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Original Research Article

EXPERIMENTAL AND NUMERICAL ANALYSIS OF PHOTOVOLTAICS SYSTEM IMPROVEMENTS IN URBAN AREA

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Abstract

Nowadays, photovoltaic systems installed in urban areas have to be an essential part of distributed generation systems, and lead to improve energy efficiency of buildings. The paper describes the operation aspects of the 7,5 kWp photovoltaic installation located on the roof of the didactic building of AGH University of Science and Technology. The significant part of the roof Is occupied by HVAC installation, so the periodic shading is occurring. It makes, that a level of energy generated in the PV system is lower than expected. The first part of the test was focused on the validating model of the installation and determine its impact on the CO_2 emissions. Then, modifications in the arrangement of the panels were considered (redirecting of additional light stream). Moreover, an economic and environmental analysis of proposed improvements were conducted.

Keywords: renewable energy sources, solar energy, sun-tracking devices, TRNSYS, dynamic simulations

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1. INTRODUCTION

Due to climatic changes and environmental pollution, topics connected with renewable energy sources are very important in the international policy. It causes also constant development of new RES applications. The PV technology seems to have the widest range of them all. It might be used in family houses as well as in photovoltaic power plants. Moreover, new technologies linked with solar- powered vehicles and devices are still being developed. Photovoltaic integrated with building structure (BIPV) is expanding as well. Several examples of installations including such solution are adopted: tiles, shingles, skylights, standing seam products, curtain wall products, spandrel panels, glazing, etc.[1]. Numerical and mathematical methods are frequently used during projects preparation and its further analysis. Computer modelling allows to calculate many physical parameters like energy output or thermal behaviour. The description of commonly used tools for calculation of thermal and electrical performance, efficiency, exergy, etc. is contained in [1].

The net zero energy buildings (nZEB) for the proper operation demand renewable energy generated on site. The solar energy may be widely used in such cases but the possibility of installing PV system in particular place is restricted by roof characteristics, electricity demand and consumption pattern. In general, such installations need financial support to be economically viable, as shown by Haegermark et al. [2]. The study carried out by Good and Hestnes [3] for a Norwegian residential building shows that the highest- efficient PV panels could help to reach zero energy balance. Moreover, the boundary conditions and building energy system have a great impact on results of this simulation.

BIPV in commercial and office buildings can significantly reduce the consumption of electricity from the local grid. To achieve that aim, the best production – consumption profiles match should be obtained. Real cases presented in [4] shows that in first approach all facades that are not oriented to the North may play a role in energy production and improve the degree of building self – sufficiency degree.

Each building needs both thermal and electrical energy which can be provided by solar collectors and photovoltaics. There is also a possibility to build integrated photovoltaic-thermal systems (BIPV/T) [3]. Hybrid photovoltaic–thermal (PV/T) modules can potentially lead to a higher total efficiency by controlling PV cells temperature and converting infrared radiation to thermal energy. The required space to build integrated system is also lower. As shown in [5] there is a possibility to add a water cooling system to existing photovoltaic units: the film cooling and the spray cooling methods have been considered. In [6] is presented the influence of the air layer thickness and a shadow casted by frame border over the cells in PV installation located in Hefei at azimuth angle

45^0. The results show that the frame shadow reduces system photovoltaic efficiency to 2.6% (normal efficiency, 13.0%).

According to [7] shows the influence of natural ventilation in PV facade systems. There was developed a numerical model in TRNSYS and verified by a series of data collected through a long term. The results helped to assess the performance of 7.4kWp of such installation in Izmir, Turkey.

In regions where access to power grid infrastructure is limited the hybrid installations integrated with buildings could be used to provide electric power. In [8] an example of such situation is described on basis of a Turkey region. The complex installation which contains PV panels, diesel and battery was simulated with TRNSYS software. The results shows that panels can produce 60.84 MWh of electric energy and reduces CO_2 emission by 42.53 tons. Unit cost of generated energy was calculated as 0.24 €/kWh. According to [9] such a integration increases the reliability of the power system. The continuity of power supply can be obtained through the integration of RES and proper operation and maintenance of npower system. In case study described in [10] another software - Building Information Modelling (BIM) was used to analyse energy performance of four BIPV installation from in the Industrial Technology Research Institute (ITRI), Hsinchu, Taiwan. The results of simulation are compared with three-year measured data and they show that a reasonably good estimation of the electrical energy production of the BIPV at the building design stage was obtained. Particularly, the examinated and compared photovoltaics systems were composed of: Sun Shield, transom, side vertical and ordinary PV panels.

