Beyond Fixed Limits

Baseline-driven, trend-focused Online DGA alarm strategy

Part I

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ABSTRACT

Across the various condition monitoring options available for transformer health, Online Dissolved Gas Analysis (ODGA) has become the go-to early warning system. Yet too often, alarm logic still relies on static ppm thresholds that ignore a unit's context, leading to nuisance alarms and operator fatigue. This article presents a practical, standards-aligned methodology moving from fixed limits to transformer-specific baselines, population statistics, and noise-robust Rate-Of-Change (ROC) and explains how to cut false positives without compromising sensitivity. It draws on advice from IEC 60599, IEEE c57.104-2019, CIGRE TB 771 & TB 783, and recent industry experiences.

KEYWORDS:

DGA, online DGA, transformer condition monitoring, monitoring systems

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1. Introduction

Online DGA (ODGA) monitors provide unprecedented visibility into transformer behaviour, enabling continuous trending of key fault and insulation gases. However, end users frequently report one of two outcomes:

- Excessive nuisance alarms shortly after commissioning, or
- Alarm thresholds set so high that early fault development is missed.

Both outcomes stem from a fundamental mismatch: standards written for periodic laboratory DGA are applied directly to high-resolution online data.

IEC 60599:2022 [1] and IEEE c57.104:2019 [2] clearly state that gas concentration limits are guidance values rather than absolute acceptance criteria. Yet, in practice, many online systems still rely on static thresholds without adequate consideration of baseline behaviour, measurement uncertainty, or trend dynamics.

This article argues that effective ODGA alarming must be baseline-driven, trend-focused, and statistically informed, rather than purely threshold-based.

2. Why are end users tired of responding to online DGA alarms?

For many asset managers and control-room operators, ODGA alarms have become a double-edged sword. While these systems promise early fault detection and improved reliability, the reality is often a flood of alerts, many of them false or non-actionable. Persistent nuisance alarms erode trust in monitoring technology, consume valuable engineering time, and create alarm fatigue that can desensitize teams to genuine risks. When every spike triggers a warning, operators face a dilemma: investigate every alert at high cost or risk ignoring the one that matters. This growing disconnect between alarm intent and operational value, which is driving the industry to rethink how ODGA alarms are set, managed, and acted upon.

Recent industry commentary has highlighted these alarm-strategy pitfalls and proposed more nuanced approaches anchored in trends and context rather than single thresholds.

Common experiences for fatigue include [3, 5]:

- **Static Thresholds Ignoring Context:** Fixed ppm limits applied uniformly across diverse transformers, without considering design, age, or operating conditions.
- **Short-Window ROC Alarms:** Using 1-day or 7-day rate-of-change triggers that amplify noise, temperature effects, and other dynamics.
- **Stray Gassing Misinterpreted as Fault Activity:** H_2 generated by non-fault oil chemistry (CIGRÉ TB 771 category "S"), particularly in newer mineral oil formulations and ester-based liquids, triggering false alarms when static H_2 thresholds are applied.
- **Persistent Alarms for Chronic Gassing:** CO, CO_2, or Total Dissolved Combustible Gas (TDCG) alarms that never clear on certain asset types, creating “always red” conditions. CO in particular reflects oil oxidation chemistry rather than fault activity (Höhlein-Atanasova & Frotscher, 2010), making it a primary source of fleet-level false positives when used as a fault alarm trigger.
- **Unclear Action Mapping:** Alarms without defined “what to do” steps, causing confusion and wasted engineering time.

- **Overuse of Ratio Methods and Duval Triangles:** Applying diagnostic tools prematurely, before confirming abnormal trends, leading to false fault classifications.

Nuisance alarms don't just irritate operators; they erode trust in monitoring systems and drain resources. In short, poor alarm logic translates into inefficient decision-making, wasted budgets, and elevated operational risk: exactly what modern guidance on alarm strategy warns against.

