HVPACE

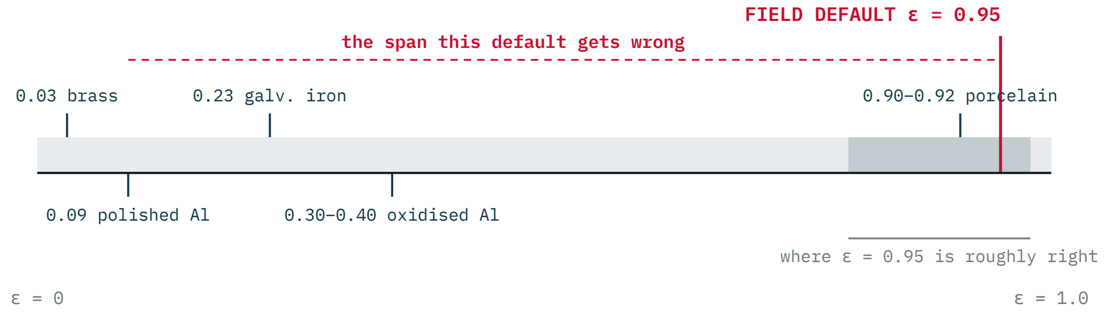
CONDITION ASSESSMENT · TECHNICAL REFERENCE

Infrared thermography for live power equipment

Inspection cadence, anomaly grading, and emissivity reference

Infrared finds loose connections, contact oxidation, internal heating and insulation degradation without taking an outage. Whether it finds them reliably comes down to three things: how often you look, how you grade what you find, and whether the emissivity you assumed was anywhere near the surface you pointed at.

HVPACE Technical Paper WP-03 · Rev 1.2 · For substation maintenance teams, thermographers and asset condition engineers



Common high-voltage surfaces span almost the entire emissivity range. The field default sits at one end of it.

01

Why this matters

Infrared thermography is one of the highest-yield diagnostic methods available for in-service high-voltage equipment. It finds thermal anomalies caused by loose connections, contact oxidation, internal heating and insulation degradation — and it does so without an outage.

Its diagnostic value rests on three things: how often inspections are carried out, how anomalies are classified once found, and how accurately surface temperature can be derived from radiometric data. This paper covers all three, and includes a working emissivity reference for the surfaces actually encountered on power plant.

> The guidance on cadence and grading below is drawn from established industry practice for infrared diagnostics of live electrical equipment, as codified in utility technical standards. Local network rules and asset owner policy take precedence where they differ.

02

Inspection cadence: substations and converter stations

Inspection frequency should scale with voltage level, equipment criticality and operating conditions rather than being fixed across the fleet.

- **220 kV and below substations, distribution stations and converter stations.** A minimum of one IR inspection per year. Critical hub substations, and stations serving priority customers, should increase both routine and diagnostic IR frequency.
- **Equipment under stress.** Increase frequency for equipment in poor environments, at long service life, with known defects, during heavy-load periods, after system reconfiguration, or under rising load.
- **New, expanded, refurbished or long-idle equipment.** One IR inspection within one month of returning to load — but **no earlier than 24 hours after energisation under load**, so that the thermal signature of a joint or contact defect has time to develop.
- **Owner-operated facilities.** At least one annual diagnostic IR inspection on key electrical equipment, or diagnostic IR integrated into routine patrols, with all results entered into an IR inspection database.

