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Energy Balance of a Prosument Microinverter On-Grid Photovoltaic System

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Summary. The paper presents investigations into the energy balance of a prosument photovoltaic system. The tests were performed on selected days from July through December 2013. The core element of the on-grid photovoltaic system was a WVD-260-230V/50Hz microinverter. The test stand allowed monitoring the parameters of the PV system operation. An effective monitoring was realized through the WVC modem software. In the energy balance, two types of PV modules were included: monocrystalline (AEMF130) and polycrystalline (CL130-12P).

Key words: photovoltaics, photovoltaic module, on-grid PV system, inverter, monitoring, energy balance, prosument.

INTRODUCTION

Photovoltaics (hereinafter referred to as PV) is a new interdisciplinary field of science and technology comprehensively dealing with the process of direct solar energy conversion into electricity [5, 6, 10, 11, 12, 16, 18, 19]. Currently, in Europe, approximately 3 % of the generated energy comes from photovoltaics (the second RES after windfarms) [23]. PV systems are built from several components, depending on the type. The basic component of each PV system is a generator composed from a certain number of connected modules. It is estimated that in the total expenditure on the construction of a PV system, the cost of purchase of the modules amounts to approximately 45 % of the entire investment project [1, 17]. Fig. 1 presents data on the current world production of PV modules. Until 2012 Europe was a leader in the installed capacity of PV systems (approx. 70 GW_p – where W_p denotes the peak power determined under STC laboratory conditions). The total power of the PV systems installed worldwide as at the end of 2013 is estimated at 136.7 GW_p, approx. 37 GW_p of which was installed last year and a majority of new installations is located in China and Japan (11.3 GW_p and 6.9 GW_p respectively) [23]. Last year, Europe tended to lag behind in terms of production of the PV systems (Fig. 1). It is predicted that in a few years Europe will account for less than half of the total worldwide installed capacity of PV systems.

The fundamental factor facilitating the advancement of photovoltaics are properly planned mechanisms of support. The ranking of attractiveness of selected PV markets by Ernst & Young allows for the macroeconomic, political, technological and legislative conditions. In the last ranking [1] covering 40 countries, Poland was on the 35th position (a year before – 2012 – Poland was the 26th) while Germany was the 3rd (until last year it had held the 1st position). New legislation introduced in Poland known as ‘small energy tri-pack’ and new mechanisms of support, such as the PROSUMENT scheme [22], have not brought any significant changes in this matter. At the current legal status quo, there are no economic grounds for rapid advancement of photovoltaics due to insufficient mechanisms of government support that is currently directed towards energy policy based on coal.

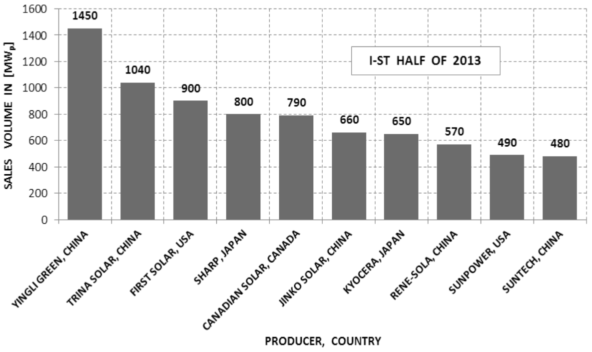


Fig. 1. The sales of PV modules in the first half of 2013 (own study based on data available from [22])

Quite different in this matter is the policy of Germany that introduced very attractive mechanisms of support for photovoltaics. Photovoltaics in Germany is in the phase of a stable and predictable growth. It is possible that within five years it will start advancing without government subsidies.

CONSTRUCTION OF THE TEST STAND

The investigations were conducted on a test stand whose diagram is shown in Fig. 2. It is an on-grid PV system built from two WVD-260-230V/50Hz microinverters adapted for continuous monitoring of their basic operating parameters. Individual elements of the PV system are stand-alone; hence, maintenance works do not disturb the operation of the other inverters. The monitoring system also allows deactivating the microinverter prior to physical disconnection of the MC4 connectors, which eliminates the risk of an intense arc occurring when connecting and disconnecting live wires in the DC circuit.

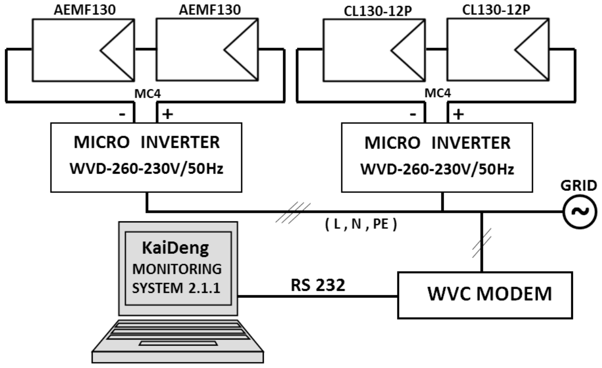


Fig. 2. Schematics of the test stand for the on-grid microinverter PV system

The main components of a PV system are two generators built from serially connected monocrystalline (AEMF130) and polycrystalline (CL130-12P) modules. Such a configuration results from earlier research of the author on an autonomous system of the inverter rated voltage of 12 V [14] and the necessity to adapt the parameters of the microinverter to the parameters of the PV modules of which the generators were built.

