REAL TIME DETECTION AND LOCALIZATION OF SELF EXTINGUISHING DEFECTS ON A MEDIUM VOLTAGE NETWORK

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ABSTRACT

Considering Medium Voltage (MV) buried networks, self-extinguishing defects [1] are known to be precursors of potential breakdown during operations especially at the level of accessories. A great interest among the DSO community for a system able to detect these defects before breakdown was raised.
Nexans in collaboration with CEATech developed a system able to capture perturbations or events on a dedicated portion of a given MV network. This system is based on very sensitive and precise acquisition boards (signal amplitude versus time) which can be located at different points of the monitored network. Thanks to a post processing algorithm of the collected data based on time reversal techniques, an accurate localization of relevant events can be made. Due to the fact that each acquisition board shares a clock reference based on a GPS antenna, the localization accuracy is within tens of meters.
This paper validates the method with measurements performed on real life network exploitation, together with potential developments like the establishment of defects typology and self-learning expertise.

INTRODUCTION

Medium Voltage buried networks are vastly used in power distribution systems for their reliability. However, they are not exempt from deterioration over time. The costs and efforts necessary for their maintenance are high because of their buried structure that limit the access to cables. To facilitate fault location and reduce costs, some work has been done to propose efficient non-destructive localization methods, often based on reflectometry or wave propagation theory [1]. In [2] and [3], it was proposed to use the analysis of the load of relays as a marker for self-extinguishing defects. In his work, R. Razzaghi studied the possibility of using Time Reversal (TR)-based methods to determinate the position of elusive faults in MV networks [4, 5, 6] and presented results of experimental setups on real-life networks [7]. By using a well-defined mesh combined with precision hardware, his work showed good results in giving a precise location of single events. Still, it needed the presence of adapters to fix the load on the network extremities and the tests were limited to an offline network.
The proposed method extends the possibilities of monitoring MV networks on a larger scale by placing sensors on well-chosen nodes of the network for continuous monitoring. By using an accurate shared time synchronization system between sensors, transient signals can be recorded with precision then processed on-the-fly with the FasTR algorithm described in this paper.

PRESENTATION OF THE METHOD

Global setup

The real time detection and localization method is based on four components: distributed high-speed measurement devices, accurate time synchronization, a communication tool between sensors and a new elaborate post-processing algorithm based on TR, called FasTR. The principle is the same as for classical TR methods. High-precision measurement devices are installed on distant points of a MV network and monitor signals over one of the phase in operation. When a transient fault occurs, the burst of tension and current is propagated through the network and recorded by the devices. All of these sensors are precisely synchronized and therefore share the same time reference. Thus they are able to emit a timestamp which marks the moment of detection of the burst. Through the communication network, the sensors transfer the recorded data affiliated with their respective timestamp to a server which then runs the FasTR algorithm to precisely and quickly locate the branch in defect and the position of the event, as explained in Figure 1.

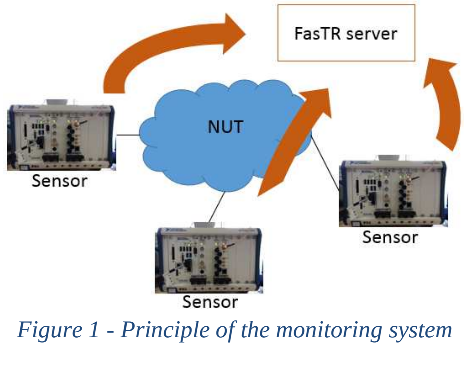

Figure 1 - Principle of the monitoring system

FasTR method

FasTR method is a variation of classical TR methods which allows a faster fault localization with a limited required knowledge on the monitored network and with a moderate need for computing resources. It uses recorded signals from sensors placed on several strategic points on the network, calculates their time-reversed version and estimates a function representative of the energy propagated in the network. But rather than calculating it for a highly refined mesh along time and distance, it calculates it for one singular point in the network. Thanks to an optimization method, it gets the position of the maximum energy (the position of the event) in a few steps. To construct the energy function, it only needs the time-reversed signals and the topology of the network. The more detailed information, the more precise the results will be. But with just the connection matrix and the length of each branch, it is enough to get a precision around one meter. The computing time is around a minute with a non-optimized version of FasTR on a standard desktop computer. Speed improvement can be achieved by reducing the aimed precision, and inversely for an emphasis on precision.

