DISCERN has demonstrated replicable and cost-effective solutions for the enhancement of network observability to enable DSOs to address current and future challenges of network management.

In DISCERN a set of advanced Smart Grid functions – the DISCERN sub-functionalities – has been defined for investigation through demonstration projects. The sub-functionalities implemented within the demonstration sites during DISCERN are as follows:

- Enhanced monitoring and control of MV and LV network – Vattenfall, Sweden
- Real-time monitoring of LV network – Iberdrola, Spain
- Optimised Advanced Meter Reading (AMR) data collection and analysis using virtualised as well as physical concentrators – Unión Fenosa Distribución, Spain
- Calculation and separation of technical and non-technical losses – Unión Fenosa Distribución, Spain

**Real-time monitoring of LV network**
- LV advanced supervisor
- LV power quality
- LV field data collection
- Benefits to distribution networks

**Calculation and separation of technical and non-technical losses**
- Losses estimation
- Non-technical losses
- Energy balancing
- LV state estimation

**Optimised AMR data collection and analysis**
- AMR optimisation
- Virtual concentration
- Meter data concentration
- BPL communication
DISCERN FIELD TEST – DEMO I
ENHANCED MONITORING AND CONTROL OF MV AND LV NETWORK – VATTENFALL, SWEDEN

The DISCERN Vattenfall field trial has been designed with the overall purpose of increasing the functionality of MV network monitoring through fault identification. The main objective is to geographically pinpoint faults in the distribution network and the use of MV monitoring for fast and reliable fault identification and indication of distance to fault has been evaluated.

SHORT SYSTEM DESCRIPTION

Fault detection in high impedance grounded distribution grid:

- Swedish MV networks are high impedance grounded meaning that the active part of the earth fault current is limited with a resistor in the neutral to 4 – 10 A, a fraction of what the fault current would be otherwise.
- There is also a reactor in parallel with the resistor, with the purpose of eliminating the reactive current at the fault location.
- In small overhead lines resistor switching can be used to completely eliminate the current at the fault allowing an arc to be extinguished thereby removing the fault.
- During an earth fault, customers’ voltage is unaffected due to the delta winding in the MV part of the secondary substation.
- However, a low fault current makes it extremely challenging to identify and calculate a distance to fault, and this has not previously been possible without voltage measurements.
- DISCERN combined a unique method for fault passage indication using only current measurement together with a new algorithm built into a station.
DISCERN DEMONSTRATION I – VIRTUAL TOUR
VATTENFALL, SWEDEN

INSTALLATION IN FEEDING 70/10 KV SUBSTATION

- Station computer
  A station computer installed at the 70/10 kv substation calculates a distance to fault from disturbance records collected from the 10 kv protection relay.

- IED new protection relay
  Protection relay sends fault recording to station computer that calculates a distance to fault.

- Wällange old substation
  Outgoing lines of the old substation
  One line is kept in operation for DISCERN tests. A second line can be energized to verify no cross faults etc.

DOUBLE FAULT PASSAGE INSTALLATION ON LINE BRANCH

- Pole mounting of two sensors in branching pole
  CTs on main line and line branch, one VT for power supply.

FAULT PASSAGE INSTALLATION ON 10 KV OVERHEAD LINE

- Cabinet with FPI and GPRS modem
  Fault Passage Indicator
  Communication modem
  Battery

Example: Station computer calculates a distance to fault beyond first line branch.

FPI 1 here has not seen the fault on its branch ...
... so SCADA concludes the fault is here.

FPI 2-5 do not report a fault behind them (increasing confidence that the correct line segment is identified).

With knowledge of fault location, maintenance teams save time locating faults. Reconfiguration of grid with remotely controlled disconnectors starts immediately, which significantly reduces customer outage times – measured as SAIFI and SAIDI.

