STUDY OF VQ MEASUREMENTS IN LV DISTRIBUTION GRIDS WITH PV PLANTS

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ABSTRACT

This paper deals with the impact of renewable energy sources (RES) on voltage quality (VQ) parameters in low voltage (LV) distribution grids. This impact is demonstrated by study of VQ measurements in 23 other LV grids.

INTRODUCTION

The supply territory of E.ON Distribution in the Czech Republic, run by E.ON Czech Republic, accounts for approximately 1.5 million customers. More than 900MW of photovoltaic (PV) plants were connected to this network. The mass operation of generating plants also results in poorer voltage quality parameters in the distribution network. The operation of each power plant, including a small one, increases the voltage values in the place of connection to the distribution grid. In case of accumulation of sources in one part of distribution system, it is possible that overvoltage will occur respective voltage variations will not comply with the requirements of the standard EN 50 160. Theoretical impact of RES on voltage quality was described in many papers, but practical experience of RES operating in real distribution grids are not available, or are available only in case studies. So 23 other representative LV grids with PV plants were chosen and these grids were measured.

DESCRIPTION OF GRIDS

In each LV grid were made two week VQ measurements at the same time, firs in the substation (LV level respective output of the transformer 22kV/0,4kV – point U2 in the Fig. 1) and second in the point of connection of PV plant to LV distribution grid (supply terminal of PV plant - point U4 in the Fig. 1). In each point of measurement was calculated parameter short circuit power (Sk”). The nominal active power (AP) of each PV plant was available.

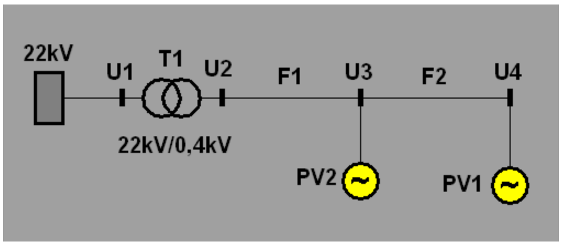

Fig. 1: general block diagram of measured LV grids

Measured PV plants in Fig. 1 are connected in the point U4. Other PV plants in the some LV feeder (when exist) are connected in the point U3. When not existing other PV plants active power of PV2 is zero (see Tab. 1). T1 is distribution transformer, F1 and F2 are LV feeders. In points U2, U3 and U4 are connected customers with load. From feeders F1 and F2 are supplied other customers (only with load), but these are not marked in the Fig. 1 (for a simplicity).

grid	power of T1	Sk" [MVA]		AP of PV [kW]	
No.	[kVA]	U2	U4	PV1	PV2
1	250	6,28	0,6	4,8	5
2	400	9,55	1,01	21	14
3	400	9,52	2,55	3	18
4	400	9,52	0,43	5	0
5	400	9,51	0,9	24	14
6	160	4,14	1,78	79	0
7	400	9,52	3,76	4	0
8	400	9,52	0,4	19	3
9	630	13,9	1,39	7	3,5
10	400	9,55	2,63	13	0
11	160	4,14	0,67	28	0
12	100	3,23	1,07	9	30
13	250	6,26	0,406	7	10
14	250	6,04	0,28	15	0
15	160	4,15	0,44	5	0
16	160	4,14	0,89	19	0
17	250	6,25	0,25	5	0
18	630	16,36	0,87	9	0
19	400	9,52	0,84	7	0
20	250	6,16	1,46	4	0
21	400	8,41	0,46	12	0
22	630	16,28	1,18	6	0
23	400	9,5	1,57	30	30

Tab. 1: parameters of measured LV grids

VQ MEASUREMENTS

The measurements were under way from May to July 2011. All the measurements were evaluated according to the EN 50160 standard [1].

<u>Requirements of the EN 50160 standard</u>

Under normal operating conditions excluding the periods with interruptions, supply voltage variations should not exceed ± 10% of the nominal voltage Un. Test method (under normal operating conditions) is following [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 respective voltage variations will not comply with the requirements of the standard EN 50160.