There are available various technical solutions for tracking solar position so it makes this solution suitable for BIPV. According to [11-13] the possibility of increasing the amount of generated energy is significant. The reported energy gain is about 30-35% for single axis systems rather than for systems set at a fixed angle. Rizk and Chaiko [11] used a tracking control based on voltage output analysis. A Wheatstone bridge with two light dependent resistors and two usual resistors were applied as a detector of a relative solar radiation angle by Aziz S and Hassan [12]. As reported by Bazyari et al. [13]. Nevertheless, the difference in energy output gain between two and single axis tracking system is not relevant. The reported gain was only 4% percent.

These data was used to estimate energy gain for system described in this paper, what is described in further part

2. ANALYSIS OF EXISTING SYSTEM

2.1. Energy demand

Krakow is a city located in in southern Poland, Malopolskie voivodship (50°03′41″N latitude and 19°56′11″E longtitude). The existing photovoltaic system which is located on the roof of the building of Faculty of Energy and Fuels has been designed to partially meet energy demands of it. This building contains several rooms with various applications and equipment:

- Two lecture rooms equipped with projector, PC computer, and sound system,
- One computer laboratory, equipped with PC computers,
- Several laboratory rooms, equipped with different electrical devices (including computers, and specialist test rigs with electrical engines, fans, pumps, controllers etc.),
- Several office rooms, equipped with PC computers, printers and other office devices,
- Technical rooms (e.g. server room), social room, lodge, toilets, etc.

Lighting and air-conditioning system (central system located on the roof) is located in every room. Typical opening hours of this building are 8 AM - 8 PM. The annual power consumption is about 250 MWh (+/- 10%).

2.2. Existing PV system

The PV system is located at the roof of the Energy and Fuels Faculty building of the AGH University of science and technology, Krakow. The installation consists of:

- 14 polycrystalline panels Schuco MPE 245 PG 09 connected in 2 strings with 7 panels each, oriented on east. The angle between horizontal surface and the panel surface is equal to 10 degrees,
- As above but panels are west oriented,
- 12 thin film panels SHARP NAE-135L5 connected in 2 strings with 6 panels each, oriented on south. The angle between horizontal surface and the panel surface is equal to 7.5 degrees.

Detailed data of the installation are presented in the table 1.

Two strings with the same orientation were connected to one inverter. The FroniusSymo 3.0-3 unit (nominal power of 3 kW and efficiency of 96.2%) and Fronius IG-15 (nominal power of 1.3 kW and efficiency of 91.4%) were used for polycrystalline panels and thin film panels, respectively. The diagram of the installation is presented in Figure 1.

Table 1. Summary of the analyzed installation

	unit	Schuco MPE 245 PG 09	SHARP NAE-135L5
Module efficiency	%	14.9	9.6
Rated power (Pmpp)	Wp	245	135
Rated voltage (Umpp)	V	29.92	47.0
Rated current (Impp)	A	8.2	2.88
Open circuit voltage (Voc)	V	37.98	61.3
Short circuit current (Isc)	A	8.62	3.41
Temperature coefficient α (Pmpp)	%/K	-0.47	-0.24
Temperature coefficient β (Isc)	%/K	+0.05	+0.07
Temperature coefficient X (Voc)	%/K	-0.34	-0.3
Normal Operating Cell Temperature (NOCT)	oC	43	46
External dimensions	mm	1652 x 994 x 40	1402 x 1001 x 6.7
Module weight	kg	20	24
Performance warranty on 90% (Pmpp min)	years	12	10
Performance warranty on 80% (Pmpp min)	years	25	25

