Reduction of fault location time and troubleshooting time in low voltage distribution networks by analysis of smart meter PLC communication data traffic and alarm messages

Patrick Favre-Perrod[1], Enea Auberson[1], Cédric Bernasconi[1], Gaël Mauron[2], Arnoud Bifrare[2]*

[1]*HES-SO University of applied sciences and arts western Switzerland, Bd. de Pérolles 80, Fribourg, Switzerland*
[2]*Romande Energie, Rue de Lausanne 53, Morges, Switzerland*
**patrick.favre-perrod@hefr.ch*

Keywords: Smart meter, Fault location, Power line communication

Abstract

Locating faults in LV networks represents a substantial share of the total interruption time, that could be reduced as an additional benefit of smart meter deployment. This contribution presents a technique to locate faults by combining smart metering alarm and PLC communication data (path requests). The algorithm allows to identify the location by sending path requests to those smart meters which are most distant (within the PLC network) to the transformer. Based on received replies, potentially interrupted customer connections are identified until the fault location can be determined based on the knowledge of all affected customers. The proposed approach has been validated by simulation and in a simple experimental setup located in a real distribution grid. The use of this approach reduces the time needed in order to locate the fault compared to on-site search, but also compared to polling techniques using PLC communication. In combination with the possible reduction of the total customer interruption time, planning for a deployment of this solution has recently started.

1 Introduction

The ongoing rollout of smart meters is expected to support the reduction of consumption, the adequate remuneration of distributed generation and self-consumption, improved conditions for competition in electricity retail, and demand flexibility. Despite these advantages, an estimate shows that the direct cost of rolling out smart meters to Switzerland would exceed the benefits by 680 MCHF until 2035 [1]. Similar findings have been made in other European countries [2]. Beyond the controversy associated to cost estimates, a legitimate consequence of this is the search for additional benefits or uses of the smart metering infrastructure, e.g. in network operation.

The additional benefits of a smart metering infrastructure could include fault location in LV grids, LV grid observability (state estimation or other approaches), capacity monitoring, infeed management, and others. This contribution will focus on the use of the smart metering infrastructure for fault location in LV distribution networks.

Present solutions for fault location include approaches using real-time data to reconstruct phasors, impedances or related data that can help to determine the type and the location of a fault [3-5]. Such systems rely on a high bandwidth communication infrastructure. Other systems rely on polling of smart meters using PLC [6, 7], which nevertheless requires a substantial number of messages to be transmitted via PLC. In smart metering systems using PLC, two approaches have mainly been followed in the past: using alarm messages and polling of smart meters. This paper presents an approach based on the mechanism of PLC communication itself, i.e. communication hops. The status of the PLC communication is then used to identify the location of the fault.

2 Principle of fault location using PLC

Figure 1 shows the principle of PLC communication between a data concentrator and a smart meter. In order to overcome the range limitations implied by the low sending power and the poor characteristics of power cables and lines, data packets are sent using so-called "hops", i.e. they are repeated by intermediate smart meters between the sender and the receiver. The route to each smart meter is stored in a routing table in the data concentrator. These routing tables, which allow to identify which hops are necessary to reach a selected smart meter, can be updated several times per day.

The consequence of this mechanism is that a communication with a distant smart meter is successful only if the intermediate smart meters are operational and permit the "hops" of the messages. Sending and receiving a message to one strategically chosen smart meter can thus reveal the status of several smart meters in the network. The fault location procedure presented in this contribution relies on sending and receiving a limited number of messages to chosen smart meters, so-called "path requests". When a fault is suspected (presently based on a customer phone call), path-requests can be sent to strategically selected smart meters, and the combination of several requests can help to determine which section of the distribution system has lost supply without sending requests to each smart meter. As the time needed to locate the fault depends on the number of messages to be sent, the use of path-requests drastically reduces the search time compared with systematic polling of all smart meters in the considered network. Initial estimates show that with the proposed algorithm the time required to locate a fault within Romande Energie's (DSO in western Switzerland) LV network is less than 7 minutes for 97% of its final consumers.

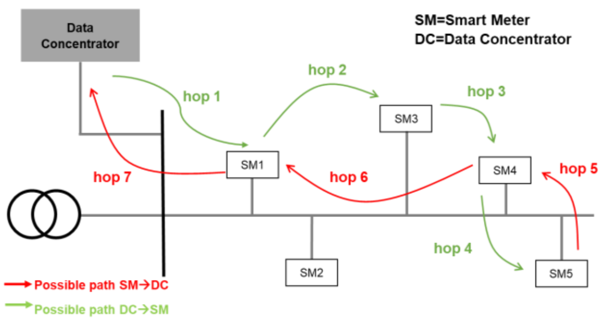

Figure 1: PLC communication scheme, example for the communication between the data concentrator and one of the smart meters (SM5).

