INFLUENCE OF PV PLANT 1 MWp CONNECTED ON MV OVERHEAD LINE ON VOLTAGE QUALITY IN PCC – CASE STUDY

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ABSTRACT

This paper analyses influence of PV plant with great power on MV grid rated voltage 10 kV, considering voltage quality parameters. PV plant is connected on MV overhead line feeding rural customers (ACSR conductors). Point of common coupling (PCC) has relatively low value (weak grid). According to EN 50160:2011, measurement is performed in PCC point. Analysis and comparison of results before and after PV plant connection is performed. These measurements are necessity, so that potentially negative influence of PV plant on distribution grid can be seen. Obtain results of voltage quality parameters are compared with EN 50160:2011 limit values. Further, general impact of PV plant on distribution grid in PCC was analysed. Specificity of this paper is that analyzed PV plant is with great power and connected on MV weak grid. This PV plant is one of only few connected on MV grid in Bosnia and Herzegovina.

INTRODUCTION

Distributed generation (DG) rapidly penentrate in distribution system. Thae main reason for that are existing incentive schemes for their construction. It is ongoing process that is long-term due demands for decreasing of CO_2 emission. Before DG penentration, distribution grid was passive grid. Today, distribution grid is active grid, very similar to transmission grid. DG penetration leads to change in philosophy of distribution grid in terms of load flow, voltage quality, system protection etc. For example, before DG presence, main problems in distribution grid was potentially low volatage at consumers (voltage drop). Today, penentration of DG leads to opposite problem, voltage rise at distribution grid with DG. Those problems are described in [1, 2].

Objective of this paper is analyse of PV plant influence on distribution grid in terms of voltage quality. PV plants use energy of the Sun and convert it to electrical energy. PV plants regarding rated power can be connected on each voltage level. This chapter considers dependence between strength of the grid (PCC of PV plant and the distribution grid) and PV plant rated power.

Using of legal regulations become very important fact for proper function of distribution grid in case of DG penentration. Legal regulations can be related for individual country but can be international too. The most exploiting legal regulation in terms of voltage quality which is in common use in Europe is EN 50160. It is a Norm issued first time by CENELEC in middle 90's. By today it had a several issues. This Norm refers to normal weather conditions and excludes situations like storms. This Norm gives quantitative characteristics of voltage. EN 50160 gives characteristics of voltage parameters considering permissible deviations. EN 50160 analyses voltage characteristics like: frequency, waveform, symmetry and magnitude. Measurement of voltage must be performed for seven days. Instruments for power quality measurement are described by IEC 61000-4-30 Standard. Procedure for power quality parameters measuring, according to EN 50160, is defined by IEC 61000-4-x Standards.

Limits of voltage quality parameters which are in scope for this paper are listed in Table I according to EN 50160:2011 (further in paper: Norm) for 10 kV voltage level.

TABLE I. SUPPLY VOLTAGE PARAMETER LIMITS (IN ACCORDANCE WITH EN 50160:2011)

Supply voltage parameter	Statistical evaluation	Compliance limit
Slow voltage variations (U)	99 % of the time in 1 week	U ± 10 %
	100 % of the time in 1 week	U +10 %/-15%
Voltage unbalance (u)	95 % of the time in 1 week	u < 2 %
Long term Flicker (P_{lt})	95 % of the time in 1 week	$P_{lt} \leq 1$
Total harmonic distortion of voltage (THDU)	95 % of the time in 1 week	THDU < 8 %

INFLUENCE OF PV PLANT CONNECTION ON DISTRIBUTION GRID IN PCC

PV plant generally has influence on distribution grid in PCC. But, this influence is dependable upon PV technology, PV rated power, strength of the grid etc. Connection point of PV plant in distribution grid can be in each bus (PCC). Influence of PV plant connection in distribution grid (in terms of voltage quality) will be presented. Various literature analyse this influence.

