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Insulation Design & Partial Discharge Testing: A Methodology for the 800 V Platform

Clearance/creepage, PDIV testing and winding structure — how 800 V magnetics actually pass insulation coordination

Item	Detail
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Document	Insulation Design & Partial Discharge Testing — 800 V Platform Methodology
Scope	Clearance/creepage coordination, PDIV testing and insulation structure for 800 V-class magnetics
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Summary & key takeaways

Bottom line

An 800 V magnetic isn't safe just because insulation is "thicker." Three things must be calculated separately: (1) creepage distance from working voltage, pollution degree and material group (IEC 60664-1); (2) clearance from impulse withstand voltage, overvoltage category and altitude correction; (3) partial discharge (PD) — the invisible killer of insulation life. A part can pass a hipot test and still be riddled with PD that erodes insulation over years via electrical treeing. Miss any one of the three, and an 800 V magnetic can fail prematurely in the field.

Key takeaways:

- **Clearance and creepage are two different things:** clearance prevents arcing through air (impulse voltage, overvoltage category, altitude); creepage prevents surface flashover (working voltage, pollution degree, material group/CTI). Neither substitutes for the other.
- **A hipot pass is not proof of insulation life:** hipot only checks whether breakdown happens right now; PD reveals whether microscopic defects (voids, bubbles) are already discharging under working voltage — the actual root cause of long-term failure.
- **PDIV is the key acceptance criterion:** the partial discharge inception voltage must sit comfortably above system working voltage; factory acceptance is typically "PD charge below a threshold (in pC) at a specified test voltage," with the threshold set per project/applicable standard.
- **Process controls PD more than material choice:** vacuum impregnation to remove winding voids, void-free potting, and insulation free of wrinkles/sharp edges affect PDIV more directly than swapping insulation material.
- **800 V platforms usually need reinforced insulation:** whether primary-to-secondary (or to core/ground) is basic or reinforced insulation directly sets the safety factor applied to clearance/creepage margins.
- **Altitude must be corrected:** clearance withstand capability drops with altitude (thinner air, lower dielectric strength); high-altitude applications need additional clearance margin.

Note A ProMagTech engineering reference (not an official standard); sister to the 800 V Pillar, CLLC transformer selection and AEC-Q200 articles — filling the insulation/PD methodology gap specifically.

1. Why 800 V magnetics need a dedicated insulation article

Moving from a 400 V to an 800 V platform doubles working voltage, but clearance/creepage margins don't simply double — IEC 60664-1's lookup relationships are piecewise nonlinear, and partial discharge risk escalates nonlinearly as voltage rises (higher field strength ignites microscopic defects more readily). If an 800 V magnetic (OBC PFC inductor, CLLC transformer, bus-side CM choke) reuses 400 V insulation margins, it will likely fall short; but simply "thickening insulation" sacrifices window area, adds leakage inductance and cost. This article lays out the methodology for insulation coordination and PD testing so engineers can compute their own margins and read a PD report — instead of signing off on a supplier's "we passed hipot."

2. Clearance vs. creepage: two entirely different calculations

Dimension	Clearance	Creepage
Prevents	breakdown through air (arc)	surface flashover (pollution/ moisture conductive path)
Determined by	impulse withstand voltage, overvoltage category, altitude	working voltage (RMS/DC), pollution degree, material group (CTI)
Typical reference	IEC 60664-1 Tables 2–4	IEC 60664-1 Tables F.4–F.8
800 V illustrative magnitude	~2–3 mm order (after altitude correction)	~8 mm order (before design margin)
Common mistake	checking clearance and assuming it covers creepage	enlarging creepage but forgetting altitude correction

Table 1 — Clearance vs. creepage (illustrative magnitudes; use measured/tabulated values)

In short: clearance manages "will the air arc over," creepage manages "will the surface slowly track conductive." Both must be looked up and calculated independently for an 800 V platform — one cannot substitute for the other.

3. Calculating clearance: from impulse withstand to altitude correction

Step 1 System voltage + overvoltage category (e.g. CAT II/III) → rated impulse withstand voltage (kV)
Step 2 Impulse withstand + pollution degree → base clearance (mm, IEC 60664-1 table)
Step 3 Altitude correction: above 2000 m, scale clearance by the altitude correction factor
Example (illustrative only): impulse 2.5 kV, base clearance 1.5 mm, altitude factor 1.48 → corrected clearance ≈ 2.22 mm

Key Impulse withstand voltage is set by system voltage and overvoltage category — not an arbitrary choice; 800 V platforms typically fall under CAT II/III and must be aligned with the system safety engineer, not defined by the magnetics team alone.

