Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech Division

REEL Demo – Romande Energie ELectric network in local balance Demonstrator

Deliverable: 1b Experimental validation of the FLISR functionality

Demo site: Rolle

Developed by
Lorenzo Zanni, Mayank Nagendran, Zaphiro Technologies SA
in collaboration with
Romande Energie

[Lausanne, 17.01.2022]

1. Description of deliverable and goal

1.1. Executive summary

The goal of this part of the project was to experimentally validate in a real distribution grid the performance of a FLISR function (fault location, isolation, and service restoration) based on synchrophasor measurements provided by PMUs. To this end, the innovative PMU-based fault location method developed by Zaphiro Technologies was implemented in the medium-voltage grid of Rolle operated by the DSO Romande Energie.

An effective and rapid FLISR function is fundamental to ensure a reliable power supply to electricity customers, as the number and duration of power interruptions are minimized. FLISR can be divided in two parts: 1) fault location via manual field search or dedicated software that uses field measurements, 2) fault isolation and service restoration via switching maneuvers. In the whole FLISR process, the initial search of the faulted equipment in a distribution feeder is by far the most time-consuming part. Zaphiro's innovative fault locator uses synchrophasor measurements to locate faults in an automated way and very quickly, down to < 1 second. The main novelty is that this new method combines high-resolution and synchronized measurements coming from multiple PMUs located at strategic points in the grid to provide an accurate fault location. This fault locator is ideal to be used in distribution grids, as it works for all the grid types (solidly grounded, isolated, and compensated), all the fault types (1-2-3 phase faults, low- and high- impedance), also in presence of distributed generation, and it is very simple to deploy as it relies only on current measurements (no need to install new voltage sensors that are expensive and cumbersome to deploy).

1.2. Research question

The research question that this activity aims to respond is the following: is a fault locator based on PMU measurements able to locate real faults in a medium-voltage distribution grid in a quick and accurate way? And what is its improved performance compared to current utility practices and existing state-of-the-art solutions?

1.3. Novelty of the proposed solutions compared to the state-of-art

Typically, protection relays and breakers are placed only at the root of medium-voltage feeders. When a fault occurs, the relay opens the breaker at the root of the faulted feeder, causing a blackout for all the customers connected to that feeder. Before restoring the service, the specific faulted element needs to be found and disconnected from the grid. In the whole process of power restoration, fault location is the most time-consuming part. A typical way DSOs locate a fault in distribution grid is by "field search" that takes hours, as it consists in doing many switching maneuvers and sending technicians to patrol kilometers of power lines, which are very inefficient practices. Sometimes DSOs have some intelligent devices installed along the feeder, such as fault passage indicators (FPIs) or reclosers, which help operators in the fault location process, but have several limitations, such as they fail to identify certain fault types
(e.g. earth faults in isolated/compensated grids), they are too expensive or they are very difficult and costly to install.
Zaphiro has integrated a novel fault location method into its software platform SynchroGuard, which is the first to solve all these issues of existing state-of-the-art solutions by leveraging on distributed measurements from PMUs. SynchroGuard decreases dramatically the fault location time to just few seconds and the computed fault location is immediately communicated by SynchroGuard to the utility operators through a dedicated user interface or through the utility's DMS/SCADA system. In the near future, SynchroGuard will also maneuver the grid switches to isolate the faulted element from the grid and restore the power in a few seconds, so that even the power restoration process is going to be fully automated.
The main novelties of SynchroGuard approach are the following:

- The method is centralized, as it combines multiple synchronized measurements coming from different PMUs located at strategic points in the grid, thus improving significantly the accuracy, sensitivity, and reliability of the fault location.
- Fault location is computed in an automated way thanks to advanced algorithms specifically designed to take advantage of synchronized and high-resolution measurements from PMUs.

