Analysis of Network Voltage Quality Parameters Before and After Connecting the Photovoltaic Power Plant

Nedžmija Demirovic[1], Sejdina Goletić[2], Izudin Softić[1], Samed Bajrić[3]
[1]Faculty of Electrical Engineering, University of Tuzla,Tuzla, Bosnia and Herzegovina
[2] Rudnik mrkog uglja "Đurđevik", Bosnia and Herzegovina
[3]Jožef Stefan Institute, Laboratory for Open Systems and Networks, Ljubljana, Slovenia
E-mail: nedzmija.demirovic@untz.ba

Abstract. *In this paper the technical effects of a real photovoltaic power plant on the distribution network are considered. The total power of the system is 21 kW. It is known that distributed production has a significant impact on power flows, voltage profile, voltage stability, system protection, and quality of electricity. This influence can manifest as negative and positive depending on the distribution system, the characteristics of the distributed generator, and the load characteristics. Given that the technical criteria and conditions for connecting the photovoltaic power plant to the distribution network and the safe parallel operation of such a production facility with the power system are defined by certain standards, a check was made to meet the mentioned criteria based on measurements and analysis of the obtained results. The level of technical impacts of the photovoltaic power plant on the operation and characteristics of the distribution network was made based on measurements before and after the connection of the photovoltaic power plant. The analysis of the results of the measurement of electrical quantities at the low-voltage fider of the considered solar power plant showed that there are no negative effects on the quality of electricity and that it meets the connection conditions prescribed by technical recommendations and standards.*

1 Introduction

By connecting distributed generators (DG) to the power distribution network, the network no longer has a classic passive status. It takes on an active character, which requires adequate resolution of technical, economic, and regulatory issues, which concern all participants in the power sector. To limit the negative effects of DG on the electricity distribution network, technical criteria for connection are prescribed, and technical norms and standards are established. In Bosnia and Herzegovina, the connection of distributed generators to the power distribution network is defined by the technical recommendations of the power companies. Given that the number of small power plants is constantly increasing, and that Public Enterprise Electric Utility of Bosnia and Herzegovinais is obliged to take over all produced electricity from renewable sources, within the approved connection capacity of the power plant, the acceptance of distributed production is becoming an increasing challenge for electricity distribution.

A small power plant such as a PV power plant that meets the technical conditions defined by the European standard EN 50160 can be connected to the distribution network [1].

2 Description of the photovoltaic system

The photovoltaic generator is composed of 84 PV modules of the Seraphim SRP 250-PB6 type, which are distributed on the land, the orientation of the photovoltaic modules is in the south direction, at an angle of 30°, the inclination of the modules is -1°. The modules are divided into 7 rows and 12 columns, and in this way, 4 PV arrays of 21 serially connected modules were formed, which are then connected to the REFUsol 020K SCI inverter. The nominal power of each panel is 250 Wp, and the total installed power of the system is 21.00 kW. The PV power plant is located in Nevrenča, Đurđevik B&H: 44.41° 18.66ˈ(Figure 1).

Figure 1 Layout of the photovoltaic power plant

The photovoltaic (PV) power plant is connected to the DSS-P 10/0.4 kV substation with a power of 400 kVA. The single-pole connection and connection scheme of the PV power plant to the distribution network is shown (Figure 2).

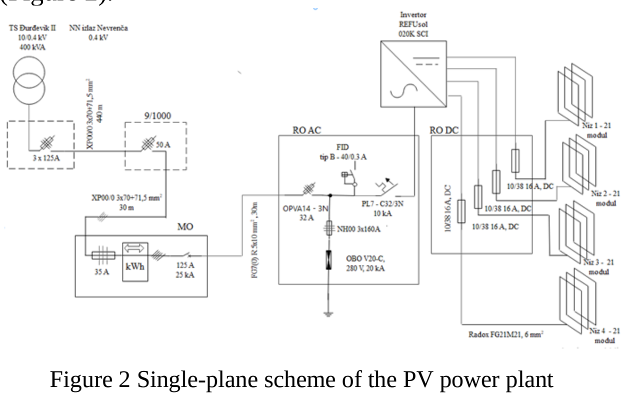

Figure 2 Single-plane scheme of the PV power plant

3 Technical criteria for connecting the PV power plant to the distribution network

The basic technical criteria for the connection of a PV power plant to the distribution network and the safe parallel operation of such a production facility with the power system are: criterion of permitted deviation (change) of voltage, criterion of permitted power, criterion of flicker, criterion of permitted currents of higher harmonics, criterion of increase in short-circuit power. The distribution operator is obliged, after submitting the application for the Preliminary Electricity Approval, which contains basic technical data about the DG, to analyze and define the conditions for connecting the DG to the electrical distribution system in accordance with the valid legal, regulatory and technical regulations and internal procedures of the Distribution Operator [2], [3]. Checking the technical conditions for connecting a solar power plant is carried out by checking the criteria for the permitted power of a small power plant. It is defined by the distribution network rules that the short-circuit power criterion is not checked for photovoltaic power plants [3].