Evaluation of VQ measurements

Grid	V100%max [%Un]		V100%min [%Un]	
No.	U2	U4	U2	U4
1	105,78	108,17	102,33	95,53
2	106,63	107,59	103,35	101,37
3	109,31	109,46	103,77	99,73
4	104,59	107,23	101,56	95,11
5	105,76	107,39	102,44	100,31
6	109,14	110,89	103,77	101,44
7	105,41	106,23	101,26	99,88
8	106,47	107,96	102,57	98,28
9	106,27	106,35	103,05	100,62
10	106,58	106,79	103,32	102,96
11	106,04	107,34	100,63	98,20
12	106,00	107,07	101,33	98,65
13	105,74	106,38	101,63	100,89
14	106,07	110,97	102,74	95,13
15	107,15	108,64	103,20	94,86
16	106,80	108,87	102,59	101,32
17	109,30	112,22	106,13	103,06
18	105,26	107,87	101,36	96,33
19	104,91	106,11	99,54	97,67
20	105,84	106,13	99,48	97,24
21	106,30	110,03	102,48	99,84
22	110,47	110,54	105,90	103,89
23	107,80	112,55	98,70	96,86

Tab. 2: evaluation of maximal/minimal 10 min mean r.m.s. values of supply voltage (V100%max/V100%min) in 23 LV grids during week measurements in points U2 (substation) and U4 (PV plant No. PV1)

From Tab. 2 you can see, that in 6 cases (grids No. 6, 14, 17, 21, 22, 23) was overvoltage evaluated (V100%max>110% Un). In case of the grid No. 22 was overvoltage evaluated in the substation too, but the overvoltage was caused by bad set tap charger on the distribution transformer. In cases of grids No. 6, 14, 17, 21, 23 was overvoltage evaluated only in the supply terminal of PV plant, voltage variations in the substations comply with requirements of the standard EN 50160. The overvoltage in these cases (grids No. 6, 14, 17, 21, 23) is caused by operation of PV plants. Also in 22% (5/23*100%) of LV grids with PV plants voltage variations do not comply with the requirements of the standard EN 50160 and solutions of this problem have to be found.

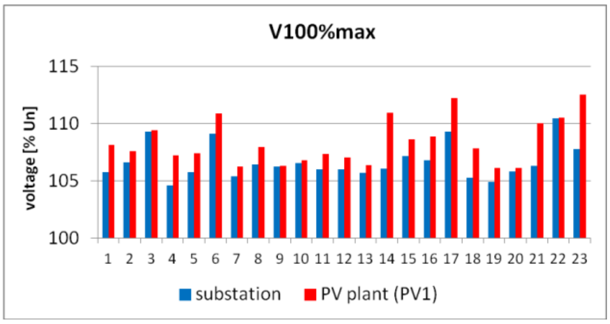

Fig. 2: evaluation of maximal 10 min mean r.m.s. values of supply voltage (V100%max) in 23 LV grids during week measurements in points U2 (substation) and U4 (PV plant No. PV1)

Next was evaluated big fluctuation in supply terminals of PV plants – see Fig. 3

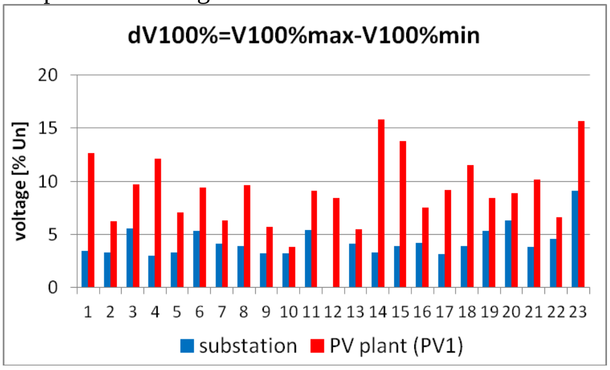

Fig. 3: difference between maximal 10 min mean r.m.s. value and minimal 10 min mean r.m.s. value of supply voltage during week measurements

Fig. 3 shows that the fluctiation of 10 min r.m.s. values of supply voltage increases (in grids No. 14 and No. 23) 15% of nominal voltage Un. Voltage in substation does't fluctuate so much and is influenced by sources in HV level too.