If we want to expand the PV system to a size beyond individual demand of the investor, a reverse power flow controller can be applied in the system [20] that will direct the surplus energy to power the heater in a domestic hot water (DHW) system.

Table 1 presents the basic parameters of the microinverter provided by the manufacturer.

Table 1. Basic technical parameters of the microinverter [20]

Parameters	Values:
Models	WVD-260-230V/50Hz
Manufacturer	KAIDENG ENERGY
Recommended solar panels	300 W_p
DC MAX input current	20 A
AC MAX output power	260 W
DC MAX Open-circuit input-voltage	50 V
DC input voltage range	22 V ÷ 50 V
MAX output power factor	0.99

Table 2 presents the basic parameters of the modules from which the PV generators were built. The analysis of the data has confirmed a correct range of output parameters of the PV generators, compared to the input parameters of the microinverter. As results from the data presented in table 2, the PV modules made in different technologies have identical nominal parameters, which also allowed a comparison of the efficiency of the monocrystalline and polycrystalline modules operating with the same type of microinverter under the same conditions. The monocrystalline modules are characterized by a higher nominal efficiency of individual PV cells but they use smaller working area. Visually, the monocrystalline modules have cells with a specifically cut edges, which results from the technology of their production.

Table 2. Basic parameters of the PV modules: AEMF130 and CL130-12P [21, 23]

Parameters:	**Values:**	
	AEMF130	**CL130-12P**
Manufacturer	ACTIVE ENERGY	SOLTEC
Type of PV cells used	monocrystalline	polycrystalline
Maximum power P_{MPP}	130 W_p	130 W_p
Maximum power voltage U_{MPP}	17.2 V	17.2 V
Maximum power current I_{MPP}	7.56 A	7.56 A
Open circuit voltage U_{OC}	21.6 V	21.6 V
Short circuit current I_{SC}	8.02 A	8.02 A
Dimensions	1483x655x35 mm	1483x655x35 mm
Weight	12 kg	12 kg

During the measurement, the generators were set at the southern direction at the inclination angle of 35°. Such a setting, based on previous analyses of the author and other research [7, 8, 13] can be deemed optimum for this geographical location. The GPS position of the test stand was: 52.48°N and 19.67°E (vicinity of Płock).

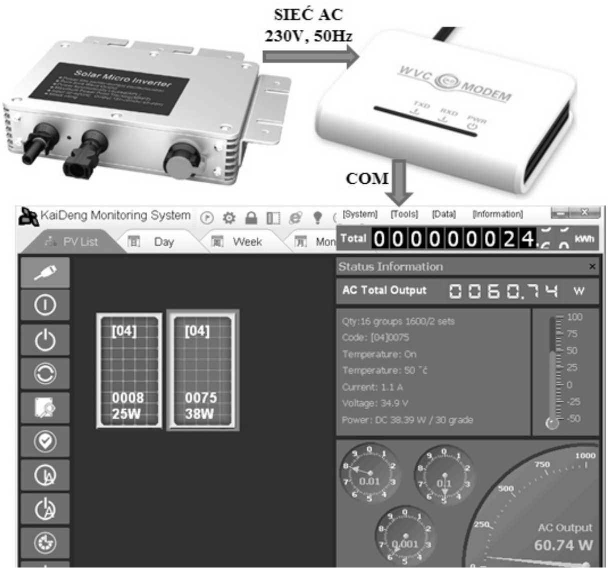
The other elements of the PV system are: special PV wiring (cross-section of 4 mm^2) fitted with MC4 connectors, special overcurrent protection on the DC and AC sides along with a B+C surge protection.

METHODOLOGY AND SCOPE OF RESEARCH

The tests were performed on a complete low voltage on-grid PV system through two WVD-260-230V/50Hz microinverters. The microinverters have a special anti-islanding protection that disconnects it from the grid if blackout occurs. A reason for disconnecting from the grid may also be a case of a naturally sudden reduction in sun radiation [3, 4, 9, 12] to the level at which the output parameters of the PV generators are too low.

A component of a PV system that enables a continuous monitoring of its operation is the WVC modem. Its characteristic feature is that it does not require separate wiring to communicate with the inverters using the already existing one on the AC side.

Fig. 3 presents an example screenshot of a system monitoring the PV system. The only downside is the need of a permanent connection of the modem with the PC through a serial COM. The PV modules bearing numbers [04] 0008 and [04] 0075 presented in Fig. 3 in the application window [04] 0008 and [04] 0075 actually represent pairs of units of serially connected modules: AEMF130 and CL130-12P, respectively (Fig. 2). An additional advantage of this monitoring system is the possibility of separate supervision of individual components without interrupting the work of the other system elements. In this way, we can avoid many undesired phenomena that are likely to happen in systems built from serially connected PV modules (shading, malfunction of one of the modules, current or voltage incompatibility of the modules).