- All types of faults can be located, 1-2-3-phase faults, both low- and high-impedance faults (even small fault currents similar to the load currents can be detected). It works in all types of grids, both radial and meshed, with solidly-grounded, isolated, and compensated neutral. SynchroGuard is also able to detect intermittent/incipient faults in order to provide an early-stage detection of these faults, thus avoiding eventual damage to grid equipment and blackout.
- The installation is extremely easy because, unlike other methods, SynchroGuard needs only the installation of current sensors along the feeder. Only one voltage measurement is needed which is typically taken at the primary substation via existing voltage transformers. Other methods instead require the installation of voltage sensors at every measurement point. Voltage sensors are costly, cumbersome to install and invasive, because they are directly connected to the power lines, thus adding possible points of failure and decreasing the grid reliability.

1.4. Description of Zaphiro's innovative fault location function

Zaphiro's SynchroGuard solution is the first power grid monitoring and automation system based on synchrophasor data. The novel fault location method integrated in SynchroGuard combines multiple synchronized measurements coming from different PMUs located at strategic points in the grid. It firstly separates the monitored grid into multiple *areas* where a fault can be located based on the measurement placement. An area is composed of busbars, lines, or a combination of them delimited by PMUs. In each area, the fault locator continuously calculates a fault indicator and compares it with a threshold that is dynamically updated based on grid loading and measurement accuracies. A fault is detected when the fault indicator rises over the threshold.

The method works for many types of faults (permanent/incipient, single/multi-phase, as well as high-impedance faults with currents as low as 0.5A), in underground and overhead networks, independently of the network topology (radial/meshed) and the neutral treatment (solidly grounded, isolated, and compensated with arc suppression coil) and even in presence of distributed generation.

The faulted equipment is identified in few seconds and communicated to the utility operators via a dedicated interface or through the DMS/SCADA system. A further

functionality (not analyzed in this report) also provides the exact location of short-circuits within a line.

1.5. Validation on a medium-voltage distribution grid

In what follows we present three faults that occurred in the monitored medium-voltage grid in Rolle:

- Fault in the line Hopital – Bellefontaine (03-05-2020)
- Fault in the substation Ch-Combe (18-01-2021)
- Fault in the line Rolle – Route de la Vallée (26-06-2019)

For each fault we describe the fault event and how Romande Energie located the fault and restored the service. Note that SynchroGuard was not connected to the SCADA system, so the operators could not take advantage of the fault location provided by SynchroGuard. However, in this way we can estimate how much time SynchroGuard would have saved in the fault search process, which directly corresponds to a reduction of the customer service interruption.

1.5.1. Fault in the line Hopital – Bellefontaine

A fault occurred in the medium-voltage Feeder 51 in Rolle on the 3rd of May 2020. The fault was due to a cable insulation failure in the line connecting Hopital and Bellefontaine.

