LV GRID DATA ANALYSIS DEMONSTRATED AT DSO ARBON ENERGIE

Ingo HERBST
Siemens – Switzerland
Ingo.Herbst@siemens.com

S.LUKOVIC & A.GASPARIN
USI – Switzerland
Slobodan.Lukovic@usi.ch
Alberto.Gasparin@usi.ch

N.SCHULZ & J.WITZIG
FHNW – Switzerland
Nicola.Schulz@fhnw.ch
Jens.Witzig@fhnw.ch

Silvan KIEBER
Arbon Energie – Switzerland
Silvan.Kieber
@arbonenergie.ch

ABSTRACT

With today's renewables integration and market deregulation low voltage (LV) grid operation becomes challenging, requiring much better transparency of the system. We present a powerful LV data management system enabling data analysis like network power flow, consumption prediction or new prosumer business case calculations. Tools support data validation, correct correlation and easy access. Voltage measurements are compared to calculations based on smart meter load data

INTRODUCTION

In Switzerland the roll out of smart metering has been decided – until end 2027 80% of all end user nodes need to be metered by smart meters (SM). This puts up the request for heavy investments.
In our paper we want to address use cases other than the meter-to-cash process, that can be accomplished through the use of SM data and that will both improve the operation of the LV network and reduce maintenance costs.

PILOT DEMONSTRATOR ARBON

The DSO Arbon Energie has performed a 100% SM roll out during the years 2008-2013 and is operating the SM-systems AMIS (Automated Meter Information System, Siemens) since then to full satisfaction (approx. 10'000 SM). The replacement of an old ripple control by AMIS has been done and an optimized load management (using >1'500 AMIS load switches) has resulted in improved load flow. So Arbon (and neighbouring communities using the same SM control) is "100% smart" already today. Also a GIS database is available that contains data of all power lines from the transformer stations (TS) to the end customers.

With this experience Arbon is an ideal candidate to study additional use cases based on SM data. It is for that reason, that Arbon was selected as one of two demonstrator projects in the Swiss national SCCER FURIES project framework [1], [2]. Arbon as a typical Swiss DSO also serves as a good benchmark for our lowest cost SW solution based on open source SW components.

Our project aims at using the available 15' SM load data complemented by additional measurements:

- Power Quality (PQ) data taken at the 50 TS with dedicated PQ devices
- Synchronized Power SnapShot (PSS, [3]) data taken by the AMIS SM system.

STATE OF THE ART

Grid monitoring and observability has attracted increased attention in recent years thanks to digitalization trends supported by proliferation of smart meters, power quality measuring devices as well as improved communication and IT structures. On the other hand, tremendous amounts of collected data require advanced computing infrastructures. To improve data analysis and accelerate queries authors in [4] propose DGFIndex, an index structure for Apache Hive that efficiently supports multidimensional range queries for massive meter data and extends. Hive, a warehouse-like tool built on top of Hadoop provides users with an SQL-like query language. To enable big data analytics the authors in [5] propose an innovative ICT-solution to streamline smart meter data analytics. The proposed solution offers an information integration pipeline for ingesting data from smart meters, a scalable platform for processing and mining big data sets, and a web portal for visualizing analytics results.
Swiss ETHZ spin-off company Adaptricity has developed a data-driven solution for monitoring, asset management and grid planning also used for decentralized load management in several projects [6].

DATA MANAGEMENT SYSTEM

As a first step towards LV data analysis and visualization we have built a data management system for injection, normalization and storing of provided measurements as well as asset related information. Heterogeneous data sources have been standardized and consolidated to enable efficient utilization of relevant grid information. Static data of the geographic information system (GIS) are coupled and correlated with dynamic ones (SM and PQ measurements) to obtain a holistic view of the grid. The unstructured data are stored in an open-source non-SQL database (see Fig. 1). The solution enables standardized access to the grid data for various "services" that can be used by third parties. The entire system is encapsulated in three layers: Input-output interface; data validation and database status management.

