

Photovoltaic Laboratory Trainer in Student Educations for Renewable Energy Sources

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Abstract: *This paper describes a lab setting for a photovoltaic system which was delivered at the Faculty of Technical Science (FTS) in Kosovska Mitrovica and is now at the stage of preparation for teaching. The Photovoltaic Laboratory Trainer enables project work to be carried out with industrial components. The solar trainer permits realistic simulation of the progression of the sun. Emulators make it possible to carry out the experiments in the laboratory without the sun. The Interactive Lab Assist and Advanced Photovoltaic multimedia course is designed to convey the theoretical information and practical know-how, and performs the PC-supported evaluation of measurement data.*

Keywords: *Photovoltaic; Renewable; Educations*

1. INTRODUCTION

In developed countries, renewable energy sources have a significant percentage of the installed power of the power electricity system. For their connection to the classic power distribution network or supply local consumers in place of electricity production have been developed special devices of the power electronics, as well as intelligent components for their control and supervision, [1]. All these power electronics, control, measurement and communication components of decentralized power electrical sources make up an intelligent system called a Smart Grid. Based on smart sensors, digital measuring devices, IT technologies such as the Internet, communication protocols (LAN, WLAN, RS485) and software, Smart Grid systems improve the coordination between power consumption and production via intelligent switching of load depending on the available energy, [2].

As part of the plans and projects of FTS KM for the development of teaching process and modernization of curricula, as well as their harmonization with the needs of the European power electricity market, it is envisaged to form a complex laboratory setting for the analysis and work on the training of the Smart Grid system in laboratory conditions, [3]. The structure of this lab set consists of three subsystems of the Smart Grid system. These are production subsystem, management and control subsystem, and consumption subsystem.

The first subsystem represents all lab settings that represent controlled distributed sources of power electricity from renewable sources in lab conditions. This subsystem includes photovoltaic systems,

wind generators of various configurations, fuel cells, etc. which can be hardware and software integrated into a unique Smart Grid system.

The second subsystem is the control part of the Smart Grid system with SCADA software and the accompanying equipment for hardware simulation of the switching states of the dual bus terminals and power switches in the distribution switchgear (cells) which are standard configuration in the power distribution stations.

The third subsystem includes hardware simulation of variable loads in distribution networks with the possibility of changing load impedance, i.e. with independent change R, L and C. This subsystem will also contain a part for compensation of reactive power and protective devices against electrical faults. Dynamic variable load is an induction cage motor that drives a variable mechanical load that is simulated by a hardware-controlled servo drive.

2. LAB EQUIPMENT

As shown in Figure 1 Lab setting for Photovoltaics Laboratory Trainer consists of: a mobile aluminum experiment stand, solar altitude emulator, PC, monitor and printer, [4].

The experiment instructions come in the form of an Interactive Lab Assistant course. This multimedia course is a step-by-step guide through the topic of modern photovoltaic energy systems, [4]. The physical fundamentals are conveyed using easy to understand animations. The Interactive Lab Assistant in conjunction with the virtual instruments constitutes a comfortable experimenting environment, [5].

An interactive multimedia user guide is installed on the PC. As well as software (VI Starter) for virtual

instruments supported by for Digital/analog multimeter, [6]. For the functioning of this software, a USB connection between the PC and the Digital/analog multimeter is required, as well as the installation of the appropriate drivers.

It is also installed on the PC as an additional option for the Photovoltaics Laboratory Trainer and powerconfig software that supports the power monitoring device PAC4200, [7].

