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Study Committee B1: Insulated Cables
PS2: FUTURE FUNCTIONALITIES AND APPLICATIONS

Maintenance and asset management digitalisation with cable monitoring systems supervision

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SUMMARY

Monitoring solutions for underground and submarine power cables are both part of a global trend and included in RTE's strategy regarding asset management as a mid-term objective (2025). The ambition is to have 50% of the grid assets monitored by then. In order to serve this strategy, projects have been launched to study, evaluate and deploy monitoring systems, including a restructuring of the company to open asset management centres running 24/7. Regarding insulated cables, two specific projects and related systems have been studied and are being developed:

- Cathodic protection sensing (CPS)
- Temperature and acoustic sensing using DTS and DAS systems (Distributed Temperature Sensor and Distributed Acoustic Sensor).

Two on-going projects are presented in this paper, regarding cables monitoring with a focus on each key link in the measurement chain (from the sensors to the end-users):

- The sensors are specific and adapted for each monitoring need: local voltage and current sensors for CPS and distributed fibre optic sensing for DTS/DAS.
- The connection of the systems to the IT network is sensor specific and based on the amount of data to be transmitted and on the criticality of the data itself: the wireless LoraWan network has been chosen for CPS since it allows little data to be transmitted over a wide area whether the usual internal wired IT network is used for DTS/DAS large data transmission. A special care is taken to the design regarding cybersecurity in the data transmission solutions (monitoring network strictly separated from the operation network …).
- All these data are gathered on an internal cloud server and then displayed to the end-users in an intranet web-application in development. This UI will allow to visualise consolidated data providing context (geographical map, points of interest), generate alarms and reports. This web-application is being designed with and for the end-users in the maintenance teams. In particular, graphs and useful data are displayed in a user-friendly and efficient way, allowing responsive actions to be taken (on-site intervention…).

KEYWORDS

Underground cables, monitoring, Cathodic Protection, LoraWan network, voltage and current sensors, DTS, DAS, web application, supervision

1. Introduction

Monitoring solutions for underground and submarine power cables are both part of a global trend and included in RTE's strategy regarding asset management as a mid-term objective (2025). The ambition is to have 50% of the grid assets monitored by then. In order to serve this strategy, projects have been launched to study, evaluate and deploy monitoring systems, including a restructuring of the company to open asset management centres running 24/7. Regarding insulated cables, two specific projects and related systems have been studied and are being implemented:

- Cathodic protection sensing
- Temperature and acoustic sensing using DTS and DAS systems (Distributed Temperature Sensor and Distributed Acoustic Sensor).

2. Cathodic protection centralised monitoring

Cathodic protection systems used in France

Corrosion can occur when metallic pieces are buried. To prevent damage on grounding circuits and steel pipes, which could lead to ground collapse or unsafe situation in case of fault, two types of protections can be installed:

- Cathodic protection: this system is used to control the corrosion of metal by making it the cathode of an electrochemical cell. Its main components are a sacrificial anode, a battery, and a rectifier as shown in Figure 1. In the French network, all the steel pipes used for High Pressure Oil Filled cables are protected by this method.

