μH per phase. Note: at 20 kW (lower current, higher ripple acceptable), L per phase is typically 200–300 μH. At 60 kW (higher current), the core must be rescaled for the larger window and thermal budget — it is not a simple proportional scale of the 30 kW design.

4. Core Selection

4.1 Core Material Comparison for 20–60 kW PFC

Core Material	Loss at 50	Isat Characteristic	Relative	Best For
Iron Silicon Aluminium	Low–moderate	Soft saturation; gradual roll-off	Moderate	General-purpose PFC, good DC bias stability
Iron Powder (Sendust type)	Moderate	Very soft saturation; high Isat	Low	Cost-sensitive designs; good at lower frequency
Ferrite (MnZn)	Very low	Hard saturation; sharp cut-off	Low	High-frequency (>100 kHz) with gap control
Nanocrystalline	Very low	High permeability; check Isat margin	Higher	Low-loss designs; 800V high-voltage platform

For 20–60 kW PFC inductors at 16–50 kHz, iron silicon aluminium (KoolMu / Sendust) cores are the most common choice: they offer soft saturation behaviour that provides a natural safety margin at peak current, moderate loss, and good temperature stability. Ferrite cores are preferred when switching frequency exceeds 100 kHz and the inductor is small enough that a gapped ferrite geometry fits the window efficiently.

4.2 Core Saturation Current Verification

The core must be sized so that the inductance at peak current I_pk remains within the acceptable specification window (typically L −20% at I_pk). Verify at the maximum operating temperature, as B_sat of powder cores decreases 10–20% from 25°C to 100°C.

> **Critical:** For bidirectional energy storage PCS designs, the saturation current must be verified in both charge and discharge directions independently. A winding configuration that achieves the required Isat in one direction may be asymmetric in the other.

5. Thermal Design

5.1 Power Loss Decomposition

Total inductor loss at rated operating point:

$$P_{total} = P_{copper} + P_{core} = I_{rms}^2 \times R_{AC} + P_{core}(f, B_{ac}, V_{core})$$

For a 30 kW PFC at 50 kHz with flat wire winding and KoolMu core, typical split is 60–70% copper loss and 30–40% core loss. Reducing DCR through flat wire winding therefore has a proportionally larger impact on total loss than a core material change.

5.2 Temperature Rise Estimation

Temperature rise can be estimated using the Rth thermal resistance model or empirical volume-based methods. A practical first-pass estimate for a natural-convection inductor:

$$\Delta T \approx P_{total} \times R_{th}(surface) \quad \text{where } R_{th} \approx 53 / A_{surface}^{0.54} \quad (^\circ\text{C/W, area in cm}^2)$$

Flat wire winding provides a shorter thermal path from the conductor interior to the core wall, typically reducing peak winding temperature by 15–25°C versus round wire in the same core at the same loss level.

Design Approach	DCR vs Round Wire	Copper Loss	Temperature Rise
Round wire, natural convection	Baseline	Baseline	Baseline (e.g. 75°C rise)
Flat wire, natural convection	20–30% lower	20–30% lower	~50–60°C rise (15–25°C lower)
Flat wire, forced-air cooling	20–30% lower	20–30% lower	<40°C rise (target for EV charger PFC)

6. Insulation Design

6.1 Voltage Stress and Clearance Requirements

The PFC inductor in an 800 V system is subject to significant voltage stress between the winding and the core (and chassis ground). IEC 60664-1 sets minimum clearance and creepage distances based on working voltage, pollution degree, and material group.

