Analysis Environment for Low Voltage Networks

Analysis of LV Network Model Parameters by Smart Meter Measurements

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***Abstract*—Making the best use of low voltage networks will play an important role the in future, because of the increase of photovoltaic and electric vehicles connected to the households. For better understanding and modeling of low voltage networks, the Power Snap Shot method has been developed. This work describes the principles of the information and communication system to automatically manage the measurement data and analyze the grid models by means of automated load flow simulation.**

Keywords-component; smart grid, smart meters, simulation, low voltage grids, integration of distributed generation.

I. Nomenclature

DC: Data Concentrator

GIS: Graphical Information System

PSS: Power Snap Shot

PSSA: Power Snap Shot Analysis

PSSH: Power Snap Shot Host

LV: Low Voltage

PV: Photovolatic

EV: Electric Vehicle

CIM: Common Information Model

PF: DIgSILENT/Power Factory

II. Introduction

About 70% of the voltage band available in existing low voltage grids is typically allocated to the voltage drop at maximum load. This means that distribution grids are not designed for a high penetration of distributed energy resources (DER) such as PV systems. The assessment methods for planning the interconnection to the grid are based on worst-case assumptions due to the lack of detailed knowledge. Conservative scaling factors (e.g. 100% generation and 0% load) must be used in planning in order to ensure the compliance with the operational limits. Moreover, single phase components are usually considered in the interconnection assessment [1] by using the six fold power in order to take the voltage drop in the neutral into account. In order to be able to investigate impacts of DER on low voltage grids and to suggest suitable solutions to the voltage rise problem, a funded knowledge is needed.

In the project ISOLVES:PSSA-M, a method has been developed to capture a time-synchronous image of all node-characteristics of the grid, the so-called "Power Snap Shot Analysis by Meters" (PSSA-M). The basic principle is to record at each meter simultaneously 900 measurement values (1-second-rms P, Q, U). After this recording period, a selected set of meters (10% - 30% of all the meters) sends proposed trigger indices (between 1 and 900) according to well defined criteria like maximum or minimum voltage levels to the system control (data concentrator DC) unit at the transformer station. The most representative indices are selected by applying a special ordering algorithm. The result of the trigger selections is broadcasted to all meters which are responding by transmitting the corresponding measurement values. The result is a set of synchronous measurements for several different interesting instants: so-called Power Snap Shots [2].

In this work the simulation and result of the first Power Snap Shots for one network model will be presented. The objectives are to study LV grids in detail and to close gaps of important knowledge about the real impact of asymmetric load or feed and of grounding on voltage profiles. A significant number of LV feeders (about 100) are under investigation and modeled as 3 phase / 4 wire models. The records of the data will be evenly distributed over the weekdays and non-weekdays for a longer time range to get representative data. This results in several 100.000 Snap Shots which are grouped in single campaigns.

The analyzing process is done by automated load flow simulation using four wires grid model including grounding. The measurement data of all active and reactive power is fed into the simulation in order to calculate the voltages of the nodes. The differences between calculated and measured voltages will allow developing realistic and accurate grid models, to learn about given uncertainties and to identify the main influencing factors. The main expected source of inaccuracy is the modeling of the grounding for which experience and data is missing.

These resulting grid models together with a representative load and generation data are prepared to be used in large numeric case studies. Therefore grid models and load data are stored in a database which can be directly addressed by a simulation tool (script-based automated load flow). The power system simulation (DIgSILENT/PowerFactory [3]) is remotely controlled via software interfaces and runs in engine mode to simulate the network models.

In the future this method shall be useful for analyzing the performance of smart grid systems in operation and to allow a better planning of distribution networks. The developed grid models and measured loads can be used to simulate future scenarios with high penetration of PV-Systems or e-vehicles including single phase or three phase components. Further developments shall provide useful applications and tools to operate and manage smart low voltage grids (e.g. identification of critical voltage conditions and fault localization) [4].

III. Related Work

The few studies dealing with the impact of distributed energy resources on LV networks (e.g. [5]) are usually based on restrictive assumptions due to the lack of information on load and generation profiles and asymmetry. Modeling and simulation of low voltage distribution networks in three phase / four wire representation based on synchronized measurement data has not been carried out before on this scale. The impact of EV and PV or other asymmetric load or feed has not been studied on basis of measured data neither on real grounding values, because these are not known in detail.