The procedure developed in this work attempts to find interrupted fuses or branches using a tree representation of the network as suggested in Figure 2. Based on the result of an initial path request, the next request is generated using a decision tree until only one possible cause for the identified outage exists. An alternative outcome can also be that no fault is present in the DSO's network and the customer's call originates in a problem within his domestic installation.

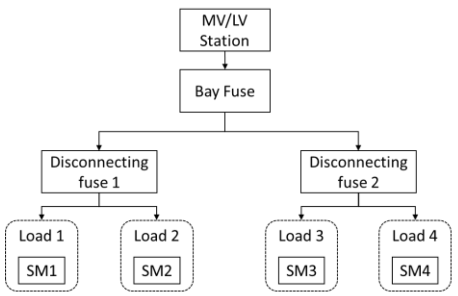

Figure 2: Tree structure of the LV network used for locating the fault.

The fault search algorithm (Figure 3) is triggered by a customer call. The first step of the fault location is the analysis of alarms sent by the smart meters. Alarms are spontaneously sent by smart meters in a limited number of cases (e.g. the interruption of a phase which is not the one used for powering the smart meter PLC modem). If any alarm have been received, a preliminary conclusion, i.e. a reduction of the search perimeter is established.

In a second step, path requests are sent to selected smart meters. Typically, path requests are sent to those smart meters which are most distant (within the PLC network) to the transformer, which in turn gives an information on the status of the intermediate smart meters (used for the hops) according to the routing table. Each answer to the path-request (either successful or unsuccessful) allows to progress through a search tree. The supply status of the network is thus determined in a stepwise manner.

In a final step, the most probably interrupted fuse (or element) is identified. If relevant, the information for the alarms-based and the PLC hops-based search are combined. The location of the interrupted element is communicated to the service personnel and suppresses the need for stepwise on-site search of the fault. Even if the indication is imprecise, it helps to reduce the fault identification time and thus reduces the interruption duration.

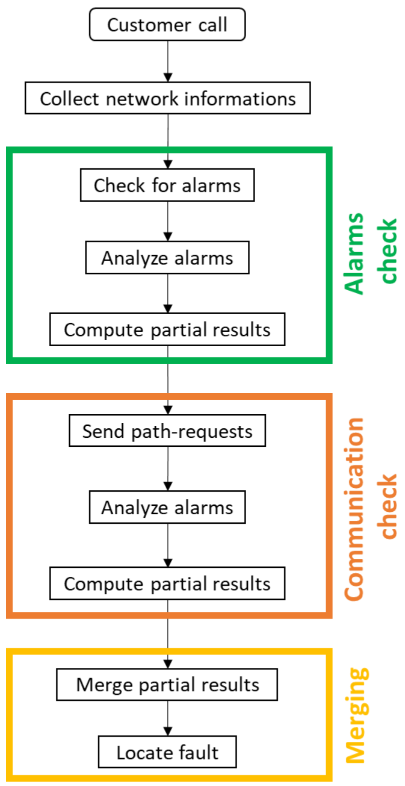

Figure 3: Fault location procedure based on alarms and PLC path requests.

3 Initial testing

To test the feasibility of sending requests and evaluating them, four smart meters (with no customer connected) have been added to an existing grid containing other commercially used smart meters. The added smart meters were interrupted on purpose without adverse consequences for real customers. Sending path requests and interpreting the results was successfully tested. Based on an offline (manual) implementation of the search procedure, the fault added on purpose could be correctly identified remotely. The fault situation that could be simulated without impacting other consumers in the network were however restricted. In complement to testing the concept using real devices, a number of past fault scenarios was also reviewed and the action of the proposed fault location procedure was simulated.

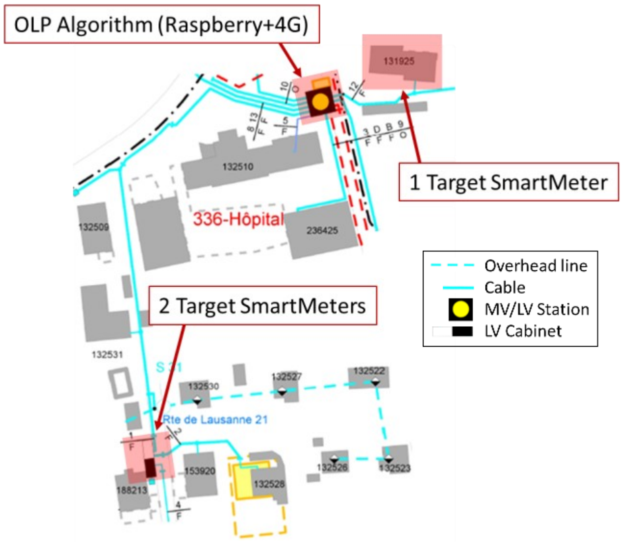

Figure 4: Placement of test smart meters for the initial testing of the proposed fault location procedure.

