ONLINE MONITORING OF LARGE FLEET OF SUBSTATION POWER TRANSFORMERS

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ABSTRACT

Online monitoring offers new opportunities for DSOs to modernize their network management processes and switch to a predictive maintenance.

The benefits offered by this technology are the use optimization of transformers. This allows them to be used as close as possible to their physical and condition limits. This system also increases the lifetime of the equipment, offering a direct financial gain.

In addition, monitoring helps to avoid damaging incidents, and thus to make the network and electricity supply more reliable.

This paper will first analyse the functions of the online monitoring and identify the components related to them. Second, a qualitative classification in terms of costs of different monitoring components will show that our operating and maintenance model could be improved with minimum investment. Finally, the paper will present the Enedis solution based on innovative sensors and home-made data acquisition system.

INTRODUCTION

Enedis established a Smart Grid Roadmap in France [1] with two main objectives:

- Modernize network management processes and infrastructures, with predictive maintenance solutions (big data & analytics, monitoring of primary substations…), the improvement of its quality of service using new sensors, data, and automation, and the modernization of its network assets,
- Provide assistance to stakeholders of the electric power system or of regional territories in the French energy transition, with innovative grid connection solutions and processes/automation for facilitating the integration of RES.

Hence, at Enedis, maintenance will become more predictive and adapted to each type of equipment, based on their health index. Sensors in primary substations, data monitoring combined with big data models will help to optimize maintenance operations.

Enedis has a large fleet of substation power transformers. To improve reliability, minimize outages and maximize lifetime of these strategic grid components, Enedis decided to deploy a large number of online monitoring systems in an innovative and cost-effective way.

In this paper, we will describe the reasons that led us to develop a home-made solution with a high level of sensors interoperability and adaptable to changes in our information system and its telecom environment.

ONLINE MONITORING TO IMPROVE OUR OPERATING AND MAINTENANCE MODEL

The key drivers of the online monitoring roll-out are the following:

- New primary substations or new transformers.
- Primary substation with specific characteristics (such as transformer load level).
- Critical substations, for example, situated in very dense urban areas.
- Primary substation renovation or upgrade works (e.g. Instrumentation & Control).
- Primary substation with significant renewable energy generation connected to medium voltage networks, and especially with energy flows form distribution to the transmission grid.

Online monitoring condition of our transformers and their accessories must lead to an improvement of our operating and maintenance model. We focused mainly on the factors influencing the lifespan of power transformers and on which we could have an action:

- Losses of cooling capacity.
- Transformer physicochemical parameters in particular oil moisture.
- Prolonged or unsuitable overload of the equipment.

Online monitoring could help us to prioritize

maintenance interventions by conditional criteria:

- **Continuous measurement of the clogging state of the air-coolers** by means of differential pressure sensors installed between fins and fans. Correlation between the clogging condition and the increase of the oil temperature will prioritize the cleaning of the concerned unit.
- **Continuous measurement of the efficiency of breather** by comparing the incoming and outgoing air humidity. Another criteria of prioritizing the change of breather desiccant could be the total air volume breathed by the transformer, estimated from oil dilatation.
- **Continuous assessment of OLTC *(OnLine Tap Changer)* behavior.** Monitoring the change on the shape of the motor current, high number of commutation or non-solicitation of the reverser position, will lead to prioritize the maintenance of the OLTC.

Online monitoring allows measuring the effectiveness of maintenance actions. For example, after a cleaning of the cooler, the differential pressure sensors will indicate the clogging mitigation. Hence, the maintenance operation will improve the transformer overloading capacity.

A continuous online monitoring of physicochemical parameters of the transformer in particular oil moisture and Hydrogen content allows to adapt the transformer loading in accordance with its real condition. For example, in case of cooling degraded mode (fan or pump shutdown) monitoring will give new duration limits for normal and overload operation.

Monitoring improves the diagnosis by indicating relationships between transformer components and alarmed condition. For example, a Buchholz alarm will be analyzed regarding load factor, OLTC position and oil temperature just before the event. Hence, a rapid and reliable diagnosis of the situation will be done.

AN OPTIMIZED SOLUTION FOR THE ENEDIS POWER TRANSFORMER FLEET

The decision to develop an internal solution starts from the following observations:

- Several Monitoring systems exist today “on the shelf” but unfortunately not adapted technically and economically to our fleet (large number of transformer with power range 20MVA to 100MVA).
- The total cost is relatively high: cost of material, installation and the costs related to configuration, software updates and sensors maintenance. The lifetime of electronic equipment is far lower than transformers and could be renewed three to four times during the lifetime of a transformer.
- Supervision models is based on international feedback and are not really open and easy to adapt.
- True multi-vendor interoperability is not fully effective today. This will complicate the management system of different monitoring solutions coming from different manufacturers.

