European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

Technical Report TA User Project

DEcentralized **F**ault **I**de**N**t**I**fica**T**ion for distribution grids using a limited number of measurements of LV voltage and current and MV current

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Abbreviations

DER	Distributed Energy Resource
TA	Trans-national Access

Executive Summary

This project aims at testing capability of GridEye measurements and algorithms for fault identification in distribution grids. The decentralized fault identification algorithms use a limited number of measurements to identify different types of faults in distribution grids. The fault identifications algorithms integrated in the GridEye system allows utilities to deploy a unified solution for observability, control, and fault management in their distribution grids. This will effectively improves the security of supply by decreasing the average outage duration for each end-customer which consequently increases the end-customers satisfaction.

Four GridEye cells are installed in the network measuring voltages and currents in MV and LV network. The available sensors and measurement equipment in the PNDC network are also used to collect further measurement data and to compare the measurement data. A comprehensive set of tests are carried out focusing on the verification of fault identification functions for MV faults and LV faults at different locations and in different loading profiles and different MV grid configuration (radial and ring).

The realization of this project allowed testing and improving the performance of fault identification algorithms of GridEye system. The GridEye measurements from the thrown faults are used to primarily evaluate the performance of GridEye's fault identification algorithms for determining type and location of faults and also for possible improvement of the algorithms.

1 General Information of the User Project

The project is entitled "**DE**centralized **F**ault **I**de**N**t**I**fica**T**ion for distribution grids using a limited number of measurements of LV voltage and current and MV current" with acronym ***DEFINIT***. The project aims at testing and validating the fault identification algorithms in distribution power grids using limited number of measurements. The proposal was submitted to ERIGrid trans-national access application submitted by DEPsys on 14th May 2018.
The Power Networks Demonstration Centre (PNDC) for the University of Strathclyde was the host institute providing access to their infrastructure. These infrastructure include i) the medium and low voltage network with a primary substation and 4 secondary substations, ii) fault thrower for throwing different single-phase, two-phase, and three-phase faults, iii) single-phase and three-phase loads for providing different operating loading levels, iv) switch to modify grid configuration from radial to ring, and v) measurement equipment including MV sensors with Beckhoff automats and LV Fluke power quality measurement device. The GridEye measurement devices, provided by DEPsys, were installed in the distribution network to measure voltages and currents across the MV and LV network. The period of access was from 19th November 2018 to 23rd November 2018.
The user group was included of following people:

- Omid Alizadeh-Mousavi, R&D director at DEPsys, participated in the activities related to the preparation of the proposal and tests as well as using measurement data for evaluating the performance of fault identification algorithms and improvement of algorithms.
- Antony Pinto, Electrical Engineer at DEPsys, participated in the activities related to the field installation, configuration, and commissioning of GridEye devices in the PNDC network as well as collecting the measurement data.
- Yann Chenaux, Embedded Software Engineer at DEPsys, participated in the activities related to the configuration, and commissioning of GridEye devices as well as the acquisition of measurement and collecting the measurement data.
- John Paraskevas, Business Development director at DEPsys, supported the activities related to the preparation of the proposal and performing the tests.

2 Research Motivation

GridEye is a decentralized solution deployed in distribution networks primarily for grid monitoring and control purposes. During the past two years, several algorithms are being developed by DEPsys to identify different types of faults, such as earth fault, between two-phases, two-phase to ground, and three-phase to ground as well as fault direction from the measurement point, i.e. upstream versus downstream. These algorithms are designed to use GridEye measurements for fault identification in low and medium voltage grids. The particularity of these algorithms are i) only a limited number of measurements, including LV voltages and currents and MV currents are needed, ii) removing the hardware and installation costs for MV voltage measurements, iii) decentralized approach with minimum use of communication, iii) no need to a dedicated device only for fault identification and removing its hardware and installation costs. So far the developed algorithms by DEPsys are tested using the outputs of simulation software such as EMTP-RV and MATLAB. This project allowed us to evaluate the performance of the algorithms using real faults measured by GridEye.

