Fragmented vendor ecosystems in transformer condition monitoring

Practical challenges and a roadmap toward interoperable asset intelligence



Bhaba Das



ABSTRACT

Transformer condition monitoring has evolved from isolated Online Dissolved Gas Analysers (ODGA) to sophisticated multi-parameter online monitoring ecosystems. However, many end users now face a new systemic challenge: fragmented vendor environments that limit the full value of Online Condition Monitoring (OCM) investments. While sensing technologies have matured, interoperability, data consistency, and alarm governance often lag. This article examines the root causes of ecosystem fragmentation, discusses the operational and engineering issues observed in real end user environments, and proposes a pragmatic path forward based on layered architectures, open data principles, and centralized analytics.

KEYWORDS:

Fragmented transformer monitoring, Interoperability, Asset Analytics, Fleet Management, Open Data.

Fragmentation creates hidden complexity that undermines asset intelligence, increases engineering overhead, and contributes to alarm fatigue

1. Introduction

Over the past decade, transformer Online Condition Monitoring (OCM) has transitioned from periodic laboratory testing toward continuous online surveillance. Online Dissolved Gas Analysis (ODGA), bushing and Partial Discharge (PD) monitoring, and thermal models are now widely deployed across different segments such as industries, renewable developers, data centres, etc. [1] – [5].

Despite this technological progress, many end users report that the operational value of online monitoring programs has plateaued [6]. A major contributing factor is the emergence of fragmented vendor ecosystems, where multiple monitoring platforms coexist without effective integration.

In practice, the same end user may often operate:

- multiple ODGA brands.
- different bushing & PD monitoring systems.
- different central transformer monitoring systems.
- independent vendor dashboards.
- inconsistent alarm philosophies.

This fragmentation creates hidden complexity that undermines asset intelligence, increases engineering overhead, and contributes to alarm fatigue.

This paper examines why fragmentation occurs, how it impacts real-world operations, and what practical steps end users can take to move toward a cohesive, scalable monitoring architecture.

2. How vendor fragmentation developed

As transformer condition monitoring systems evolve, many end users find themselves grappling with "fragmentation", a situation where different transformers, substations, or system components are monitored using sensors and platforms from multiple, incompatible vendors. This fragmentation creates barriers to consistent analytics, centralized risk tracking, and strategic asset management.

Three key factors have been particularly influential in driving this fragmentation: procurement patterns, organizational silos and proprietary technology evolution.

For many end-users, this leads to a fleet of transformers where no two units are monitored in the same way, creating inconsistency in data quality, format, accessibility, and interpretation.

2.1 Procurement patterns

Most end users did not intentionally design fragmented ecosystems. Fragmentation typically results from procurement patterns, not technical design:

- Procurement diversity: In theory, procurement diversity has valid and strategic objectives: competitive pricing, supply chain resilience, flexibility. However, without clear synergy, they create a patchwork of incompatible systems.
- Open ended specifications: When transformer specifications are open ended, the purchase includes different vendor OCM systems depending on lowest cost of monitoring equipment.
- Project-based procurement: Engineering, Procurement and Construction (EPC) contractors choose sensors independently, often based on lowest cost or local availability.
- Legacy integration attempts: Older transformers retrofitted with sensors using proprietary protocols.

Because power transformers have service lives exceeding 40 years, online monitoring fleets have naturally accumulated technology diversity over time. While each procurement decision may have been technically justified, the collective outcome became a heterogeneous monitoring environment with limited interoperability and increasing integration complexity.



