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FAILURE ANALYSIS 14 min read Updated May 2026

Porcelain Insulator Flashover: Causes, Mechanisms, and Prevention

How surface discharge develops across porcelain insulators — and the engineering controls that prevent it.

TECHNICAL REFERENCE

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Flashover Mechanism: How It Happens

A flashover occurs when the electrical stress across an insulator surface exceeds the surface's dielectric strength. Unlike puncture (which destroys the insulator body), flashover is a surface phenomenon — the discharge arc travels along the insulator's external profile from the high-voltage fitting to the grounded end fitting.

The arc path follows the shortest available route across the insulator surface. For a standard disc insulator string, this means the arc jumps across the air gaps between sheds and travels along the wet or contaminated glaze surface. The total flashover path length is shorter than the insulator's leakage (creepage) distance, which is why creepage distance alone does not fully determine flashover performance.

Three conditions must be met simultaneously for flashover to occur:

— **Sufficient surface conductivity** — wet glaze, contamination layer, or both

— **Adequate voltage stress** — system voltage, switching surge, or lightning impulse

— **Continuous arc path** — uninterrupted conductive film from HV end to ground end

Removing any one of these three conditions prevents flashover. This is the basis for all prevention strategies.

Three Types of Flashover

1. Dry Flashover

Dry flashover occurs under clean, dry conditions when the applied voltage exceeds the insulator's dry flashover voltage (DFV). This is the highest flashover threshold — a properly selected insulator should never experience dry flashover under normal operating voltage. Dry flashover is primarily a concern during lightning impulse events (BIL testing) or extreme switching surges.

Standard test: IEC 60060-1 / ANSI C29.1 — power-frequency dry withstand voltage applied for 1 minute. Typical dry flashover voltage for a standard 70 kN disc insulator: 75–80 kV (power frequency).

2. Wet Flashover

Wet flashover occurs when rain or condensation creates a continuous water film on the insulator surface. Water reduces surface resistance dramatically — clean water resistivity is approximately

100–10,000 Ω·cm depending on mineral content. The wet flashover voltage is typically 50–70% of the dry flashover voltage for the same insulator.

Standard test: IEC 60507 — artificial rain at 1–1.5 mm/min, water resistivity 100 Ω·cm, applied at 45° angle. Wet flashover voltage is the primary design criterion for outdoor insulators in regions with frequent rainfall.

3. Pollution Flashover

Pollution flashover is the most operationally significant failure mode. It occurs when a contamination layer (industrial deposits, sea salt, cement dust, fertilizer) is wetted by fog, dew, or light rain — creating a highly conductive surface film. Unlike wet flashover, pollution flashover can occur at voltages well below the rated wet flashover voltage, making it the dominant cause of unplanned outages in contaminated environments.

Pollution flashover is a progressive process, not an instantaneous event. It develops over minutes to hours as the contamination layer wets uniformly. This distinguishes it from lightning-induced flashover and makes it predictable and preventable through proper maintenance.

Pollution Flashover: The Four-Stage Process

Pollution flashover follows a well-documented four-stage sequence. Understanding each stage is essential for designing effective prevention measures.

Stage 1 — Contamination Accumulation

Soluble and insoluble contaminants deposit on the insulator surface over weeks to months. The top surface accumulates less contamination than the underside of sheds (which is sheltered from rain self-cleaning). Equivalent Salt Deposit Density (ESDD) and Non-Soluble Deposit Density (NSDD) are the standard metrics for quantifying contamination severity, measured in mg/cm².

Typical ESDD thresholds by pollution class (IEC 60815-1):

- Light (a): ESDD 0.03–0.06 mg/cm²
- Medium (b): ESDD 0.06–0.10 mg/cm²
- Heavy (c): ESDD 0.10–0.25 mg/cm²
- Very Heavy (d): ESDD >0.25 mg/cm²

Stage 2 — Wetting

Fog, dew, or light drizzle wets the contamination layer without washing it away. This is the critical trigger condition. Heavy rain actually reduces flashover risk by washing the surface. The most dangerous condition is light wetting of a heavily contaminated surface — common in coastal areas at dawn or in industrial zones during fog events.

Stage 3 — Dry Band Formation

Leakage current flows through the conductive wet contamination layer. Joule heating evaporates moisture at the narrowest cross-sections (typically near the metal fittings), creating dry bands. Dry bands have high resistance and concentrate the voltage stress — the electric field across a dry band can reach 10–20× the average field along the insulator.

Stage 4 — Arc Bridging and Flashover

Partial arcs ignite across the dry bands. If the arc energy is sufficient to bridge the remaining wet contamination path, the arc extends to a full flashover. The critical condition is when the arc's thermal energy exceeds the energy needed to sustain propagation across the remaining leakage path. This is described by the Obenaus model and its derivatives (Rizk, Jolly).