Qty:16 groups 1600/2 sets
Code: [04]0075
Temperature: On
Temperature: 50 °C
Current: 1.1 A
Voltage: 34.9 V
Power: DC 38.39 W / 30 grade

Fig. 3. Monitoring of an on-grid PV system (own study based on [20])

In the monitoring system built in this way, it is difficult to maintain the continuity of long-term measurements. Each application hang or an instantaneous blackout results in a system pause and it requires action of the operator to resume it. For this reason, the paper presents results of measurements for 7-day measurement intervals in each of the tested months. Fig. 4 shows an example screenshot of the monitoring application (KaiDeng Monitoring System 2.1.1.) Fig. 4 presents a recorded course of the subsystem operation for the AEMF130 monocrystalline modules in August 2013. The application allows an analysis of daily, weekly and monthly output parameters of the operation of individual PV generators and current temperature of individual inverters. Whether or not the continuity of monitoring is maintained, the total energy value generated by the PV system is also recorded.

The most difficult to record were the December data, when frequent outages of the microinverters operation occurred resulting from low insolation or presence of snow on the PV modules.

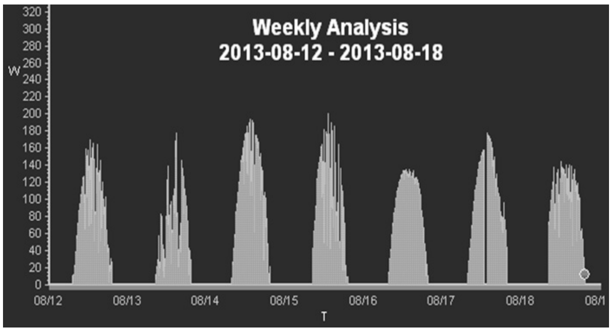


Fig. 4. Example screenshot of the WVC modem application

RESULTS

Fig. 5 presents the energy balance of an on-grid PV system for the period from July through December 2013. The graphs show average daily values calculated based on a set of seven consecutive days in each month. The results for generators built from monocrystalline and polycrystalline modules have been distinguished.

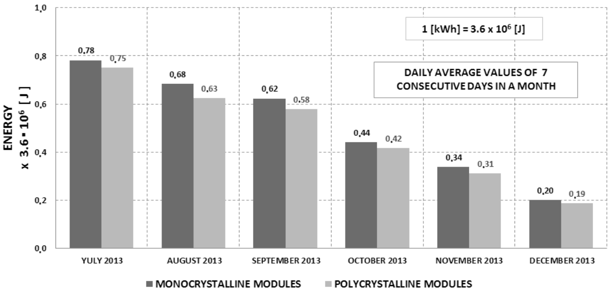


Fig. 5. Amount of AC output energy from the on-grid PV system

Numerous measurements [2, 17] have proven that PV systems built from modules based on crystalline silicon may generate a maximum of approx. 950 kWh per 1 kW_p of installed capacity assuming an optimum direction and inclination of the PV generator. Analyzing the investigated system, we may estimate the yearly amount of generated energy in a PV system at 732 kWh for monocrystalline modules and 685 kWh for polycrystalline modules per 1 kW_p of installed capacity of the PV generator.

CONCLUSIONS

1. The application of microinverters for the construction of PV systems slightly increases the cost but allows the system to be easily extended and reduces the risk of possible malfunctions of the entire system.
2. In the conducted investigations, more energy was obtained from a PV generator built from monocrystalline silicon at identical power outputs of both generators.
3. The obtained measurement values of the generated energy are slightly lower than expected, which is most likely related to worse (in terms of photovoltaics) radiation structure in the second half of the year in our geographical area.

4. The application of monitoring systems allows recording operating parameters of the entire PV system without deactivating it for measurements. This also enables diagnosing malfunctioning system subcomponents and their quick renewal.
5. An additional advantage of photovoltaic systems built from microinverters is the possibility of independent monitoring of each PV module separately, which facilitates the identification of possible malfunctions.
6. The lack of vital economic mechanisms of support in Poland in the area of photovoltaics makes small prosument PV systems especially advantageous, and the energy from them could be used exclusively for the investor's needs.

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BILANS ENERGETYCZNY PROSUMENCKIEGO MIKROINWERTEROWEGO SYSTEMU FOTOWOLTAICZNEGO DOŁĄCZONEGO DO SIECI

Streszczenie. W pracy przedstawiono badania bilansu energetycznego prosumenckiego sieciowego systemu fotowoltaicznego. Badania prowadzono w wybranych dniach od lipca do grudnia 2013 roku. Centralnym elementem sieciowego systemu PV był mikroinwerter WVD-260-230V/50Hz. Stanowisko badawcze umożliwiało monitorowanie parametrów funkcjonowania systemu PV. Efektywny monitoring prowadzono wykorzystując oprogramowanie dołączone do modemu WVC. W bilansie energetycznym uwzględniono dwa rodzaje modułów PV: monokrystaliczne – AEMF130 oraz polikrystaliczne – CL130-12P.

Słowa kluczowe: fotowoltaika, moduł fotowoltaiczny, sieciowy system PV, inwerter, monitoring, bilans energetyczny, prosument.