Because power transformers have service lives exceeding 40 years, online monitoring fleets naturally accumulated technology diversity over time

2.2 Organizational silos

OCM often spans multiple departments:

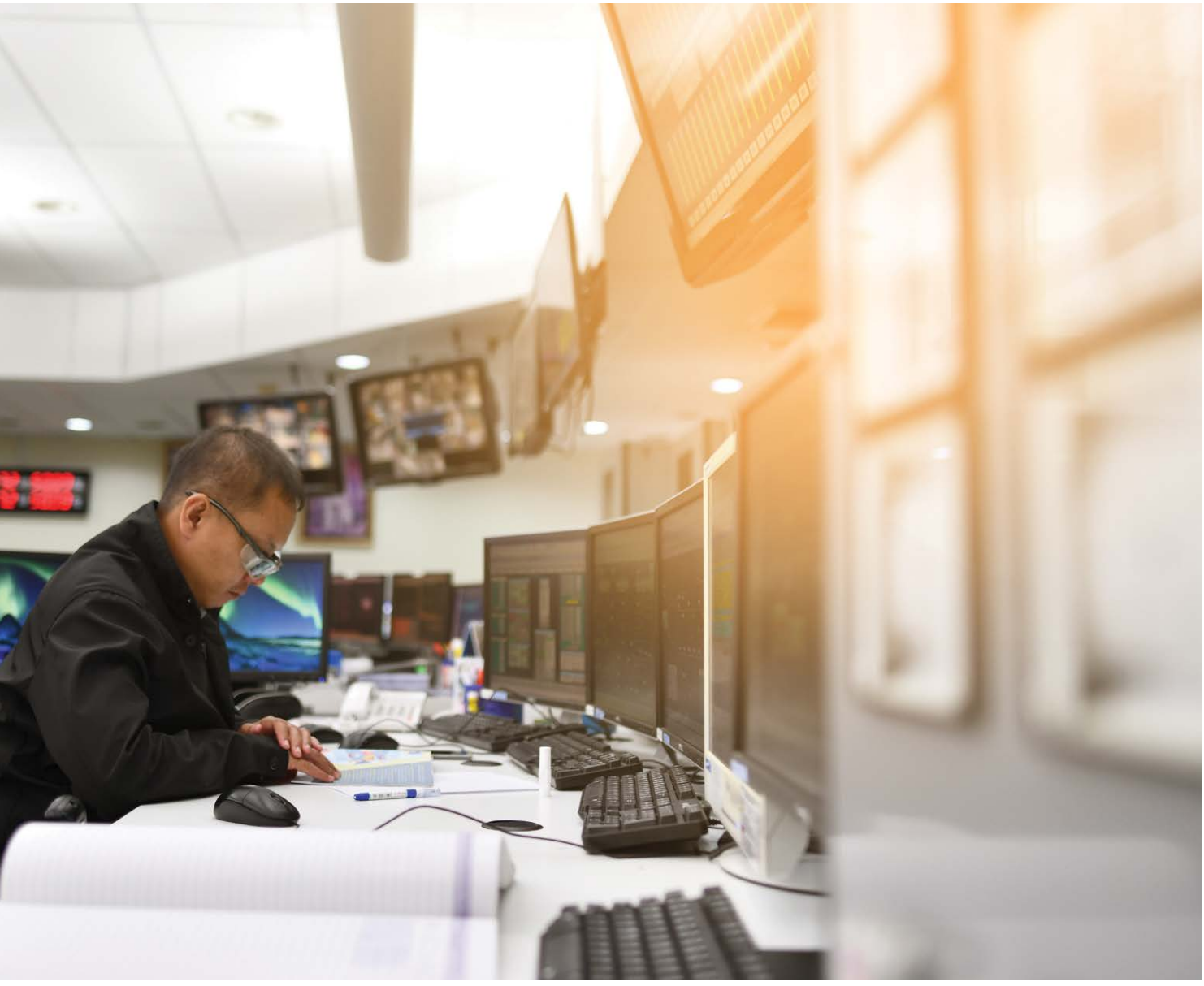
- Asset management
- Supervisory Control and Data Acquisition (SCADA) operations
- Protection engineering
- Information Technology / Operational Technology (IT/OT) cybersecurity
- Maintenance teams

Organizational silos are often one of the most significant and least recognized drivers of vendor fragmentation in transformer OCM.

For example, operations teams are primarily concerned with maintaining network reliability and may prioritize monitoring systems that provide clear alarms and seamless SCADA integration. Asset managers, on the other hand, are focused on understanding asset health, remaining life, and maintenance optimization, often requiring access to detailed diagnostic information and long-term trending capabilities. Maintenance personnel may value systems that simplify troubleshooting and reduce field interventions, while cybersecurity and IT departments emphasize network security, data governance, and compliance requirements. As a result, different stakeholders may select different monitoring solutions based on their immediate needs, even when those solutions perform similar functions.

