ENHANCED LV SUPERVISION BY COMBINING DATA FROM METERS, SECONDARY SUBSTATION MEASUREMENTS AND MV SCADA

Nicholas ETHERDEN
Vattenfall R&D – Sweden
nicholas.etherden@vattenfall.com

Anders Kim JOHANSSON
Vattenfall Services – Sweden
anderskim.johansson@vattenfall.com

Ulf YSBERG
Vattenfall Distribution - Sweden
ulf.ysberg@vattenfall.com

Kjetil KVAMME
Powel A/S – Norway
kjetil.kvamme@powel.no

David PAMPLIEGA
Schneider Electric – Spain
david.pampliega@schneider-electric.com

Craig DRYDEN
GE – U.K.
craig.dryden@ge.com

ABSTRACT

This paper describes a practical demonstration of low and medium voltage network monitoring through information exchange between metering, SCADA and network information systems. The goal of the project is to increase observability of the network for operators, and provide more information for network planners. Practical experiences and recommendations for secondary substation retrofitting are provided based on 18 installations of remote terminal units, fault locators and line sensors in 10/0.4 kV secondary substations.

INTRODUCTION

Upgrid (www.upgrid.eu) is a European Horizon 2020 project with the goal to demonstrate active demand and flexible integration of distributed generation, through a fully controllable low voltage (LV) and medium voltage (MV) distribution network [1]. This paper describes one of the four demonstrations within Upgrid.

After development and tests of various Smart Grid systems, technologies and methodologies in a series of isolated pilots, Vattenfall is now having a demonstration within the Upgrid project, together with present metering, SCADA and NIS suppliers, in order to prepare and enable future Smart Grid solutions to be implemented in full scale in the daily operations. The main focus is on LV network in order to prepare for anticipated future higher requirements on quality of supply by the customers. The aim is to improve the monitoring and controllability of the network by harnessing real time network data from multiple sources and thereby increase the efficiency of system operation and planning.

DEMONSTRATION SITE

The demonstrator is placed in a rural part of southern Sweden. It includes MV lines involving 528 customers, all of them equipped with smart meters. As part of this demonstration 16 out of 51 secondary substations (10/0.4 kV) along two 10 kV overhead lines have been retrofitted with monitoring and supervision equipment such as self-regulating transformer to maintain LV voltage levels near solar PV installations, remote terminal units (RTU), fault passage indicators (FPI) and overhead line sensors. In order to demonstrate interoperability, equipment is provided by six different vendors, where vendors have

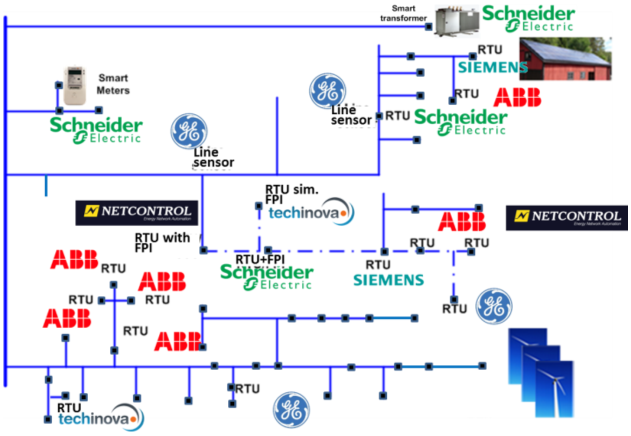

Figure 1 Overview of field installations in the demo

been encouraged to supply new product variants combining innovative and cost efficient ways to fulfil the requirements for LV monitoring. Advanced methods to determine customer outage and shunt faults, blown fuses, earth fault etc. are being implemented in both field equipment and overlying systems. An overview of the installations is provided in Figure 1.

