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PROCENA ISPLATIVOSTI UGRADNJE POLUTRANSPARENTNOG FOTONAPONSKOG STAKLA NA AUTOBUSKOM STAJALIŠTU

EVALUATION OF INSTALLING SEMI-TRANSPARENT PHOTOVOLTAIC GLASS ON THE BUS STOP

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REZIME

Upotrebom „EnergyPlus“ softvera, analizirana su tri slučaja polutransparentnih fotonaponskih stakla (10% propustljivosti vidljivog dela spektra sunčevog zračenja) instaliranih na autobuskom stajalištu za vremenske uslove koji se odnose na Kragujevac. Prvi slučaj se odnosi na instalaciju FN ćelija na horizontalni krov stajališta, dok se drugi slučaj odnosi na njihovu instalaciju na vertikalnoj sekciji stajališta. Treći slučaj se odnosi na kombinaciju prva dva slučaja. Optimalna pozicija za instalaciju polutransparentnih fotonaponskih stakla određeno je na osnovu proizvodnje električne energije na godišnjem nivou, kao i ostvarenog profita nakon 30 godina rada ćelija (sva proizvedena el. energija se prodaje elektrodistributivnoj mreži) i perioda otplate početne investicije. Nakon sprovedenih simulacija, horizontalno postavljene polutransparentne ćelije imaju najniži period otplate početne investicije (19.2 godine) u poređenju sa vertikalno postavljenim i kombinacijom prva dva slučaja (24.2 i 20.25 godina, respektivno). U pogledu profita nakon 30 godina rada FN ćelija, treći slučaj (kombinacija prva dva slučaja) pokazuje najbolje rezultate sa 35.86% i 73.83% višim profitom u odnosu na prvi i drugi slučaj, respektivno.

Ključne reči: fotonaponska stakla, period otplate, EnergyPlus, električna energija, FN, ćelija

SUMMARY

Considering the constant growth in electricity demand, it is necessary to take into account new

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ways for electricity generation. Therefore, a significant number of transparent and semi-transparent solar cells have been developed. Three cases of semi-transparent PV glass (10% visible light transmission) installations on bus stop are analysed for Kragujevac weather conditions by using "EnergyPlus" software. In the first case, PV glass is installed on the horizontal roof of the bus stop, while in the second case PV glass is installed on a vertical section of the bus stop. The third case is the combination of the first two cases. An optimal semi-transparent glass installation spot on the bus stop is determined based on annual electricity yield, as well as profit obtained after 30 years of operation from electricity generation (electricity is sold to the grid) and payback period. Conducted simulations show that horizontally placed semi-transparent PV cells have the lowest payback period (19.2) compared to vertically placed PV cells, and both cases combined (24.2 and 20.25 years, respectively). In terms of profit after 30 years of operation, the third case (a combination of first two cases) shows the best results, with 35.86% and 73.83% higher profit compared to the first and second cases, respectively.

Keywords: photovoltaic glass, payback period, EnergyPlus, electricity, PV, cells

INTRODUCTION

It is estimated that solar photovoltaic (PV) global installed capacity in 2019 is around 615 GW. In 2019, newly installed PV is about 115 GW which represents increase of 12%. This increment was higher than in any previous year [1]. In Kragujevac, solar irradiation is higher (1448 kWh/m^2) than the European average (1096 kWh/m^2), which makes it more suitable for electricity generation using solar energy [2, 3].

With respect to the constant growth of electricity demand, it is necessary to consider new ways for electricity generation. Therefore, transparent and semi-transparent solar cells have emerged. It is estimated that transparent and semi-transparent solar cells will have their place in the solar market until 2025th with Europe estimated to have the highest share of the solar-powered window market [4]. In [5] one of the first applications of luminescent solar concentrators installed on bus stops in Rome was analysed. In [6] bus shelter based on green technologies in Kazakhstan was developed and analysed by using the "HOMER legacy" software, whereas, it was concluded that by using grid only electricity (compared to solar) electric load is better carried out. In Malaysia [7], an off-grid photovoltaic system for purposes of electrification an existing bus stop was considered. In [8] four solutions are proposed for installation of PV systems on bus shelters, with a conclusion that the best option (from an economic point of view) is to use PV systems connected to the electric grid where payback period is around 11 years and profit of around 1,000 € is achieved after 20 years of operation.

