# Power quality measurement of small solar off-grid system

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*Abstract:* - Energy from renewable energy sources increase of recent years. This increasing is consequence of reduction of $CO_2$ effort and it reduces the price of renewable energy sources. Development of distributed generation and energy self-sufficient regions supported also by the development of a smart grids research contributes significantly to the diversification of primary energy sources and helps to increase the energy efficiency. Smart grids, distributed generation and self-sufficient off-grid systems are becoming one of the priorities for research in EU Member. The interest in off-grid systems is proved by the number of research and pilot projects. Aim of this paper is presented an example of stand alone low power photovoltaic off-grid system and an analysis of the power quality carried out for the system working to load control system. This load control system was developed to make the tests and simulations of this off-grid system with optional and user predefined load profiles in laboratory environment. In the last part of paper are results from in-situ measurement in small off-grid installation. All the results give information for better knowledge about off-grid operation and power quality.

*Key-Words:* - Off-grid system, power quality, load profile, load control, appliance simulator, smart grid, renewable energy sources

## 1 Introduction

The topic of renewable energy sources has gained so much attention as the internet and information and communication technologies in the 1990s – it has become the hottest and most discussed topic among global leaders, investors and in mass media [1]. Many planners and decision makers agree that the off-grid PV system has the potential to become a valued and straightforward source of electricity for remote rural communities. However, there are several challenges that need to be addressed to realize the potential of PV as a sustainable solution. [2] Stand alone PV, micro-hydro and micro-wind systems have been widely adopted in developed nations as an effective method of complementing available grid power, often incentivized by Governments and regulators to encourage uptake and increase penetration of renewable technologies as a mechanism for offsetting carbon emissions. There is an opportunity for such technologies to provide a relatively cost effective method of opening up access to electricity for the rural poor of developing countries. The World Bank identified the four main reasons for including stand alone renewable energy initiatives in rural electrification programs as: (i) least cost economic solution; (ii) environmentally sustainable; (iii) contributing to Millennium Development Goals and renewable energy targets; and (iv) ability to bring service faster than awaiting grid supply [3]. The development and increasing number of micro grids and stand alone off grid system requires a new approach to the grid operation. The problem of power quality first came up at the beginning of the 20th century. Nowadays, with the increasing number of non-linear and disturbing loads it is particularly current. In developed countries more and more photovoltaic (solar) power plants are built and usually operated in two modes as grid-connected systems or as off-grid or island systems. [4]. Because of the new challenges coming up together with off-grid systems operation in power grids, the government counts with the assistance from scientific programs. The cooperation between Institute of power and Applied Electrical Engineering at STU in Bratislava and the company RMC s.r.o. enables the research activities in off-grid systems. The outline of this paper is as follows. In Sect. 2, we provide some basic information about a low power solar off-grid system, which has been used for testing. The load control system is briefly described in Sec. 3 and finally the Sec. 4 contains the results from power quality measurement. Concluding remarks are given in Sect.5.

## 2 Off-grid solar system

The laboratory test of the off-grid system operation and the power quality measurements were done on the solar off-grid system with a build in accumulation system. (Fig.1) The system is constructed as one phase solar system (230V, 50Hz). The peak power of the photovoltaic source is equal to 1kW and the maximum capacity of the build in accumulation system (batteries) is equal to 14kWh. The solar system was designed to the optimum daily electricity consumption of 1 – 5 kWh and the maximum daily electricity production from the photovoltaic source is estimated to 6kWh. The overall output power of solar system is equal to 3kW (limited by the capacity of batteries). This system is also equipped by the remote control using the GSM network.

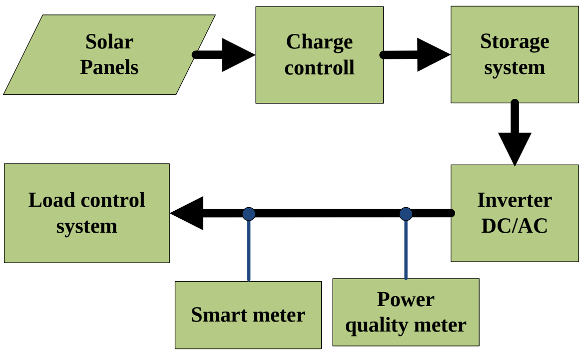


Fig.1 Low power solar off-grid system

## 3 Load control system for testing the off-grid systems

For the analysis of the solar off-grid system operation with different load profiles, we developed a load control system. This system was used to simulate the switching of different load equipments according to the selected load profile. This system is based on application created in the LabVIEW environment, while the load profile for each equipment with graphical representation is entered in a spreadsheet editor, for example an Excel file. The advantage of this system is the simple way to create any load profile defined by the user. The next Fig .2 shows the graphical user interface of the application.