2.1 Objectives

The main objective of this project was to test and validate the use of GridEye measurements and its algorithms for fault identification in distribution grids. The fault identifications algorithms integrated in the GridEye system allows utilities to deploy a unified solution for observability, control, and fault management in their distribution grids. This will effectively improves the security of supply by decreasing the average outage duration for each end-customer which consequently increases the end-customers satisfaction.

2.2 Scope

The performed tests in this project are in line with the activities in DEPsys for developing fault identification algorithms characterized by decentralized approach and minimum use of communication system and using a limited number of measurement points. The fault identification algorithm with these characteristics is suitable for integration in GridEye system. These tests not only allowed evaluating the performance of developed algorithms but also were used for improvement of the algorithms.

3 State-of-the-Art

We have precisely studied the existing fault identification algorithms in literatures and patents as well as the current industry practices and products [1] [2] [3] [4]. Figure 1 summarizes the result of our studies on different fault identification algorithms and classifies them according to i) electrical quantities used for fault identification (currents, voltages, ensemble of voltages and currents, impedances, energies, electrical charges), ii) signal processing type (time domain, frequency domain, normalized values), iii) type of function (signal, derivatives, aggregation, transients, average, likeliness, memory). In. Figure 1, the size of circles illustrate the percentage of algorithms using a specific electrical quantities - signal processing type - function type for fault identification. For instance, in Figure 1-left, the algorithms using the electrical quantities of voltage and current (given by U&I) in the time domain (given by t), shown with a large grey circle, has been widely used with respect to other electrical quantities and signal processing types.

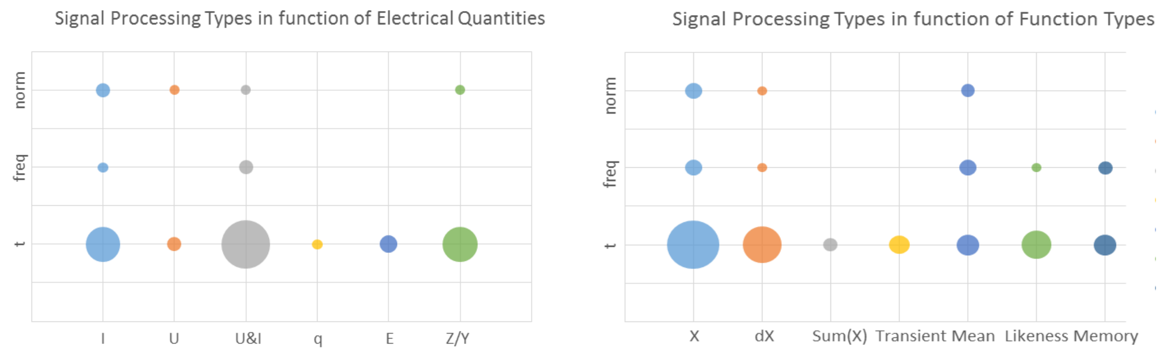

***Figure 1. left**) signal processing type as function of electrical quantities, **right**) signal processing types as function of function types.*

Electrical quantities include: I: current, U: voltage, U&I: voltage and current, q: electrical charge, E: energy, Z/Y: impedance and/or admittance.
Signal procession types include: t: time domain signals, freq: frequency domain signals, norm: normalized data.
Function types include: X: signal itself, dX: signal derivative, sum(X): accumulated signal, Transient: transients behavior of signal, Mean, average values of signal over an a-priori defined period, Likeness: likelihood between signals, Memory: signal correlation with its behavior in previous instances.

Based on these investigations we have identified following challenges for fault identification in MV grids
- need a dedicated device for fault identification with its infrastructure and installation costs
- need for MV voltage measurements and voltage measurement transformer
- using a centralized approach which requires communication infrastructure
- impact of bidirectional power flows are not taken into consideration

noting that the fault identification in LV grids has received very little attention.

GridEye fault identification application intends to remove the abovementioned challenges for fault identification in distribution grids. Thus the GridEye fault identification algorithms are designed to identify faults in LV and MV grids in a decentralized way and with limited number of measurements, including LV voltages and currents and MV currents. Note that GridEye hardware and measurements are primarily used for grid monitoring and control purposes and the fault identification application is an additional application.

