Measuring Electric Power Quality of Renewable Energy Sources

Case study

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Abstract *– Over the past few years, the potential for building renewable energy sources has come to recognition in Slavonia, which resulted in building two new renewable energy sources in the area of HEP ODS Elektra Vinkovci. In this paper, we did the analysis of the electric power quality in these sources according to the HRN EN 50160:2008 norm. We measured quality with stationary measure terminal MT-20QL for a small biogas plant Farm Osatina in Ivankovo with installed power of 1MVA (generator 110 kV) and a portable measuring device Analyst 3Q produced by LEM company for the solar power plant Sikirevci, with installed power of 10 kVA. The results of our measurements were analyzed by using the corresponding software of the above mentioned measuring devices.*

Keywords *– flickers, harmonic distortion, power quality, renewable energy source*

1. INTRODUCTION

Croatia has great natural potentials for building renewable energy sources. For years, we have been witnesses of using wind energy on our coast. Considering the fact that agriculture is the main branch of activity in Slavonia and Srijem, it is immediately obvious that there are great potentials for building biogas plants in the mentioned parts of Croatia. We should not neglect solar energy either, because Ilok, for example, has almost the same number of sunny days as Dubrovnik.

HEP ODS Elektra Vinkovci has received 17 applications so far from potential renewable energy sources producers of the total power of 54.8 MVA. Up to now, the biogas plant in Ivankovo, with connective power of 2 MVA, has been connected to the network. The investment was done by agricultural cooperative (AC) Osatina and Bovis. Apart from biogas plants, the solar power plant Sikirevci is also active, with installed power of 10 kVA, which was built on the roof of an apartment and a business building.

In this paper, we are going to analyze the quality of electric power in renewable sources of electric power built in the area of Elektra Vinkovci. We start with the HRN EN 50160:2008 norm which defines and describes important features of the distribution voltage and a supplier has to make sure that voltage meets a basic level of this norm. Furthermore, basic characteristics of measurement devices MT-20QL and Analyst 3Q are outlined. Each of those devices measured the electric power quality in a suitable power plant. Measurements results are given in conclusion.

2. ELECTRIC POWER QUALITY

2.1. MISCELLANEOUS

We could say that electric power has become a consumer good, and this is why it is necessary for the producer to be able to guarantee that his/her product complies with certain standards in terms of quality and safety [1]. Thereby, it is assumed that the supplier has to make sure that voltage meets a basic level of quality (e.g. HRN EN 50160:2008 for a low-voltage and middle-voltage distribution network, or IEC 61000-4-30 for a high-voltage transmission network) [2]. The HRN EN 50160:2008 norm defines and describes important features of the distribution voltage in the place where it is delivered to a user in public low-voltage and middle-voltage networks in normal operational conditions [3], [4], [5].

According to the HRN EN 50160:2008 norm, the values of the basic eight parameters of electric voltage in a low-voltage (up to 1,000 V AC) or middle-voltage network (1,000 – 35,000 V AC) are measured and recorded [3]:

1. voltage fluctuations,
2. flicker: short-term (Pst) and long-term (Plt),
3. harmonics: from the 2nd to the 40th,
4. signaling voltages (Ripple Control – signal control voltages), interharmonics, MTU,
5. frequency of the distribution voltage,
6. asymmetry of voltage,
7. voltage dips and/or surges, overvoltages,
8. supply disruptions

An ordinary electric power system works on the principle that large central generators deliver electric power to the high voltage transmitting network. After being transmitted, electric power is transformed and through the middle and low voltage distribution networks it is delivered to the users.

In an ordinary electric power system, the responsibilities of the participants in its work can be divided in the following way: the users are responsible for control of the emissions of harmonic currents caused by functioning of their loads to the public distribution network, whereas the distribution company is obliged to maintain the quality of supply [3].

The users of electric power affect its quality more (non-linear loadings) than its producers and suppliers. This is why there exists a certain partnership between the user and the supplier when it comes to providing quality of electric power. Apart from that, the user is also affected by electric power pollution when it occurs.

The greatest number of voltage dips and disruptions occurs in the distribution and transmission networks, which means that suppliers and electrical utilities bear responsibility for them. However, users are almost always accountable for the problems caused by higher harmonics in the system. This is typical of ordinary production, but when it comes to distributed production of electric power, things are a bit different.