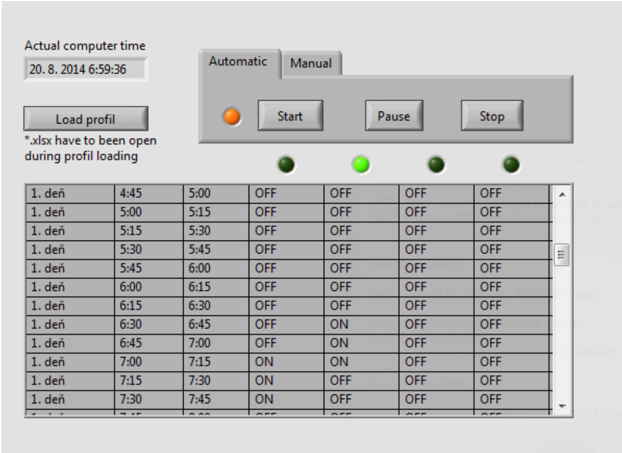


Fig.2 Graphical user interface of load control system

## 4 Results of laboratory measurements

In this paper, the time period for analysis is one month. Over the evaluated operation of the solar off-grid system loaded by the four different equipments, selected electrical parameters were monitored with the emphasis on the qualitative indicators. As for the island systems there is not currently standard defining the power quality, the power quality was evaluated according to the standard EN 50160. [5] Requirements on power quality in off- grid systems are partially described in the standard EN 61000. [6] The next Fig. 3 shows the voltage and current measurement from the selected time period with the duration of 13 days.

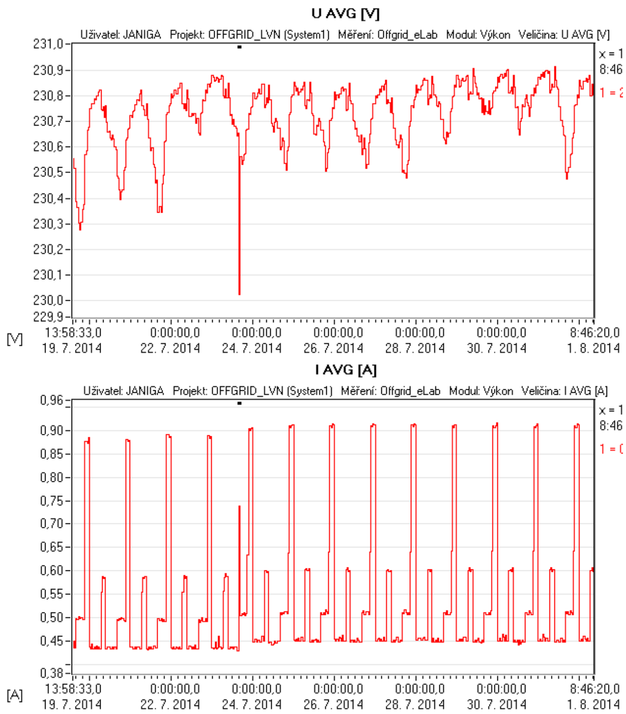


Fig.3 Output voltage and current of the solar off-grid system

From the voltage and current curve can be seen, that at the date of July 24 the voltage and current transient has occurred. This rapid change was caused by the service intervention during the load control system setting. Because the load profile is the same for each day, the next measurement results are presented from one selected day. Next Fig. 4 and Fig. 5 and Fig. 6 displays the measurements from selected time period (one day duration).

