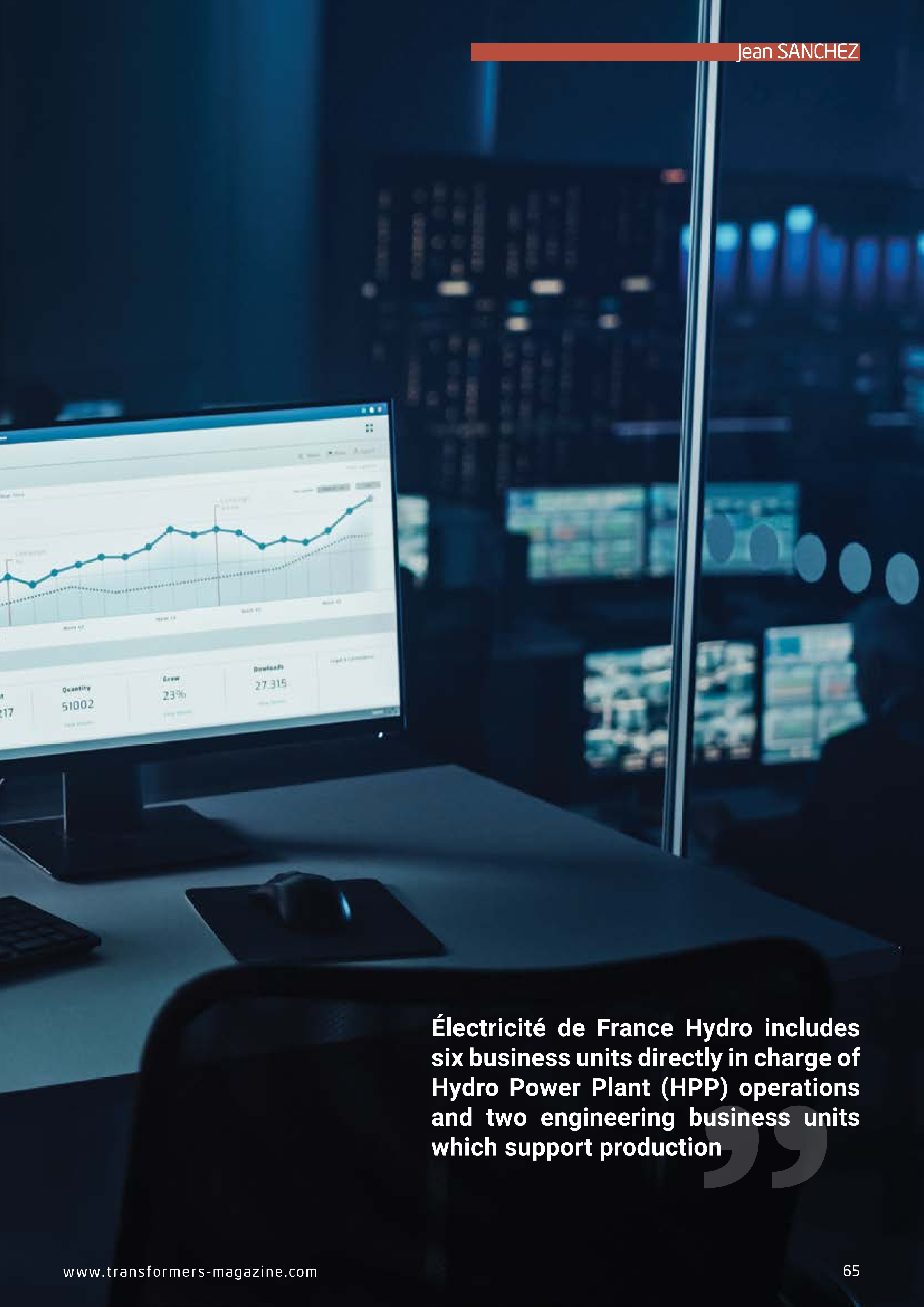
EDF Hydro's approach to monitoring

ABSTRACT

France's primary electricity generation utility, Électricité de France (EDF), chose its Hydro power plant division for implementing a large-scale digital monitoring project in 2012. Currently, 630 turbines have been monitored, totaling 18.7 GW of installed power. This strategic initiative targets enhancing plant performance, safety, maintenance and availability with the expectation of a Return On Investment within 3 to 6 years. This article presents related data and a case study with the diagnosis of a power transformer based on monitoring in the field of Dissolved Gas Analysis (DGA) and Partial Discharge (PD).