Critical Flashover Voltage (CFO) and Design Parameters

Critical Flashover Voltage (CFO) is the voltage at which an insulator has a 50% probability of flashover under a given set of conditions. It is the central parameter in insulation coordination and insulator string design.

CFO Values — Standard 70 kN Disc Insulator (146 mm spacing)

CONDITION	CFO (KV, POWER FREQUENCY)	STANDARD
Dry	75–80	IEC 60383 / ANSI C29.1
Wet (100 Ω·cm rain)	40–50	IEC 60507
Pollution — Light (ESDD 0.03)	35–45	IEC 60507
Pollution — Heavy (ESDD 0.20)	15–25	IEC 60507

String Length and CFO

CFO scales approximately linearly with the number of discs in a string for short strings, but the relationship becomes non-linear for long strings due to the non-uniform voltage distribution across discs (capacitive grading effect). The disc nearest the conductor carries the highest voltage stress — typically 2–3× the average disc voltage in a standard string without grading rings.

Grading rings (corona rings) redistribute the voltage more uniformly across the string, increasing the effective CFO and reducing corona discharge at the HV end. They are standard equipment on strings of 8+ discs (≥115 kV systems).

Creepage Distance and Pollution CFO

The specific creepage distance (SCD) required to achieve acceptable pollution flashover performance is defined in IEC 60815-1. The minimum SCD values (mm/kV of Um) are:

- Light (a): 16 mm/kV
- Medium (b): 20 mm/kV
- Heavy (c): 25 mm/kV
- Very Heavy (d): 31 mm/kV

These values apply to standard disc insulators with smooth glaze profiles. Anti-fog and aerodynamic shed profiles can achieve equivalent pollution performance with shorter physical string lengths by increasing the effective creepage-to-arcing distance ratio.

Prevention Strategies

1. Correct Insulator Selection (Design Stage)

The most cost-effective prevention is selecting insulators with adequate creepage distance for the site pollution level. Conduct an ESDD/NSDD site survey before specifying insulator strings. Use IEC 60815-1 pollution maps as a starting point, but site-specific measurements are more reliable in industrial or coastal zones where pollution gradients are steep.

For Very Heavy pollution environments (ESDD >0.25 mg/cm²), consider: (a) anti-fog disc insulators with increased creepage per unit length, (b) composite insulators with hydrophobic silicone rubber sheds, or (c) increased string length beyond the IEC 60815 minimum.

2. Periodic Cleaning

Live-line washing (high-pressure water, 3–5 MPa) removes soluble contamination without de-energizing the line. Cleaning frequency depends on ESDD accumulation rate — typically 1–4 times per year in heavy pollution zones. Dry cleaning (compressed air or brushing) is used for insoluble deposits (cement, gypsum) that are not removed by water washing.

Cleaning is most critical before the fog season in coastal and industrial areas. A contaminated insulator that survives the dry season will flashover during the first heavy fog event if not cleaned.

3. RTV Silicone Coating

Room-temperature vulcanizing (RTV) silicone coatings applied to porcelain insulators transfer hydrophobic properties to the surface, causing water to bead rather than form a continuous film. This interrupts Stage 2 of the pollution flashover process. RTV coatings are effective for 5–10 years before reapplication is needed. They are widely used as a retrofit solution for existing porcelain strings in areas where pollution levels have increased since original installation.

4. Insulator Replacement with Composite

Composite (polymer) insulators with silicone rubber sheds are inherently hydrophobic and transfer hydrophobicity to the contamination layer itself — a property unique to silicone rubber. This makes composite insulators significantly more resistant to pollution flashover than porcelain at equivalent creepage distances. The trade-off is shorter service life (25–30 years vs 40–50 years for porcelain) and the need for UV/IR inspection tools since damage is not visually obvious.

5. Leakage Current Monitoring

Leakage current monitoring detects the onset of Stage 3 (dry band formation) before flashover occurs. Sensors measure the peak leakage current on each insulator string; a sustained increase above threshold (typically 10–20 mA peak) triggers a maintenance alert. This approach is increasingly used on critical transmission lines where unplanned outages have high economic consequences.

Content produced from heritage manufacturing knowledge of Zibo's insulator production cluster, including KEMA type-test records for the ANSI C29.7 line post series and DNV ISO 9001 audit documentation maintained continuously since 1998.

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FREQUENTLY ASKED QUESTIONS

FAQ

What is the difference between flashover and puncture in a porcelain insulator? +

Why does pollution flashover occur at night or early morning more often than during the day? +

How many discs are needed in an insulator string to prevent flashover at 132 kV in a heavy pollution area? +

Can RTV silicone coating be applied to energized insulators in service? +

What leakage current level indicates imminent flashover risk? +

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