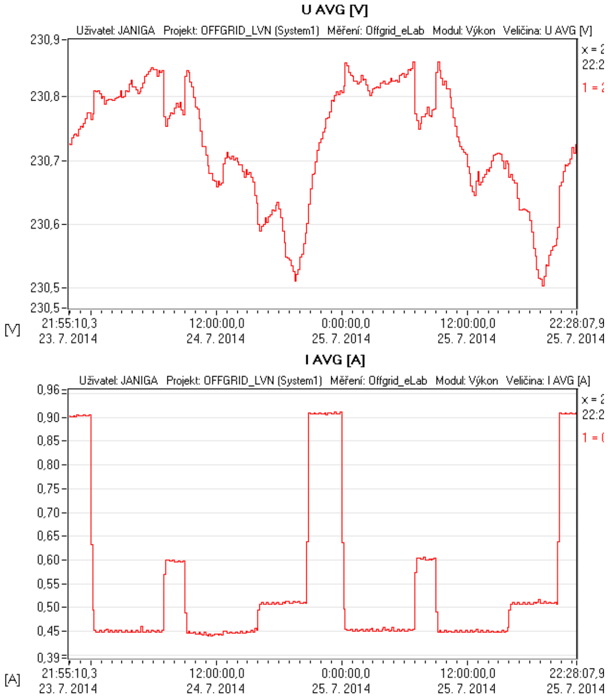


Fig.4 Output values: Voltage and current

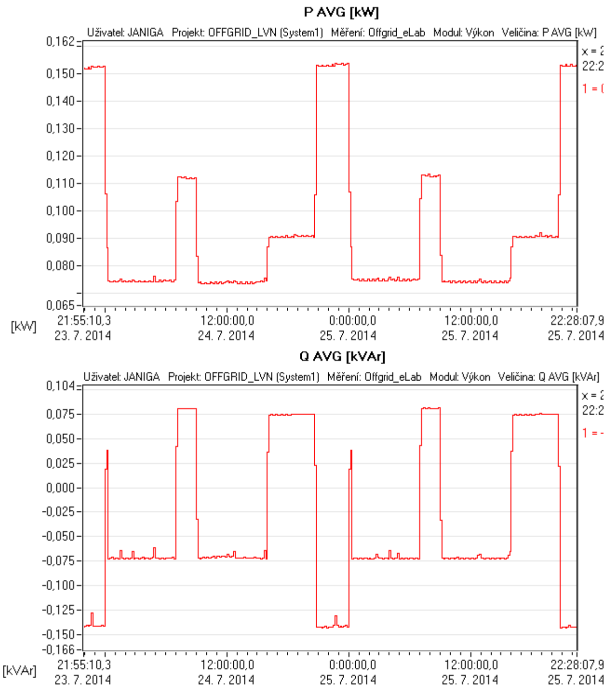


Fig.5 Output values: Active and reactive power

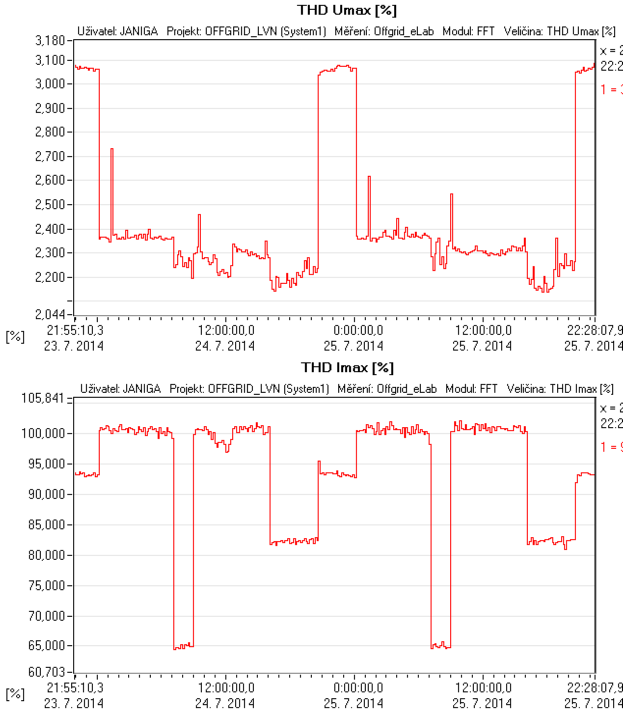


Fig.6 Output voltage and current total harmonic distortion (one day)

The measured data shows very good voltage stability. Voltage at the output of the inverter has a minimal deviation from the value of 230 V. Although the voltage changes corresponds to the size and change of the load power, but the output voltage is stable and inverter maintains the voltage and minimize the variations. Instantaneous voltage values were throughout the whole analyzed period within the range of 222V-233V. In term of power quality parameters, the analysis of measurements identified a problem with the frequency limits. In some cases, the frequency dropped down to the unacceptable value of 49Hz. The next Fig. 7 shows the measurement with the frequency drops. Strong systems eliminate voltage drop [8].

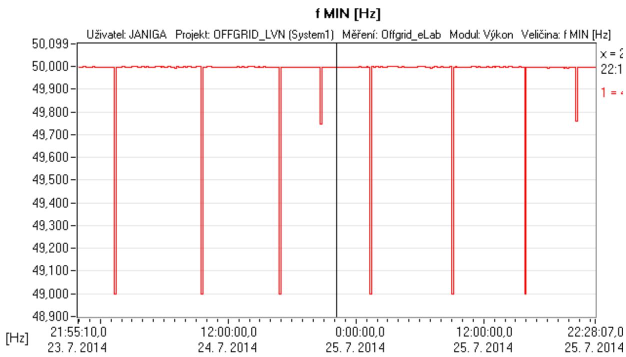


Fig.7 Frequency measurement

On the following figures the voltages and currents are displayed from different operational states. In case of supplying the loads with electronic switching power sources, the upper harmonics occurs in electrical grids. The Fig. 8 displays the voltage and current curve in the case of an electronic load connect to the solar off-grid system.