Persistent nuisance alarms erode trust in monitoring technology, consume valuable engineering time, and create alarm fatigue that can desensitize teams to genuine risks

3. What do the standards actually say?

Both IEC 60599:2022 and IEEE c57.104-2019 emphasize that concentration limits are guidance values, not acceptance/rejection thresholds; assessments should weigh design, history, and trend behaviour (including ROC). The diagnostic primacy of trend over absolute level has been discussed in detail for hydrogen interpretation [6]. IEEE augments this with population-based 90th and 95th percentiles and regression-derived gassing rates that reflect months-long windows.

IEEE c57.104, IEC 60599 and CIGRE TBs say "ROC", not how to calculate it. Part II will detail why a fixed (midnight-to-midnight) ROC is preferred over a rolling calculation.

CIGRE TB 771 [4] contributes empirical typical, intermediate and pre-failure bands for both absolute levels and rates, and TB 783 [5] details accuracy verification and best-practice deployment for ODGA monitors which are crucial context for setting practical alarm margins.

Unlike laboratory DGA instruments, ODGA monitors are not yet covered by a single, comprehensive international performance standard. Users therefore bear the responsibility to verify the analytical performance of each monitor, for example using the procedures outlined in TB 783. Each device, even within the same product line, should be evaluated individually. The ability to distinguish unacceptable spikes from genuine, concerning increases in any gas directly depends on this performance verification.

A practical alarm strategy must also account for the analytical limitations of each online DGA monitor. Alarm settings

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should not be defined solely based on gas concentrations, but also on the monitor's accuracy, calibration status, repeatability, detection limits, gas-specific uncertainty, and response stability under field conditions. Short-term fluctuations close to the detection limit or within the expected uncertainty of the instrument should not be treated as confirmed transformer behavior. Before major operational decisions are taken, such as load reduction, outage planning, oil treatment, or transformer replacement, online indications should be verified by properly sampled laboratory DGA and interpreted together with transformer history, loading, temperature, and recent maintenance activities.

4. Toward a baseline-driven approach

A baseline-driven alarm strategy starts by establishing a transformer's "normal" DGA profile. This involves:

- Data collection: Compile a sufficiently long history of DGA measurements, ideally combining laboratory tests and validated online monitoring.
- Statistical analysis: Compute baseline levels, variability, and percentile ranges (e.g., 90th or 95th percentiles) for each gas.
- Contextual adjustment: Incorporate known transformer parameters, including load, temperature, age, and type.

With this approach, alarms are no longer absolute but relative to the transformer's own behaviour. This principle is consistent with a comprehensive, multi-parameter DGA approach [7]. While IEC 60599 and IEEE c57.104 focus on long-term changes, ODGA monitors remain essential on shorter terms. They are not trip or protection devices and must not be treated like Buchholz or differential relays; instead, their primary value lies in providing dense, high-availability measurements on individual transformers, enabling robust baselines, percentiles and long-window ROC that cannot be achieved with even highly frequent offline sampling.

4.1 Baselines as the reference state

For ODGA, this reference must be established individually for each transformer. A baseline represents the transformer's normal gas behaviour under stable operating conditions and should be derived from:

- at least 30–90 days of steady service.
- exclusion of commissioning and oil-handling effects.
- consistent measurement methods: online data should not be mixed with laboratory values without prior bias characterization. CIGRE TB 783 documents systematic biases between laboratory and ODGA results that can exceed ±20–30% for individual gases. Combining uncorrected data sources will create false baseline drift.

4.2 Median and percentiles

For ODGA, the median is preferred over the mean, as it is less sensitive to spikes

Table 1. Interpreting transformer-specific 90th percentile values

Condition (relative to baseline)	Interpretation	Operational meaning
≤ 10th percentile	Below normal range	Low gassing; no concern
10th–90th percentile	Normal baseline behaviour	Expected operating scatter
> 90th percentile (single point)	Statistical outlier	Investigate only if repeated
> 90th percentile (sustained)	Abnormal condition	Monitor, not alert or alarm

Table 2. Contextual matching of percentiles

Percentile concept	What it represents
Transformer 90%	Upper bound of normal behaviour for that transformer
IEEE 90%	Upper bound of typical population behaviour
IEEE 95%	Rare but acceptable population behaviour

The 90th percentile represents the gas concentration below which 90% of the observed values lie

Table 3. Combining transformer and population thresholds

Condition	Interpretation	Recommended action
≤ Transformer 90%	Normal	Inform only
> Transformer 90% < IEEE 90%	Elevated vs self	Warning / monitor
> Transformer 90% > IEEE 90% (rising ROC)	Elevated vs self and population	Alert
> IEEE 95% (rising ROC)	High probability of abnormality	Alarm (Level 1)
≈ CIGRE Level 2	Abnormal	Alarm (Level 2)

and transient effects. Normal variability is best described using percentiles, particularly the 10th and 90th percentiles.