CT: Current Transformer
FPI: Fault Passage Indicator
IED: Intelligent Energy Device
LV: Low Voltage
MV: Medium Voltage
SAIFI: System Average Interruption Frequency Index
SAIDI: System Average Interruption Duration Index
SCADA: Supervisory Control And Data Acquisition
VT: Voltage Transformer
EVALUATION

OF THE FIELD TEST AND CONCLUSIONS

FAULT PASSAGE INDICATORS (FPI)

Advantages
- Selected because of the patent that allows directional earth fault detection without voltage measurement.
- Performance is good, above expectation.
- All in-field test cases were detected and reported correctly. Propagation time of fault typically less than 5 seconds.

Disadvantages
- Some standard IP-based settings were not available.
- Installation requires a power interruption to customers.
- Deployment on poles time consuming and also requires VT installation in one phase to power equipment.

COM A01A: DISTANCE TO FAULT CALCULATIONS

Advantages
- All files containing fault current curves were processed.
- IEC 61850-bus based, COMTRADE files from all relays in the station could be analysed by one COM600.
- Accuracy of around 75-90%, but heavily dependent on exact line parameters.

Disadvantages
- Time consuming installation and configuration (parameter settings).
- Algorithm still under development (R&D).
- Full system testability must be incorporated into the design.

SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)

Advantages
- Simple implementation.
- Fast evaluation of results.

Disadvantages
- The user interface output is image based, not connected to Distribution Management System (DMS).

OVERALL CONCLUSION

Fault Passage Indicators (FPI) and substation computer solutions, when configured correctly, help to reduce the time needed for fault restoration. Integration into existing DMS/SCADA is beneficial. The distance to fault calculations are acceptable, however the method to test and verify an installation and its parametrisation requires further development. Drawbacks identified include the fact that configuration work is time consuming and can be problematic, and cost per sensor is still high at present.

BEYOND DISCERN

Additional areas of work have been identified, with some already underway:

- Investigate new fault location methods and their suitability for different networks.
- Explore technologies for self-healing in networks of differing grid topologies.
- Develop methods to use smart meter data to locate faults.

DISCERN FIELD TEST – DEMO II

REAL TIME MONITORING
OF LV GRID – IBERDROLA, SPAIN

The main objective of the DISCERN Iberdrola field implementation is to increase the observability of the Low Voltage (LV) network exploring the collection of field data with higher granularity. Beyond the project, the field implementation will contribute to the improvement of LV network management and operation with the enhanced data available processed by an LV network management system. The innovation focuses on increasing knowledge of LV power quality, for example harmonics.

SHORT SYSTEM DESCRIPTION

The Iberdrola demonstration includes the installation of new measurement equipment in a Secondary Substation (SS) to improve the observability of the LV network. The equipment consists of Intelligent Electronic Devices (IEDs) used for advanced LV supervision, which monitor each of the SS LV feeders. The IEDs are as follows:

- LV Feeder Monitoring Unit (LV FMU)
- LV Supervisor Manager Node (LV SMN)

One of the key differences compared with the existing solution is that some measurements and calculations (e.g. three phase voltage and current measurements, energy, average voltage/current per phase, and average neutral current) are now provided for each of the LV feeder lines, whereas under the existing situation these measurements are only available at the output of the transformer, before the outgoing LV feeders. LV power quality measurements at bus bar level are also captured. These features make an important contribution to LV grid monitoring leading to greater knowledge of the network’s state.

SHORT SOLUTION DESCRIPTION WITHIN THE FULL BUSINESS MODEL

2. Sending the collected information to centralize systems in form of reports (based on STG-DC data model).
3. Data storing in AMI Head End.
4. Data processing by LV network management system and system operators.
5. Reflect the enhanced information obtained to improve the operation and management of LV network.
**DISCERN DEMONSTRATION II – VIRTUAL TOUR**

**IBERDROLA, SPAIN**

The flow of information from/to SMs and the measurements of voltage (direct connection to the LV bus) and current (from the current transformers) are transmitted via the Meter Data Concentrator. This has a three phase meter. One communication port is enabled for the LV Supervisor Manager Node (LV SMN). This cabinet and its content existed prior to the LV advanced supervision installation, with the communication equipment used for managing required communications.