4 Fault location case examples

The proposed algorithm has been applied in a simulation to several real fault cases previously logged by Romande Energie. The approach permitted to adequately indicate the location of all and the type of most (96% of investigated cases) faults. The following two sections will present two representative situations and the use of the fault location procedure will be illustrated.

4.1 Single phase interruption in cabinet

Figure 5 shows an illustrative example of a faulted fuse in a cabinet that resulted in the interruption of one of the phases. Several consumers were affected as shown in the Figure. Both classical and smart metering-based fault location begin when an affected customer calls the DSO's in order to request a repair. Without fault location, the service personnel has to expect anything from no fault within the grid (and hence a defect in the customer's home installation) to a total outage of the affected secondary distribution substation. With the fault location based on smart metering, the search perimeter can be reduced as discussed below.

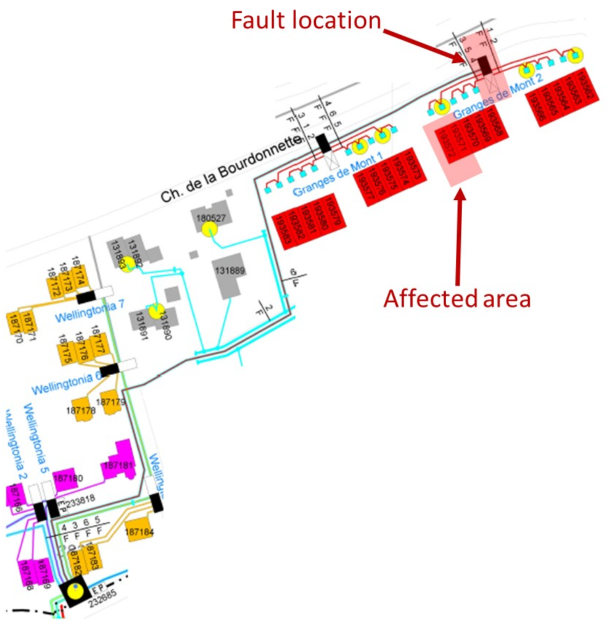

Figure 5: Example for the detection of an interrupted fuse in a cabinet.

The fault location procedure is started during the call with the affected customer. Based on previously analyzed routing tables, several target smart meters are chosen for sending path requests. The "hop lists" contain the list of intermediate smart meters used for the hopping of the messages between the data concentrator and the considered smart meter. Table 1 shows a few of these steps and the partial results of the fault location based on the result of the respective path request in a simplified form.

Table 1: Path requests sent and interpretation of the result for the example of the interrupted fuse.

Path request target	Fail/Success	Hop list	Status	Fuse
193572	Fail	193577	OK	f6_5
		132556	Unknown	f6_4_5
		193572	OK	f6_5
193571	Fail	[…]	…	…
193577	Success	193579	OK	f6_2
		193570	OK	f6_4_4
		193579	OK	f6_2
193579	Success	[…]	…	…
193573	Success	[…]	…	…
…	…	[…]	…	…
Final result: Fuse f6_4_5				

In Table 1, success or failure of a path request means that a response to the path request is received or not. The first entry in the table is a path request to smart meter 193572, which fails. Two fuses might be interrupted based on this sole information: f6_5 and f6_4_5. There are two intermediate hops. Thanks to several other request sent, 193577 is identified as still supplied and thus the hypothesis that fuse f6_5 is interrupted can be rejected. For this reason, the entries for 193577 and 193572 are updated to OK, based on information gained by analysing the outcome of other path requests. The final result of similar analyses is that fuse f6_4_5 is interrupted. This is correct. Hence in this case, the service personnel can be directed to this particular fuse, with a high likelihood to reduce the interruption time significantly.

4.2 Overhead line breakage

Figure 6 shows another situation where an aerial line (dashed) was interrupted at the location marked, resulting in four unsupplied customers. The affected location corresponds to a branch-off. The conductor was interrupted in a manner that no short-circuit occurred and thus no fuse was affected.