Monitoring initiatives may be funded through transformer replacement projects, substation upgrades, operational expenditure programs, or digital transformation initiatives

The challenge is often compounded by separate budgeting and procurement processes. Monitoring initiatives may be funded through transformer replace-



A strong example of proprietary technology evolution can be seen in the way vendors implement ODGA Rate of Change (RoC) analytics [7]

ment projects, substation upgrades, operational expenditure programs, or digital transformation initiatives, each managed by different teams. Without a coordinated monitoring strategy, these projects frequently proceed independently, introducing additional vendors, software platforms, and communication architectures into the end user environment. Over time, the monitoring ecosystem becomes increasingly complex, with multiple databases, user interfaces, alarm management systems, and reporting tools operating in parallel.

Furthermore, the emergence of digitalization programs has introduced additional stakeholders, including data scientists, enterprise architects, and digital transformation teams. While these initiatives aim to unlock greater value from monitoring data, they can inadvertently add further layers of complexity if implemented without alignment to existing asset management and operational processes. The result is often a collection of disconnected digital tools that struggle to deliver cohesive asset intelligence.

2.3 Proprietary technology evolution

OCM vendors historically differentiated themselves through proprietary:

- communication protocols
- alarm algorithms
- diagnostic rules
- data formats
- visualization platforms.

While this accelerated innovation, it also created closed ecosystems that are difficult to integrate at fleet scale.

Even where standard protocols exist such as IEC 61850, semantic differences remain. For example:

- gas naming conventions,
- timestamp resolutions,
- rate-of-change definitions,
- data quality flags

may be inconsistent or not harmonized, which may result in "syntactic interoperability but semantic incompatibility."

One of the most immediate consequences of a fragmented monitoring environment is the creation of data silos

Table 1. Different approaches used by OCM vendors

Feature	Example Variations
Gas Rate of Change	ppm/day vs ppm/month
Bushing Monitoring	Polar Plots vs Leakage current thresholds
Alarm Logic	Fixed threshold vs adaptive threshold
Trending Method	Moving average vs instantaneous
Data Quality Handling	Filtered vs raw

A strong example of proprietary technology evolution can be seen in the way vendors implement ODGA Rate of Change (RoC) analytics [7]. Although most transformer monitoring specialists agree that gas generation rates are often more valuable than absolute gas concentrations for identifying developing faults, there is no universally adopted methodology for calculating or alarming on RoC. Different vendors may calculate rates using instantaneous measurements, rolling averages, adaptive baselines, or proprietary trending algorithms. Some systems report gas generation in ppm/day, others in ppm/month, while some apply filtering techniques to suppress noise or compensate for sensor uncertainty. Alarm thresholds can also vary significantly between vendors, with one system triggering an alarm based on a short-term increase while another requires sustained gas generation over a longer period. Consequently, the same transformer operating under identical conditions may produce different alarms and risk assessments depending on the monitoring platform being used.

The ODGA RoC example illustrates a broader industry challenge: while communication standards can ensure that gas concentration values are transferred between systems, they do not guarantee that diagnostic interpretations are calculated consistently. True interoperability therefore requires not only common data exchange protocols but also greater alignment in the way critical condition indicators and analytics are defined, calculated, and presented. As end users increasingly seek fleet-wide asset intelligence rather than device-level diagnostics, the standardization of key analytical metrics such as RoC is becoming an important step toward reducing the effects of vendor fragmentation. Examples of different vendor approaches are listed in Table 1.

3. Operational consequences observed

While vendor fragmentation is often viewed as an integration challenge, its consequences extend far beyond information technology. The real impact is felt by operations personnel, maintenance teams, asset managers, and ultimately the reliability of the

transformer fleet itself. As end users continue investing in digital monitoring technologies, fragmented ecosystems can significantly reduce the expected return on investment by limiting visibility, creating inconsistent diagnostics, and increasing operational complexity. The following sections highlight the most common challenges observed in multi-vendor transformer monitoring environments.