KEYWORDS:

EDF hydro, power transformers, DGA monitoring, Partial Discharge, bushing monitoring, alarms



Électricité de France Hydro includes six business units directly in charge of Hydro Power Plant (HPP) operations and two engineering business units which support production

From 2012, EDF Hydro launched large-scale monitoring of strategic plants, enhancing plant performance, safety, and optimizing maintenance

1. EDF Hydro assets and global monitoring

1.1 EDF Hydro's transformer fleet

Électricité de France Hydro includes six business units directly in charge of Hydro Power Plant (HPP) operations and two engineering business units which support production. One engineering unit is dedicated to hydro engineering, with responsibilities from transformer supply and maintenance up to an entire new HPP. The other specializes in technical measurements, diagnoses, and fleet assessment. The latter unit includes civil engineering, e.g., river water flow forecasts, and mechanical engineering, e.g., High Voltage (HV) power transformer bushings in HPPs.

Électricité de France's hydro Generator Step-Up Transformer (GSU) fleet consists of nearly 800 GSUs with approximately 20GW of installed HPP capacity in France. The fleet includes many small transformers, and some are rated up to 400kV / 370MVA in Gas Insulated Substations (GIS).

1.2 EDF Hydro global monitoring

Beginning in 2012, EDF Hydro began large-scale monitoring and digitalization of strategic plants. The plants were classified according to their economics. The higher the stakes, the more monitoring sensors were added to machines. The objective was to cover all possible failures by continuous monitoring. This allowed us to increase plant availability, performance, and safety, as well as to optimize maintenance, all while remaining independent from manufacturers.

Today, we remotely monitor 630 turbines, totaling 18.7 GW of installed power plants.

Many different devices were instrumented on GSU transformers. Most were Dissolved Gas Analysis (DGA) monitors, but turbine penstocks, mechanical shafts, and grid services (e.g., voltage and frequency reserves) were also instrumented. Next, we will monitor temperature, pressure, vibration, and operation time.

Clearly, the key points to monitoring are:

- Which data? Sift copious data.
- Who is using it in practice? Optimize efficacy.

Historically, one risk of monitoring was the collection of large amounts of data without processing, at least enough, the data. Failure analysis experts would be tasked to try to find what was going on by digging through years of (stagnant) data. To improve, we have dedicated teams to look at live data and raise alarms as soon as possible. A team should act on incipient faults at the earliest appearance.

1.3 EDF Hydro monitoring organization

Targeting performance goals, we built five regional monitoring centres to assess live data. Today, we have more than 100 employees in monitoring. They are organized into three levels, as detailed in Table 1.

Level 1 / Plant monitoring takes place directly in plants where operators regularly inspect, monitor key indicators, and manage alarms.

Level 1 / Monitoring is carried out remotely by monitoring specialists, some of whom were former operators. Working in the monitoring center, they use specialized software to identify drifts and machine behavior from multi-parametric analysis models. The latter may include thousands of real-time or long-term data points. Teams of two or three technicians perform live data analyses and check short-term tendencies (Figure 1).

Level 2 monitoring is typically conducted by two support engineers watching tendencies mainly in mid-term to long-term time frames (Figure 2). A significant part of their day-to-day work is distinguishing false alarms from genuine trends. They set alarm criteria to best trigger further analyses. At this level of monitoring, engineers diagnose the causes of drifts and, most importantly, recommend corrective

Table 1. EDF Hydro Monitoring Organization

	Level 1 / Plant	Level 1 / Monitoring	Level 2	Level 3
Who	Plant operations technicians	Monitoring center (2-3 people, mostly from plants)	Support for monitoring centers (≈ 2 engineers)	Experts (from many business units)
When	24h	Daytime	Weekly	On demand
What	Live operations surveillance	Live monitoring/check alerts/alarms on all data and devices	Tendency checks, medium/long term	Investigations / specific tests / assessments and recommendations, as needed
Alarms	Live alarms / protections on-site	« Self » specified, below protection settings	Statistical tools	-

actions to prevent failure. In EDF's hydro fleet, we detect more than 1500 precursors, or "pre-monitoring alarms" annually. This allows us to protect our assets from incidents or damage.

