HV PACE

Infrared Thermography for Live Power Equipment

Inspection Cadence, Anomaly Grading, and Emissivity Reference

A Technical Reference by HV PACE™

Power Asset Condition Engineering Limited

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Why this matters

Infrared (IR) thermography is one of the most cost-effective diagnostic methods for in-service high-voltage equipment. It detects thermal anomalies caused by loose connections, contact oxidation, internal heating, and insulation degradation — all without requiring an outage.

The diagnostic value of IR depends on three things: how often inspections are carried out, how anomalies are classified once they're found, and how accurately surface temperatures can be derived from radiometric data. The technical guidelines summarized below — drawn from a recently updated industry technical standard on IR diagnostic application for live electrical equipment — address all three.

1. Inspection cadence for substations and converter stations

Inspection frequency should scale with voltage level, equipment criticality, and operating conditions:

- **220 kV and below substations, distribution stations, and converter stations:** A minimum of one IR inspection per year. Critical hub substations or stations serving priority users should increase routine and diagnostic IR inspection frequency.
- **Equipment under stress:** Inspection frequency should be increased for equipment with poor operating environments, long service life, known defects, heavy-load periods, system reconfigurations, or rising load conditions.
- **New, expanded, refurbished, or long-idle equipment:** One IR inspection within 1 month of returning to load — but no earlier than 24 hours after energization under load, so that thermal signatures of joint and contact defects have time to develop.
- **Owner-operated facilities:** At least one annual diagnostic IR inspection on key electrical equipment, or integration of diagnostic IR into routine patrol inspections, with all results entered into an IR inspection database.

2. Inspection cadence for transmission & distribution lines

For overhead lines and cable systems:

- **500 kV AC, ±400 kV DC and above overhead lines, plus critical 220/330 kV overhead lines:** Connection hardware (clamps, fittings) inspected at least annually.
- **110/66 kV lines and standard 220/330 kV lines:** Interval not exceeding 2 years.
- **Distribution lines:** Critical-supply or heavy-load lines inspected annually; others not exceeding a 3-year interval.
- **Newly commissioned or post-refurbishment lines:** IR inspection within 1 month of returning to load (≥24 hours after energization).
- **Power cables:** Focus on terminations and accessible joints. For cables run in large-diameter tunnels, full-length inspection is required — ≥2 times per year at 110 kV and above, and once per year at 35 kV and below.
- **Series reactors, line traps, lightning arresters:** Inspection cycle aligned with the parent line.
- **Adverse environments, heavy-load, or critical lines:** Increase frequency as warranted.
- **Porcelain and composite insulators:** Inspected under the patrol-with-diagnostic methodology; can be combined with line patrol work.

3. Three-tier anomaly classification

When an IR inspection identifies a thermal anomaly, it should be entered into the equipment defect management system. Three grades are commonly distinguished:

a) General Anomaly

The equipment shows a thermal-distribution irregularity but continues to operate normally. Typically only logged. Investigation can be scheduled during planned outages or routine maintenance. For current-carrying equipment exhibiting low load with small temperature rise but significant relative temperature difference, a retest under increased and stable load current (held for several hours) is recommended to determine whether the defect is trending. Otherwise, it is treated as a general anomaly.

b) Severe Anomaly

For externally current-carrying equipment, follow-up actions are required: increased inspection frequency, correlation tracking against load, environment, time, and peak operating load, and defect elimination scheduled within the annual maintenance window. For non-external (internal) current-carrying equipment, inspection frequency is increased within the current cycle and complemented with other diagnostic methods (electrical tests, oil analysis, etc.) to identify the root cause before scheduled defect elimination.

c) Hazardous Anomaly

For external current-carrying equipment, when the hot-spot temperature exceeds the specified maximum limit, defect elimination should be scheduled immediately. For non-external current-carrying equipment, hazardous defects should be confirmed via combined IR diagnosis and expert consultation, with parallel deployment of more invasive diagnostic methods — electrical testing, chemical/DGA analysis, disassembly inspection. Where internal hazardous defects can be directly identified — e.g., severe oil starvation in oil-filled bushings, closed cooler oil valves, severe SF_6 leaks — the defect should be handled immediately per on-site operating regulations.

4. Reference emissivity values for common materials

Why emissivity matters

Infrared thermography measures radiated energy, not temperature directly. The conversion from radiance to absolute temperature depends on the emissivity (ε) of the surface being measured. Even a small error in the assumed emissivity can translate into a temperature error of tens of degrees — enough to misclassify a defect or miss one entirely.

This is especially critical in power equipment diagnostics, where the same physical asset may present a wide range of surface conditions: polished aluminum bus bars (ε ≈ 0.09), oxidized aluminum connectors (ε ≈ 0.30), galvanized steel structures (ε ≈ 0.23), porcelain insulators (ε ≈ 0.90–0.92), and painted equipment housings (ε ≈ 0.80–0.98). Using a single default value of ε = 0.95 across all of them — a common field shortcut — introduces systematic measurement bias.