3.1 Data silos and limited fleet visibility

One of the most immediate consequences of a fragmented monitoring environment is the creation of data silos. At many end users, ODGA data, thermal monitoring information, and bushing condition data are stored in separate vendor platforms, each with its own database, dashboard, and reporting tools. Engineers often need to access multiple systems to obtain a complete picture of transformer condition.

This lack of data consolidation makes fleet-wide asset management increasingly difficult. Rather than evaluating transformers using a common framework, asset managers must manually reconcile information from multiple sources, often requiring spreadsheets, custom reports, or engineering judgement to bridge the gaps between systems. As fleets grow and monitoring coverage expands, this approach becomes increasingly unsustainable.

Data silos also limit the end users' ability to identify fleet-level trends. Questions such as whether a particular transformer population is aging faster than expected, whether specific transformer designs are exhibiting common failure modes, or whether maintenance strategies are delivering measurable benefits become difficult to answer when information resides in disconnected systems. Consequently, valuable data remains trapped within individual monitoring platforms rather than contributing to enterprise-wide asset intelligence.

Ultimately, fragmented data environments prevent end users from realizing one of the key promises of digitalization: transforming large volumes of monitoring data into actionable fleet-level insights.

Over time, excessive or inconsistent alarms can erode operator confidence

3.2 Alarm fatigue and inconsistent decision-making

OCM systems are intended to improve situational awareness by providing early warning of developing transformer problems. However, in fragmented vendor environments, differing alarm philosophies often have the opposite effect, generating confusion and alarm fatigue.

Each monitoring vendor typically develops its own approach to alarm generation, incorporating different thresholds, diagnostic rules, RoC calculations, and persistence settings. A gas concentration that generates a caution alarm in one system may produce no alarm in another, while the same operating condition may be classified with different severity levels depending on the platform.

The challenge becomes apparent when end users operate multiple DGA monitoring technologies. As discussed previously, even fundamental metrics such as gas RoC can be calculated differently by different vendors. Consequently, operators may receive conflicting indications regarding the urgency of the same transformer condition.

Over time, excessive or inconsistent alarms can erode operator confidence. When personnel are routinely exposed to alarms that do not require intervention, they may become desensitized to notifications and overlook genuinely significant events. This phenomenon, commonly referred to as alarm fatigue, has been recognized across many industries as a major operational risk.

From an asset management perspective, inconsistent alarm philosophies also complicate maintenance prioritization. Engineers may struggle to compare risk levels across assets monitored by different systems, leading to uncertainty in maintenance planning and resource allocation.

3.3 Reduced effectiveness of advanced analytics

The value of modern OCM systems increasingly depends on analytics rather than measurement alone [8]. End users are seeking to leverage OCM data to develop health indices, predict failures, optimize maintenance schedules, and support digital twin initiatives. However, fragmented monitoring environments often limit the effectiveness of these advanced analytical applications.

High-quality analytics depend on consistent and reliable data. Unfortunately, multi-vendor fleets frequently exhibit differences in sampling frequencies, data formats, timestamp resolution, engineering units, and quality indicators. These inconsistencies make it difficult to combine information from different sources into a unified analytical framework.

For example, a fleet-wide health index may require DGA data, moisture measurements, loading information, and thermal performance indicators. If these parameters originate from multiple systems using different methodologies and update intervals, considerable effort is required to normalize the data before meaningful analysis can occur.

The challenge extends beyond raw measurements. As vendors increasingly incorporate proprietary analytics into their platforms, end users may find that important diagnostic information is embedded within vendor-specific algorithms and

Perhaps the most important lesson from end user experience is that most monitoring challenges are no longer related to sensor technology

Historically, transformer monitoring systems were implemented as standalone solutions, with each device responsible for measurement, diagnostics, alarming, visualization, and reporting

cannot be easily exported or compared. This limits the ability to develop consistent fleet-wide models and reduces the transparency of engineering decisions.