Through apparition of renewable resources whose power is relatively small the need emerged for connecting production facilities to the distribution network. This is how distributed production of electric power came to be.

One of the problems of distributed production is the quality of electric power. Distributed production mostly affects flickers and harmonics. Voltage flickers cause repetitive fluctuations of voltage values and light density, which is visible to the naked eye. This mostly appears because of changes of loading which are due to activation of new, bigger units or abrupt changes in unit injection [3], or in other words, flickers are made by loads with a high rate of change of power with respect to the short-circuit capacity at the point of connection to the supply [6]. Harmonics are brought to the network by all non-linear loads, e.g. converters which connect distributed production to the network [7], [8], [9].

2.2. DEVICES FOR MEASURING ELECTRIC POWER QUALITY

Quality control of voltage in low-voltage and middle-voltage distribution networks (from 0.4 to 35 kV) can be made with help of devices prescribed by HRN EN 50160:2008. Measurement of the quality of electric power is performed in the way that we collect measuring values (current values, voltage and frequency) within a certain period of time. With this done, the data are then arranged and computerized according to recommendations for the quality of electric power. Results of such measurements show us whether the quality of electric power in a respective place is satisfactory or not.

Today, most of the devices used for measuring the quality of electric power have setups for electric power quality recommendations (norms) incorporated in their software (most commonly HRN EN 50160:2008), so that voltage quality reports in respective places can be made automatically within a time period prescribed by the recommendation.

If we are interested in only a few of the parameters of the quality of electric power and not in the complete quality report, these devices can also be helpful because most of them give us diagrams of particular values analyzed by a respective norm.

All these devices are mostly used for voltage quality analysis on demand, so that their performance is transmittable (offline measurements). The adjustment of its parameters and sensing of measured data are done in the way that the device is directly connected to a PC with a communication cable (RS-232 or Ethernet). An example of such device is Analyst 3Q produced by LEM company (today, Fluke 1735) which we used for measuring the quality of electric power in the photovoltaic plant in Sikirevci. Analyst 3Q [3] is a three-phase offline analyzer of the electric power and network quality. This device measures parameters in all three phases and null conductor in three-phases systems. It can also record electric power parameters for 45 days. The device measures higher harmonic components and it can quickly analyze the compliance of voltage with the HRN EN 50160:2008 norm, with the option of extracting a problematic parameter for its further analysis.

Apart from on-demand electric power quality analyses or periodical measurings, there are also systems for continuous electric power quality assessments in the system (online measurements). An example of such system is a measuring device called MT-20QL produced by IEL Ltd. Company, which was built in the biogas plant Farm Osatina for the purpose of electric power quality analysis on the middle-voltage level.

MT-20QL [10] measure terminals are designed for permanent measurement and registration of electrical network parameters, as well as for control and analysis of the electric power quality in low-voltage and middle-voltage networks, distribution and industrial substations. Thanks to digital processing of the signal, the device does calculations of a range of electrical network parameters (power, power factors, frequency, energy, etc.) based on measurements of input voltages and currents. It also calculates network quality parameters (voltage and current harmonics, voltage flickers, asymmetry, etc.). MT-20QL measure terminals provide an insight into electric power quality parameters and enable registration of measured values in 16 MB memory. All values are measured according to the IEC 61000-4-30 A class standard and registration of values is conducted in the way that an analysis and making a report according to the HRN EN 50160:2008 are enabled. For data sensing, analysis, graphic presentation and making reports on the measured values, we use the following program tools:

- MT-DIALOG 3 - for the analysis of some MT-20 measure terminals,
- MT-QUALITY - for the analysis of a greater number of MT-10S, MT-10SX and MT-20, measure terminals, which are communicationally connected.

The most significant difference between the two measuring devices we used in this project is that Analyst 3Q normally does harmonic analysis to the 40th harmonic, and it only records the total harmonic distortion (THD) to Random Access Memory (RAM), which means that by using this device, we cannot do a real harmonic analysis.

3. MEASURING ELECTRIC POWER QUALITY OF RENEWABLE RESOURCES

In the next part of this paper, we will make an analysis of the results referring to the electric power quality we measured in the biogas plant and the photovoltaic power plant. Thereby it is important to mention that the quality of electric power in the biogas plant has already been measured by the Faculty of Electrical Engineering in Osijek (ETFOS). The electric power quality was satisfactory then [11].