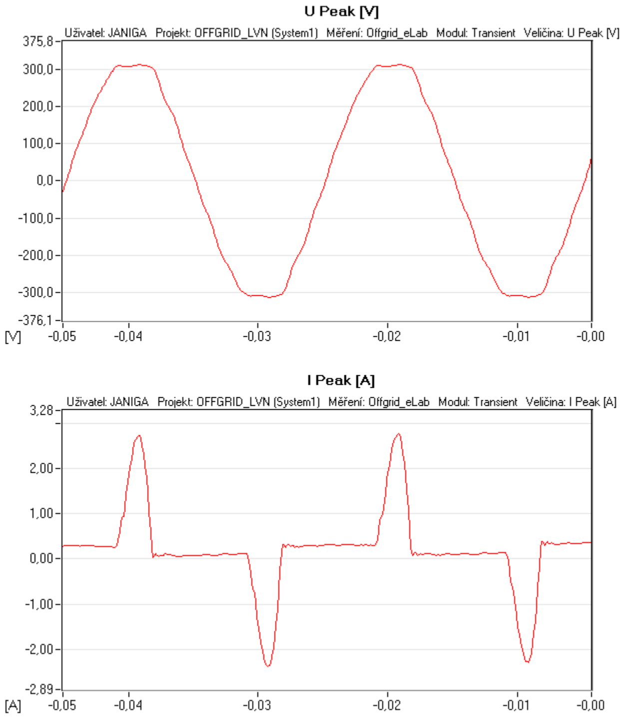


Fig.8 Distorted output voltage and current curve in case of electronic load

In this case the total harmonic distortion of voltage THDu was equal to 3,64% and this value was not worst during the whole evaluated period.

## 5 Results of in-situ measurements

The results of laboratory measurements provide good information for understanding the operation of off-grid networks but new problems are growing in real operation of these networks. Not all states are possible to simulate in laboratory condition. Results of measuring in-situ measuring on small off-grid system in house can show some typical problems in real off-grid network.

In-situ measuring realized in small house in Slovakia. Off-grid technology was similar like in laboratory measuring. In home network is small gas generator for supplying when energy from RES and battery is not enough. Measuring was focused to transients during switching and behaviour during supplying. We measure typical home appliance:

- Well water pump 2.7kW
- Irrigation water pump 1.3kW
- Iron
- Notebook power supply adapter
- LED lighting
- Motor with frequency inverter

In Fig 9. to Fig. 11 are results of measuring electrical parameters during well water pump operation.

