ANALYSIS OF VOLTAGE QUALITY PARAMETERS IN LV DISTRIBUTION GRIDS WITH CONNECTED DES

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ABSTRACT

This paper describes the impact of operation of distributed energy sources on voltage quality parameters in low voltage distribution grids. The survey is based on the evaluation of 60 voltage quality measurements which were carried out in 30 different low voltage distribution grids with connected power sources. These 60 measurements were made in 2016 and were evaluated according to the standard EN 50160. The impact on voltage variations and other voltage quality parameters was analysed.

INTRODUCTION

The supply territory of the E.ON Distribution in the Czech Republic, operated by the company E.ON Czech Republic, accounts for approximately 1.5 million customers. More than 1000 MW of distributed energy sources (DES) were connected to this network mainly in photovoltaic (PV) sources. The mass operation of generating plants also results in poorer voltage quality parameters in the distribution network. In case of accumulation of sources in one part of distribution system, it is possible that overvoltage will be detected or else voltage variations will not comply with the requirements of the standard EN 50160 [1]. The theoretical impact of DES on voltage quality (VQ) has already been described [2]. Practical experience of the operation of DES from the distribution network operator´s (DNO) side is not available or the measured data are not from the area E.ON Distribution. This paper brings a current study of VQ measurements which were carried out in 2016.

DESCRIPTION OF MEASURED GRIDS

Thirty other representative LV distribution grids with connected PV plants were chosen and these grids were measured. Each measurement lasted at least one week according to the EN 50 160 standard. Two VQ measurements were made at the same time in each grid, first in the substation (on the LV level, on the output of the transformer 22kV/0.4kV – node U2 in the Fig. 1) and second in the point of connection of PV plant to LV distribution grid (supply terminal of PV plant – node U3 in the Fig. 1). The nominal active power (AP) of each PV plant, rated power of supply transformer (T) 22kV/0.4kV and measurement period are available – see the Tab. 1.

Grid No.	Measurement period	power of T [kVA]	AP of PV [kW]
1	30.6.-12.7.2016	400	7
2	4.5.-18.5.2016	400	13
3	7.6.-22.6.2016	160	5
4	19.6.-29.6.2016	400	3
5	26.5.-7.6.2016	400	24
6	2.5.-10.5.2016	250	30
7	11.5.-19.5.2016	160	19
8	23.5.-31.5.2016	400	24
9	24.5.-1.6.2016	400	19
10	22.6.-30.6.2016	250	4,8
11	7.6.-22.6.2016	400	65
12	11.7.-21.7.2016	400	21
13	13.6.-22.6.2016	400	7
14	14.6.-22.6.2016	630	6
15	22.7.-1.8.2016	630	9
16	18.7.-9.8.2016	400	4,5
17	15.7.-22.7.2016	250	4,6
18	30.5.-10.6.2016	400	12
19	13.5.-30.5.2016	400	30
20	12.7.-28.7.2016	400	6
21	1.7.-11.7.2016	400	9
22	30.6.-11.7.2016	250	10,8
23	11.5.-18.5.2016	400	11
24	22.7.-1.8.2016	250	5
25	4.5.-16.5.2016	160	5
26	19.5.-26.5.2016	400	16
27	28.6.-11.7.2016	400	5,7
28	10.5.-19.5.2016	250	8
29	1.7.-14.7.2016	160	25
30	10.6.-1.7.2016	250	70

Tab. 1 Rated power of the transformer MV/LV, rated power of PV plant, measurement period

Measured PV plants are connected in the node U3 when T1 is distribution MV/LV transformer and C1, C2 and C3 are customers with the load profile – see general block diagram in the Fig. 1. It was not measured at the end of the LV feeder (node U4 in the Fig. 1) because of a lot of data. We wanted to discover the problem with overvoltage, if this problem occurs. For that reason we suggested to measure in the point of connection of PV plant to gird. For decision about responsibility for potential overvoltage we suggested to measure in the substation too (on the output of transformer MV/LV). Sometimes overvoltage occurs in the substation due to incorrect set tap changer on the supply transformer.