INTEGRATIONS

Within the demo, Vattenfall partners have in parallel demonstrated LV supervision in three systems by combining data from meters, secondary substations measurements and MV SCADA. Two of the systems are

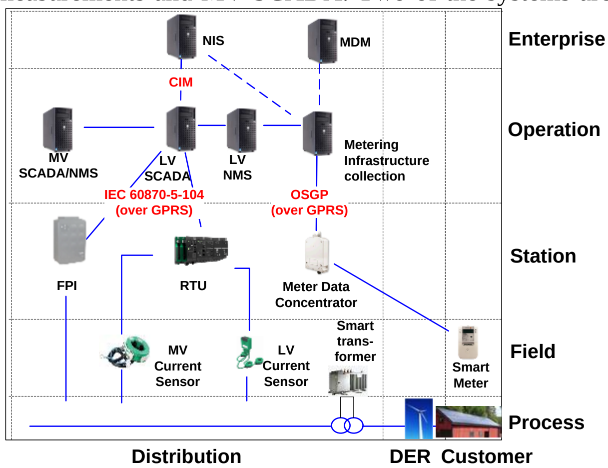

Figure 2 Smart Grid Architecture Model (SGAM) of involved equipment and systems in the demonstration

on-line; namely Network Management System (NMS) with SCADA from GE and the Network Information System (NIS) from Powel. The third system from Schneider Electric is built on top of the Metering Data Management (MDM) system and provides off-line post-analysis comparing aggregated meter values from each LV feeder with substation measurements. Figure 2 categorises the system components in the component layers of the Smart Grid Architecture Model (SGAM).

A central feature of the project is integrating various sources of information into the same operator and analysis platforms, in order to achieve a greater observability of the LV grids. This in effect dissolves the traditional functional division of the metering, NIS and SCADA system. A number of integrations are implemented to exchange information between the systems. Figure 3 provides an overview of the integrations required between the systems in order to achieve LV monitoring functionalities in the SCADA, NIS and metering dashboards.

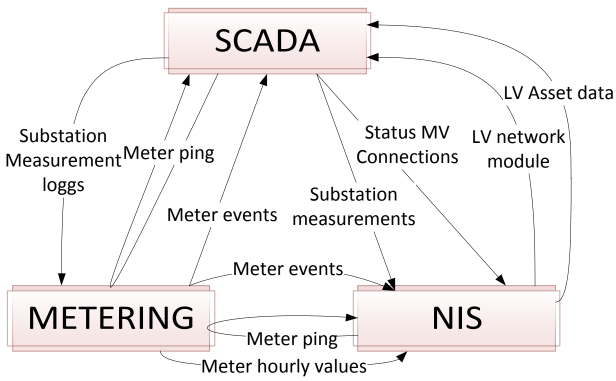

Figure 3 Overview of integrations required for LV observation in the three systems

To obtain these integrations a number of communication solutions are utilized, namely:

- Common Information Model (CIM) IEC 61968 to exchange LV network model and LV asset data
- Web services (SOAP) for status MV connections
- Web services (SOAP) and XML file format to send meter ping requests and replies
- Open Smart Grid Protocol (OSGP) and GS2 file format to send meter hourly values
- Web services (REST) with XML for meter events
- Excel files to send logged substation measurements for comparison with aggregated meter readings

Use of meter events

The metering system, with more than 800 000 meters deployed between 2002 and 2008, plays a central part in improving LV monitoring. Initially the metering collection system was envisioned for billing purposes and meter events were collected in a database available only for off-line retrieval of events from specific meters for case-to-case investigations. Over the decade since the 100% smart meter coverage was achieved in Vattenfall Swedish network, gradual improvements have been introduced in the metering system. The number of power system events detected by the end-customer meters have increased and the following are used for LV monitoring; detection of zero fault, broken fuse, switching meter on and off, reverse energy flow and power outage at the meter. Phase wise detection is also possible of under- and overcurrent events, phase inversion and phase loss.

The time to receive meter events has been improved greatly over the last couple of years; from hours or even days down to the current delay of 10-15 minutes. This drastic reduction in delay has opened up the possibility to use the meter events in the control room for operational purposes. As the average time to report, locate, and restore a fault in the LV network is a couple of hours, using the information from meter events during the fault localisation and restoration has a large potential to decrease the overall outage time for customers. Previous field demonstrations at Vattenfall indicate a potential to reduce annual average customer outage time (SAIDI) with 5-12% with secondary substation measurement [2]. Initial use of meter event for operation has shown a comparable potential for 4-10 % decrease in SAIDI. Although the outages will still occur their duration can be reduced, possibly decreasing SAIDI to an amount comparable even to those from more expensive measures like the wide-scale cablification of overhead lines.