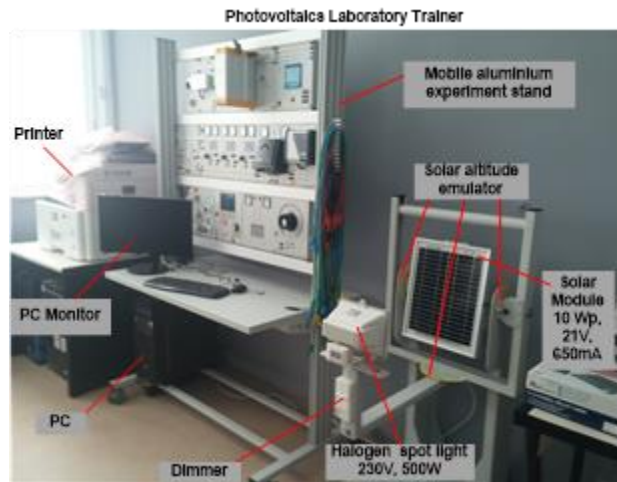


Figure 1. Photovoltaics Laboratory Trainer – Laboratory for Renewable Energy Sources, FTC-KM

Experiment stand is divided into three levels, or three lines of equipment, as shown in Figure 2.

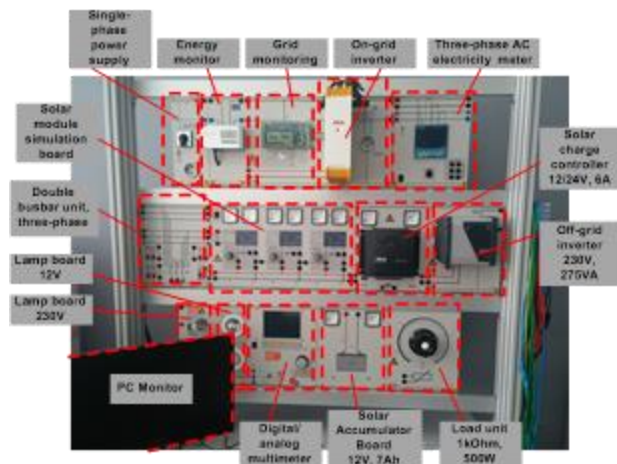


Figure 2. Photovoltaics Laboratory Trainer – Disposition and designation of the main part of equipment

2.1. Solar module with solar altitude emulator

The solar module rack consists of a polycrystalline solar module and a halogen spot light as solar simulator [8]. The brightness of the halogen spot light can be adjusted using a dimmer, Figure 3. Various roof top angles can be emulated using the tilt adjustment of the solar module allowing these effects on the solar module to be investigated. The halogen spot light is swivel mounted permitting it to simulate the progression of the sun over a whole day. To be able to emulate the various progressions

of the sun over the entire year, the tilt angle of the sun’s progression can be adjusted.

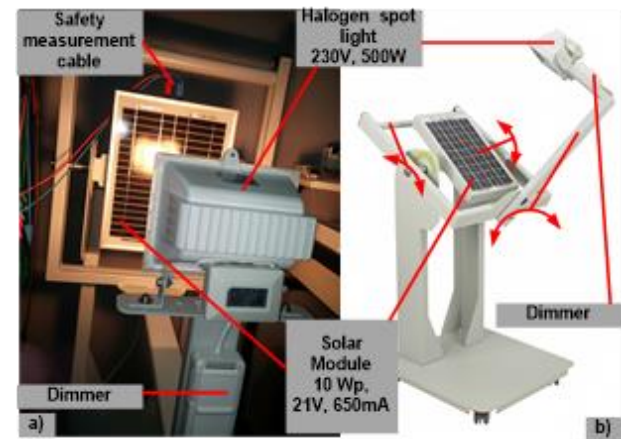


Figure 3. Solar altitude emulator – a) Work without sun light, b) Construction

2.2. First line of the experiment stand

The first line (Figure 4) of the experiment stand consists of: variable resistor as a load unit (1kΩ, 500W), Solar accumulator board (12V, 7Ah), Digital/analog multimeter, Lamp board 12V and Lamp board 230V.