To customize a monitoring system for Enedis power transformer fleet, we split the monitoring to two functions serving two main business use cases:

- Maximize transformer lifetime with an appropriate maintenance activity and switching to condition based maintenance rather than time based maintenance.
- Minimize downtime and consequence of failures by detecting earlier incipient fault.

Obviously the monitoring is often linked to the second function where the cost-effectiveness is easily justifiable especially for a power plant step-up transformer. This is less obvious for a substation transformer.

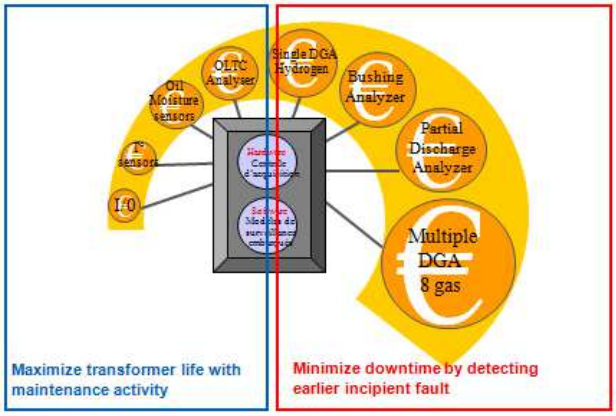

Figure 1: Qualitative qualification in term of cost

A qualitative classification in terms of cost and functions of different monitoring components shows that the operating and maintenance model could be improved with minimum investment.
The following figure shows the Enedis solution based on selected sensors and a home-made data acquisition system allowing an easy integration to the information system and a quick installation by the Enedis operators:

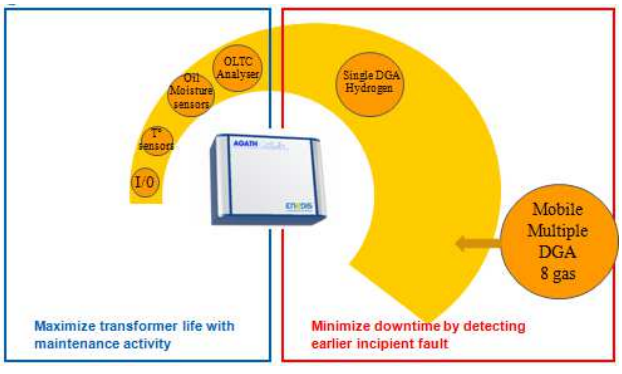

Figure 2: Optimized solution for Enedis

- The first function is fulfilled by a limited number of sensors as oil temperature, differential pressure…
- The second function is mainly covered by a Hydrogen sensor. The costly multi-gas analyzer is mobile and could be installed only in diagnosis mode after alarming situation (Buchholz alarm, H2 exceeded threshold...)

COMMUNICATING CHAIN

The system installation is done with ease thanks to a Plug & Play system, minimizing commissioning and configuration constraints for Enedis operators. The Local Area Network (LAN) communication is performed with fibre optic cables. It is to be noted that the installation works could be performed without the necessity to put the transformer under release from service.

Transformer monitoring uses a secure IP connection between the data acquisition system and the central platform used by the operators. The corresponding communicating chain tracing monitoring information, breaks down as follows:

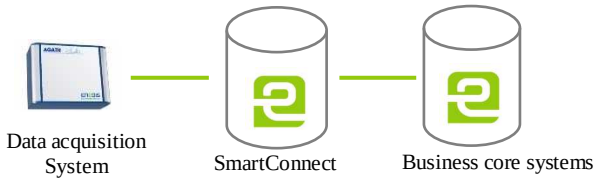

Figure 3: Communicating chain

SmartConnect: the platform of connected objects Enedis which ensures the restitution of data.
Business core systems: Primary Substation intervention management tool.

To manage the data from the data acquisition system to the server, we use the Enedis SmartConnect platform.
This platform aggregates all the data from connected objects used by Enedis.
The platform is broken down into three technical blocks:

- The web interface
- The mobile app
- The server-side data treatment and service provider

The main features of the online monitoring apps are:

- The data visualization through graphics illustrating information such as transformer load, temperature measures, oil moisture measures…
- The ability to develop specific business rules for alarm trigger such as temperature threshold setting.

This Man-Machine Interface dedicated to Enedis operators is developed in order to monitor the entire transformers fleet and allows focus on a specific transformer if necessary.

MONITORING TO IMPROVE MAINTENANCE & DIAGNOSIS

In terms of monitoring data operation, there are two main business use cases served by the substation transformer online monitoring.