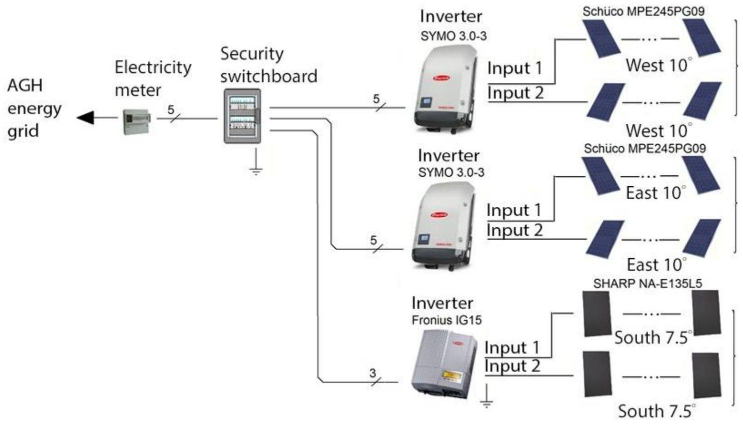

Fig. 1. Diagram of the analysed PV installation

Figure 2 shows the location of PV panels arranged into three fields at the roof of the building. It is clearly visible that a major part of the roof is occupied by the HVAC system. Moreover, cover specifications of the roof constrained the slight tilt angle of the PV panels. Furthermore, mounting dedicated frames which could alter tilt angles was impossible.

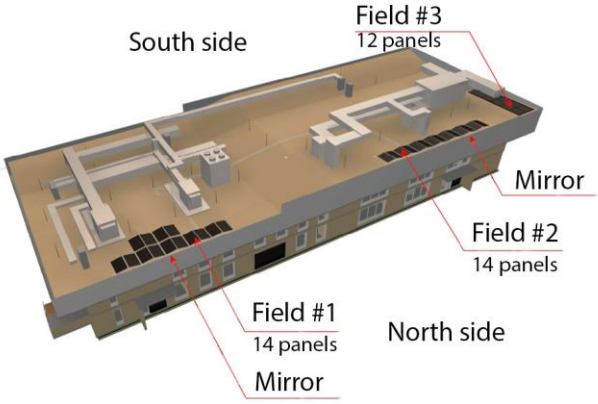

Fig. 2. The roof view with indicated position of three fields with PV panels and mirrors

2.3. Simulation details

As mentioned, two software: TRNSYS - Transient System Simulation tool and Polysun were used to carried out the simulations. First of them is commonly used for commercial and scientific purposes because it allows to simulate both simple or complex energy systems and processes. It is easy in use due to extensive built–in library of components which are based on experimental and/or manufacturer data. There are also information about weather in indicated place collected for many years. The software allows the dynamic calculation of temperatures, solar insolation, powers and many other parameters. In this simulation following components were used: PV panel (type 562 a), inverter (type 48a), Meteonorm weather data processor (type 15-6). The electrical performance of the PV panel depends on the absorbed solar energy and convectional energy losses from the top and back surface of the PV. Total array efficiency ηT which was assumed as a constant in time was the base to calculate the performance of PV panel.

$$\eta_T = (1 + \eta_{T,coef}(T_{PV} - T_{ref}))(1 + \eta_{I,coef}(I_T - I_{T,ref}))\eta_{ref} \qquad (1)$$

η_T - the overall efficiency of the photovoltaic array calculated via TRNSYS,
$\eta_{T,\ coef}$ - a coefficient that describes the change of photovoltaic array efficiency

as a function of cell temperature;
T_{PV} - the PV cell temperature;
T_{ref} -cell temperature at the condition under which the reference PV efficiency was measured;
$\eta_{I,coef}$ - a coefficient that describes the change in photovoltaic array efficiency as a function of incident solar radiation;
I_T -the total amount of solar radiation incident on the PV collector surface;
$I_{T,ref}$ -the total amount of solar radiation incident on the PV collector surface at the conditions under which the reference PV efficiency was measured;
η_{Ref} - the overall efficiency of the photovoltaic array under reference conditions.

The models of such components are here omitted since they are available in the TRNSYS software reference [14]. The each simulation of the developed system was performed assuming a one-year time period with a time step of 0.1 hours. Moreover, in order to perform the simulation, PV modules efficiency, solar field area, and emissivity were set accordingly to the available data of the investigated system. In addition, external data regarding the shading factor of the photovoltaic field has been used for the dynamic simulations.

The second software, Polysun gives similar opportunities to TRNSYS in simulation energy systems. It also contains built-in components library with manufacturers data and Meteonorm weather data. It allows to work quickly and easily during preparation the models of the systems due to a user-friendly interface. The components used in this model corresponded to the ones installed on the roof. The H.G. Beyer model [15] based on the Equations (2, 3) was used to calculate the parameters of investigated installation.

$$\eta_{PMPP}(I, T_{ref}) = a1 + a2 + a3 \cdot \ln(I \cdot \frac{1}{[Wm^2]}) \tag{2}$$

$$\eta_{PMPP}(I, T) = \eta_{PMPP}(I, T_{ref}) \cdot (1 + \alpha(T - 25^{\circ}C)) \tag{3}$$

Where T_{ref} is 25°C and a1 - a3 are device specific parameters. The performance at operation temperatures other than 25°C may then be modeled by the standard approach using a single temperature coefficient α: Irradiance I at an operation temperature of 25°C. T-current operation temperature. The parameters a1-a3 and α should be determined using procedure described in [15]. This simulation investigated amount of produced energy by the installation every month during one year.