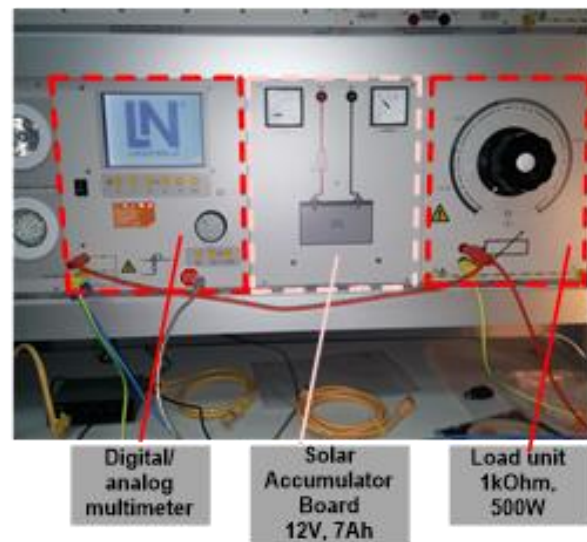


Figure 4. Photovoltaics Laboratory Trainer – Equipment on the first row of the experiment stand

Load resistor is the load unit for solar module and solar power units. The resistor (0...1 kOhm/500W) are continuously adjustable, with stepped winding can be used as load resistance for Solar module, Solar charge regulator and Solar Inverters, [8].

2.3. Second line of the experiment stand

Figure 5 and Figure 6 show the magnified details of second line of the experiment stand that includes the following components: Solar module simulation model (3x, 23V/2A), Solar charge controller (12/24V,6A) and Off-grid inverter (230V, 275VA), [8].

The solar module simulation board offers three independent simulations of a solar module that

enable the realistic emulation of the solar module. Higher voltages and stronger currents can be realized by means of series and parallel circuit configurations. For each simulation a separate solar light intensity can be set and a bypass diode added.

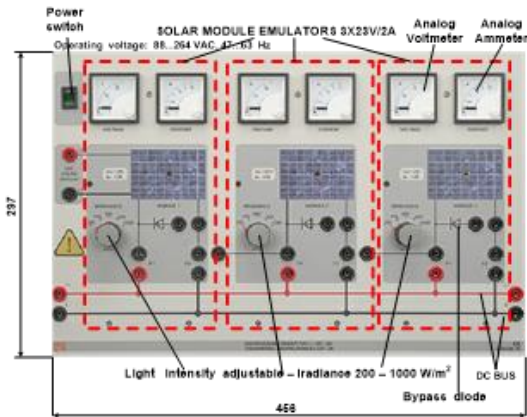


Figure 5. Solar model hardware simulation board -3x23V/2A with adjustable level of irradiation

The solar charge controller (12/24V,6A) monitors the charge level of the accumulator (12V,7Ah) and protects this against excessive and deep depletion. To charge up the lead accumulator, the charge controller uses the IU charging processes. LEDs provide information regarding the operating and charge status. The charge regulator is equipped with the following features: Automatic 12/24V switching, Maximum Power Point (MPP) – Tracker, Terminal connection for Solar generator, Solar accumulator and DC load, [9].



Figure 6. Solar charge controller and Off-grid inverter

To operate standard commercially available electrical devices used in standalone solar power systems, the generated DC voltage must be converted into AC voltage. In the second line of the experiment stand the board consists of a commercially available off-grid inverter which generates an output voltage of 230 V AC from an input voltage of 12VDC. The off-grid inverter is equipped with a deep depletion protection facility with which it can be connected directly to a lead accumulator. The off-grid inverter is equipped with the following features: On/ off switch, LED display of operating status, Output voltage: sinusoidal

230V +/- 5%, Efficiency: 93%, Cut out for excess battery voltage, Over temperature and overload protection, Short –circuit protection and Pole reversal protection, [10].

2.4. Third line of the experiment stand

Modern solar power systems use grid-connected inverters to feed electric power into the mains. Experimental setup of a Photovoltaics Laboratory Trainer for grid parallel operation consists of a grid-connected inverter (StecaGrid 300) with a separable external monitoring unit (ENS26NA), [11].

The ENS unit monitors the mains voltage, frequency and impedance and switches the system off in the event of deviations. The ENS26NA automatic isolation units continually monitor the following parameters of the public electricity supply: overvoltage and undervoltage, frequency deviation and Impedance jumps, [11].

