EVALUATION OF THE IMPACT OF HIGH PRESENCE OF SMALL DERS CONNECTED TO THE URBAN LV NETWORK

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ABSTRACT

The subject addressed in this paper is the evaluation of the impact of small Distributed Energy Resources (DER) connected to the low voltage network in an urban area of the distribution network. The aim of this paper is to show the impact of the DERs by analysing key performance indices of the network, with and without DER connected, and by analysing different DER output. To address the problem, the authors have used advanced distribution management system (ADMS) and performed analysis in study mode on real network model. Results obtained by software simulations were verified with real measurements data from the field.

INTRODUCTION

Energy supply is one of the major issues of modern society. Shifting from fossil fuels to renewable ones is ongoing and solar energy is expected to have leading role in the future, anticipations are that by 2050 it will contribute up to 35.8% to the global generation [1,2].

In USA and India there are already PV plants with over 100 MW of installed power and solar projects exceeding 1 GW are expected to be deployed in near future [1]. However, most of the deployed PVs are in small rooftop arrays of less than 20 kW and their number is growing fast. Most of the distribution network operators (DNO) monitor and control the DN in real-time using some type of SCADA and, in some cases, distribution management system (DMS). In most cases these solutions cover models of the medium voltage (MV) networks, while low voltage (LV) networks are rarely modelled. This also means that the impact of the DER connected to LV network are not considered in full amount.

Furthermore, in most cases, utilities are still neglecting the DER impact on network capacity in long term planning. Great Britain is the only country in the world today that has defined the rules for considering DER impact on network capacity when planning its reinforcement [3]. This means that most (if not all) utilities still consider traditional energy resources as the only source of supply when planning costly network investments.

This paper will focus on the evaluation of the impact of DER connected to the LV network in an urban area of the DN. It will show that high presence of modern PV systems connected to LV network, may have significant impact on network operation, and cannot be neglected in analysis.

To do this, authors have modelled a test LV network, based on a real LV network data, using one commercial solution of advanced distribution management system (ADMS) to analyse different test cases.

METHODOLOGY

LV network modelling

Real urban LV network, supplied by one 10/0.4 kV (MV/LV) substation with one transformer, was used for the simulation. Thanks to the collaboration of the local distribution company, the authors were able to get:

- The schematic and geographic scheme of the LV network (AutoCAD files);
- Technical data about the LV underground cables
- Exact number of customers supplied by each feeder and by supply point
- Measurement data of the max. current on the 10 kV feeder head, in 35/10 kV supply substation,
- Measurement data of the active energy on all MV/LV transformers of the 10 kV feeder,
- Typical load curves of the consumer group.

The authors have also retrieved the min. of necessary technical data for MV network from which test network is supplied (MV feeder and supply substation), as necessary to run the load flow (LF) calculation in ADMS. The logical scheme of the real LV network used for testing (test network) is presented on Fig. 1.

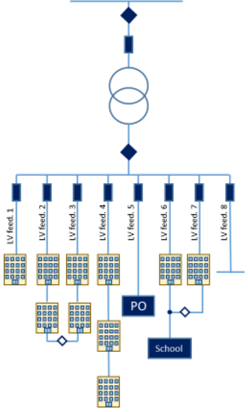

Fig. 1 LV test network scheme

The test network consists of:

- MV/LV substation:
  - 1 x 10kV normally closed disconnector
  - 1 x 10kV fuse
  - 1 x 10/0.4 kV (630 MVA) transformer
  - 1 x 1kV normally closed disconnector
- 8 LV feeders underground cables (PPOO 4x95 Cu):
  - LV feeder 1: 1 building, 30 customers,
  - LV feeder 2: 1 building, 2 entrances x 16 customers
  - LV feeder 3: 1 building, 2 entrances x 16 customers
  - LV feeder 4: 1 building, 3 entrances x 16 customers

  - LV feeder 5: supplies post office (PO),
  - LV feeder 6: 1 building, 88 customers and a school,
  - LV feeder 7: 1 building, 88 customers,
  - LV feeder 8 is normally open and serves as backup supply to the neighbouring MV/LV substation.
  - LV feeders 2 and 3 as well as 6 and 7 are connected via normally open 1kV point,
- To each supply point a set of normalized daily load diagrams (load curves) is assigned. Different load curves are available for different seasons, characteristic days and temperature ranges.