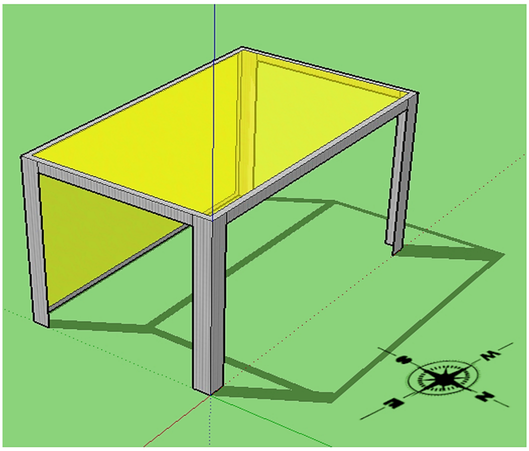

Fig. 1. Bus stop 3D model created in "SketchUp" software

In this paper, the implementation of transparent solar cells on the bus stop will be simulated and analysed by using the "EnergyPlus" software (which is tested and validated software [9]), for Kragujevac weather conditions. The analysis will focus on the annual electricity production of semi-transparent solar cells by installing them on the horizontal roof of the bus stop in the first case, by installing them on a vertical section oriented towards the south in the second case, and combination of the first two cases as the third case. An optimal case will be determined with the evaluation of performance (electricity generation), respective payback periods for those cases, and profit after 30 years of operation.

MATERIALS AND METHODS

A bus stop is modelled in "SketchUp" (see Fig. 1) which is compatible with the "EnergyPlus" software (used to conduct electricity production simulations for each case of PV installations) [10].

The active surface area of the bus stop is 15m^2 for the horizontal roof, as well as 15m^2 for the vertical section. Semi-transparent PV cells that will be used for energy generation calculations have the parameters shown in Table 1.

Tab. 1. Optical and thermal properties of semi-transparent PV cells [11]

Configuration	3.2 (amorphous silicon layer) + 4 (clear glass)
Technology	Amorphous silicon glass
Solar heat gain coefficient [%]	29
U-value [W/m2K]	5.7
External light reflection [%]	7.6
Visible light transparency [%]	10
Efficiency under optimal conditions [%]	4

For electricity generation from semi-transparent PV glass, a simple mathematical model (used by software "EnergyPlus") will be implemented, according to the following equation [10]:

$$P = A_{surf} \cdot f_{activ} \cdot G_{\mathrm{T}} \cdot \eta_{cell} \cdot \eta_{invert} \quad (1)$$

Where:

A_{surf} [m^2] - The net area of the surface covered by PV glass,

f_{activ} [$-$] - A fraction of surface area with active solar cells (value of 1 is in analyzed cases),

G_{T} [W/m^2] - Total solar irradiation incident on PV array,

η_{cell} [$-$] – Semi-transparent glass solar to electrical conversion efficiency and

η_{invert} [$-$] - DC/AC conversion efficiency.

In Table 2, an overview of three analyzed cases is presented, as well as their initial cost of production, import customs, and installation costs. Initial costs are calculated per one unit with dimensions 3x1.25m, whereas, the price for one unit is 528.75 € (ExWorks conditions).

Tab. 2. Prices for components with the installation of photovoltaic glass

	Case I	Case II	Case III
No. of pieces [-]	4	4	8
Installed surface [m^2]	15	15	30
Peak installed power [Wp]	600	600	1200
Installation location	Horizontal roof section	Vertical section	Both horizontal roof and vertical section
Semi-transparent glass cost (production costs only) [€]	2115	2115	4230
Import customs clearance costs	423	423	846

(20% on total amount) [€]			
On/Off Inverter Pro-User NV600N 12V 600W/1200W [€] [12]	77	77	77
Transportation costs [€]	550	550	900
Installation costs [€]	80	80	160
In total [€]:	3245	3245	6213

In each of the three cases presented, all of the generated electricity will be sold to the distribution grid at the price of 0.2066 €/kWh [13].

RESULTS AND DISCUSSION

In Fig. 2, simulation results for each of the three analyzed cases in "EnergyPlus" software are shown.