Finally, Level 3 monitoring goes even further. Networks of experts in different business units are capable of producing advanced and on-demand diagnostics conducted remotely or on-site, thanks to dedicated technical teams. They analyze the most daunting field cases.

Today, there are seven networks of experts at EDF Hydro. They rely on EDF Hydro's expertise, augmented by the experience of other fleets, namely nuclear, fossil fuel, wind, and solar.

Deployment of monitoring to scale enables us to reduce the rate of inopportune unavailability by nearly 20% and startup incidents of production units by 35%. Monitoring responds to severe security and safety issues. It pays dividends for hydropower plants because it prevents material damage and power outages. The Return On Investment (ROI) of monitoring at EDF Hydro is calculated to be three to six years.

2. EDF Hydro monitoring field cases

2.1 Typical field cases

Two separate cases of effective monitoring follow.

Figure 3 shows the operating points of reactive power vs. generator voltage over time, showing internal limits. We compare measured points to limits. Then, we can detect which group is working as a set and if there are deviations that require attention.

Thanks to monitoring, inopportune unavailability has been cut by nearly 20%, and startup incidents have been reduced by 35%, with a Return On Investment period of 3 to 6 years

EDF Hydro's robust monitoring organization is structured into three levels, from plant operations to specialized expert assessments

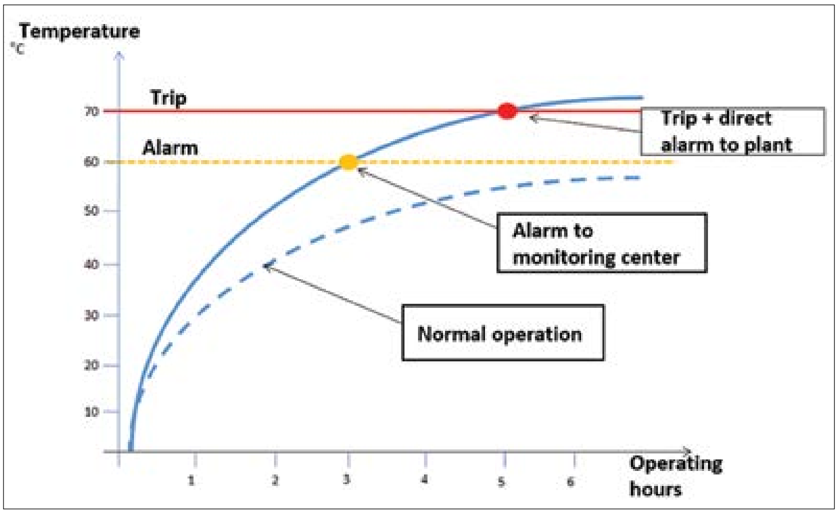


Figure 1. Examples of short-term alarm and trip

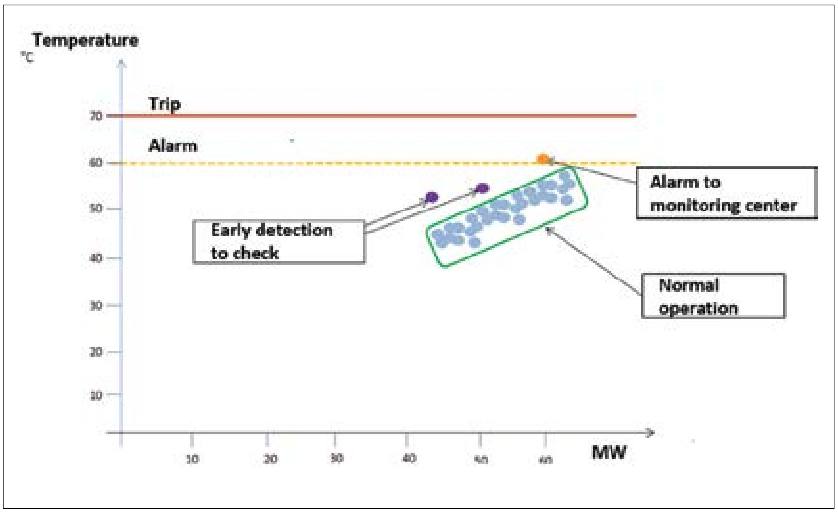


Figure 2. Example of long-term alarm and trip

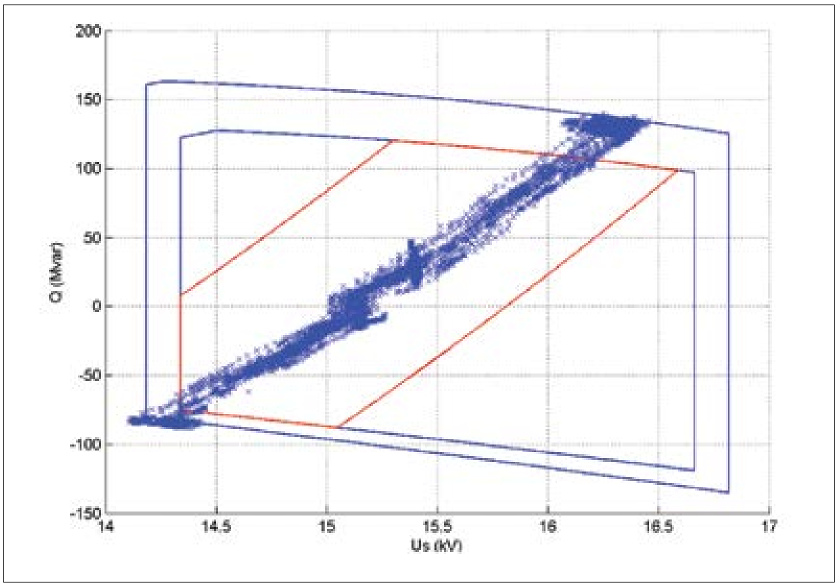


Figure 3. Reactive power vs. voltage: operating points and limits

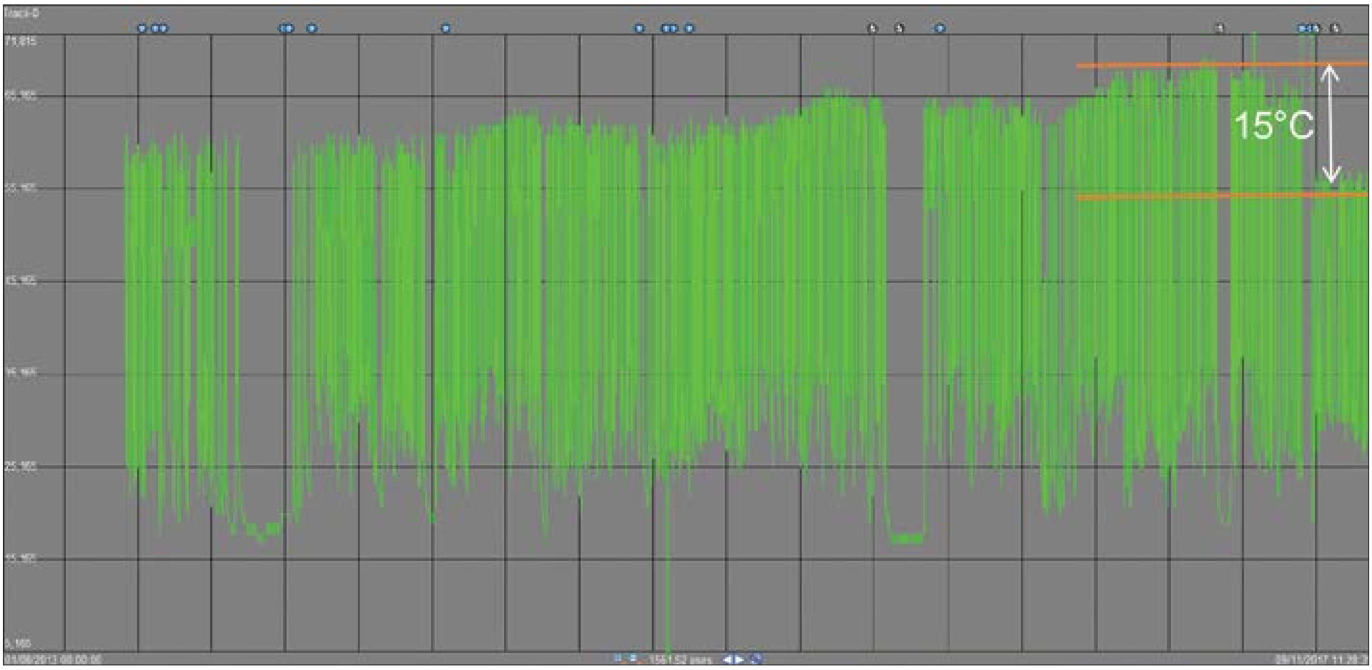


Figure 4. Bearing temperature over 4 years, followed by the corrective action!

Although transformer monitoring is interesting, the literature does not include many criteria other than IEEE C57.143 and CIGRE Technical Brochures #630 and #783, EDF prefers to determine its own criteria internally