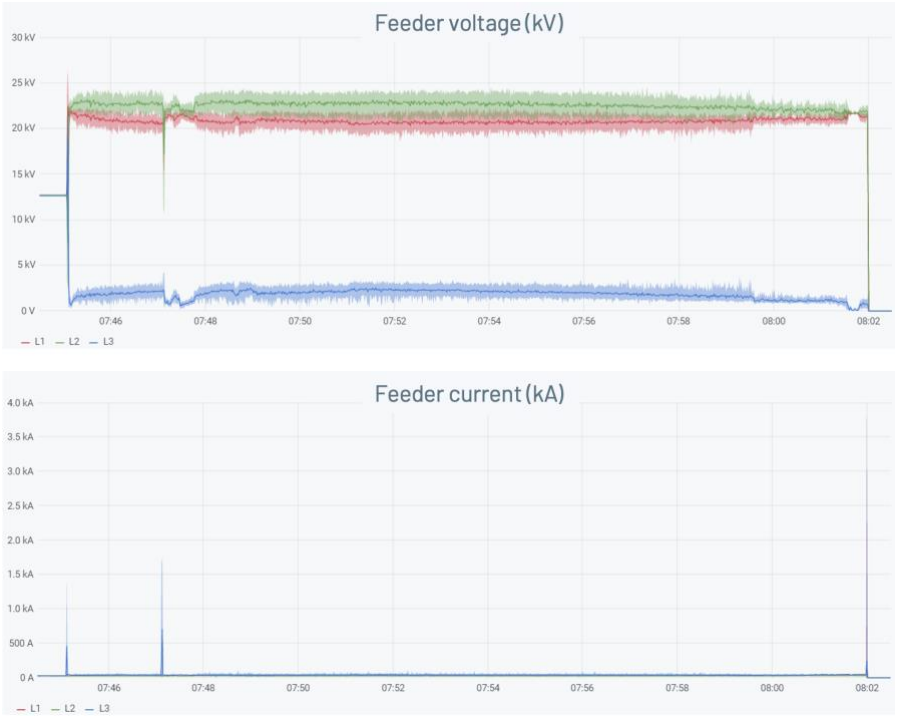

Figure 1 – Voltage and current amplitudes measurements at the root of Rolle 51 feeder during a fault in the line Hopital – Bellefontaine on the 3rd of May 2020. The initial earth fault evolved in a phase-to-phase fault that finally caused the power outage in the entire feeder.

As can be seen in Figure 1, an earth fault started at 07:45. As the network is grounded through a Petersen coil, the fault current was small and the grid continued to supply the customers even after the occurrence of the earth fault. However, at 08:02 the fault evolved into a phase-to-phase fault with high short-circuit currents (about 4 kA), which caused an immediate opening of the breaker at the root of the feeder and a service interruption in the entire feeder.

The earth fault lasted for about 17 minutes, the phase-to-phase fault lasted about 80 ms, but the blackout in the feeder lasted way more, indeed it took about 1.5 hours to reconnect all the customers of the feeder. The DSO operators had to do several manual switching manoeuvres to find the faulted line, while SynchroGuard located the earth fault in the line Hopital – Bellefontaine after a few seconds.

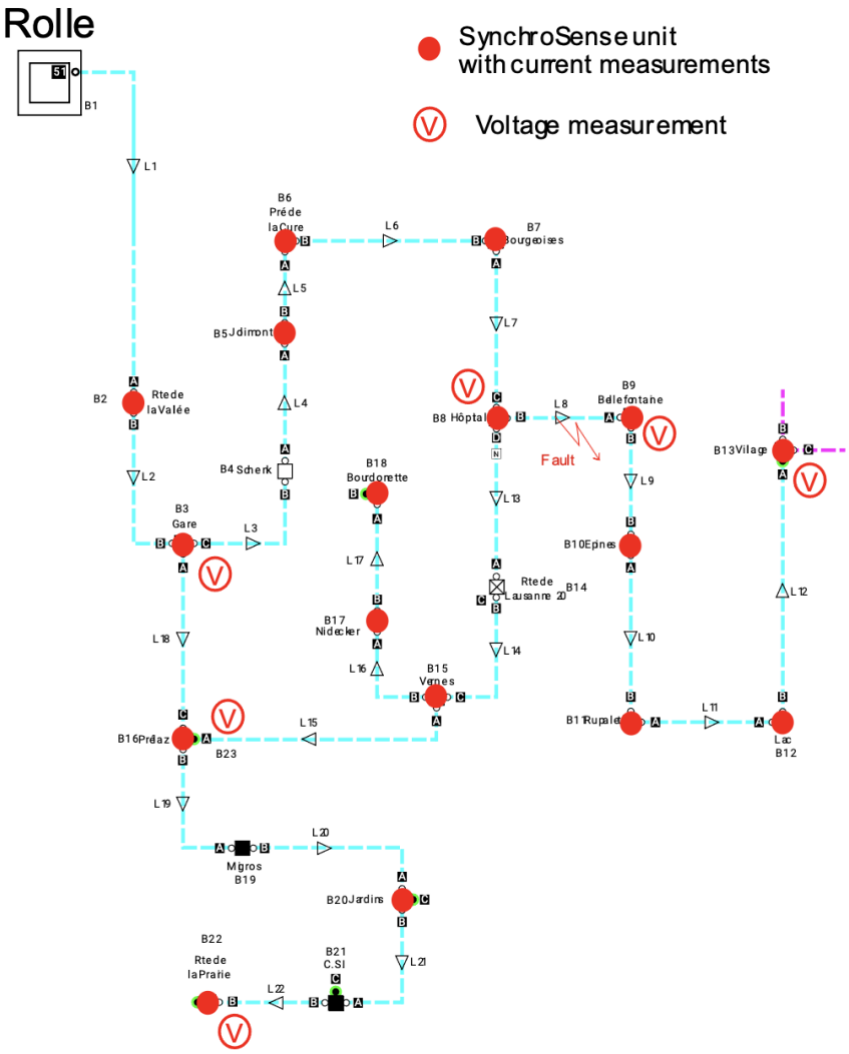

Figure 2 – Grid topology and measurement configuration in Rolle 51 feeder the 3rd of May 2020.