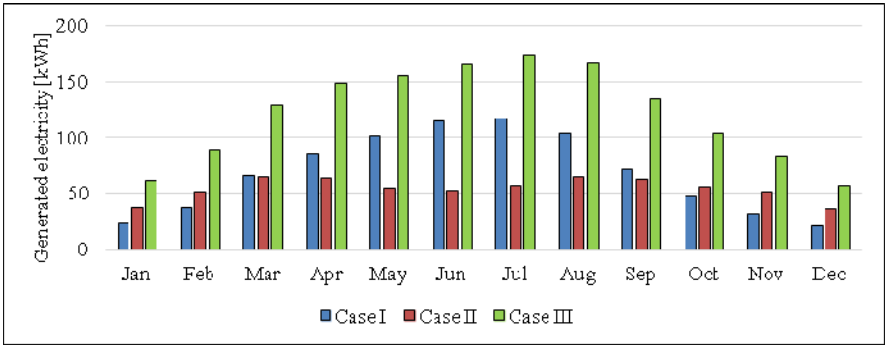

Fig. 2. Bus stop 3D model created in "SketchUp" software

It can be noticed from Fig. 2 that the highest energy yield in each separate month is for the third case (approximately 122 kWh per month on average). On the other hand, the first case (semi-transparent PV cells installed on the horizontal roof of the bus stop) has a better performance compared to the second case during the summer period with 68.28 kWh and 53.69 kWh of average produced electric energy per month, respectively. The payback period for each of the analysed cases, as well as profit obtained after 30 years of operation, is shown in Fig. 3.

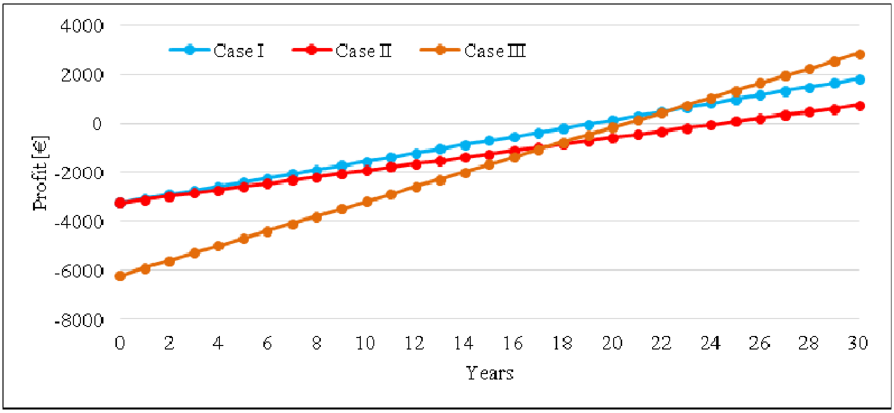

Fig. 3. Payback period of initial investment and obtained profit after 30 years of operation

Considering the data presented in Fig. 3, the shortest payback period is for Case I (19.2 years) when semi-transparent PV cells are installed on the roof of the bus stop, while the longest is for Case II (24.2 years) when semi-transparent PV cells are installed on the vertical section of the bus stop. On the other hand, Case III has somewhat higher payback period (20.25 years) compared to semi-transparent PV cells installed on the roof only but has higher profit after 30 years of operation (2858 €) compared to first and second case (1025 and 1110.3 € higher, respectively). Also, horizontally placed PV cells (Case I) yield 2.45 times higher profit compared to vertically placed semi-transparent PV cells. This can be mainly explained by the angle at which PV cells are installed, thus, horizontally placed semi-transparent PV cells receive more solar irradiation (at a more convenient angle) than vertically placed.

By analysing the data, horizontally placed PV cells have a 20.66% shorter payback period and yield 27.18% more electricity annually compared to vertically placed semi-transparent PV cells. On the other hand, the first case has 44% less electricity generation annually compared to the third case (both horizontally and vertically installed PV cells), but given less initial investment (2968 € less than the third case), its payback period is 5.18% faster.

CONCLUSION

Different cases of installation of semi-transparent PV glass (with 10% visible light transmission and 4% solar to electric energy conversion efficiency) based on amorphous silicon technology on a bus stop are simulated in „EnergyPlus“ software. The aim of simulations have been to estimate yearly electricity generation for three analyzed cases. The first two cases apply to horizontal, as well as vertical semi-transparent PV installation, while the third case applies to a combination of both horizontal and vertical cases. The paper aims to determine the optimal installation position of semi-transparent PV glass for a bus stop in terms of payback period, profit, and annual electricity generation, considering the Kragujevac weather conditions. According to the preliminary analysis, the first case (horizontally placed semi-transparent PV cells) has the shortest payback period (19.2 years), while the second case (vertically placed cells) has the longest payback period (24.2 years). In terms of profit after 30 years of operation, the third case (combined first two cases of semi-transparent PV cell installation) has higher profit compared to the first and second cases (35.86% and 73.83%, respectively).

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