3.1 Criterion of permissible power

The permitted power of the solar power plant with regard to the rapid change in voltage ensures that during switching on/off the voltage change at the point of connection to the electrical distribution system will not exceed 4% in the case of connection to the medium voltage network and 5% for connection to the low-voltage network [3]. This condition is satisfied if:

$$S_{DG} \leq \frac{\Delta u(\%)}{100} \frac{S_{K3}}{k} \qquad (1)$$

where are:

$\Delta u(\%)$ – allowed rapid change of voltage on site connections when switching on/off DG;

S_{K3}- three-pole short-circuit power at the generator connection point;

$k = {}^{I_p}\!/_{I_n}$ the coefficient determined as the quotient of the start-up current and the rated current of the generator

4 Measurments results anaylisis

4.1 Measurement equipment

Recording of voltage quality parameters was performed with a multifunction instrument for power quality analysis and energy efficiency Power Master, model MI 2892 with integrated software for data processing. The device performs measurements in accordance with EN 50160 [4], [5]. The technical impact of the PV power plant on the the distribution network was assessed through seven-day measurements before and after the connection of the power plant.

4.2 Quality parameters

The basic technical criteria for connecting the solar power plant to the distribution network and its safe parallel operation with the network is determined by the deviation of the parameters given in the Table 1, where U_n is rated network voltage. The level of technical impacts of the PV power plant on the operation and characteristics of the distribution network was made on the basis of a seven-day continuous measurement before and after the connection of the PV power plant.

Table 1 Limit values of voltage quality parameters for low voltage plants (0.4 kV)

Parameter	Limit value
Frequency deviation	49.95 do 50.05 Hz
Voltage deviation	U_n ± 10 % U_n +10 % / - 15 %
Total harmonic distortion – THD	≤ 2.5 %
Flicker strength index	≤ 0.7(within10 min) ≤ 0.5(within 2hour)
Voltage asymmetry	≤ 1.3% U_n

4.3 Grid voltage with no connected PV power plant

Voltage fluctuations measured before power plant connection shown in Table 2. Figure 1 shows a diagram of the voltage values defined by the norm and the measured mean effective voltage values in the network with no connected power plant for the duration of seven days. Limit values are shown on the diagram as U(-15%), U(-10%) i U(+10%) (Figure 3).

Table 2 Deviation of the voltage before connecting the PV power plant

phase	Required number 10' intervals in a week (%)	Minimum value (V)		Maximum value (V)	
		EN 50160 (V)	Measured (V)	EN 50160 (V)	Measured (V)
L1	95	207	207.89	253	248.9
L1	100	195.5	207.89	253	248.9
L2	95	207	207.67	253	247.72
L2	100	195.5	207.67	253	247.72
L3	95	207	207.14	253	244.07
L3	100	195.5	191.74	253	244.07

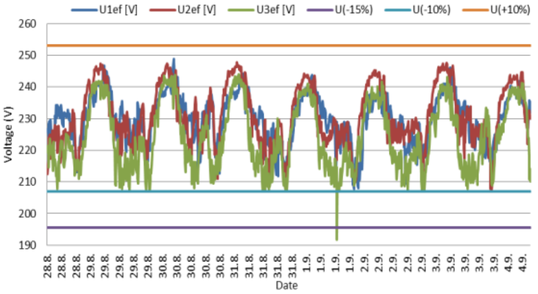

Figure 3 Effective voltage values without connected power plant

It is noticed that the 10-minute mean effective voltage values in all three phases are slightly lower than the ideal 230 V. During the measurement period, no events were recorded, which are defined by the standard as voltage dips and overvoltages. During the seven-day measurement, the measuring device recorded a breakdown in phase L_3 of 191.74V. Given that the failure occurred during measurements before the power plant was connected to the LV network, its cause could not be the power plant but problems in the network caused by the consumer.

4.4 Network voltage after connecting the PV power plant

Figure 4 shows a diagram of the voltage values defined by the standard and the measured mean effective voltage values in the network without a connected power plant.

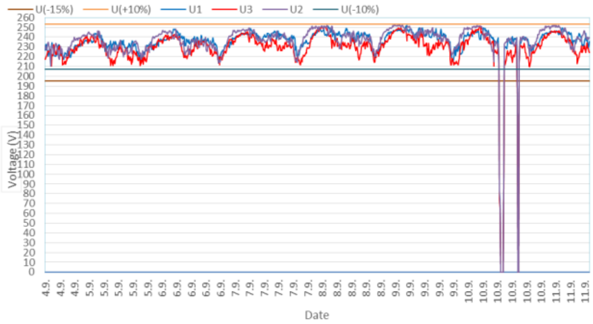

Figure 4 Effective voltage values with connected PV power plant

The voltage in all three phases was on average slightly higher than 230 V, but within the limits prescribed by EN 50160. Long-term voltage interruptions were recorded due to the loss of electricity in the grid, as a result of power interruptions in to the grid, independent of the PV power plant.