In essence the solution allows:

- Data collection and normalization
- Input data validation (SM vs. PQ data)
- Data storage of unstructured data in the open-source database (MongoDB) and appropriate database management structures
- Data analysis based services for third parties

The implemented solution is fully scalable with large data amounts, it is portable to other data types and provides very fast data access, querying as well as basic analytics.

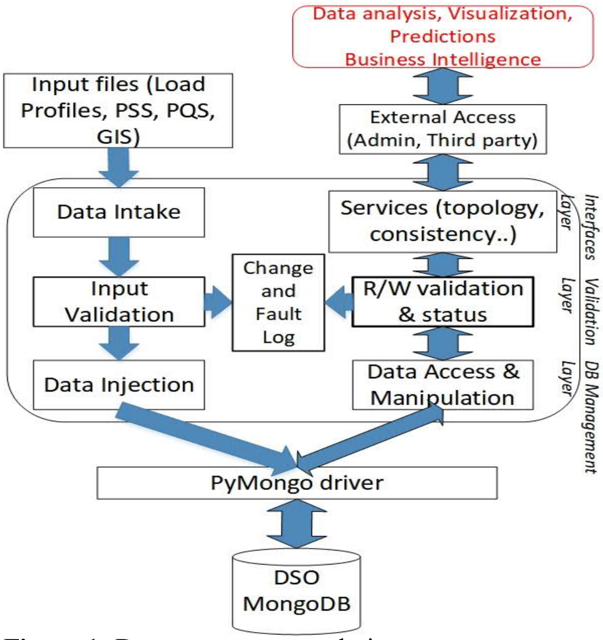

Figure 1: Data management solution

Static Data in DB

The static data contain objects representing nodes and cables with the following attributes:

node location, associated SM, node type (TS, cable cabinet, building), ObjectIDs of connected lines

line technology code, cross-section, location of end and waypoints, information for each line end if the switch is open or closed, ObjectID of the nodes connected to the end points

From the static data a correct graph of the electric network of each transformer station can be generated.

Dynamic Data in DB

The dynamic data contain all available measurements. The load profiles are stored per day (96 quarterly hour values) and per smart meter. The power quality data measured at the TS contain, among other variables, the average voltage in 10min-measurement intervals stored per day and device.

On top of this architecture, a number of advanced services such as power flow analysis and useful visualization are provided and presented here. Future options like load and generation prediction, optimized battery management as well as business intelligence features are enabled.

DATA CONSOLIDATION

The initial state of this project was that each SM is associated to a mailing address in the so-called meter to cash system. These data are used to send the electricity bill to the customer. For an advanced data analysis with focus to the grid, the meters have to be associated directly to an exact position in the energy distribution network.
For maintenance, the cables and electric connection points (TS, cable cabinets, house connection boxes) are represented with their exact location in the geographic information system (GIS). The cables and electric connection points correspond to edges and nodes in a mathematical graph.
The distribution system operator (DSO) adds the meters in a laborious and fault-prone process to the GIS system.
In order to receive meaningful results from the load-flow calculation, it is indispensable that all feed-in and consumption at each point of the grid is known. Every missing meter on the graph represents a deviation of this assumption and contributes to a possible inaccuracy of the results. Therefore data are consolidated in a top down sequence on different grid levels (LE):

- global substation level, medium voltage (MV) (LE4)
- macro transformer station level, LV or MV (LE6)
- micro building level, LV (LE7)

After this initial data consolidation process we can assume that all feed-in and consumption in the grid is known and correctly positioned in the network.

Consolidation on the global level (substation)

For the entire grid operated by the DSO the sum of all 10’000 load profiles is compared to the total consumption measured. The difference should represent the sum of transfer losses in the distribution system (Fig. 2). This should be roughly constant over time and systematic variations in time point to data inconsistencies.

Consolidation on the macro level (TS)

The grid below each TS is consolidated in three steps:

1. Analysis of the difference between the sum of all loads and the total consumption of this TS (Fig. 3): losses should be roughly constant.
2. Check if all smart meters that send load profile data are connected to the TS in the GIS.
3. Visual inspection on the map, information of GIS is plotted in parallel with meters that are not included in GIS but are known by mailing address via the meter to cash process (Fig. 4).

