

# Magnetic Components for Energy Storage PCS

## Design & Selection Guide (3 kW – 5 MW)

### Abstract

This white paper presents a standardized magnetic component design framework for bidirectional energy storage converters (PCS), from 3 kW residential systems to 5 MW commercial & industrial (C&I) platforms. It covers compliance targets derived from GB/T 34120-2023, GB/T 36547 / 36548 and IEC 62477-1, core material selection, flat-wire winding technology, magnetic integration, anti-saturation design margins, and a sample-stage verification checklist.

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**NOTICE: All values in this document are design targets based on engineering calculation and project experience. Final performance must be confirmed by sample test data for each project.**

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## 1 Introduction

In a bidirectional energy storage converter (PCS), the magnetic components — isolation transformer, power inductors, grid-side filter reactors and EMI chokes — perform four functions: energy conversion, galvanic isolation, harmonic suppression and conducted-noise filtering. Field experience shows that five recurring PCS problems — core saturation, grid harmonic violations, conducted EMI failures, excessive temperature rise and efficiency shortfall — usually trace back to core material selection, winding technology, or insufficient design margin.

With 800 V DC-bus platforms and SiC devices pushing switching frequencies higher, conventional round-wire windings and single-material core strategies are increasingly the limiting factor for power density and thermal performance. This document defines a component-level design framework that supports system compliance without over-claiming system-level results.

## 2 Compliance Targets & Applicable Standards

Magnetic components have no dedicated ESS standard; design targets are derived from the PCS system-level standards below.

Standard	Title / Scope	Relevance to magnetics
GB/T 34120-2023	Technical requirements for PCS in electrochemical ESS	Electrical & safety envelope
GB/T 36547 / 36548	Grid-connection requirements / test spec for electrochemical ESS	Harmonics, PF, response — filter design targets
GB/T 42717-2023	Grid-connection performance evaluation for ESS stations	Acceptance-stage verification
GB/T 14549	Power quality — harmonics in public grids	THD budget at PCC
IEC 62477-1	Safety of power electronic converter systems	Insulation coordination, dielectric tests
UL 1741 / UL 9540	Inverter interconnection / ESS safety (North America)	Export project certification

### Derived component-level design targets

- Grid current THD < 5% (system); filter-section budget < 3%
- Full-load temperature rise ≤ 60 K; ≤ 55 K for daily deep-cycling C&I duty
- Power-frequency withstand 2,500–3,000 VAC (per bus platform); insulation resistance ≥ 100 MΩ
- Saturation current ≥ 1.5 × rated current
- Two-stage CM + DM filtering to support Class B conducted limits

## 3 PCS Magnetic Component Architecture

A complete PCS power chain divides into five magnetic functional units. Each unit is standardized independently for material, winding process and parameters.

Functional unit	Components
DC-side power magnetics	Bidirectional storage inductor, DC smoothing reactor, buck-boost inductor
High-frequency isolation	LLC resonant transformer, DAB transformer, discrete resonant inductor
Grid-side filtering	1-ph / 3-ph filter reactors, SVG reactor
EMI suppression	CM chokes, DM inductors, ferrite ring assemblies
Integrated magnetics	Leakage-integrated transformers, coupled inductors

### Voltage platform mapping

- 48 / 51.2 V residential: lightweight high-frequency magnetics, natural cooling, low acoustic noise
- 700 / 800 V C&I: SiC-adapted low-leakage magnetics, full-range soft switching, CM current control
- 1,500 V utility-scale: engineered per project after design review

## 4 Residential PCS Solution (3 – 20 kW)

**Topology:** bidirectional LLC, 50–120 kHz    **Platform:** 48 V / 51.2 V battery, 400 V DC bus

### 4.1 LLC high-frequency isolation transformer

PC95 MnZn ferrite core with flat-wire vertical winding, window fill factor  $\geq 90\%$ . The transformer's own leakage inductance replaces the external resonant inductor, reducing component count. Triple-insulated wire, withstand  $\geq 2,500$  VAC; low acoustic noise for indoor installation.

### 4.2 Bidirectional flat-wire storage inductor

FeSiAl (Sendust) powder core: high saturation flux density with soft permeability roll-off under DC bias, suited to wide battery voltage swing. Flat conductor reduces DCR by 20–40% versus round wire at equal volume, cutting copper loss and temperature rise.

### 4.3 Grid filter + EMI assembly

Output-side current THD budget  $\leq 3\%$ ; UU-core CM choke suppresses high-frequency grid noise, supporting system-level Class B conducted compliance.

**Component-level benefit:** magnetics loss reduction can contribute approx. 0.3–0.8% to converter efficiency; silent operation; 10-year design-life target.

### 4.4 Typical design envelope

Parameter	Design target
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Power range	3 – 20 kW
Switching frequency	50 – 120 kHz
Transformer withstand	≥ 2,500 VAC / 60 s
Inductor DCR vs round wire	–20% ~ –40% at equal volume
Output THD budget	≤ 3%
Temperature rise	≤ 60 K at rated load

## 5 C&I PCS Solution (50 kW – 5 MW)

**Topology:** T-type 3-level + DAB, SiC devices    **Platform:** 700 V / 800 V DC bus

### 5.1 DAB bidirectional isolation transformer

N87 MnZn ferrite, multilayer flat copper foil winding. The key process capability is precisely controlled leakage inductance (20–40  $\mu$ H, tolerance per project), the precondition for full-load-range ZVS. Primary-secondary isolation 3,000 VAC, adapted to 800 V SiC circuits with high dv/dt; limits common-mode leakage current.