4.5 Frequency analysis before and after power plant connection

According to EN 50160, the nominal frequency of the supply voltage is 50 Hz. Under normal operating conditions, the 10-second value of the fundamental frequency in the network connected to the power system must be within the following limits - 50 Hz +/- 1% during 95% a week, - 50 Hz +4%/-6% during 100% a week. According to IEC 61000-4-30, during recording with aggregation time ≥10 sec frequency reading shall be obtained every 10 s [6].

The measured frequency before connecting the PV power plant, is shown in (Figure 5).

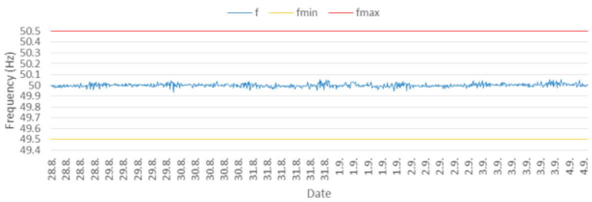

Figure 5 Frequency values with no connected PV power plant

For most of the monitoring period, the frequency remains well within the acceptable range. However, there are a few brief instances where the frequency dips below the lower threshold, which could be indicative of transient events or minor disturbances in the power system (Figure 6)

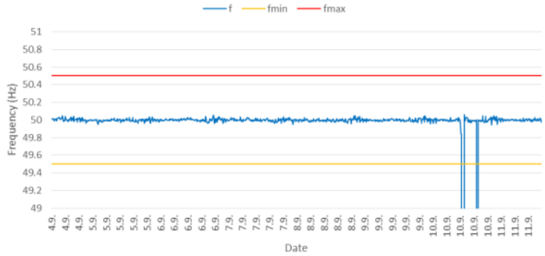

Figure 6 Frequency values with connected PV power plant

4.6 Analysis of long-term flickers

The diagram of the maximum values of long-term voltage flickers which are the result of a seven-day measurement without and with the power plant connected to the grid is shown in (Figure 7, Figure 8). In phase L3 during the 7-day measurement, at one point the limit value was exceeded, i.e. $Plt3$ has a value of 1.23 before connecting the PV power plant. After the connection of the PV power plant, value of the flicker is exceeded, which coincides with the loss of electricity in the network, as was shown in the previous diagrams (Figure 8).

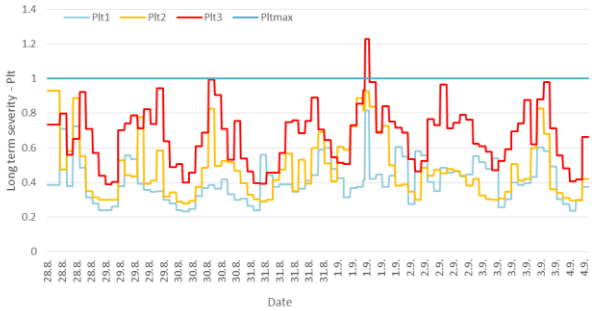

Figure 7 Diagram of long-duration voltage flickers with no connected PV power plant

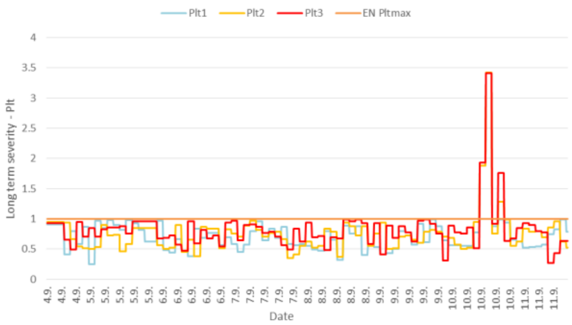

Figure 8 Diagram of long-duration voltage flickers with connected PV power plant

4.7 Voltage unbalance

The supply voltage unbalance is evaluated using the method of symmetrical components. In addition to the positive sequence component, under unbalanced conditions there also exists at least one of the following components: negative sequence component u_2 and/or zero sequence component u_0. The evaluation of the zero-sequence unbalance ratio u_0 is optional, not mandatory [6]. Under normal operating conditions, during a week, 95 % of the 10 minutes mean RMS values of the negative sequence of the supply voltage should be within the range from 0 % to 2 % of the positive sequence, and in this case this condition is satisfied. In the case where the PV power plant is connected to the grid, the highest value of the zero sequence unbalance is 1.987%, and the negative sequence unbalance is 2.28%, as is shown in (Figure 9) and in (Figure 10). The analysis of the results shows that the 10-minute averaging values were exceeded in 3.3% of the intervals over the seven days.