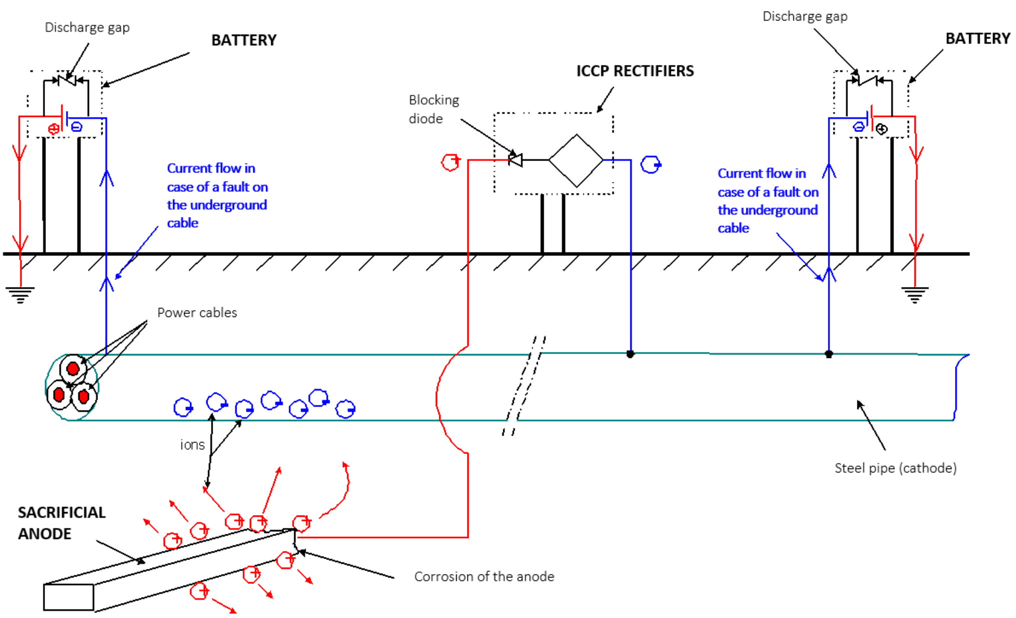

Figure 1: Cathodic protection installed on HPFF cables

- Drainage: Stray currents refers to currents flowing through paths other than the intended electrical circuit. As an example, electric railways are one of the principal sources of stray currents in the ground. Any buried metallic structure then becomes a privileged passage for these return currents and corrosion occurs at the point of discharge. Even though, this degradation only occurs during the passage of the trains, the stray current intensity can be significant considering the currents involved for train operation. The corrosion being proportional to the intensity, the corrosion phenomenon can be very damaging and quick (a few weeks/months may be enough to observe significant degradation).The drainage system, exposed in Figure 2, is used to safely evacuate stray currents caused by trains or other sources.

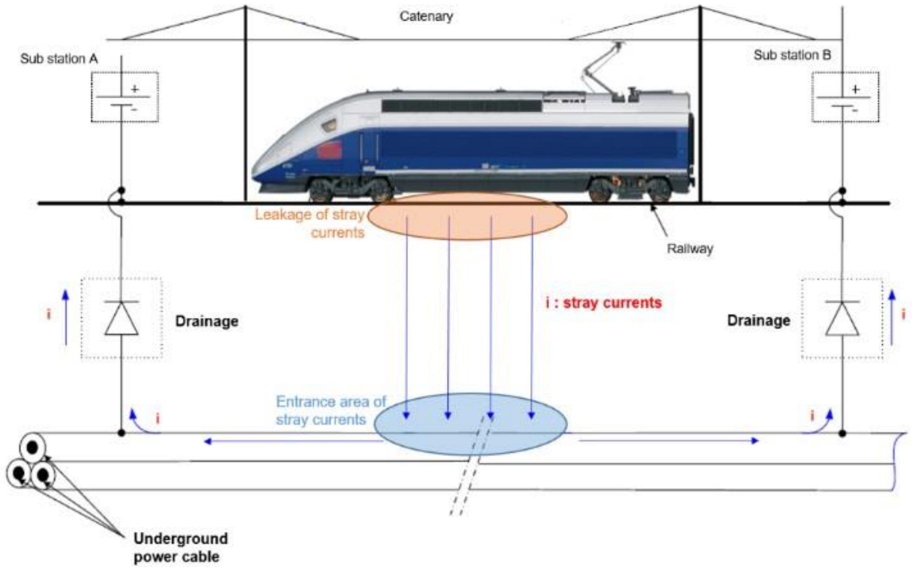

Figure 2: Drainage system to evacuate stray currents caused by trains

Since corrosion can happen very quickly, the French standards require to check these equipment (rectifier, battery and drainage) every month, representing approximately 4800 hours of work per year on the French HV grid. This generates a strong workload for maintenance teams with many trips involved. As an addition, an annual measurement campaign of all the test stations[1] is performed. Therefore, the “Cathodic Protection Monitoring” project was launched in 2018 with the objective to improve and facilitate maintenance actions related to steel pipes cathodic protection for High Pressure Oil Filled cables and stray currents drainage systems. This innovative topic was introduced in CIGRE TB 825 [1] as a case study, and will be here developed.

The “Cathodic Protection Monitoring” project involves the installation of sensors on all equipment that ensure cathodic protection and stray current drainage:

- Impressed Current Cathodic Protection (ICCP) rectifiers,
- Batteries installed in series with the rectifiers to ensure that the impressed current flows through the steel pipe and not through the substation grounding circuit (it should be noted that adapted power diodes did not exist at the time of conception some decades ago),
- Stray current drainage bond.

Data collected by sensors are sent to the TSO’s intranet platform using LoraWan Network (see Figure 3 for the architecture). A key feature of this internally developed interface is its ability to process the data and generate alarms when out-of-bounds values are detected. It allows operators to consult real time equipment’ voltage and current for a faster reaction time when incidents occur and a better diagnostic.