PV modelling

In the same area is the University of Novi Sad, which is supplied from the neighbouring MV/LV substation. The University of Novi Sad has a roof-top PV plant consisting of 40 modules with total installed power of 9600 Wp [4]. The PV modules are connected to the public grid through the grid-tied inverter and the data regarding its generation are monitored in real time. The authors have used these data to test connection of the PV in every consumer point of the test network.

Software for the simulation

The test network and PVs were modelled using one commercial ADMS solution. Authors have used the study mode to run LF calculation (and other advanced DMS applications) for different test cases.

As no telemetry is available in the LV network, ADMS is using virtual load curves in order to determine the consumption on supply points at any moment. Furthermore, ADMS integrated with weather system can retrieve weather signals such as insolation and temperature in (near) real time and estimate the production of PV in accordance with the typical PV output curve.

Case study

The impact of PV on LV network operation was tested through simulation of 20 use cases using ADMS software:

1. **Scenario 1** - Workday, summer, 18.7.2017 - hot summer, long days, min. or average power load and max. PV production:
   a. Time: 03:00 am, 26°C, no insolation: system min. load, 0 PV production
   b. Time: 09:00 am, 25°C, 300W/m2 insolation, average power load, small PV production – 4 cases were observed:
      i. no PV connected,
      ii. PV connected in 5/12 conn. points
      iii. PV connected in 9/12 conn. points,
      iv. PV connected in 12/12 conn. points
   c. Time: 03:00 pm, 35°C, 1020 W/m2, average power load, max. PV production, same cases as in 'b, i-iv'
   d. 09:00 pm, 25°C, no insolation, max. power load for summer day, 0 PV production
2. **Scenario 2** - Workday, winter, 15.1.2018 - cold winter, short days, max. power load and min. PV production:
   a. Time: 02:00 am, -4°C, no insolation min. power load for winter day, 0 PV production
   b. Time: 10:00 am, 0°C, insolation 108W/m^2 , average power load for winter, average to max. PV production for winter, same cases as in '1. b, i-iv'
   c. Time: 02:00 pm, 2°C, insolation 42 W/m^2, average power load for winter, small to average PV for winter, same cases as in 'b, i-iv'
   d. Time: 08:00 pm, 0°C, No insolation, power system max. load, 0 PV production

RESULTS AND DISCUSSION

Case study results

Impact to key performance indices

When PV connects to the LV grid, it supplies some amount of power, and the power injected (Pi) from the MV/LV transformer is diminishing. Unless the software can account for the growing number of PVs connecting to the LV grid – the utilities deal with discrepancy of injected and consumed power data.

Results of the **generated power** (Pg) by PVs (in kW), for analyzed cases are presented in Tab. 1 and Tab.2

Tab. 1 PV generation, summer day

Pc	T	h	Ins	Pg 0	Pg 5	Pg 9	Pg A
198.6	26	3	0	0	0	0	0
308.3	30	9	300	0	12.2	21.9	29.2
356.5	40	15	1020	0	35.2	63.4	84.6
397.2	30	21	0	0	0	0	0

Tab. 2 PV generation, winter day

Pc	T	h	Ins.	Pg 0	Pg 5	Pg 9	Pg A
223.1	-4	2	0	0	0	0	0
421.4	0	10	108	0	4.7	8.4	11.2
394.5	2	14	42	0	1.8	3.3	4.4
518.7	0	20	0	0	0	0	0

The meaning of variables are as follows:

- Pc – Power consumed by the LV test network (kW), calculated at the LV busbar (source),
- T – temperature (°C)
- h – hour
- Insolation (W/m^2)
- Pg – x – Pi (kW) by PVs, x PVs, A – all 12 PVs

The highest generation is, of course, detected for the max. insolation value – in the hot summer day.

Next, the impact on the total Pi (in kW), will be commented - Tab. 3 and Tab. 4.