Influence of PV plants on waveform distortion in PCC was analysed in [3, 4]. Conclusion is that, if size of PV system is relatively low with respect to the short circuit power of the grid, there is no significant influence of PV plant on the grid voltage quality. If short circuit power is relatively low, regarding PV system rated power, voltage quality problems can occur. Influence of PV plant in PCC is marginal in case of flicker and harmonics, according to measurements in some LV PCC [5]. PV plants should not seriously degrade quality of supply with regard to harmonics [6]. PV plant connection on MV grid is analysed in [7]. It is concluded that PV plant has positive contribution to the reduction of THDU. In rural grids (due to longer feeders and small cross section of conductors – usually weak grids) voltage quality problems are more often than in urban distribution grids (usually strong) when DG is connected [8]. PV plant penetration in weak grids can cause even better performance of those grids (improving voltage profile). Each case of PV plant connection in distribution grid should consider individually. It is because there is no generally rule about PV plant influence on distribution grid.

CASE STUDY

Grid properties and measurement procedure

This case study refers to PV plant with rated power (S_r) 1 MWp (0.920 MVA) connected on MV grid rated voltage 10 kV. PV plant is connected on MV overhead line feeding rural customers (ACSR conductors). PCC is 10 kV bus in transformer station (TS) where energy from 0.4 kV voltage level (voltage level of PV plant) transfers to 10 kV (step-up transformer) grid voltage level. Measurement of voltage quality is performed in PCC. This is presented in Fig. 1. where position of PQ analyser is visible too.

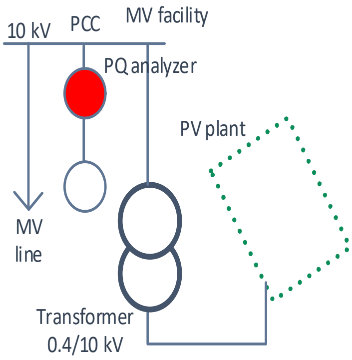

Fig. 1. Scheme of voltage quality measuring in MV facility.

On site voltage quality measurement is shown in Fig. 2.

Fig. 2. On site voltage quality measurement.

Voltage quality measurement is performed a week before PV plant connection and a week after PV plant connection. Measurement was performed with power quality (PQ) analyser class A, according to IEC 61000-4-30:2015.

In PCC, short circuit power of MV distribution grid (S_{SC}) has known value . Basic properties of MV distribution grid and PV plant are presented in Table II.

TABLE I. BASIC PROPERTIES OF MV DISTRIBUTION GRID AND PV PLANT

Sr (MVA)	0.920
Ssc (MVA)	25.46
Ssc/Sr	27.67

S_{SC}/S_r ratio presents relatively low value.

Voltage quality results using EN 50160:2011

Analytical approach

This voltage quality measurement procedure is obligation for DG in trial connection period on distribution grid. The goal is to determine potentially negative influence of DG on distribution grid in PCC. Voltage quality influence of PV plant on distribution grid in PCC is hard to determine. Measurement is only valid path for determination of PV plant influence on distribution grid in PCC.

THDU, P_{LT} and unbalance are parameters whose values after PV plant connection is hard to predict with analytical approach.

Opposite on that, slow voltage variation is parameter which is very important and which can be easy, but approximately determined before PV plant connection. With simply calculation potentially voltage rise after PV plant connection can be predicted:

$$\Delta u(\%) = 100 \cdot \frac{S_r}{S_{SC}} \cdot \cos(\psi_k + \phi) \qquad (1)$$

Where ψ_k is phase angle of the network impedance and ϕ phase angle of DG output current. Eq. 1 is simplified, but accurate enough for practical purposes of maximum steady-state voltage change determination [9]. Worst case considering voltage increase in PCC is for $\cos(\psi_k + \phi) = 1$. In this case study, result for max. steady-state voltage increase is 3.60% (after PV plant connection) for $\cos(\psi_k + \phi) = 1$.

Measurement approach

Generally, voltage quality measurement results before and after PV plant connection must be in accordance with the Norm. Measurement approach is only valid approach for determination of PV plant influence on distribution grid PCC.

Several assumptions are included in measurement analyses:

a) For measurement before PV plant connection there was one long-term interruption (grid failure) lasted 11 minutes and it was not considered in analysis and

b) For measurement after PV plant connection there was one long-term interruption (grid failure) lasted 106 minutes (grid failure) and it was not considered in analysis.

Results of voltage quality measurements before and after PV plant connection are presented in Table III.