Two further features have been introduced in the metering system with great potential for LV monitoring. The first one is a last gasp function, in which data concentrators automatically send an event when they are unpowered which can be used to distinguish power outages at secondary substations from an outage at end customer. The second one is the so called ping request where the individual meters can be requested to return an acknowledgement to confirm that they are online. This functionality is further enhanced by triggering a send of stored events to derive status. It is also envisioned to request multiple pings from meters in an area to identify where outage has occurred and to include voltage reading in ping request in near future to enable the creation of a voltage profile along a feeder or in a network section.

THOUSANDFOLD INCREASE IN DATA AND OBSERVED LOCATIONS

Today the total line length of Vattenfall distribution and regional sub-transmission network is 120 000 km. The low voltage (0.4 kV) network constitutes 50 % of this line length and is unmonitored. The medium voltage network (6-20 kV) constitutes an additional 40 % of the total distance and is in principle only monitored at outgoing feeders in the primary substations.

The vast majority (98%) of the substations are secondary substations (10 or 20 kV to 0.4 kV) that are, like in most utilities, usually without measurements. Including both secondary substation measurements and end-customer meter information to the control room thus constitutes a thousand fold increase in the number of data points to be monitored in the control room, as shown in Figure 4.

As was observed in Upgrid, the number of measurements in RTU from secondary substations was comparable to

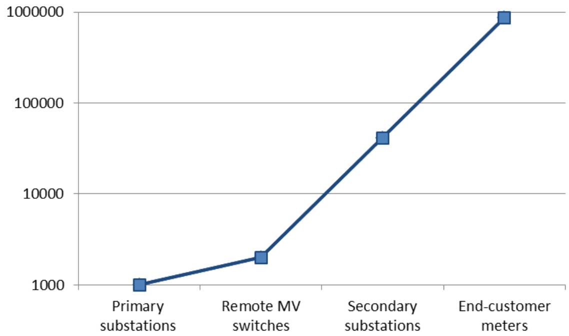

Figure 4 Increase in number of data points when extending monitoring to secondary substations and end-customer meters (note logarithmic scale)

the number of data points typically sent to the control room for primary substations (in total 2800 signals were received from the 16 substations). Given also the large number of events possible to be received from the meters it is likely that the amount of data that would need to be handled for a full-scale roll-out of LV monitoring could be in the order of a thousandfold more than handled today. The vast majority of collected information is only stored in historians for post-analysis, automated decision tools or network planning purposes. Clearly it is not a viable solution to "just" add meter and secondary substation events to a traditional event list and handle data in the same way as in today's control room. Instead, LV monitoring must be accompanied by a complete rethinking about how incoming data is handled by using more advanced filtering and data analytics to select what information is shown to operators.

FIELD INSTALLATIONS

Remote Terminal Units (RTUs)

Sixteen secondary substations where outfitted with RTUs. Each supplier was requested to demonstrate a retrofit solution for both a pole mounted and ground cabinet secondary substation. In addition, the cheapest bidder was contracted to supply four additional substations with monitoring. Based on the solution proposal received from the six equipment suppliers a solution was decided in individual workshops with each supplier that utilised the suppliers low-end RTU, but demonstrating the maximum possibilities of this product. Examples of the installations are given in Figure 5.

The total cost of the secondary substation solution can be broken down into four main parts:

1. RTU and LV sensor hardware cost
2. Cost to adapt generic solution and configure
3. Installation cost
4. Communication verification and SCADA import

A traditional procurement has a tendency to focus mainly on the first item above, trying to minimise cost for a predefined set of functionalities. Within Upgrid the focus has instead been on the evaluation of the cost for installation and integration with SCADA. This focus is important as most market offering were found to be

Figure 5 Example of RTU installations

downscaled versions of RTU developed for sub-transmission applications were more time is acceptable for configuration, cabinet wiring, and testing. To roll-out measurements to even a fraction of Vattenfall secondary substations would of necessity be in nature much more similar to an end customer smart meter roll-out than to a traditional primary substation installation.