IV. Conceptual System Architecture

The main parts of the PSSA architecture shown in Figure 1 consist of the Siemens AMIS metering system, the network data model (coming from GIS), the database backend and the PSS Analyzer, the application which is a synonym used for the PSS Host. The PQ Guard in this illustration is basically a histogram functionality of the classified mean values of the voltage over a period of time. This characterization data will also play an important role in future network planning [5].

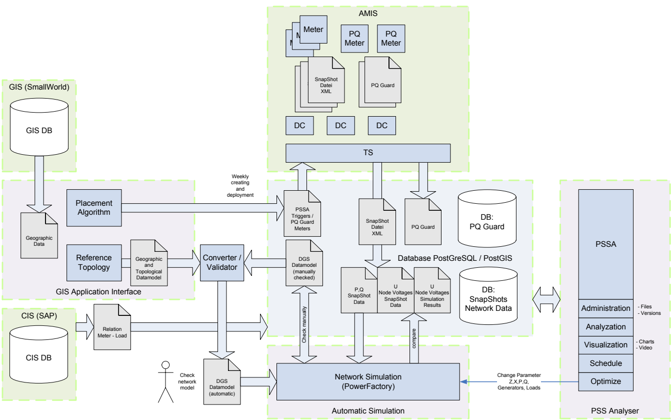

Figure 1. Conceptual architecture of the PSSA system

V. Metering System

A. *Automated Metering Infrastructure*

Based on the existing automated metering infrastructure AMIS from Siemens, the meter firmware functionality has been adapted to implement the PSSA method. The existing communication infrastructure is used for exchanging the PSS specific data.

1) *Smart meter*

A part of the available bandwidth for the metering service is available for the PSS service. Since the priority is low, the delay times for communicating the triggers and measurement are quite high. For the correct assignment of the measurement data to the loads in the network model, the right phase assignment must be known. In the real world, the phase information is not available at the customer premises. For this reason, a methodology for phase detection has been developed and successfully implemented.

2) *Data concentrator*

The data concentrator is responsible for managing the trigger and polling the measurement data. According to an algorithm for performing equal measurement cycles over the day the DC leads these campaigns for both weekdays and non-weekdays.

3) *Transaction server*

The TS is used only to poll the data from the participating DCs and transfers them to the PSSH. To keep the amount of data as small as possible, the PSS files are sent compressed and transferred uncompressed to the PSSH. Future considerations will include a web service based interface for providing the measurement data for integration into enterprise service architecture (ESB) according to IEC 61968 (CIM) [6].

B. *Power Snap Shot method*

1) *PSS sequence*

The following flow of information is used for exchanging the measurement data:

(1) Synchronizing of all meters: Accuracy requirement for the synchronized one second rms values is about 100 ms, which is easily met by the system.

(2) Starting of the measurement interval by broadcasting it to all meters in an instant.

(3) Synchronized measurement interval for 900 seconds.

(4) Collecting the proposed trigger indices from the meters which have been configured as trigger meters. The trigger meters have to be polled to return their trigger proposition.

(5) Alternatively the proposed triggers can be sent to the PSSH for external evaluation and selection according to other objectives (e.g. manually).

(6) Broadcasting the selected triggers, which have been selected according to the specific evaluation process,

e.g. based on their statistical frequency. After the internal storing of the selected measurement data, the meter is capable of starting a new measuring interval.

(7) Polling of all measurement data regarding to the selected triggers (timestamps). This is done by addressing every meter and transferring the data.

(8) Providing the measurement data to the transaction server (TS) which transfers them to the PSS Host. The transaction server pulls the data from the various DCs in the substations and transfers them to the PSSH via email or file transfer.