Consolidation on the micro level (building)

The 2’400 buildings are consolidated as follows:

- The quarterly hour metered energy, in the daily transferred load profile, is summed up and compared to the daily energy count that is transferred separately.
- Cascaded SM are installed for special customer groups such as self-consumption communities and photovoltaic prosumers. Also multi-family-houses frequently have this situation. The occurrence of such cascaded smart meters is detected by analyzing if load profiles in the same building are correlated. Such smart meter data need to be removed from the sample.

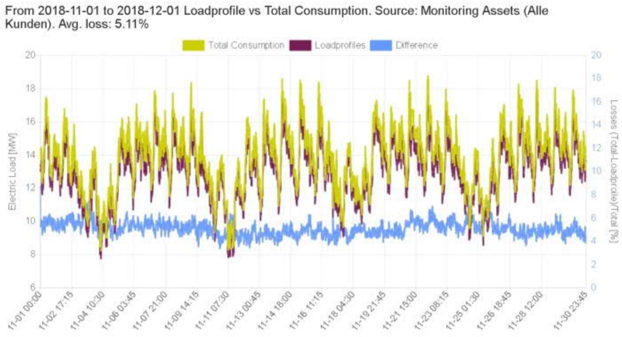

Figure 2: Total consumption entire city, 1-30 Nov 2018
Yellow: P[MW] measured at the substation
Magenta: sum of all 10'000 load profiles
Blue: LV&MV network losses in %, right scale, av. 5.1%

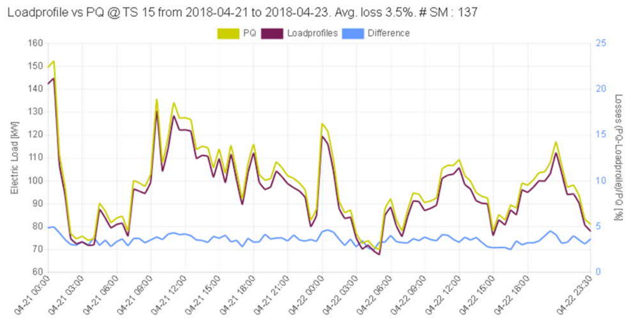

Figure 3: TS15, 21-23 April 2018 – power balance
Yellow: P[kW] measured by PQ device,
Magenta: sum of all load profiles of this sub grid,
Blue: network losses in %, right scale, average 3.5%

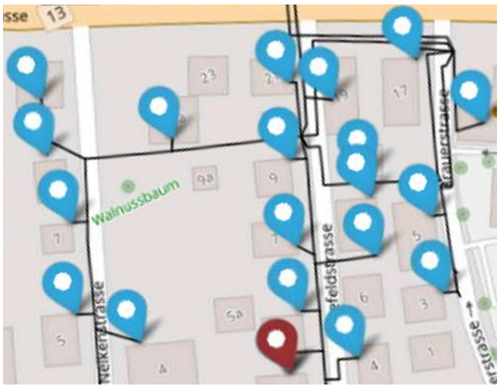

Figure 4: TS44 – grid data on OpenStreetMap
Blue: smart meter positions from GIS
Red: smart meter not in GIS but in load data sample used for the meter to cash process

LOAD FLOW CALCULATION

The major goal in this project is to investigate the location and occurrence of violations of voltage limits and furthermore the detection of overloaded lines.
It is obvious for cost reasons that the installation of additional measurement equipment all over the grid is no feasible solution. Instead of such direct measurements we use the load flow calculation based on load profiles from smart meters and the voltage measured at the TS captured by a power quality device.

The power flow calculation is performed by a software engine written in Python. The core of the engine is the open-source tool pandapower, which is a network calculation program based on the data analysis library pandas and the power flow solver PYPOWER [7].
The data streams needed for the calculation are stored in the DB and structured in static and dynamic data as described in the paragraph "Data Management System".

Taking the voltage measured by PQ at the TS we calculate the voltage at all nodes and store these voltages in the DB for further display in different analysis plots – on a map with color coded topology (Fig. 5) or along a line (Fig. 6).
One can nicely see the effect of photovoltaic infeed on the voltage during day (increase) and night (usual voltage drop in the morning).