[1] electrodes connected to the pipe and regularly installed all along a cable. They enable the measurement of the pipe potential at different points.

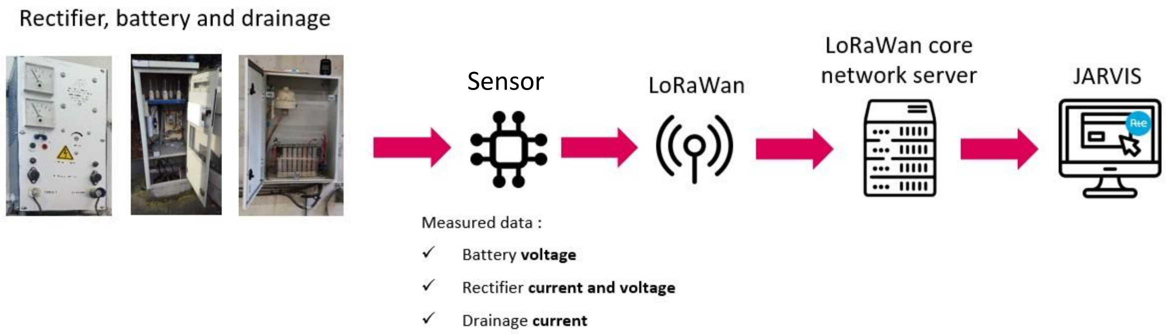

Figure 3: Description of the monitoring architecture for the Cathodic Protection Monitoring

The sensors used in the project:

The sensors used for the monitoring are the sensors designed by a French firm specialized in the manufacturing of cathodic protection equipment (see Figure 4). The sensors can be deployed on the GSM or LoraWAN network. The LoraWan network has been chosen since it allows for low-power wide-area network which fitted perfectly with the project's need (little data to be transmitted over a wide area). Besides, LoRa is a modulation technique less expensive than GSM where monthly subscriptions are needed.

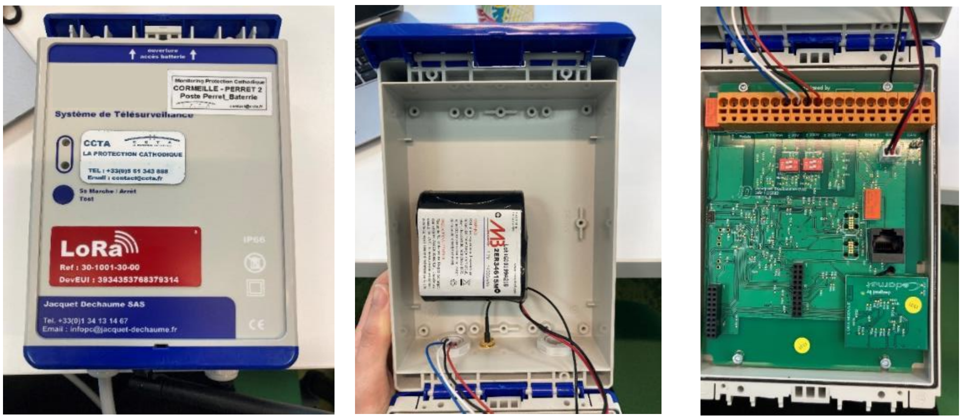

Figure 4: The sensor used for the Cathodic Protection Monitoring Project

The sensors focus on monitoring:

- The ICCP rectifier's voltage and current,
- The batteries voltage,
- The current flowing through the drainage bond.

They are powered by batteries with a lifespan of 5 years.

From the sensors to the LoRaWAN core network:

There are four channel of data acquisition per sensor. In LoRaWAN mode, the system acquires one measurement per channel every minute (the sampling rate is configurable according to the needs). These measurements are stored in memory and are summarized periodically; every hour for the Cathodic Protection Monitoring. The minimum, the maximum and the average values of the preceding hour are sent within one to three messages to LoRaWAN core network server. The sensor system implements the LoRaWAN protocol at version 1.0.3 to communicate with LoRaWAN core network server. This protocol implies a certification of the sensor by the LoRa Alliance.

As the messages transmitted by LoRaWAN are not acknowledged by the server, it is possible to activate a redundancy mechanism in the transmission in order to make the transmission of messages more reliable. Following the activation of this mechanism, the same message will be transmitted several times on different frequencies in order to maximise the probability of good reception by the server (at the expense of energy consumption). It is thus possible to adjust two parameters related to this mechanism:

- Redundancy factor: number of retransmissions of the same message.
- Frequency of retransmissions.