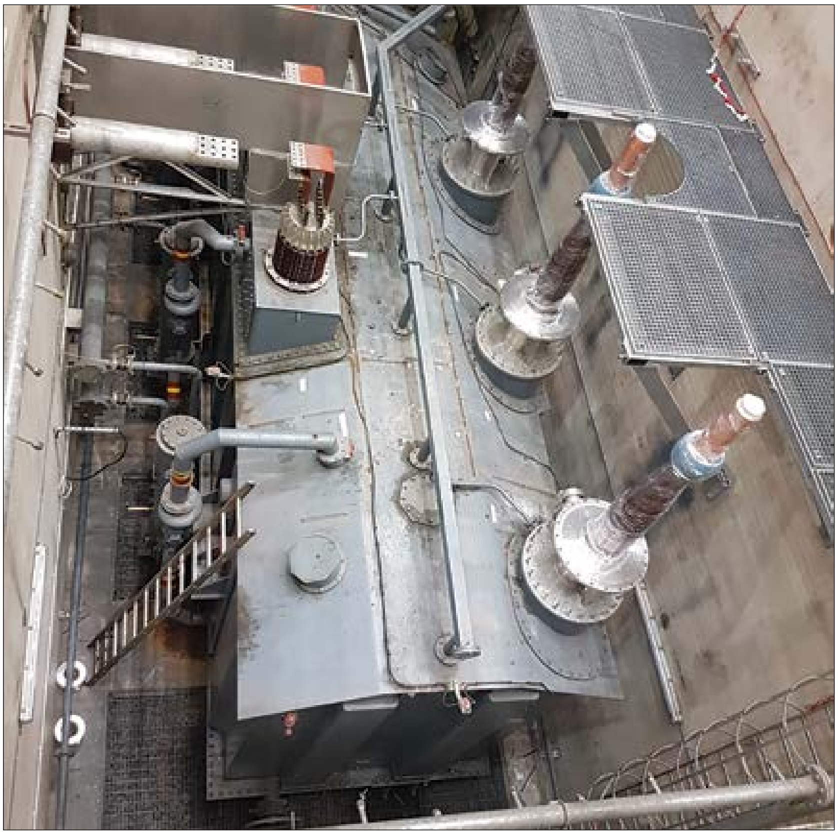


Figure 5. 400 kV / 250 MVA monitored transformer

Figure 4 shows an interesting case of bearing temperature over four years. A trend of slowly increasing temperatures triggered mechanical inspection. After moving one pad by 0.05 mm, the bearing temperature decreased by 15°C.

2.2 Transformer monitoring field case

Although transformer monitoring is interesting the literature does not include many criteria other than IEEE C57.143 [1] and CIGRE Technical Brochures #630 [2] and #783 [3]. In any case EDF prefers to determine its own criteria internally. It is linked with expert analyses based on field experience according to asset behavior. Separately a CIGRE Joint-Working Group (A2/D1.67) is currently creating the "Guideline for Online Dissolved Gas Analysis Monitoring" for reference globally.

An interesting monitoring case from recent years is that of a 400 kV / 250 MVA transformer (see Figure 5). It is a 5-limb core design manufactured in 1981. This transformer experienced no prior issues. Bushing and DGA monitors were operating.