1ST FIELD EXPERIMENTATION

During our work, we achieved a first prototype with on-the-shelf boards of the aforementioned method with an effort made for size management and automation. The measurement devices consist in National Instrument racks including a PXIe-5122 oscilloscope with a sample rate of 100 MSamples/s and 14 bit resolution, a PXIe-6674T clocking board and a PXI-6683H GPS transceiver. The role of the oscilloscope is to sample the high frequency signals. Using a 100 MSamples/s sample rate allows us to set one point every 10 ns which is at least two orders of magnitude shorter than the expected rise time of the fault. Through the GPS transceiver, each sensor is set to the UTC every second. However, the time dispersion of the internal clock of the oscilloscope is too high to ensure a correct synchronization between sensors. Difference in time can be up to 10 µs, which correspond to an error in position of 2 km. A better time synchronization is obtained thanks to the PXIe-6674T clocking board which integrates an Oven Controlled X-tal Oscillator (OCXO). It reduces the time difference by three orders of magnitude and ensures an error of localization in the range of two meters.

Test bed

This prototype was validated in real conditions on a MV network. A part of the MV network powering a town in Switzerland and the close-by Nexans factory was chosen for the test, as presented in figure 2. This network is a three-phase 20 kV buried. It presents many interesting features for the test. First, it possesses built-in protection systems necessary to avoid damaging private properties when generating a transient fault. Then the chosen part is a Y-shaped network 2646 m long in total. Its extremities are easily accessible as the couplers are installed in MV/LV transformation stations. It gives the opportunity to demonstrate the robustness the monitoring system to work for on-line monitoring.

The connection with the cable has been realized with inductive couplers installed on the screen around a phase of the network. These devices, usually used for BPL communication, insure a protection from the low frequency voltage and give great coupling factors in the 300 kHz to 5 MHz frequency band.

For the selected network, three sensors have been installed on MV/LV stations: sensor A in Nexans factory, B and C in town. Sensor A is connected to the phase L3 whereas Sensor B and Sensor C are connected to the phase L1 for practical reason. The GPS antennas are extended outside the transformation station with a 30 m coaxial cable and each sensor is in communication with a central server through a 4G network.

To generate the fault, an industrial circuit breaker in derivation was installed 696 m away from Sensor C. The circuit breaker is manually controlled with a simple procedure. A phase of the network is connected to it, as well as the ground. An operator pushes the activation switch, connecting the phase with the ground and approximately 1 s later pushes the release button to open the circuit and stop the fault. The sudden connection to the ground creates a distortion of the tri-phased voltage which propagates towards all the extremities of the network. The corresponding currents go through the couplers and are recorded by the oscilloscope of each sensor. The measurements are then processed with FasTR algorithm and the localization is obtained.

A series of tests were made following this setup on November 22nd 2018. In total, 4 faults were generated successively at the same point of connection. Two of them were made on the phase L2, one on the phase L1 and one on the phase L3.

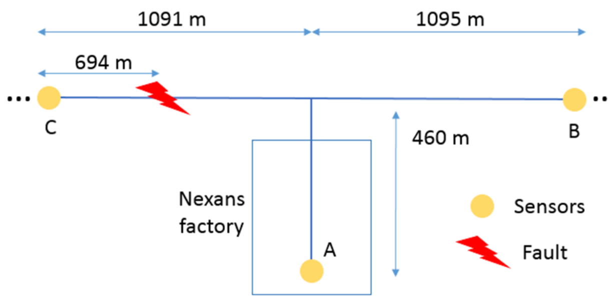

Figure 2 - NUT topology. Past Sensor B and Sensor C the network extend to other parts not covered by the system.