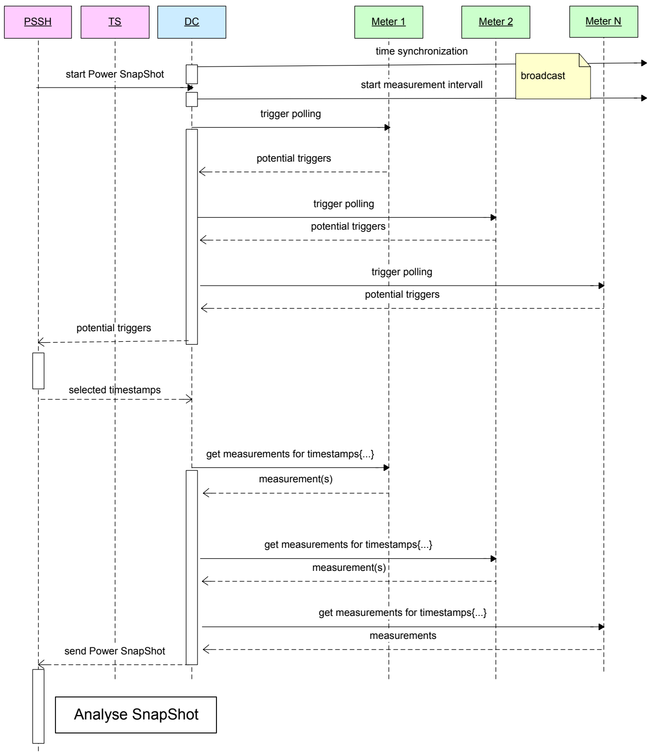

Figure 2. Sequence diagram for the PSS method with alternative path for selecting the trigger timestamp by the PSSH

2) *PSS format*

The data format of the PSS is based on XML (Figure 3). It consists of the message header and payload (chosen in respect to the Basic Message Structure of the CIM XML format).

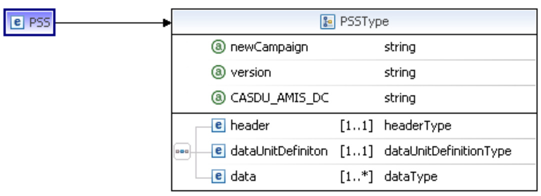

Figure 3. Schema for the PSS format, including header, data and the data unit definitions

VI. Analysis and Simulation Framework

A. *GIS*

Normally the utility has no data of the low voltage network directly usable for power system analysis. But mostly utilities manage the data in a GIS, which is the also the case in this project. It is planned to automatically trace the topology from the GIS and export it to a format which can be imported into the used network simulation application DIgSILENT/PowerFactory. The standardized format of the Common Distribution Power System Model (CDPSM) [6] is planned to work as the intermediate open and interoperable exchange interface format in future between GIS and PF.

B. *Visualization*

For presentation and exploration purpose, a small, fictive and simplified LV network model (Figure 4 “smarty grid”) has been created to visualize the network voltages and power flows. PV systems are depicted as suns, EV as cars and farms are in green/brown. This model is also used for illustration and visualization in various publications and an animation [2], [7].

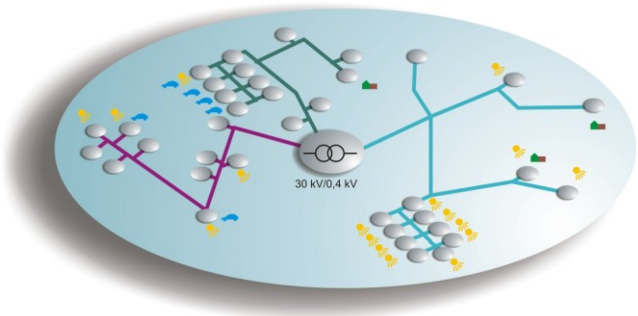

Figure 4. The "Smarty Grid": A simplified LV network for exploration of simulation results and demonstration purposes.

1) *Data*

For about 30 households, detailed measurements of active and reactive power for every phase have been recorded for a period of two weeks and a time scale of one second. This was done in the project (ADRES [8]).

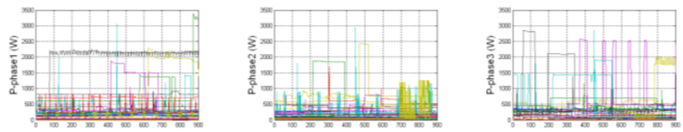

Figure 5. Power per phase at the network nodes for 15 minutes (1 second rms)

2) *Simulation*

Loads and PV are assigned according to this real measurement data at one second time scale for a whole day. The results of the power flow are used to visualize the data graphically according to chosen color scheme for the power flow and the voltage level.