### 5.2 Amorphous alloy storage reactor

1K107 amorphous ribbon core: mid/low-frequency core loss approx. 1/3 of conventional silicon steel; full-load temperature rise  $\leq$  55 K; withstands 2 $\times$  rated current short-time overload — suited to daily multi-cycle deep charge/discharge duty.

### 5.3 Three-phase filter reactor + nanocrystalline CM choke

Filter reactance 4–5%, supporting system power factor  $\geq$  0.95. Nanocrystalline CM choke provides high initial permeability and wide effective suppression band, reducing ground leakage current and RCMU nuisance trips.

### 5.4 Typical design envelope

Parameter	Design target
Power range	50 kW – 5 MW (modular)
DC bus	700 V / 800 V
DAB leakage inductance	20 – 40 $\mu$ H, controlled tolerance
Isolation withstand	3,000 VAC / 60 s
Reactor temperature rise	$\leq$ 55 K, daily deep-cycling duty
Short-time overload	2 $\times$ rated current
Filter reactance / PF	4 – 5% / $\geq$ 0.95

Utility-scale projects (1,500 V platform) are engineered per project after a joint design review — contact us with your parameters.

## 6 Core Material Selection

Material	Frequency	Typical use	Key property
PC95 / N87 MnZn ferrite	50 kHz – 500 kHz	HF transformers, small filter inductors	Very low HF eddy loss
FeSiAl powder (Sendust)	20 kHz – 150 kHz	Bidirectional storage inductors	High Bs <sub>at</sub> , soft DC-bias roll-off
1K107 amorphous	1 kHz – 50 kHz	High-power storage reactors	Low core loss, low temp rise
Nanocrystalline	10 kHz – MHz range	CM chokes	Very high initial permeability

**Selection rule: frequency selects the material; DC bias sets the air gap; temperature rise sizes the conductor.**

## 7 Winding Technology & Magnetic Integration

### 7.1 Flat-wire vertical (edgewise) winding

Window fill factor  $\geq 90\%$ ; DCR copper loss reduced 20–40% at equal volume versus round wire. The thin conductor dimension mitigates skin and proximity effects at SiC switching frequencies, keeping the AC/DC resistance ratio under control.

### 7.2 Magnetic integration

Three integration paths — leakage inductance reuse, multi-winding shared core, and filter + isolation composite — merge several components into one assembly. Project measurements: magnetics weight down ~30%, volume down 25–50%, with corresponding BOM and assembly savings.

### 7.3 Anti-saturation margin design

All storage-duty magnetics carry a uniform 1.5× rated-current saturation margin. Air-gap length and core cross-section at flux concentration zones are optimized to prevent waveform distortion and efficiency collapse under overload and wide bus-voltage swing.

## 8 Sample-Stage Verification Checklist

PROMAGTECH recommends the following checkpoints before design freeze. Items marked (S) are system-level tests performed by the PCS maker.

Item	Method	Acceptance
L vs I curve (DC bias)	LCR + DC bias source	Roll-off within design limit at $1.5 \times I_n$
Temperature rise mapping	Thermocouple / IR at rated load	$\leq 60$ K ( $\leq 55$ K C&I duty)
Dielectric withstand	Hi-pot, 60 s	2,500–3,000 VAC, no breakdown
Insulation resistance	Megohmmeter 500/1000 VDC	$\geq 100$ M $\Omega$
Leakage inductance (DAB/LLC)	LCR, secondary shorted	Within agreed tolerance of design value
DCR	Micro-ohmmeter	Per drawing
Conducted EMI (S)	LISN scan	Supports Class B limits

## 9 FAQ

### Q1: Why FeSiAl rather than ferrite for storage inductors?

Storage inductors carry heavy DC bias. FeSiAl offers high saturation flux density and gradual permeability roll-off; ferrite saturates early and requires large air gaps with high fringing loss.

### Q2: Why must DAB transformer leakage inductance be precisely controlled?

Leakage inductance is the energy-transfer element in a DAB. It sets transferable power and the soft-switching range; excessive deviation loses ZVS at light load, degrading both efficiency and EMI.

### Q3: Is flat wire always better than round wire?

No. Flat wire excels in high-current, high-fill-factor designs. For very high turn counts or extreme frequencies, eddy loss must be evaluated case by case — PROMAGTECH provides simulation-based comparison on request.

## 10 About PROMAGTECH & Disclaimer

SHENZHEN PROMAGTECH CO.,LTD. (founded 2013) specializes in flat-wire power inductors and high-frequency transformers for energy storage PCS, EV charging, solar inverters and industrial power. Core capabilities: flat-wire edgewise winding, controlled-leakage transformer design, and project-specific inspection covering inductance, DC bias, leakage, DCR, hi-pot and insulation resistance.

### Engineering collaboration workflow

- Step 1 — Send operating parameters: topology, current waveform, frequency, voltages, cooling, envelope
- Step 2 — Design review & initial proposal within 1 business day
- Step 3 — Simulation, drawing and sample build; free sample evaluation available

- Step 4 — Joint validation against Section 8 checklist; approval and production

**Sample evaluation and design review: [www.promagtech.com](http://www.promagtech.com) | [zyong@promagtech.cn](mailto:zyong@promagtech.cn) | +86 13537658938 (WhatsApp)**

*Disclaimer: This document is for engineering reference only and does not constitute a performance guarantee. Specifications are subject to change without notice; final parameters are defined by the approved product specification of each project.*

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