



WHITEPAPER · SOLAR & ENERGY STORAGE

Solar Energy Storage: Magnetic Components Whitepaper

Inductor and transformer requirements for solar string inverters, micro-inverters, and energy storage PCS — MPPT boost inductors, bidirectional DC-DC inductors, and EMI filter magnetics

Applications: Solar String Inverters (20–150 kW) · Micro-Inverters · Energy Storage PCS · Grid-Tied Storage

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1. Key Finding

Key Finding: Energy storage PCS magnetic components must be reviewed around bidirectional current, DC bias stability under full current in both directions, and thermal cycling — not only rated inductance at zero bias. An inductor that passes room-temperature, zero-bias inductance measurement can still fail in-system if Isat margin or thermal performance is inadequate at operating conditions.

2. Solar Energy Storage Market Context

Solar inverters and energy storage converters (PCS) are the core power conversion equipment in solar-plus-storage systems. Their efficiency, reliability, and component lifetime directly determine system economics — particularly in commercial and industrial storage installations where annual cycling rates are high (one or more full charge-discharge cycles per day, potentially 6,000+ cycles over 20 years).

Magnetic components — inductors and transformers — are among the highest-stress passive elements in these converters. Thermal cycling, bidirectional current stress, and sustained operation at partial load all impose requirements that must be addressed at the component selection stage, not only at system integration.

3. Solar Inverter Magnetic Components

3.1 String Inverter Topology and Magnetic Component Roles

String inverters (20–150 kW per unit) are the market mainstream for commercial solar. They use a two-stage structure:

- Front-end DC-DC (MPPT boost/buck): converts variable PV string voltage to regulated DC bus. The MPPT boost inductor is the primary magnetic component in this stage.
- Back-end DC-AC (inverter stage): converts DC bus to grid-frequency AC. Common mode inductors and differential mode inductors filter conducted EMI at the grid interface.

3.2 MPPT Boost Inductor Selection

Parameter	Typical Value	Notes
Power range	20–150 kW (per string inverter)	Scale with string count
PV string voltage	600–1500 V DC	Determines insulation class
Operating frequency	16–50 kHz	Ferrite or KoolMu core
Inductance formula	$L = (V_{in} \times D) / (\Delta I \times f_s)$	D = duty cycle; ΔI = ripple target
Efficiency target	≥ 98%	Flat wire essential above 30 A
Core selection	KoolMu / Sendust or ferrite + gap	Soft saturation preferred for MPPT
Temperature cycle	-40°C to +85°C outdoor	Core Bsat and DCR must be verified at 85°C

3.3 Micro-Inverter Transformers

Micro-inverters (200–500 W per unit) require high power density in an extremely compact package. Planar transformers are the preferred choice because they offer low profile, good thermal spreading, and repeatable production geometry.

- Planar transformer: height ≤ 8 mm (latest generation); up to 200 kHz with SiC/GaN switching
- PCB winding reduces component count and improves manufacturing consistency
- High isolation voltage: AC 3000–4000 V for safety between PV rail and grid-connected side

4. Energy Storage PCS Magnetic Components

4.1 PCS Topology Overview

Energy storage converters commonly use DAB (Dual Active Bridge) or three-phase modular topologies. The magnetic components in these topologies experience:

- Bidirectional DC-DC inductor: current flows in both directions during charge and discharge; the inductor must maintain adequate I_{sat} margin in both directions
- Transformer (in DAB topology): operates at high frequency, often 20–100 kHz; flat wire or Litz wire winding required
- AC-side filter inductor and CMC: similar requirements to solar inverter grid interface

4.2 Bidirectional DC-DC Inductor Requirements

The bidirectional DC-DC inductor is the most application-specific magnetic component in the energy storage PCS. Its requirements differ from a conventional unidirectional boost inductor in three important ways:

Key Differences vs. Unidirectional PFC Inductor:

- Saturation current must be verified in BOTH charge and discharge directions — many designs have asymmetric winding structures that provide different I_{sat} in each direction
- DC bias stability across the full operating current range in both directions — the inductor must remain within specification at maximum charge current AND maximum discharge current
- Cycle life requirement: 6,000+ charge/discharge cycles over 20 years imposes thermal fatigue requirements on winding insulation and core-to-winding bonding
- Temperature range: outdoor battery enclosures typically require -40°C to $+65^{\circ}\text{C}$; verify core B_{sat} and DCR at both extremes
- Grid-side fault current: PCS inductors may be subject to short-circuit fault currents; I_{sat} must include appropriate transient margin (typically 1.5–2× rated current)