In LoRaWAN mode, the sensors need to be configured onsite with a computer software, the computer being physically connected to the sensor. This can be done from remote with GSM Network.

From the LoRaWAN core network to the TSO servers:

The LoRaWAN provider offers an interface named "Objenious" to configure routing scenarios to send data to the TSO servers. On the TSO side, sensors data are stored in a big data infrastructure based on NoSQL databases. This type of infrastructure enables large volume of data to be stored and data are easier to query. Consideration is being given to store data in a datalake in order to keep even larger amount of data.

Security aspect:

First of all, it should be noted that data collected from the "Cathodic Protection Monitoring" project are confidential but not critical for the electricity grid management. This is why data are transmitted through a network different from the operation network.

Besides, the LoRa Alliance has kept security front and centre in its development of the LoRaWAN specification and has been highly transparent about the protocol's security features. Between the sensors and the LoRaWAN core network, the LoRaWAN protocol natively integrate security features. The following parameters need to be configured in the sensors:

- DevEUI: this the unique ID of the end device,
- AppEUI: this the unique ID of the server application to which to transmit data,
- AppKey: security encryption key between the source of the message and the destination of the message.

Between the LoRaWAN core network and the TSO servers, data are still encrypted and HTTPS or MQTTS protocols are used.

Finally, the last step is to make relevant data available through an intranet application.

The intranet application JARVIS:

An internal web application, currently being developed by the French TSO, allows to visualise all sensors data from all the monitoring projects. This web application JARVIS, as a reference to a famous fictitious supervision computer, is accessible by all employees of the TSO. As shown in Figure 5 and 6, the web application was developed in order to be easy to use and to display only information relevant for maintenance. Regarding the "Cathodic Protection Monitoring", the web application performs two functions:

- Display the measurements collected by sensors data (live measurements and historical data graphs),
- Alarms when out-of-bounds values are detected. These alarms are viewable directly on the web application (red color) however the application send the summary of alarms detected during the previous month per equipment and for each cable to the teams in charge of maintenance.

In details, the application is divided into three different windows:

- Asset base (Figure 5): contains sensors' live measurements (voltages and currents) for each equipment and a map view displaying the cable route and the equipment's location directly imported from the internal asset database,
- Measurements (Figure 6): contains the current and voltage profiles of the various pieces of equipment of a chosen link as well as the different thresholds. It is possible to display raw data from the sensors or daily mean for time windows of 7 days, 1, 3, 6 or 12 months.
- Background: contains a summary of the number of alerts per equipment and per month.

The TSO is currently considering the possibility of developing a smartphone version of Jarvis so that teams in charge of maintenance could access directly to the application and its information during on-site visit.
Besides, as the web application is only accessible by internal employees, a function will enable downloading all data in a .csv format. This function will be particularly helpful for the annual control of cathodic protection by an external company specialized in corrosion. Indeed, the highest the amount of data measured per equipment, the best the understanding of the cathodic protection and its efficiency.