Hydrogen (H_2) levels increased in 2019 with a Partial Discharge (PD) pattern in Duval triangles and pentagons. It was triggered at a few hundred ppm in our monitoring center. Monitoring Level 3 experts

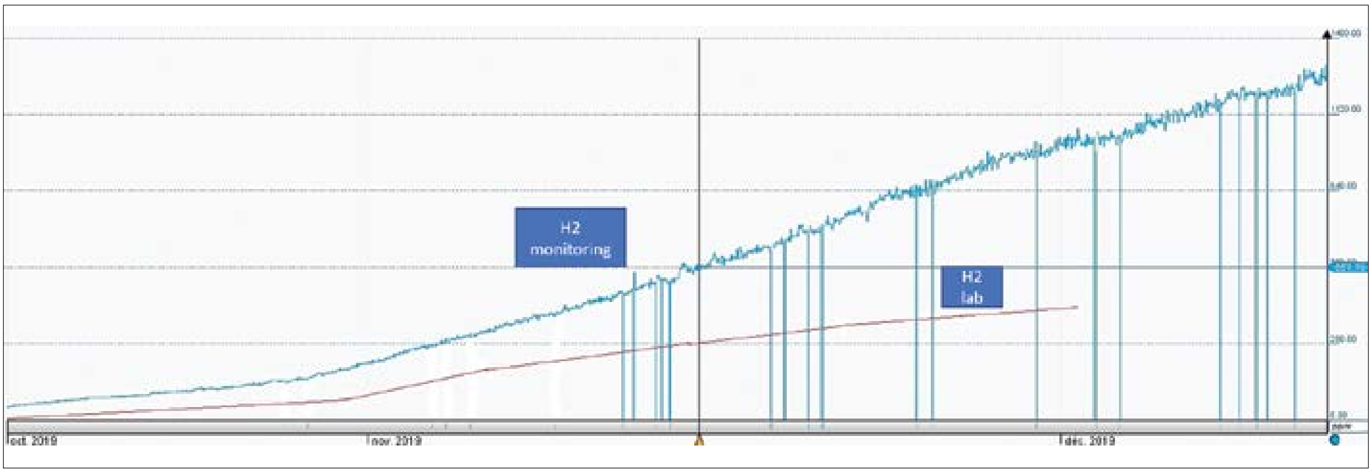


Figure 6. Hydrogen trends from transformer monitoring and from the laboratory over months

were brought on board for months of global analyses. No other oil or operational parameters were determined abnormal.

The monitoring level rose steadily for months (Figure 6) on the monitored device and on laboratory samples. The latter was approximately half of the former. Hydrogen levels even exceeded 3000 ppm, which is far above any known criteria. Based on experience, we decided on an oil treatment for a rather unusual reason: "just" to remove dissolved gas from oil and to not saturate the hydrogen sensor above 5000 ppm; we had to be able to continuously monitor live DGA trends of our incipient PD in service. Since we did not fix the root cause, of course, hydrogen continued to increase.

We were faced with a tricky monitoring question in this "grey zone", above all known criteria but below the unknown technical limit of possible flashover: "When should we stop?" Today, the answer is linked to: 1) the specifics of each individual case, 2) periodic decisions involving all stakeholders according to risk analyses, and 3) past experience and pattern recognition by internal experts.

Along with investigations such as on-site PD testing, we decided to install one of EDF's first PD measurements of bushings. We recognized a floating potential PD pattern in one phase, as shown in Figure 7.

Finally, we decided to investigate the active part on-site. This winding design included a "line shield" over the entire height of the winding directly connected to the 400 kV line. In addition, a top static end ring (aluminum toroid wrapped in paper insulation) measured 2 m in diameter. This diameter was the same as that of the high-voltage winding. It included a metal weld to fix the potential of the top static end ring. This contained a fault underneath approximately 2 cm of wrapped paper (see Figure 8). Consequently, the static end ring floated near the rated line voltage. The bad connection was proper-

One tricky monitoring question in this huge "grey zone", above all known criteria but below the (unknown!) technical limit of the possible flashover: "When should we stop?"