> **The 24-hour rule is the one most often skipped. Inspecting a newly energised joint before it has carried load simply produces a clean image of a defect that has not yet warmed up.**

03

Inspection cadence: lines and cables

- **500 kV AC, ±400 kV DC and above overhead lines, plus critical 220/330 kV lines.** Connection hardware — clamps and fittings — inspected at least annually.
- **110/66 kV lines and standard 220/330 kV lines.** Interval not exceeding two years.
- **Distribution lines.** Critical-supply or heavy-load lines annually; others at intervals not exceeding three years.
- **Newly commissioned or post-refurbishment lines.** IR inspection within one month of returning to load, and not less than 24 hours after energisation.
- **Power cables.** Focus on terminations and accessible joints. Cables in large-diameter tunnels require full-length inspection: at least twice per year at 110 kV and above, once per year at 35 kV and below.
- **Series reactors, line traps and surge arresters.** Inspection cycle aligned with the parent line.
- **Porcelain and composite insulators.** Inspected under the patrol-with-diagnostic methodology; can be combined with line patrol work.

Adverse environments, sustained heavy load and critical circuits all justify shortening these intervals.

04

Three-tier anomaly classification

Once an IR inspection identifies a thermal anomaly, it should be entered into the equipment defect management system and graded. The grading is what separates *monitor* from *act*.

TABLE 1

Anomaly grades and required response

GRADE	CONDITION	REQUIRED RESPONSE
General	Thermal distribution is irregular but the equipment continues to operate normally	Log the defect. Investigate at a planned outage or during routine maintenance. Where load is low and temperature rise is small but the **relative** temperature difference is significant, retest under increased and stable load current held for several hours to establish whether the defect is trending
Severe	Confirmed defect requiring intervention within the maintenance cycle	**External current-carrying:** increase inspection frequency, track correlation against load, environment, time and peak operating load, and schedule elimination within the annual maintenance window. **Internal:** increase frequency within the current cycle and add complementary diagnostics — electrical tests, oil analysis — to establish root cause before scheduled elimination
Hazardous	Hot-spot temperature exceeds the specified maximum limit, or an internal defect of equivalent severity	**External current-carrying:** schedule defect elimination immediately. **Internal:** confirm by combined IR diagnosis and expert consultation, with parallel deployment of more invasive methods — electrical testing, DGA, disassembly. Where the internal defect is directly identifiable, such as severe oil starvation in an oil-filled bushing, a closed cooler oil valve, or a severe SF_6 leak, act immediately per site operating regulations

Relative temperature difference. $\delta t = (T_1 - T_2) / (T_1 - T_0) \times 100\%$, where T_1 is the hot-spot temperature, T_2 the temperature of a comparable normal point under the same conditions, and T_0 the reference ambient temperature. Absolute hot-spot temperature limits and δt thresholds are set per equipment type by the governing standard and by asset owner policy — apply the limits in force on your network.

05

Emissivity: the silent error source

An infrared camera measures radiated energy, not temperature. Converting radiance into an absolute temperature depends on the **emissivity** (ε) of the surface being measured. Get that assumption wrong and the error is not marginal: assuming 0.95 on a surface that is actually 0.10 puts the reading tens of degrees adrift — enough to misclassify a defect, or to miss one entirely.

This matters more in power equipment than in most applications, because a single asset presents a wide range of surface conditions within one image: polished aluminium bus bars near $\varepsilon \approx 0.09$, oxidised aluminium connectors near 0.30, galvanised steelwork near 0.23, porcelain insulators at 0.90–0.92, and painted housings between 0.85 and 0.95.

> **Applying a single default of $\varepsilon = 0.95$ across all of them — the most common field shortcut there is — introduces systematic measurement bias precisely where the readings matter most.**

Metallic surfaces

TABLE 2

Reference emissivity — metallic surfaces

MATERIAL	TEMPERATURE (°C)	EMISSIVITY (ε)
Polished aluminium / aluminium foil	100	0.09
Lightly oxidised aluminium	25–600	0.10–0.20
Heavily oxidised aluminium	25–600	0.30–0.40
Polished brass (mirror finish)	28	0.03
Oxidised 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 oxidised steel	22	0.66
Fully rusted iron plate	25	0.80
Fully rusted cast iron	40–250	0.95
Galvanised bright iron sheet	28	0.23
Solder-coated copper (aged, tarnished)	—	0.35
Copper wire (oxidised)	—	0.87–0.88

