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An original design and implementation of a stand used to test the power efficiency of two-axis tracking structures in photovoltaics

Summary: *The work presents the design and the physical construction of a test stand consisting of a two-axis tracking installation with astronomical positioning and a fixed structure with the specific surface inclination angle (determined through the power efficiency optimization process) and the azimuth angle. On the basis of the analyses as well as the model tests performed, the control type and the components, such as: the power inverter, monitoring devices and external radiation power density sensors were selected. The system makes it possible to perform measurements of electric energy generation throughout the year and to estimate the efficiency of the tracking structures used in the conditions specific to the city of Poznań.*

Streszczenie: *W pracy przedstawiono projekt oraz realizację stanowiska składającego się z układu nadążnego dwuosiowego z pozycjonowaniem astronomicznym i układu stacjonarnego pracującego z kątem pochylenia płaszczyzny (określonym na podstawie obliczeń optymalizacyjnych) i kątem azymutu. Na podstawie wstępnych analiz i obliczeń modelowych określono rodzaj sterowania jak również dobrano: mikroinwertery, układ monitoringu oraz czujniki gęstości mocy promieniowania słonecznego. System umożliwia przeprowadzenie pomiarów całorocznych produkcji energii elektrycznej oraz oszacowanie wydajności jednostki nadążnej dla warunków odpowiadających miastu Poznań. (**Projekt i konstrukcja stanowiska do pomiaru energooszczędności nadążnych układów pozycjonujących dla ogniw fotowoltaicznych**).*

Słowa kluczowe: traker, układ stacjonarny, zysk mocy, gęstość mocy promieniowania, energia odnawialna.
Keywords: tracker, fixed system, power gain, radiation power density, renewable energy.

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Introduction

In most photovoltaic systems, both low - power used by individual consumers, as well as objects of high - power (photovoltaic farms) there is a fixed solution for setting the PV modules in accordance with an average year - round optimization. *Essentially, only impact of latitude of PV installation is included. Sometimes, in order to reduce the impact of time parameters and weather conditions a seasonal change* of setting of modules is allowed to better adapt to current altitude of Sun in the sky, during the day (e.g. twice) or year (summer - winter). For the summer months, it is recommended to use lower inclination angles, for Poland from range of 25° - 35° (depending on the reflectivity of the basis), during astronomical winter, due to the low altitude of the Sun during the day "movement" from east to west, optimal values of inclination angles, in case of energy gain, are greater than 50° [1].

It is possible to increase the efficiency of solar energy systems using one - axis or two - axis tracking systems. The last allow to increase the size of power generated by the modules about 30 % [2,3] wherein recorded also 40 % - 50 % energy gain comparing to stationary systems. Such large gains usually describe tracking systems with radiation concentrators that are used in countries with high insolation. Czech scientists have shown that, properly chosen concentrator (with a relatively low coefficient of concentration) works in climate conditions of Central Europe [4].

Control process in tracking system can be realized using clock positioning, where the system in not susceptible to external disruption or sensor positioning comparing differences in illumination of photosensitive elements to reorient the plane in order to compensate them.

In order to determine the rightness of using tracking systems for local geographic and climatic conditions, comparison of simultaneous electricity production by the two PV systems should be made, taking into account the energy consumption for own control and the initial cost of investment [5].

In order to examine the effectiveness of two - axis Sun tracking system, in geographic and climatic conditions of Poznan, photovoltaic system consisting of fixed and tracking unit, has been installed on the roof of the Faculty of Electrical Engineering Poznan University of Technology building.

Stationary unit of PV stand

Fixed unit, which is a part of overall photovoltaic system installed on the roof of the Faculty of Electrical Engineering Poznan University of Technology building, is an object whose design and construction was preceded by optimization calculations. The aim of the calculations was to determine the optimal value of inclination angle β of PV module plane. The value of solar radiation power density on inclined surface was also calculated as well as correction factors for components of total solar radiation. Based on the implemented mathematical model and calculations, including declination angle, hour angle, ground reflectivity coefficient, proper value of inclination angle was set to 37°. Fixed unit is oriented in south direction, therefore the value of azimuth angle is equal to 0°. Design of fixed system is presented in figure 1.