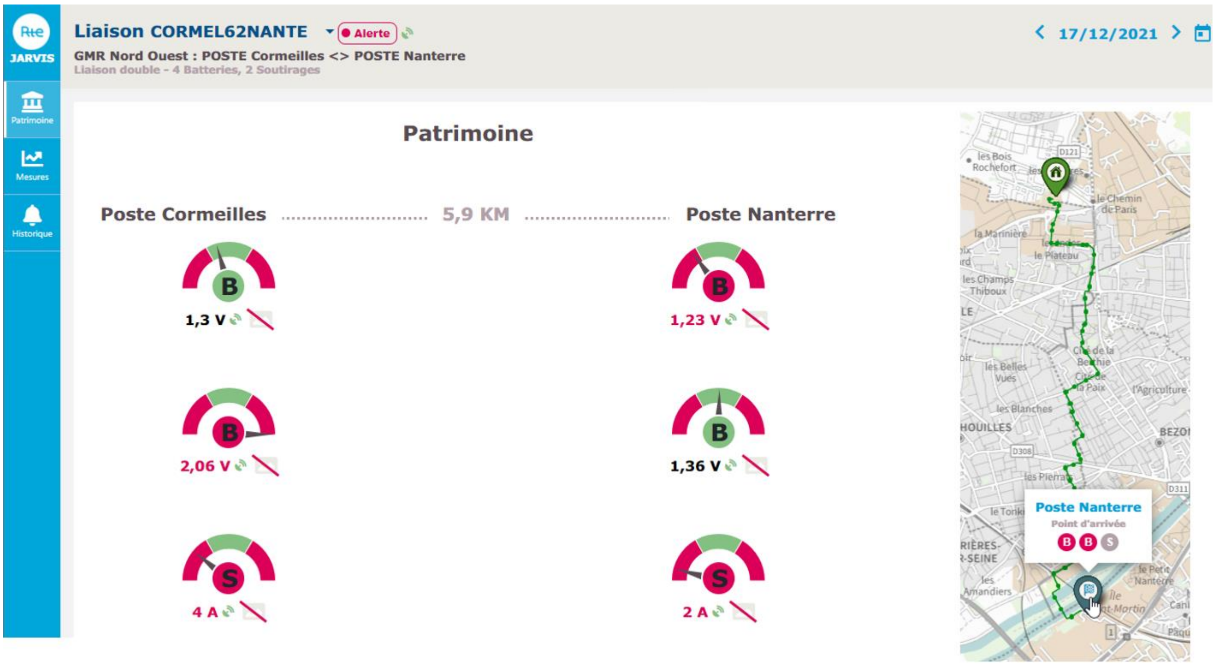

Figure 5: CPS web application, "Asset base" window, B refers to batteries with voltage live measurements and S refers to rectifiers with current live measurements

Figure 6: CPS web application, "Measurements" window, B refers to batteries

The integration in the Maintenance process:

All employees in charge of Cathodic Protection maintenance will have an easy access to the sensors data through the web application Jarvis and through the automatically sent summary of alarms detected during the previous month per equipment and for each cable. This report will be analysed each month by people in charge of maintenance planning to decide if an on-site visit is necessary or not. This analysis is based on the number of alarms on and on the equipment's history. A response time has been defined per equipment and the on-site intervention should be planned in this time period. Teams in charge of maintenance have attended training sessions to learn how to use Jarvis and understand maintenance processes evolution.
The long-term objective of implementing such sensors is to reduce the maintenance time for ICCP rectifiers and drainage systems, by keeping maintenance visits only when needed, coupled with a faster detection of failures. The first months of experimentation of this monitoring will help to better define the different threshold and the maintenance processes and actions following an alarm.

Figure 7: Monthly maintenance visit of a battery ensuring cathodic protection

3. Thermal and acoustic sensing centralised monitoring

The sensors used in the project:

The "DTS-DAS Monitoring" project, launched in 2018 after a few years of experimentation with both systems, follows a similar trend as Cathodic Protection Monitoring. The sensors used are DTS (Distributed Temperature Sensor) and DAS (Distributed Acoustic Sensor), based on an optical fibre and measuring either temperature for the DTS or the acoustic environment of the power cable for the DAS. These pieces of equipment are installed on strategic power cables such as interconnectors, offshore wind farms export cables and domestic transmission system safety nets. It is a singularly reduced field of application compared to other monitoring sensors because of the high equipment costs which need to be economically justified. In order to assess the economic valuation of the installation of DTS and DAS, a calculation tool based on an Excel file has been developed. It can be configured with each project (length of the power cable, underground or submarine, power rating, number of links, failure rate…) data to evaluate the profitability of installing DTS and DAS.

The monitoring system provides, the temperature for the DTS, and the acoustic levels for the DAS, on the whole length of the underground and submarine cables, except for too long submarine cables, still having a "grey" zone with absence of data in the middle of the power cable route. Temperature and acoustic data are then used for various existing or foreseen applications:

- Fault location based on the acoustic system pinpointing the exact spot of the fault,
- Long-term fault prevention based on the temperature evolution of the cable and its environment,
- Short-term sinister prevention using DAS system to identify potential TPI (Third Party Interference),
- Submarine cable depth of burial monitoring.

The connection of the systems to the IT network:

In order to convey and display data for the end-user, the first step is to extract the data from the equipment. The process is identical between DTS and DAS on different types of data.

- For the DTS an auto-export function is required by the TSO in the specifications. This export takes the format of a .csv file entitled with the timestamp of the measurement and containing two columns with the distance and the corresponding temperature. In order to aggregate data coming from various manufacturers, a unique export format (cf. Figure 8) is from now on included in the specifications to avoid file manipulation and simplify the process. Temperature alarms are not exported from the DTS but internally generated using temperature data gathered in a central server.

- For the DAS it is impossible to export and display the live waterfall in a centralized tool. The choice has been made to export only the DAS alarms, also in a .csv file. Those files contain the timestamp of the alarm, its nature, selected among a predefined list (fault, TPI, anchor…), the distance from the "main" substation and the GPS coordinates of the location of the alarm.

