Smart Area Aachen – State Estimation in Distribution Grids

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Abstract

Along with a rising of distributed generation capacities in distribution grids, distribution system operators (DSOs) are facing new problems and challenges. The abstract term “smart grid” incorporates different technologies and methodologies which enables DSOs to handle these new challenges. The target of the project “Smart Area Aachen” is to design, install and test these new technologies and to operate a smart grid in a local distribution grid. In order to do so the project consortium consists of partners from science as well as partners from industry. “Smart Area Aachen” is divided into different sub-projects which focus on individual aspects of future smart grids, e.g. communication infrastructure, remote controlled substations and network planning considering new equipment and infrastructure. The following paper presents the sub-project “State Estimation in Distribution Grids” which focusses on distribution system state estimation and optimal meter placement.

1 Introduction

Due to an increasing share of distributed renewable generation in distribution grids there is a rising need for grid enforcements. This need can be reduced by terms of smart grid technologies e.g. control of load, generation and voltage, but also by higher utilizing existing network structures. In order to do so the DSO requires knowledge of the actual network state, which is mostly unknown in distribution grids.

1.1 Distribution System State Estimation

In transmission grids there are real-time measurements available at each grid node for protective reasons. All these measurements are superimposed with small unknown measurement errors e.g. due to saturation of measurement transformers. A state estimation algorithm is used to calculate the most probable network state based on all available measurements.

Whereas the number of real-time measurement devices in transmission grids is very high it is rather low in distribution grids. In most of them there are only real-time measurements available in the high-voltage-to-medium-voltage substations to control the transformers tap changers and the protection relays of the medium voltage feeders. In the remaining medium voltage grid there are if at all, only little and in the low voltage network no real-time measurements at all. Therefore DSOs have to rely on a large number of pseudo-measurements to achieve observability.

Pseudo-measurements are mostly estimates for load and generation and are rather based on time series, standard load profiles or meteorological data instead of real-time measurements. Consequently their measurement error is very high compared to the one of real-time measurements, resulting in a deviation between estimated network state and real network state.

1.2 Optimal Meter Placement

If a DSO intends to utilize the estimated network state for grid operations e.g. voltage control, the deviation between estimated and real network state should be rather low. In order to keep this deviation in a tolerated range the DSO can place additional real-time measurements with small measurement errors. But as these devices are expensive their position and number should be chosen wisely which requires an algorithm for cost optimal meter placement.

2 Project Description

The (sub-)project “Smart Area Aachen - State Estimation in Distribution Grids” has the target to develop an efficient algorithm for state estimation and meter placement in distribution networks. But unlikely other (research-) projects the algorithms are not only to be developed and tested on virtual grids. Furthermore they are being implemented in a real world control centre and verified on parts of a local distribution grid.

The project started in October 2012 and is led by PSI AG, a well-known provider of solutions for operations control and monitoring of complex network infrastructures. The academic part of analysis and development of algorithms is conducted by the Institute of Power Systems and Power

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Economics (IAEW) at RWTH Aachen University. The third project partner is Stadtwerke Aachen (STAWAG), the local utility company. The developed algorithms will be tested in their control centre and in a part of their distribution grid.

2.1 Algorithm for Distribution System State Estimation

Whereas state estimation algorithms for transmission grids have been researched and used for many years there is still need for research and testing in the area of distribution system state estimation. This project especially focusses on creation of pseudo-measurements and their measurement errors. These pseudo-measurements can be created e.g. based on meteorological data, time series and standard load profiles.

2.2 Methodology for optimal Meter Placement

The deviation between estimated and real network state is mainly induced by pseudo-measurements' measurement errors as described in section 1.2. A reduction of this deviation can be achieved by placing additional real-time measurements with low measurement errors (or by improving pseudo-measurements' quality). In order to find the cost optimal number and position of additional real-time measurement devices it is necessary to calculate the expected estimation deviation.

Based on an artificial reference situation distribution functions, modeling the measurement error of each real-time and pseudo-measurement, are used to create a measurement set superimposed with measurement errors. This measurement set is alike the set a DSO would see in his control system. The measurement set and a network model are passed to a state estimator and subsequently the resulting estimated state is compared to the reference situation to quantify the estimation deviation at each network node. As measurement errors are varying over wide ranges a Monte Carlo approach is chosen and numerous measurement sets are being created and evaluated based on the measurement error distribution functions, resulting in a distribution function for the estimation deviation at each node. These estimation deviations are subsequently used to decide where to place additional real-time measurements.

The proposed methodology requires detailed information on measurement errors especially of pseudo-measurements. In collaboration with STAWAG pseudo-measurements are being calculated and verified with already existing real-time measurements. Figure 1 shows an exemplary measurement error distribution of pseudo-measurements for small photovoltaic units' feed-in. The measurement error in figure 1 is thereby scaled with the unit's average feed in.

It becomes obvious, that the measurement error can be significant e.g. due to different alignment or partial shadowing of individual generation units. Similar error distribution functions are derived for other pseudo-measurements e.g. wind generation units and low voltage loads (customers).

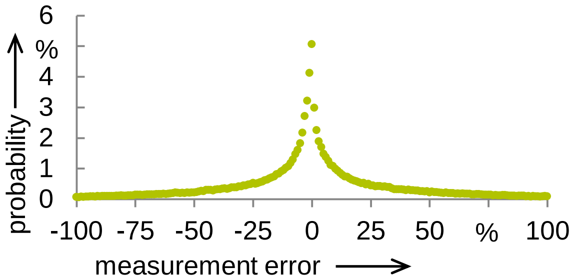

Figure 1: error distribution of pseudo-measurements for small photovoltaic units

2.3 Verification of developed Algorithms

The developed algorithms for state estimation and meter placement are to be verified in the local distribution grid operated by STAWAG. Their control room is equipped with a PSI control system. In order not disturb every day operation a second control system is installed by PSI. This test-system includes the newly developed distribution system state estimator. For safety reasons the new test-system can receive all Scada data but can not send out any commands to the process layer (compare figure 2)

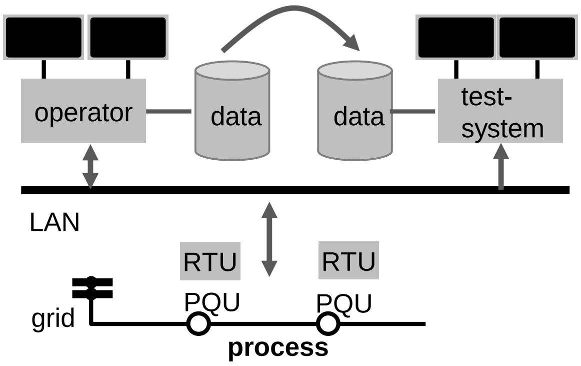

Figure 2: control centre set-up with test-system

In order to verify the algorithm for optimal meter placement it is necessary to equip an entire feeder of the medium (and low-) voltage grid with real-time measurements. The chosen feeder is located in Aachen-Richterich where most of the secondary substations have access to a communication cable operated by STAWAG. In total 14 substations are being equipped with voltage, active and reactive power flow measurements. Their data is send in real-time to the central control center via cable (where available) or via wireless technologies. It is further planned to utilize measurements from an underlaid low voltage grid provided by the project "econnect Germany".

In order to verify the calculated optimal meter positions each additional measurement can be selected individually to be considered in the testsystem's state estimator.

3 Summary

Currently the analysis of measurement errors is finished and the development of the algorithms has started. The test region has been identified and additional real-time measurements are to be installed at the secondary substations. The project will be ongoing till beginning of 2016.