Before the LV advanced supervision installation, the Meter Data Concentrator collected SM readings (PRIME injection signal) and LV supervision (voltage and current at LV bus bar level) data. After implementing the solution, the PRIME signal injection is done by the LV SMN that is also in charge of aggregating the data generated by all the LV FMUs. The current measurements at bus bar panel level are held in the Meter Data Concentrator (due to retrofitting reasons) and available for reporting purposes. This information is then transmitted to the AMI Head End (or to another SS before reaching the AMI Head End where BPL is used as the communications medium).

The information acquired by each of the LV FMUs is transferred to the LV SMN that consolidates the LV feeders information into XML reports to be subsequently sent to the AMI Head End system. The LV SMN also hosts the Smart Meter PRIME signal injection (SM readings) and LV feeder identification for PRIME SMs. Based on the information that the LV FMU regularly sends, the LV SMN identifies the line that the SM is connected to.

Due to retrofitting, the Meter Data Concentrator and the IED (LV SMN) are separated in two different devices connected by an Ethernet cable.

Prior to installation the Meter Data Concentrator collected SM readings (PRIME injection signal) and LV supervision measurements (voltage and current) at LV bus bar level. After installation, the PRIME signal injection is done by the LV SMN that is also in charge of aggregating the data generated by all the LV FMUs. The current measurements at bus bar panel are kept in the Meter Data Concentrator and available for reporting purposes.

The LV FMU is an advanced three phase meter that collects measurements of each phase on each line (e.g. three phase voltage and current measurements, energy registers, imported and exported active energy & reactive in the four quadrants), average voltage/current per phase, average apparent power, average neutral current (calculated), maximum voltage/current per phase, maximum apparent power, maximum neutral current (calculated). One unit is connected to each LV line.

It is used to determine in which line each SM is connected to. The PRIME sensor is installed specifically to determine which line each smart meter is connected to. One sensor is installed on one phase of each LV line, and each is directly connected to the IED (LV FMU) of the LV line where it is located.

**Diagram:**

- **LV Supervision Manager Node (LV SMN)**
- **LV Feeder Monitoring Unit (LV FMU)**
- **AMI Head End**
- **Communication equipment**
- **Meter Data Concentrator**

**Legend:**

- AMI: Advanced Metering Infrastructure
- BPL: Broadband Power Line
- FMU: Feeder Monitoring Unit
- IED: Intelligent Electronic Device
- LV: Low Voltage
- MV: Medium Voltage
- MV LV: Medium Voltage – Low Voltage
- SMB: Smart Meter
- SMBN: Supervision Manager Node
- SS: Secondary Substation
- DER: Distributed Energy Resources
- Customer Premises
EVALUATION OF THE FIELD TEST AND CONCLUSIONS

FIELD INSTALLATION

Advantages
- Easy to install solution, compatible with most of the existing infrastructure.
- Consumer inconvenience during installation can be minimised.
- Opportunity to integrate the installation with the current mass AMI deployments procedures.

Disadvantages
- New devices need to be installed inside secondary substations.
- Repeat administrative procedures (e.g. permissions and contracts) to deploy the solution in SSs where the AMI infrastructure has already been installed.

LV ADVANCED SUPERVISION PERFORMANCE (INCLUDING LV POWER QUALITY MEASUREMENTS)

Advantages
- Compatibility with communications and data models already used within the business.
- Good performance of LV power quality measurement data collection.
- No impact on the performance of PRIME operating alongside the new LV monitoring solution.
- Other Smart Grid functionalities can use the higher granularity of measurements provided by this solution to achieve more accurate results.
- The solution allows modular architecture to separate functionalities based on DSO business roles.

Disadvantages
- Increased volume of data to be processed and stored.
- Few solutions are available from vendors at present.
- Additional field experience will be required to determine the final system architecture (single unit vs. multiple units) and to establish full integration with higher-level systems.

OVERALL CONCLUSION

LV network observability is minimal in comparison with other voltage levels, and LV advanced supervision solutions could offer significant operational and planning benefits to DSOs, supporting various Smart Grid functionalities. Such deployments will allow MV operational approaches to be translated to LV networks, bringing benefits to distribution networks and their consumers.