Date:	20.12.2021
Time:	09:43:42
X Units:	[m]
Y Units:	[°C]
0	12.25
1	12.36
2	11.87
3	11.80
4	11.65
5	11.51
6	11.37
7	11.27
8	11.35
9	11.39
10	11.50

Figure 8: DTS auto-export format

Those automatically exported data are also stored in a local server located inside the cubicle containing the DTS and DAS, in the substation. They are then extracted and gathered in a central server using SFTP protocol to send the files on the internal network (cf. Figure 9). The path of those data is precisely defined using a data matrix flows channelling the different uses of the monitoring systems: Remote Desktop Connection to access the manufacturer interface on the local server, files collection through SFTP, synchronization of the clocks using NTP, production and administration flows…

The files are then read and data are extracted in a centralized server in the TSO's cloud. From this instant, any operation on the data can be performed, either displaying them, post-treating them, analyse them to generate alarms.

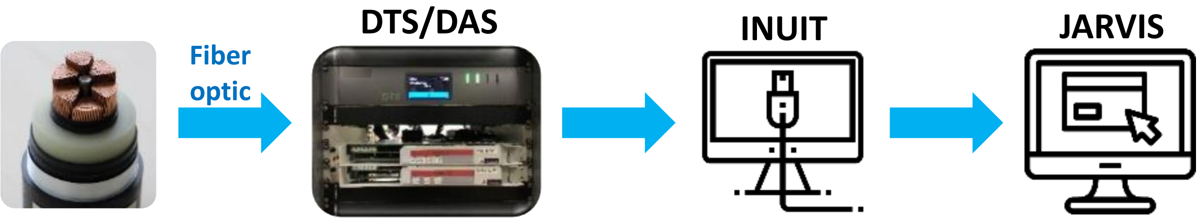

Figure 9: Description of the monitoring architecture for the Temperature and Acoustic Monitoring

The cybersecurity aspects need to be taken into account. To ensure the safety of the electrical grid, the monitoring communication network is strictly separated from the operation network and remote access to the sensors is restricted. Special care must be applied with interconnectors between countries where the DTS and DAS gather data from both sides of the link. The data exchange has to be strictly limited which leads to the implementation of specific firewalls to prevent cyber-attacks.

The intranet web application:

The post-processed data are then displayed in the same web-based application as for Cathodic Protection Monitoring (Jarvis), accessible through any authorised computer connected to the TSO internal network. This web application, still under development, gathers data from various asset monitoring solutions including transformers and GIS alongside power cables.

The screenshots presented in Figure 10 and Figure 11 are extracts from the MVP (Minimum Viable Product) of the application containing the essential functionalities. Depending on the use of the solution and the application and on the needs from the end-users, additional functionalities could be added to the web application.
The current version of the tool provides general information of the asset, the DTS temperature traces and generates temperature alarms. It also provides DAS alarms, live DAS data generation being too large to be displayed in the web application.
In details, the application is divided into three different windows:

- Link: shows the route of the underground power cable with points of interest, alarms and their locations (distance) on top of a map view with zooming possibilities (cf. Figure 10),

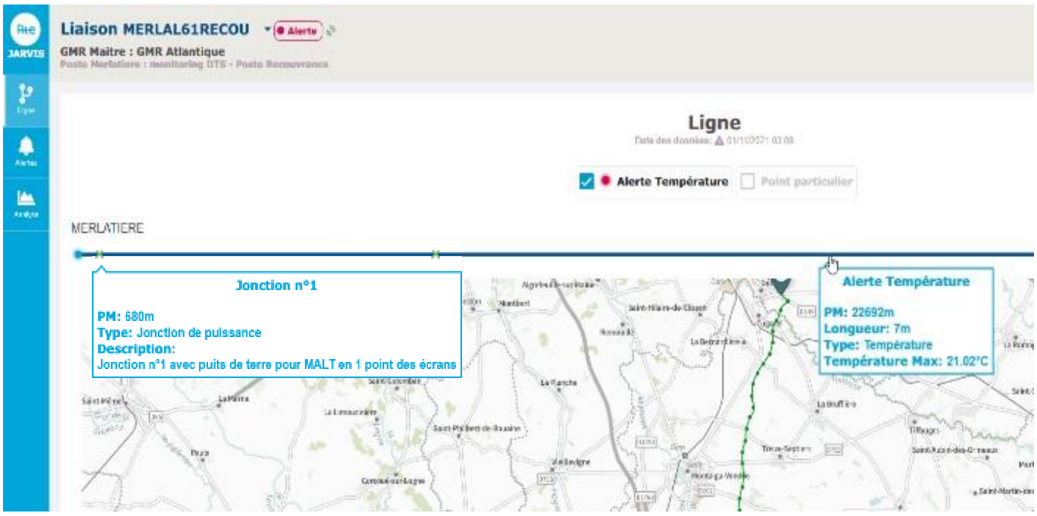

Figure 10: DTS-DAS web application, "Link" window, showing points of interest "joint #1" on the left side, and "temperature alert" on the right side