Furthermore, the shading of the photovoltaic modules has been included in the analysis, because the presence of the objects on the case study building roof has been considered within the Polysun software.

3. RESULTS

Mean monthly data regarding the four-year operation of the photovoltaic system have been compared with the ones obtained by the simulation carried out with both software (Figure 3, 4 and 5).

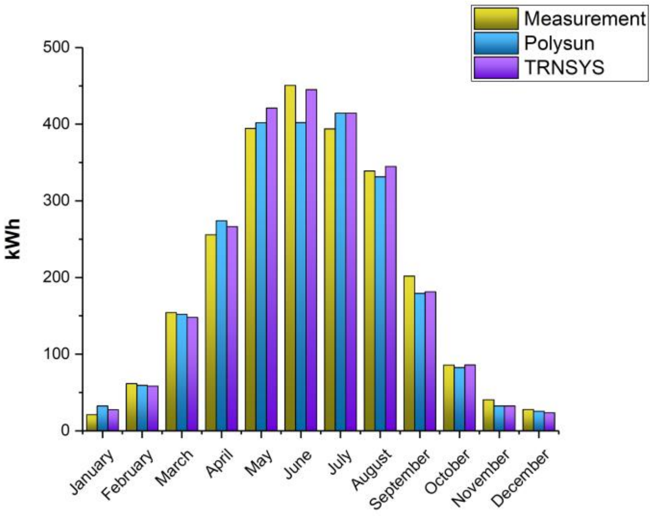

Fig. 3. Comparison of measurements and simulations results for east side

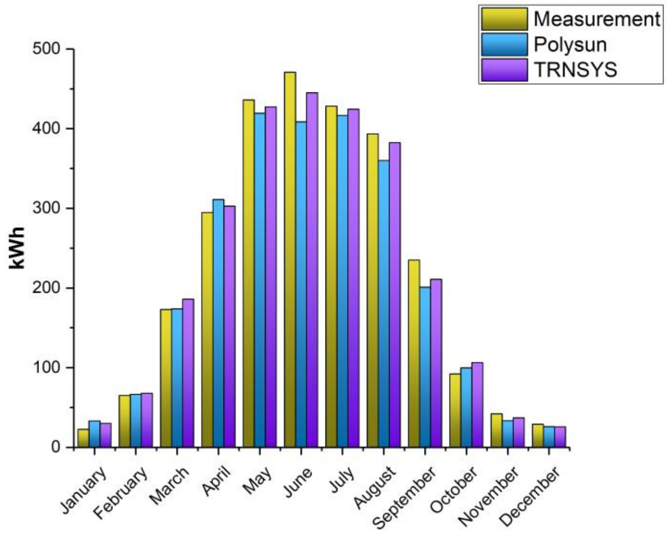

Fig. 4. Comparison of measurements and simulations results for west side

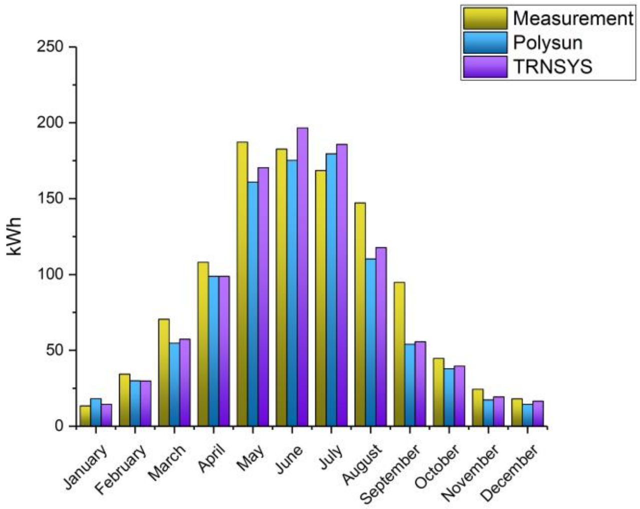

Fig. 5. Comparison of measurements and simulations results for south side

The mean annual production of electrical energy measured on site resulted 6201 kWh, while 6096 kWh and 5888 kWh were calculated with TRNSYS and Polysun software, respectively. Therefore, the simulation of the PV system with Polysun software showed that this software underestimates of 5.3% the annual electrical energy production, while the TRNSYS software underestimates the production of 1.7%. This results outlined that the simulations carried out with both software were performed correctly. The actual configuration of the PV field achieves an electrical energy production that a matches 2.5% of the overall electrical energy demand of the building.