BEYOND DISCERN

Additional areas of work have been identified, with some already underway:

→ Explore the possibility of further developments relating to LV power quality measurements.
→ Continue with the integration of new data reports into the Advanced Meter Infrastructure (AMI) system.
→ Increase the number of secondary substations with this solution, and the criteria for prioritisation.
→ Develop LV network management systems.
→ Overall, continue developing the full LV data collection and analysis chain: data collection, data processing and information usability.

DISCERN FIELD TEST – DEMO III

OPTIMISED ADVANCED METER READING (AMR) DATA COLLECTION AND ANALYSIS USING VIRTUALISED AS WELL AS PHYSICAL CONCENTRATORS – UFD, SPAIN

Data concentration is necessary in order to gather the data generated by smart meters located at customer premises and make this information available for other applications. The functionality tested aims at optimising the task of gathering data from smart meters taking into account different geographical concentrations of customers, as well as the various communication technologies available.

SHORT SYSTEM DESCRIPTION

This DISCERN field trial tests alternative solutions for data concentration that can be used considering different communications technologies as well as the number and geographical concentration of customers that are fed on the LV side of secondary substations. The solutions to be trialled for sending data from smart meters to the Meter Data Management System (MDMS) are as follows:

1. Conventional Meter Data Concentration (MDC): using a physical concentrator located in the secondary substation. Once the data has been collected by the concentrator, there are two possibilities for sending data on to the MDMS:
   a. mobile networks (conventional solution)
   b. MV Broadband Power Line (BPL) communications (new solution tested)

2. Virtual Meter Data Concentration (VDC): a software application running in central systems to collect data directly from smart meters (new solution tested).

For case (1), the smart meters communicate with the conventional MDCs located in secondary substations via PLC. For case (2), the virtual MDC application running in central systems communicates directly with dispersed smart meters using mobile networks, for example to collect data from areas with low concentrations of smart meters or where LV PLC communications between conventional MDCs and smart meters do not work properly.
DISCERN DEMONSTRATION III – VIRTUAL TOUR
UNIÓN FENOSA DISTRIBUCIÓN, SPAIN

AMR DATA COLLECTION PATHS

- Conventional contractor + GPRS: Reports generated at smart meters are sent to the Meter Data Concentrator (MDC) using LV PLC-PRIME communications. Then, MDC sends the reports collected to the Meter Data Management System (MDMS) using GPRS communications from public operators.

Solutions tested at the demo sites

- Conventional contractor + MV BPL: Reports generated at smart meters are sent to the Meter Data Concentrator (MDC) using LV PLC-PRIME communications. Then, MDC sends the reports collected to the Meter Data Management System (MDMS) using MV BPL communications through the DSO-owned MV lines.

- Virtual concentration: Reports generated at smart meters are sent directly to the MDMS via Virtual Meter Data Concentrator, using GPRS communications.

SGAM representation of the solution (component layer)

1. BPL modem
   Sends the information from the Meter Data Concentrator to MDMS.

2. BPL coupling devices
   - Couple the signal from BPL modem to the MV line.
   - Different types of couplers available for different topologies and characteristics of MV cables.

3. Eiris network
   Underground

4. Grela network
   Overhead + Underground

Server
Virtual concentration application is running in a server installed in central systems. The application can be replicated as needed to collect reports from any increasing number of smart meters.

Configuration console

Virtual Meter Data Concentrator

AMR DATA COLLECTION PATHS

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- Conventional contractor + MV BPL:
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EVALUATION

OF THE FIELD TEST AND CONCLUSIONS

CONVENTIONAL METER DATA CONCENTRATORS

Advantages
- High success index in meter reading (~92%).
- Lower communication costs per smart meter.

Disadvantages
- Deployment costs per secondary substation are high, making marginal costs high where there are low numbers of customers.

VIRTUAL CONCENTRATION

Advantages
- Reliability is valid for billing purposes.
- Lower communication costs for scattered smart meters.

Disadvantages
- Lower success index in meter reading than conventional concentrations (~75-95% vs 92%).
- High development cost of virtual concentrator solution only worth if there is a sufficient amount of secondary substations with few customers.
- Not plug & play. Firmware updates required to integrate new models of GPRS meters.
- Dependency on GPRS availability.