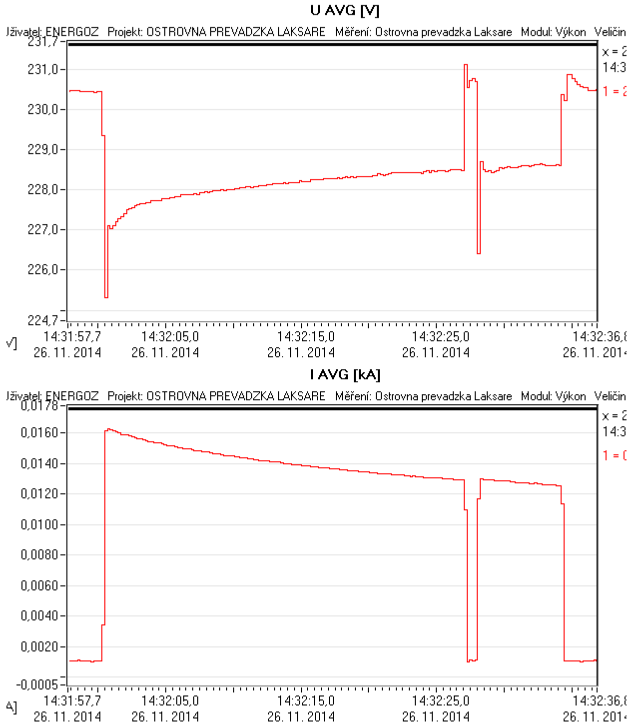


Fig.9 Voltage and current during well water pump operation

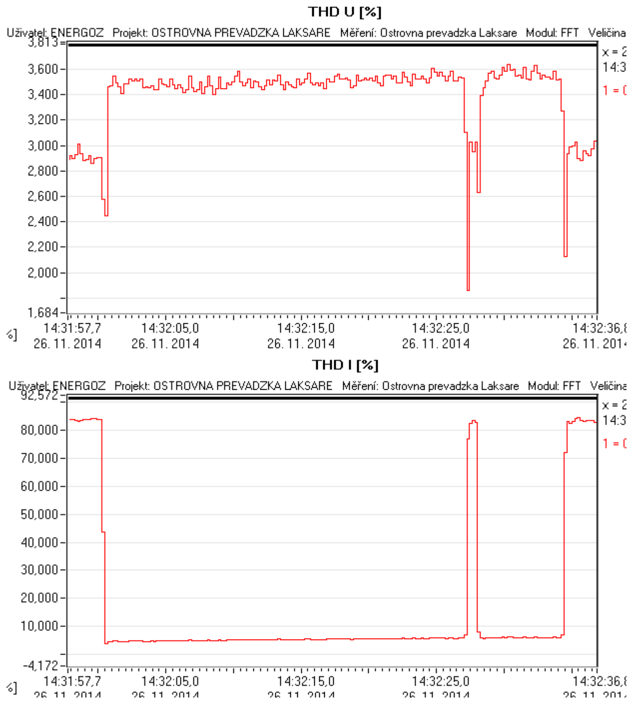


Fig.10 Voltage and current total harmonic distortion during well water pump operation

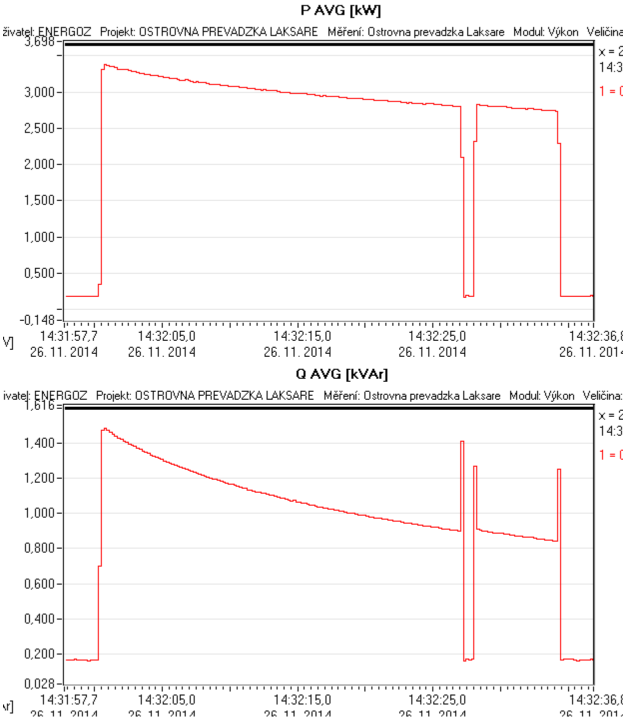


Fig.11 Active and reactive power during well water pump operation

Well water pump has inductive motor. On results of measurement is show start up current and stabilisation of parameters. Measuring sensors were connected on output connectors of supply system.

Next measuring was with iron, what is typical home appliance.