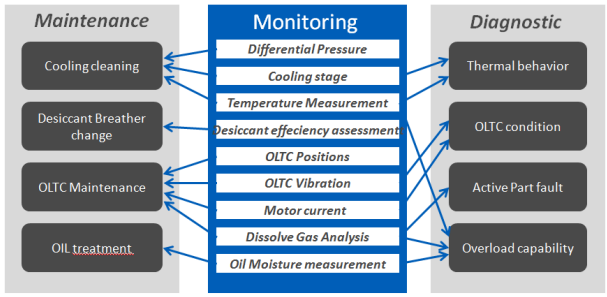

Figure 4: Monitoring to improve maintenance & diagnosis

- Provide indicators to maintenance team to prioritize their interventions towards a condition based maintenance.

- Improve the diagnosis by indicating relationships between transformer components and alarmed condition.

The benefits of the online monitoring break down as follows:

On a **short term** run, online monitoring gives a scoring of the condition of monitored transformer and its equipment. This scoring is based on several criteria such as temperature, air-coolers clogging, breather efficiency, oil moisture, on-load tap changer range of use. Those criteria will be weighted by the transformer load. This will give a ranking between transformers and will allow maintenance prioritization.

Management System (CMMS) for primary substations summarizes all the work orders for Enedis operators in charge of primary substation operation and maintenance. All the asset parameters of the transformers are described in that system as well as the history of maintenance acts (e.g. intervention after failure). This information is linked to a specific equipment, that is to say, a transformer identified by a dedicated ID. In the CMMS, the

measurement unit and the sensors will be described in order to identify potential faults on these devices, providing associated work orders.
The work orders produced by the CMMS will be of different types:

- To fix the online monitoring communication chain, at a local or central level (e.g. Loss of communication with the measurement unit or with a specific sensor).
- Alert on the transformer itself (e.g. Threshold trigger, air-cooler clogging because of pollen during the spring season). This kind of alert won't be fixed up in real time or on a short term run but will trigger specific supervision of the transformer by Enedis operators and specific maintenance tasks.
  In terms of maintenance, there are 3 types of tasks: air-cooler cleaning, Silica gel replacement on dryers and OLTC handling.
- Failure alarm as programmed in the model (e.g. abnormal shape of the OLTC motor current, air-cooling system failure, Hydrogen detection) that will lead to an urgent intervention such as limitation of the transformer load, oil sampling for diagnosis or permanent supervision through mobile 8-gases analyzer

On a **long term** run, a health index will be defined per transformer in order to feed a global maintenance policy at a transformers fleet scale, requiring a sufficient observation timeframe. More important maintenance tasks could be decided on that basis such as air-coolers replacement.

A big data approach is being considered in order to take into account all the asset description, the interventions chronicle, the information provided by the online monitoring and specific external data (e.g. meteorological data) in order to provide specific data visualization and associated maintenance prioritization suggestion.

A workstream is underway exploiting the data collected and contributing to the analysis models and algorithms improvement.
One of the main issues to address is the location of the intelligence: at the local level in the embedded software of the measurement unit or at the central system level?
This intelligence could be analysis model, algorithms and computation capabilities…
The global answer could be a hybrid solution, embedding both local and central intelligence, tailored to our needs.

ROLL OUT OF THE SOLUTION

Today, more than 75 (seventy five) of these systems are communicating with sometimes more than one year of data storage. It is still soon to measure accurately all the benefits on a massive fleet of the solution that need data and time to be precisely measured.

We expect 600 of these systems communicating by the end of 2020 and 1000 by the end of 2022.

Nevertheless, we already have at our disposal individual positive returns of experience on specific issues or equipment such as air-coolers.

CONCLUSION

In conclusion, this Enedis home-made solution was considered as the best answer to our specific DSO needs.

In other contexts, out of France, this solution could also provide added-value to some actors similar to Enedis, such as DSO who faced the same challenges for large transformers fleets.

Our expectation is that this solution could positively influence the market innovation to develop cost-effective, easy to install and interoperable solution to face those kinds of challenges.

Online monitoring condition of our transformers and their accessories must lead to an improvement of our operating and maintenance model.

Ultimately, this smart solution deployed for monitoring of critical transformers will allow Enedis to adopt a more predictive and cost-effective maintenance policy.

REFERENCES

[1] L. KARSENTI, P. DAGUZAN, 2017, "ENEDIS APPROACH FOR THE ROLL-OUT OF TECHNICAL SMART GRID INDUSTRIAL SOLUTIONS", CIRED 2017, paper 0040.