3.1. MEASURING ELECTRIC POWER QUALITY IN THE BIOGAS PLANT

The biogas plant in Ivankovo, investment done by AC Osatina and Bovis, has connective power of 2 MVA (Figure 1). For the purpose of this paper we did measurements only in the field of generator 1 (=J06) – biogas aggregate of a small power plant on the farm AC Osatina of the installed power of 1MVA. The installed aggregate of 1 MVA power produces electric power on low voltage, 420 V, and delivers it to the distribution network HEP ODS Elektra Vinkovci on 10 kV voltage.

The biogas plant has the option of double-sided power supply from 10 kV networks through the line 10(20) kV "Slatina" supplied from the substation 35/10(20) kV

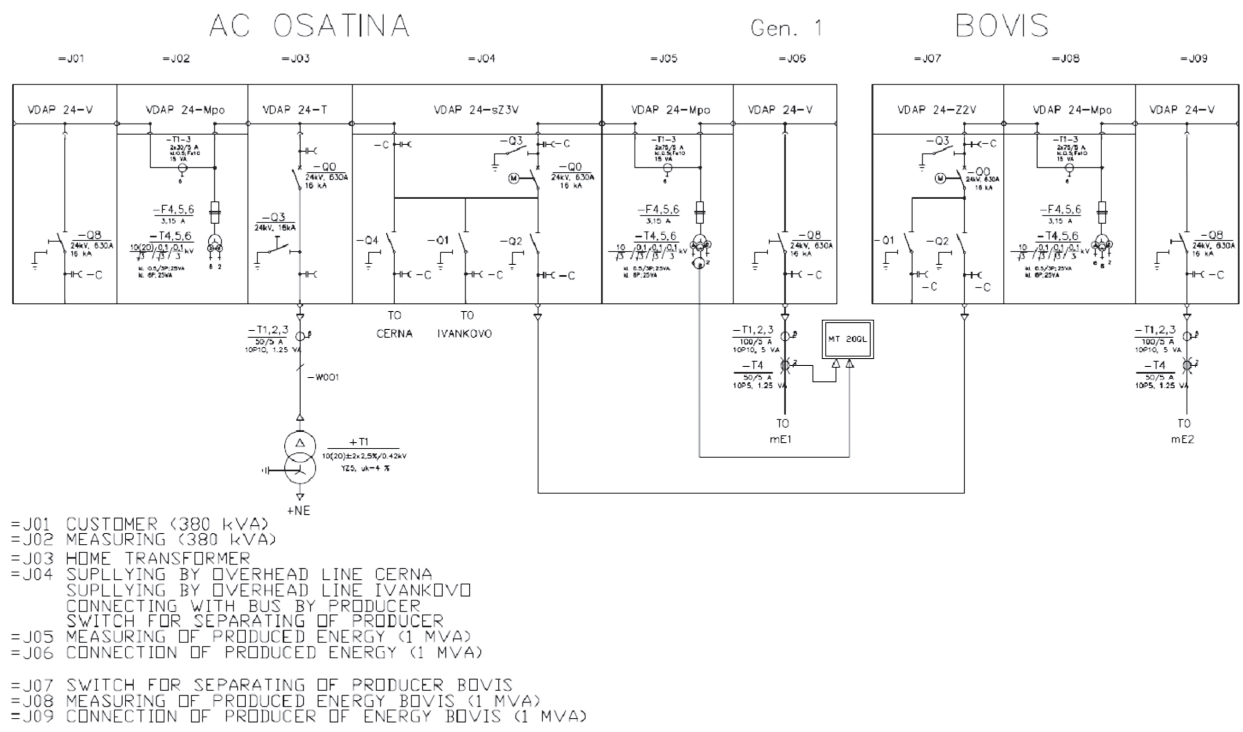

Fig. 1. Electrical scheme of a small power plant in Ivankovo

"Cerna" and through the line 10(20) kV "Ivankovo" from the substation 35/10(20) kV "Vinkovci 5".