The outcome of the graphical visualization has also been used for producing an animation to explain the principle of the Power Snap Shot Analysis to a broader audience [9].

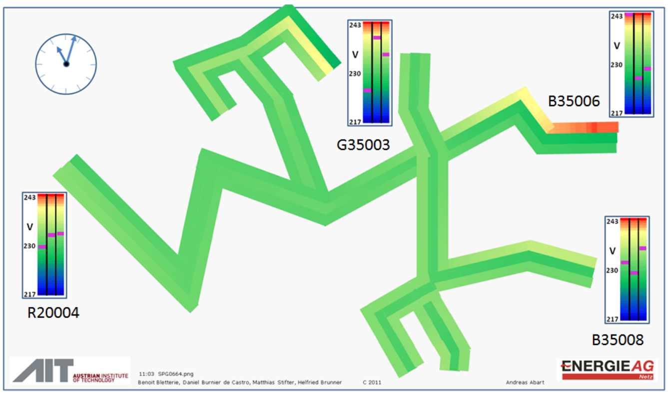

Figure 6. Animation of the voltage temperature map for a LV network ("Smarty Grid") based on real measurement data.

Figure 7. Sequence of the animation of the power flow at the three phases for the "Smarty Grid".

Figure 8. Sequence of the animation for the voltage levels of the three phases for the "Smarty Grid".

C. *PSS Analyzer / Host*

The PSSA has the task to provide the data files with the active power (P) and reactive power (Q) for the network simulation. The task of the PSS Host includes the following:

- Manage the PSS: Start, stop and monitor the PSS campaigns of different networks.
- Parse and prepare the PSS files for storing into the database (with correct phase referencing)
- Providing the data files with the active power (P) and reactive power (Q) for the network simulator.
- Start the network simulator in engine mode and remotely control the simulation (e.g. load network, time steps, export results)
- Parse the results and compare with the real voltages
- Vary the network model parameter to adjust the model to reflect the real world measurements.

Figure 9 represents a screenshot of the PSSA in action. In front the graphical analysis of the deviation between the measured and simulated data is shown.

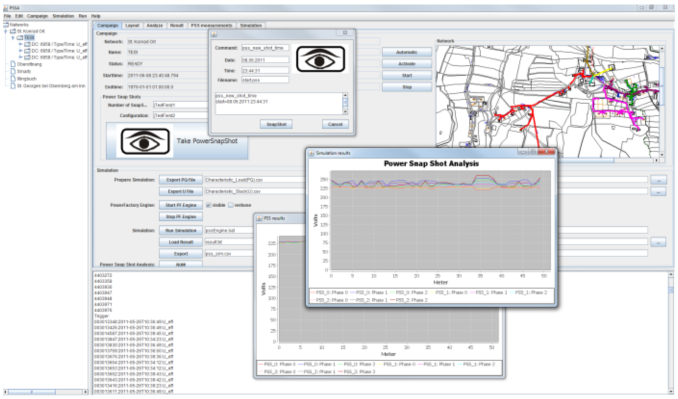

Figure 9. Screenshot of the PSSH. Analysis of the deviations between model and measurement.

D. *Network simulation*

To accurately describe the initial starting parameters for the simulation the voltage and angle of each phase at the transformer is modeled as a voltage source. This data also has to be provided by the PSSH. The loads in network model have to be configured to refer to these generated external files (called characteristics in PF). Figure 10 shows the network schema for the Smarty Grid with PV (yellow) and EV (green)