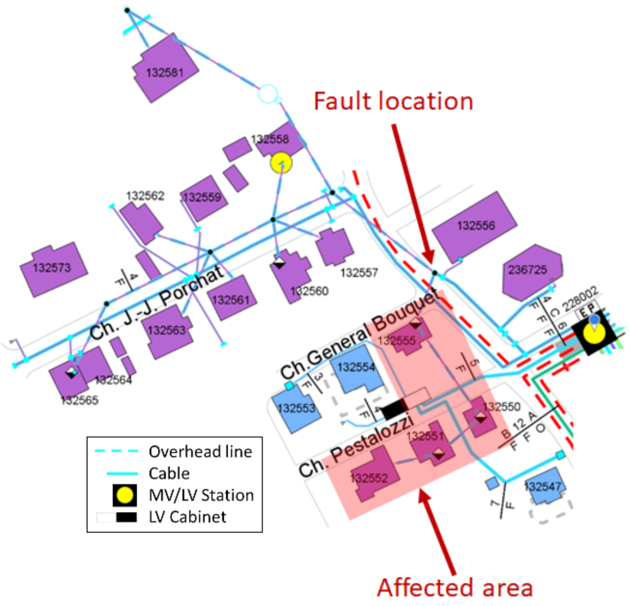

Figure 6: Example for the detection of an overhead line breakage.

Similar to any other outage in the low voltage network, the search for the fault location is triggered by a customer call. The operators can start the search, which will send the path requests listed in Table 2. The successive path requests allow step by step to eliminate the hypothesis for most fuses, while certain number remain unknown. The comparison with the simplified topology however reveals that the observed pattern of smart meters not responding does not correspond to a fuse interruption. Hence the result of the fault location is the indication that the service personnel should be looking for an overhead line breakage at a branch-off. For this case, the outcome of the search procedure is again confirmed by the real situation. Such comparisons have been made on an additional number of cases, systematically leading to a satisfactory identification of the cause for the observed fault.

Table 2: Path requests sent and interpretation of the result for the example of the line breakage.

Path request target	Fail/Success	Hop list	Status	Fuse
132552	Fail	236725	OK	f4
		132556	OK	f4
		132550	Unknown	f4
		132559	OK	f4
		132552	Unknown	f4
		132556	OK	f4
132551	Fail	[…]	…	…
236725	Success	236725	OK	f4
		132556	OK	f4
		132551	OK	f4
		132557	OK	f4
		236725	OK	f4
132551	Success	[…]	…	…
132559	Success	[…]	…	…
…	…	[…]	…	…
Final result: No faulted fuse detected, might be a branch-off problem.				

5 Possible implementation and concluding remarks

Based on the positive results, the implementation of the presented fault location procedure is now in planning. This will e.g. require to adapt several IT tools and systems, but also a systematic choice of which phase is used for powering each smart meter within an LV network. Obviously, this can only be done in an economic way before the roll-out to a target area.

Beyond potential financial gains related to the reduced amount of time needed to locate the fault, the improved service quality (reduced customer interruption time) is an important factor for this decision.

6 Acknowledgements

The work presented in this article is carried out within the frame of the Swiss Centre for Competence in Energy Research on the Future Swiss Electrical Infrastructure (SCCER-FURIES) with the financial and technical support of the Swiss Innovation Agency (Innosuisse - SCCER program) and Romande Energie.

7 References

[1] Ecoplan AG, "Smart Metering Roll Out – Kosten und Nutzen," Aktualisierung des Smart Metering Impact Assessments 2012, Ecoplan AG, Bern, 2015.

[2] World Bank, "Impact Assessment on Smart Metering," Data and methodologies for a cost-benefit analysis of smart metering implementation in Romania, World Bank Group Romania, Bucharest, 2018.

[3] R. Pérez & C. Vásquez, "Fault Location in distribution systems with distributed generation using Support Vector Machines and smart meters," in *2016 IEEE Ecuador Technical Chapters Meeting (ETCM)*, 2016, pp. 1-6.

[4] F. C. L. Trindade & W. Freitas, "Low Voltage Zones to Support Fault Location in Distribution Systems With Smart Meters," *IEEE Transactions on Smart Grid,* vol. 8, pp. 2765-2774, 2017.

[5] F. C. L. Trindade, W. Freitas & J. C. M. Vieira, "Fault Location in Distribution Systems Based on Smart Feeder Meters," *IEEE Transactions on Power Delivery,* vol. 29, pp. 251-260, 2014.

[6] S. Noske, D. Falkowski, K. Swat & T. Boboli, "UPGRID project: the management and control of LV network," *CIRED-Open Access Proceedings Journal,* vol. 2017, pp. 1520-1522, 2017.

[7] S. Noske, D. Falkowski & A. Babs, "Advance control and monitoring in secondary substation – project UPGRID," *CIRED - Open Access Proceedings Journal,* vol. 2017, pp. 6-9, 2017.