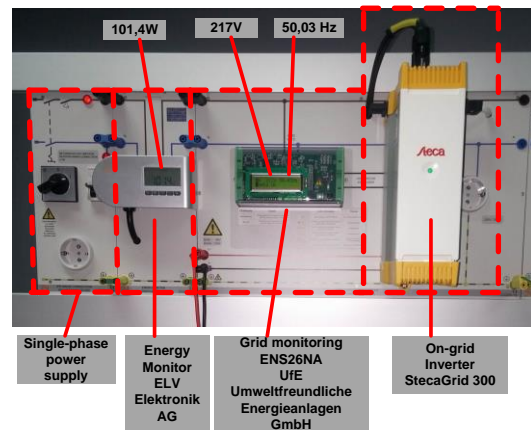


Figure 7. Solar power generation system connected to the low-voltage distribution network

The ENS26NA (designed for StecaGrid 300 and StecaGrid 500) is a single-phase power generation systems protection with integrated 25 A relays according to VDE-AR-N 4105 with the respective declaration of conformity and tested functional safety. The device has a test key and an LCD display showing trigger values, current measurements, status and the last 9 grid errors and can either be employed as power generation systems protection pursuant to VDE-AR-N 4105. Due to its islanding detection function, any supplier can be used even if they have no islanding detection properties of their own. Thanks to the built-in 25 A relays, no further contactors are required. The ENS26NA is the grid monitoring device for single-phase systems up to 5.7 kW, [11].

In the event of faults in the mains supply, the ENS26NA interrupts the feeding of electricity in the mains to prevent island effects. The safety functions are executed in a dual channel system, whereby each channel monitors the proper function of the other channel. In case of a failure the channels disconnect independently from each

other. The channels monitor each other mutually to increase error protection, [11].

3. MEASURING INSTRUMENTATIONS

In a laboratory setup of a Photovoltaics Laboratory Trainer two measuring devices, digital/analog multimeter and three-phase power monitoring meter are installed.

3.1. Digital/analog multimeter

Digital/analog multimeter is the universal measuring device has been designed particularly to satisfy following requirements: high-performance overload protection, acquisition of measurement values must be performed accurately and independently of the curve's shape. It can simultaneously replace as many as four different measuring instruments – constituting a current/voltmeter, power and phase angle meter all in one. The graphic display allows for both student as well demonstration experiments, [6].



Figure 8. Digital/analog multimeter with USB interface and internal display

The VI Starter software allows all the measurements to be displayed on the PC, [6]. Up to 17 different displays can be opened:

- Oscilloscope display of voltage, current and power
- Consumption meter to display power consumed and output
- Data logger for 14 different variables
- Data export for data logger
- Characteristic recorder

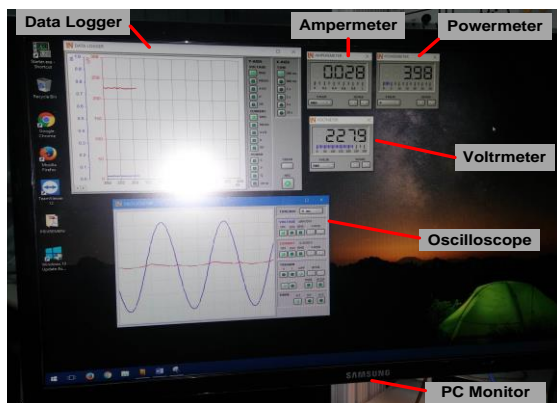


Figure 9. The VI Starter software allows all the measurements to be displayed on the PC

3.2. Power monitoring device

The digital energy monitor SENTRON PAC4200 is a three-phase AC electricity meter which makes it possible to simply measure the energy output by a solar electricity generator or energy consumed by an electrical appliance [12].

The SENTRON PAC4200 is a feature packed power monitoring device that is suitable for use in industrial, government and commercial applications, [7].