TABLE III. VOLTAGE QUALITY RESULTS

Param-eter	Limit		Before PV plant connection		After PV plant connection	
			Measured value	In accordance with EN 50160:2011	Measured value	In accordance with EN 50160:2011
U	+/- 10%	99% week	-6.20%/2.73%	**YES**	-0.06%/4.91%	**YES**
	+ 10% -15%	100% week	-1.05%/2.86%	**YES**	-0.06%/4.91%	**YES**
u	2%	95% week	0.40%	**YES**	0.40%	**YES**
P_{lt}	1	95% week	1.57%	**NO**	1.70%	**NO**
THDU	8%	95% week	2.29%	**YES**	2.51%	**YES**

In this table, accordance of each parameter with Norm limit values is simply marked with **YES** or **NO**.

It is visible that analysed parameters are in accordance with the Norm, beside P_{lt} values.

P_{lt} is obtained for 2-hours period, by:

$$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{i=1}^{12} P_{st,i}^3} \quad (2)$$

P_{lt} is obtained by (2) using Pst. So, for analysing P_{lt}, Pst should be considered. Generally, P_{st} values are increased with/without PV plant connection in this case. P_{st} value increasing after PV plant connection is negligible comparing period before PV plant connection. Fig. 3. shows min. values of line voltages, currents and P_{st} for a week after PV plant connection. From Fig. 3. is visible that the greatest value of P_{st} is obtained for a period when failure occurred and voltage was 0.

If that period is excluded, max short-term flicker values were up to 4. But, in accordance with Norm, for 95% of week max. P_{lt} value was 1.70%. Analyzing this case study, P_{lt} had usually increased value only while PV plant was not producing at all (night hours). It is a fact too that P_{st} increasing is accompanied with decreasing in min. voltage values. It is probably due to short-term failures in grid. Generally conclusion is that after PV plant connection, all voltage quality parameters are in accordance with Norm (all which were in accordance before connection). This is a fact, regardless of PV plant connection in relatively weak grid.

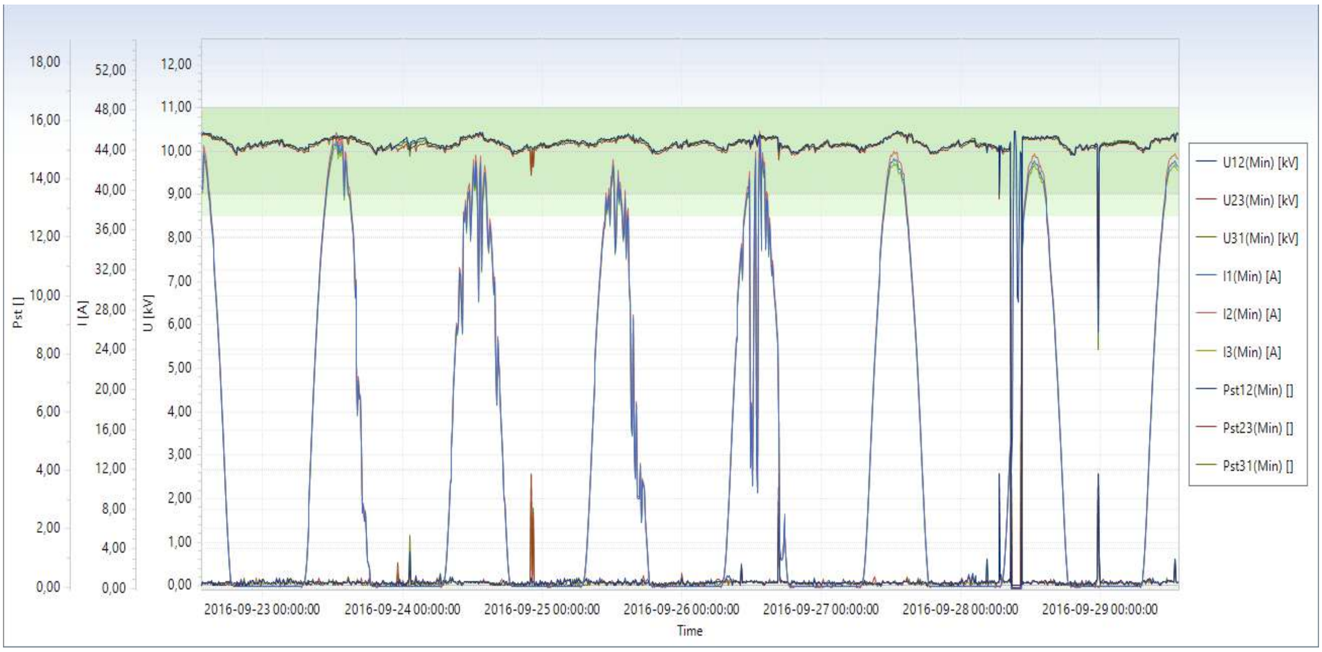

Fig. 3. Value of U, I and P_{st} after PV plant connection (min.values).