Results

For each event, Sensor B and Sensor C successfully recorded a powerful transient signal and the corresponding timestamp. The measured signals are presented in figures 3 to 6. By analyzing these curves, we can first observe that despite the length of the network and all the attenuation factors, the transient is so powerful that it creates a quick saturation of the oscilloscope. It goes through the complete network and “rebounds” on all the extremities several times before fading away. It is also interesting to note that even when the test is done on a not monitored phase, the transient signal is powerful enough to still be recorded on another phase. This result confirms the possibility of monitoring the three phases of the network with only one coupler. However, it also means that as it is, this setup cannot differentiate between phases by itself.

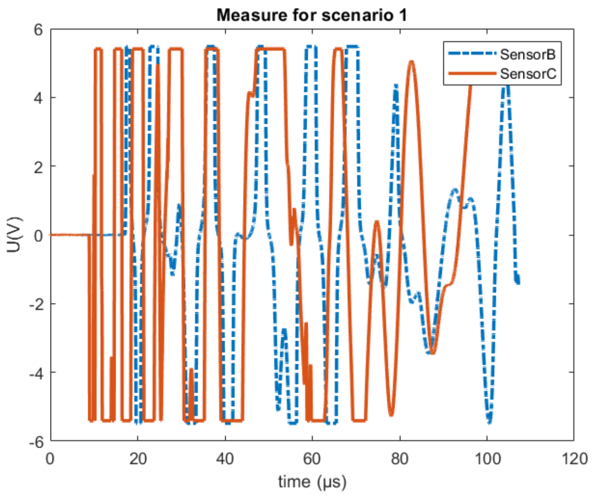

Figure 3 - Voltage measured by Sensors B and C during Scenario 1.

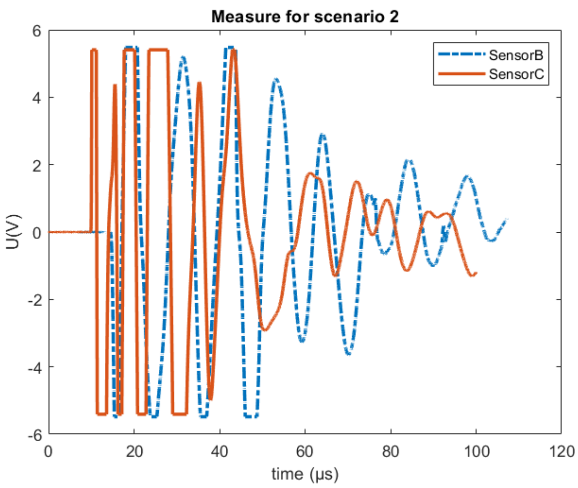

Figure 4 - Voltage measured by Sensors B and C during Scenario 2.

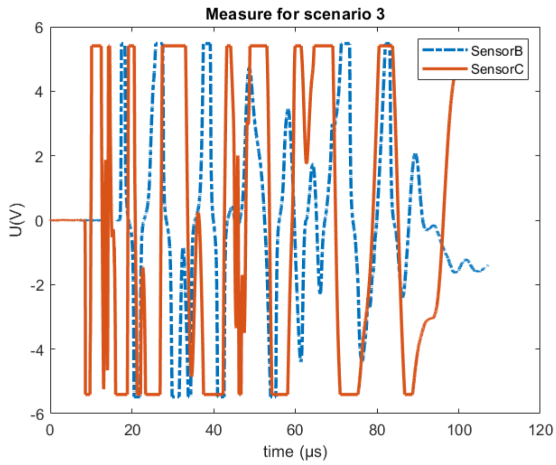

Figure 5 - Voltage measured by Sensors B and C during Scenario 3.

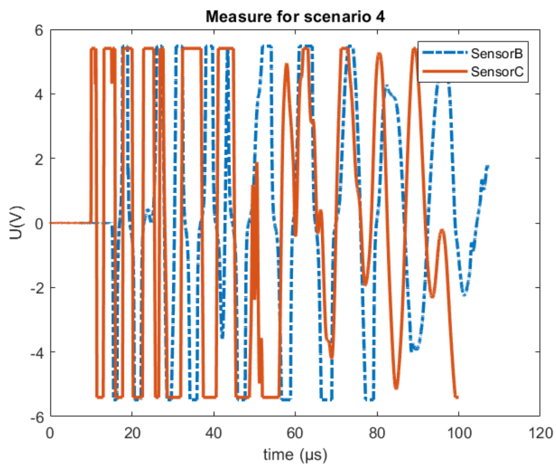

Figure 6 - Voltage measured by Sensor B and C during Scenario 4.