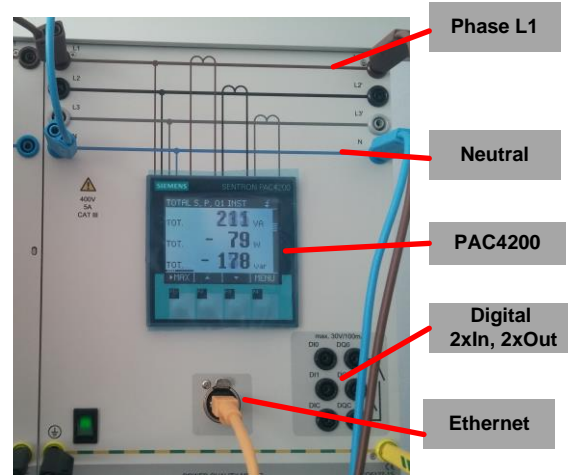


Figure10. Three-phase AC electricity meter with power monitoring device SENTRON PAC4200

The energy monitor *SENRON PAC4200* includes the following features:

- Three-phase measurement of current and voltage, 3x 400 V/5A
- Measurement of phase voltages, line-to-line voltages, currents
- Determination of apparent, active and reactive power
- Determination of active and reactive energy
- Determination of frequency and power factor
- Large, high-contrast background-lit graphic display

Powerconfig software is not delivered as part of the package in a laboratory setting for photovoltaic systems, but is taken as a free application from the website the manufacturer and installed on the PC and used as additional powerful tool for analysis of the measurements during the lab experiments.

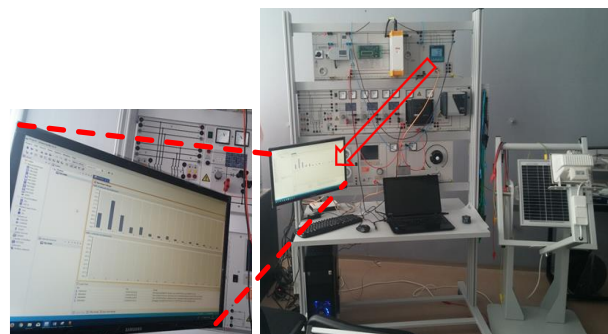


Figure 11. One screen of the Powerconfig software on PC. An overview harmonic content of the phase voltage and phase current.

The Powerconfig software is commissioning and service tool for communication-capable SENTRON measuring devices with PC. The power monitoring devices (PAC4200) with Powerconfig software tool for PC can be parameterized, documented, operated and monitored using various communication interfaces, [7].

4. EXAMPLE -ON-GRID OPERATIONS

The multimedia animation is used as guide to prepare the experiment by setting animated virtual connectors and virtual wired connections. The user can clearly see how to connect the corresponding points on the modules. Figure 12 shows the final animation scene from the Interactive Lab Assistant with highlighted animated graphic elements that place on the fixed image of the equipment in the background, [12].

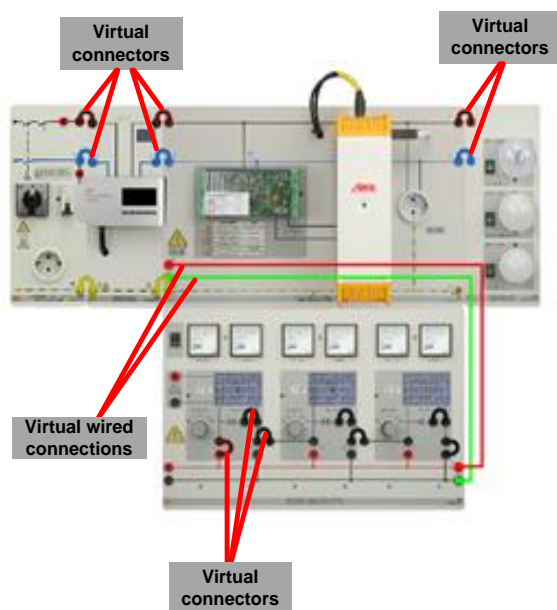


Figure 12. Experiment: Photovoltaic system with On-grid inverter. Animated virtual connectors and virtual wired connections in Interactive Lab Assistant as multimedia support tools.