Figure 2 shows Feeder 51 departing from the primary substation of Rolle and its measurement configuration. SynchroSense is the name of Zaphiro's PMU device.

In each of the substations equipped with a SynchroSense unit, SynchroSense monitors the current flowing in all departing lines and, sometimes also the voltage. It is worth to remind that the innovative fault locator needs only one voltage measurement. In this demonstration project voltage sensors were installed at multiple substations for validation and redundancy reasons.

Figure 3 shows the result of Zaphiro's fault locator that after few seconds had already identified the earth fault with high confidence in the line Hopital – Bellefontaine. Instead, the existing protection equipment did not see the earth fault, so DSO operators noticed the fault only when the entire feeder blackout occurred due to the phase-to-phase fault. From Figure 3, it can also be seen that other grid elements close to the fault, namely Hopital substation and the line Bourgeoises – Hopital, were identified as

possible faulted areas but with very low confidence. This is due to the high oscillations in voltage and current during this fault, which are typical of earth faults in compensated grids and are particularly high in Rolle due to an old Petersen coil, which indeed was replaced in the summer of 2020.

The following phase-to-phase fault was instead detected and located by SynchroGuard in < 1 second with 100% reliability.

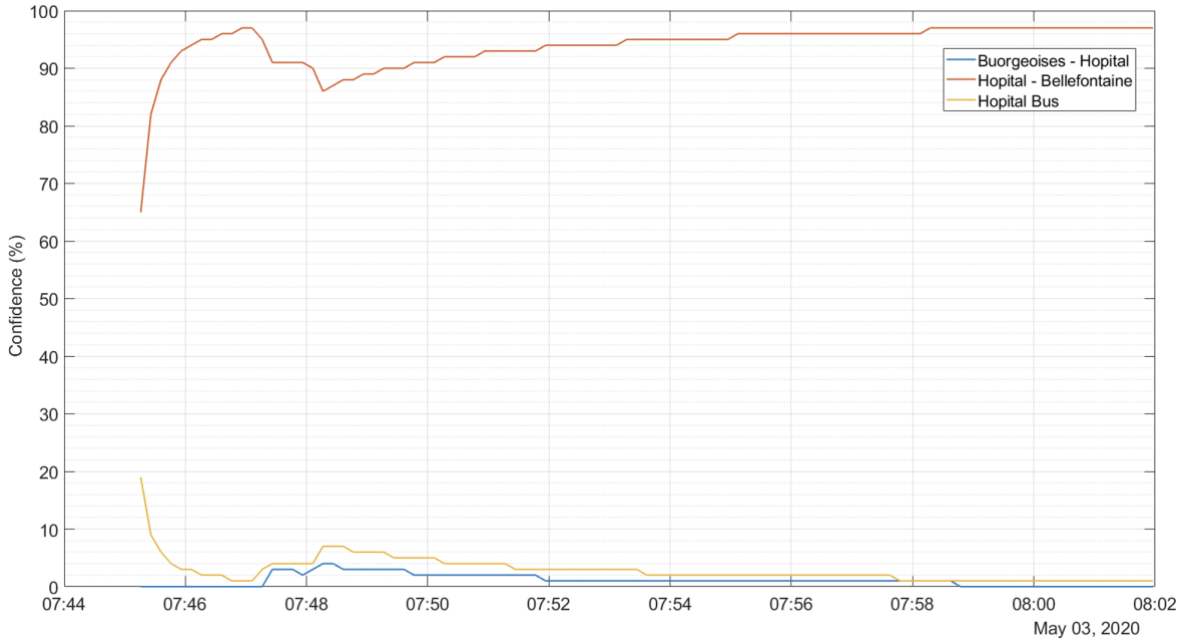

Figure 3 – Faulted element located by the fault locator during the initial earth fault.