In the next step possible improvements of the existing PV field configuration are analysed in order to enhance the electrical energy production. Method allowing the improvement of the electrical energy production is redirecting of solar radiation beam on the surface of the panels. This is possible with the installation of flat mirrors on the northern edge of the roof reflecting solar radiation on the panels. The analyses for this configuration were performed and shows that it is possible to increase generated energy from 25 to 45% per year. The monthly energy results with and without mirrors are shown in Figure 6.

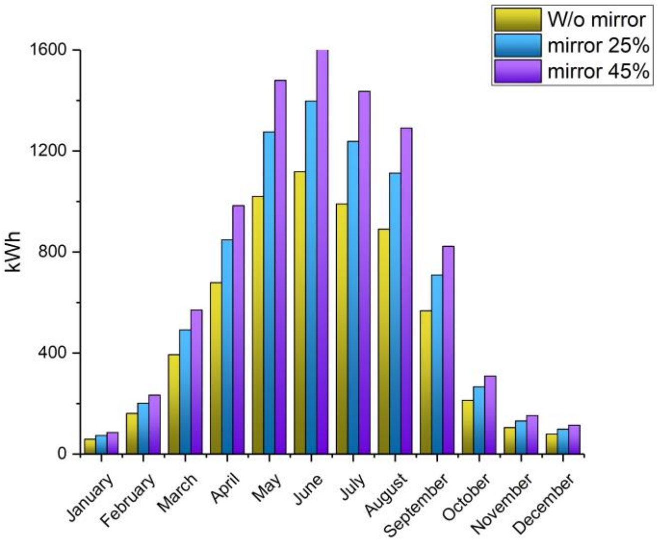

Fig. 6. Simulation of energy generation for system with mirrors

4. CONCLUSIONS

Analyses developed in the study shows a potential of improvements for investigated PV installation. Redirecting od solar radiation proposed in a paper allows an increase of the annual electrical output of about 20 – 45%, which could determine a decrease of the building operation cost and also environmental benefits. Further analysis will include the effect of PV panels cooling, which could increase energy gains and allow to redirect another light stream.

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EKSPERYMENTALNA I NUMERYCZNA ANALIZA USPRAWNIEŃ SYSTEMU FOTOWOLTAICZNEGO W TERENIE MIEJSKIM

Streszczenie

Obecnie instalacje fotowoltaiczne zainstalowane na obszarach miejskich muszą stanowić istotną część rozproszonych systemów wytwarzania energii i prowadzić do poprawy efektywności energetycznej budynków. Najpopularniejszym sposobem montażu paneli fotowoltaicznych na dachach budynku jest zamontowanie ich pod optymalnym kątem względem słońca. Niestety w wielu miejskich przypadkach niemożliwe jest umieszczenie fotowoltaiki na najlepszej dostępnej pozycji ze względu na efekt cieniowania lub specjalne warunki budowlane. W artykule opisano aspekty eksploatacyjne instalacji fotowoltaicznej o mocy 7,5 kWp zlokalizowanej na dachu budynku dydaktycznego Akademii Górniczo-Hutniczej. Znaczna część dachu jest zajęta przez instalację HVAC, więc występuje okresowe zacienienie. To sprawia, że poziom energii generowanej w systemie PV jest niższy niż oczekiwano. Przedstawiono analizę możliwości zwiększenia wydajności instalacji za pomocą narzędzia Transient System Simulation (TRNSYS). Pierwsza część badania koncentrowała się na walidacji modelu instalacji i określeniu jej wpływu na emisję CO_2. Następnie rozważono modyfikacje układu paneli (przekierowanie dodatkowego strumienia świetlnego). Ponadto przeprowadzono analizę ekonomiczną i środowiskową proponowanych ulepszeń.

Słowa kluczowe: Odnawialne źródła energii, energia słoneczna, systemy nadążne, TRNSYS, symulacje dynamiczne.

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