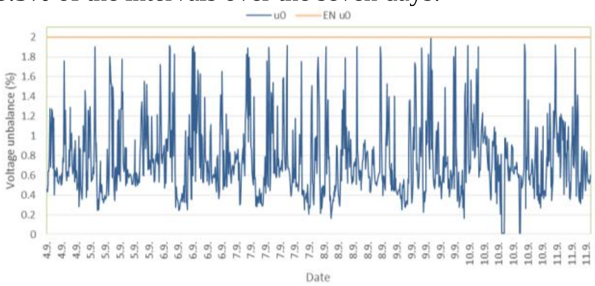

Figure 9 The negative sequence unbalance component with connected PV power plant

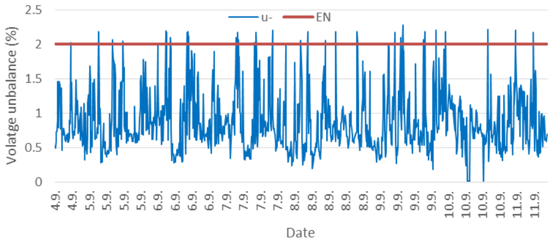

Figure 10 The zero-sequence unbalance component with connected PV power plant

4.8 Harmonic quality analysis and total harmonic voltage distortions

The diagram of the THD coefficient of phases L1, L2 and L3 after PV power plant connection to the grid is shown in (Figure 11). The maximum value of the coefficient is 8% (phase L2), which is at the limit of the permissible value.

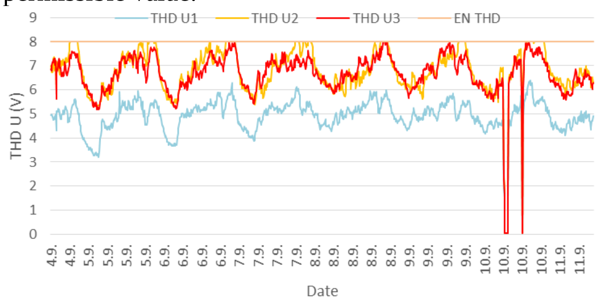

Figure 11 Total harmonic distortion of the voltage of phases L1, L2, and L3 with connected PV plant

The seven-day measurement recorded the values of all 25 harmonics in 10-minute intervals when the PV power plant was connected to the grid (Figure 12).

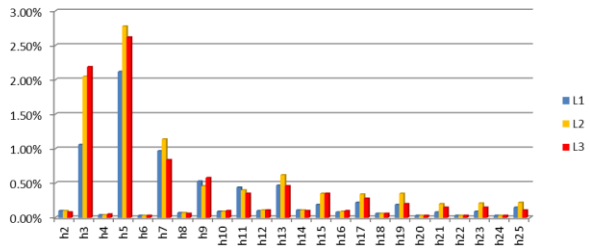

Figure 12 Amplitudes of higher-harmonic components with connected PV power plant

All parameters of higher harmonic components remained within the permissible limits according to the EN 50160 standard, which means that the PV power plant meets the criterion of higher harmonics according to the EN 50160 standard.

5 Conclusion

The measurements conducted with the photovoltaic (PV) power plant connected to the grid, along with the subsequent analysis, indicate that the feedback effect of the PV power plant on the grid and the quality of electricity remained within the permissible limits prescribed by EN 50160.

Despite the PV power plant meeting the criteria for grid connection, the measurement diagrams revealed a slight disturbance in certain electricity parameters. This suggests that if the number of PV power plants connected to the same low-voltage network continues to increase, the limit values of electricity quality parameters defined by EN 50160 could potentially be exceeded. In such a scenario, further testing of the network would be necessary.

Future research will focus on network modeling and scenarios that could lead to a decline in electricity quality parameters. Additionally, the impact of seasonal changes and load variations on the distribution network with connected PV power plants will be investigated. The research will also propose potential solutions to mitigate any adverse effects resulting from the integration of PV power plants into the network.

6 References

[1] CENELEC, European Committee for Electrotechnical Standardization, European Standard EN 50160, 2010

[2] B. E., Dž. Izet, Kriteriji za priključenje distribuiranih generatora sa osvrtom na Tehničku preporuku JP Elektroprivreda BiH d.d. Sarajevo, Neum: BHK CIGRE, 2009.

[3] Network distribution rules of the distribution system operator of the public company Eelektroprivreda BiH, https://www.epbih.ba/upload/documents/Mrezna%20pravila%20distribucije_ODS%20EP%20BiH.pdf

[4] Power Master MI 2892 Instruction manual Version 8.5.7, 2020 METREL

[5] IEC 61000-4-30: Electromagnetic compatibility (EMC) – Part 4-30