As a conclusion, we experimentally validated in a real medium-voltage grid that the proposed novel fault location method is able to:

- Detect and locate earth faults in few seconds, which allows DSO operators to repair the fault before it evolves in a more severe short-circuit (in this case it evolved in a phase-to-phase fault of 4 kA), thus preventing an unplanned outage and larger damages to the grid equipment.
- Detect and locate short-circuits (phase-to-phase or three-phase fault) in less than a second, which enables to:
    - decrease the fault location time from 1h07m to a few seconds, thus decreasing significantly the total outage time.
    - avoid several unsuccessful reclose attempts (switching maneuvers are a typical practice used for fault search) which stress all grid components, cause multiple service interruptions for customers, and threaten the safety of the operators.

1.5.2. Fault in the substation Ch-Combe (artificially injected by Romande Energie)

Romande Energie injected an earth fault in the medium-voltage feeder 60 in Rolle on the 18th of January 2021 for testing purposes. Phase L2 was earthed through an earth switch at one side of the line connecting Rte de Gilly and Ch. Combe, as shown in Figure 4, which are placed in the middle of the feeder. A PMU was installed at Rte de Gilly and monitored the currents of all its departing lines. SynchroGuard fault locator was able to correctly locate the fault between Rte de Gilly and Ch. Combe. In addition, no false alarms were raised in other lines/nodes of the grid during th fault.

The fault current waveform measured by a SynchroSense unit at the root of the feeder is shown in Figure 5. Indeed, SynchroSense integrates also an event-triggered waveform recording function in addition to the PMU functionality.

The fault current estimated by SynchroGuard fault locator was 12.9 A, which is very close to the 12 A measured at the fault point by Romande Energie with an amperemeter.

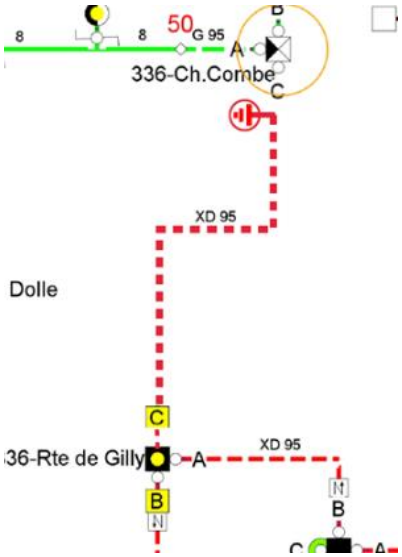

Figure 4 – Romande Energie carried out a test where operstors manually earthed phase L2 at the end of the line Rte de Gilly – Ch- Combe (feeder 60 in Rolle) on the 18th of January 2021.

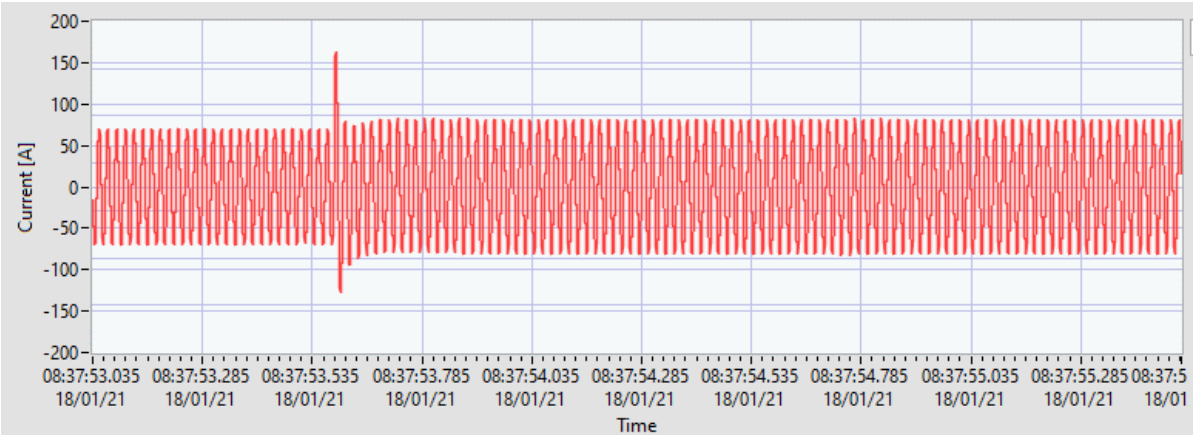

Figure 5 – Current waveform of the faulted phase L2 recorded by the SynchroSense unit in Rte de l'Etraz (root of the feeder).