4 Executed Tests and Experiments

The system under test was GridEye monitoring system of DEPsys. This is comprised of an MCU100 unit and up to three SUR100 units daisy chained to the MCU as depicted in Figure 2. An SUR provides current monitoring through the attached Rogowski coils. Voltage is measured directly by the MCU. A GPS antenna is connected to the MCU for time synchronisation. Communication to the device is possible via a cellular connection, however this was not used during testing and communication over wired LAN were used instead. The system were installed by PNDC authorised staff. Configuration and commissioning of the system were performed by DEPsys.

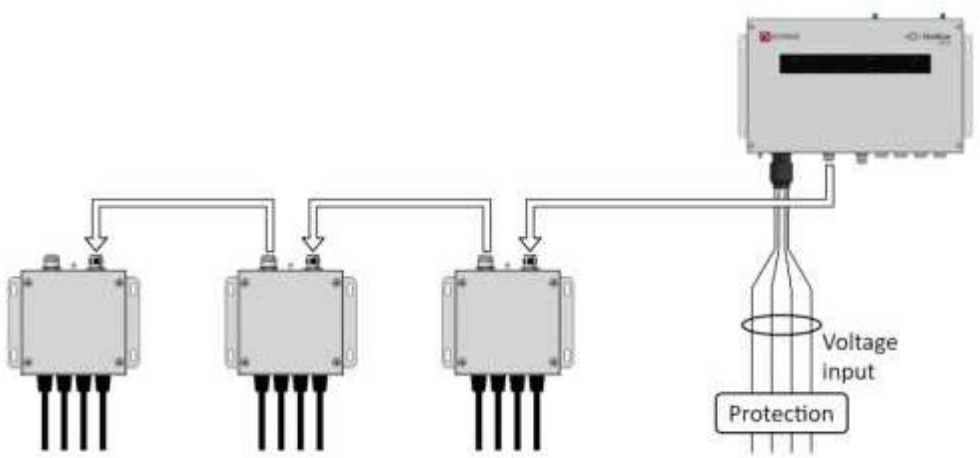

Figure 2. DEPsys GridEye monitoring system

4.1 Test Plan

The accomplished tests are summarized in
Table 1. The following initial conditions are applied:

- 160 kW, 80 kW and 80 kW balanced three-phase loads for substations A, D & G respectively. These values may vary depending on the LV voltage.
- The voltage set point for the motor-generator set excitation system are 11 kV.
- The frequency set point for the motor-generator set governor are 50 Hz.

Table 1. *test schedule.*

Test category	Tests applied
MV faults	• Fault location: A, B & C. • Fault type: L1-G (R_f = 20 Ω), L1-L2 (R_f = 60 Ω), L1-L2-L3-G (R_{f1-3} = 150 Ω, R_{fg} = 20 Ω) Each fault type will be repeated three times at each location. The fault scenarios will be applied for radial and ring network configurations.
LV faults	• Fault location: X, Y & Z applied at LV test bays downstream of the substation LV output. • Fault type: L1-G (R_f = 0 Ω), L1-L2 (R_f = 0 Ω), L1-L2-L3-G (R_f = 0 Ω). Each fault type will be repeated three times at each location.
Loading conditions	• Reduction of total load by 20 kW steps to 0 kW. • Increase of total load by 20 kW steps from 0 kW to maximum loading. • Apply a power factor of 0.9 to the total load. The above loading scenarios will be repeated for radial and ring network configurations. • Apply a single-phase load of 30 kW to substation A, while three-phase loads of 80 kW are applied to substations D & G.
Transformer inrush	Close MV circuit breaker at the primary substation to energise the test network while substation transformers A, D & G are connected.

4.2 Standards, Procedures, and Methodology

GridEye is certified according to EU directives (e.g. EMC, safety) and its installation in LV grids does not need additional hardware and/or material. The GridEye devices were installed by PNDC authorised staff. Configuration and commissioning of the system were performed by DEPsys.