ETFOS analyzed the electric power quality during the trial run of the power plant [11]. This was done on demand of Belišće d.d., a factory producing electrical equipment. Measurements were conducted according to the European norm HRN EN 50160:2008 with TOPAS 1000 network analyzer within the period beginning on 22 October 2009 at 10:00:00 o'clock and ending on 29 October 2009 at 10:00:00 o'clock (Figure 2). In general, the values of voltage quality parameters ranged within the limits prescribed by the HRN EN 50160:2008 norm, except for flicker parameters. The conclusion of the project was that the quality of the distribution voltage is on a satisfactory level.

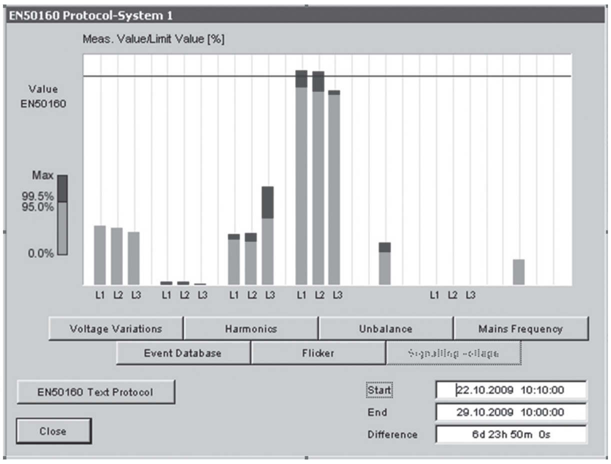

Fig. 2. Electric power quality according to the HRN EN 50160:2008 norm, measured with the TOPAS 1000 analyzer [11]

In order to analyze functioning of this power plant measurements were conducted by means of the MT-20QL inbuilt stationary device. Measurements conducted in the period between 21 January 2010 at 0:00:00 o'clock and 27 January 2010 at 23:50:00 o'clock (Figure 3) showed that, similarly to measurements during the trial run, the values of voltage quality parameters did not exceed the values prescribed by the HRN EN 50160:2008 norm, except for flicker parameters.

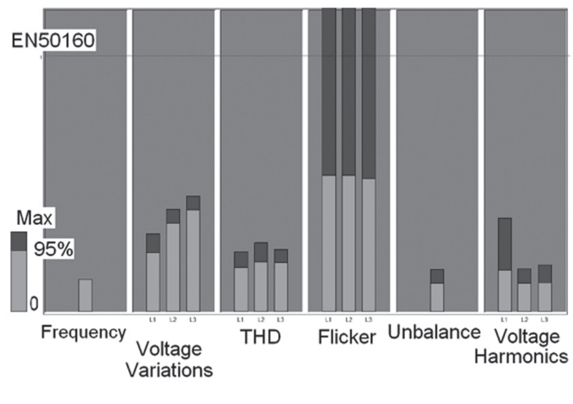

Fig. 3. Electric power quality during the time period between 21 January 2010 at 0:00:00 o'clock and 27 January 2010 at 23:50:00 o'clock

The middle values of the line-to-neutral voltage in the L1 phase shown in Figure 4 (Measurements in the field =J06 generator 1) are compatible with the values prescribed by the HRN EN 50160:2008 norm.

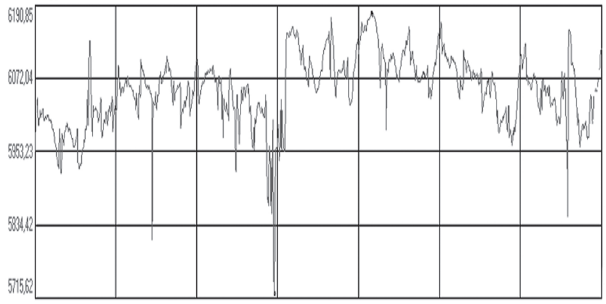

Fig. 4. The middle values of the line-to-neutral voltage in the L1 phase (Measurements in the field =J06 generator 1)

A significant amount of flickers in the measuring period (21 January 2010 to 27 January 2010) is caused by the fact that the second generator "Bovis" 1 MVA in Osatina Farm was still not commissioned in the period between the last measurement (TOPAS 1000 device -period between 22 October 2009 and 29 October 2009) and the new measuring period (21 January 2010 – 27 January 2010). Since the producer in the biogas plant connects generators 1 and 2 to the network through synchronization according to the biogas availability (as well as to the operative readiness of the plant), he also autonomously disconnects them for the same reasons. In addition, disconnection of generators 1 and 2 from the network due to 10 kV network failures also has an effect on the occurrence of flickers. As for the generators, it is not allowed to let them work isolatedly with the equivalent consuming load (<2 MVA) after network dropout, because of the possibility of network voltage restoration. This is why (abrupt changes of injected energy) the total proportion of flickers (%) in the network voltage increased.