1.5.3. Fault in the line Rolle – Route de la Vallée

A fault occurred in the medium-voltage Feeder 51 in Rolle on the 26th of June 2019. The fault was due to a cable insulation failure in the line connecting Rolle primary substation and Rte de la Vallée. The fault event was composed of multiple stages comprising intermittent faults, an earth fault in phase L3 and a final phase-to-phase fault. The interesting feature of this fault are the multiple intermittent faults in the initial phase of the fault event. Figure 6 shows the graphical user interface of SynchroGuard (dated to 2019), where it can be seen that SynchroGuard recorded and detected these events. Raising early alarms on intermittent faults, which sometimes last for hours/days, is valuable to repair the fault before it evolves in a permanent fault, which stresses the cable insulation and might lead to a high-current short circuit with subsequent unplanned blackout.

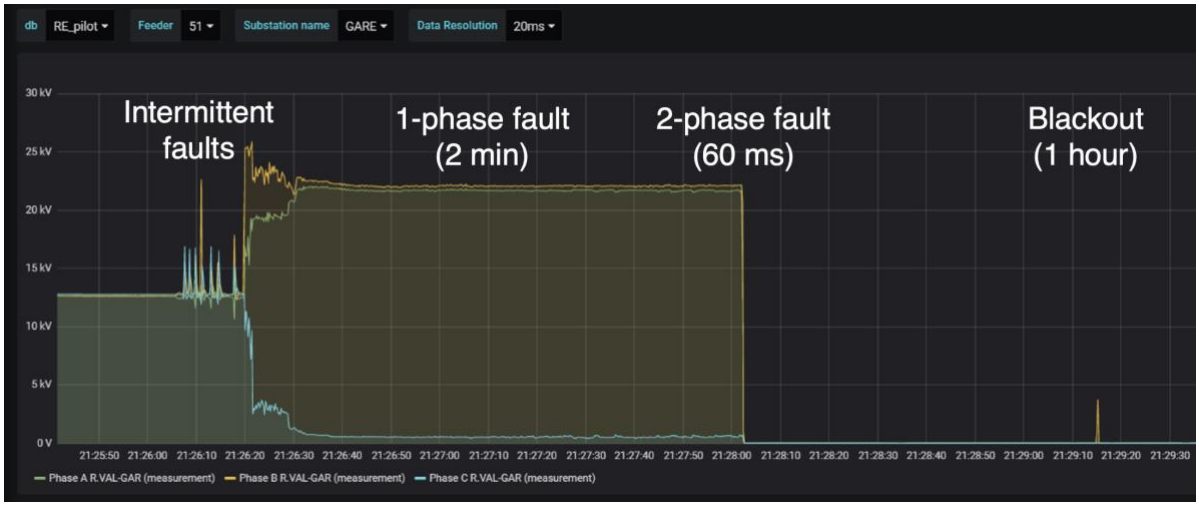

Figure 6 – RMS voltage in the three phases (L1, L2, L3) along the entire fault event: multiple intermittent faults → earth fault → 2-phase fault of 4.5 kA → breaker opening → blackout of the entire feeder

1.6. Regulatory and legal barriers for implementation

[Please state any necessary regulatory or legal change to implement the proposed solutions in practice]

There is no regulatory or legal barrier associated to the implementation of the proposed method per se.

2. Achievement of deliverable:

2.1. Date

17.01.2022

2.2. Demonstration of the deliverable

This deliverable has been achieved through:

- the implementation of the fault location algorithm provided by Zaphiro Technologies in the medium voltage grid of Rolle,
- the use of synchrophasor measurements (high-resolution and time-synchronized) generated by PMUs.
- the field validation in a full-scale real environment via the REeL demonstrator site in Rolle.