4.3 Test Set-up

The PNDC MV test network configuration and installation locations of the GridEye system are illustrated in Figure 3.

The supply to the test network is using a 5 MVA motor-generator through an 11/11 kV delta/star isolating transformer. Two 11kV cable circuits are used to form a radial or ring network configuration as required by the test scenarios.

The GridEye devices are installed at four locations as summarised in Table 2 and depicted in Figure 3. Communication to the GridEye installations are performed using a LAN. Each MCU is connected to a local network switch. Static IP addresses for each MCU is advised by PNDC.

In addition to the GridEye measurement points, there are PNDC measurements performed in parallel for comparison. Additional LV and MV measurements are indicated in Figure 3. The LV measurements are performed using Fluke 430-II power quality analysers. The PNDC MV current measurements are performed using Rocoil Rogowski coils and integrators. The PNDC MV voltage measurements are performed using 11/0.11 kV VTs. Measured MV voltages and currents are sampled at a rate of 4 kHz.

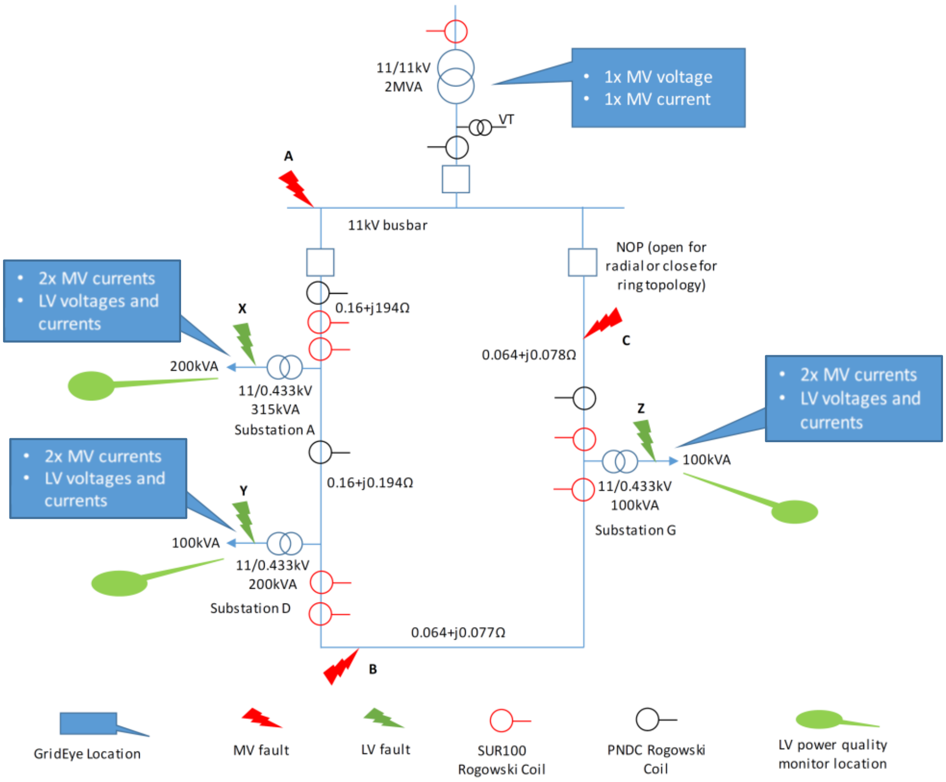

Figure 3. Test network configuration

Table 2. GridEye installation location summary

GridEye installation location	GridEye measurement points	Additional notes
Primary substation	• MV voltage via 11/0.11kV VT. • MV current measured around isolating transformer input cables.	• MCU will be powered using a 5V dc supply. • Measuring the current at the input of the isolating transformer eliminates cable screen current caused by simulated earth faults in the test network. • MV cables are 95 mm^2 XLPE single-core.
Secondary substation A	• LV transformer output voltage. • LV transformer output current. • Upstream MV current (duplicated)	LV cables are 185 mm^2 four-core SWA.
Secondary substation D	• LV transformer output voltage. • LV transformer output current. • Downstream MV current (duplicated).	MV voltage and current will be measured inside the substation MV cable end boxes where the MV cable screens are accessible.
Secondary substation G	• LV transformer output voltage. • LV transformer output current. • Upstream MV current. • Downstream MV current.	