4.3 Interpreting the 90th percentile in ODGA

The 90th percentile represents the gas concentration below which 90 % of observed values lie. In online DGA, it defines the upper envelope of normal behaviour, not a fault threshold. Table 1 presents the interpretation of transformer-specific 90th percentile values.

To avoid nuisance alarms, a sustained exceedance of the 90th percentile for 7–14 days, combined with ROC confirmation, is recommended. Fault classification methods (Duval Triangle, Rogers, IEC 60599 ratios) should be applied only after a confirmed abnormal trend is established — not triggered automatically by every exceedance of a concentration threshold.

4.3.1 Why transformer-specific percentiles change over time

An individual transformer's 90th percentile can change over time, and IEC 60599 / IEEE c57.104-2019 both implicitly expect this. What matters is how, why, and how fast it changes?

An individual 90th percentile is:

- A statistical descriptor of normal operating gas levels.
- Derived from a stable operating window.
- Reflects design, load profile, oil condition, and age.
- It is not a fixed nameplate value.

A common source of confusion is the misinterpretation of IEEE "90%" values

It should be emphasized that IEEE and CIGRE limits are population-based screening values derived from large international data sets

There are reasons for individual 90th percentile to change over time:

- Ageing and insulation condition
  - Slow increase in H_2, CO, CO_2 - typically indicative of normal thermal and oxidative ageing of oil-paper insulation.
  - Individual 90th percentile shifts upward gradually.
- Load and thermal regime changes
  - Higher average load.
  - More frequent cycling (common in BESS step-up transformers).
- Oil processing or maintenance
  - Oil replacement or degassing: 90th percentile decreases.
  - Dry-out.

The recommended approach is to evaluate individual 90th percentile every 12-24 months, exclude fault and maintenance period, update annually or biannually.

4.4 Aligning transformer baselines with IEEE and CIGRE guidance

A common source of confusion is the misinterpretation of IEEE "90%" values. IEEE c57.104-2019 does not define these as statistical percentiles of a specific transformer's data; they are population-based screening thresholds. Table 2 provides a contextual matching of percentiles.

Table 3 combines transformer and population thresholds, which allows a layered approach to enable graded escalation rather than binary alarms.

It should be emphasized that IEEE and CIGRE limits are population-based screening values derived from large international data sets (IEEE > 1,000,000 DGA samples, CIGRE > 330,000 DGA samples). They cannot be directly applied as definitive limits for a specific transformer, manufacturer or duty cycle. Users remain responsible for constructing unit- and fleet-specific statistics and operating envelopes by combining laboratory DGA, fixed monitors and ODGA data.

4.5 Absolute gas values in the guidance context

These values provide context, not alarm limits, and should be interpreted relative to transformer-specific baselines.

It should be noted that all population statistics in Tables 4–6 are derived from mineral oil transformer databases. For transformers filled with natural or syn-

Table 4. 90th percentile absolute gas values from guides/standards.

Gas	CIGRE 771 (ppm)	IEC 60599 (ppm)	IEEE c57.104-2019 90 % (ppm)*
H_2	118	50–150	75–100
CH_4	85	30–130	45–110
C_2H_6	111	60–280	30–150
C_2H_4	56	20–90	20–90
C_2H_2	5	2–20	1–2
CO	700	400–600	500–900
CO_2	6300	3800–14000	5000–10000

*IEEE values depend on transformer age and O_2/N_2 ratio.