CONVENTIONAL CONCENTRATION + MV BPL

Advantages
- High performance: bandwidth 85 MB, download speed 1000 kbps, latency 2ms, comm. success 99%.
- Good coexistence with existing NDLC modems used for telecontrol.
- Sufficient communication distances achievable.
- Minimal influence of air-ground transitions.
- Uses the DSO owned MV network for communications.
- Communication path for areas with poor GPRS.
- Adaptability to different MV network configurations.

Disadvantages
- Communication performance is very sensitive to interference caused by the incorrect installation of current transformers for LV supervisors in secondary substations.
- High price of some coupling devices at present.

OVERALL CONCLUSION

Virtual concentration is a cost efficient alternative for collecting data from dispersed smart meters, where the marginal cost of installing conventional Meter Data Concentrators is too high. The meter reading success is acceptable for billing purposes. BPL communication is a reliable and efficient technology for collecting data from conventional Meter Data Concentrators using the DSO owned MV lines. This avoids costs from using public GPRS operators, and provides a communication path in areas with poor GPRS availability.

BEYOND DISCERN

- It is expected that the virtual concentration solution will be used in secondary substations with few customers, and also where conventional solution is not working properly.
- An energy management gateway solution will be tested as an intermediate solution for secondary substations with few customers. The gateway will act as a multiplexing device for meters communication, thus avoiding costs related to the use of GPRS for each smart meter.
- Security of the communication protocols for the virtual concentrator will be improved, providing a slight data overhead in comparison to base R&I situation.
- Updates will be made to the virtual concentrator application to improve performance in light of lessons learned during the trial.
- BPL communication has shown promising performance. Future exploitation plans are under evaluation.

DISCERN FIELD TEST – DEMO IV

CALCULATION AND SEPARATION OF TECHNICAL AND NON-TECHNICAL LOSSES – UFD, SPAIN

This losses related field trial aims to estimate losses in LV networks using data collected from smart meters at customers’ premises and from Low Voltage (LV) supervisors located on the LV side of secondary substations. Through the use of energy balances and state estimation algorithms, both technical and non-technical losses can be estimated.

SHORT SYSTEM DESCRIPTION

Data collected from smart meters and LV supervisors in LV networks provides useful information that can be used for various applications. Once the data is collected in the Meter Data Management System (MDMS), it is made available for other functionalities. This field test takes advantage of this data to compute technical as well as non-technical losses. The stages of the process are as follows:

- Energy balances are created using hourly energy data from LV supervisors and smart meters, together with hourly estimates of energy made for customers that do not yet have smart meters (e.g. commercial/industrial consumers). The difference between the energy delivered through the secondary substation and the energy billed to customers indicates the overall energy loss.
- State estimation is undertaken using available data [currents, voltages and energy measurements] hourly measured by smart meters and LV supervisors, together with LV network models [topology, connections, lengths and parameters of cables] from the Network Information System (NIS).
- Technical losses are determined from the estimated current flows and the impedances of network branches.
- Once technical losses are estimated, non-technical losses can be derived using the energy balance.

A Power Analysis Tool (PAT) has been developed to undertake the losses calculation. The PAT performs the calculations to determine technical and non-technical losses in LV networks from measurements and reports collected at the MDMS. The other applications that form part of the solution (NIS and MDMS) already exist within the centralised systems of the demonstration site.
DISCERN DEMONSTRATION IV – VIRTUAL TOUR
UNIÓN FENOSA DISTRIBUCIÓN, SPAIN

INPUT DATA – SMART METERS AND LV SUPERVISOR

Data used in algorithms for losses calculation is obtained from reports generated at smart meters and LV supervisors deployed in LV networks. Hourly energy reports S02 and daily reports S05 from smart meters are used together with reports from LV supervisors. From reports collected, power flows and losses estimation are performed. Finally, energy balances are performed and reports on losses are generated.

POWER ANALYSIS TOOL – Services

The Power Analysis Tool is the application responsible for running the algorithms.