The MT20QL IEL electric power quality analyzer provides a detailed presentation of specific phases of harmonic analysis of generator 1 voltage and currents. It is interesting to see which current harmonics (and with which relative %) are injected by the generator to the 10 kV electrical network.

In Figure 5, there is a harmonic analysis of the generator current in the field =J06 generator 1 represented, which was conducted between 21 January 2010 at 0:00:00 o'clock and 27 January 2010 at 23:50:00 o'clock in the L1 phase. The odd harmonics are propounded, with the highest magnitude of the fifth harmonic (H5). The harmonic analysis of the line-to-neutral voltage in the L1 phase is presented in Figure 6, where one can see how current harmonics cause distortion of voltage.

The total harmonic distortion is far below the level prescribed by HRN EN 50160:2008 (8%). The total harmonic distortion also satisfies the requirements of the Network rules given by Hrvatska elektroprivreda (HEP) which allow the contribution of the generator to the total harmonic distortion of 2% [12]. The measured THDv in the figure is actually the sum of the contribution of generators 1 and 2 (2 MVA) and all users connected to buses submitted to measurements. This figure shows us the network voltage distortion. Considering the fact that the total THDv presented in Figure 7 only slightly exceeds the value of 2%, we can conclude that the effect of the generator on the total harmonic distortion is less than 2%.

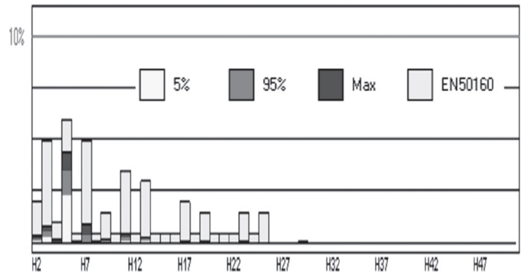

Fig. 5. Current harmonics in the L1 phase (Measurements in the field =J06 generator 1)

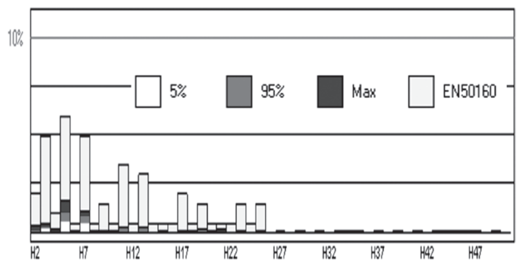

Fig. 6. Voltage harmonics in the L1 phase (Measurements in the field =J06 generator 1)

The total harmonic distortion is far below the level prescribed by HRN EN 50160:2008 (8%). The total harmonic distortion also satisfies the requirements of the Network rules given by Hrvatska elektroprivreda (HEP) which allow the contribution of the generator to the total harmonic distortion of 2% [12]. The measured THDv in the figure is actually the sum of the contribution of generators 1 and 2 (2 MVA) and all users connected to buses submitted to measurements. This figure shows us the network voltage distortion. Considering the fact that the total THDv presented in Figure 7 only slightly exceeds the value of 2%, we can conclude that the effect of the generator on the total harmonic distortion is less than 2%.

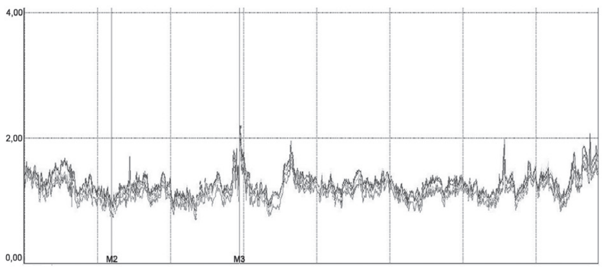

Fig. 7. THDv of the line-to-line and line-to-neutral voltages (Measurements in the field =J06 generator 1)

3.2. ANALYSIS OF POWER QUALITY IN THE PHOTOVOLTAIC POWER PLANT IN SIKIREVCI

The photovoltaic power plant was built on the roof of an already existing residential and business building in Sikirevci. There have been 100 photovoltaic modules installed on the area of 143 m2, which have the power of 100 VA and which were produced by SCHOTT company. The total power of modules, when adjusted to the converter, amounts to 10 kVA. The converter type SMA 10000 TL has the power of 10 kW and efficiency of 97.3% with the total maximum power of 10.9 kW. It is estimated that the photovoltaic power plant produces 10,400 kWh annually. There is a three-phase connection employed, and the connection voltage amounts Un=0.23/0.4 kV 50 Hz.