4.4 Data Management and Processing

GridEye devices at the installed points collect the measurement data with 52 kHz sampling rate. In addition to the GridEye measurement points, there are PNDC measurements performed in parallel for comparison. Raw measurement data performed by the PNDC are provided to DEPsys after test completion.

The GridEye measurement data are used by DEPsys to evaluate the performance of the fault identification algorithms and the possible improvements.

5 Results and Conclusions

The performed tests have allowed to collect measurements data when different types of faults (earth fault, 2-phase fault, 3-phase fault) happening in MV and LV grids, resembling various real grid operating conditions and configurations. Examples of earth fault measurements are given in Figure 4.

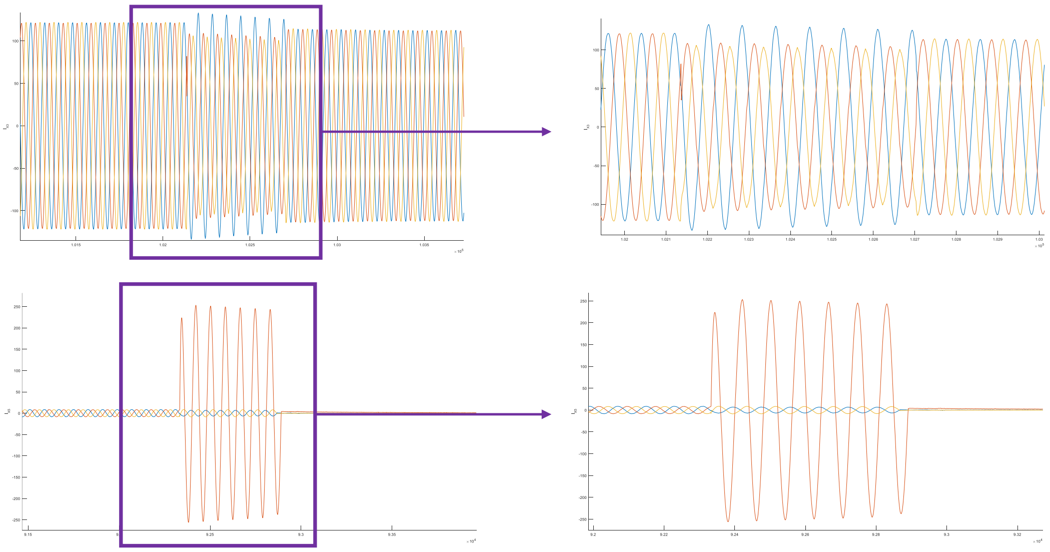

Figure 4. Examples of measurements for earth faults.

These measurement data has allowed us to validate the fault identification algorithms. It has eventually helped us to accelerate the time-to-market for the fault identification application.

6 Open Issues and Suggestions for Improvements

This project has been planned and accomplished by having access to excellent facilities with direct support and recommendation of expert personnel, allowing to timely conclude several tests.

7 Dissemination Planning

It is planned to prepare a white paper for DEPsys website. We are evaluating the possibility to file a patent.

8 References

[1] B. Drouere and J. Mecreant, "Directional detection of a ground fault in an electrical distribution network". European Patent 3001524, 30 March 2016.

[2] Valroos and A. Janne, "Method and device to determine direction to fault point". European Patent 2624397, 07 August 2013.

[3] N. Baumes, T. Neveu and V. Guillaume, "Directional detection of a sensitive medium-voltage earth fault by linear correlation". European Patent 2687860, 22 January 2014.

[4] M. Kereit, M. Lukowicz, M. Michalik and W. Rebizan, "Detection of ground faults in energy supply networks with a compensated star point". World Patent 2014194941, 11 December 2014.

9 Annex

9.1 List of Figures

9.2 List of Tables