- Alarms: contains a list of all past and active alarms with a short description and the location on the interactive map view (cf. Figure 12),
- Analysis: contains the temperature profile with by default the last trace measured by the DTS, the possibility to display older traces or minimum, mean and maximum values on 1 day, 1 month or 1 year starting at the selected timestamp (cf. Figure 11).

Finally, the warning method is based on e-mails sent to pre-identified users.

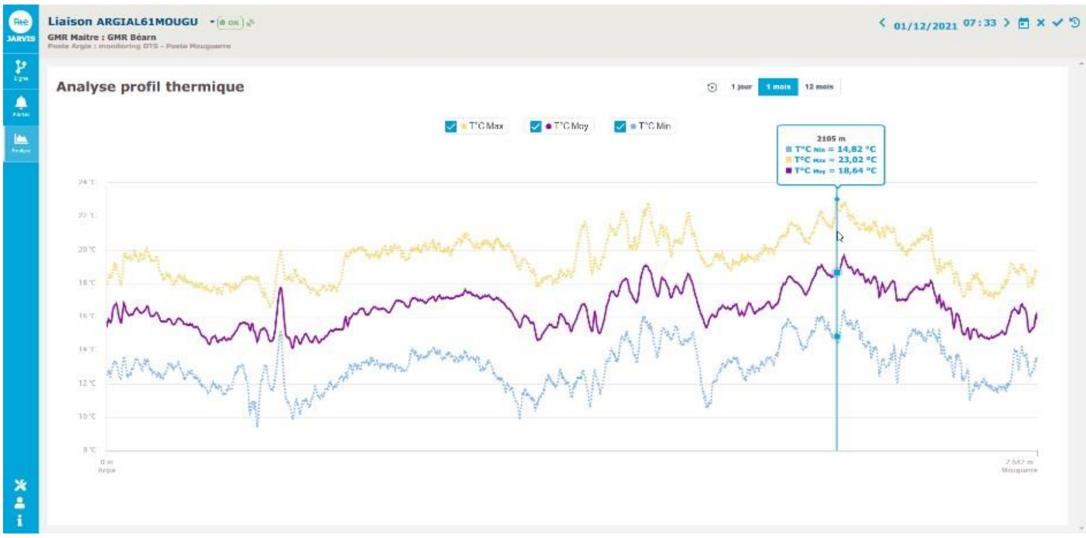

Figure 11: DTS-DAS web application, "Analysis" window

The integration in the Maintenance process:

The alarms generated (DTS) or conveyed (DAS) by the web application are received by the Maintenance team users. Depending on the degree of emergency of the alert, the end-user will be different.
The DAS generates alarms for real-time threats or events, thus the need for immediate actions: the recipient of the alarm is the local maintenance team with the shortest distance from the underground cables and the best knowledge of the cables route.
The DTS generates alarms for mid- or long-time threats, with usually slow temperature increase (or decrease) trends. There is then a need to analyse in depth the data and temperature history, examine the local area on the available maps, and even check the thermal design if needed. Taking into account this large amount of analysis, the dedicated user is different for the DTS, still in the Maintenance teams but with a wider scope and further from the field action.
When it comes to alarms, three different categories can be separated:

- DAS alarm – TPI (Third Party Interference): observations made have concluded that, currently, too many alarms are generated on long underground cables even with an intensive and thorough fine tuning (around one alarm per week on a 40 km underground cable). The option currently studied is to insist on the zones where most of the TPI alarms are located during the annual route inspection (see Figure 12).
- DAS Alarm – Fault: with this type of alarm, the first step is to confirm the fault using internal “electrical grid state” tool, then go on site using GPS coordinates and the map view offered through the web application. As a next step for this application, a way to corroborate the alarms with the work declarations received in the vicinity of the cable in the web application could help understanding the possible cause of the fault before going on site.