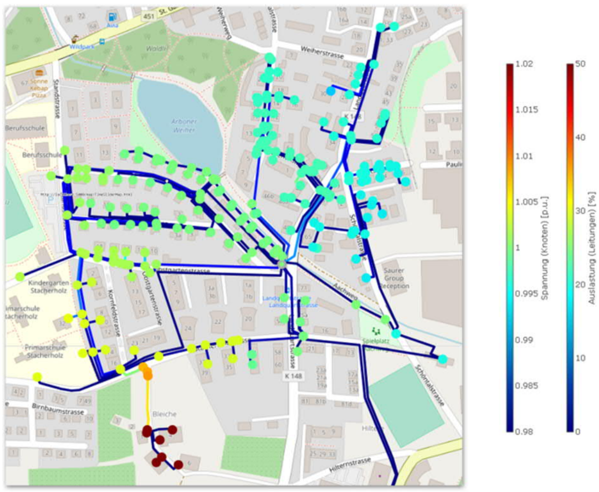

Figure 5: Load flow presentation TS 1
Nodes: Color coded voltage with respect to TS
Brown nodes due to PV voltage increase
Lines: Color coded loads with respect to cable design

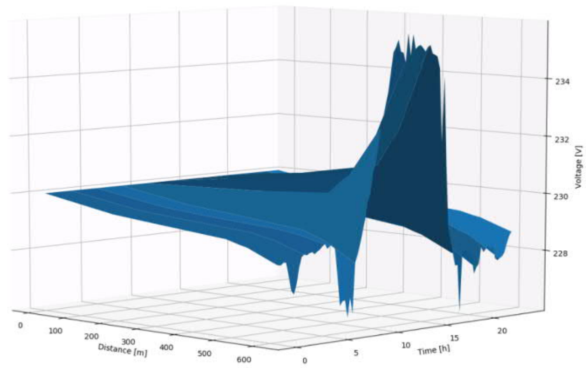

Figure 6: Load flow calculation voltage along a line to a PV installation 600m away from the transformer station

Workflow of load flow calculations

The following main steps are supported by the SW:

- Build the topology from static data
- Add dynamic data to the topology
  - load profile data
  - voltage measurements at the TS
- Perform the load flow calculation
- Store results per node and cable in the DB

ANALYSIS OF RESULTS

The accuracy of the load flow calculation is dependent on the completeness of all loads in the grid and the correctness of the grid impedance, given by cable parameters and topology.

In order to validate our method we compare the load flow calculation results with measurements. For this we use the Siemens smart grid option called "Power SnapShot" (PSS) that uses smart meter measured voltages without installing additional hardware (Fig.7). For reason of data consistency we use only PSS for voltage measurements.

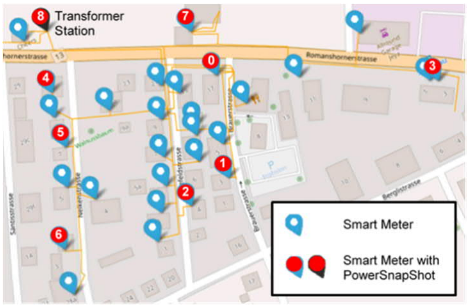

Figure 7: Low voltage grid of transformer station 44
The selected SM with PSS functionality are shown

This option PSS enables triggered SM measurements synchronized to within 1s. We use the 10' mean voltage and the momentary voltage at trigger time to be compared with the load flow calculation for our analysis.

Figures 8-10 show first results on TS 44 as an example:

- The statistical distribution of the deviation between load flow calculations and measured 10min mean absolute voltages (Fig. 8, data 15th December 2018)
- The voltage difference between a node in the grid and the TS. The voltage drops are compared in time sequence and scatter (Fig. 9, same data as Fig. 8).
- The statistical distribution of deviations between voltage drops derived from load flow calculations and measured 10min mean voltages (Fig. 10, same data).