Analysis of relationship between Sk" and AP

We can assess the situation in the LV grid when problems with voltage variations. We can define relationship between short circuit power (Sk") in the LV grid and active power (AP) of PV plant connected to this grid by means of coefficient R, when

$$R[-]=\frac{S_k^{"}[MVA]\cdot 1000}{AP[kW]}$$

Eq. 1: definition of ratio R

grid	R [-]=Sk" [MVA]*1000/AP [kW]	
No.	AP of (PV1+PV2) [kW]	AP of PV1 [kW]
1	61	125
2	29	48
3	121	850
4	86	86
5	24	38
6	23	23
7	940	940
8	18	21
9	132	199
10	202	202
11	24	24
12	27	119
13	24	58
14	19	19
15	88	88
16	47	47
17	50	50
18	97	97
19	120	120
20	365	365
21	38	38
22	197	197
23	26	52

Tab. 3: ratio R in measured 23 LV grids

Tab. 3 shows that problem with voltage variations was detected in grids with the small ratio R. For example in grid No. 21 is ratio R=38.

$$R=\frac{0{,}46\cdot 1000}{12}=38$$

Eq. 2: calculation of ratio R for grid No. 21

Practical experience

We can recommend connection of PV plants (or generally power sources) to LV grids when ratio R is minimal:

a) R=50 for 3-phase PV plants
b) R=85 for 2-phase PV plants
c) R=165 (250 in rural areas) for 1-phase PV plants

In a different way there's a danger that voltage variations will not comply with the requirements of the standard EN 50 160 (see Tab. 3 and Tab. 2). In practice when applications for grid connection processing each application has to be considered by means of calculation. In a different way overvoltage will occur, see example in Fig. 4

Case study of a small PV plant

We connected experimentally (provisional) small PV plant of 3kW nominal active power to the LV grid with the small value of short circuit power (Sk"=230kVA) in the supply terminal of PV plant. It was demonstrated the operation of PV plant in the unrepresentative (rural) LV grid, we expected poor voltage quality caused by operation of the PV plant.

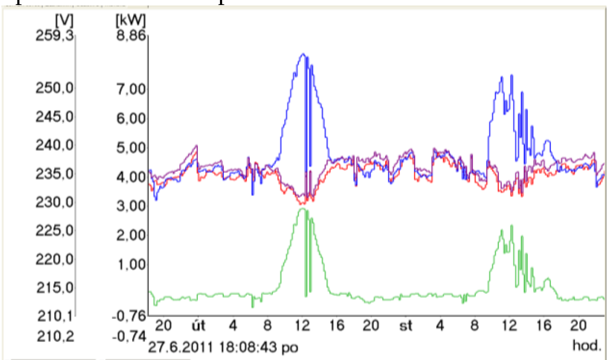

Fig. 4: 1-phase PV plant of 3kW nominal power and overvoltage (blue line) caused by its operation in the LV grid (green line – generated active power in the phase L2, violet, blue, red – voltage variations of phases L1, L2, L3)

Voltage in the phase L2 goes up to the value V=256V by nominal power of PV plant 3kW. Also ratio R for this grid is only 77 but should be at least three times higher.

$$R=\frac{0{,}23\cdot 1000}{3}=77$$

Eq. 3: calculation of ratio R for case of operation of PV plant in the unrepresentative LV grid

Also overvoltage was occurred (256V~111% Un, when nominal phase voltage Un=230V), as we expected.

CONCLUSION

It is also a question how voltage quality will develop in the LV distribution network due to the operation of a growing number of power resources. The experience of electricity distributor shows that the number of LV grids with nonconforming VQ will grow due to operation of the disperse resources.

REFERENCES

[1] EN 50160 Ed.3 Voltage characteristics of electricity supplied by public distribution systems. Brussels: European Committee for Electrotechnical Standardization, 2010. 20 p.