4. Calculating creepage: working voltage × pollution degree × material group

Pollution degree	Environment description	Typical scenario	Effect on creepage
PD1	no pollution, or only dry non-conductive pollution	sealed/potted, dust-free	lowest requirement
PD2	normally only non-conductive pollution, occasional condensation	common automotive assumption (unpotted)	moderate, most common assumption
PD3	conductive pollution, or dry non-conductive pollution that becomes conductive from condensation	outdoor/unprotected industrial	significantly higher requirement

Table 2 — Pollution degree definitions and typical scenarios (simplified from IEC 60664-1; re-verify per actual environment)

Material group (CTI, comparative tracking index) also affects creepage — material group IIIa/IIIb (lower CTI) needs greater creepage than material group I (CTI ≥600). Winding insulation, bobbin and potting material CTI must all be confirmed at the design-input stage, not discovered as a shortfall at the sample stage.

> Creepage = f(working voltage, pollution degree, material group) — a table lookup, not a linear formula
> Example (illustrative only): DC 800 V, pollution degree 2, material group IIIa → creepage floor ≈ 8 mm (before design margin)

5. Basic vs. reinforced insulation: which for an 800 V platform

Insulation class	Definition	Typical 800 V application
Functional insulation	ensures circuit operation only, no safety function	not applicable to human-safety interfaces
Basic insulation	provides basic shock protection (single insulation)	internal low-risk nodes, or where another protection layer exists
Supplementary insulation	an independent second layer added to basic insulation	combined with basic insulation for double insulation
Reinforced insulation	a single insulation system providing protection equivalent to double insulation	primary-secondary isolation (CLLC/LLC transformer), bus to touchable parts

Table 3 — Insulation class definitions (simplified from the IEC 62368-1/60664-1 framework; final determination per applicable product standard)

> **Reminder** Primary-secondary windings on a CLLC/LLC isolation transformer almost always require reinforced insulation design — meaning clearance/creepage margins, insulation material CTI class and inter-winding isolation structure must all be raised, not estimated at basic-insulation BOM levels.

6. Partial discharge (PD): the invisible killer a hipot test can't catch

Partial discharge (PD) is a small, localized discharge — typically at a void, bubble, or an insulation/conductor interface — that occurs before the full insulation system breaks down. PD alone does not cause instant breakdown, but sustained PD progressively damages insulation through electrical treeing and erosion, a leading mechanism behind long-term field failures of transformers and inductors — and precisely the failure mode a routine hipot test cannot detect: hipot only judges "does it break down now," not "is the insulation already discharging chronically."

Test	What it measures	Limitation
Hipot (withstand voltage)	whether breakdown/excess leakage occurs under applied voltage	cannot reveal PD from internal insulation voids
Insulation resistance (IR)	DC resistance level of the insulation	does not reflect PD behavior under AC working conditions
Partial discharge test (PD/PDIV)	inception voltage (PDIV) and discharge magnitude (pC) at a specified voltage	requires more capable equipment; typically applied to critical interfaces via sampling or 100% test

Table 4 — Positioning and limits of the three insulation test types

PD test method (simplified from the IEC 60270 framework): apply an AC voltage across the device under test and ramp it up while a high-sensitivity detection circuit measures apparent charge (pC); record charge vs. voltage and take the voltage at which charge first exceeds a specified threshold (e.g. 10 pC) as the partial discharge inception voltage (PDIV).

> PDIV should sit comfortably above the system's maximum working voltage, leaving a safety margin
> Example acceptance criterion (illustrative only, confirm per project/applicable standard): at 1.5× working voltage, discharge magnitude < specified threshold (commonly tens of pC; tighter than 10 pC for high-reliability cases)

> **Key** PD acceptance criteria are not universal — dry-type transformers, automotive magnetics and consumer electronics all use different thresholds and test-voltage multiples; determine per the applicable product standard or customer specification, not by borrowing numbers from another industry.

7. Process control of PD: eliminating voids matters more than material choice

- **Vacuum pressure impregnation (VPI):** winding-internal voids are the most common PD origin; VPI significantly reduces winding void content and is the first line of PD control.
- **Void-free potting:** unremoved bubbles during potting-resin cure become discharge initiation points under working voltage; potting requires vacuum degassing and cross-section/CT sampling on critical lots.
- **No wrinkles or sharp edges in insulation layers:** wrinkles or sharp edges in insulation material (e.g. triple-insulated wire, insulation film) formed during winding concentrate the local electric field, significantly lowering PDIV.
- **Creepage-path structure design:** ribs and grooves on the bobbin effectively extend the creepage path without increasing outline size — the main lever for balancing compactness against insulation margin.
- **Triple-insulated wire (TIW):** for small, high-density designs, TIW meets reinforced insulation requirements without an added insulation layer — a common choice for CLLC/LLC transformers.