As the industry moves toward predictive maintenance and risk-based asset management, data quality and consistency become critical success factors. Fragmentation therefore represents a significant obstacle to realizing the full potential of advanced asset analytics such as:

- Machine learning applications.
- Digital twins.
- Fleet risk models.

4. Field reality: Common pain points

Across multiple end users' environments, several recurring challenges appear:

- manual reconciliation of DGA trends.
- inconsistent asset naming conventions.
- duplicate alarms between SCADA and vendor systems.
- unclear responsibility for alarm tuning.
- high engineering effort for each new deployment.

In a recent field example [7, 11], the same online DGA dataset produced repeated false alarms under a 24-hour rolling Rate of Change calculation, with RoC values of about +3 ppm/day against an IEEE-equivalent rate of 0.033 ppm/day. The alarms appeared whether the threshold was set at 1, 2 or 3 ppm/day. Applying a fixed midnight-to-midnight window to the identical data produced a single screening indication. The data was the same; only the vendor's calculation choice differed, and it decided whether operators saw one notification or many. Multiplied across a fleet using several ODGA platforms, this is how fragmentation turns into alarm fatigue.

These issues consume significant engineering time and reduce confidence in OCM initiatives. Perhaps the most important lesson from end user experience is that most monitoring challenges are no longer related to sensor technology. Modern monitoring devices are generally capable of producing accurate and reliable measurements. The greater challenge lies in transforming information from multiple sources into coherent, actionable asset intelligence.

As transformer fleets become increasingly digitalized, the ability to integrate, contextualize, and govern monitoring data is emerging as a more important success factor than the selection of any individual monitoring device. The end users that successfully address these challenges are typically those that view monitoring as an enterprise asset intelligence capability rather than a collection of independent monitoring products.

5. A practical way forward

The solution is not vendor homogenization. Technology diversity will remain. Attempting to replace all existing monitoring systems with a single vendor solution is rarely practical or economically justified.

The objective should be to create a monitoring architecture where data from multiple sources can be seamlessly integrated, interpreted consistently, and transformed into actionable asset intelligence. Achieving this requires a combination of technical standards, organizational alignment, governance frameworks, and forward-looking procurement strategies.

5.1 Shift from device-centric to data-centric architectures

Historically, transformer monitoring systems were implemented as standalone solutions, with each device responsible for measurement, diagnostics, alarming, visualization, and reporting. While this approach was suitable when monitoring technologies were relatively isolated, it becomes increasingly inefficient as end users deploy larger numbers of devices from multiple vendors.

A more sustainable approach is to adopt a data-centric architecture in which monitoring devices focus primarily on collecting reliable measurements, while diagnostic interpretation and asset management functions are performed within centralized platforms [9].

Under this model, OCM devices become data providers rather than isolated decision-making systems. Raw measurements, calculated values, and status information are transferred into enterprise-level platforms where information from multiple sources can be consolidated and analysed consistently.

This approach offers several advantages:

- Reduced dependency on vendor-specific analytics.
- Easier integration of new monitoring technologies.



- Consistent condition assessment methodologies.
- Improved fleet-wide visibility.
- Greater flexibility in future technology upgrades.

Most importantly, it enables end users to retain ownership of their most valuable asset: the data itself.

5.2 Establish common data standards

True interoperability requires more than simply connecting devices to a network. While standards such as IEC 61850 have significantly improved communication interoperability, many integration challenges arise from differences in data interpretation rather than data transmission.

End users increasingly recognize the need for common data models that define:

- Parameter naming conventions
- Engineering units
- Timestamp formats
- Data quality indicators
- Alarm classifications
- Asset identification structures

The challenge becomes even more pronounced when considering derived indicators such as:

- Health Index calculations.
- Thermal ageing estimates.
- Moisture risk assessments.
- Remaining life calculations.

Developing common definitions for these parameters allows end users to create meaningful fleet-wide comparisons and avoid inconsistent engineering interpretations.

As end users increasingly pursue digital twin and predictive maintenance initiatives, unified data platforms are becoming a foundational requirement

5.3 Separate measurement from analytics

One of the key lessons learned from multi-vendor monitoring environments is that measurement interoperability does not guarantee analytical interoperability.