Tab. 3 – Pi - summer day

Pc	T	h	Ins.	Pi 0	Pi 5	Pi 9	Pi A
198.6	26	3	0	199.5	199.5	199.5	199.5
308.3	30	9	300	**310.6**	**298.4**	**288.8**	**281.5**
356.5	40	15	1020	**359.5**	**324.5**	**296.5**	**275.5**
397.2	30	21	0	401.1	401.1	401.1	401.1

Tab. 4 - Pi - winter day

Pc	T	h	Ins.	Pi 0	Pi 5	Pi 9	Pi A
223.1	-4	2	0	224.2	224.2	224.2	224.2
421.4	0	10	108	**425.7**	**421.1**	**417.4**	**414.6**
394.5	2	14	42	**398.3**	**396.5**	**395**	**394**
518.7	0	20	0	525.5	525.5	525.5	525.5

When the insolation is small and the consumption is high (winter), total Pi diminished by barely **1%**. However, when the insolation is high and the consumption is low (summer), the Pi can be diminished over **23%**! This delta is nicely illustrated in Fig. 2 and Fig. 3.

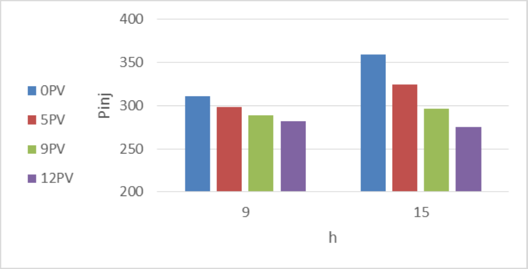

Fig. 2 Pi, summer day

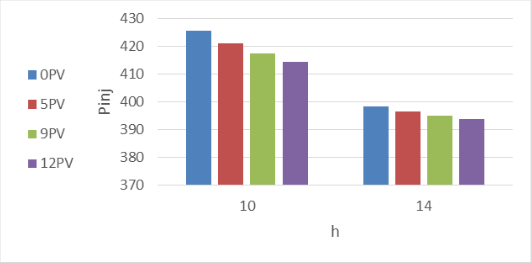

Fig. 3 Pi, winter day

Furthermore, the impact on the **power factor (**Pf), in relative units is presented in Tab. 5.

Tab. 5 Impact to power factor – summer day

Pc	T	h	Ins.	Pf 0	Pf 5	Pf 9	Pf A
198.6	26	3	0	0.94	0.94	0.94	0.94
308.3	30	9	300	0.94	0.94	0.93	0.93
356.5	40	15	1020	0.94	0.93	0.92	0.91
397.2	30	21	0	0.94	0.94	0.94	0.94

Modern PV units produce active power, with small capacities in reactive power. With the high production of PVs, the injected power in LV network diminishes, and so does the Pf on the entry point. The effects are subtle but persistent in all cases.

As the Pi diminishes, the current through LV feeders is smaller, thus creating smaller **active power losses** (Pl) [5,6]. Tab. 6 and Tab. 7 show the change in the total amount of Pl (in kW).

Tab. 6 - Pl, summer day

Pc	T	h	Ins.	Pl 0	Pl 5	Pl 9	Pl A
198.6	26	3	0	0.9	0.9	0.9	0.9
308.3	30	9	300	2.2	2.1	2.1	2
356.5	40	15	1020	3	2.6	2.5	2.2
397.2	30	21	0	3.8	3.8	3.8	3.8

Tab. 7 - Pl, winter day

Pc	T	h	Ins.	Pl 0	Pl 5	Pl 9	Pl A
223.1	-4	2	0	1.1	1.1	1.1	1.1
421.4	0	10	108	4.3	4.3	4.2	4.2
394.5	2	14	42	3.8	3.7	3.7	3.7
518.7	0	20	0	6.8	6.8	6.8	6.8

When the insolation is small and the consumption is big, Pl diminish hardly over **2.5%**. However, when the insolation is high and the consumption is low, the reduction of Pl is over **26%**! This impact of PVs is completely neglected if utilities are unable to account for their presence. The delta is illustrated in Fig. 4.

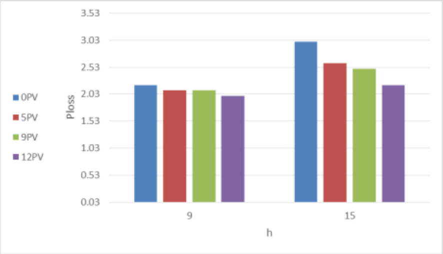

Fig. 4 Pl, summer day

Finally, the change of the voltage level (% of rated voltage) will be observed on the LV network entry point (secondary of the MV/LV transformer) -

Tab. *8*. As the Pi diminishes, the current passing through the grid is smaller, thus creating smaller voltage drops, and the voltage on LV entry slightly increase [5,6].