Three solar modules (23V, 2A) are connected in serial and supply the On-grid inverter input. Value of irradiance on the hardware solar module simulator are set to 800W/m².

Figure 13 shows the connected pieces of the modular type equipment using Safety connecting plugs and Safety measurement cables with built-in safety plugs at both ends.

Figure 13 shows the lab setting for the production of electricity from the solar system and delivery to the power supply network via an on-grid inverter. Instead of a bulb module, the power monitoring device SENTRON PAC4200 is connected to measure voltage and current at one phase.



Figure 13. Lab setting for the Experiment: Photovoltaic system with On-grid inverter.

Measured values for apparent, active and reactive power during this experiment are listed on the display of the power monitoring device PAC4200, as shown in Figure 10.

The harmonic content of the phase voltage and phase current of up to 31 harmonics at the output from the inverters obtained by measuring the PAC4200 are shown on the PC screen using the Powerconfig software, Figure 14.

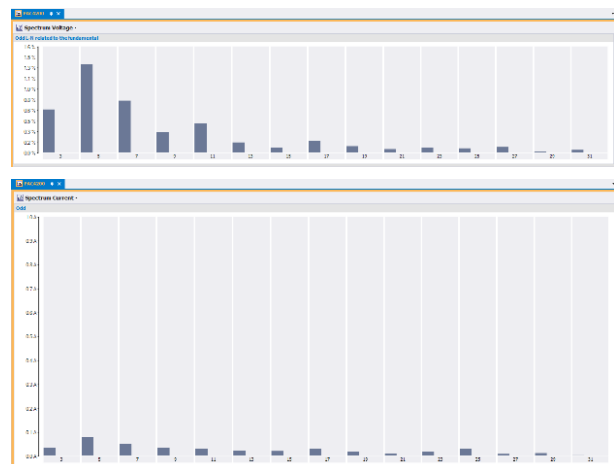


Figure 14. Experiment: Photovoltaic system with On-grid inverter. An overview harmonic content of the phase voltage and phase current

5. EXAMPLE OFF-GRID OPERATIONS

Three solar modules (23V, 2A) are connected in parallel and supply the Solar charge controller input. Value of irradiance on the hardware solar module simulator are set to 200 W/m².

In Figure 15 shows the lab setting to produce electricity from the solar system, and delivery to the consumer who makes bulb module with three lights (230V AC) through of-grid inverter, [13].

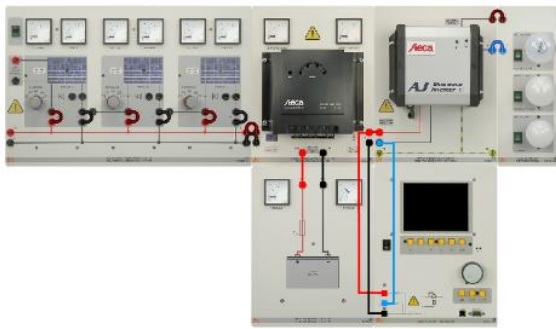


Figure 15. Experiment: Of grid inverter. Animated virtual connectors and virtual wired connections in Interactive Lab Assistant as multimedia support tools.

On Figure 16 shows the connected pieces of the modular type equipment using Safety connecting plugs and Safety measurement cables in the Experiment: Photovoltaic system with Of-grid inverter.