As discussed previously, different vendors may interpret identical data in different ways. Variations in DGA Rate of Change calculations, alarm thresholds, thermal models, and health scoring methodologies can lead to different conclusions regarding transformer condition.

A growing number of end users are therefore adopting a layered architecture where:



Establishing common objectives and governance structures ensures that monitoring investments support both operational requirements and long-term asset management goals

A) **Monitoring Devices Responsible for:**
- Data acquisition
- Local processing
- Sensor validation
- Basic status monitoring

B) **Central Analytics Platforms Responsible for:**
- Fault interpretation
- Health index calculations
- Fleet comparison
- Predictive analytics
- Risk assessment

This separation allows end users to apply consistent analytical methodologies across the fleet regardless of which monitoring vendor supplies the underlying data.

The result is greater transparency, consistency, and confidence in engineering decision-making. Centralized governance also supports alarm rationalization programs aimed at reducing nuisance notifications and minimizing alarm fatigue.

The objective should not be to generate more alarms, but to generate better alarms.

5.4 Unified asset intelligence platform

Perhaps the most significant opportunity for end users lies in consolidating monitoring information into a single asset intelligence environment.

Rather than requiring engineers to access multiple vendor portals, a unified platform can provide:

- Fleet dashboards.
- Transformer health rankings.
- Risk assessments [10].
- Maintenance recommendations.
- Historical trend analysis.

By integrating information from ODGA monitors, Bushing & PD systems, thermal monitoring devices and SCADA systems, end users can create a comprehensive view of transformer condition. The platform effectively becomes the "single source of truth" for asset health.

There are several benefits of the unified platform:

- Faster engineering assessments.
- Improved maintenance prioritization.
- Better capital planning.
- Reduced training requirements.
- Enhanced fleet visibility.

As end users increasingly pursue digital twin and predictive maintenance initiatives, unified data platforms are becoming a foundational requirement.

5.5 Clear data ownership principles

One of the most important lessons from digital transformation initiatives is that data ownership must remain with the asset owner.

Historically, monitoring data has often been stored within vendor-specific databases and software platforms, creating challenges when end users seek to migrate systems or adopt new technologies.

To avoid future lock-in, end users should ensure that:

- Historical data remains accessible.
- Export mechanisms are available.
- Data formats are documented.
- Migration pathways are defined.
- Long-term retention strategies exist.

Ownership of asset intelligence should not depend on ownership of a specific monitoring platform. End users that establish clear data governance frameworks are better positioned to adapt to future technology developments while protecting decades of asset history.

5.6 Foster cross-functional collaboration

Technology alone cannot solve fragmentation. Many of the challenges discussed throughout this paper originate from organizational boundaries rather than technical limitations.

Successful monitoring programs increasingly involve collaboration between:

- Operations.
- Asset management.
- Maintenance.
- Protection engineering.
- IT/OT cybersecurity.
- Digital transformation teams.

Establishing common objectives and governance structures ensures that monitoring investments support both operational requirements and long-term asset management goals.

Cross-functional steering groups, enterprise monitoring standards, and shared performance indicators can significantly reduce the organizational fragmentation that often accompanies technical fragmentation.

Ultimately, interoperability is as much a governance challenge as it is a technology challenge.

5.7 Strengthen procurement specifications

Many of today's interoperability challenges originate from procurement decisions made years ago when integration requirements were less prominent. Future procurement strategies should therefore place greater emphasis on openness and interoperability. End users should also require vendors to demonstrate practical interoperability with existing monitoring systems rather than simply claiming standards compliance. Increasingly, procurement evaluations should consider not only monitoring performance but also:

- Ease of integration
- Data accessibility
- Lifecycle support
- Future scalability

This shifts the focus from purchasing individual devices to building sustainable monitoring ecosystems.

6. Conclusion

Vendor fragmentation has largely been an unintended consequence of technology innovation, project-based procurement practices, and organizational structures that developed over many years. The result is a complex ecosystem of OCM devices, software platforms, communication protocols, and analytical methodologies that frequently operate in isolation. While each system may perform its intended function effectively, the lack of interoperability often limits fleet-wide visibility, increases engineering effort, contributes to alarm fatigue, and reduces the overall value that end users derive from their monitoring investments.