Here the cost is most likely determined by the number of secondary substations that can be outfitted per day by a single team of field technicians. In the demo this varied between 2-3 days for one substation. In comparison it was possible to make installations of data concentrators for up to 4 per substation per day in previous installations smart meters roll-out campaigns at Vattenfall. This included new LV fuse for supplying data concentrator and connection to LV groups to read out the power line carrier messages on the LV cables. For RTU installations the estimate is that the most efficient Upgrid installation solutions demonstrated could – in a streamlined and large roll-out – result in installation of up to 2 secondary substations per day. The requirements to achieve this are:

- Adaptations of an individual solution would need to be minimised, if possible reduced to entering station name, IP-address and number of LV groups where a pre-set group of signals are sent for each LV group.
- No site-specific terminal wiring in the cabinet (sensors and voltages connected directly to RTU).
- A trade-off between functionality and simplicity for installation (and configuration). Based on the experience from Upgrid field installations the measurement of voltages on individual LV groups (to determine blown fuse and complement current criteria for loss of power) would not be possible.
- A single fuse unit for powering and measurement of LV three phase busbar voltage, with a single pre-defined connection point on the RTU.
- Snap-on current transformers or Rogowski coil current sensors wrapped around the individual phases of each outgoing LV group.
- Re-use of meter concentrator GPRS communication

Within Upgrid two equipment solutions attempted to optimise the installation effort; namely Schneider Electric by use of wireless LV sensors and GE through Rogowski coils connected directly to RTU, as shown in Figure 6.

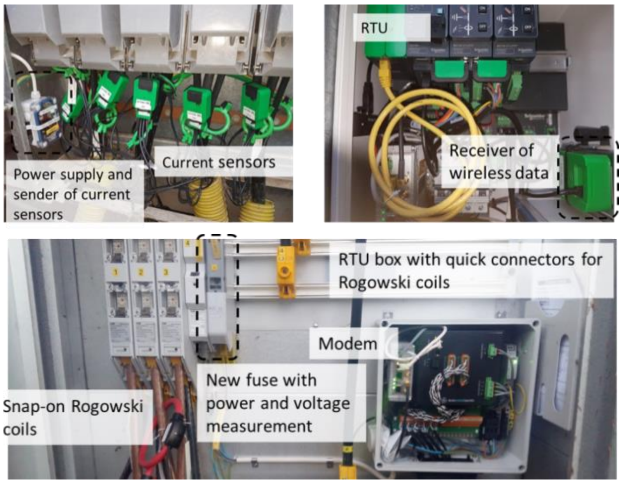

Figure 6 RTUs with wireless LV sensors and snap-on Rogowski coils

Line sensors

Similar requirements apply for the line sensors mounted directly on the overhead line. A base station is mounted on an adjacent pole and communicates with radio to the line sensors. The line sensors were applied with live line work to minimise the outage time, see Figure 7.

Figure 7 Mounting of line sensors

The cost of installation was considerably lower in locations with a nearby secondary substation that could power the base station. In future finding such cheap installation locations may be more important than optimising placement from a network perspective.

SYSTEM IMPLEMENTATIONS

LV monitoring application

This LV monitoring application from Schneider Electric is built on top of the MDM. It compares meter and substation measurements. Together with the possibility to detect abnormal losses, meters associated with wrong feeders, overloads and unbalances, a complete diagnosis of secondary substations is performed.

Meter events related to power quality issues (voltage sag, swell, overcurrent, etc.) are also planned to be added into the LV monitoring application in order to be analysed along secondary substation measurements. Several analyses will be performed:

- Indication of which substations present more power quality issues, regarding the reported meter events.
- Indication of which meters present more power quality issues, and statistics about them (e.g. time that the customers have been without power).

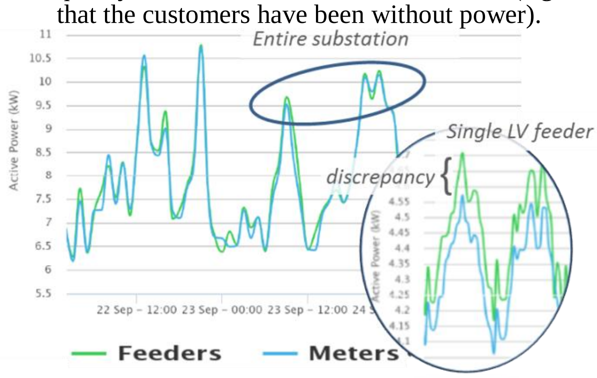

Figure 8 Comparison of aggregated end-user meter values and secondary substation measurements

- Presentation of events along secondary substation measurements. For instance, a chart representing the amount of sag/swell events that are reported against the measured voltage profiles. The objective is to analyse the effect of the voltage in the secondary substation in producing sag/swell meter events.

SCADA with LV Network Management System

The GE LV NMS system brings together information from the Metering System, from the LV SCADA indications, and from the MV DMS system. This is dynamically presented using alarms, events and indications on the diagram, as well as historical longer term storage of data. This information is provided to the operator for decision support in network operation and the analysis and location of faults and outages.

