Conceptual Analysis of Distribution System State Estimation of Low Voltage Networks

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I. Abstract

Distribution System State Estimation (DSSE) has great potential in the integration process of renewable energies, energy storage and active participation of the customers. The international state of the art pilot projects showed that there are many use cases, such as indication of operational limit violations and enhancing strategic development and asset management by useful in-depth information about the electrical behaviour of the system. However, the concept of **state estimation at the distribution level is still a developing research area** due to the structural differences of the network structure and parameters from the transmission applications which is also discussed in detail. Based on the value proposition identified through the literature review, **simulation studies are carried out on distribution test system** with different scenarios based on renewable penetration levels and measurement data availability. T**he main contribution of this research is a conceptual overview of the possible application of distribution system state estimation and validation** of the operation on a case study, which could serve as a foundation for testing the proposed viable use-cases.

II. Problem definition

Background – process of state estimation

Network data
Measurements
Pseudo measurements

Topology process
Observability analysis
State estimation

Bad data identification
Human/Machine Interface
Applications

Theoretical challenges of LV DSSE compared to TSSE

High R/X value (resistance to reactance ratio) which means that conventional direct current (DC) (where resistances are neglected in the calculations to increase computing speed) SE algorithms are unusable.

Low amount of data about the exact connecting elements, such as distributed generation and individual loads. Limited observability due to small number of measurements.

Larger network with model uncertainities, radial topology.

Higher complexity due to the unbalances in the system (single phase elements).

Experiences from state of the art pilot projects

Flexibility estimation & voltage profile calculation at substation level – further load/generation addition without DSO investments.

Hosting capacity increase due to increased observability - thermal and voltage limits planned on long-term measurements.

Use of smart meter data as an input to continously analyze power quality – instrumentation needs could be reduced.

Comparative analysis of potential algorithms for calculation

Method	Pros and Cons
Weighted Least Square (WLS)	(+) Fast, simple, widely-used, (-) Sensitive to bad data
Least Median of Squares (LMS)	(+) Robust against bad data and leverage points, (-) High computational cost, high redundancy requirements
Least Trimmed Squares (LTS)	(+) Robust against bad data, (-) High computational cost and memory requirement
Least Absolute Value (LAV)	(+) Robust against bad data, small sensitivity to line impedance uncertainty, (-) High computational cost, sensitivity to leverage points and measurement uncertainty
Generalized Maximum Likelihood (GM)	(+) Robust against bad data, (-) Parameter selection sensitivity

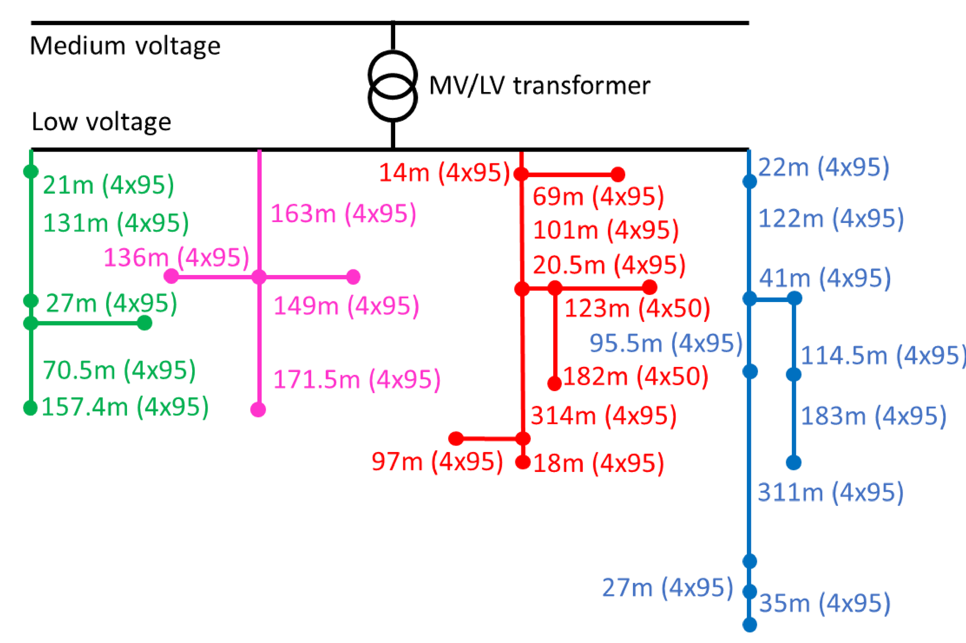
Table. 1: State estimation algorithm comparison

III. Results

The main aim of the work is to answer the questions, whether increasing share of solar photovoltaics has already affected the DSSE accuracy. To evaluate this question, a real Hungarian MV/LV transformer area was analyzed in DigSilent PowerFactory 2019.