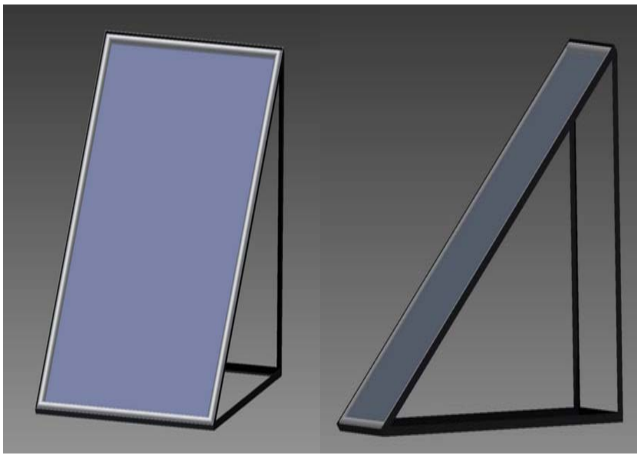

Fig.1. Design of fixed system installed on the roof of the Faculty of Electrical Engineering Poznan University of Technology building

The real implementation of fixed stand is shown in figure 2. Unit was modified by adding a frame made of aluminum profiles where microinverter is installed. The system is attached to the surface of roof in three places and leveled to proper position. Unit will be also closed from each side to prevent water and mechanical damage.

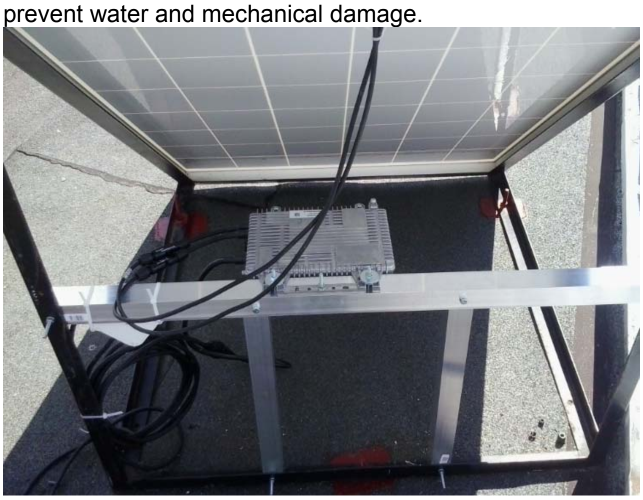

Fig.2. Stationary system with photovoltaic module, radiation power density sensor and microinverter

Directly under the surface of installed polycrystalline PV module with a maximum power equal to 210 W manufactured by Yohkon, DC/AC Enecsys microinverter with maximum power equals 240 W is placed. Selected electrical parameters of photovoltaic module are shown in table 1.

Table 1. Electrical parameters of photovoltaic tested polycrystalline module

-	Module parameters	Value
1	Maximum power	210 Wp
2	Voltage at the maximum power point	29,64 V
3	Current at the maximum power point	6,98 A
4	Open circuit voltage	35,94 V
5	Short circuit current	7,6 A
6	Efficiency	12,61 %
7	Power tolerance	+/- 3 %

Selected electrical and non - electrical parameters of installed microinverters are shown in table 2.

Table 2. Electrical and non - electrical parameters of installed microinverters

-	Microinverter parameters	Value
1	Nominal input power	240 W
2	Maximum DC voltage	44 V
3	Minimum DC voltage	20 V
4	Range of MPPT voltage	23 V…35 V
5	Maximum input current	12 A
6	Operating temperature	-40 °C…85 °C
7	Protection against water and dust	IP66
8	Cooling	Natural

Due to the wireless communication between microinverter and internet gateway, in technical room a locker with measurement unit, which archives data from radiation power density meters and a gateway device, connected using ethernet cable with server is installed, providing remote access to test results. In addition, daily, weekly and monthly consumption of electricity for controlling two - axis tracking system is monitored and recorded.