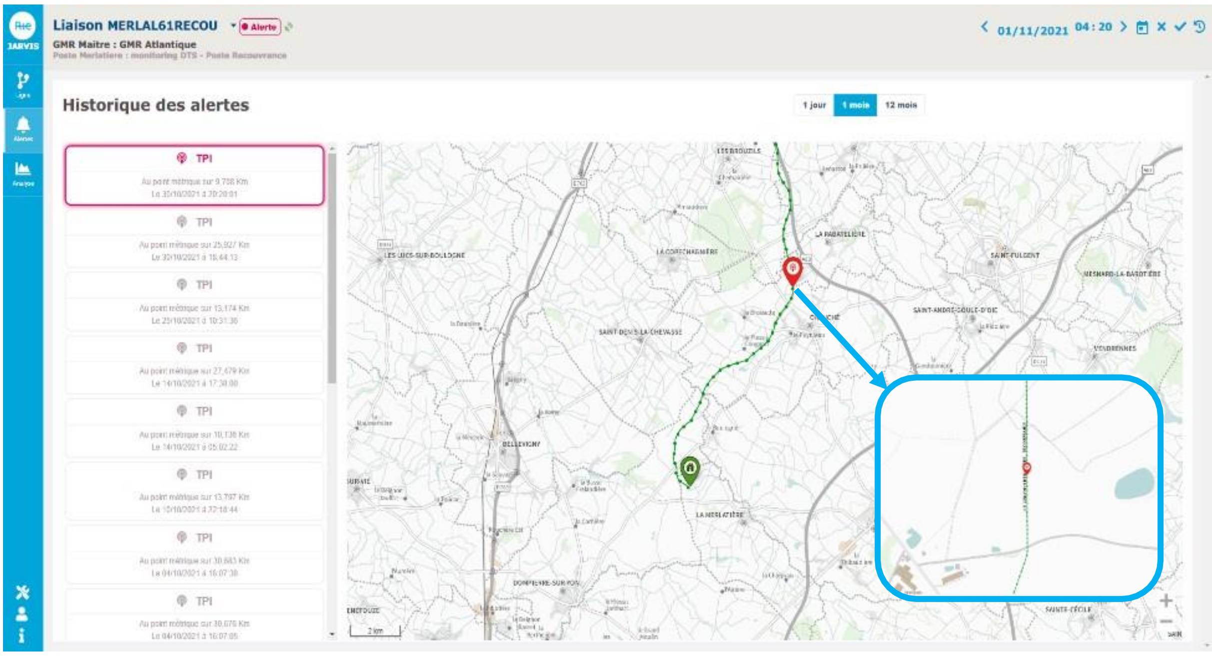

Figure 12 : DTS-DAS, web application, "Alarms" window, location of a TPI alarm

- DTS Alarms: when a DTS alarm is triggered (currently a threshold overshoot) the first step is to find the location of the alarm on the map. Using the simplified profile, thermal or electrical proximities can be identified in the vicinity and might explain the measured temperature. Then the “Analysis” window can be used to display the latest temperature profiles, the temperature history of the zone, or even the global trend of the whole region temperature. There is not a unique way of finding the cause of a temperature alarm as they can be quite different depending on the region, the soil characteristics, the local human activities… If the remote analysis is not sufficient to conclude on the thermal threat, the next step is to send the local maintenance team to the location identified in the alarm. Finally, depending on all the information gathered, the choice has to be made between remedying to the situation (moving a manure deposit from the top of the underground cable as can be seen in Figure 13 – Note that the site picture is not included in the web application), putting the zone under surveillance by checking the temperature evolution carefully, or clearing the alarm which might finally not be a threat.

Additionally to the actions following alarms, a monthly check has to be made on the temperature profile to ensure its consistence, even if no temperature alarm has been triggered.

The success of the deployment of such a solution for local maintenance teams requires dedicated trainings, presentations and a support from the national expertise team. Regular meetings to share practices between users, identify possible improvements will be organized.

Figure 13: Temperature profile and manure deposit hotspot

CONCLUSION

RTE industrial strategy plan is to couple the digital network to the power grid, with the ambition to have 50% of its assets monitored in the coming years. To achieve this challenging objective, a tailor-made IoT and Big Data architecture is being developed to gather all data measured by various sensors in substations.

Among all the projects of this programme, two ongoing projects are presented in this paper, dedicated to underground links. They both aim at integrating all Cathodic Protection Monitoring systems and Temperature and Acoustic monitoring systems into a unique supervision system, user-friendly and largely accessible to end-users in maintenance teams. The ongoing developments detailed all along the paper (installation, data transmission and collection, cybersecurity) proved to be challenging, and the first results (User Interface, ergonomics …) showcased here are promising. Both projects are expected to be fully operational by 2023.

BIBLIOGRAPHY

[1] CIGRE TB 825, “Maintenance of HV Cable Systems”, 2021