Modeling considerations

The test system is the supply area of an MV/LV transformer (depicted in Fig. 1.). There are available measurements from the LV terminal of the transformer (voltage, current magnitude, active and reactive power) and the endpoints of circuit 1,2 and 4 (voltage magnitude) – see an example on Fig. X.



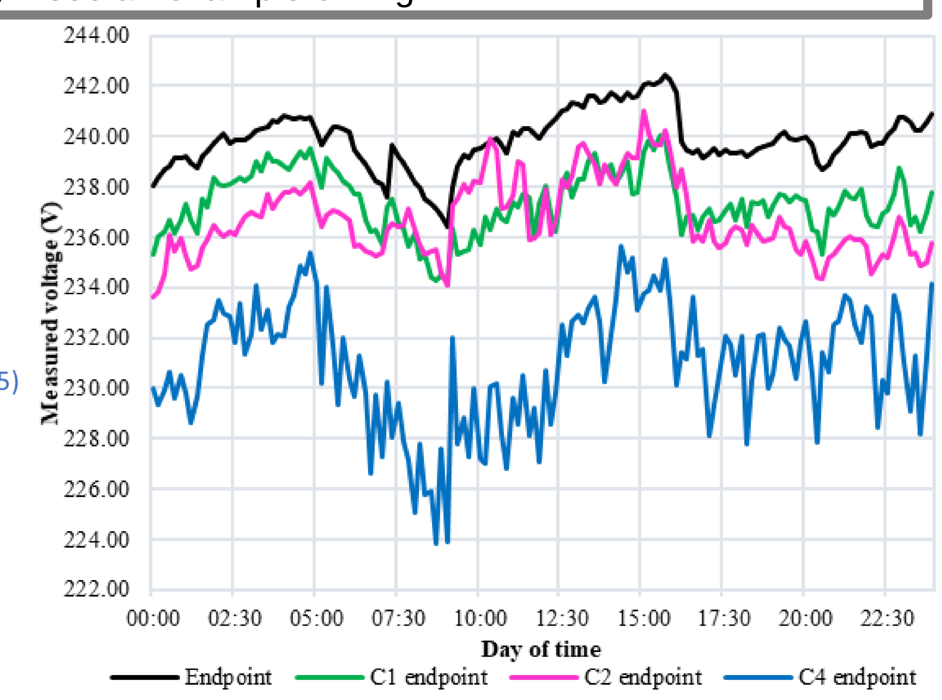


Fig. 1. Topology of the considered test system (left)
Fig.2. Averaged measured values from the location (right)

DSSE results and key findings

There are two study cases with respect to the nature of measurement data which were considered
1. base case behaviour of the DS,
2. increased number of PV generators – 20% penetration (compared to nominal load)

Premise

Load and PV generation profiles are provided by local DSO profile database.