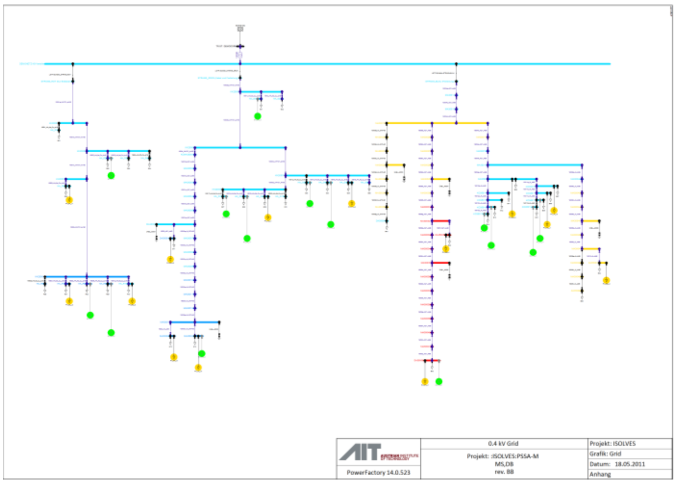

Figure 10. Network schema of "Smarty Grid". Yellow symbols depict PVs and green symbols EVs for this particular simulation scenario.

VII. Simulation Scenarios

Different load cases can be simulated based on the PSS measurement data and assumptions of PV and EV penetration.

A. *Without PV and without EV*

The first load scenario is without additional PV or EV in the network. The result of the voltage drop diagram for a single PSS depicts Figure 11.

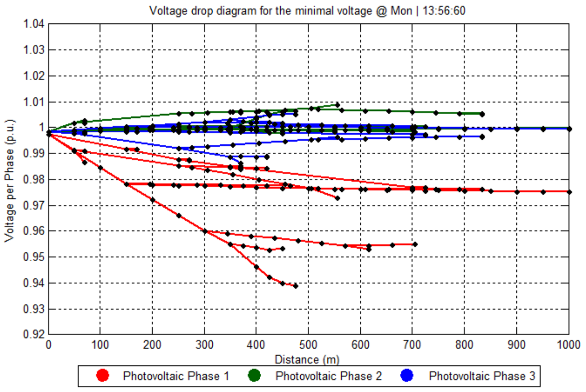

Figure 11: Scenario A. without PV and EV

B. *With PV*

This scenario includes PV distributed in the network and shows the impact on the voltage level. In this particular case illustrated in Figure 12, the allowed voltage level exceeds the limits and further actions have to be taken to integrate this share of DG in this network. Moreover, the large asymmetry between phases is visible (about 8 % at the end of the long LV feeder)

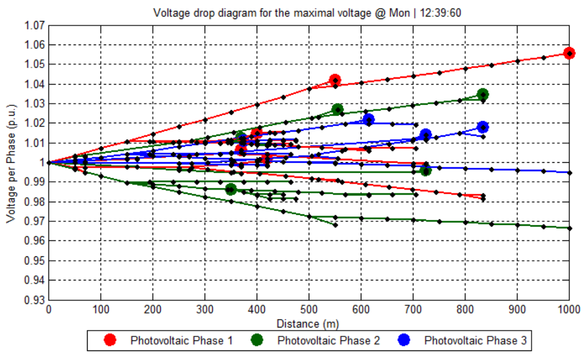

Figure 12. Scenario B. with PV

C. *With PV and EV*

If additional load due to EV is located, the voltage drop diagram in Figure 13 - as a result of the simulation - shows that the voltages at the end of the longest LV feeder is even more spread over the voltage band. This illustrates the challenges which await LV networks in case of high penetration of DG and EV in terms of voltage control and asymmetric load.

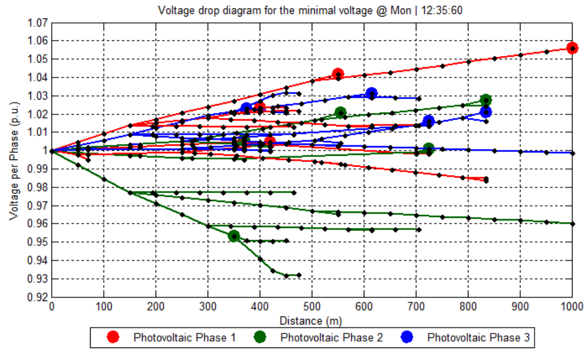

Figure 13. Scenario C. with PV and EV

VIII. First Power Snap Shot

The PSS method was implemented into the firmware and updated in the meters in the field and the first power snaps shots have been carried out to test the system. The update of the existing firmware is a tedious process, since it has to be tested thoroughly in advance before it can be released and it could take up to several days until the update of every meter is performed. The first measurements have been compared with synchronized power quality measurement device to determine the accuracy of the measurement and the influence of the power consumption of the meters on the measurement.