Table 5. Above-typical absolute gas values

Gas	IEEE 95 %	CIGRE Intermediate 1	Intermediate 2	Pre-failure
H_2	100–125	200	280	725
CH_4	120–150	135	180	400
C_2H_6	150–200	210	300	900
C_2H_4	80–100	120	200	800
C_2H_2	3–5	19	40	450
CO	1000–1200	970	1180	2100
CO_2	11000–13000	11600	16700	50000

Table 6. Generic 2-level provisional screening values for ODGA monitors (non-nursing transformers*)

Gas	Alarm L1 (ppm)	Alarm L2 (ppm)	Technical basis
H_2	**100**	**250**	L1 ≈ IEEE 95% lower bound, L2 ≈ CIGRE Intermediate-2
CH_4	**120**	**180**	L1 ≈ IEEE 95% lower bound, L2 ≈ CIGRE Intermediate-2
C_2H_6	**150**	**300**	L1 ≈ IEEE 95% lower bound, L2 ≈ CIGRE Intermediate-2
C_2H_4	**80**	**200**	L1 ≈ IEEE 95% lower bound, L2 ≈ CIGRE Intermediate-2
C_2H_2	**5**	**40**	L1 ≈ IEEE 95%, L2 ≈ CIGRE Intermediate-2
CO	**1200**	**2000**	L1 ≈ IEEE 95%, L2 ≈ CIGRE Pre-failure onset
CO_2	**13000**	**20000**	L1 ≈ IEEE 95%, L2 ≈ CIGREIntermediate-2

* These values are screening values and should be adjusted after transformer-specific baseline, monitor performance, operating history, and fleet experience are established.

Field experience shows that waiting for gas concentrations to reach CIGRE pre-failure levels before acting often results in missed intervention opportunities

thetic esters — which exhibit higher stray gassing, different CO/CO_2 sources (ester linkage pyrolysis), and different gas solubility behaviour — these population values are not transferable. Baseline-driven approaches become even more critical for alternative liquids, where large population datasets do not yet exist.

Table 4 shows the typical 90th percentile absolute gas values from guides/standards.

The installation of an ODGA monitor is not, by definition, a plug-and-play exercise. Each device must be configured, validated and integrated into a clearly defined alarm and interpretation philosophy adapted to the specific transformer and end user practices.

4.6 Above-typical absolute gas values (95th percentile and beyond)

Table 5 highlights the important distinction between elevated gas concentrations that are still statistically typical within the global transformer population and those associated with an increased probability of active fault development. The IEEE 95th

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When an online DGA monitor is used to “nurse” a transformer (i.e., consciously operate it in a controlled, degraded or life-extension mode), alarm philosophy must change

percentile values represent the upper tail of normal in-service behaviour and are therefore well suited as conservative early-warning thresholds in ODGA monitoring. In contrast, the CIGRE “Intermediate” and “Pre-failure” levels are derived from case histories of transformers approaching or experiencing failure and should not be interpreted as acceptable operating limits. Field experience shows that waiting for gas concentrations to reach CIGRE pre-failure levels before acting often results in missed intervention opportunities. Consequently, Table 5 should be read as a risk escalation framework, where IEEE 95th percentile values indicate abnormality relative to the population, while CIGRE categories describe progressively higher fault likelihood.

To make this practical, setpoints can be anchored to conservative population thresholds (IEEE 95th percentile) and to CIGRE intermediate bands as listed in Table 6. These values reflect a philosophy aligned with IEC/IEEE guidance and CIGRE pre-failure framing and are meant to be tuned per transformer / fleet based on local validation.

4.6.1 Special case: ODGA monitor under nursing

When an ODGA monitor is used to "nurse" a transformer operating in a known degraded condition, standard alarm philosophy which assumes a healthy baseline will generate permanent alarms. Adapting alarm logic for nursing (e.g., using the current elevated baseline as the reference, applying ROC-only alarming) is addressed in Part II.

5. Summary and outlook

Part I has established that effective ODGA alarming must be baseline-driven, trend-focused, and statistically informed. Transformer-specific baselines, population-calibrated escalation thresholds, and sustained exceedance criteria replace static ppm limits. Part II will address ROC calculation methods, alarm escalation workflows, and practical implementation for fleet-level deployment.

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The second part of this article will be published in an upcoming issue of Transformer Magazine.

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