12 PV systems are operating in the MV/LV area.

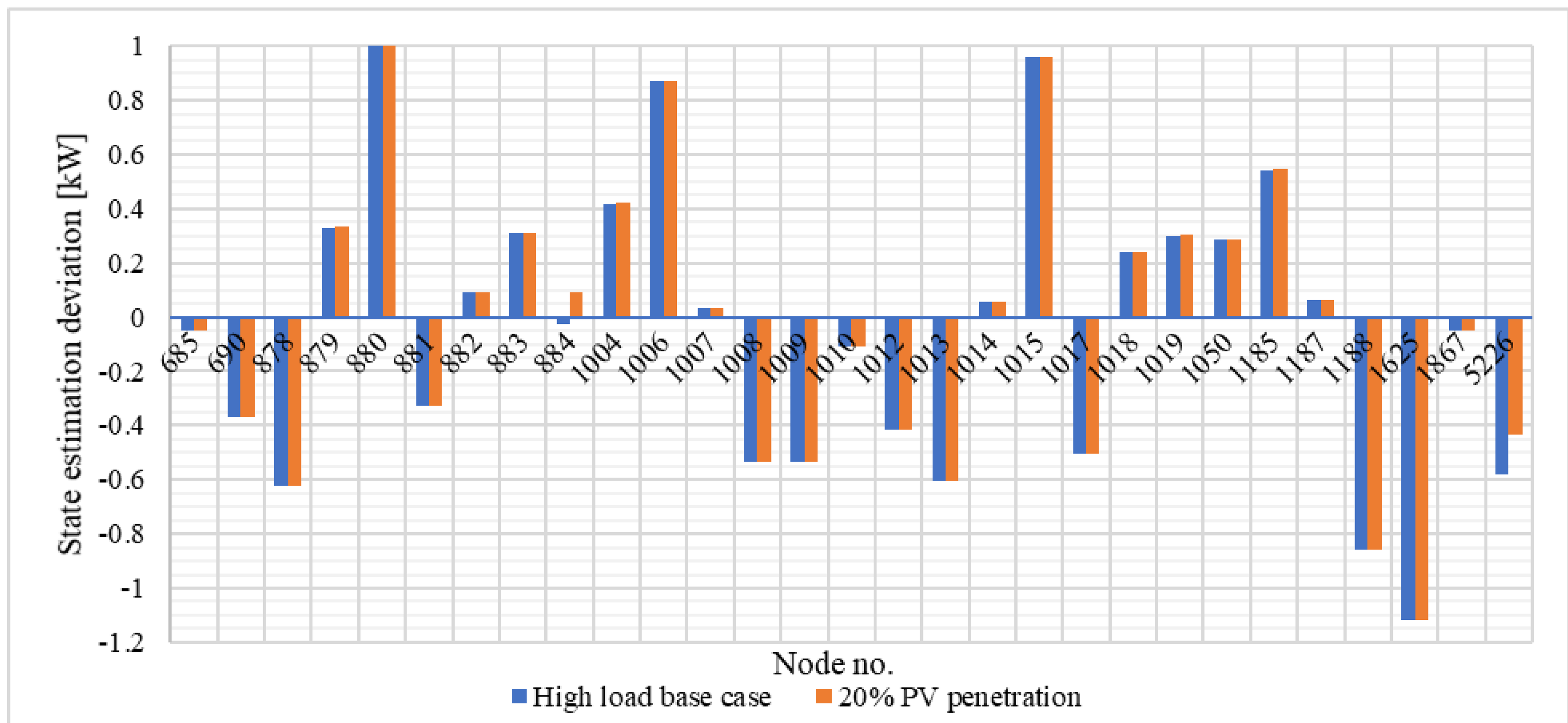
Since the data about phase connections for both loads and generations is unavailable, balanced conditions were assumed.

Findings

Profile-based pseudo measurements resulted ~18% estimation accurary for individual customers.

Branch current and endpoint voltage increases the accuracy of LV DSSE.

Smart metering points of PV generation compensate intermittency issues, pseudo measurement errors are dominant.



Node no.	685	690	878	879	880	881	882	883	884	1004	1006	1007	1008	1009	1010
High load	3.80%	20.22%	23.52%	-18.64%	-35.87%	26.11%	-9.98%	-20.16%	0.78%	-13.28%	-29.16%	-3.82%	30.18%	30.08%	3.82%
20% PV	3.73%	20.11%	23.48%	-18.70%	-35.27%	26.03%	-10.09%	-20.22%	-2.52%	-13.34%	-29.19%	-4.07%	30.07%	29.97%	3.79%
Node no.	1012	1013	1014	1015	1017	1018	1019	1050	1185	1187	1188	1625	1867	5226	
High load	20.16%	23.54%	-18.67%	-35.72%	26.08%	-9.69%	-20.08%	-13.30%	-29.14%	-3.86%	30.18%	30.06%	3.84%	31.29%	
20% PV	20.11%	23.47%	-19.00%	-35.76%	26.03%	-9.73%	-20.15%	-13.34%	-29.25%	-3.92%	30.11%	30.03%	3.76%	23.44%	

Fig. 3. Load flow and State estimation difference on each node
Table. 2. Relative state estimation error on each node

Main references

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