For the voltage drop measurement we use the difference of PSS SM at the specific node and at the TS 44 (node 8). When we subtract from this measurement the calculated voltage drop at the specific node we get the difference μ[mV] with the 1 sigma error σ[mV] around 280mV. The required up-sampling from 10' (PSS) to 15' (load flow calculation) leads to a systematic error of node 8 (Fig. 8).

From the measurements at node 0 to 7 we deduce a statistical measurement error of a single SM voltage measurement at approx. 200mV (σ=280mV/√2).

The systematic measurement error of the SM is at least 200mV. Additional systematic errors can be attributed to inconsistencies of GIS data (incorrect cable material or cable parameters). For this reason our voltage drop measurements and calculations are consistent within the given statistical and systematic errors. Further analysis on more data samples is needed to present detailed error estimates extending the results presented in Fig. 10.

Figure 9 also shows peak voltage drops in green. These data stem from triggered events (min and max voltages at a dedicated "trigger SM"). These extreme values show a higher spread still consistent with the 10' av. calculations.

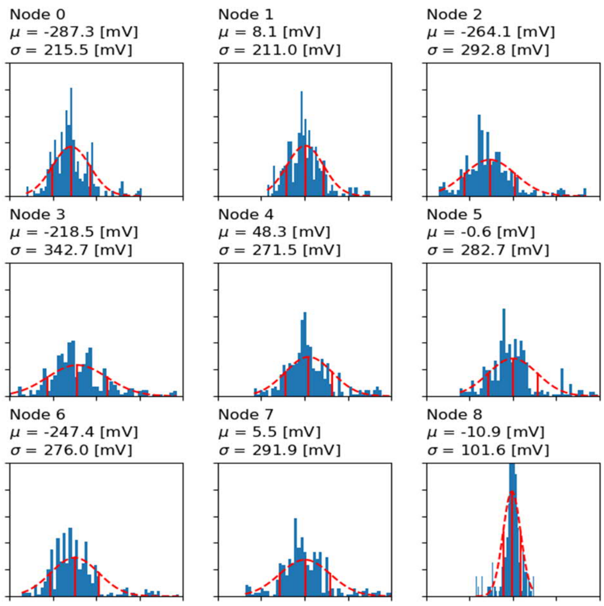

Figure 8: Differences between the measured and calculated absolute voltages for each node, the Gaussian fit is plotted with additional markers for μ and σ (red)

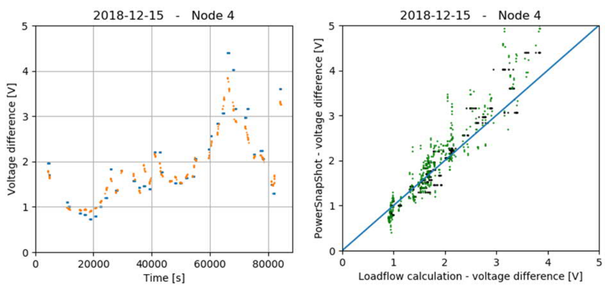

Figure 9: Voltage drop between node 4 and the TS

Left: Time sequence one day
Blue: PSS measurement, 10' average voltage
Orange: load flow calculation

Right: Scatter plot measured vs. calculated voltage drop
Black: 10min average measured voltage PSS
Green: min/max-triggered measured voltages PSS
Ideal correlation indicated by the blue line

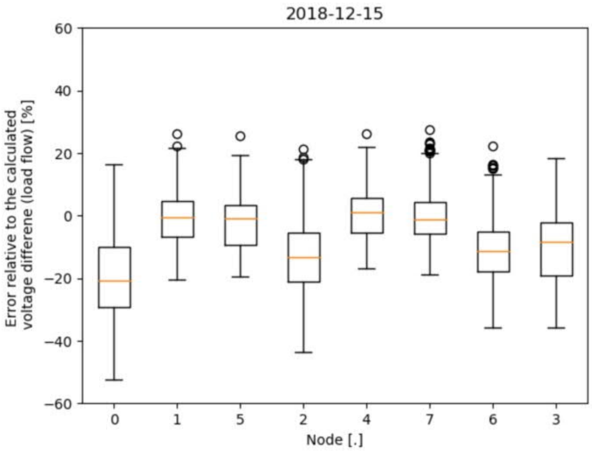

Figure 10: Box plot for the deviation of measured versus calculated voltage drop in the LV network with nodes sorted by distance to the TS (150m/n0 to 450m/n3)