Parameter	Small Commercial Storage	Large Industrial Storage
Power rating	10–100 kW per PCS unit	100–500 kW per PCS unit
Operating frequency	8–20 kHz	8–20 kHz (lower for efficiency)
DC bus voltage	400–800 V	800–1500 V
Rated current (each dir.)	25–125 A	125–600 A
I_{sat} requirement	≥ 1.3× rated, at 65°C	≥ 1.4× rated, at 65°C
Temperature cycle life	25 years outdoor service	25 years, outdoor enclosure
Insulation (800V bus)	AC 2000–3000 V hi-pot	AC 3000–4000 V hi-pot

5. EMI Filter Magnetics for Solar and Storage

Grid-connected solar and storage systems must meet conducted and radiated EMI limits at the grid interface. CISPR 11 Class A (or B for certain installation categories) is the typical conducted emission standard. Common mode inductors and differential mode inductors at the AC output of the inverter are the primary EMI suppression elements.

Component	Core Material	Frequency Range	Key Requirement
Single-phase CM choke	Nanocrystalline / Amorphous	150 kHz – 30 MHz	High CM impedance; low DM inductance imbalance
Three-phase CM choke	Nanocrystalline	150 kHz – 10 MHz	Three-winding balance; AC 2000V+ insulation for 800V bus
DM filter inductor	Iron powder / KoolMu	150 kHz – 5 MHz	Low DC loss; bidirectional current in ESS applications
LCL output filter	Iron powder / Ferrite	16–50 kHz	Grid-side inductance; THD target drives design

6. Specification Checklist

Parameters Required for Solar/Storage Magnetic Component Review:

- System type: solar inverter (MPPT) / ESS PCS / combined solar+storage
- Power rating and number of phases
- DC voltage range (PV string or battery voltage, including min/max/transient)
- AC voltage range and grid frequency
- Current (RMS, peak, bidirectional if applicable)
- Switching frequency (Hz or kHz)
- Target inductance or turns ratio and acceptable tolerance
- Isat requirement — specify direction(s) and percentage definition (L-20%?)
- Temperature rise limit and ambient temperature range
- Insulation voltage and hi-pot test level
- EMI standard (CISPR 11 Class A/B, local grid code)
- Service life and cycle count target (for ESS applications)
- Package envelope and mounting method

7. FAQ

Q1: Why must Isat be checked in both directions for ESS inductors?

In a bidirectional energy storage inductor, the DC bias from charge current and discharge current both stress the magnetic core. If the winding structure is asymmetric (e.g., tapped winding, asymmetric air gap positioning), the effective Isat can differ between charge and discharge modes. A component that passes Isat verification in one direction may saturate in the other. Both must be verified on approved samples at the maximum operating temperature.

Q2: What is the typical efficiency target for solar inverter magnetic components?

String inverters targeting $\geq 98\%$ system efficiency require magnetic components with low combined copper and core loss. This typically means flat wire winding (for low DCR and AC resistance at 16–50 kHz), and core material selection optimised for the operating flux density and frequency. At 30 A and above, flat wire is generally required to keep copper loss within budget at the target efficiency level.

Q3: Can production values be used directly from this whitepaper?

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

8. Contact and Related Resources

Resource	URL
Energy Storage Inductor Product	promagtech.com/products/energy-storage-inductor.html
Three-Phase Common Mode Inductor	promagtech.com/products/three-phase-common-mode.html
20–60 kW PFC Inductor Design Guide	promagtech.com/technical-resources/20-60kw-pfc-inductor-selection-guide.html
High Power Density White Paper	promagtech.com/technical-resources/high-power-density-flat-wire-magnetics-white-paper.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

<p>Shenzhen PROMAGTECH Co., Ltd.</p> <p>zyong@promagtech.cn</p> <p>WhatsApp: +86 135 3765 8938</p> <p>www.promagtech.com</p>	<p>Response Commitment</p> <ul style="list-style-type: none"> • Preliminary design assessment within 24 hours of complete specification • Formal quotation within 3 business days • Sample delivery: 5–7 business days (standard custom design)
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