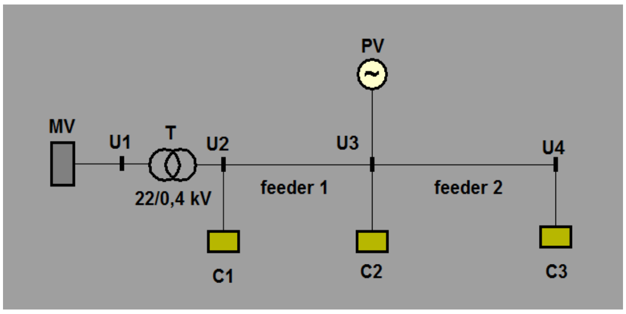

Fig. 1 General bloc diagram of measured grids

REQUIREMENTS OF THE EN 50 160 STANDARD

Voltage variations

All the LV measurements were evaluated according to the standard EN 50160 [1]. Under normal operating conditions excluding the periods with interruptions, supply voltage variations should not exceed ± 10% of the nominal voltage Un. A test method for low voltage level (under normal operating conditions) follows these rules/requirements [1]:

- During each period of one week 95% of the 10 min mean r.m.s. values of the supply voltage shall be within the range of Un ± 10%; and
- All 10 min r.m.s. values of the supply voltage shall be within the range of Un + 10%/-15%

Also when one 10 min mean r.m.s. value of the supply voltage exceeds during the week the limit Un + 10% (110% Un), it results in overvoltage and voltage quality or voltage variations will not comply with the requirements of the standard EN 50160.

Flicker

Under normal operating conditions, during each period of one week the long term flicker severity P_{lt} caused by voltage fluctuation should be less than or equal to 1 for 95 % of the time.

Harmonic voltage

Under normal operating conditions, during each period of one week, 95 % of the 10 min mean r.m.s. values of each individual harmonic voltage shall be less than or equal to the values given in [1] when the limit value for the 3rd voltage harmonic is 5%, for the 5th voltage harmonic is 6%, for the 7th voltage harmonic is 5% and for the 15th voltage harmonic is 0.5% of nominal voltage (only the most important harmonic voltages were selected). Moreover, the THD of the supply voltage (including all harmonics up to the order 40) shall be less than or equal to 8 %.

Unbalance

Under normal operating conditions, during each period of one week, 95 % of the 10 min mean r.m.s. values of the negative phase sequence component (fundamental) of the supply voltage shall be within the range 0 % to 2 % of the positive phase sequence component (fundamental).

Frequency

The nominal frequency of the supply voltage shall be 50 Hz but frequency is set from the transmission system so it is not evaluated in this paper because of its small role for LV systems with synchronous connection. It is important to evaluate frequency in LV systems with no synchronous connection when the power source operates in an island mode [3].

REFERENCE IMPEDANCE

IEC 60725 [4] sets the reference impedance value, or more precisely, a reference (relative) short circuit impedance (short circuit power) value for the LV distribution network and electric equipment of nominal current less than 16/75 A. It is assumed that if the required impedance value is met at the point of network connection, an electric appliance will not produce any adverse retroactive impacts on the network therefore no interference in the network will occur.

Electric equipment with nominal current	Reference impedance $Z_{phase\text{-}earth}$	Reference short circuit power Sk”
up to 16A	0.47 Ω	570 kVA
up to 75 A	0.35 Ω	760 kVA

Tab. 2: Reference impedance for equipment with current ratings ≤16A/75A

The question is when the DNO and when the customer is responsible for poor voltage quality (VQ). It can be used the reference impedance as the guideline for decision about responsibility for poor VQ. The experience of DNO shows that keeping of the reference impedance will not guarantee full voltage quality for all LV grids. In this paper the short circuit impedance was evaluated and compared with the reference value, see the Fig. 2.

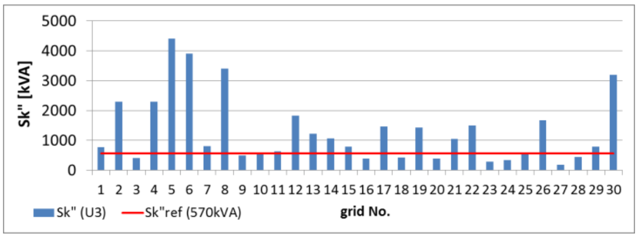

Fig. 2 Evaluation of short circuit power in the supply terminal of PV plant (node U3 in the Fig. 1), comparison with the reference value 570 kVA (reference impedance 0.47 Ω)

EVALUATION OF VQ MEASUREMENST

Voltage variations

In the Fig. 3 and Fig. 4 you can see the evaluation of maximal/minimal 10 min mean r.m.s. values of supply voltage (V100%max/V100%min) in 30 LV grids during week measurements in nodes U2 (substation) and U3 (PV).