The facility on which the photovoltaic power plant was built is connected with an XP00-A 4x25+1.5 mm2 cable through the point of presence to the low-voltage network run over the concrete pillars with X00/0 3x70+71.5+2x16 mm2 self-bearing cable bunch. The respective network is supplied from a low voltage output of the substation 10(20)/0.4 kV "Sikirevci 1". This substation is supplied from the substation 35/(20)10 kV Drenovci which is radially supplied from the substation 110/35/10 kV Županja 2.

For the purpose of connecting the photovoltaic power plant HEP ODS d.o.o. Elektra Vinkovci analyzed the power quality in place of connection of the power plant before it was connected, during and after its trial run. Voltage is measured directly and the current is measured by Rogowski bobbins. The last measurements were conducted according to the HRN EN 50160:2008 European norm with the network analyzer Analyst 3Q during the time period between 3 October 2011 at 12:06 o'clock and 10 October 2011 at 12:25 o'clock and they lasted for 7 days and 19 minutes (Figure 8). In general, the values of voltage quality parameters did not exceed those prescribed by HRN EN 50160:2008, except for flicker parameters (too high values with the total duration shorter than 5% of the measurement week, which is not allowed).

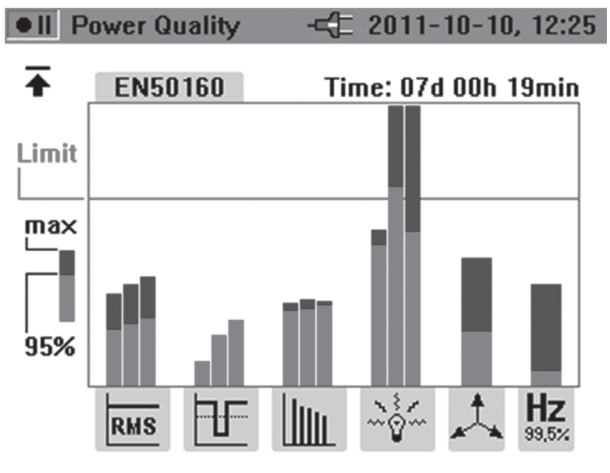

Fig. 8. Power quality during the period between 3 October 2011 at 12:06 o'clock and 10 October 2011 at 12:25 o'clock

The middle values of voltage (Figure 9) range within the value limits prescribed by the HRN EN 50160:2008 norm, and they meet the rules given in the Regulation on the standardized voltages for the distribution low-voltage electrical networks and electrical equipment (Narodne novine 28/00).

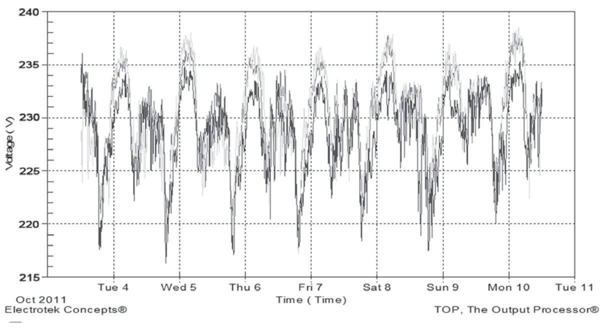

Fig. 9. Middle values of voltage after the power plant was put to work (in all 3 phases)

The total harmonic distortion after the power plant was put to work (Figure 11) is far below the level prescribed by the HRN EN 50160:2008 norm (8%). The total harmonic distortion also satisfies the requirements of the Network rules given by HEP which allow the contribution of the generator to the total harmonic distortion of 2.5% [12] (the measurements done before the photovoltaic power plant was put to work, which were conducted in the place of connection of the existing facility amounted 2%-3% on average - Figure 10).