Comparison of theoretical approach and measurement
Voltage rise after PV plant connection in theoreticall aspect and after performed measurement can be compared. In accordance with (1), max. voltage rise can be 3.60% after PV plant connection. Max. voltage rise of 4.91%-2.86%=2.05% after PV plant connection was measured. This increase of 2.05% is value for measurement period of 1-week. Still, it is a quiet under 3.60%.

Generally influence of PV plant on distribution grid in PCC

In accordance with Norm, PV plant does not have any negative influence on distribution grid in PCC. Still, influence exists, but in this case study that influence did not contribute to distortion of voltage quality according to the Norm. Previously, P_{lt} was analysed. Voltage unbalance has the same value, before and after PV plant connection.

According to Table III., THDU was slightly increased after PV plant connection. Fig. 4. shows THDU values (%) compared to current I (A) values. There is no any correlation between PV plant production (I) and THDU values. So, PV plant does not contribute to increasing of THDU, even in this relatively weak grid. It is visible from Table III. that voltage is increased after PV plant connection. Fig. 5. shows I (A) values compared to voltage increasing over rated value U_{over} (%). There is strong correlation between PV plant production (I) and voltage increasing in percent values. So, PV plant contributes to increasing of voltage in percent value. It is because voltage is increased while PV plant produces electrical energy. In this case, that increasing considering Norm is not significant. But, problems can occur in even weaker grids or in feeders with more than one PV plants. For multiple DG on one feeder, sharing of hosting capacity of the distribution grid should be considered as in [1].

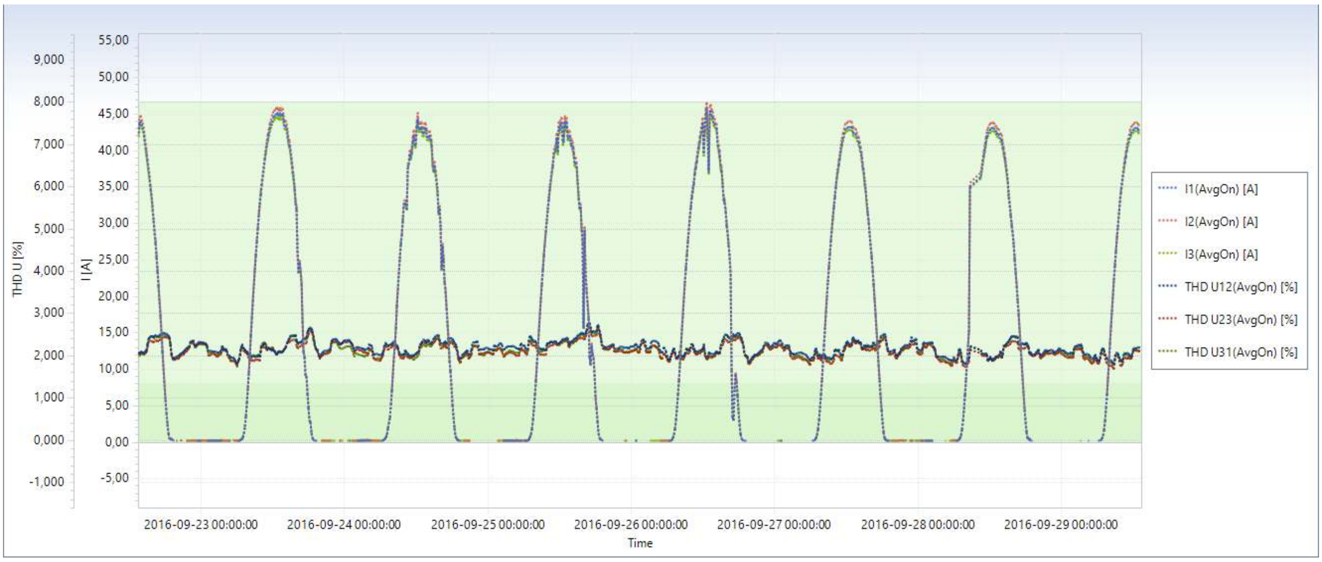

Fig. 4. THDU (%) vs. Current (A).