SUMMARY AND CONCLUSIONS

In our SCCER Arbon demonstrator project we study additional use cases based on smart meter data:

- A SCADA type of application reported in this paper to visualize the system status (voltage at the nodes, load on the lines, load on the distribution transformer, losses in the grid).
- Estimation and reduction of no-load-losses at distribution transformers reported earlier [8].
- Estimation of the introduction of new prosumers to the grid – based on measured real load. Such a detailed analysis reveals cost reduction potential as a network upgrade can be postponed if actual loads are below safely assumed values.

The voltage increase due to PV installations visible in Fig. 5&6 highlights the strength of such visualization to point towards interesting network elements. Given this transparency one can optimize the network if needed.

We believe that such use cases are so valuable, that we recommend a smart meter roll out following the following guideline:

- SM rollout per TS. Get 100% of all load below a transformer equipped with smart meters. This will also improve the PLC-communication of the SM to the central unit and ease the commissioning phase.
- Validate in parallel GIS-data and EDM-data during SM roll out with a workflow utilized by the DSO. This will give immediate benefit concerning transparency of the TS being equipped and will save time of data clarification.

In this paper we have evaluated measured voltages at various nodes in the LV network to estimate the voltage drop in the LV network. We also compared these to pure estimations based on 15’ SM load data. We have shown that the computed values are close to the measured values after proper validation of GIS and SM data.

This means, that for practical use one can rely on load data if sufficient work has been dedicated to a proper GIS database (correct topology) and SM data (all SM attached to the network, no double counting).

As a next step we will extend the measurements to more TS to get an even better grip on systematic data handling, i.e. missing data. Also the most interesting use case of network analysis for the introduction of new prosumer will be implemented to best accommodate daily DSO work with our cost effective solution based on open source SW. These steps will allow a cost/benefit calculation needed to convince DSO’s of our proposal.

ACKNOWLEDGEMENTS

This project 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 support of the Swiss Innovation Agency (Innosuisse - SCCER program).

REFERENCES

[1] I.Herbst, 2017, "Arbon Demonstrator, Digitalization beyond smart metering”, *SCCER FURIES annual conference, Lausanne, Nov. 2nd, 2017.* https://sccer-furies.epfl.ch/files/content/sites/sccerfuries/files/Document/2017_Annual_Conference/23_Herbst_Arbon-Demo.pdf

[2] S.Lukovic et al., 2018, "Arbon Demonstrator Eye-on-the-grid, from concept to Results”, *SCCER FURIES annual conference, Lausanne, Oct. 22, 2018, poster presentation* https://sccer-furies.epfl.ch/files/content/sites/sccerfuries/files/Picture/Arbon-demo-FURIES-Annual-meeting.pdf

[3] A.Abart et al., 2011, "Power Snapshot Analysis: a new method for analysing low voltage grids using a smart metering system”, *CIRED 2011, 21st International Conference on Electricity Distribution, Frankfurt,* Paper 1083.

[4] X.Liu, P.S.Nielsen, "A hybrid ICT-solution for smart meter data analytics", *Elsevier,* Energy Vol. 115 (2016) 1710e1722

[5] Y.Liu, S.Hu, T.Rabl, W.Liu, H.Jacobsen, K.Wu, J.Chen, J.Li,"DGFIndex for Smart Grid: Enhancing Hive with a CostEffective Multidimensional Range Index", *Proceedings of the 40th International Conference on Very Large Databases, VLDB Endowment,* Vol. 7, No. 13

[6] N.Stocker, F.Toffanin, A.Ulbig, “Results of the Sologrid Pilot Project - Decentralized Load Management to Increase the Efficiency of Local Energy Communities”, *CIRED 2018*

[7] Pandapower: https://www.pandapower.org/

[8] S. Zehnder, D. Buff, “Leerlauf vermeiden“, *Bulletin VSE*, 6/2018, pp. 35-38