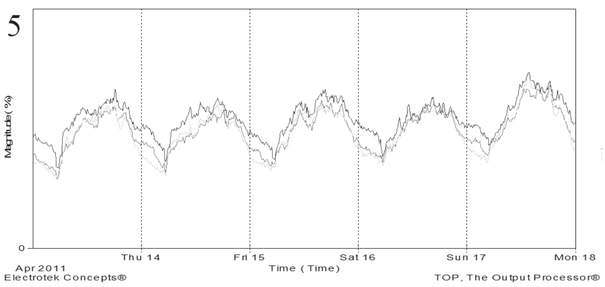

Fig. 10. The total harmonic distortion THDv in %Un before the power plant was connected (in all 3 phases)

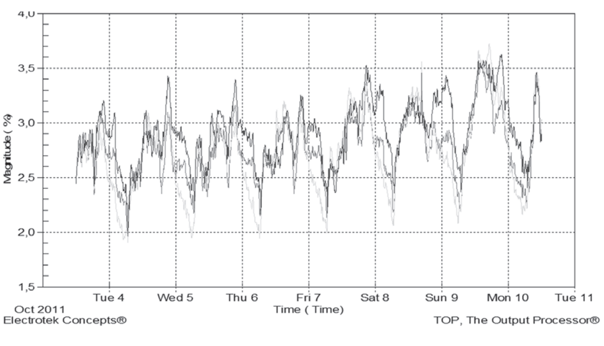

Fig. 11. The total harmonic distortion THDv in %Un after the power plant was put to work (in all 3 phases)

The photovoltaic power plant Sikirevci has lower installed power (10 kVA), so its contribution to the relative increase of flickers in the network is negligible. Long voltage flickers do not meet the rules prescribed in the HRN EN 50160:2008 norm in the second phase in 95% of the measurement period (Plt<1), and especially not in the remaining 5%. However, the measurements done before the solar power plant was put to work (Figure 12) did not satisfy the norm either.

Plt was higher than the permitted value 1 every day during the measuring period (Plt max=1.4 - Figure 12). The fact is that the HEP electricity network in rural grids has already had flickers Plt and Pst [13], [14]. It is well known that flickers are generated by impact loadings and unloadings of the HEP system (as well as the individual elements of the electric power system in the HEP network - regardless of whether it includes connection or disconnection of electric power plants or connection, disconnection or unloading of consumers) [3], [6].

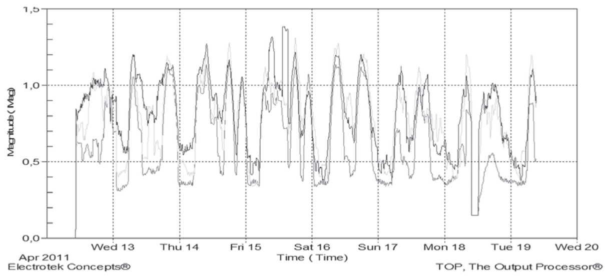

Fig. 12. Long voltage flickers before the power plant was connected (in all 3 phases)

In the Elektra Vinkovci network, the analysis of appearance of flickers in the network has not been done yet, which means that the measures which should be taken in order to reduce the amount of flickers have not been determined yet. The device used for the analysis is of lower quality, but it is still capable of recording the appearance of flickers.

In Figure 13, you can see joint voltage of the electric power plant and the HEP network. The proportion of flickers Plt was Plt>1 as before the power plant was put to work. In Figure 13, we can also see 3 important excesses of Plt with the maximal value >1.7. Those 3 excesses may come from anywhere, but it is not expected that the power plant is the source. If the power plant were the source, we would then have Plt>1 in all 3 phases. We notice that, with the exception of these excesses, other values are almost within the prescribed limits.

We concluded that the power plant did not significantly affect the occurrence of flickers. That is the reason why the solar plant is still connected to the network although one of the parameters (Plt flickers) is over the limit in one phase. Our future task will be to thoroughly analyze the appearance of flickers in the Elektra Vinkovci network and to take measures to reduce them. Some steps in this direction were made in HEP, Elektroistra [14]. How complex it could be is shown by measurements and research in the Slovenian transmission network [15].

In Figure 14, it is visible that higher harmonics of the supply voltage are mostly caused by higher harmonics of the current of nonlinear user's load (THDc before the power plant was connected).