Back Office
Contains information regarding the status of the reports received, reading success ratio, and web services to make queries to download network data and reports.

Front End
Contains the main Power Analysis Tool view, where the LV networks are shown in a map, and the different services can be accessed using tool bars.

POWER ANALYSIS TOOL – TOOLBARS

Settings toolbar
- LV network selector
- Show/hide layers
- Show/hide cable sections
- Cable sections information
- Threshold adjustment

Functions toolbar
- Meter consumption
- Voltages and currents (LV supervisor)
- Energy balances (secondary substation)
- Voltages in nodes
- Cable sections information

POWER ANALYSIS TOOL – LOSSES CALCULATIONS AND REPORTS

Evolution of consumptions, technical and non-technical losses can be shown in graphics for a given period:
- Energy delivered through the secondary substation (LV supervisor)
- Energy consumed by customers (smart meters)
- Technical losses, non-technical losses

Total energy consumptions, estimations, forecasts and losses can be calculated and shown in the Power Analysis Tool for any given period.
OVERVIEW
OF LINKS TO DELIVERABLES

MAIN SOURCE

OTHERS
[D2.1] – DISCERN DELIVERABLE 2.1: “CATALOGUES AND REQUIREMENTS FOR DISTRIBUTED DEVICES AND COMMUNICATION ARCHITECTURES”
[D2.4] – DISCERN DELIVERABLE 2.4: “EVOLUTION OF LEARNER’S SOLUTIONS: FROM REQUIREMENTS TO IMPLEMENTATION”
[D4.3] – DISCERN DELIVERABLE 4.3: “PREFERABLE GENERAL SYSTEM ARCHITECTURE, INTEGRATIONS AND USER INTERFACE”
[D5.3] – DISCERN DELIVERABLE 5.3: “TECHNICAL SPECIFICATIONS FOR IMPLEMENTATION AND ECONOMICAL ANALYSIS”
[D8.1] – DISCERN DELIVERABLE 8.1: “BUSINESS CASE ON USE CASES AND SENSITIVITY ANALYSIS”
[D8.2] – DISCERN DELIVERABLE 8.2: “SWOT ANALYSIS OF APPLIED TECHNOLOGIES AND SOLUTIONS”

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EVALUATION
OF THE FIELD TEST AND CONCLUSIONS

POWER ANALYSIS TOOL

Advantages
✓ The application takes advantage of data available at the MDMS due to the Advanced Meter Infrastructure (AMI) deployed for other purposes.
✓ Both technical and non-technical losses are computed.
✓ The solution helps to identify potential energy theft and target activities to reduce losses.
✓ Successful integration of energy reports from different types of smart meter.
✓ High availability and maturity of smart meters that provide hourly measurements, available for any residential, commercial and industry consumers.

Disadvantages
✓ The current low maturity of technology means that solutions are not yet available in the market and a tailor made solution had to be developed.
✓ The solution relies on an accurate LV network model, and such accuracy may not typically be available in current network information systems.
✓ High deployment costs of AMI infrastructure where this has not already been deployed for AMR functionality. The Power Analysis Tool provides an economic solution for identifying and tackling losses where AMI is already deployed, or where there is similar wide-spread monitoring of LV networks.

OVERALL CONCLUSION

The Power Analysis Tool (PAT) helps to estimate technical and non-technical losses in LV networks, for which there has not traditionally been any type of monitoring or estimation of losses. Estimation is based on real energy data, making use of reports generated from the recently deployed Advanced Metering Infrastructure. This provides valuable information on the technical and non-technical losses for inform decisions on activities to reduce losses. For the demonstration site in question it was observed that technical losses are very low in comparison to non-technical losses.

BEYOND DISCERN

Additional areas of work have been identified, with some already underway:

✓ It is expected that the Power Analysis Tool will be used for assessing other LV network area, to take advantage of the mass roll-out of smart meters and LV supervisors within UFD networks.
✓ It is a valid tool to detect non-technical losses for big customers.
✓ Once the PAT application has been developed, the solution can be readily scaled and replicated to other LV networks, subject to availability of an accurate network model.