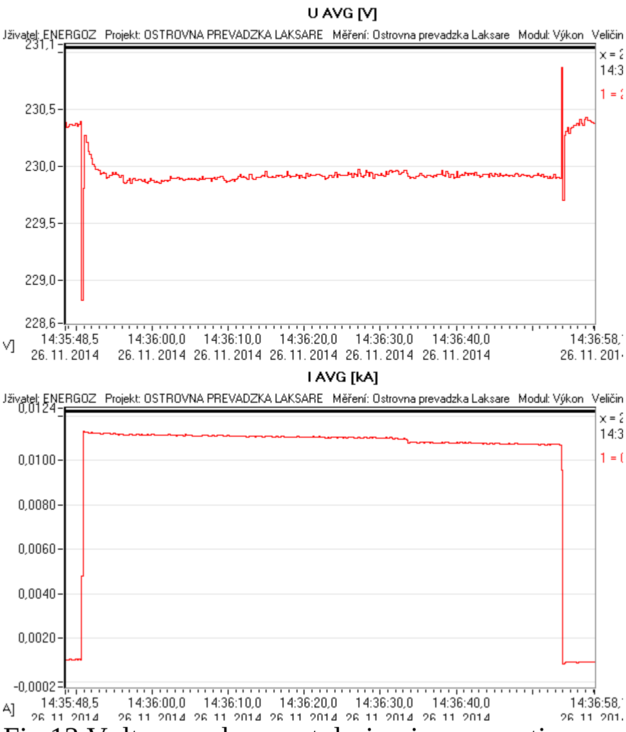


Fig.12 Voltage and current during iron operation

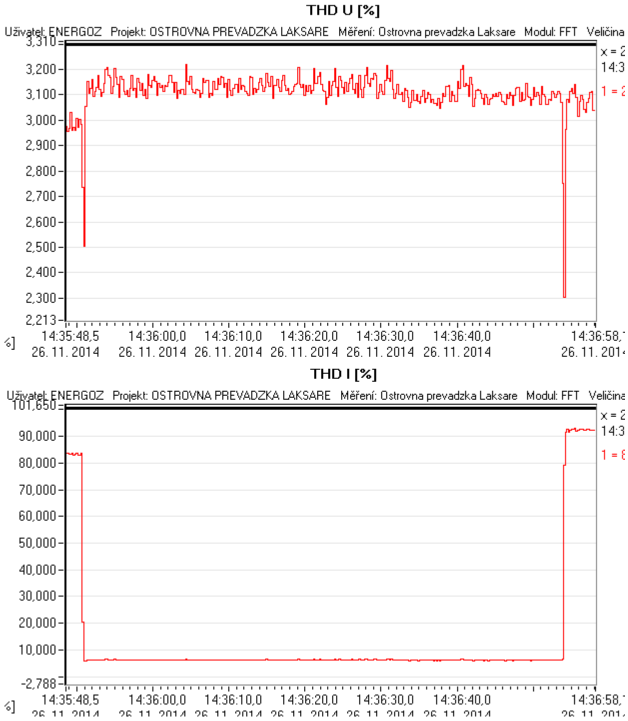


Fig.13 Voltage and current total harmonic distortion during iron operation

Transient During appliance switching transient cause voltage flicker. This event was visible on lighting system but not in all house.

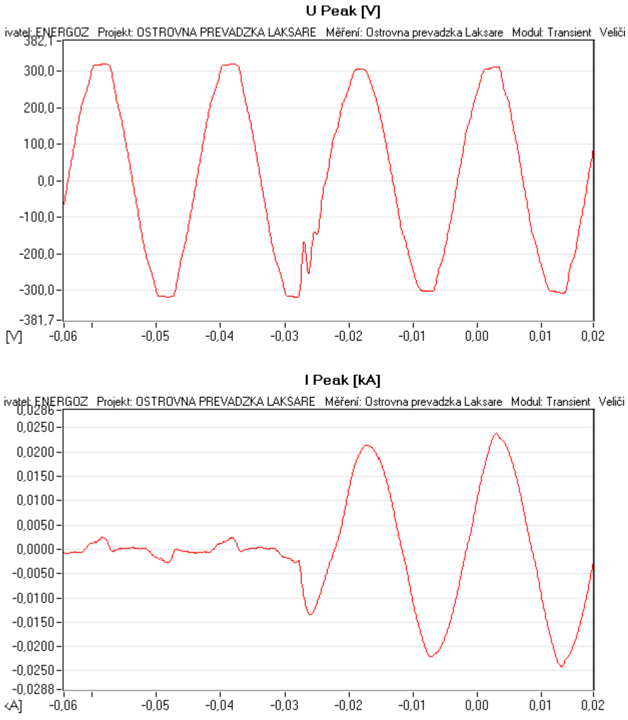


Fig.14 Flicker during well water pump starting

In some part with better installations is minimal flicker. This phenomenon is depend on some properties of installations like size of conductors, distance from source, battery level, dimension of inverter and phase of voltage during switching. [11]

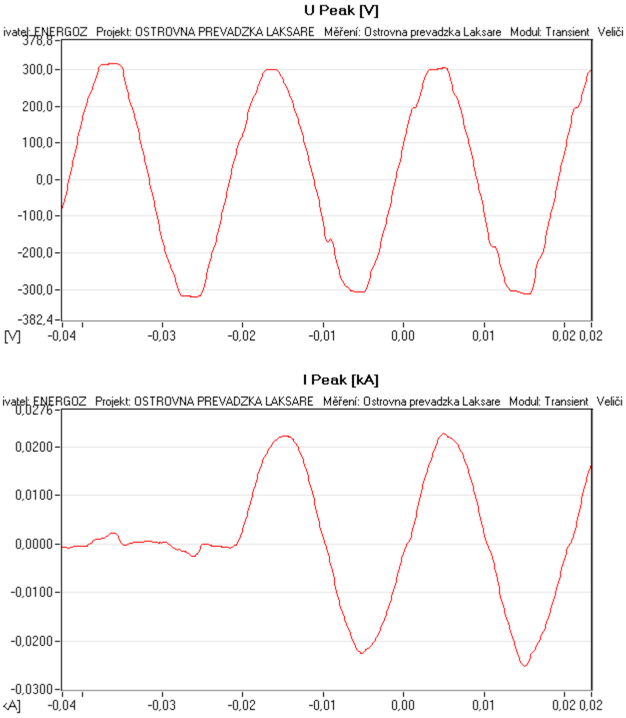


Fig.15 Flicker during iron starting

Other aim of in-situ measuring was analyse of cooperation between photovoltaic system, battery system and gas motor generator. In small off-grid system gas generator is for supplying when energy from RES or battery is not enough.