A geographic view of the LV network topology, including a background map, is presented to the operator. In the Upgrid project the LV network model is exported from the NIS as a standardised CIM file according to IEC 61970/61968. The file is imported with electrical connections, asset information and references to meter IDs. The LV network for an area is imported and applied as a patch, in effect imported in the same manner as an extension of the network would be. After the import, the LV network is displayed on the geographical map as shown in Figure 9.

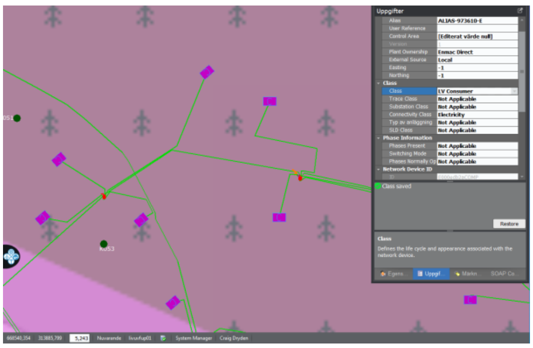

Figure 9 LV network from NIS in NMS, showing 0.4 kV cables between customers and street cabinets

The network is modelled from the secondary substations down to the LV customer supply points which are linked to the meters. The secondary substations provide the integration points between the MV DMS and the LV DMS, allowing dynamic state changes to be passed from the MV DMS to the LV DMS.

An interface between the LV Network Management System and the Metering system, allows the operator to make meter ping requests and for the most recent ping results to be presented on the LV diagram. Critical meter events are presented to the operator in near real-time, in a similar way to SCADA events being presented on HV and MV DMS systems. Critical and non-critical meter events are recorded and can be requested and presented for background analysis.

LV SCADA measurements are recorded and presented within the operator diagram, generating alarms and events where applicable. A history of these is recorded for analysis. Measurements are also passed to other LV and MV systems, using ICCP protocol.

Network Information System with LV DMS

The NIS from Powel contains analytic functionality to perform historical load flow calculations based on hourly meter values as shown in Figure 10. For this purpose an integration is set up to retrieve meter readings (load) directly from the meter database.

Figure 10 LV Load flow calculation in NIS showing calculated hourly flow

The electric calculations provide both the operators and network planners with an understanding of the power fluctuations over a long time interval, which is especially valuable for LV and MV lines and cables without any direct measurement.

Metering event Dashboards

The amount of meter events at Vattenfall is overwhelming and calculated in the millions, or even tens of millions when looking over time. Therefore a monitoring dashboard was established for both reporting and operational and historical visualisation. By utilising network information, outages reports and meter events the state of network can be determined. Further functionality allows to filter, correlate and aggregate information. Envisioned is also the use of this information for power quality investigations following customer complaints.

LV DMS

The NIS provider also delivers a DMS system that receives on/off status from the MV SCADA and can display the networks dynamic state in both geographical and schematic views, with full access to NIS data.

Conclusions

By exchanging information between metering, network management and network information systems the observability of the low and medium voltage networks can be greatly increased in the respective systems. This in turn has a large potential to decrease outage duration (SAIDI) for customers, providing improvements possibly comparable even to those from more expensive measures like the wide-scale cablification of overhead lines.

Valuable decision support for network planners and optimisers is also obtained by providing secondary substation measurements and metering events in dashboards and monitoring applications with advanced filtering and data analytics techniques. However, the vast increase in data means that LV monitoring must be accompanied by rethinking of how incoming data is handled, filtered and shown to operators.

In some cases, end-customer meter events and aggregated measurements were shown to provide valuable and complementary information. It cannot be excluded that further reduction in delay in receiving meter data, together with advances in utilising metering system events, can mitigate needs for secondary substation installations. Thus, careful analysis is required to prioritise what information is gathered in which locations, so as to minimise the overall investment to obtain a desired gain in low and medium voltage observability.

Finally, practical experiences from 18 multi-vendor field installation of various monitoring equipment, along two medium voltage lines, showed that a cost-efficient roll-out requires as much consideration of practical installation issues as attention to equipment functionality and cost.

REFERENCES

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2] U. Ysberg, 2016, "dD2.4-Demo2-Demonstration activities and results", available at www.grid4eu.eu