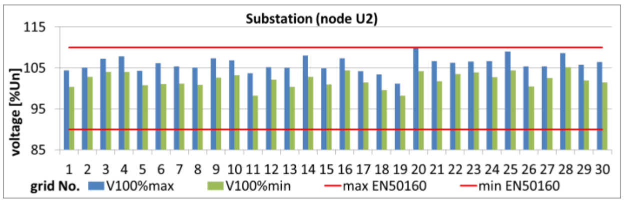

Fig. 3 Evaluation of voltage variations (substation)

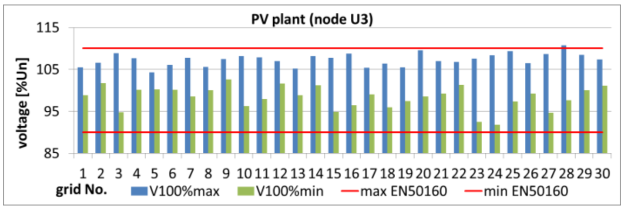

Fig. 4 Evaluation of voltage variations (PV plant)

Fig. 3 shows conforming voltage variations in all grids. Voltage approaches the upper limit 110% Un in grids No. 20, 25, 28 but the upper limit is not exceeded. This operation state is not optimal and can be caused by bad set tap changer.

Fig. 4 shows exceeding of the upper voltage limit in the grid No. 28. There was detected overvoltage only in the supply terminal of PV plant, voltage variations in the substations comply with requirements of the standard EN 50160. The overvoltage in this case is caused by operation of PV plant and solution of this problem has to be found.

We evaluated the voltage difference dU between maximal and minimal voltage values during the measurement too – see the Fig. 5. The voltage difference reaches the value 5% Un for substation and 16% Un for PV plant.

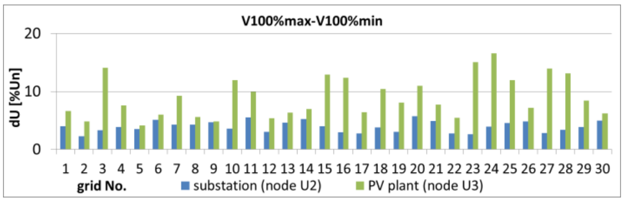

Fig. 5 Voltage difference between maximal and minimal voltage values

Flicker

In the Fig. 6 and Fig. 7 you can see the evaluation of long-term flicker (Plt) and short-term flicker (Pst) in 30 LV grids during week measurements in nodes U2 (substation) and U3 (PV).

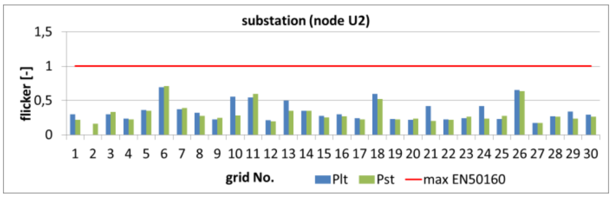

Fig. 6 Evaluation of flicker (substation)

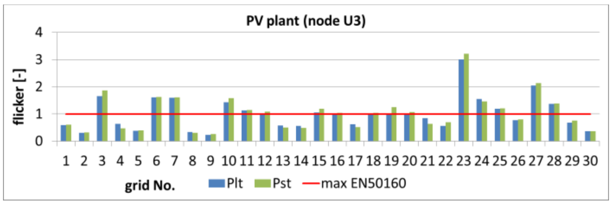

Fig. 7 Evaluation of flicker (PV plant)

The flicker level was exceeded in sixteen cases (grids No. 3, 6, 7, 10, 11, 12, 15, 16, 18, 19, 20, 23, 24, 25, 27, 28) only in the supply terminal of PV plant (node U3), flicker level in substations (node U2) complies with requirements of the standard EN 50160. It is the question if the flicker problem is caused by operation of PV plants or not. It means that in 53% (16/30*100%) of LV grids with PV plants, flicker does not comply with the requirements of the standard EN 50160 and solutions of this problem have to be found.

Harmonic voltage and THD

The Fig. 8 shows no problem with the 3rd voltage harmonic, the Fig. 9 shows no problem with the 5th voltage harmonic and the Fig. 10 shows no problem with the 7th voltage harmonic. The Fig. 11 shows the problem with the 15th harmonic voltage in two cases (grids No. 23, 24). This could be caused by high penetration of appliances producing 15th harmonics current which isn't our case, the measurement was done in standard rural and small city area. The second reason could be a low limit value for the 15th harmonic voltage when measurement uncertainty for generally used power quality analyzers (class S according to the IEC 61000-4-30:2008 standard [5]) is +/- 0.5% of nominal voltage. The standard IEC 62749 [6] recommends limit values up to the 50th voltage harmonic and the limits for some harmonics (with the multiple of three) are only 0.2% of the nominal voltage. Precise VQ analyzers with low system noise should be used for measuring of low harmonic voltage values. For some measuring equipment the internal noise of the instrument could disqualify VQ analyzer from measuring of such low harmonic levels [7]. The experience of the DNO shows that no complaints regarding harmonic voltage were obtained up till now. Exceeding of the limit value for the 15th harmonic voltage is hardly perceived by the customer and has no influence on operation of commonly used electrical devices.