Two - axis tracking unit of PV stand

Two - axis tracking unit, with control using astronomical positioning is installed next to the stationary system.

The plane, which is a place of working polycrystalline photovoltaic module, consists of a lightweight aluminum profiles, that are connected to the mast using main joint realizing reorientation in north - south axis between 0° and 100°. Two sleeves located at the ends of the support pipe allow tilting in the east - west axis from 0° to 180°.

Because of the height of place where the PV system is installed (about 25 meters above the surface of ground), in order to provide sufficient stabilization of the structure in case of strong wind, the whole unit attached to the structure of the steel beams arranged in triangle shape.

It is possible to control the actuators using manual mode from software level via RS485. Second microinverter is attached to the mast and linked with photovoltaic module using DC cables, whereas AC side, like in stationary unit, is connected to AC grid. Design of two - axis tracking unit is shown in figure 3.

Fig.3. Design of two - axis tracking unit installed on the roof of the Faculty of Electrical Engineering Poznan University of Technology building

The realization of two - axis Sun tracking system is shown in figure 4

Fig.4. Two - axis tracking system with photovoltaic module, radiation power density meter and microinverter

Extra accessories

Additional protection against strong wind can be achieved by programming the setup, where actuators, according to the value of strokes, will arrange orientation of plane of PV module in horizontal position, reducing air resistance. Tracking unit will be equipped with wind sensor that will automatically change the position of photovoltaic module to safe orientation and move back to proper position, according to the hour of day, when wind speed will decrease below set value. One of the components of both systems is the equipment to measure the solar radiation power density on the plane of the module for both fixed and tracking configurations. Single - channel sensors, consisting of a microprocessor and a sensor realized on silicon diode, are connected through overvoltage reduction unit with a system for archiving measurement data. Selected electrical and non - electrical parameters of radiation power density meters are shown in table 3.

Tab.3. Electrical and non – electrical parameters of the radiation power density meter

	Parameter	Value
1	Range of input voltage	-10…+10 mV
2	Inaccuracy	0,05 %
3	Temperature	-30 °C…+70 °C
4	Humidity	0 %…100 %
5	Current consumption	to 25 mA
6	Voltage supply	8…25V DC

Elements like overvoltage reduction unit, internet gateway AC and DC supply and recording system are shown in figure 5.

Fig.5. Equipment of photovoltaic system consisting of overvoltage reduction unit, computer, gateway modem and supply

The whole PV system is connected to the existing lightning protection system located on the roof of the building. Currently there are many modern solutions for photovoltaic installations on the market, which even in case of damage or overload of the overvoltage reduction unit protect against fire, for example three - stage switching system [6].

Lightning protection system protects whole building against direct lightning. Photovoltaic system should be installed on the roof with lightning conductor. It is required to maintain insulation gaps between components of PV system and elements of lightning protection devices [7,8].

Conclusion

1. The proposed two - axis tracking unit, using monitoring system, shows daily, monthly and annual movement of the Sun on the sky, increasing amount of the solar energy reaching the surface of the PV module.
2. Comparison of the energy produced by the modules using both photovoltaic units showed the advantage of using two - axis tracking unit rather than optimized annually fixed unit.
Energy gain, reached as a result of continuous reorientation of two - axis tracking system was equal to 42 % in July and 35 % in August.
3. Due to the fact that, the actuators are switched on only when there is a periodic change of the position of PV receiver, to ensure the perpendicularity of incidence of solar radiation on photovoltaic plane, the energy consumption for control process is small and for example, in July diminished energy production by tracking unit about 9 %, in August approximately 8,6 %.
4. There is a possibility to extend the time when the tracking system will not change the position of photovoltaic module from software level. The situation will decrease the number of starts and stops of two actuators causing small reduction of control precision.
5. As a summary, the energy balance taking into account the sum of all costs at the design stage, the costs associated with the implementation of the control process and the differences in electricity production by both photovoltaic units will be presented. It will also allow to estimate future production of electricity.

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