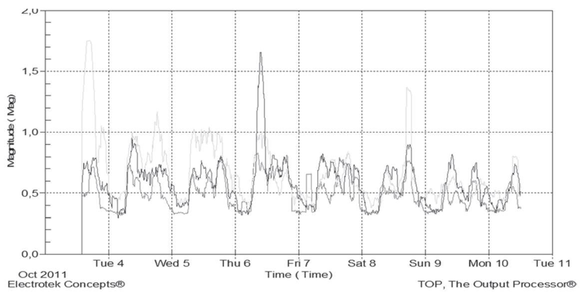

Fig. 13. Long voltage flickers after the power plant was put to work (in all 3 phases)

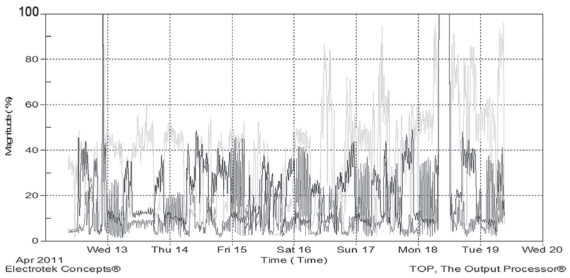

Fig. 14. The total harmonic distortion of current (THDc) in %In before the power plant was connected (in all 3 phases)

It is visible from Figure 15 that the converter through which the photovoltaic power plant is connected to the network adds current harmonics to the network to a significant extent. Harmonics increase the losses, additionally overload the equipment, can damage delicate equipment and diminish the lifespan of the engine, transformer and battery capacitor. We can notice here that the occurrence of current harmonics is connected to the amount of light flow which enhances panels, following the daily diagram of power production, and especially during the sunny days. The occurrence is periodically repeated every day at approximately the same time (from 7.00 to 8.00 am and from 4.00 to 6.00 pm).

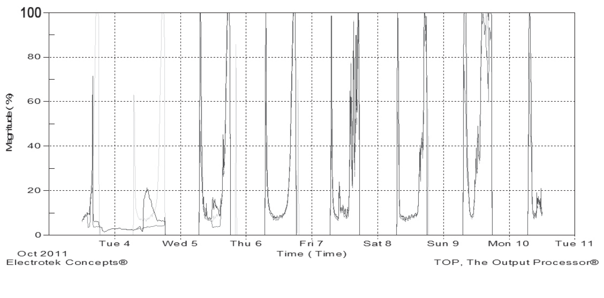

Fig. 15. The total harmonic distortion of current in %In after the power plant was put to work (in all 3 phases)

4. CONCLUSION

The biogas plant fulfils the power quality criteria prescribed by the HRN EN 50160:2008 norm and does not have a negative effect on the power quality. This was expectable because the values satisfied the norm even during the trial run of the plant, and the plant itself is properly connected to the middle voltage HEP network. It is important to notice that the biogas plant, as a distributive producer of electric power, will contribute to the relative (%) increase of the amount of flickers during its connection to the network, disconnection and occasional abrupt changes of the injected energy to the 10 kV network. In addition to that, the biogas plant will, through its injection of energy to the network, participate in the relative increase of THDv% (THDc %), because of the presence of current harmonics of generator 1 and 2. It has been proved that for the connected power of the biogas plant Osatina (the total of 2 MVA), THDv% does not deteriorate from 2% onwards (contribution of THDv% is <2%, which satisfies the HEP network norms).

The solar power plant Sikirevci also fulfils the voltage criteria given by the HRN EN 50160:2008 norm. The solar power plant Sikirevci has lower installed power (10 kVA), so that its contribution to the relative increase of flickers in the network is negligible. The increase of the total THDc of the solar power plant in Sikirevci reduces the power quality because it participates in voltage distortion, i.e. in the relative increase of THDv% of the network. For the purpose of further analysis it is necessary to make a detailed harmonic analysis of currents with a more precise measuring instrument, because the one we used, Analyst 3Q, can make a harmonic analysis up to the 40th harmonic, but it records only THD to RAM (it does not provide presentations of separate harmonics).

Renewable energy sources certainly have their place in the future; they have many advantages as well as disadvantages, but with an increasing number of such sources it will be necessary to devote particular attention to the problem of power quality.

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