Tab. 8 - Voltage on the entry point - summer day

Pc	h	Ins.	V 0PV	V 5PV	V 9PV	V 12PV
198.6	3	0	102.53	102.53	102.53	102.53
308.3	9	300	101.28	101.31	101.34	101.36
356.5	15	1020	100.7	100.81	100.89	100.95
397.2	21	0	100.2	100.2	100.2	100.2

The changes to the voltage balance (and thus voltage drops) are more subtle (moving in range 0.02% - 0.25%), but persistent in all cases.

As PV units do not produce reactive power and consume very little of it from the network, the case study results have shown little or no impact to the **reactive power flow** in the test network, on the level of decimal values, and therefore they will not be presented in details.

Other effects

Reliability indices – in no use case the Pg by PVs could supply the total demand of the LV feeders – in urban network many customers are connected to the same supply point creating a big demand, impossible to satisfy with rooftop PV. Therefore, analysis have shown that PVs have no potential as a backup source of supply in case of an incident on LV laterals. However, they have proven to have great impact on the installed capacity – which should be considered when planning network reinforcement.

Range of change to the power flow – in no use case the Pg by a single PV could supply the demand of one supply point. For small rooftop PV units connected in the urban area of the grid energy flow remains radial from the grid (source) to LV consumers. This can be a green light to install small PV units on the urban building rooftops – as there are no disturbances to the energy flow.

Fault Calculation and impact to protection settings – Using Fault Calculation in ADMS - short circuit analysis was tested. As PV units are not synchronous machines - the results are showing that connection of PV units has little impact on the results, regardless of the fault place, type and number of PVs connected. Characteristic results are summarized in the Tab. 9

Tab. 9 - Fault Calculation

	I	**V - F.**	**V - E.**
3Ph 0 PV	4,094.35	0.00	6.27
3Ph 12PV	4,100.14	0.00	6.27
1 Ph 0 PV	2347.14	0.00	6.13
1 Ph 12 PV	2,349.10	0.00	6.13

3 phase (3 Ph) and 1 phase to ground fault (1 Ph) are presented, for no PV (0 PV) and all PVs connected (12 PV). The place of the fault was on the LV Feeder 5, during summer day. The columns show values of the current and voltage in the place of the fault for the affected phase – I (A); V– F (kV) and voltage on the entry point– V– E. (kV). This also can be seen as the green light, as rooftop PVs do not have impact on incidents on LV feeders or to the protection settings.

Validation of case study results

In order to validate the results, the input data for the software simulation was compared to the field measurements.

Firstly, to verify LF calculations of the ADMS software, authors have used real measurements by Utility: max. load (current) on the 10 kV feeder head and active energy on each MV/LV transformer. The max. power on the MV/LV transformer supplying test network, according to real measurements, was approx. 500kW in the winter. The max. power calculated by the software never exceeded the real max. power value - in case of highest demand the value calculated was 518kW, matching the expectations.

Furthermore, the university provided the PV measured data and authors compared the estimated software production with the measurements. Characteristic test results are presented in the Tab. 10. The error was in no case greater than 10%.

Tab. 10 PV output validation

Ins.	**Sim. Pg**	**Meas. Pg**	**Error**
250	2.4	2.2	8.33%
400	3.5	3.5	0.00%
440	3.8	3.8	0.00%
580	4.7	5	6.38%
700	5.9	6.1	3.39%
800	6.9	6.9	0.00%

Authors concluded that the software LF and PV production results are eligible to draw conclusions in this paper.

CONSLUSION

Using software simulations, 20 use cases with different load and generation were analyzed to show thT impact of high presence of small PVs in the LV network is not insignificant. The results have shown that Pi from the MV network can be diminished over **23%**, Pl in the LV network can be reduced over **26%** and voltage profiles can be improved in the range of **1%**. Simulation results were validated with field measurements, showing that modern software can accurately analyze LV network operation.

This is especially important to utilities with high presence of PVs in LV network, which is a growing trend in Europe. Unless they account for the effect of PVs they may:

- Produce wrong reports on network operation analysis: discrepancy in energy injected and energy consumed; energy losses division and causes; voltage profiles
- Produce over estimations of the costly future investments in network capacity reinforcement
- Lack to produce sufficient data/motivation to seek investments in the renewable technology

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