Sensor A was not able to detect any signal during the tests. There are several hypothesis that can explain this result. First, Sensor A was located at the very end of its branch, which is terminated by an open circuit, contrary to Sensors B and C. No current should be going through the screen at this point, and thus transients cannot be detected with such a positioning. Furthermore, this branch of the network is located inside the Nexans factory and it is possible that connection to the external network can work as a lowpass filter, blocking transient signals.
Fortunately, FasTR can operate with an incomplete data. It reduces the portion of the network where a position can be pinpointed, but as the source of the transients is on the direct path between Sensors B and C, the algorithm can still converge to an exact solution. The computing time and the resolution of the localization are linked together: for a high resolution, a long computing time is needed and with a short computing time, the system will be limited to a low resolution. FasTR gives the possibility to balance both parameters. In this case where time was not a constraint, a priority given to the high resolution. Table 1 presents the

results in fault location after use of FasTR for each scenario.

Test	Phase	Branch detected?	Result (m)	Fault location (m)	Computing time (s)
1	L2	Yes	640.5	696	156
2	L2	Yes	640.5	696	146
3	L1	Yes	640.5	696	132
4	L3	Yes	640.5	696	146

Table 1 - Results after use of FasTR algorithm

Analysis

The results reported in Table 1 are rich in information. They first prove that the correct branch is identified by FasTR in all scenarios despite the phase at fault. Secondly, the position of the fault found by FasTR is always the same, meaning that the obtained precision is excellent given different transient signals. The computing time is approximately two minutes on an Intel I5 2.3 GHz processor with a non-optimized version of the algorithm and an emphasis on resolution. This is in the scope of making an on-the-fly analysis of transient events.

However, the accuracy of the system is limited with a constant error of 55.5 m, which is higher than the theoretical bias introduced by the oscilloscope sampling and the use of GPS synchronization summing up to five meters approximately. Still, such a difference can be explained in its most part by the rough estimation of the propagation speed in the network. In order to give a numerical estimation of the fault location, a value of the wave celerity, which is assumed constant and the same for all branches, has been used even if it was known that in this case that the monitored network is composed of at least three types of underground cables of different technologies. An error of 1% in the wave celerity can lead to an error of 25 m. With a method of precise calibration, the result should be greatly improved. Nevertheless, such a result is satisfying in locating powerful transient signals' source locations.

2ND FIELD EXPERIMENTATION

With the system installed on an on-line network, a campaign of listening was realized for over 3 months, in order to gain a better understanding of the behavior of the monitoring system over a long period of time. The experimental setup was almost the same except for the absence of circuit-breaker. This time, the objective was to look for exploitation events triggered "naturally" by the network and its users. Data were sent from sensors regularly (once a week) and analyzed with FasTR complemented with an analysis of the shape of signals. The trigger levels were set to record voltage of 500 mV, just above the noise level.

For the duration of the campaign, next to 50 events were detected by the monitoring system. These events have been sorted in three categories based on the shape of the recorded signals and a quick spectral analysis. Figure 8 to 10 show the typical shape for events of type 1 to 3 respectively. Events of type 1 occurred on a regular basis throughout the campaign, approximately at the same time in the day, whereas events of type 2 and 3 appeared only for a short period of time and were less frequent than first type.

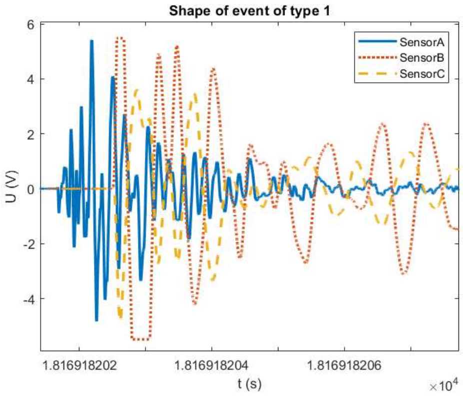

Figure 7 - typical shape of events of type 1.