8. Validation & quality baseline (DVP)

Validation item	Method / instrument	Acceptance (example, per project)
Clearance / creepage distance	gauge / 3D scan measurement	per IEC 60664-1 lookup + design margin
Withstand voltage (hipot)	hipot tester	no breakdown; leakage current ≤ spec
Insulation resistance	megohmmeter	≥ spec (at room temp / after high-temp-humidity)
Partial discharge (PDIV/charge)	PD test set (per IEC 60270 method)	PDIV ≥ margin; charge < threshold at specified voltage
Retest after thermal/humidity cycling	environmental chamber + repeat hipot/PD	still meets initial acceptance after cycling
Cross-section / CT sampling	metallographic section or CT scan	no visible voids in winding/ potting, insulation undamaged
Batch consistency	PD sampling	PDIV spread within specified range

Table 5 — Common insulation/PD validation baseline for the 800 V platform (acceptance per project/applicable standard)

Reminder PD test equipment and site requirements (shielded environment, background-noise suppression) exceed those of routine electrical tests — many smaller suppliers lack production-grade PD capability. Require a PD test report explicitly, not just a hipot report, when sourcing.

9. Frequently asked questions (FAQ)

Q We passed hipot — why do we still need PD testing?

A Hipot only answers "does it break down right now"; it does not answer "is the insulation already discharging chronically." PD is the starting point of electrical treeing and erosion, which shows up as insulation failure only after extended field operation — exactly what outgoing inspection often misses.

Q Why can't clearance and creepage substitute for each other?

A They guard against different physical mechanisms: clearance against arcing through air (impulse voltage, altitude), creepage against surface flashover (working voltage, pollution degree, material CTI). In the same structure, sufficient clearance with insufficient creepage (or vice versa) still leads to insulation failure.

Q Can 800 V platform margins just be 400 V platform margins doubled?

A No. IEC 60664-1's lookup relationships are piecewise nonlinear, and PD risk escalates nonlinearly with voltage; 800 V platforms must be recalculated from the tables, not extrapolated from 400 V by a simple multiplier.

Q What insulation class should a CLLC/LLC transformer's primary-secondary use?

A Primary-to-secondary on an isolated DC-DC transformer almost always needs reinforced insulation (or a basic + supplementary double-insulation combination), because it crosses the conventional safety isolation boundary — this must be settled at the design-input stage, not patched after the structure is frozen.

Q What PD acceptance threshold (in pC) should we set?

A There is no universal number — the threshold and test-voltage multiple depend on the applicable product standard (dry-type transformer, automotive, consumer electronics) and customer specification. Common practice: start from the closest applicable standard, then tighten iteratively based on failure-mode analysis and field data.

Q What should insulation design watch for at high altitude (mountain base stations, alpine solar plants)?

A Clearance's effective withstand capability drops with altitude (thinner air, lower dielectric strength), requiring the clearance design value to be scaled up by an altitude correction factor; creepage itself isn't directly altitude-corrected, but condensation risk (pollution degree may need to move up) should be re-assessed.

Q What can ProMagTech deliver on insulation/PD?

A Clearance/creepage design calculation per the applicable project standard, vacuum impregnation and void-free potting processes, and hipot, insulation-resistance and partial discharge (PDIV/charge) test data — with acceptance criteria and the test plan confirmed jointly with the customer at the design-review stage.

10. Glossary

- **Clearance —** the shortest distance through air between two conductors, preventing breakdown through air.
- **Creepage —** the shortest distance along an insulating surface between two conductors, preventing surface flashover.
- **Pollution degree —** a rating of the conductive pollution level of the operating environment, affecting creepage requirements.
- **Material group / CTI —** a classification of insulation material tracking resistance; higher CTI is a better material group.
- **Partial discharge (PD) —** a small localized discharge occurring in part of an insulation system before overall breakdown.
- **PDIV —** partial discharge inception voltage — the voltage at which discharge magnitude first exceeds a specified threshold.
- **Reinforced insulation —** a single insulation system providing protection equivalent to double insulation.
- **Vacuum pressure impregnation (VPI) —** a process impregnating windings with insulating resin under vacuum to remove internal voids.
- **Triple-insulated wire (TIW) —** magnet wire with three extruded insulation layers that can directly meet reinforced-insulation requirements.

11. Further reading

This page focuses on insulation coordination and PD test methodology for the 800 V platform; related deep-dives and sister pillars:

- 800 V OBC CLLC Bidirectional Transformer Selection (a typical reinforced-insulation primary-secondary case)

- OBC PFC Boost Inductor Selection (800 V platform)
- AEC-Q200 and Automotive Reliability for EV/OBC Magnetics
- 800 V EV Charging Systems White Paper
- Thermal Design & Temperature-Rise Testing for High-Current Magnetics
- 800 V Power Magnetics Selection Reference (EV & AI datacenter)
- AIDC Magnetic Components Full Power-Chain Applications

12. 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, PV inverters, energy-storage PCS, AI-datacenter power and industrial power.

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