The Fig. 12 shows no problem with total harmonic distortion (THD).

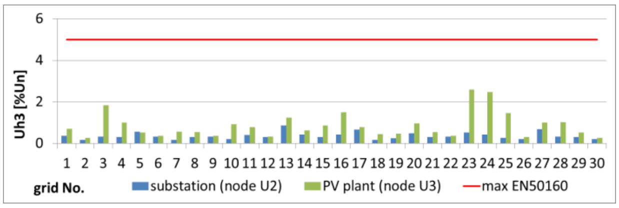

Fig. 8 Evaluation of the 3rd voltage harmonic

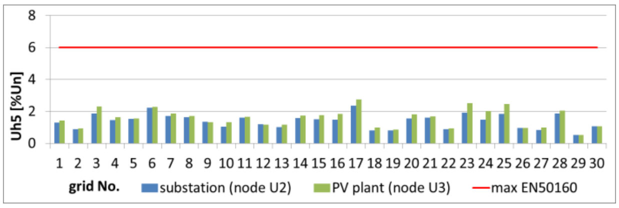

Fig. 9 Evaluation of the 5th voltage harmonic

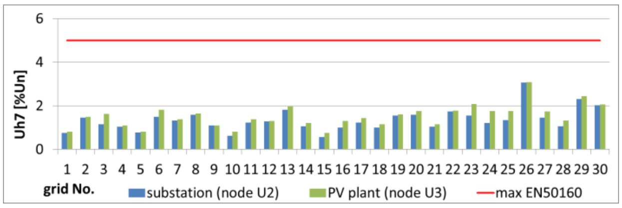

Fig. 10 Evaluation of the 7th voltage harmonic

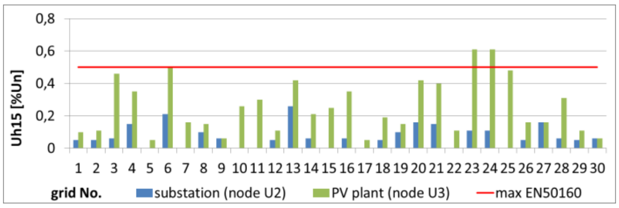

Fig. 11 Evaluation of the 15th voltage harmonic

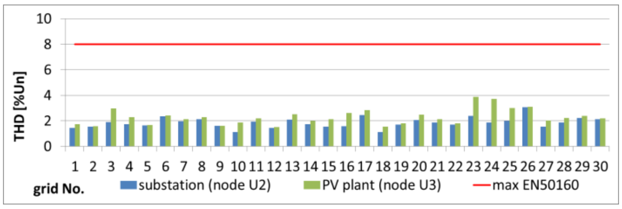

Fig. 12 Evaluation of total harmonic distortion THD

Voltage unbalance

The Fig. 13 shows the evaluation of voltage unbalance (95% percentile) in 30 LV grids during week measurements in nodes U2 (substation) and U3 (PV). There was evaluated no problem with voltage unbalance in LV grids.

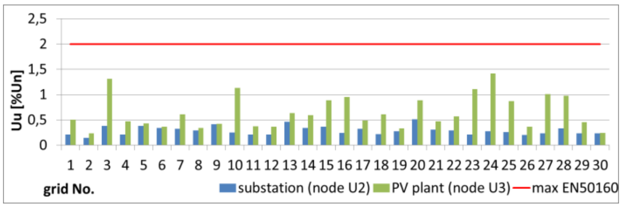

Fig. 13 Evaluation of voltage unbalance

CONCLUSION

It was demonstrated that operation of DES in the LV distribution grids can cause poor voltage quality and the problem with overvoltage has to be solved. The problem with flicker was detected approximately in 53% of LV grids and the problem with the 15th harmonic voltage approximately in 7% of grids (2/30*100%) but it is the question how the operation of DES influences these voltage parameters. It is also a question how voltage quality will develop in the LV distribution network due to the operation of a growing number of DES. The experience of DNO shows that the number of LV grids with nonconforming VQ will grow due to the operation of DES so that new and stricter conditions for the connection of DES to the distribution network have to be introduced.

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