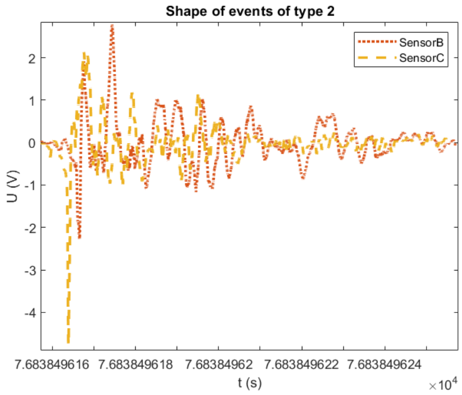

Figure 8 - typical shape for events of type 2. Sensor A was not able to record a signal at the time.

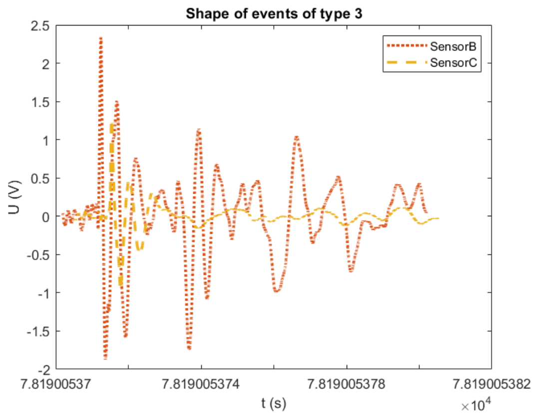

Figure 9 - typical shape of events of type 3. Sensor A was not able to record a signal at the time.

Sensor A was not able to detect fault of type 2 and 3. However, FasTR, applied on each event, localized the sources of each fault type summarized in table 2.

Event	Type 1	Type 2	Type 3
Closest sensor	A	C	C
Position	54 m	1000 m	1222 m

Table 2 - results of localization for each fault type.

For each fault type, a unique position was found. It confirmed the capability of the monitoring system to detect and analyze transient events during the life of the network.

CONCLUSION AND NEXT STEPS

This paper has demonstrated the capacity of an on-the-shelf portable system to make an on-line detection of transient faults in a complex network. First, a test was performed on a 2.5 km MV network in Switzerland by short-circuiting to the ground a phase of a power supply system. The proposed monitoring system successfully detected the transient fault through its distributed sensors, and, thanks to a high-quality time synchronization combined with the FasTR method developed by Nexans and CEATech, it was able to locate the source location with good reliability. Then a campaign of online measurement was realized for a duration of 3 months. Exploitation events were recorded along the campaign. The monitoring system was able to sort them in three categories based on the shape of their signals and FasTR localization showed a consistency for each type of event, thus proving its capability to detect small transient perturbations.
Recorded events can be consider as small events in the life of the network, but they can occur repeatedly and be the mark of a future outage. By raising an alarm, or monitoring the position were the network is weakening, this system may be a great additional tool for operators to prevent future failures. The simplicity of plugging, thanks to inductive couplers, in addition to the harmlessness of the method, facilitates its deployment. Furthermore, the fact that results were obtained on each monitored phase allows to limit the number of needed sensors and the complexity of interventions.
To further assess the potential benefits of using the proposed system for preventive maintenance, it is planned to complete theses tests with a resistive fault that will limit the power of the transient signals, and thus be more representative of small shutdown precursors.
In parallel, an effort is expected to be made for improving the versatility of the system by reinforcing the automation of FasTR treatments, facilitating the installation in MV/LV stations and collecting data. For example, each sensor could integrate a built-in communication system that could automatically send measurement data to a central server without human intervention. A calibration method is also needed to correct the bias from an incorrect estimation of wave celerity in the network. This will lead to the creation of an autonomous system which can be deployed on demand for monitoring networks at risk.
Based on the present data, combined with heuristic methods, a database of classified events is in construction. The capability of the system to record a signature for each transient signal opens the possibility of a more profound analysis of fault type and severity. It will lead to a better understanding of transient events and an adapted response upon the kind of defect detected.

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