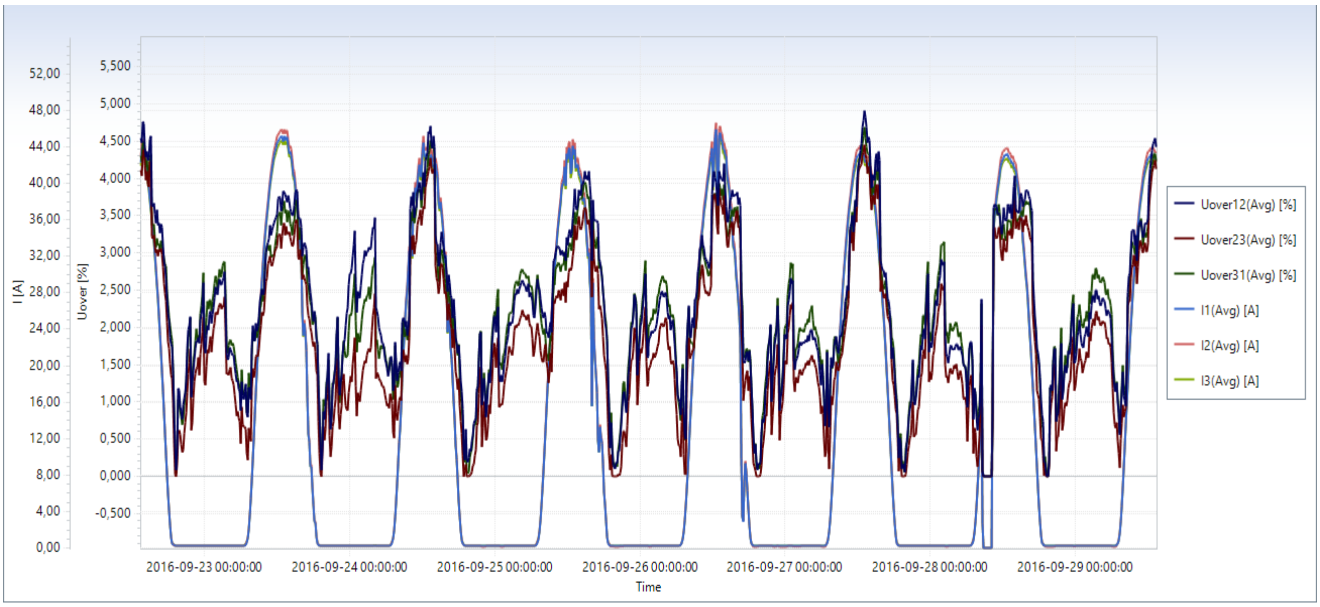

Fig. 5. Current (A) vs. U_{over} (%).

CONCLUSIONS

In this paper influence of PV plant connection in relatively weak distribution grid was analyzed. Influence was evaluated with EN 50160 :2011. Voltage values, voltage unbalance, long-term flicker and total harmonic distortion of voltage were analyzed. Only long-term flickers were not in accordance with EN 50160:2011, before and after PV plant connection. Long-term flickers have negligible increasing after PV plant connection, but it was not due to PV plant connection. Long-term flickers probably are occured due to grid failures.Voltage unbalance was not changed after PV plant connection. There is no any correlation between PV plant production and total harmonic distortion values of voltages. PV plant in this case does not contribute to increasing of total harmonic distortion of voltages, even grid is relatively weak. Slightly increasing of total harmonic distortion of voltages is not therefore due to PV plant connection. On contrary, PV plant contributes to increasing of voltage in percent value. Voltage is increased while PV plant produces electrical energy. In this case, all obtained results are in accordance with EN 50160:2011. But, problems can occur in weaker grids or in feeders with more than one PV plants. In feeders with multiple DG, sharing of hosting capacity of the grid should be considered. For this case study, voltage increasing after PV plant connection is the most vulnerable parameter of voltage quality.

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