Reference tables

Metallic surfaces

Material	Temperature (°C)	Emissivity (ε)
Polished aluminum / aluminum foil	100	0.09

Material	Temperature (°C)	Emissivity (ε)
Lightly oxidized aluminum	25–600	0.10–0.20
Heavily oxidized aluminum	25–600	0.30–0.40
Polished brass (mirror finish)	28	0.03
Oxidized brass	200–600	0.59–0.61
Polished cast iron	200	0.21
Machined cast iron	20	0.44
Fully rusted rolled iron plate	20	0.69
Fully rusted oxidized steel	22	0.66
Fully rusted iron plate	25	0.80
Fully rusted cast iron	40–250	0.95
Galvanized bright iron sheet	28	0.23
Gold-plated copper sheet	—	0.30
Solder-coated copper	—	0.35
Copper wire	—	0.87–0.88

Paints and coatings

Material	Temperature (°C)	Emissivity (ε)
Black glossy paint (on rough iron)	26	0.88
Black or white paint	38–90	0.80–0.95
Smooth black paint	38–90	0.96–0.98
Glossy paint (all colors)	—	0.90
Matte (non-glossy) paint	—	0.95

Insulating and ceramic materials

Material	Temperature (°C)	Emissivity (ε)
Porcelain (glossy)	23	0.92
Electrical porcelain	—	0.90–0.92
Glass (surface)	23	0.94
Marble	23	0.93
Asbestos board	25	0.96
Epoxy glass laminate (FR-4 type)	—	0.80

Material	Temperature (°C)	Emissivity (ε)
Insulating sheet	—	0.91–0.94
Carbon sheet	—	0.85
Metal-clad sheet	—	0.88–0.90
Opaque plastic	—	0.95
PVC plastic	70	0.93–0.94
Rubber (soft and hard)	20	0.95

Construction and structural materials

Material	Temperature (°C)	Emissivity (ε)
Stone	—	0.92
Concrete	—	0.94
Gravel	—	0.28–0.44
Wall plaster	—	0.92
Red brick	20	0.95
White brick	100	0.90
White brick	1000	0.70
Asphalt	0–200	0.85
Roofing material	20	0.91

Organic and miscellaneous materials

Material	Temperature (°C)	Emissivity (ε)
Paper	0–100	0.80–0.95
Wood	—	0.78
Tree bark	—	0.98
Cotton textiles (all colors)	—	0.95
Silk	—	0.78
Wool	—	0.78
Skin (human)	—	0.98
Water	0–100	0.95–0.96
Ice	—	0.98

Field application notes

1. **Polished metals are the trap.** Polished aluminum (ε ≈ 0.09), galvanized iron (ε ≈ 0.23), and especially polished brass (ε ≈ 0.03) reflect far more energy than they emit. Direct IR temperature readings on these surfaces are usually unreliable. Practical workarounds include applying a small patch of high-emissivity tape or matte paint to a reference point, or measuring an adjacent oxidized region instead.
2. **Oxidation dramatically raises emissivity.** Aluminum jumps from ~0.09 (polished) to 0.30–0.40 (heavily oxidized). In aged equipment, the field-relevant emissivity is closer to the oxidized value — but only after the surface has visibly weathered. New conductors should be treated as low-ε.
3. **Painted equipment is generally well-behaved.** Most coated HV equipment (transformer tanks, cabinets, painted steelwork) sits in the 0.85–0.95 range, which is why the default ε = 0.95 works reasonably well on painted surfaces only.
4. **Porcelain and composite insulators** sit predictably around 0.90–0.94, making them good targets for surface-temperature trending and pollution-induced heating analysis.
5. **Verify with a contact reference where possible.** When stakes are high (commissioning tests, severe-anomaly confirmation), cross-check IR readings against a contact thermocouple or RTD on a representative spot, and adjust assumed ε until they agree. This is the most reliable in-situ calibration method.
6. **Ambient reflections matter as much as emissivity.** Low-ε surfaces are also high-reflectance surfaces — the apparent temperature includes radiation from surrounding objects (sky, sun, nearby hot equipment). A thorough IR measurement records reflected ambient temperature alongside ε.

Engineering takeaways

1. **IR is a cadence-driven discipline, not a one-off measurement.** Inspection frequency must scale with criticality, age, and operating stress, and all results must be databased for trending.
2. **The 24-hour-after-energization rule** for new and refurbished equipment is a practical safeguard — thermal signatures of contact and joint defects emerge only after the equipment has been carrying load.
3. **The three-tier grading system separates "monitor" from "act."** General anomalies are logged; severe anomalies trigger multi-modal diagnostics; hazardous anomalies trigger immediate defect elimination.
4. **IR is rarely sufficient on its own for internal defects.** Severe and hazardous internal anomalies should be paired with electrical tests, chemical/DGA analysis, or disassembly inspection for confirmation.
5. **Emissivity is the silent error source.** A mature IR program documents the assumed ε for each measurement and verifies it against contact references on critical assets.

A mature IR program implements appropriate inspection cadence, integrates anomaly grading into the defect-management workflow, and pairs IR data with complementary diagnostic methods to confirm and prioritize action.

HV PACE

About HV PACE™

HV PACE is the trading name of Power Asset Condition Engineering Limited, a New Zealand-based supplier of test and diagnostic instruments and selected specialty equipment — such as cable sheath voltage limiters and other low-volume, mission-critical components — for high-voltage power systems. Backed by hands-on engineering expertise — including field-tested condition assessment techniques and AI-based signal analysis — we support our customers with diagnostic guidance, methodology development, and fault investigation to help them get the most value from the equipment they buy.

Areas of Expertise

- Specialty test instruments and selected critical components for HV/MV power equipment
- Acoustic and vibration diagnostics
- GIS / GIL condition assessment and fault location
- AI-based signal analysis and pattern recognition
- HV/MV circuit breaker, disconnector, earthing switchgear diagnosis and consultation
- Equipment commissioning and field testing result analysis

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