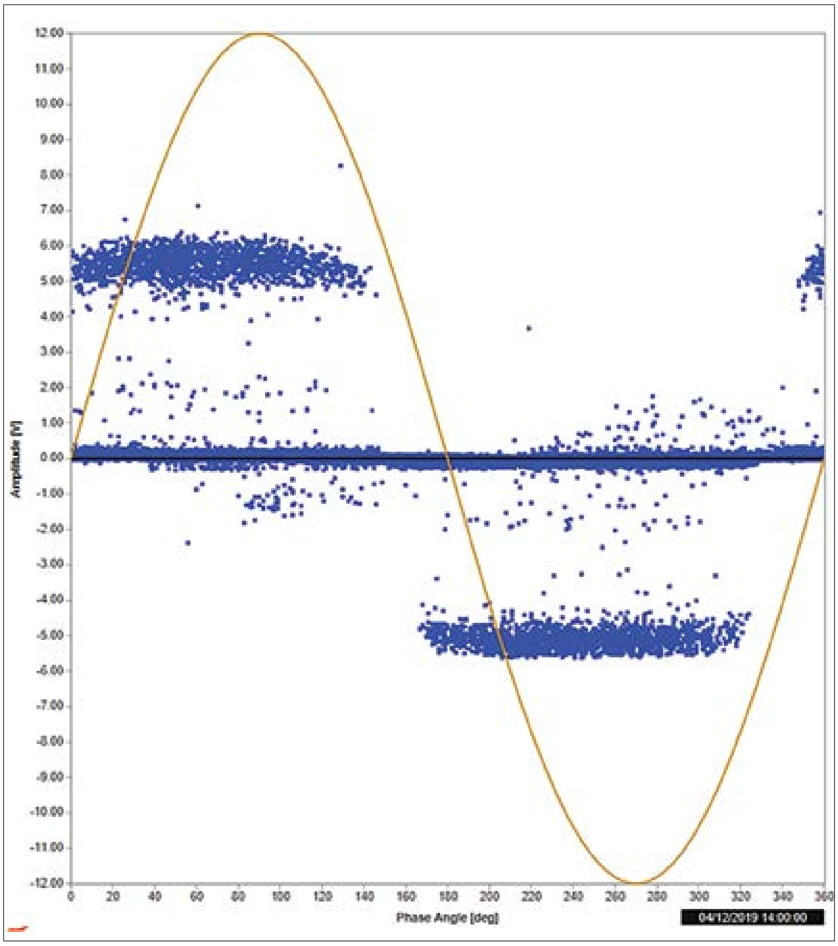


Figure 7. Floating potential PD pattern from bushing monitoring

Key points for maximum efficacy of a monitoring system are: 1) data analysts and 2) cross-functional teamwork on the most challenging cases

ly detected by the bushing PD and DGA monitoring systems. The end ring at rated voltage induced PD.

An offline PD test confirmed the efficacy of on-site repairs. Transformer monitoring is still in place for surveillance and, as of this writing, without alarm.

Transformer monitoring of DGA and bushings with PD measurements, along with teamwork (at EDF and with suppliers) led us to: 1) accurately locate the incipient fault, 2) continue to deliver power with appropriate internal follow-up, and 3) effectively focus the investigation on specifying subsequent repairs.

In addition, large GSU units such as this take years to supply. It is also difficult to provide spare parts for multiple hydro plants because they differ greatly from one another. However, EDF is addressing the problem, already including solutions in our transformer fleet.

Accordingly, we will need to install even more monitoring systems on the "classic ones" in order to improve fleet monitoring and maximize transformer life.

3. Conclusion

EDF Hydro implemented a proactive policy in 2012 for global hydropower plant monitoring. Instrumentation and internal organization efforts have proven effective.

Power transformer DGA monitoring has since been installed on the most strategic assets. Bushing monitoring with PD measurements is increasing. The combination of both monitoring systems has already been successful in incipient fault diagnoses and enabled us to deliver electricity longer than otherwise. Risk levels have decreased, and root cause analyses have accelerated.

Key points for maximum efficacy of a monitoring system are: 1) data analysts and 2) cross-functional teamwork on the most challenging cases.

Acknowledgements

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Figure 8. Line shield and connection to the top static end ring

Author

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