System Bus Voltage	Min. Clearance (Basic)	Creepage Distance	Hi-Pot Test
400 V DC	1.5 mm	3.2 mm (Pollution Degree 2, Group IIIb)	AC 1500 V / 1 min
800 V DC	3.0 mm	6.4 mm (Pollution Degree 2)	AC 2000–3000 V / 1 min
1000 V DC	3.5 mm	8.0 mm	AC 3000 V / 1 min

6.2 Partial Discharge Considerations

In 800 V systems, partial discharge (PD) is a primary cause of insulation long-term degradation. The partial discharge inception voltage (PDIV) must exceed the system peak working voltage with appropriate margin. Key design actions:

- Avoid air voids in insulation; use vacuum potting where high reliability is required
- Use low-dielectric-constant insulation film (PI or PPS preferred over PET) at high voltage

- Avoid sharp edges on winding conductors; use radius-formed flat wire terminations
- Specify PDIV testing at sample approval stage for 800V+ applications

7. Power Range Scale-up: 20 kW vs. 60 kW

Engineers sometimes ask whether a 60 kW design is a simple scale of a 20 kW design. It is not. The following table shows the principal differences:

Parameter	20 kW Design	60 kW Design	Implication
Phase current (RMS)	~17 A	~51 A	3× current → 3× wire cross-section or 9× copper loss for same DCR
Core window area	Smaller	Larger (3× copper area)	New core tooling typically required
Temperature rise	More manageable	Thermal limit often binding	Flat wire mandatory above 30–40 A
Inductance per phase	200–350 μH	200–350 μH (similar)	Same inductance, but much more copper
Housing / cooling	Natural convection feasible	Forced air or heatsink typically required	Different mechanical design

8. Specification Checklist for Custom PFC Inductor

Parameters Required for Engineering Review:

- Total three-phase power and per-phase power (kW)
- AC input voltage (line-to-line) — min / nominal / max
- DC output voltage and any transient range
- Phase current (RMS and peak) at rated load
- Switching frequency (kHz) — fixed or variable
- Target inductance per phase and acceptable tolerance (at rated bias)
- Maximum allowable DCR per phase (mΩ) at operating temperature
- Temperature rise limit (ΔT°C above stated ambient)
- Cooling method: natural convection / forced air (CFM) / heatsink
- System bus voltage for insulation and hi-pot specification
- Package envelope: max L × W × H mm; mounting method
- Certification: UL / TUV / CE / RoHS; production quantity

9. FAQ

Q1: What inductance is needed for a 20 kW three-phase PFC at 16 kHz?

At ~400 V AC input, 700 V DC bus, and 16 kHz switching, typical inductance per phase is 200–350 µH depending on allowable current ripple (15–30% of peak). Higher frequency allows lower inductance for the same ripple; higher power requires more copper area, not necessarily more inductance.

Q2: What DCR target is typical for a 20 kW PFC inductor?

For a 20 kW class PFC stage at ~17 A RMS per phase, engineers typically target single-digit milliohm DCR (2–8 mΩ range). Final DCR depends on rated RMS current, available conductor cross-section, and cooling method. Higher current requires lower DCR to control copper loss and temperature rise.

Q3: Can one PFC inductor design cover both 20 kW and 60 kW?

No. A 60 kW design needs a larger current path (approximately 3× the wire cross-section), a larger core window, and typically a different thermal management approach. The 20 kW to 60 kW range should be treated as separate custom design families sharing the same topology but not the same magnetic component design.

Q4: Can values in this guide be used directly in production?

No. All values in this guide are engineering references. Production values must be confirmed through approved samples, DC bias measurement, DCR measurement at operating temperature, thermal validation at rated current, and hi-pot testing before production release.

10. Contact and Related Resources

Resource	URL
Charging Station PFC Inductor Product	promagtech.com/products/charging-pile-pfc.html
PFC Boost Flat Wire Inductor Product	promagtech.com/products/pfc-boost-inductor.html
800V EV Platform Inductor Selection	promagtech.com/technical-resources/800v-ev-platform-inductor-selection.html
Flat Wire vs Round Wire Selection Guide	promagtech.com/technical-resources/flat-wire-vs-round-wire-inductors.html
AIDC & ESS High-Current Design Guide	promagtech.com/technical-resources/aidc-energy-storage-pcs-high-current-inductor-design.html

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