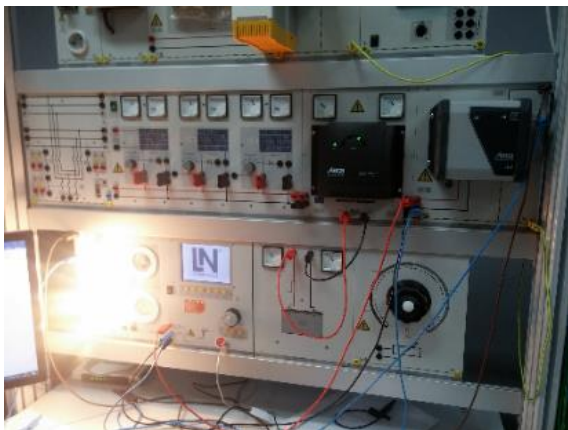


Figure 16. Lab setting for the Experiment: Photovoltaic system with Of-grid inverter

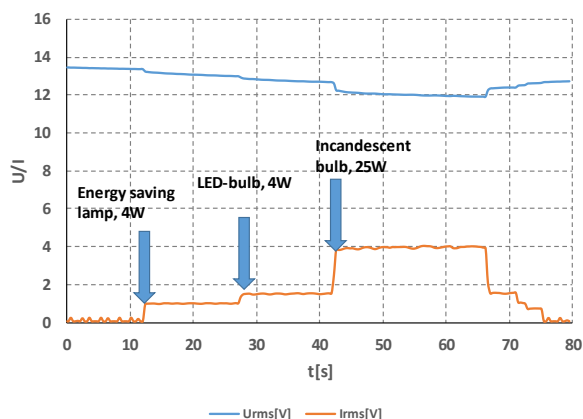


Figure 17. Supply lamp board (230V AC) from dc battery (12V, 7Ah) an Off-grid inverter. Measured voltage and current of the battery on the dc input of the inverter

The results are shown in Figure 17 obtained the recording numerical data in the data file by using option the "Export data" in the VI Starter software of the Digital/analog multimeter. The data from the

data file are then imported and graphically presented in Excel.

Figure 17 shows three moments when the lamps of different type are manually switched on but which have the same lighting effect. First, the 4W Energy saving lamp is, with a sudden leak of 1.2A current. After that, 4W LED bulb is included. The amount of current increase is about 0.6A, so the total current has increased to 1.8A. In the third transient process Incandescent lamp 25W is included, with a 2.1A jump current. The total current is 3.9A. The battery voltage is 12V.

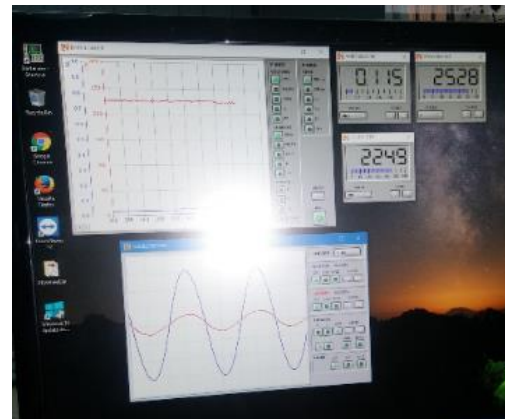


Figure 18. Supply Incandescent lamp (230V AC) from dc battery (12V, 7Ah) through Off-grid inverter. Measured wave shapes of the voltage and current on the ac output of the inverter

On the virtual oscilloscope, waveforms of ac voltage and current on resistor load which is the incandescent bulb are shown (voltage and current sinusoids are in phase), Figure 18.

6. CONCLUSION

With this Photovoltaic Laboratory Trainer, students can acquire new knowledge and skills about all parts of a photovoltaic system under lab conditions that fully correspond to actual photovoltaic systems whose solar panels are installed outside.

The multimedia interactive approach, then the virtual instrumentation software as well as the power monitoring software with all functions are powerful tools that enable the efficient transfer of theoretical knowledges and their understanding by looking at practical results as well as saving the output reports using standard software tools for word processing and data processing.

Within this lab setting, there are over 10 different lab combinations for experimental testing with full multimedia and theoretical support. It provides an excellent basis for the formation of a new teaching courses within the Power engineering module for academic studies on the Faculty of Technical Sciences in Kosovska Mitrovica.

The complete lab Photovoltaic Laboratory Trainer also has a dual bus module that allows this setting to be integrated into a complex Smart Grid system.

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