Paints and coatings

TABLE 3

Reference emissivity — 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 colours)	—	0.90
Matte (non-glossy) paint	—	0.95

Insulating and ceramic materials

TABLE 4

Reference emissivity — 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
Insulating sheet	—	0.91–0.94
Carbon sheet	—	0.85
Opaque plastic	—	0.95
PVC plastic	70	0.93–0.94
Rubber (soft and hard)	20	0.95

Construction and structural materials

TABLE 5

Reference emissivity — construction and structural materials

MATERIAL	TEMPERATURE (°C)	EMISSIVITY (ε)
Stone	—	0.92
Concrete	—	0.94
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

TABLE 6

Reference emissivity — 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 colours)	—	0.95
Silk	—	0.78
Wool	—	0.78
Skin (human)	—	0.98
Water	0–100	0.95–0.96
Ice	—	0.98

06

Field application notes

- **Polished metals are the trap.** Polished aluminium (ε ≈ 0.09), galvanised iron (0.23) and especially polished brass (0.03) reflect far more energy than they emit. Direct IR readings on these surfaces are usually unreliable. Apply a small patch of high-emissivity tape or matte paint at a reference point, or measure an adjacent oxidised region instead.
- **Oxidation raises emissivity dramatically.** Aluminium moves from about 0.09 polished to 0.30–0.40 heavily oxidised. On aged plant the field-relevant value is closer to the oxidised figure — but only once the surface has visibly weathered. Treat new conductors as low-ε.
- **Painted equipment is well behaved.** Most coated HV plant — transformer tanks, cabinets, painted steelwork — sits between 0.85 and 0.95. This is the only region where the ε = 0.95 default works reasonably well.
- **Insulators are predictable.** Porcelain and composite insulators sit around 0.90–0.94, which makes them good targets for surface-temperature trending and pollution-induced heating analysis.
- **Verify against a contact reference.** Where the stakes are high — commissioning tests, confirming a severe anomaly — cross-check the IR reading against a contact thermocouple or RTD on a

representative spot and adjust the assumed ε until they agree. This is the most reliable in-situ calibration available.

- **Reflections matter as much as emissivity.** Low-ε surfaces are also high-reflectance surfaces, so the apparent temperature includes radiation from the sky, the sun and nearby hot equipment. A thorough measurement records the reflected ambient temperature alongside ε.

07

Engineering takeaways

- **IR is a cadence-driven discipline, not a one-off measurement.** Frequency must scale with criticality, age and operating stress, and results must be databased so they can be trended.
- **The 24-hour rule is a practical safeguard.** Thermal signatures of contact and joint defects only emerge once the equipment has been carrying load.
- **Three-tier grading separates monitor from act.** General anomalies are logged, severe anomalies trigger multi-modal diagnostics, hazardous anomalies trigger immediate elimination.
- **IR alone is rarely sufficient for internal defects.** Severe and hazardous internal anomalies should be paired with electrical tests, DGA or disassembly for confirmation.
- **Emissivity is the silent error source.** A mature programme documents the assumed ε for every measurement and verifies it against contact references on critical assets.

> A mature IR programme does three things at once: it runs an inspection cadence matched to risk, it feeds anomaly grading directly into the defect-management workflow, and it pairs IR data with complementary methods to confirm findings and prioritise action.

About HVPACE

HVPACE 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 customers with diagnostic guidance, methodology development and fault investigation, so they 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 and earthing switchgear** diagnosis and consultation
- **Equipment commissioning** and field testing result analysis

---

Web hvpace.co.nz · **Email** pengwei@hvpace.co.nz · **Phone** +64 21 0259 6074 · Auckland 0616, New Zealand

HVPACE Technical Paper WP-03 · Rev 1.2 · Download as PDF
HVPACE is the trading name of Power Asset Condition Engineering Limited (NZBN 9429053607218), Auckland, New Zealand.