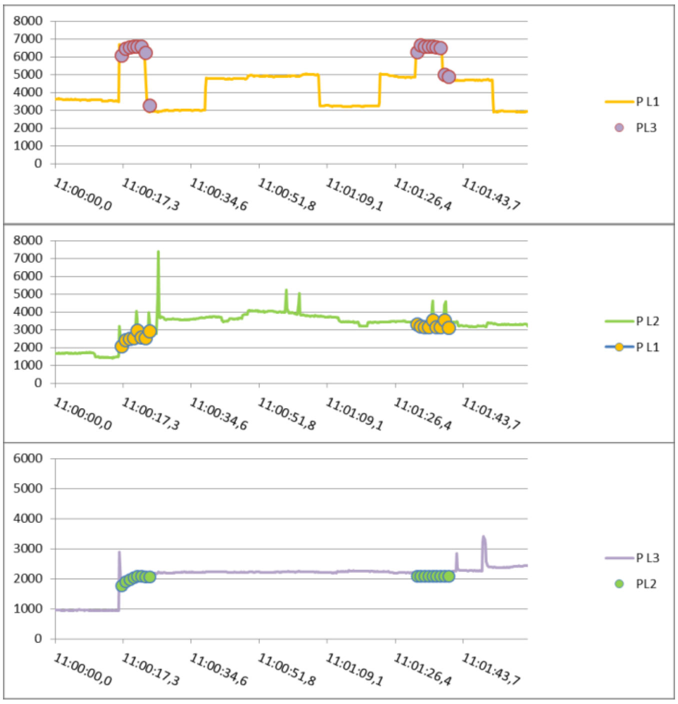

Figure 14. Comparison of the total power of the transformer measured by meters and by a power quality instrument.

The first official power snap shot has been carried out live in the LV network of “St. Konrad” during the smart grids week 2011 in Linz (Austria). Figure 15 shows the from a spreadsheet calculation application semi-automatically generated result. The load is depicted as bars at the nodes and the deviation from the secondary-voltage at the transformer (here 230V + 4%) is shown as the blue bar deviating from the +4% horizontal line. If the bar goes up this means voltage rise and if the bar goes down this means voltage drop.

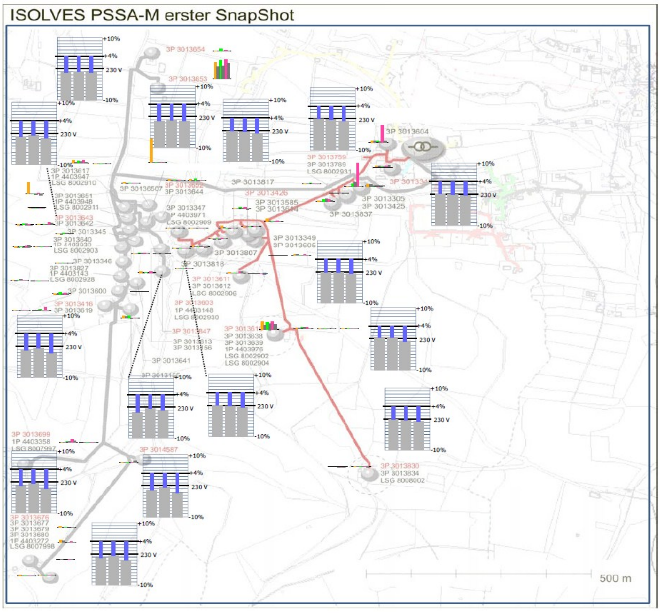

Figure 15. Result of the first power snap shot at the Smart Grids Week 2011 in Linz (Austria)

IX. Conclusion

This works shows the application of advanced smart meter functionality for the semi-automatically load flow analysis of the LV with real load data. The next step will be to carry out the PSS campaigns in up to 100 network sections to validate the three phase / four wire network models. These models are the base for developing new smart grids concepts by exact prognosis of load and generation behavior (e.g. PV and EV). The developed method and tools will allow designing and assessing smart grids controls and get a thorough insight into unexplored fields of LV networks.

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