Vendor fragmentation has been an unintended consequence of technology innovation, project-based procurement practices, and organizational structures that developed over many years

The future of transformer monitoring will not be defined by the number of sensors installed or the volume of data collected, but by the ability to transform information from multiple sources into coherent, actionable asset intelligence. Achieving this objective requires a move toward open architectures, standardized data models, centralized analytics, and clear governance of monitoring data and alarms.

Importantly, the solution is not the elimination of vendor diversity. Innovation remains essential for advancing transformer diagnostics and monitoring capabilities. Instead, end users must create environments in which technologies from different suppliers can coexist within a common framework that supports consistent interpretation and decision-making. In this model, OCM devices become sources of trusted data, while enterprise platforms provide the contextual analytics needed for fleet-wide condition assessment, risk management, and maintenance optimization.

The journey from fragmented monitoring systems to integrated fleet intelligence may be complex, but it is rapidly becoming a prerequisite for the digital utility of the future.

References

[1] C. Moldoveanu et. al, “Improvements of large power transformer condition real time monitoring and diagnosis expert system - A Romanian experience”, CIGRE Paris 2016, Paper A2-114-2016.

[2] H. Ding et. al, “Diagnosing difficult transformer problems using online condition monitoring”, CIGRE Paris 2016, Paper A2-108-2016.

[3] A. Basuki, “Integration of Online Transformer Condition Monitoring into SCADA Systems”, 53rd International Universities Power Engineering Conference (UPEC), Glasgow, 2018.

[4] D. Xianda et. al, “Online Dissolved Gas Analysis (DGA) Monitoring System”, CIGRE Paris 2019, Paper A2-40-2019.

[5] V. Goyal, “The Good and Bad about Online Transformer DGA Monitoring”, CIGRE Paris 2024, Paper A2-10930-2024.

[6] H. Gumilang et. al, “Enhancing Power Transmission Reliability: Evaluating and Strategizing Online Monitoring Implementation for Power Transformers in PLN”, CIGRE Paris 2024, Paper A2-11792-2024.

[7] B. P. Das & M.Grisaru, “Beyond Fixed Limits Baseline-driven, trend-focused Online DGA alarm strategy – Part 1,” Transformer Magazine, Special Edition: Digital Transformation, pp. 100–107, 2026.

[8] B. P. Das, “Transformer condition monitoring – Sensors vs Analytics: A chicken and egg situation revisited,” Transformer Magazine, vol. 13, no. 2, pp. 94–102, 2026.

[9] P. Picher et al., “Development and Implementation of Transformer Condition Monitoring Models for the Interpretation of Sensor and SCADA Data”, CIGRE Paris Session 2022, Paper ID:10269.

[10] T. McGrail et al. “Integration of Condition Monitoring into Substation Asset Risk Management”, CIGRE Paris Session 2020, Paper ID:B3-201.

[11] Reference [11] B. P. Das & M. Grisaru, “Beyond Fixed Limits Baseline-driven, trend-focused Online DGA alarm strategy – Part II” Transformer Magazine, vol. 13, no. 3, pp. 22–33, 2026.

Author



Dr. Bhaba P. Das is the Regional Manager (Asia Pacific) for Dynamic Ratings Australia, based in Wellington, New Zealand.
He is a Senior Member of IEEE, Young Professional of IEC, Member CIGRE NZ A2 panel, Member of Engineering New Zealand and Executive Editor of Transformer Magazine. He has published 40+ technical articles in various peer reviewed international journals and magazines. He has three patents in New Zealand and Australia related to condition monitoring. He was awarded the Best author award in 2023 and 2025 by voters of Transformer Magazine, a leading worldwide publication on transformers.
He has previously worked at Hitachi Energy Transformers Business Unit in Singapore & ETEL Transformers Ltd in Auckland, New Zealand. He has completed his PhD in Electrical Engineering from the University of Canterbury, New Zealand and Bachelors Degree in Electrical Engineering from University of Gauhati, Assam, India.