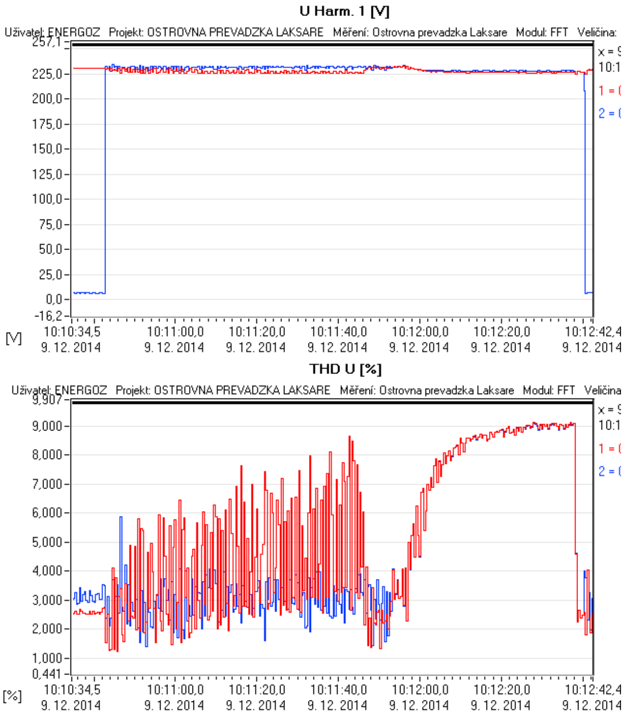


Fig.16 Voltages and $THD_U$ during connecting off-grid system and gas generator

During measuring gas generator was connected to AC side of inverter. Used inverter is designed for connection and cooperation more off-grid. There is direct support for connection between photovoltaic off-grid and gas generator off-grid.

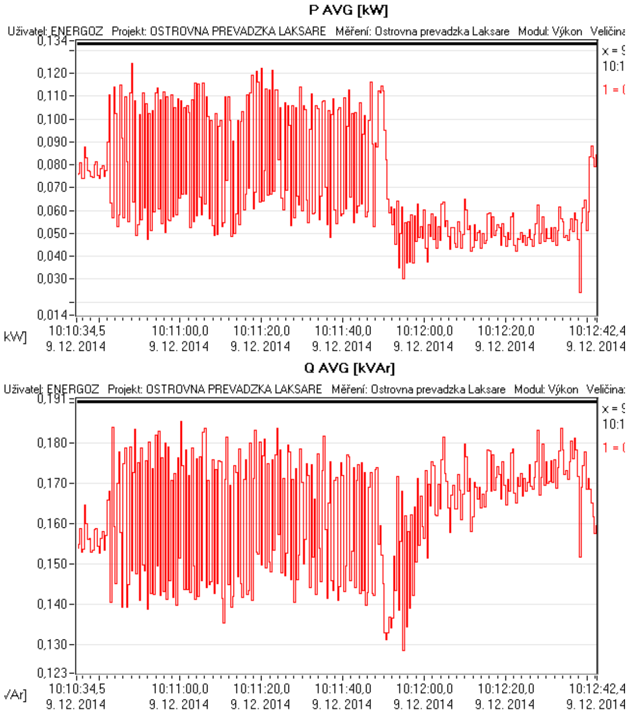


Fig.17 Active and reactive power flow from off-grid system during phasing

In Fig. 17 is behaviour active and reactive power during phasing. Power is mainly oscillated because regulator of generator rotation is not enough fast. There is oscillation of connected system. This oscillation causes problem with voltage.

In Fig. 18 to Fig. 21 oscilloscopic records show voltage on photovoltaic inverter and on gas generator during phasing. Red curve is on photovoltaic inverter and blue on gas generator.

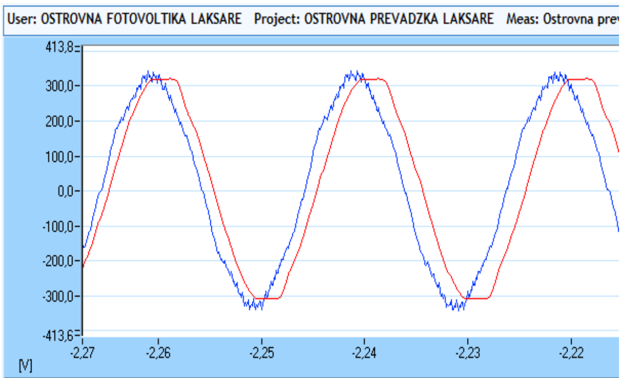


Fig.18 Voltages before connecting off-grid system and gas generator

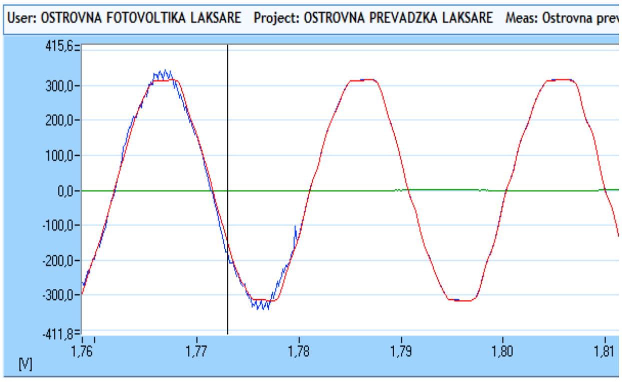

Fig.19 Voltages during connecting off-grid system and gas generator

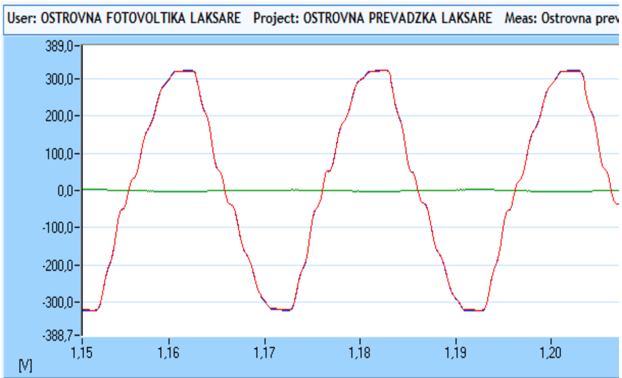

Fig.20 Voltages after connecting off-grid system and gas generator

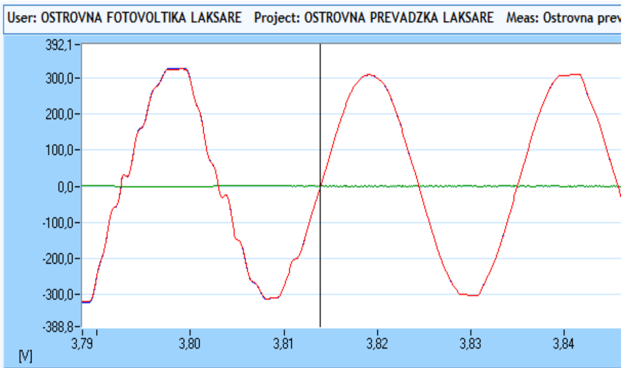

Fig.21 Voltages during disconnecting off-grid system and gas generator

Voltage was significant distorted after phasing when inverter and gas generator were connected. Total harmonic distortion of voltage ($THD_U$) was 9%. This is more than limits in EN 50 160 for on-grid systems. Limits for off-grid systems are not defined in EU standards [9].

Wrong selection of gas generator caused problems in tested home installation. Mainly problem is distortion of voltage and flicker during gas generator connection. Distortion of voltage strain parts of electronic appliances. For example high distorted current generates power supply adapter for laptop when voltage is distorted [10].

Other problem was small flicker during home appliance switching. This problem cause high start up current of some appliance and not optimal installation.

## 6 Conclusion

Distributed generation, micro-grids and off grid systems are becoming one of the most discussed topic in scientific community. In order to understand more the specifics and potential problems coming up with the off-grid systems operation, the content of this paper was aimed to the power quality of such systems. The power quality of the off-grid systems is not so investigated because of the missing experiences from the operation in real distribution networks. The papers and the results from publications related to the power quality of the off-grid systems depends on the technology but mainly on the inverter as the main unit maintaining the network. In this paper, the main results from power quality measurement performed on our small solar off-grid system and the developed load control system were described. This system is universal and can be used to simulate any load profile in any other off-grid system and compare the results obtained from different small off-grid systems. The results of the measurements showed that the analysed off-grid system maintains the voltage level, and the voltage deviations are minimal. However, some problems occurred with the frequency variation. The frequency of the system varies from 50.0 to 49.5 Hz. Such frequency drops doesn't have to significantly affect the simple load domestic appliances, but some electronic appliances with sensitive electronic circuits can have a serious problems with the frequency drops.

In-situ measurements show problems with voltage distortion and problems with phasing photovoltaic off-grid system with gas generator unit. Results of measurements are background for knowledge about off-grid systems and power quality.

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